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SOCIETY

OF THE

SCHOOL OF PRACTICAL SCIENCE

TORONTO

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PREFACE

The proceedings of the Engineering Society of the School of Practical Science for the academic year 1896-97 are herewith respectfully submitted.

The Society congratulates itself on having received such valuable contributions for the present issue, and extends its thanks to those who have taken such an interest in its welfare.

The progress of the previous eleven years has been enjoyed during the year which is just closing.

Papers in all the branches of engineering and architecture are respectfully solicited.

The demand for the publication steadily increases.

The present issue consists of fifteen hundred copies.

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ENGINEERING SOCIETY

—OF—

The School of Practical Science

TORONTO.

THE PRESIDENT'S ADDRESS.

GENTLEMEN,—As President of the Engineering Society it affords me great pleasure in welcoming you to this, the opening meeting of another academic year, and to wish you every success through it.

To those who are about to enroll themselves in our Society, I extend a hearty welcome, and assure them that the time spent with us, in pursuit after knowledge, will be most profitably spent.

The past summer has impressed upon me, very forcibly, my great inability to fill the office of President as it should be filled, and as it has been filled by those who have held the position before me: It is the highest honor it is the privilege of an undergraduate to receive, and any expression of thanks that I could make would but feebly express my sincere appreciation of the honor thus conferred upon me.

While deeply impressed by my own inability, I hope, with the assistance of the able committee you have elected to counsel me, to place the Society still higher in the engineering world than it is at present, which, gentlemen, is hoping a great deal indeed.

I am sorry that two of our most energetic members have found it necessary to tender their resignations as officers of our Society. I refer to H. L. Vercoe, corresponding secretary, and J. A. De Cew,

fourth year representative. It is pleasant to know, however, that they have obtained responsible positions, which they will, no doubt, fill with credit to themselves and to their Alma Mater.

We have great reason to be proud of the position the Society now holds. Many are the requests received from eminent engineers and men of business, and also from institutions of world-wide importance, for copies of our pamphlet. The demand for last year's pamphlet was indeed gratifying, and should be no small amount of gratification and reward to those who contributed to its success.

Owing to the untiring efforts of the past President, Mr. G. M. Campbell, and his colleagues, the financial position of the Society is beyond our wildest hopes. Their work, together with that of our present treasurer, Mr. Piper, has placed us in a financial position which we have seldom enjoyed at this time of the year.

It is proper, I think, on this occasion to take a rough glance at the aims and objects of the Society, for the benefit, chiefly, of those who are with us for the first time.

The officers consist of a president, vice-president, corresponding secretary, recording secretary, treasurer, librarian, graduate representative, and representatives from the fourth, third, second, and first years.

Our meetings are held every second Wednesday of the academic year, when papers are read by members and others on subjects of interest to us in our chosen professions.

It is well to mention that these meetings are virtually part of the regular course of the school. Drafting rooms are closed, and no lectures are given, and every student is expected to further his own interests, and those of the Society, by regular attendance at these meetings.

The objects of the Society, according to Constitution, are: (1) The encouragement of original research in the science of engineering. (2) The preservation of the results of such research. (3) The dissemination of these results among its members. (4) The cultivation of mutual assistance among the members in the practice of engineering.

In our library are many books on subjects of greatest interest to our members, and no student should let the opportunity thus afforded pass unaccepted. During the summer vast improvements have been made in the library, which will tend to give greater satisfaction to all parties desiring to borrow books.

The books are now all locked up, and access to them can only be had by two parties, viz., the Librarian and one of the Fellows of the School, whom the faculty have decided to appoint as Assistant Librarian, and whose duty it will be to look after the books lent to the faculty and to the fourth year.

Much dissatisfaction has been expressed to me of the mode followed in the lending of books, and I would earnestly propose the appointment of a committee to revise the library rules, so that it may be run on a more systematic basis.

As most of you are aware the Librarian is ready to supply drafting paper at cost price.

As regards the Constitution: It is very important in the interest of the Society that the Constitution should not only be up to date, but in such a shape as to be readily accessible to all interested in it.

In looking at the Constitution of the Society as it now stands, I find that a number of clauses have been added to those printed in 1893, with which few are familiar, also that a number of others are conflicting and misleading. I consider that the Constitution as it is to date is too bulky altogether, and that a number of laws are there which are not being followed out. For instance: A by-law now exists calling for the publication of advance sheets of the papers read before the Society, which are to be distributed to outside members soliciting discussions. Now this law has been found by experience to be too costly an undertaking by the Society, and has been discarded by the committee as impracticable. Yet, being a law of the Society it should be followed out. It has been proved beyond a doubt that we are unable to follow this law at present at least, and therefore it should be struck out.

Another case: A whole article is in our minute book, and is part of our laws, but is not published, and thus many of us are groping wildly in the dark as regards the substance of our Constitution.

I would advise a committee of five to be appointed to revise the Constitution, and report to us at the next meeting of the Society, which shall take the form of a constitutional meeting. It is of the utmost importance to us as a Society that this be done without delay, so that a published Constitution can be placed in the hands of the members as early as possible, in order that every student may be acquainted with our laws. I would advise that this committee make as few laws as possible, and to make them plain and forcible.

As most of you are aware, the Council of the School have come to the assistance of your committee in the matter of obtaining papers from the undergraduates.

Every paper read by an undergrad. is examined and marked according to merit, 100 marks being the maximum; all marks over 50 are to be considered in granting honors at the annual examinations. This in itself is a great inducement, but others of greater importance are evident.

The writing and reading of a paper before the Society is beneficial to every one. It imparts your knowledge of the subject in hand to those who are less favored in that line and solicits discussion from those who are in a position to criticize. Besides this it gives one confidence in public, and fits him to be conversant in all lines of his profession when cast adrift from his friends on the vast world, where at any time he may be called to defend his principles and assert his convictions.

I earnestly invite discussion on the papers read, as do also the writers. If anything is said that you do not understand, ask about it; and if anything is said that you do not believe, question it, as it is by this means, greatly, that knowledge is imparted. Do not let the fact of your being in the first year hinder your freedom of speech, as here in our meeting no year distinction exists as regards debate.

I most earnestly solicit papers from the undergraduate members, and hope that the inducements offered to them will be seriously considered.

While we, as a society, have been making great progress, as a student body we have been equally successful on the platform and in the field.

Last year we entered into a debate with the Literary Society of the University and came away more than conquerors. This year I hope we shall be ready to meet and vanquish the best men the University can send to oppose us.

In the field we again swept everything before us, and through "feats of strength" and "fleetness of foot" have succeeded in fulfilling the wish of all. "We have made the name of the S.P.S. both feared and respected in the College and on the Campus."

It behooves us, gentlemen, to keep the enviable position we now hold, and every one should make it his individual duty to see that we do so.

It is with deep regret that I have to record the painful accident

which has befallen one of our members, Lockie Burwash. In his endeavor to keep the name of his Alma Mater before the eyes of the public he received a hurt which will confine him to his bed for a time. On behalf of the Society I wish him a speedy recovery, and hope that ere long he may be amongst us again.

I extend the congratulation of the Society to those who have been reappointed on the staff of the School, and on its behalf promise them a loyal support.

And now, gentlemen, I will simply add that the results of the past are before you, those of the future are ours to make. May they be such as will reflect the highest credit on our preceptors, and on the School of Practical Science of our loved Province of Ontario.

C. FRANK KING.

NOTES ON THE STAMP MILL.

By J. W. BAIN, GRAD. S. P. S.

The year 1849 was a memorable one on the Pacific coast of North America; the discovery of auriferous sands of great richness attracted thousands to the wilds of California, and mining camps sprang into existence all over the country. Gradually the placers became exhausted, and when similar deposits were discovered on the Columbia in 1858, many Californians started off to try their luck in the new El Dorado.

It occurred to some Californian miners that what had been done by natural agency might also be accomplished by man, and the outcome of the idea was the application of the stamp mill to crushing gold quartz. Although successful on rich ores, the first mills were extremely crude and wasteful; but experience and careful study of their defects have brought the process to its present efficiency.

It is not the purpose of the writer to trace the evolution of the stamp mill, which would be, truly, a somewhat laborious task, but rather to describe very briefly some features of modern mills and milling.

The series of operations for the extraction of gold in most modern stamp mills may be briefly stated as follows: The ore from the mine is crushed roughly, and fed automatically to the mortar of the stamp battery; this is provided with amalgamated copper plates, which catch most of the free gold. The rest being carried by water escapes through a screen with the finely divided ore, where more of the free gold is caught on other amalgamated plates. From these plates the ore passes to concentrators, which separate most of the remaining gold and nearly all of the sulphides from the gangue. This last usually still contains some small quantity of gold, which may be extracted chemically, or allowed to run to waste.

In order that some idea of the equipments of a mill may be obtained, a few brief notes upon some of the more important machines are given:

CRUSHER.—The Blake, Dodge, Gates or Comet, are in general use. These are described fully in most works on the metallurgy of

gold, so that little need be said about them. In the Blake machine the crushing is done by that part of the jaw most remote from the supporting axle; in the Dodge this arrangement is reversed. Evidently the variation in breadth of the jaw opening of the Blake will be much greater than in the other case, and the product will be more variable in size. It must not be forgotten, as an offset, that the Dodge has not as large a capacity, and hence the matter becomes to some extent a question of preference. General practice seems to favor the Blake.

For handling large quantities in separate crusher houses, the Gates or Comet appear to be the best machines. They run very steadily, and have little jar; the capacity is larger, but on the other hand they are more complicated and very heavy.

Whatever form of crusher be used, the jaw opening should be as small as possible, because it has been found that the cost of reduction by these machines is only one-fifth of what it is by stamps. Whenever possible, the rock breaker is placed in a separate building; this is done for two reasons. In the first place, if situated high up in a mill, the reciprocating motion of the heavy jaw causes much vibration, which is most noticeable when the stamps are hung up; but it is also felt when they are in motion, as there is considerable jarring while large pieces of ore are being fed. Secondly, much fine dust is produced, and this readily finds its way into the bearings of the machines located on a lower story, with prejudicial results. In many cases, however, circumstances will not permit of this arrangement, and the crusher is placed above the ore bin.

If possible, power should be supplied from a separate motor, since the action is irregular, and tends to disturb the running of the stamps and concentrators when connected with them. The suggestion that this motor be applied at night to driving a dynamo seems to be a good one.

In many mills, a grizzly is used; this is simply an inclined grating made of long iron bars, or light rails, laid side by side, and spaced the same distance apart as the jaw-opening of the rock-breaker. The ore is dumped over it; what passes through falls into the ore bin, while the rest is fed to the crusher.

ORE BINS.—These should be as large as convenient, holding at least twenty-four hours' supply. If an accident happens to the hoist, or the mine is flooded, the mill would have to be stopped if no supply were kept; and it has been found that intermittent working is the

more costly. In some American mines as much as a fortnight's supply is always kept on hand.

FEEDERS.—The early mills were fed by hand, a practice entirely obsolete at present. The machine feeder is able to handle at least fifteen per cent. more per hour, according to a recent estimate, and this alone warrants its adoption. At present, feeders of the Challenge or Tulloch types are the most widely used. The principle upon which they are designed is this: when the layer of ore on the dies becomes thin, the stamp falls farther and strikes a bumper rod; the latter actuates a system of levers, and some ore is delivered from a hanging or revolving tray. The depth of the layer of ore in the mortar is thus automatically regulated by a simple attachment on the feeder. The Tulloch, which is the cheaper and commoner of the two, has a suspended tray; when damp ore is being fed, a hard cake usually forms on it, necessitating frequent inspection; in other respects it is a good feeder and is easily regulated. The Challenge employs a revolving plate provided with scrapers, so that it works equally well on all ores; it is slightly more complicated in construction, but is generally regarded as the better machine.

The feeders are mounted on light wooden frames, which run on rails, and are so placed that the ore shoots are directly over the hoppers. In some of the most recent machines, the hopper is done away with and the feeding mechanism attached to the shoot; a little room is gained by this arrangement.

BATTERY.—The early Californian mill had stamps weighing from 500 to 600 pounds, making 16 to 18 inch drops at the rate of 20 to 25 per minute. Contrast this with modern practice, which employs stamps weighing 850 to 1,000 pounds, making 6 to 8 inch drops at a rate of 80 to 105 per minute. This is perhaps the most radical of the many changes which have been made, but there is no doubt that it is a step forward. To day we crush from $1\frac{1}{2}$ to $4\frac{1}{2}$ tons per 24 hours, as compared with 1 ton twenty-five years ago, and the cost per ton is considerably reduced at the same time.

The modern mortar is of iron entirely; the shoes and dies of cast iron or cast steel, as may be most economical; the screens of Russia iron, tinned plate, brass wire, or phosphor-bronze; and the battery frame of wood, iron or steel. From this enumeration it can be easily seen that anything of the nature of a discussion on these parts would be much too lengthy. We may notice that the introduction of steel frames is of importance to South Africa and Western Australia, although wood is still largely used. The employment of phosphor-

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bronze screens will perhaps help the millman; hitherto rust has eaten the Russia or tinned iron and potassium cyanide has clogged the brass. Cast steel cams are in almost universal use, and much trouble and delay is spared.

Deep mercury wells are employed to prevent loss, but they are simple affairs and need no comment.

The plates are now silver plated, and are carefully tended by experienced men. In some mills the apron plate is stepped; that is, two short plates are used, one being placed two inches above the other, so that there is a slight fall. This is done because it has been noticed that the largest deposit of gold occurs at that point where the pulp from the mortar strikes the plate; the stepping saves a higher percentage of gold, but is a trifle inconvenient. As many as six steps are used in some places.

The practice of sizing the pulp before it goes to the concentrators has been adopted in many places. The most common sizer is Rittinger's pointed box, either in its original form, or a slight modification. The apparatus is simple, and can be constructed by an ordinary carpenter, so that the experiment can easily be made. A large box, if well designed, will handle very satisfactorily a considerable volume of pulp, and increase the efficiency of the concentrators appreciably.

CONCENTRATING APPARATUS.—The belt vanner is, of course, the favorite, although in Colorado and Australia the shaking table is much used. Concentrating apparatus has been a favorite field for the inventor, and a number of mills have adopted some special machine. In the main, however, the two mentioned above rank easily first. Speaking generally, the vanner is perhaps the best machine for general work, and makes a good showing on either sized or unsized pulp. The shaking table is not so efficient in rough work; on sized pulp it gives good, clean concentrates, but can not handle slimes as well as its rival. The common practice is to use two vanners, or one shaking table to every five stamps. The corrugated instead of the plain belt in machines of the Frue type is a recent improvement, which is yet apparently in the experimental stage.

The cleanness of the concentrates will be purposely varied in different mills. In an establishment where they are sent to a distant smelter the purity becomes important; if, on the other hand, there is some plant for their treatment on the premises, the more perfect separation from the gangue is aimed at.

In some localities in California the Cornish or German methods of ore-dressing are used. The pulp is treated on buddles or in tossing tubs, and the slimes in jigs. The practice is local, and is applied to high grade ores. The saving in most ores would probably not repay the outlay on plant.

Blankets or canvas tables are sometimes used instead of concentrators, or as an adjunct to them. The method is simple, and consists in running the pulp over either of the above materials; the heavier particles, being at the bottom, are caught on the rough surface, from which they are removed by washing. Canvas plants are in use in California and Colorado, and do good service with slimes, retaining nearly all the fine gold, floured mercury and amalgam.

Tailings are usually allowed to go to waste, but in South Africa they are in many cases treated by the cyanide process, and yield handsome returns. Where water is scarce they are run into reservoirs, and allowed to settle; the supernatant liquid is pumped off and used again. And here it may be noticed that very often the tailings from a mill carry a considerable amount of gold. This arises from the fact that the cost of extraction would probably be more than the value saved. The older mills lost a quantity of gold in this way, but not for the same reason. The mill man then was simply a miner or laborer, with a smattering of mechanical knowledge, who kept the machine running, and paid little attention to the plates, if, indeed, he understood anything about them. Such slipshod methods worked their own retribution, and the selection of a mill man is now an important matter.

Concentrates may be worked in three ways:

(a) **AMALGAMATION.**—This process is being rapidly superseded by others. It consists in grinding the material in a pan with mercury for some hours; the constant attrition and agitation favor the amalgamation of the gold.

(b) **CHEMICAL METHODS.**—1. Chlorination.—Concentrates have been worked very satisfactorily and cheaply in many places by this process, but there has been signal failure in others. 2. Cyanidation.—This is the most modern, and perhaps the best of these methods. Especially in South Africa has it been successful, and like instances elsewhere are not wanting. The precipitation of the gold from solution is perhaps the weakest point in the process, and the efforts of inventors have been directed towards the improvement of the operation.

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(c) SMELTING.—The concentrates are added to the charge of a lead, or copper smelting plant, and base bullion is produced. In the former case, the gold is separated from the lead by Parke's process; in the latter, the precious metal may be conveniently obtained by electrolysis. This is done by running the coarse metal into slabs, and then depositing the copper electrolytically on pure sheet copper, the precious metals separating as mud in the bottom of the vat.

The cost of treatment in some representative mills in the districts mentioned below, is seen in the following table.

DISTRICT.	PROCESS.	COST.	Tons treated per 24 hours.
California	Chlorination ..	\$13 40	3.5
South Carolina.....	“	4 62	.4
Alaska	“	8 99	12.75
South Africa.....	Cyanidation ..	92

These figures represent the cost under certain conditions, and must not be taken as general estimates.

A good deal has been written lately about the efficiency of the stamp mill. Some maintain that, as a crushing machine, it is remarkably inefficient, while it is claimed by others that although it has defects of no small magnitude, that nevertheless the efficiency is high. Certain it is that other machines, for which much has been prophesied from a theoretical point of view, have failed signally in competition with stamps. A notable instance is the Huntington mill; a good machine for soft ores, and used with great success at the Spanish Mine, California, where the cost of milling per ton is only twenty-five cents. One of the main reasons for the non-success of the Huntington mill, in many places, is that it is complicated, and requires careful watching, involving extra expense for labor. Such apparently trifling considerations carry much weight in many instances, and the best machines for a mill are not always those which are most efficient in other localities.

An improvement on the old mills is worthy of notice, viz., the automatic handling of the ore. The aim of the designer is to obviate the necessity of employing any extra labor. The reason is apparent; labor may cost two dollars per day, and in milling a low grade ore any additional expense is bound to affect the returns more or less. This calls forth the remark that the successful treatment of a low grade ore demands the most systematic handling that can be devised.

Another tendency is perceptible of late years, that directed towards improvement in concentrating. This involves the study of the various machines used in the concentration of other ores, and the result of these experiments has led to the adoption of some of the simpler apparatus, such as Rittinger's pointed box. The extent to which dressing operations should be carried is at present problematical; it is not unlikely that the nature and richness of the ore, together with the variation in the cost of operating the plant, will militate against the adoption of any common system. The importance of sizing before concentrating is being generally recognized, but the installation of a more or less complete system seems to be a rather hazardous experiment from a financial point of view. This question is a very interesting one, and would require a thorough examination of some mining district before it could be handled satisfactorily with regard to that region.

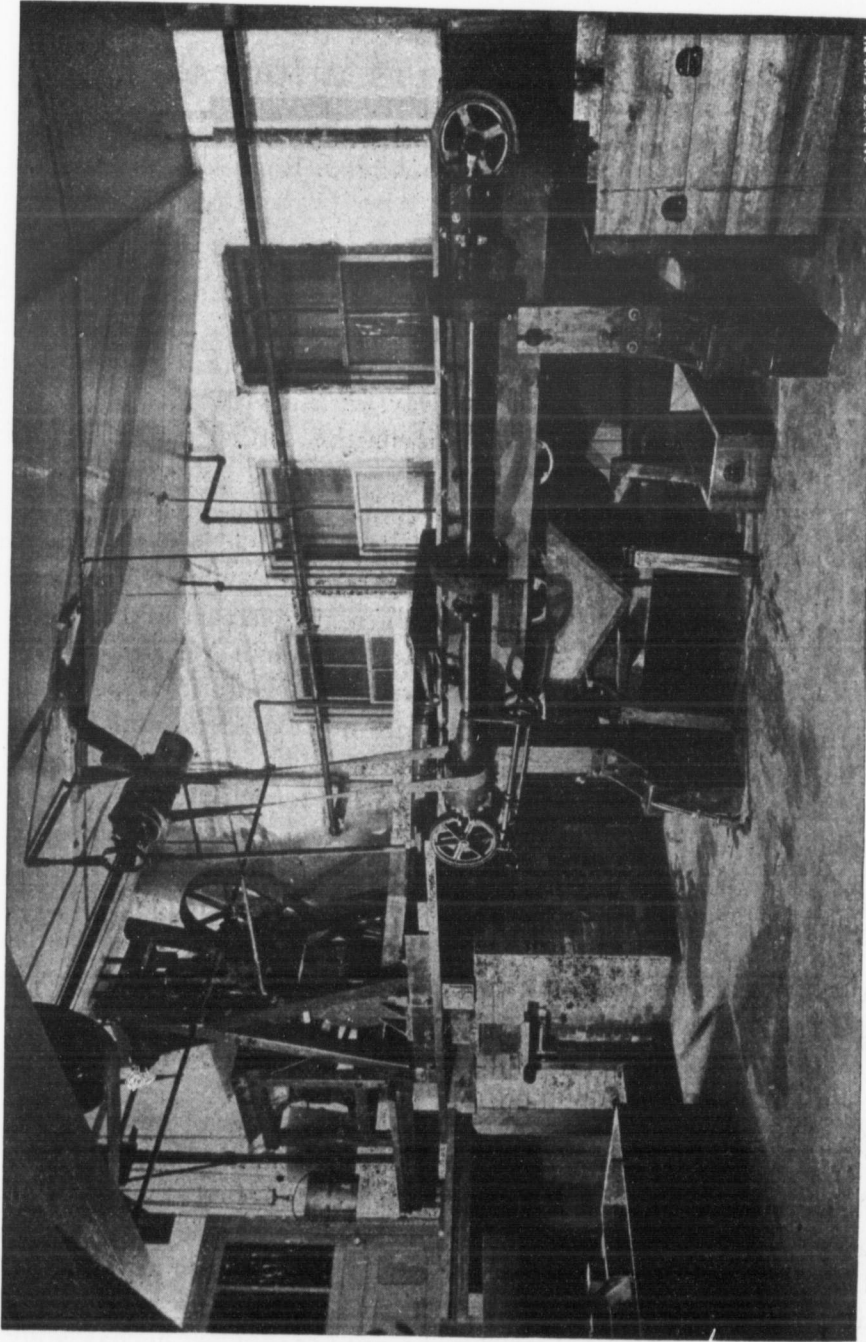
As to the cost of milling little can be said. Local conditions are the chief factors, and no one sum can be given as an average value. Water power is much cheaper than steam; the cost of the latter varies with the price of fuel, and wages differ everywhere.

The figures opposite each district in the following table represent the cost at some mill in that locality. These establishments have been chosen as representative by a good authority:

DISTRICT.	Number of Stamps Running.	Weight of Stamp.	Tons Treated per 24 hours.	Cost of Milling per Ton.
Grass Valley, Cal.....	40	850	1.6	81c.
Alaska.....	240	900	2.9	44
Nova Scotia.....	10	...	2.9	35
Bendigo, Victoria.....	40	900	2.3	58
Gilpin Co., Col.....	75	550	1.0	75

In the west of our own province the cost of milling is said to be high, but statistics are wanting, and nothing definite can be given. The district is new, and the operations carried on up to the present are, in a certain sense, experimental. Some of the results are exceedingly promising, and there is apparently nothing to prevent the establishment of a flourishing industry in gold winning.

In presenting this series of notes, the writer regrets the fragmentary nature of the whole; but as has been said before, the salient features alone have been touched on. For details, reference may be made to the following works: "Metallurgy of Gold," by Manuel Eissler; and "Gold," by T. K. Rose.



CAN. PHOTO-ENG. BU.

Stamp Mill used in Laboratory, School of Practical Science.

ROADS AND STREETS IN ONTARIO.

BY A. W. CAMPBELL, C.E., PROVINCIAL ROAD COMMISSIONER.

The study of road construction in Ontario must necessarily be very largely of a theoretical nature since we have, as yet, little or no local practice to guide us. For this reason, I purpose, in a brief paper, to merely touch upon a few of the prominent points which enter into the building of a roadway, with a view to more clearly define the situation as we find it in the settled districts of this province to-day.

The civil engineer when undertaking the construction of a road in Ontario, must first of all free himself of the idea that European practice, in all details, can be transferred to Canada without alteration. Ontario has a climate very different from that of England or France, or even of some of the Eastern States in America, to which we are beginning to look for information. Ontario is subject to extremes of heat and cold such as are not experienced in England. The English climate is largely one of continuous drizzle. In Ontario we have seasons of drought followed by torrential rains, but this drought is not so long continued as we frequently find it in some of the Eastern States. England is much more densely populated than Ontario; there is greater wealth in proportion to the road mileage, and the demands of traffic and travel are different. At the same time, all experience teaches something, and in its judicious application lies the skill of the engineer. One of the most important lessons we learn is that the methods of one country are rarely applicable in all their details to the requirements of another.

The actual construction of a road is a matter of an exceedingly local nature. Just as the methods of one country cannot be transferred, in all details, to another, so we find that the plans best adapted to one township or county, may have to be modified when transferred to an adjoining municipality, in order to fit the road to altered local conditions and requirements. Not only must the civil engineer understand how to build a good road when he has a given climate, and a given quality and class of material, but he must

remember that there is an economic fitness which must be produced, otherwise the road is a failure. There is this commercial aspect which the successful engineer always zealously regards, and which must always affect our plans, however correct from a designer's standpoint. For these reasons, one cannot condemn utterly any class of pavement. Cedar block pavement is popularly supposed to be a failure, but it is not difficult to conceive of conditions under which it would be the most suitable that could possibly be employed. An asphalt roadway has its uses, so a vitrified brick pavement, a crushed stone, or gravel, and in very many cases, from an economic standpoint, a dirt driveway is the best adapted to all circumstances.

The problem of paving and roadmaking is largely one of good drainage. I do not mean to say that the quality of the road covering is unimportant, nor the crowning, nor any of the other details, but I do mean that the object is largely drainage. We first make a proper use of underdrains to secure a firm foundation; then we round up the natural earth into such a shape as to shed the water readily to the side gutters; then over this we place a covering such as will prevent water penetrating to the earth sub-soil, and of a quality that the traffic which it must accommodate will not destroy, preventing the water passing to the gutters. The problem is very simple in the abstract. In the actual solution, there occasionally arise differences of opinion. No paving material as now used, whether asphalt, brick or crushed stone, is sufficient to bridge over a wet and yielding sub-soil, and this is more especially the case in Ontario because of the upheaving action of frost. It is important to remember that a dry natural sub-soil supports not only the weight of traffic, but the surface covering as well. It was the neglect of this principle which caused the Romans in the days of the Empire to undertake the clumsy construction of roads with artificial foundations of stone and concrete, two and three feet in thickness, a waste of energy which the nineteenth century cannot afford.

As a general thing you will find the country road already located. Unless it is an old trespass road, that is, one of the early colonization roads, it will probably follow the arbitrary lines of our system of surveys, which, as you are aware, places the road allowance in a certain fixed position, according to the width of the concessions and lots. As the cost of building and maintaining a road depends very largely upon the topography of the country and the nature of the sub-soil upon which it is laid, it will be apparent that before undertaking

the construction, it is well to consider whether any change of location is desirable. This will involve a study of the geological character of the vicinity. When the paved way can be laid on a base which is loose and porous, the drainage problem will be very much simplified. If the sub-soil is of a retentive nature, a yielding sand, a muck, or a plastic clay, the expense of drainage will be very much increased. Steep grades should be avoided since, at their best, they materially interfere with traffic, and when they necessitate cuts, the objection to them is very much increased. Under the municipal code, the location of roads can be altered, and the engineer must be able to draw almost instinctively upon his training in geology and mathematics, in order to judiciously exercise this privilege.

The metal to be used in forming the surface is an important part of the question. The choice will usually lie between an inferior quality near at hand, and a better stone from a distance. The best material which has yet come to my notice is an exceedingly tough and durable trap rock. This, however, is to be had only at rare intervals in Ontario. A variety occurs in dykes near Kingston, but the city of Cleveland is bringing this rock from Poole Island, near the north shore of Lake Superior, in Canadian waters. North and north-west of Lake Superior it is to be found in areas, millions of acres in extent. The cost of its transportation, however, is an effectual barrier to its use as yet, and the people of this province are not sufficiently educated in street construction to favor its adoption. In works on road construction you will sometimes find the rocks named in order of merit. This, however, is a very unsafe guide. There are varying qualities of the same kind of stone, just as there are varying qualities of the same species of pine. Granites are usually looked upon as excellent road metal, but any that I have yet seen in use in Ontario have not proven satisfactory. Gneiss, of which there is a vast quantity in northern districts, is of varying quality. Limestone is the most common rock in the settled parts of the province. Some varieties rank very high in wearing qualities, but as a general thing it is not the most durable stone. What this rock lacks in wearing qualities is largely offset by its splendid cementing properties. Field boulders are very plentiful in many localities, and while not sufficiently homogeneous in quality, nor of such a shape as to consolidate with the minimum of vacuum, and are apt to have been affected by the atmosphere, yet they make a good

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road metal if care is taken to discard those of an inferior variety or which show signs of decomposition. Gravel is another material commonly used. That taken from pits and of glacial origin is generally found to contain too much sand, and large boulders. By screening and crushing, however, serviceable metal will result. That in the eastern part of the province is a blue gravel, composed largely of trappean rock, while in the western district a limestone or "cement" gravel predominates. In estimating the value of any road metal, the only satisfactory test is actual wear on the road, a test which cannot be duplicated in the laboratory. Of course experiments performed in the laboratory, tests of absorption, abrasion, impact, crushing strength, etc., are by no means to be overlooked; but unless the results of these are very pronounced, a stone cannot be readily condemned in the absence of actual experience.

Street improvement in towns is in a state of transition. Places which have not quite reached the status of cities, have not yet discarded their old methods and systems which have obtained since the appearance of the first settlers, perhaps a century ago; but this condition of affairs is fortunately beginning to show signs of a change. Ordinarily we find town councils appropriating a few thousand dollars annually for street work. This is spent, usually, in endeavoring to keep dirt roads in a passable condition, in depositing a few inches of gravel annually on some of the leading streets, in patching plank sidewalks, and in making repairs to structures which have never been built. The council's chief adviser, foreman and street force frequently consist of one man, whose implements comprise a shovel and a wheelbarrow.

In a few years there is going to be a new system of administration over this important department of public work. Progressive towns all over the province are awaking to the fact that they are accomplishing little, except a waste of public money, and a continuation of bad streets. They are coming to the conclusion that expert advice is needed in designing streets, as in many other matters. The difficulty has been, very largely, that people have not known what a well constructed street meant. Not knowing how much there was to learn, they supposed they knew it all, that any man who could shovel gravel was an authority. The time is not far distant when the demand for the services of men competent to oversee street improvement will be considerable.

There is a common impression that, in such matters, it will be sufficient for the engineer to know how to build a road, how to prepare specifications, and how to lay out work for the contractor. By far the most important duty of the engineer, however, is to be able to say what class of improvement should be placed on a certain street, in view of the traffic over, and character of the street; whether asphalt, brick, macadam or some other material which perhaps local circumstances will suggest. Not only must he be able to satisfy himself as to the proper plans to be followed, but he must be able to convince the council, committee, or other body, of which he is the adviser, that he is right; and to do so he must be able to give his reasons in a way that will be understood by a man, perhaps a very stupid man, who has no knowledge whatever of engineering. One of the first steps to be taken in a well regulated administration, would be the preparation of a plan of the town, indicating the class of pavement required on each street, and establishing the grades to be followed when the improvement of any street is undertaken, whether in laying a permanent sidewalk, boulevarding, or in paving the driveway.

Not very many years ago there was little municipal business in this country for the engineer, outside the large cities. Surveying, the retracing of farm boundaries and the division of estates was about the only work for the engineer whose practice was purely local. In 1883 the Municipal Drainage Act was so constructed as to give councils the power, upon petition of the property owners interested, to lay down a scheme for drainage of a certain class, the object being to unite the forces, raise money cheaply, concentrate expenditure by letting contracts, thus accomplishing extensive works which, by the efforts of the individual landowner, could not be affected. In this Act it was specified that the survey should be made, plans prepared, and work reported upon to the municipal council, by an engineer. Strenuous opposition was at once offered by the farming community, which contended that the spirit of the Act was to create work for the engineering profession. In order to remove such opposition, the legislature found it necessary to provide that the word "engineer" may mean any person whom the council might deem competent to perform such services. Generally, in introducing the Act into the municipality, a layman was named as engineer. He staked out the work, but to take levels and determine the grade was beyond his ability, and the report usually specified the

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depth as three or four feet from the surface of the ground. This resulted in irregular grades, rapid flows and stagnant pools. It required but one experiment to convince the municipal councils that an expert was necessary to properly survey and superintend the work. To-day this class of work forms the largest portion of the business of the local engineer, especially in the western portion of the province. The same feeling exists towards road improvement as towards drainage, but in a very short time experience will demonstrate the wisdom and economy of placing public highways, both in urban and rural districts, under the care of skilled road-makers, and the field of the Canadian engineer will be very greatly enlarged, to the benefit of employer and employee. In the older countries, all public works are controlled by departments under the supervision of engineers, and Ontario must sooner or later follow their example. The improvement of roads is one of the most important questions which this country has to face. Very little attention has been given to it in the past by municipal authorities, and very little study has been made of it by engineers. I consider it one of the most important qualifications of the municipal engineer, that he possess a thorough education in this branch of his profession. The country is in need of such men, and is waiting for them.

In concluding this paper, which is necessarily a very superficial treatment of a subject upon which a library might be written, the intention of the writer will be achieved, if some members of your Society will be encouraged to closely observe during the approaching vacation, the most commonplace of our Ontario roads and streets, to notice their defects, and the best means to remedy them; further to reflect that the municipal engineer, in dealing with this branch alone, street improvement, must combine in the highest degree possible, the qualities of the student, and the diplomat.

SPECIFICATIONS FOR CEMENT CONCRETE SIDE- WALKS, WITH SUGGESTIONS.

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BY A. J. McPHERSON, B.A. Sc.
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Specifications in any case are simply a set of rules and regulations to which the parties to any agreement shall adhere, and by which they shall be governed in any relations they may have with one another, as far as the contract in question is concerned, and as such should be so explicit as to leave no room for doubt as to what they mean on any question to which they refer.

They should also cover the procedure that is to take place under any conditions that are likely to occur. Specifications should not be so severe as to cause any difficulty in having them carried out, and it should be insisted that they be carried out as fully as possible in every particular, for if they are departed from in any one case, one or other of the parties agreeing thereto may confidently expect that they may be construed rather loosely when they may affect him in some other way, and an engineer in thus departing from them would only be making future trouble for himself. Where there are sureties to the contract, also, unless the specifications are carried out in every particular, it may be difficult to hold them, when necessary, to their bond.

It will be noticed that the accompanying copy of specifications is in the form of a blank, including "Instructions to Bidders," and a "Form of Proposal," thus setting forth very plainly the procedure through which the town wishes any contractor to go, and putting all bids that may be sent in on the same basis, so that no injustice is likely to be done in awarding the contract.

The first thirteen and the twenty-sixth clauses may be termed specific, as they refer to the work in question alone, and are simply descriptions of the methods of constructing the works, and are purely engineering in their nature. The remaining clauses are general, and define the relations of the contractors and town authorities in a business way, and might be applied to any contract between the parties aforesaid. These latter clauses might be multiplied a good deal to suit fancied difficulties and conditions that may come up, but we have found that they cover nearly all the essential points, and that it is very seldom that any ambiguity occurs.

When the conditions are very complicated, and when it would be almost impossible to foresee them all, it is a good idea to specify that the interpretation of the engineer, who, most likely, wrote the specifications, and who therefore ought to know better than any others what is meant, shall be taken, and anything not covered by the specifications should be subject to the decision of the engineer or other person in authority during the construction of the works. Sometimes a good deal of trouble is caused by the contractor bringing in a bill of extras at the end of the time, and on long contracts it is very difficult to tell anything about such a bill. It is well to have the clauses relating to extra work well defined and reading in such a way that the cost of any such work would be settled before or at once after it is performed. A good specification in such cases is to require the bills to be rendered at the next payment or within a certain time after it is performed, otherwise no notice can be taken of such claims. In the accompanying specifications it is fixed by not allowing payment for any extra work unless it has been on a written order of the engineer. He has thus an opportunity of keeping a record of any work that may not be covered by the specifications, and has also an opportunity of fixing a price for it beforehand.

Some of the clauses in specifications are of doubtful use owing to their not being in accordance with the laws of contracts as held by the courts, so that wherever it is possible it is well to submit any specifications for their consideration by a lawyer well versed in such matters, and many times important changes will be found necessary and suggestions of great value will be obtained.

Great difficulty is sometimes found by a young engineer in writing specifications so as to conform to the many unforeseen conditions that may arise during the prosecution of a long contract. There are several good works on the subject that describe in a very lucid manner what is required, and a perusal of any of them will give valuable information. It is a good plan to make a collection of copies of specifications that have been found to work satisfactory, and refer to it when any similar works are required to be described. Then when any such works are being carried on, if notice is taken and recorded of where the specifications may be improved, a short experience will serve to make him quite an adept in such matters.

It will be found much more convenient to have the specifications of the standard pamphlet sizes 6" x 9", also for convenience of reference on the works to have them open, in note book form, at the

end, and printed on but one side of the paper, than if they are of the usual "legal cap" form.

Marginal notes add greatly to their convenience, and when they are long, and time would be taken up in finding any particular clause at any time, an index could be added with advantage.

These things appear to be very trivial in their nature, but by paying attention to them a material difference will be found in the expedition with which work can be carried out, and also anything which tends to help a contractor will affect the way in which he carries out the contract.

SPECIFICATIONS.

removal of old
sidewalks.

1. The corporation shall remove the old plank sidewalks, when it is necessary to do so, before the construction of the new walk can be proceeded with, but all stones, stumps, rubbish and other obstacles that may be encountered in the preparation of the foundation shall be removed by the contractor without extra charge, if not hauled more than one-half mile from the grounds.

All such material is the property of the town, and shall be disposed of as the engineer may direct.

lines and
levels.

2. The proper lines and levels for the sidewalks to be constructed will be given by the engineer, and the contractor is required to preserve all stakes and bench marks unless permission is given by the engineer to remove them.

excavations.

3. The contractor shall excavate to a depth of 10 inches below the level of the finished walk, and to a further depth than 10 inches, should circumstances require it in order to form a solid foundation. Any such excavation must be filled with gravel or other approved material, well watered, and rolled or pounded until quite solid.

The contractor shall be paid for this filling at the rate of 40c. per cubic yard when it has been previously ordered in writing, and duly certified to as correct by the engineer.

When the total excavation on any length of sidewalk extending along one block is greater than an average of 10 inches in depth, the contractor is entitled to an amount for such excess at the rate of 25c. per cubic yard, when it has been ordered in writing and duly certified to by the engineer, such excavation, however, not including the amount below the subgrade that has been excavated and filled, in order to form a solid bed, but that amount only that was necessary to bring the surface of the ground to the subgrade.

foundation.

4. Upon the subgrade, excavated to as above, and filled so as to be uniformly solid, a foundation 6 inches in depth, of broken stone, clean gravel or other approved material shall be laid, thoroughly watered, pounded and brought to an even surface.

concrete.

5. Upon the foundation thus prepared a layer of concrete shall be laid in the following manner: It shall be composed of one part of fresh Portland

cement of a quality approved by the engineer, and in accordance with the specifications for such as elsewhere described herein, and four parts of fine, clean, sharp gravel, free from clay, loam or dirt. The cement and gravel must be carefully measured and mixed while dry, then water must be added until the proper consistency is reached, and the whole must then be thoroughly worked over again. The concrete, when mixed as aforesaid, shall be immediately put in place and thoroughly rammed until it has an even surface, is perfectly and uniformly solid, and is 3 inches in depth over the foundation, and within 1 inch of the finished surface of the walk. It shall then be divided into blocks as the engineer may direct, and the joints shall be filled with clean sand, or other approved separating material.

6. Upon the concrete layer prepared as aforesaid, and before it has had time to set, a wearing surface 1 inch in thickness shall be constructed. It must be composed of 1 part of Portland cement and 2 parts of clean, sharp sand or screened gravel of approved quality, which shall pass through a $\frac{5}{8}$ inch mesh and be entirely free from clay, loam or dirt. The cement and sand or gravel must be mixed dry and then moistened, but it must be used as dry as practicable and be immediately put in place on the completion of the mixing. The layer must then be rammed or pounded and the surface worked so as to be true and even. A layer of best Portland cement must then be sifted over the surface to act as a dryer and to give a smooth finish to the walk, and the whole well trowelled to a perfectly even plane. Wearing Surface.

7. The foundation, concrete layer and wearing surface shall be of uniform depth throughout the walk, and shall be constructed so that the finished surface shall have a slope of $\frac{1}{4}$ inch in 1 ft. towards the roadway, unless otherwise directed. The joints on the surface shall be cut to correspond exactly with those in the concrete and finished in a neat manner, and the edges of the walk must be neatly rounded. Slope of Surface.

8. Stone curbing, of dimensions and quality as approved by the engineer, must be set when required along the outer line of the sidewalk in an accurate manner and true to the lines and levels given. A piece of 2 x 6 pine, dressed so as to be perfectly straight on its edges, shall be furnished and set on edge along each side of the walk, before the concrete is put in place, by the contractor, and shall be removed by him after the cement has become hard. When removing the piece, sodding or other work that may have been done must not be injured, and the space left must be filled with good soil and neatly packed in place. Curbing.

On street crossings a 4 x 6 white oak or cedar curbing shall be firmly fixed at each side in a permanent manner so as to protect the edge of the walk.

9. The contractor must carefully fit the pavement around all waterworks, service boxes, coal shutes, down pipes, projecting steps, door sills, etc., and must take special care to prevent injury to any works or appliances that may be in or under the walk. Approved iron gratings, covers, etc., for areas shall be furnished the contractor by the town or owners of properties, and he must then place them, when so required, in true position to conform to the plane of the surface of the sidewalk. Openings.

10. At lanes and private driveways the edges of the walks shall be faced with the cement mortar used for the surface to the bottom of the concrete, and if Crossings.

required the edges shall be rounded off and the surface marked in blocks or perforated to give a foothold to horses, as may be directed by the engineer.

On street crossings the concrete base shall be $3\frac{1}{2}$ inches thick and the surface layer shall be $1\frac{1}{2}$ inches thick and composed of equal parts of cement and screened gravel or sand, of a quality as aforesaid. The surface shall be rounded and finished as directed by the engineer.

11. The cement used must be fresh Portland cement of approved quality and must conform to any or all of the following tests :

(a) Its specific gravity shall not be less than 3.1.

(b) Not more than 12% residue shall be left on sifting through a No. 100 sieve.

(c) Make some parts of neat cement, about 2 or 3 inches in diameter, on pieces of glass, having the cement about $\frac{1}{2}$ inch thick at the centre and with thin edges. Allow them to set in air and then immerse in boiling water for 48 hours. They must not show any signs of disintegration or cracking on the edges.

(d) The tensile strength after being pressed into moulds neat, and allowed to stand 24 hours in air and 6 days in water, must not be less than 400 lbs. per sq. inch.

The contractor must keep on hand a sufficient stock of cement ahead of his wants to afford a reasonable time for its proper examination and testing.

12. The contractor shall be bound to maintain the walks and crossings in perfect repair for the term of five years from the date of completion thereof, and should the contractor fail to do so at any time during the said term, then the engineer may do so and retain the cost of such repairs from any moneys due or becoming due to the said contractor, on this or any other contract, between the town and the contractor, or recover the same from the contractor or his sureties in this contract as money paid at their request. The certificate of the engineer is to be final as to the necessity of repairs and the amount expended in making them.

13. The contractor shall be furnished sewer pipe, tile or other materials, and he must then lay any such drains for the carrying of surface or other water through or under the walk, as may be directed by the engineer.

14. The contractor shall make suitable and adequate provision for the safe and free passage of persons by or over the work while in progress, as may, in the opinion of the engineer, be necessary, and must confine himself to that half of the street on which the sidewalk is being put down, leaving the other half for the regular traffic.

He shall also put up and maintain such barriers and red lights and keep such watchmen as will effectually prevent any accident in consequence of his work, and he shall be liable for all damages in any way occasioned by his acts or neglect, or that of his agents, employees or workmen.

15. At all times while the work is in progress there shall be a foreman or head workman on the grounds, and instructions given to such head workman shall be considered as having been given to the contractor.

16. Whenever the word "engineer" is used herein it shall be and is mutually understood to refer to the engineer of the Town of ——— and to his properly authorized agents, limited by the particular duties entrusted to them.

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17. Failure or neglect on the part of the engineer or any of his authorized agents to condemn or reject bad or inferior work or materials, shall not be construed to imply an acceptance of such work or materials if it becomes evident at any time prior to the final acceptance of the work and release of the contractor by the Town of _____.

18. The contractor is entitled to 90% of the value of the finished work at the end of each fortnight, on the certificate of the engineer as passed by the Board of Works.

The estimate, so made by the engineer, shall not be required to be by strict measurement, but may, at the option of the engineer, be approximate.

The remaining part of the amount of the contract price, except any deductions that may, in accordance with the agreement, require to be made, shall be paid not later than _____, if in the opinion of the Town Council, on certificate of the engineer and Board of Works, the work is satisfactory, in good repair and in accordance with these specifications.

19. The contractor shall give all necessary notices to telephone, telegraph or electric light companies, waterworks or gas officials, residents or owners of properties, and others interested, and must facilitate the repairing or building up of area walls for gratings, etc., such gratings to be put in place in the sidewalk by the contractor. These areas will be counted as solid in the payment for the walk.

20. The contractor must employ residents of the Town of _____ in the prosecution of the work as far as possible, and the least rate of wages he shall pay to his workmen shall be 12½ cents per hour.

21. Any person employed on the work, who appears to the engineer to be incompetent or disorderly, shall on his requisition in writing, be immediately discharged, and such person shall not again be employed on the work without his permission.

22. The contractor must pay his workmen's wages at intervals during the progress of the work, and unless satisfactory vouchers are furnished at the completion of the work that all wages have been paid, and if any remain unpaid at such time, upon the report of the engineer, the Town of _____ shall have the right to pay such wages, and to deduct the same from any moneys due the contractor by the Town at such date of completion.

23. Any material that has been brought on the grounds, and which has been rejected on inspection, shall be wholly removed therefrom, and in case of non-compliance with this requirement within 24 hours of the time of rejection, the engineer may cause it to be removed at the contractor's expense.

24. No claim for damages shall be allowed the contractor for hindrance or delay from any cause during the progress of any portion of the work, and any part of the work may be dispensed with, and the prosecution of the work stopped at any time, and no claim for damages will be allowed for anticipated profits on the work so dispensed with, or for any inconvenience the contractor may be put to by such cessation of work.

25. The contractor shall prosecute the work on the streets, and in order thereof as directed by the engineer, and he shall employ a sufficient force to ensure that the work on each street shall be completed within a reasonable time.

sidewalks covered by contract.

26. The location and amount of the sidewalks to be put down under this contract are as follows.

STREET.	FROM	TO	WIDTH OF WALK.

instructions to bidders.

27. All tenders for the work herein specified must be made on the forms hereto attached and none other will be considered.

28. As the guarantee of the good faith of the bidder, each tender must be accompanied by a certified check, payable to the Corporation of, for the sum of \$100.

The check will be retained in the possession of the Town Clerk until the necessary contract and bond is entered into and the work commenced.

The checks of unsuccessful bidders will be returned within ten days of the opening of the tenders.

29. The Town of reserves the right to reject any or all bids, and the lowest bid may not necessarily be accepted.

30. The bona fide signatures of sureties must be given in each tender.

31. Tenders will be received until 7 p.m., 18....., and shall be sealed and addressed to the Town Engineer, and endorsed "Tender for Cement Sidewalks."

..... Town Engineer.

FORM OF PROPOSAL.

To.....Town Engineer.

The undersigned, after having carefully examined the foregoing specifications, do hereby offer to furnish all the labor and material required, and to complete the work contemplated in the said specifications in accordance therewith, and to meet all the requirements under them of the Town of, and its engineer, at the following prices :

Cement Sidewalk at.....cts. per square foot.

Stone Curbing, 4 x 24 or over, from.....quarries at cts. per lineal foot, completed.

Street Crossings, with 3 1/2 inch base, and 1 1/2 inch wearing surface, 4 x 6 curbs at each side, at.....cts. per square foot of cement surface.

If the above tender is accepted we hereby agree to furnish approved securities for the construction and completion of the said work, and to execute the bond and contract therefor, in the form approved by, and when requested so to do by, the Town of

A marked check for \$100 accompanies this tender.

..... Contractor.

Dated this..... day of..... A.D. 1897.

CEMENT CONCRETE SIDEWALKS.

We, the undersigned, do hereby offer to become bound with.....
..... in a bond for \$1,000 for the fulfilment of any contract for the works
noted in the specifications as above for the laying of cement sidewalks, etc., in
the year 18....., and for a guarantee of the substantial character of any work that
may be awarded to them.

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Sureties.

THE HIGH BUILDING PROBLEM.

BY W. B. MUNDIE, F.A.I.A.

It would be futile in the short space of time allowed for this single paper to go very deeply into the science of high building and its relation to architecture.

Assuming you are not well versed on the subject from experience, but granting you have given it some careful thought from study and such sources attainable, I propose to confine myself as much as possible to the most salient features and conditions commonly met with in high buildings.

I do not wish to speak of the propriety of high buildings; municipal laws should regulate this question.

Modern life and the customs of our people, their commercial spirit, together with quick-running elevators, inventions in heating, ventilation, electricity, sanitary and other practical conveniences, have imposed upon the architect this problem of high building. Architects as a rule are opposed to walling in the streets of our cities beyond a reasonable height, say twice the width of the street for suggestion. Some of our thoroughfares for several blocks resemble a canon in the Rocky Mountains, where the sun only shines for half an hour during mid-day.

In using the term "high building" I refer to the large commercial structures in the business centres of our modern American cities. The congestion of these business centres necessarily forces ground values to a high figure, and the land owner naturally looks for some way to increase the area of his holding without getting beyond the limits of lot lines. This condition primarily brought about the modern steel skeleton construction which made high building possible and profitable, though many minor difficulties and conditions had to be overcome to achieve success.

The sky-scraper has been ridiculed, but no doubt exists as to their necessity in order to meet a want urgently felt, and a want that

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will continue in our large cities as long as they continue to grow with a like rise in land values.

You will almost with one accord look at the commercial structure from the architect's point of view, and would probably pass judgment on an architect's ability from a single treatment of one of these structures.

There is another point of view, namely, that which the owner takes, and in most cases it involves the architect to the extent of whether he shall continue to be an architect of high buildings. A commercial building being a business venture is successful in ratio to its being profitable. These buildings are not built for glory; nor does an architect build them from choice; in fact, he can be very often seen at his worst in some of them. This percentage of profit is quite apart from architectural achievement. Few people spend great sums of money to purposely beautify a city. If it can be made a thing of beauty, well and good, but it must bring a fair rate of interest to its owner. Our high buildings would lack even architectural interest were it not for this fact that they prove safe and profitable ventures. No matter how bad the proportion of height to its width or base area, if it can be demonstrated that by the expenditure of a certain amount of money a building three times the height will bring profits proportionately greater, the question of good architecture is not considered, though our own impulse and feeling may be strongly against it. This vertical architecture is not beautiful to look upon, and we may regret it on artistic grounds, but if the owner is satisfied with the financial results, and that is what it was built for, then the critic should not find fault, for a building must pay, or no investor is willing to pay its cost. If the conditions under which high buildings are built could be understood or comprehended by the public, they would not be so quick to condemn. It is called ungraceful because it is so high; it is very plain, because of limitation of cost, etc. Remember the architect had nothing to do with the shape of the lot, nor the height, nor could he embellish the facade without increased expenditure. No architect is allowed to carry out these commercial ventures as he pleases. Invariably he is tied hand and foot by a series of conditions which he cannot alter in the least, and then held responsible by unthinking people for evils that are imposed by the problem. This commercial element may cause vexation to the artistic soul, but there is glory in being able to surmount the difficult conditions imposed. Think of what it has done for architecture

within the past fifteen years. The development of the high speed elevator has been so perfected to enable us to carry up our buildings to any given height, bringing the fifteenth story on an equality with the fifth. All mechanical devices employed in constructive science have been perfected to respond to this commercial progress, and architecture is to-day greater and grander through this course of financial conditions, while our buildings are the wonder of other nations.

Architecture has always been an art of solving conditions and forming compromises to meet limitations, and thus the creation of a modern office building becomes as great a task as many a palace or cathedral. It renders practice more difficult and complex, possibly more of a business than an art, while it is certainly more a work of science in engineering. An architect can well pride himself in the perfection of one such structure.

Let us now consider the artistic treatment of one of these lofty structures. The problem is a strictly utilitarian one that confronts the designer. It must be solved in a manner or style possessing some artistic merit, and the difficulties to overcome are immense.

Where the conditions are more than ordinary, such as irregular shape of lot, or one far removed from well proportioned base lines, it is discouraging to a degree to almost baffle education. First aim to be simple, a most difficult thing to do in composition. Try to build in a natural way, adapting precedent to your conditions, but, above all, do not adapt whole features or parts of other buildings. Compose, but do not slavishly copy existing work. It is stealing pure and simple the work of other brains. I know of, and have seen buildings, the authors of which owe the public and the original artist an apology for breaking one of the Ten Commandments.

As the high office building is a series of cells, or offices in tiers or stories, the facade should interpret this interior condition, indeed it is hard to get away from it. The height of stories are alike, or nearly so, thus bringing all openings on a line horizontally, while office over office brings them one over the other vertically. Here is where the architect has to keep within bounds. The question of daylight is the most important; it is the great essential feature in every commercial building in which the object is to provide the greatest number of rentable offices well lighted from the street. This presents a monotony, as the windows are numerous, and of similar size and shape. The windows are the all important feature upon the street fronts. The use of steel brought with it the use of large areas

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of plate glass. It has become epidemic in Chicago, and an immense amount of glass, many times more than necessary in some office buildings, has been the means of ruining the architectural effect. It is not necessary to have every office window a show window. Some object to the use of arch head windows in exterior treatment, because the circle cuts off some of the light. I know of one office tenant, when asked if he objected to the arch on that account, seemed surprised that his windows had circle-headed sash. He had been a tenant two years, and never raised his shades full height. Why curtail the wall surface to enlarge the glass area when tenants as a rule keep out one-third of the light with shades. Thus far we have outlined the utilitarian part of the problem, and now we reach the point of slow-going study.

We have no historic buildings of the past to turn to for grouping of windows, and contrasting wall surfaces for ornament, sixteen or twenty stories high. The designer must use here his own ingenuity and plan his attack. It is easy to leave these window-pierced walls plain, and the wall surface also, but you have a factory or warehouse. It adds but little to the task to decorate the wall surface, but this is not an artistic solution, it becomes decoration, and might be said to be "pretty"; it looks bald from a short distance, and suggests timidity. It is not architecture. Any good building looks well at all times, and from any reasonable point of distance. How can this be accomplished? First, try and contrast your openings as to size, space and grouping, then, if possible, combine some stories or bays as features or motifs; contrasting materials might be employed, together with ornamental detail, but let the detail be architectural. Use pediment, pilaster, cap, shield, base, architrave, key, or whatever your taste and instinct may prompt, as best for the place, and suitable to style. Avoid frivolous decoration of a wall paper or lace-like nature on an exterior claiming any pretence to dignity; it is not forceful architecture.

Now, we being the artist and the engineer together, for high building is engineering, even if devoid of all artistic claims, and the two make the architect—an engineer will tell you that architects waste material; they make things too heavy. We grant this to the engineer, for engineering, but it must possess beauty. A railroad bridge is ugly; so is machinery. Why? They are skeletons. Clothe your framework, and you have an ornamented bridge or machine.

A man can be an engineer and know little or nothing of architecture, but to-day a man can only be an architect by knowing a great deal about engineering—indeed it is almost essential that he should be an engineer. This has been brought about by the advance and change of materials in scientific construction. The old builders of cohesive construction were just as scientific, but the use of iron and steel was denied to them, except as jewelry for ornament.

Our ancestors have bequeathed us valuable examples of constructive form, but all in masonry, forms of construction which I have called cohesive.

To-day we have the skeleton construction. The manufacturers have come to the front with new materials, the liberal use of which it is ours to enjoy, and to such an extent as to be beyond the wildest dream of the old Roman, whose work was almost entirely monumental, and in this class of building we to-day honor him by sticking close to his time honored materials. Thus the architect has to design the entire work. It should look architecturally constructive, possessing architectural proportion with architectural materials, although its interior skeleton is mechanical.

The manner of erecting these structures is very similar. In general practice one building differs from another but little, except in detail. The cage or skeleton of steel is assembled story by story, each one independent and separate, having its own frame and covering, with only the weight of itself to support, and so framed that the outside covering of masonry can be started at the top, and built downward if necessary.

The present steel skeleton when first used had for its foundation the ordinary offset dimension stone footing. In Chicago the original surface level is of hard blue clay, very hard and tough. The streets of Chicago were raised so that the top of this clay is found about twelve feet below the street grade. This stratum of clay varies in depth, and will average ten feet thick. Below this is a spongy, sandy formation of about sixty feet, beneath which is another clay stratum before reaching rock. This rock will average about ninety feet below grade throughout the business centre. Pile foundations have been used to some extent, but buildings of this class always occupy a confined site, so that adjoining buildings have been seriously damaged by the pile driving. Besides, absolute safety demands, if piles are to be used, they should go to the rock. Our new public library, a very heavy building of cohesive construction, was founded in this way, rock being reached between eighty and ninety feet.

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The nature of this compressible soil, with a shallow bed of top clay, prevented the use of stone footings, unless the basement could be given up for the use of the offset footings, while the weight of stone footings themselves is quite an item in the weight of a building. Thus the old method gave place to the new steel and concrete foundation, the steel skeleton being then complete in itself from bottom to top.

The cage is calculated scientifically to carry first its own weight, then the material covering of masonry, tile floors, and partitions, etc., together with the allowance for live load distributed on the floors.

The present building ordinance in Chicago permits 3,500 pounds per square foot on the clay, though many of the first planned buildings of this class were calculated for 4,500 pounds, and even more. This has proven too much, for some have settled badly and very unevenly.

Isolated piers in place of continuous footings are used so that the settlement can be controlled, though in many places where the footings overlap they are coupled in pairs on one increased footing.

This point of equality of settlement is extremely important. A building that shows settlement of eight inches, which is extreme, though some have gone more than sixteen inches, is nothing compared to one that shows a variation of five or six inches between maximum and minimum levels of piers. The former will show no cracks, while the latter will be racked and strained in parts, beyond calculation, and will show bad constructional cracks. Some high buildings have shown such variations as to cause uneasiness and call forth the question of safety, but where a building is honestly calculated, leaving out such short weight phrases as "take it for granted," "assuming this to be or that," weigh a building in its dead load as it actually is as near as possible, with proper allowance for wind pressure, and live load required, it becomes then a mistake in figures or negligence that permits any great variation of settlement. This short weight has caused much trouble. Our buildings are calculated with a factor of safety of four on the steel frame, and this is the fur-lined feather pillow that allows the engineer to sleep at night. Throughout the building numerous cross partitions are built on each floor all of different plans to suit tenants. They are not located when the foundations are put in. So it happens with toilet rooms containing heavy marble work and plumbing, corridors with heavy marble floors and wainscot, while the offices have none. Some architects allow this all to fall on

the factor of safety, while the different piers become unequally loaded, and so on down through ten, twelve, or fifteen floors, until the bearing on the clay is but little better than guesswork. On account of the varied uses some of these buildings are subjected to, such as several tenants with heavy samples, in one end of the building, or probably a printing establishment with heavy vibrating presses, slight variations in settlement are expected, but extreme variation of settlement can be set down as an error unless gross abuse of the building by tenants can be proven.

This point of settlements in high buildings is a vital spot, that is, when built on compressible soil. If the foundation is upon solid rock or very unyielding hard pan, it is not so material, in fact, if on rock it would only be the crushing of the material.

Next to foundation in importance is the tying and bracing together at all points, making the skeleton one structure with no loose joints, taking vibration as a whole and not in any one part. Unless this is done and done well oscillation from wind will cause unequal straining of parts, even reaching to foundations in a heavy gale. At first it may not be of consequence, but continual loosening of the frame will cause damage at some future time. Every part strengthens a part and wherever a tie or fastening can be riveted on it is good practice to put it in. The reed in the river may bend and let the storm blow over it, but after a dozen floods it is far from being upright.

Wind bracing for the steel skeleton is of later development, and it is only within the last four years that it has been very thoroughly and scientifically applied to buildings. Each building for wind straining is in itself almost a different problem from any other on account of governing conditions, such as area of base, height of surrounding buildings, interior walls, light or heavy floor construction, etc. The maximum pressure being taken at forty pounds per square foot, a certain proportion, say one-fourth, or one-third, possibly one-half, may be taken by the buildings as constructed in proportion to the governing conditions, the balance to be taken up by special bracing designed either by gusset or angle plates at junctions of girder and column concealed in the exterior masonry walls, or by floor bracing on the corner bays of the building, or directly through the centre. Another form of wind bracing is applied as an angle or knee brace from the side of the column to bottom of girder projecting below the ceiling, covered in usually by a dividing office partition or segmental

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arch in plaster. Its application and design can only be determined by conditions, and is largely a matter of experience besides calculation.

We know that in a city where a good foundation can be counted on that the limit of height whereby these buildings can be made safe depends on the non-corrosive qualities of the steel and the danger from fire and earthquake.

The first of these requires more than ordinary precautions in building, and chemists are devoting time and study to rust preventive when metal is imbedded in concrete or masonry. At this time, in Chicago, the United States Post Office and Custom House is being raised to make way for a new structure. The iron beams are in an excellent state of preservation and the red lead paint in general looks as good as the day it was put on, but some parts have peeled off, and where this occurs you can invariably find rust underneath it, showing that rust had already formed before painting. Then again some beams show the ends built into the wall considerably corroded with rust; these had been built in as they came from the mill, and the balance of the beam painted afterward before being inclosed. Another instance came to light last week where we are adding three stories to one of the first high buildings built in Chicago. The building fronts on two streets, one front in granite, the other in brick. The iron removed from behind the granite is perfectly sound, while the iron close to the face of the brick front showed signs of corrosion. This has only been in thirteen years, but it shows the brick absorbed the moisture and transmitted it through to the iron, while the granite was almost proof against it in ordinary weather. In demolishing a roundhouse here some few years ago the roof beams were found to be so corroded that you could push your finger through the web of the beam. These beams had been exposed to the combustion fumes and hot steam from the engines. Numerous instances can be cited where corrosion has reached a stage that would prove fatal to our buildings, but you can always find some substantial cause for it. That iron and steel will last in masonry for some time whether painted or not is backed up on every hand. A few years ago I picked out of the walls of Hadrian's villa, near Rome, the head of an anchor bolt that was still doing small duty holding marble veneer to the solid brick behind. The bolt itself was a mere thread, and deep in the brick could only be traced by iron dust, but the thick bead of the bolt was still alive, so to speak. The date of this structure, or structures, as it was built in parts, and at different periods, is given by authorities

several centuries before Christ. The inference is that it was never painted, but it shows the material is lasting.

The best practice as followed to day is to coat the beams at the mill with linseed oil, then just before bricking in, to paint with graphite or red lead. This coat of oil is very necessary, as I have pointed out, and it is astonishing how it sticks to the metal. Unless a beam is free from rust before painting the rust will continue under the paint. I believe foundation beams put in in this way, solidly encased in concrete, will last centuries—longer probably than they will be called upon to do service. Protection from dampness as well as from fire must be sought after.

The second of these essential points, protection from fire, ought to be as near absolute security as can be obtained. I say ought, because many are not. Many buildings have thoroughly protected skeletons, but contain too much combustible material in trimming and furnishing. There is still much to be accomplished to eliminate inflammable material from fireproof buildings. They are comparatively safe from injury within, as has been demonstrated in several small accidental fires that have occurred in Chicago to prove it, and as a barrier to conflagrations, on the exterior, they are very valuable.

Fire engineers say that the covering of terra cotta or brick is liable to destruction from a furious heat suddenly cooled by water. This applies both to exterior and interior, and there is some truth in it. There are instances where it has peeled off, and exposed the steel work, but it has invariably shown careless and indifferent workmanship. This has caused many to scoff at the fire-proof building, and condemn the whole for the weakness of a part. Among this class you find some experienced firemen. A fireman is a bad critic on fire prevention; his business is fighting it, and he rests the whole case on the fact that a fire occurred. When a fireman criticizes a building in part or in detail, in regard to its construction, he is a safe man, and worth attention. It is only when these small imperfections and weaknesses are brought to the surface that the perfect can obtain. In the past ten years fires in any of our fire-proof buildings have been very rare. In fact, with one exception, they have never amounted to anything, and that one exception, the burning of the Athletic Club, was under circumstances that exist only during construction. It is seldom now that a fire in the business district of Chicago gets beyond the building in which it starts. The high building should never be built on the plan of what is known as semi-fire-

proof; it is an unreliable system of building, not without some merit in a building of seven or less stories.

High buildings are severely criticized by few, many buildings deservedly so, but whether it is approved or not, it has come to stay. It is the outgrowth of our present needs. The world will have buildings, and it will have them as it wants them. It demands all that scientific and industrial researches has brought forth in materials. It demands the use of steel, and in the architecture of our cities it will become more and more imperative. The future may demand larger and loftier buildings, and the architect must progress and fit himself for these duties before him.

NIAGARA FALLS SEWERAGE SYSTEM.

BY J. B. GOODWIN, B.A.Sc. (*Tor. Univ.*)

INTRODUCTION.—The subject of a "Sewerage System" is one upon which so much has been written that the writer would hesitate in presenting it before the Society, were it not for two reasons, which were deemed of sufficient importance to overcome such an objection, and it is to be hoped that something of interest and of possible benefit may result from the paper herewith presented, notwithstanding the fact that subjects of this nature are apt to be pretty well discussed.

One of the reasons which recommended itself in the design of the paper, and in the preparation of which was kept prominently in view, is the fact that the Engineering Society of the School of Science is essentially a students' body, the members of which form the basis of supply from which the practising engineer is taken, and therefore is not in a position to immediately adapt himself to methods of procedure in practice upon assuming responsibility. Some suggestion along the line of actual practice possibly would be of service to such a one.

It is not expected that the experienced engineer will be able to derive much benefit from the paper, and no attempt has been made to establish any new principle, or to point out any defects in the methods of modern practice.

The nature of the "outlet works" of this system also seemed to offer justification for presenting the paper, chiefly on account of the novel application of the "stave pipe works" in their construction. As far as can be learned there is nothing of a similar nature in any outlet for sewerage, at least in Canadian cities.

DESCRIPTION OF TOWN AND SYSTEM.—Niagara Falls is an incorporated town of about 5,000 people, and comprises about 2.0 square miles within its limits. There is already a good system of waterworks, by which the Town of Niagara Falls and the Village of Niagara Falls (Drummondville) are supplied.

A system of waterworks must, for good sanitary reasons, be followed by a system of sewerage, and the problem of the disposal of the increased liquid wastes, due to increased use of water, emphasized the need of the immediate construction of a system of sewerage.

Previous to the construction of this system certain streets were sewerred with pipes of various kinds and sizes. Where these proved efficient upon inspection they were incorporated in the system, and the cost of their connection with the system included in the estimate.

TOWN.—The town is situated on the west bank of the Niagara river, below the Falls, and is opposite the City of Niagara Falls, N.Y. The business position of the town is about 240 feet above the level of the river.

At the principal outlet of the system the current is especially strong, being but a few feet above the Whirlpool rapids. It is admirably adapted for the disposal of sewerage without a possibility of stagnation.

ROCK.—Immediately at the cliff forming the banks of the river, the live rock crops out at the surface. Further up into the town depths of from twelve to twenty feet of clay were found. In this clay was found a layer of sand which, not being of an exact quicksand variety, yet upon excessive working, would become troublesome. This layer was from one to two feet thick, and did not prove particularly difficult in shoring up.

The rock here is the regular Niagara limestone formation—in some places soft and full of holes, while in other places hard, compact and flinty.

There is an elevation of rock outcrops near the Wesley Park locality, about half way between the Railway Suspension Bridge and the Falls. This forms a sort of hog's back from which the rock slopes both north and south, the total difference being in places as much as thirty feet.

Through the town runs a stream known as the Muddy Run Creek, whose normal summer flow is about 1.0 cubic feet per second.

FLOODS OF "MUDDY RUN."—During certain periods of the year, especially in the latter part of March or first part of April, the melting snow soon transforms this innocent looking stream into a veritable river, which overflows into the lower parts of the town, flooding business streets and over-running the yards of the G. T. R.

CULVERT.—This is due to a certain extent to the bad proportioning of culvert, which carries this stream beneath the town. It is built to join on to the culvert, built by the G. T. R., which carries it under their tracks.

The portion beneath the town was built as it was needed, and it goes without saying that the cross section is not at all uniform throughout. The smallness of the section at the entrance, compared with that built by the G. T. R., the many subsidences and collapses due to bad construction, and the collection of debris in the many turns and angles, all go to make the culvert of little service.

SYSTEM.—Taking into consideration this portion of the creek, and other topographical features, whereby a suitable system of street grades could be established, to give quick drainage, either into this creek or the river itself, the "separate system" was recommended and adopted.

In one or two points this system was modified. Where it was impracticable to establish a grade whereby the street water could readily be taken into natural channels, it was more economical to place catch basins connected with the sewers of either the "separate" or storm system

RELIEF OF "MUDDY RUN."—It was also necessary to relieve, in some way, the overflow of the creek. Even were the culvert taken up and replaced, yet in some places property would be overflowed. The building of a large brick culvert to replace the old was recommended as a means to partially relieve the flood. This will, in the near future, prove an almost absolute necessity. It was not, however, connected in any way with this sewerage system.

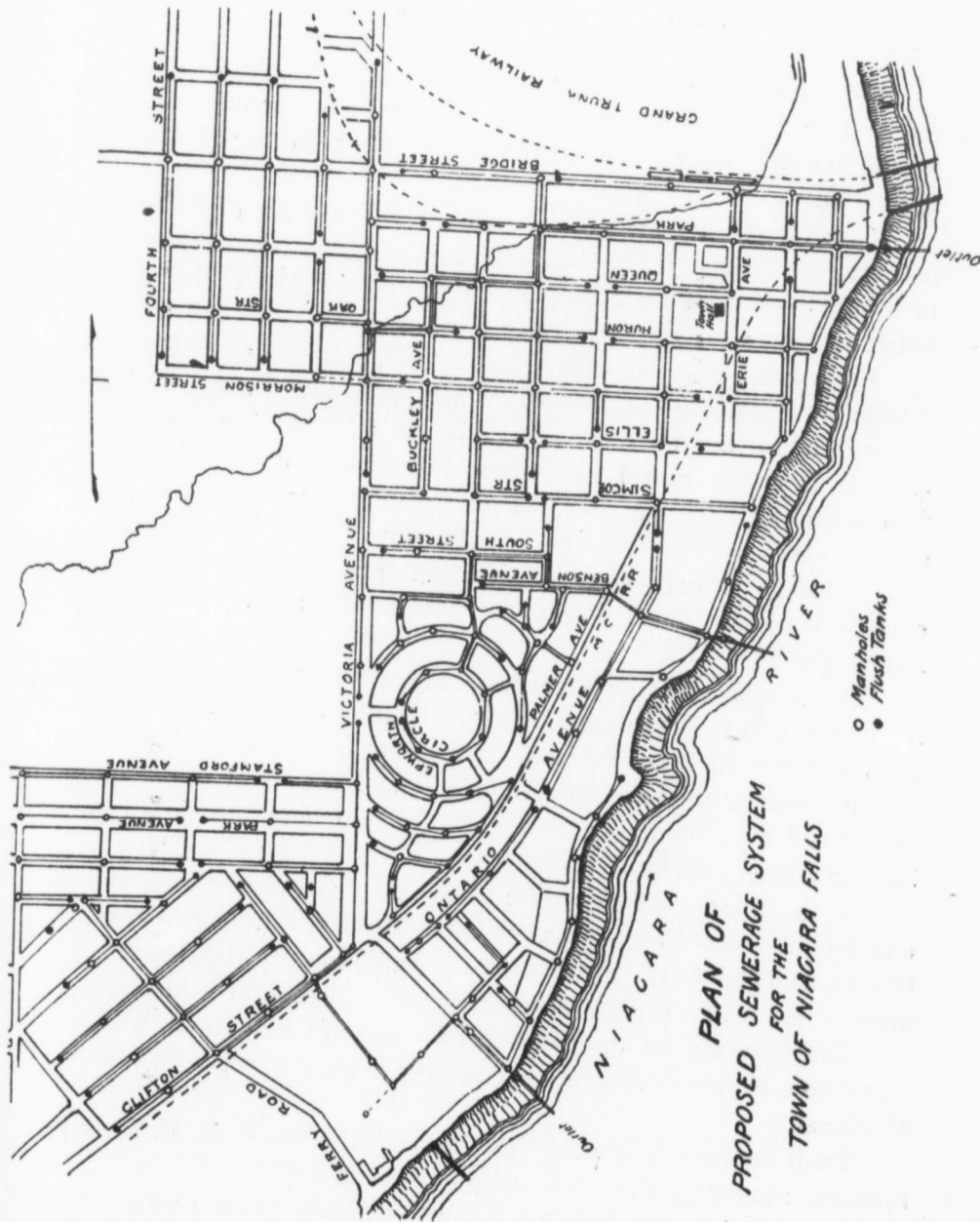
The size of the Park street trunk sewer was made four feet high by three feet wide and egg shaped, for the purpose of taking off part of this creek water, and was extended up the street to its intersection with the creek.

At another point in the "trunk" sewer an inlet was built which could be utilized for purposes of relief. This tapped the stream yet farther up.

OUTLETS.—The "outlets" for the system had to fulfil the requirements of the Queen Victoria Park Commissioners, the Provincial Board of Health, and the demands made upon them from an engineering standpoint.

The Park Commissioners required a covered conduit almost to the water's edge such that the natural scenery of the slope below the





cliff would not be destroyed; they, together with the Board of Health, required some plan whereby the sewage would be safely disposed of without rendering the banks filthy and unhealthful.

Provision was also to be made for a possible "low level" electric road.

For sewerage purposes the town was divided into three districts, the first and largest being relieved by the Park street outlet, the second by the Seneca street outlet, and the third by the Bender avenue outlet.

Park street outlet is situated about 150 feet south of the Cantilever railway bridge. The Bender avenue outlet is about one-quarter of a mile below the upper Suspension Bridge near the Falls, and the Seneca street outlet about midway between the two.

ESTIMATE.—Mr. Mitchell, in his report, estimated the complete system at \$109,000—\$40,000 of which was apportioned for outlets and brick sewers, the remainder for "lateral" system. The \$40,000 is to be raised by general taxation, and the \$69,000 by frontage tax of four cents per foot frontage per year for forty years, or seventy cents per foot frontage, payable down, or "commuted."

Frontage of corners assessed on both streets, but subject to an exemption of one hundred feet. Provision also made for triangular lots in gores.

The length of Park street brick sewer was 2,433 feet, and near its intersection with the creek an eighteen inch trunk line led into it. This eighteen inch line followed the general trench of the low levels of the creek, as near as the arrangements of the street would allow, and ended at a point near where the inlet, before mentioned, was built to connect with the creek.

In the Seneca street system there was also a short piece of two feet by three feet brick sewer made of this size, to relieve excessive street drainage, where, on account of private property and the embankment of the M. C. R., it is impracticable to dispose of otherwise.

The estimate for three outlets over the cliff was about \$12,000. They were of similar design, varying only in sizes of pipes and inverts of tunnel.

Each consists of a shaft just inside of the tracks N. F. P. & R. railway, into which the brick or pipe sewer is built.

From the bottom of the shaft out to the face of the cliff a tunnel carries the sewage to a wooden stave pipe laid about six or eight feet underground, parallel to the slope of the bank below the cliff.

This discharges into an open channel at the bottom, the point of discharge being far enough back to permit the end of the pipe and the masonry anchor to be sufficiently removed from any possible danger from high water and ice jams.

WORK OF 1896.—The work for the year 1896 comprised the Park street and Bender avenue outlets and the trunk sewers relieved by them, together with a part of the lateral system. The Seneca street outlet, its trunk system and the remainder of the lateral system, will be finished during the coming season.

Last season's work was estimated at \$19,000, which included engineering and inspection, and was divided into two separate contracts. The two outlets and the brick sewer on Park street, forming contract No. 1, and the pipe work of the trunks and laterals remaining, made up contract No. 2.

BY-LAW.—Mr. Mitchell's report was adopted and a by-law prepared to provide for the estimated amount. While the by-law was before the people, the plan of the complete system was exhibited in a conspicuous window for the purpose of giving the people some intelligent idea of what they were going to receive for the money so provided. Upon this plan were to be found the streets sewered, sizes of sewers, position of manholes, lampholes, flush tanks, inlets, etc.

Plan, location of outlets, position of prominent buildings, and the work covered by estimate, colored red.

It also showed the way in which provision was made for all possible additions to the system, these being colored blue.

The voters very much appreciated the effort to place before them something tangible on which to base their decisions.

The by-law was passed Jan. 6th, 1896, and Mr. Mitchell received the appointment of Engineer of Construction.

BY-LAWS.—Two by-laws provided for two separate amounts: One for \$40,000 for trunk sewers and outlets, and the other for \$69,000 for laterals. By-laws also authorized the town to issue thirty-years debentures, paying five per cent., and the whole amount of interest and principal to be paid back in thirty yearly and equal instalments.

The time between the passage of the by-law and the beginning of operations was necessarily short, as the work was quite extensive, compared to the length of the season.

PREPARATION OF PLANS AND SPECIFICATIONS.—In this time plans and profiles of all streets sewered had to be made, details of all parts of construction had to be prepared, and specifications, forms of con-

tract and proposal sheets had to be arranged. Advertisements for tenders were put in "Engineering News" and Toronto dailies, and bids were received up to 12 o'clock noon of May 13th. Up to this time plans and specifications were to be seen and examined by the contractors who were bidding on the work.

BIDS.—Fourteen bids were received on contract No. 1, and thirteen for contract No. 2.

The contract price of No. 1 was \$18,203 on the basis of no rock trench excavation, and the contract price of No. 2 was \$16,328.27 upon the same basis. For the purposes of comparing bids 1,600 yards of rock were estimated for No. 1, and 1,900 yards for No. 2. This made the bid of No. 1 \$21,003, the price additional for rock being \$1.75 per cubic yard, and No. 2 \$19,653.27 (rock at same price).

Each bid was accompanied by certified check of \$2,000, and satisfactory bonds equal to forty per cent. of contract price of the work bid upon.

CONSTRUCTION.—In this paper it will be impossible to enter into details of all parts in the construction, and only those features of greater interest and importance will be brought out.

OUTLETS.—Beginning with the outlets as a starting point for description, more space will be given this especial part, on account of the peculiar nature of design.

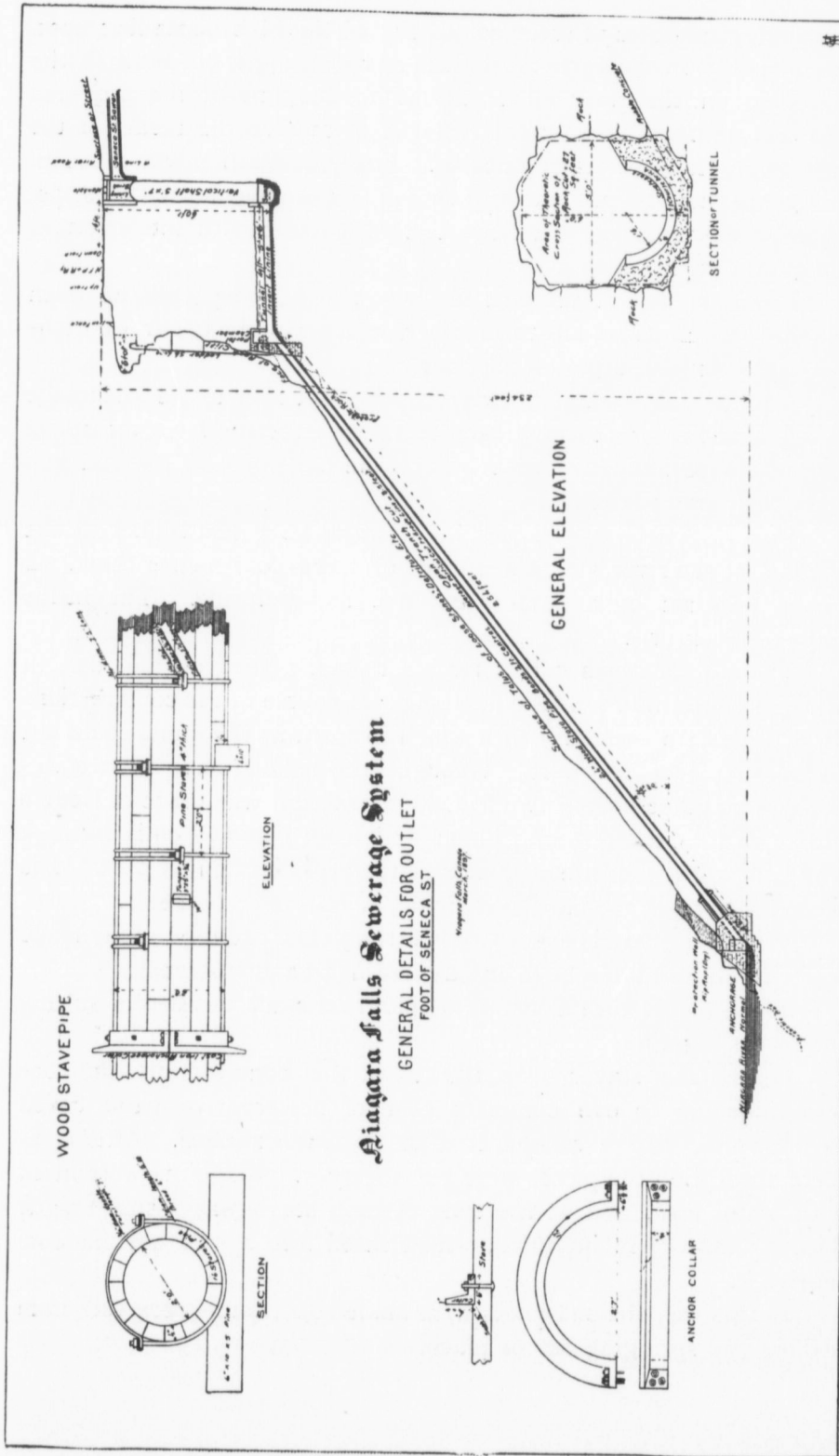
In addition to the requirements that these outlets had to fulfil, those of greater engineering importance were the "life" and "stability" under circumstances which were not at all favorable.

On account of the similarity of all the outlets the description of one will answer for all. The Park street outlet will be taken on account of its size, being the outlet for the overflow of creek waters.

A point was fixed upon far enough back from the water, and high enough up the bank, to be made safe from ice jams, and high water location of the masonry anchorage for the stave pipe.

In this case it was twenty or twenty-five feet back from the edge of the river. It was made of rubble masonry, into which were built two cast-iron collars which received the pipe. These collars were one inch less in diameter than the outside of the pipe. About eight or ten feet up the pipe was placed a third collar of the same shape and size.

A wooden frame of six by eight feet stuff was fitted round below the flange of the collar and struts placed between each corner of this frame and the masonry anchorage. The pipe was thus anchored



from slipping down at three points, the whole three depending upon the masonry in the anchorage. There were wing walls built to the masonry, on the river side, parallel to the line of the pipe and four feet apart. These were battered to receive the thrust of the pipe as nearly direct as practicable. Every precaution was taken in this connection to prevent any sliding of the pipe down the slope, whereby it would be broken away, at its junction with the invert at the mouth of the tunnel.

From the end of the pipe and between the wing walls an open channel was made leading to the river, which would have at least four feet water at low stages of the river.

A protection wall, of dry riprap, was built over to the anchorage in a V-shape to prevent any damage to the structure from masses of rock which periodically break away from the edge of the cliff and make their way to the river.

PIPE.—The pipe carrying the sewage from the tunnel to the channel at the river's edge was made of staves four inches thick, six inches wide on outside face and five inches inside. The inside diameter was three feet.

The specifications called for clear pine, planed on all sides, in pieces not less than fourteen feet long; of course in the constructions short pieces are necessary with which to start, as the joints could not be less than two feet apart. Wrought iron bands (made in two sections) were placed every two feet. One section was made of double three-quarter inch "round," bent and looped at the ends through which to allow the threaded ends of the other section to pass. The second section of the band was single, of one inch diameter.

With these bands every two feet the joints could be easily made water-tight, and brought to any desired degree of closeness.

These bands form a sort of templet that could be used in putting the pieces together.

Before the staves were allowed in the construction each one was subjected to one complete coat of preservative paint called carbolineum, and a second coat on the outer surface. After complete absorption the pieces were put together. All joints were fitted with white lead, and at the ends of each stave was a steel tongue 3 in. x 5 in. x $\frac{3}{16}$ in. thick, which fitted into a saw cut made to receive it.

In this way the end joints were made rigid, and preserved from leaking and springing out of place.

Cross ties, 6 x 10 inches, by eight feet long, were spaced every ten feet apart under the pipe, and bedded solidly in the bottom of the trench.

These were placed against the lowest side of the wrought iron bands so that in case of the slipping of the bank there would be less danger of this sliding, and tending to carry the pipe with it.

Clear pine stave construction was chosen in preference to iron, chiefly because of its lightness and adaptability to the many possible changes of alignment and grade which the slowly sliding bank made quite probable.

No very serious effect of excessive velocity in a pipe of this kind could be anticipated in any case, as the scouring effect of running water upon planed wood is not very perceptible, and in any case the system being separate for the part, it is only occasionally that sand and silt would be carried. Another feature in which wood was preferable to iron was that of freedom from rusting, a very serious effect in such a position.

The length of the pipe was 254 feet and inclined at about thirty-six degrees, the total fall from the mouth of the tunnel to the normal water level of the river being 149 feet.

In the wall built at the portal of the tunnel another cast iron ring was placed, for the additional precaution against the slipping of the pipe down the slope.

PORTAL WALL.—This was eighteen feet high, eight feet wide, four and a half feet thick, battered to 2.8 feet at the top. The face of the wall was flush with the face of the cliff, the mouth of the tunnel being enlarged for this purpose. A brick chamber was built immediately behind, and bonded into the wall; this was for purposes of inspection, and also formed a means of entrance to the tunnel. An opening was made through the wall and over the pipe into this chamber, for which a hinged grating was placed, provided with lock and key.

In case of blocking in the pipe an elliptical shaped plate of iron was provided and placed so as to readily slide into place over the entrance to the pipe.

By this means the pipe could be cleaned or repaired without difficulty.

The opening in the wall over the pipe would in that case form a place of discharge during the repairs in the pipe.

LADDER.—From the edge of the cliff an iron ladder hung to a point at the base where it was anchored. At two or three places additional anchors were put into the face of the rock, and fastened to the rungs of the ladder.

This ladder was only accessible through a trap door provided with lock and key.

TUNNEL.—From the chamber at the "Portal" the tunnel led back from the face of the cliff to a point under the end of the brick sewer, a distance of about fifty-three feet.

This was given an inclination of about one foot in ten.

Its cross section was six feet high by five feet wide, less the corners, which made it twenty-seven square feet. This was about as small as could be conveniently worked and at the same time give a cubic yard per foot of tunnel.

The single coursed invert lining of brick was built, laid in best cement and backed by concrete. The radius of the invert lining was one foot nine inches and semi circular in form.

All loose or dangerous pieces of hanging wall were removed before the invert was built.

SUMP.—At the head of the tunnel and at the bottom of the shaft was a "sump" or silt basin, so contrived as to receive the impact of the falling water in its deepest part. The first aim of the "sump" was to deaden or render of less effect the fall of the sewage.

A longitudinal section in the centre line would somewhat resemble a spoon, the bottom of the "sump" being about three feet lower than the grade line of the invert produced back.

At the entrance to the tunnel, on the river side of the base of the shaft, was built an arched wall. This supports the junction of shaft and tunnel, and at the same time binds the brick work of the invert with that of the "sump."

The brick work of the "sump" is double coursed work of best vitrified brick laid as stretchers, with the courses transverse to the line of the tunnel.

The inside dimensions correspond with those of the shaft, five feet wide and seven feet long.

The brick walls are thus set back under the walls of the shaft.

SHAFT.—Size, 5 x 7 feet.—The depth of shaft required was fifty-six feet, and with the exception of the lining at the top, there was nothing needed to support the rock walls, which were of a substantial, solid formation, and no danger from crumbling or disintegration is expected.

LINING.—The lining at the top of the shaft extends about fifteen feet below the general level of the street. The walls are twelve inch brick work, built with Flemish bond.

The inside dimensions are five feet, two inches wide, by seven feet, six inches long, made so as to correspond to the general dimensions of the shaft, and at the same time to fit the standard shapes of buckle plates of which the covering was composed.

The original design called for these walls to be built on the ledges cut out of the walls of the shaft, but not being sufficiently careful in blasting the main dimensions of the shaft were enlarged, and no suitable ledges could be found for a safe foundation. Instead of having the walls supported at all points, four-ringed arches of brick were adapted, having the points of support in the corners of the shaft. Intersection with the brick sewer was made in one of the walls.

COVERING.—Over the top are built eight inch I beams and channels, set into the brick work, the top flanges being flush with the top of the brick work of the walls. These I beams and channels carry a buckle-plate construction filled in with concrete to the tops of the beams. Near one side of the shaft and between the two centre I beams an opening was left for inspection. Over this opening was placed a standard manhole cap, resting on the I beams; the top of which was the grade of the street. Over the whole floor and around the manhole cap is put the ordinary road metal, bringing the whole up to street grade. On the side of the wall near the manhole are iron steps, and on all sides are placed steps so arranged that a movable platform could rest upon them, which is used on examination or inspection of the sewer or shaft.

BRICK SEWER EXCAVATION ROCK.—In the excavation for the rock trench for brick sewer every precaution was taken to prevent damage to property. Each blast was covered with a mat of logs securely chained together, close enough to prevent pieces from flying. No blasting was allowed within thirty feet of the finished sewer during construction, and where laterals were taken out for house connections in rock, the trench was excavated at least fifteen feet out from the edge of trench.

The maximum economic depth to which holes were drilled was about eight feet, and spaced from two to three feet, depending on the nature of the rock, a row being put in about six inches from the theoretical side of the trench. Holes were generally sunk about one

foot deeper than the required depth of trench. Where the drill could be readily moved 100 to 150 feet of holes could be sunk per ten hours, ordinarily about 75 to 100 feet was the average. For 100 feet per day, and spaced two feet apart and holes six feet deep, the excavation corresponds to about twelve cubic yards per drill per day, taken out usually in benches of five or six feet.

EARTH.—Just above the Cantilever bridge approach the grade line left the rock, and no more was encountered for about 1,400 feet up the street. The excavation in earth was made more quickly, and all through the business part of the town the trench was in earth. The width of trench in earth was eighteen inches wider than external width of the brick sewer.

In this work the first two or three feet, after the macadam was removed to its separate place, was taken out by plough and scraper.

The average cut in this street was 11.5 feet to grade of invert.

In some places shoring was necessary, especially in deep cuts and where the bed of quicksand became bad by water leaking from water pipe or some old sewer pipe.

Small one-horse derricks were used to remove the earth from the trench, where the depth of excavation precluded economic handling by shovelling and staging. These buckets would hold from six to ten cubic feet of loose material, which was dumped into carts and taken back along the trench, or to some low points within the 400 yards limit of haul.

Not more than 200 feet of trench was allowed open ahead of the brickwork, and the back filling followed within 100 feet. Tunnelling in earth was provided for by special permission, in such places where the sewer crossed under the street railway or steam railway tracks.

The objection to tunnelling in general was that in backfilling the material cannot be sufficiently well rammed or tamped under the arch of the tunnel, and a consequent settlement takes place, which in time allows the whole arch to break away and fall in. In such places rigid inspection was enjoined.

BRICK SEWER CONSTRUCTION IN ROCK.—As before stated the size of the brick sewer was three feet wide by four feet high inside, with egg-shaped cross-section. It was made of double ring work of hard burned, best quality sewer brick.

The construction of such a sewer in rock requires close inspection and superintendence.

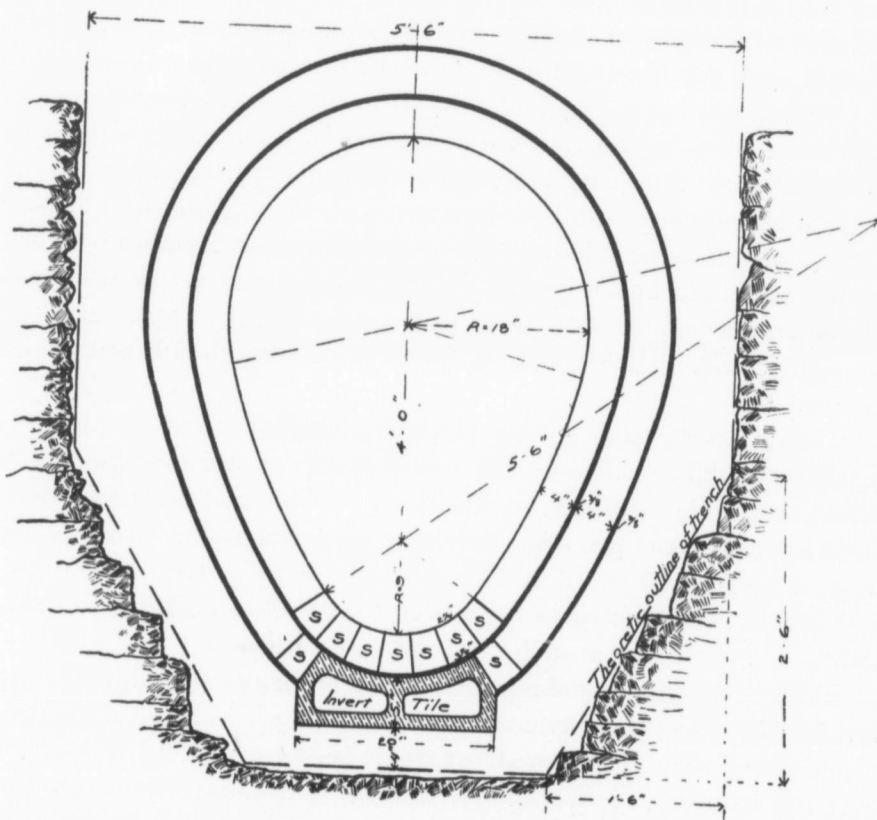
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At the bottom the trench was shaped to suit the form of the sewer, i.e., at a point about three feet above the theoretical bottom of trench; each side was battered off to a point one foot and six inches from the side at the bottom, the trench itself being theoretically twelve inches wider than external diameter. Upon this basis was the amount of rock figured.



SECTION OF 3 X 4 BRICK SEWER—SHOWING TRENCH, SPECIAL BRICK AND INVERT TILE.

NOTE.—Outer course contains 54 Standard and 2 Special (S) bricks.
 Inner " " 50 " " 7 " " "

The bottom of trench was to be $13\frac{3}{8}$ inches below the flow line, to allow: First, a bed of four inches softer material upon which to set the invert; next, five inches for the invert itself, and then $4\frac{3}{8}$ inches for the inner course of brick, and a collar joint of mortar.

The section of sewer was built with fifty-four brick in the outer course, and fifty in the inner; seven of the inner course being specials of size $2\frac{1}{4} \times 3\frac{1}{4}$ by 8 x 4 inches, and two of the outer course being of the same pattern and size.

The tile invert was made of same material as the ordinary pipe, a salt-glazed vitrified clay with an admixture of fire clay. They were eighteen inches long, with a dividing partition along the centre.

These proved of great service during the construction by keeping down the water in the trench. The outer course of brick was started from the faces of this invert, which were corrugated.

Where the sewer was being constructed in rock a line of inverts was set to proper grade and bedded securely, and a "cradle" was made of such dimensions that the outside corresponded to the outside shape of the brick sewer at the bottom; this fitted down over inverts, and behind was packed with gravel or concrete backing, as the case may be, filling the corners and crevices up to the top of the cradle.

The cradle was then removed, and the work of laying brick commenced.

Lines stretched from the same templets as above guided the bricklayer. The outside course would back up against the gravel filling that was put in behind the cradle. This insured a more solid backing than if tamped after the sewer was completed to the same height.

Bricks were laid with push joints with three-eighth inch collar joints, and three-eighth inch plastering outside.

With all conditions favorable three bricklayers could lay fifty feet of this sewer in a day.

Centres were not allowed out till at least two feet of filling was over the arch, and the work fairly well set. The time limit for this was at least six hours, but generally averaged ten hours.

BRICK SEWER IN EARTH.—The construction of brick sewers in earth was similar in nearly all respects, with the exception that no extra excavation was required beneath the invert tile. Before the trench was firmly bottomed the sides and bottom were trimmed so that the outer course would back against it, as in the filling behind the cradle of the brick sewer work in rock.

BACKFILLING.—In backfilling over the sewer, the first two feet above the arch had to be spread and tamped in layers not exceeding six inches, and after that in layers of one foot in thickness.

Care was taken to remove shoring before the backfilling went too far, so that the vacancies could be well filled.

SLANTS.—Slants for house connections were placed at points convenient for use, and a wire attached to each, which was carried to the street surface.

Where the slant was over ten feet deep vertical pipe were joined to the slant to carry the connections to a point not more than ten feet from the street surface.

PIPE SEWER, POINTS OF JUNCTION.—As before intimated the pipe sewer construction was under a separate contract from that of the brick sewer and outlets.

CATCH BASINS.—In this system the introduction of catch basins was an economical necessity, in points where the natural drainage was not quickly enough effected. In one case the embankment of the M. C. R. along Clifton street prevented an easy means of taking care of the street water, and at two low points where the grades from either side met, catch basins were put in, and connections made to the sewer. At several other similar points this plan will also be followed.

FLUSH TANKS.—At the dead ends of laterals flush tanks were constructed. (See plan of system.) These periodically discharge a quantity of water that effectually keeps the sewer clean. In some places these flush tanks were combined in the construction with a manhole. These are special features of a separate system.

AGRICULTURAL TILE.—Another important feature in a system is the use of agricultural tile.

These are laid parallel and a little lower than the main sewer on boards about twelve feet long and six inches wide.

These tile relieve the general soakage of the ground, and give drainage to cellars, with which they are connected. The coming year considerable glazed tile will be used instead of agricultural tile, joints being caulked with hemp, but not cemented.

The accompanying table (page 54) shows the streets built upon, the limit of construction, sizes of pipes, length, appurtenances, etc.

The width of trenches in earth was specified to be twenty-one inches wider than exterior diameter of pipe, which gave sufficient room for tamping round and under the main pipe and the agricultural tile.

TRENCHES.—In rock the width of trench was twenty-one inches

STREET Number	FROM	TO	SEWERS		MANHOLES	FLUSH-TANKS	"Y" Con's		DRAIN TILE		SPECIAL	ADDITIONAL	
			Size, inches	Length			4 Inches	6 Inches	Size	Length			
1	Bender ave 1	Clifton st	15	816.5	3		18	5	840.5		1 lamp hole.	24 ft. of 15" iron pipe.	
2	Bender ave 2	Falls ave	18	500	2		12	5	500				
3	Clifton st 1	Magdalen st	9	858	1	1	23	2	4	858			
4	Clifton st 1	Centre st	12	872	2		24	2	4	872	1 catch basin.		
5	Clifton st 2	Walnut st	15	482.5	2		24	2	4	482.5	1 catch basin.		
6	Centre st 1	Bender ave	9	360	2		8	1	4	360	1, 6" comb'd F. T.	10 ft of 9" pipe on Lewis.	
7	Centre st 1	McGrail st	10	666	2		26	4	4	666			
8	Victoria ave 2	College Place	8	677	1	1	40	4	4	677			
9	Victoria ave 2	Jepson ave	9	755	2		16	1	4	424			
10	Simcoe st 1	Victoria ave	10	424	1		16	4	4	424			
11	Buckley ave 1	Simcoe st	10	756	2		48	4	4	756			
12	Buckley ave 1	Morrison st	12	360	1		8	5	360				
13	Huron st (Trunk)	Victoria ave	18	424	1		24	4	348		1 flush gate, det ¹³	72 ft of 18" iron pipe, or concrete, beneath creek	
14	Superior ave "	Huron st	18	336	1		8	5	336		{ 25ft 9" con to St	100 ft of 4" glazed pipe.	
15	Queen st "	Superior ave	18	746	2		52	5	446		{ L. complete 6"	348 ft of 5" glazed pipe.	
16	Welland ave "	Queen st	18	345	1		34	5	345		{ con. to Welland		
17	Welland st 1	Second st	12	724	1		34	4	724		{ 1, 6" comb'd F. T		
18	Victoria ave 3	Chestnut st	12	1075	4		50	2	4	1075		{ 30ft 6" con com.	
19	Bridge st 1	Welland ave	8	861	1	1	28	4	861			24 ft of 9" iron pipe.	
20	Bridge st 1	Manhole	9	426	1		8	4	450				
21	Bridge st 1	Erie ave	10	751	2		24	9	4	751			
22	Cataract ave 2	Bridge st	12	360	1		12	4	360				
23	Bridge st 2	Victoria ave	9	1060	2	1	62	4	1060			{ 48 ft of 9" iron pipes.	
24	Welland ave 2	Bridge st	9	329	1		8	4	329			{ 48 ft of 4" glazed pipe.	
25	Huron st 2	St. Clair ave	8	414	1	1	24	4	414				
26	Huron st 2	Welland ave	9	421	2		24	4	421		1, 6", 1, 9" connect		

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wider than interior diameter for pipes twelve inches and under ; for over twelve inches the trench was eighteen inches wider than interior diameter. The depths had to be such as to allow six inches soft material to bed the pipe, and for pipes over twelve inches diameter the trench had to allow a bed of at least seven inches.

Where the grades were flat, cross-heads, for giving grade, were set every fifty feet, otherwise they were placed every 100 feet.

LAYING PIPE.—The bed for the pipe having been prepared, the pipe is lowered in place.

Grade is given by use of a rod with a shoulder at the bottom, with sometimes an iron shoe upon it, and at the number of feet that the cross-heads are set a small cross piece is nailed ; the distance between the top of the cross-piece and the bottom of the shoe being the number of feet that corresponds to the end from the cross-heads. With the shoe just resting in the bell end of the pipe, just laid and held perpendicular, the pipe is lowered or raised as the inspector gives the signal. With a piece of black paper on the small cross-piece on the rod, and white papers on the boards of the cross-heads, a well defined line is obtained.

While giving the sight for grade from one of the cross-heads the inspector can give the centre line by means of plumb lines, being from centres of the cross-heads.

JOINTS.—Having satisfactorily laid the pipe to grade and centre, the joint is partially completed. These joints are made with three or four strands of jute and cement mortar. The jute or gasket is first laid in the bottom of the pipe, against the shoulder, and a bed of cement holds it in place for about one-third way around. The pipe is then carefully put into place and forced tight against the shoulder. The ends of the jute are gathered up and rammed into place between the spigot and hub. The joint is then left till the next one is completed as far, and then it receives the cement mortar well pressed in and around the joint, and bevelled off, and the joint is considered finished. The cement mortar for pipe joints is made of one cement to one sand.

CONSTRUCTION OF APPURTENANCES.—The appurtenances of the pipe system comprised flush tanks, manholes, combined flush tanks and manholes, lampholes, catch basins and inlet.

FLUSH TANKS.—The flush tanks were of the Miller automatic type, and were of two sizes—those with five inch and six inch siphons. The capacity of the flush tank with five inch siphon was

250 gallons, and were set to discharge every twenty-four hours. Capacity of six inch was 300 gallons, and set at same interval. These would discharge in a few seconds, and were found very effective and satisfactory.

The tanks were circular and plastered inside up to the water-line. The walls were single course brick walls laid as headers, and were brought up to receive a manhole cap, which was set to grade, and paved round with cobble stones.

MANHOLES.—In the standard manhole construction a foundation of six inch concrete was laid, upon which the brickwork was carried. Channels were formed in concrete between the incoming pipe and the one leaving the manhole.

Where four lines joined at one manhole the junction of the agricultural tile would have to pass beneath the flow line of the sewage from the main pipes, and take the form of an inverted syphon. The objection to this construction was the collection of silt at the junction of the four lines, which made it of questionable service.

It was found simpler and better in such a case to discharge the agricultural tile into the manhole through a trap built into the wall. The next line below could start at the manhole, with a plug put in the dead end, in which a hose could be inserted when flushing was needed.

Manholes were built as flush tanks with eight inch wall laid as headers, circular cross-section three feet six inches at bottom, tapering to two feet one inch at top, fitted with iron steps inside, and plastered outside. On the top was a standard manhole cap of height of ten inches, weight of head 350 lbs., and cover 130 lbs. This was paved round as was the flush tank cap.

SPECIAL CONSTRUCTION.—The crossing of the creek at different points, and the necessity of relieving the creek at high water, made special construction at these points a feature in the work.

INLET AT PARK STREET.—At the head of the brick sewer connection was made with the Muddy Run Creek for the purpose of keeping the water down during danger of flooding the lower part of the town. This took the form of masonry inlet with iron grating. It was located just at the west line of Welland avenue, on the line of the brick sewer. The inlet was made of substantial rubble masonry, with inside dimensions of four feet long and eight feet wide. The wall on the creek side was carried up to within four inches of the normal level of the creek, and a sill of eight inches high built on it. The wall opposite, into which the brick sewer was

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bonded, was four feet higher, and the side walls were built to suit the shape of the iron grating, which was carried from the sill in the front wall to a similar piece in the rear wall.

The area of opening, exclusive of grate, is twenty square feet. In the bottom is a silt basin two feet below the grade of the brick sewer. This collects silt and sediment, and may be cleaned out periodically.

At the time of writing this creek has risen to a very high level, owing to recent rains, etc., and the inlet has worked admirably, commencing to take surplus water as soon as it rises. By a system of stop-logs the whole creek may be turned into the inlet.

In addition to this relief inlet that at the end of the eighteen inch line also served as a relief, though as designed it is a flushing device, and built to receive the water at any level of the creek.

It was made of a single eight inch brick wall in the form of a chamber. The eighteen inch pipe is built into the two opposite sides, and the sewage is carried through the chamber through a half pipe. A partition wall divides this half pipe from a silt basin, into which the water of the creek flows upon opening the gate. The water flows from the basin over the partition wall and into the sewer, thereby serving the purpose intended. The level of the sill of the gate opening is six inches below normal level of water, and by raising the gate the whole ordinary flow can be turned into the system.

SPECIAL MANHOLES.—At a point in the Bender avenue sewer it was found necessary to adopt some special form of manholes in order to make a drop in the grade at a steep point in the street. It was impracticable to arrange a grade to overcome the difficulty without extra cost.

A special form of manhole was designed to meet the case. The incoming sewer was brought to a point about two feet away from the man-hole, and dropped outside the brickwork and entered the manhole at the base. This was accomplished by the use of a T pipe, one leg of which was carried on and entered the manhole about eight feet above where the outgoing pipe left. The sewage discharged down the stem of the T through two or three lengths of vertical pipe, and into the bottom of the manhole through a quarter bend.

Thus the grades of the two lines would meet about eight feet apart, and this construction thereby saved excavation, or if more breaks of grade were made, it saved another manhole or lamphole. This plan is also used extensively for smaller drops.

COMBINED F. T. AND M. H.—The combined manhole and flush tank was simply a flush tank built alongside a manhole.

In all flush tank construction arrangements were made to flush the tile drains by simply pulling out a wooden plug in the bottom of the tank, and allowing the discharge to take place into the tile instead of through the syphon.

SEWERS UNDER CREEK.—Special construction was also used where the lines crossed the creek.

Where the sewer was in rock ordinary tiles were used, and were surrounded on all sides with a six inch coat of cement. Where the excavation was in earth iron pipe of twelve foot sections was used, and four inch glazed pipe and cement joints were used instead of agricultural tile. Iron pipe was also used beneath railway tracks when crushing in of the pipes was quite possible.

FIELD WORK IN CONNECTION WITH THE FINISHED RECORDS AND PLANS.—During the time the work was in progress data of various kinds had to be gotten for purposes of final estimate, records and plans.

As an additional price per yard was paid for rock excavated, levels were taken on the rock trench as soon as it was stripped. These levels were plotted on the profiles, and by the use of a planimeter the quantities could easily be calculated. These quantities were placed on this profile for record. The Y's for house connection were also recorded and plotted on the plan, showing size and location referred to the stationing on which the plan was based.

Old sewers, sizes and water pipes were also located and plotted on the same plan.

The data for assessment work was also a part of this finished plan.

The frontage of all lots on the streets where sewers were built was obtained. Location of houses, lot lines, sizes of triangles and gores had to be obtained and recorded. The finished plan would therefore show the sewer of the street, its size and length, location of Y's and their sizes, and the sides on which they were placed, old sewers, water pipes with sizes, lot lines, houses, frontages, position of manholes, flush tanks, lamp holes, etc. Thus a concise and complete record would be had in a convenient shape.

INSPECTION.—During the busiest time of the work, when eight or ten places were open at once, it required quite a number of inspectors. By good arrangement of the work five men were found sufficient to inspect all the points.

Inspectors were appointed upon recommendations by the engineer, and reported directly to him. They acted as his representatives, made reports of number of men daily employed, inspected pipes and all materials, and superintended construction.

MATERIALS.—The materials used in the whole work of both contracts were specified to be the best of their kind.

CEMENT CONTRACT 1.—Cement for No. 1 has to be equal to the best Canadian Portland cement, ninety-five per cent. to pass through a No. 50 sieve, and neat cement to stand two hundred pounds per square inch tension, after sixty hours in water with previous twelve hours in air, setting at a temperature of 70° Fahrenheit.

Sewer brick had to have a clear ring, be hard burned, and not absorb more than seven per cent. moisture by weight.

Sand to be clear and sharp.

Cement mortar used in brickwork was made of strength of one part cement to two of sand. The concrete used in this work was made of one part cement, three sand and three stone.

MATERIALS, CONTRACT 2.—In contract No. 2 cement had to pass a more rigid test for fineness—ninety per cent. to pass a No. 80 sieve. It had to show a tensile strength of two hundred and fifty pounds per square inch after sixty hours setting in air, with previous twelve hours in water at a temperature of 70° Fahrenheit. No absorption test required for brick. Sand and cement to be the same as in No. 1. Pipe had to be salt glazed vitrified, preferred in lengths of three feet. Size of hub and socket was to be of size to allow three-eighth inch joint all round. Sockets of pipes up to and including 9" diam. were to be 2½" top, and over 9 and including 3" top with corrugations. Thickness of 18" and 15" pipe was specified 1½", of 12" 1", of 9" and 10" ¾", and of 8" ¾".

PIPE.—Forty per cent. of each lot of pipe inspected had to be truly circular and of the remainder pipes of twelve inches and under must not show one-fourth of an inch divergence from being circular, and for pipes over twelve inches the divergence was not to be over half an inch.

Alignment was not to show a variation of over three-fourths of an inch in three feet. The pipes used were made in Toronto, Ont., of best fire clay, and proved a uniformly first class lot of pipes, fully complying with the specifications.

FINAL.—Many points in this paper have of necessity been only touched upon, and even with only superficial reference in many places, the paper has grown to the extent that is not warranted by the nature of the subject.

If it has grown somewhat lengthy, it has been made so from the attempt to make clear the different features of construction, thereby aiming to bridge the gap that seems to separate the theoretical and the practical.

Many points arise in supervision of work to which the theory of school training is not directly applicable, and these call for immediate decision on the part of the engineer in the work.

The interpretations of plans and specifications have often to be made on the spot, and this requires a quick appreciation of the results of the interpretation that may be arrived at.

The material attainable, the stability and efficiency of the arrangements so decided upon, are points that call for the quick exercise of originality and ingenuity of contrivance on the part of the engineer or his representative.

THE GAS ENGINE.

BY R. W. ANGUS, GRAD. S. P. S.

The following paper has been written more with the object of bringing before the members of the Society an engine which seems to be pretty much neglected in this country, than of bringing up anything new in regard to it. In fact very little theory has been touched upon, and what is here given is along the lines of the experimental work of Mr. Dugald Clerk, who perhaps has done more than any other person in England or America towards bringing out an explanation of the phenomena shown in this engine.

The efficiency of the engine and a few points in regard to the practical construction have been given.

If the paper should serve to awaken in the members an interest in its subject, the writer will feel well repaid for his work.

HISTORY OF THE ENGINE.—The history of the gas engine covers a period of over two hundred years, the first work being done by D'Hautefeuille in the year 1678. His invention, however, must have been very indefinite, as there seems to be little record of it.

In 1680, however, Huyghens built an engine in which gunpowder was employed. This was placed in a vertical cylinder under a piston and exploded, when the piston was driven to the top of its stroke. The gases in the cylinder were then cooled, and the difference in pressure between them and the atmosphere caused the piston to descend, and it was on this downward stroke that the work was done.

Barber, an English gentleman, secured in 1791 a patent on an engine operated by the explosion of a mixture of carburetted hydrogen and air, and used the direct effect of the explosion.

Robert Street seems to have been the next inventor, and it is interesting to note that he applied in 1794 the principle which was so successfully used in after years by Otto, the action being to allow the gas to explode under a massive piston which rose freely and did work on the downward stroke. The principle was poorly applied, however.

In 1799 Franzose Lebon made some inventions in this line, and seems to have had the right ideas, although his engine, like the others, did not accomplish much. He described the process of the distillation of carburetted hydrogen from coal, and used a mixture of this gas and air in his engine.

The engine was self-regulating and operated two pumps, the one for gas and the other for air, compression being performed in a separate cylinder, which communicated with the working cylinder, when the ignition and explosion occurred.

The next inventor was Samuel Brown, who, during the years 1823-26, secured several patents on an engine similar to that of Huyghens', in which work was performed by the excess of the atmospheric pressure.

The discovery in 1823 by Davy and Faraday, of the means of liquefying gases by pressure, and the fact that these liquids again formed the original gases when pressure was released, caused inventors to choose a new method for the operation of gas engines. An apparatus which depended upon the above facts was proposed by Brunel in 1825, and deserves some notice. He used five cylindrical

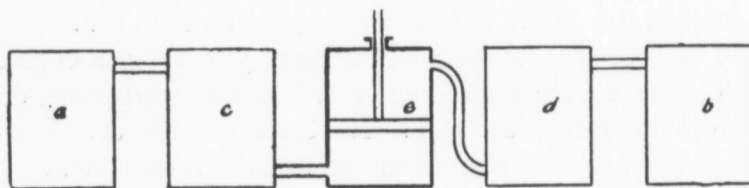


Fig. 1

vessels—*a b c d e*, Fig. 1—of which *a* and *b* are called *receivers*, and contain coils of pipes and also liquid carbonic oxide. These vessels, *a* and *b*, communicate, as shown in the figure, by means of two tubes with two intermediate vessels, *c* and *d*, called *expansion* vessels, partly filled with oil, and which in turn communicate with the bottom and top respectively of the working cylinder *e*, in which the piston moves.

If now hot water be passed through the coils in the vessel *a* and cold water through the coils of the other one *b*, there will be a considerable difference in the expansive force of the liquids in these vessels which will be transmitted by means of the oil in the expan-

sion vessels to the piston of the engine causing it to move upwards. The hot and cold water supplies are then interchanged and the piston moves downward.

It is found that if water at a temperature of 120° be passed through *b*, the expansive force of the liquid would be about 90 atmospheres, while cold water in *a* causes a pressure of only 40

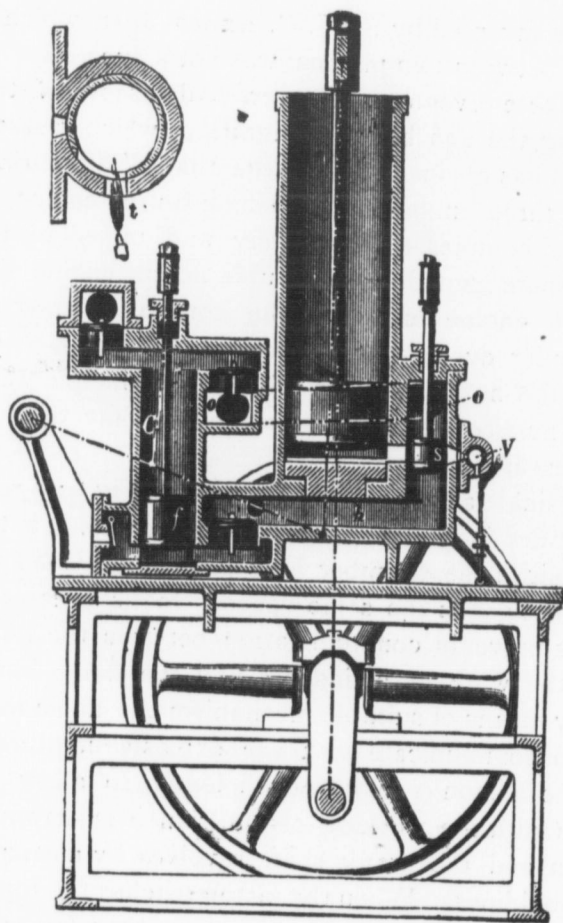


FIG 2.

atmospheres, the difference, 50 atmospheres, being the working pressure. The reason of the failure of the engine will be obvious.

Several other minor inventions now followed, although they all seem to have been on the principles of the earlier inventors, and Brunel's seems to have been the only one of any account of this class.

W. L. Wright proposed, in 1833, to draw into the working cylinder air and gas separately, then mix and ignite them, using the expansive force of the gases as in the case of the steam engine.

Cooper, in 1835, and Johnson, in 1841, ignited in their engines mixtures of hydrogen and oxygen which, after explosion, produced a vacuum and allowed the atmospheric pressure to perform work on the piston.

An engine invented by Sir J. C. Anderson in which gun cotton was exploded between two pistons, was not a success.

None of these inventors, however, had discovered the necessity of compressing the gas before its ignition, which is essential to the economy of all gas engines. It is true that William Barnet did, in 1838, invent three engines, (1) a single acting engine in which air and gas were compressed separately and mixed in the working cylinder and there ignited, (2) a double acting engine similar to the above, (3) an engine in which the compression occurred in the working cylinder during one stroke and ignition took place at the beginning of the next stroke, in which this principle was employed, yet he does not seem to have seen the economy of it and did not bring it successfully forward.

Barnet's single acting engine is shown in Fig. 2; *a* represents the working cylinder in which the explosion occurs, *C* is the pump for compressing air in the chamber *h*, while behind *C* is another pump compressing the gas in the same space. In its present position the piston valve *s* prevents communication between the mixture in the chamber *h*, the working cylinder *a* and the flame burning in the valve *V*. By means of suitable mechanism the flame in the valve *V* is allowed to communicate with the explosive mixture at the same time that the piston *s* moves sufficiently to allow the gas to communicate with the working piston, which is driven upwards by the explosion and the crank shaft revolves by means of the rods shown in dotted lines. When the piston reaches the top of its stroke, the flywheel draws it down and at the same time forces the piston *s* down far enough to allow the burnt gases to pass from *a* out through the pipe *o* into the pump *C*, from which they are exhausted into the atmosphere.

By means of a screw contrivance the flame is cut off from the working cylinder during exhaust.

Millon, the French inventor, and Schmidt, the German engineer, seem, however, to have been the first to show the advantage of com-

pression. The former in his patent of 1861 says : * “ In usual forms of engines the operation of the working cylinder is similar to that of pumps, the effect being to give two cylinders acting against each other, the pump even presenting higher resisting pressures than are found in the driving engine. The engines are thus made very large for the power produced. On the other hand, the engines working gases under the described conditions (pre-compression) will give great power in proportion to their size. The sudden firing of the gases compressed into the working cylinder gives the latter a much higher pressure than is perceived in the pumps.”

We have now come to the point at which the gas engine began to be no longer a speculation, but a reality.

The first engine in practical use was the Lenoir, introduced in 1860. In this engine air and gas in proper proportions were drawn in

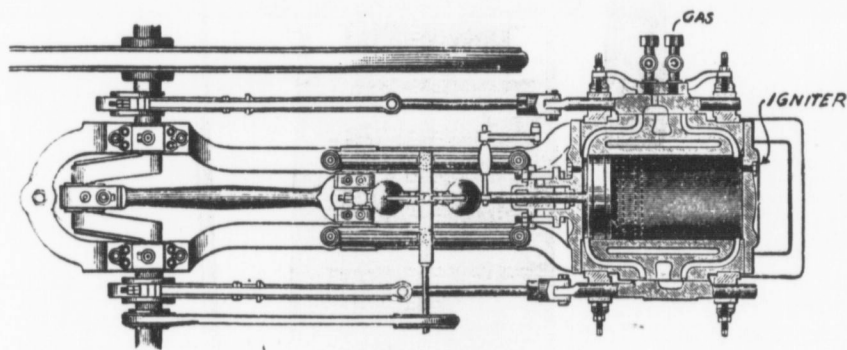


FIG. 3.

during the first half of the stroke, when the admission was closed, the ignition caused by an electric spark and the gases did work by expansion during the remaining half stroke, and were expelled during the return stroke. An indicator card from this engine is shown in Fig. 4, and the engine itself in Fig. 3. Air and gas enter on the upper side of the engine, as shown in the figure, through a valve and ports in a similar way to steam in the steam engine. The exhaust takes place on the lower side through a valve, both the inlet and outlet valves being operated by eccentrics fastened to the crank shaft. The electric ignit-

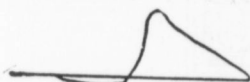


FIG 4

* THURSTON—Heat a form of Energy.

ers are indicated in the two heads of the cylinder. No pumps were used in this engine, and the whole machine bears a striking resemblance to a steam engine in which the steam and exhaust parts are separate and on opposite sides of the cylinder. Compression was not used, and the heat taken off by the water jacket bore a large proportion

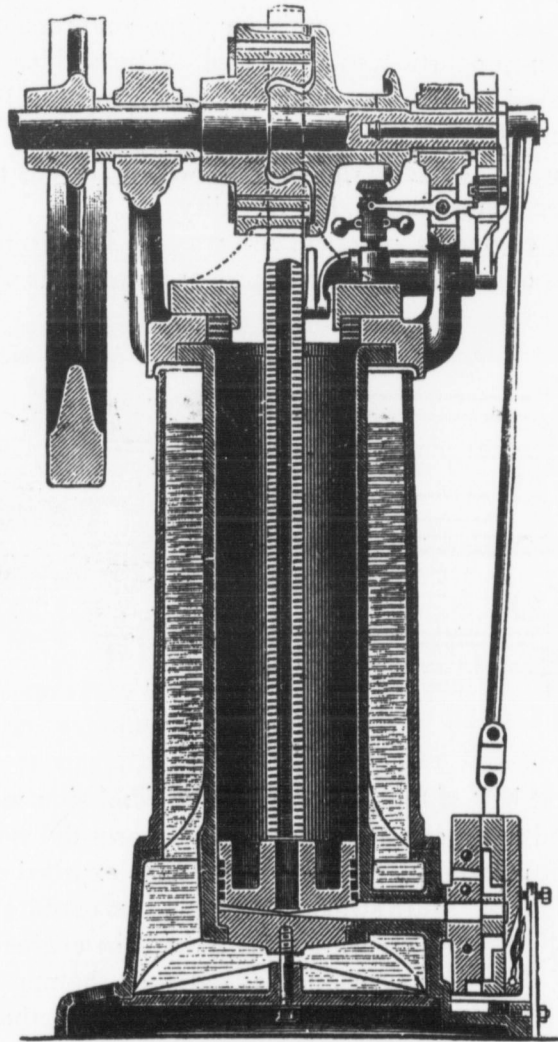


FIG. 5.

to the total heat ; the efficiency, therefore, was very low. The consumption of gas was about 95 cubic feet per horse power per hour, as against about 22 cubic feet in many engines at present in operation.

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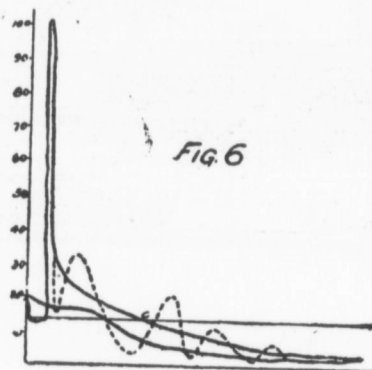
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Hugon used a non-compression engine, with a jet of water for cooling. The only remaining engine of this type is the Bischoff.

The Otto and Langen engine introduced in 1866 used no compression, but was comparatively economical. The engine is shown in Fig. 5, and the working cylinder is vertical. Gas and air are admitted and exploded at the bottom of the cylinder, causing the piston to rise with great velocity without doing work. When it reaches the top of its stroke the water jacket cools and rarifies the gases and the atmospheric pressure and weight of the piston cause the latter to drop downward, during which motion it engages with the crank shaft and causes it to revolve, the burnt gas being dis-



charged near the end of the down stroke. Fig. 6 is an indicator card from this engine, although Mr. D. Clerk points out * that it is incorrect, owing to the vibration of the indicator. This is readily seen, for the area below the atmospheric line must be less than the area above the line by an area representing twice the amount of work done in raising the piston; c should therefore be nearer to the right hand end. The engine used about 40 cubic feet of gas.

The necessity of compression to economy had, however, again been brought out by Beau de Rochas in 1862, who suggested the four-stroke cycle engine, in which the gas and air are drawn in during the first forward stroke, compressed during the return stroke, ignited and allowed to expand during the second forward stroke, and the burnt products of combustion discharged during the second return stroke. He also showed that the conditions for maximum efficiency in this cycle were (1) the cylinders should have the greatest

* CLERK—The Theory of the Gas Engine.

volume with the least amount of circumferential surface, (2) the speed should be as high as possible, (3) the cut-off should be as early as possible. (4) the initial pressure should be as high as possible.

However his suggestions were not carried out till 1876, when Otto rediscovered the four stroke cycle, and invented his "silent" engine, which has now displaced all others.

The engine is shown in Fig. 7 and is horizontal. The piston is shown at the back end of its stroke, and the air and gas valves are open to the cylinder. The air and gas are admitted through ports in

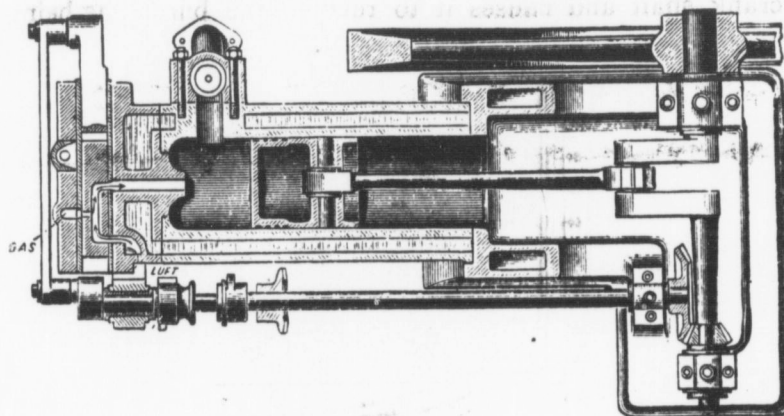


FIG. 7.

a long rectangular valve, which is operated by means of a horizontal shaft running at one-half the speed of the crank shaft, from which it is driven by means of gears. The mixture of gases passes into the cylinder during the first forward stroke of the piston and the admission is then closed, the gases in the cylinder being compressed during the return stroke. At the beginning of the second forward stroke a flame burning at C is allowed by the valve to communicate with the gases in the working cylinder, the ignition and explosion of these gases driving the piston forward. The burnt products are discharged during the second return stroke, and the cylinder is then ready for a new charge.

Atkinson endeavored to improve this engine by making the ratio of expansion greater than the ratio of compression, for in the Otto engine the exhaust temperature is high and the gases are still capable of doing considerable work when discharged. He used alternately long and short strokes, but the mechanical complexity was great and the plan has not been generally adopted.

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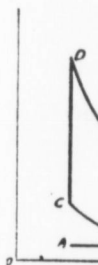
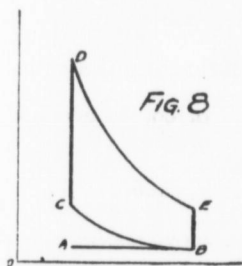


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THEORY OF THE GAS ENGINE.—Mr. Dugald Clerk classifies* gas engines in three distinct types: (a) An engine drawing in air and gas at atmospheric pressure for a portion of the stroke, then cutting off the supply and igniting the mixture, causing work to be done on the piston during the remainder of the stroke by the expansion of the burnt gases, which are exhausted during the in-stroke. This is similar to the Bischoff engine. (b) An engine in which air and gas are drawn in, mixed, and compressed in a reservoir. The reservoir communicates with the working cylinder and the mixture is allowed under a state of compression to enter the working cylinder, being ignited at constant pressure as it enters, and causing the piston to move forward. The burnt gases are discharged during the return stroke. (c) An engine in which a mixture of gas and air are compressed in the working cylinder and ignited at constant volume, thus causing the piston to move forward. The burnt gases are discharged during the return stroke. He has compared these engines theoretically under as near as possible their working conditions, and finds their efficiencies to be respectively .21, .36, .45. The compression engine igniting at constant volume having a decided advantage over the others, it is the only one which will be considered in this paper.



The theoretical form of diagram for such an engine is shown in Fig. 8, in which O A represents the clearance volume and A B the volume swept out by the piston. A B is the admission at atmospheric pressure, B C the compression, C D the rise of pressure caused by explosion, D E the expansion line, and E B A the exhaust, the lines B C and D E being adiabatics.

It would hardly be supposed that the diagram actually obtained from the gas engine would show a close resemblance to the theoretical diagram on account of the water jacket surrounding the cylinder, which is known to take away a very great per cent. of the total number of heat units generated by the explosion of the gas.

There is a remarkable resemblance, however, between the actual and theoretical diagrams, and this led to considerable investigation of

* DUGALD CLERK—The Theory of the Gas Engine.

the subject, and the writer desires to insert the result of part of Mr. Clerk's work. He constructed an engine having a cylinder 6 inches in diameter and 12 inches stroke, and making 150 revolutions per minute. Fig. 9 is a diagram from this engine, which shows maximum



pressure to be 220 pounds per square inch above the atmosphere, and that before ignition to be 41 pounds. The temperature before compression was 17°.3C., after compression 150°.5C., and that at maximum pressure was 1,537°C., at exhaust 656°C. The results obtained in a similar perfect engine, assuming the working

fluid to be air, and that it is compressed to 40 pounds above the atmosphere and then suddenly raised in temperature to 1,537°C., he finds to be :

1 cubic foot of air at 17°C., and atmospheric pressure at constant volume, requires to heat it from the temperature of 150°.5C. to 1,537°C., an amount of heat equivalent to.....	24,416 ft. pds.
Maximum pressure above atmosphere	220 pds.
Pressure at end of stroke, per square inch.....	49 pds.
Mean available pressure above atmosphere	89.8 pds.
Temperature at end of stroke	953°C.
Work done on piston	7,888 ft. pds.
Efficiency	$\frac{7888}{24416} = .323$

These results may be readily verified from the following data :

Specific heat of air at constant volume	0.169, water=1.00
Specific heat of air at constant pressure.....	0.238
Mechanical equivalent of heat in foot pounds, Centigrade	1,389.6
Weight of 1 cubic foot of air at 17°C. and atmospheric pressure	0.075 lbs.

The work actually done by the engine, as shown in the diagram, was, however, only 6,851 foot pounds per cubic foot of combustible, considering only $\frac{9}{10}$ of stroke, the mean effective pressure for this portion being 78.0 pounds, as against 89.0 pounds per square inch on the theoretical card. The calculated duty of the engine was thus $\frac{6851}{24416} = .28$. Now, taking ordinary samples of coal gas he found that 3.92 cubic feet would, if its whole heat were converted into mechanical work, develop one horse power per hour. The *calculated* consumption of gas was then for the theoretical diagram $\frac{3.92}{.28} = 12.1$ cubic feet, for the actual diagram $\frac{3.92}{.28} = 14.1$ cubic feet, and the actual consumption by

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experiment was 22 cubic feet. While then the difference between the actual and theoretical *calculated* efficiencies from the diagram is only small, yet the *actual* difference is great. Now the number of cubic feet of combustible required per H.P. per hour by the engine is $\frac{1980000}{6881} = 289$, so that for each cubic foot of combustible mixture there is $\frac{22}{289} = .0761$ cubic feet of gas, while in the perfect engine there would be required but $\frac{12.1 \times 7888}{1980000} = .0483$ cubic feet. It would, therefore, appear that while the actual diagram would indicate an efficiency only 4 per cent. below that calculated from the theoretical diagram; yet the actual difference is much greater than this, and the actual efficiency is only about 55 per cent. of the theoretical. It is quite evident, then, that the amount of heat passing between the cylinder walls and the outside, and hence the efficiency of the engine, cannot be found by comparing the theoretical and actual diagram. "This fact was first pointed out by Prof. Rücker, of Leeds, and does not seem to have been noticed by early experimenters, so that results given by them as to efficiency are considerably too high."*

Authorities on the gas engine seem to differ as to the cause of the phenomena above noted, some of them affirming that they are a result of slow inflammation of the gas. The gas, they maintain, is only gradually ignited; as the piston moves forward the heat added by the slow ignition keeps up the pressure.

Mr. Clerk, however, does not agree with this explanation, and his objection seems to be sustained by the results of experiments made on various mixtures of gas and air, the proportions ranging from 1 of gas to 5 of air, to 1 of gas to 15 of air. When the ratio was 1 of gas to 6 or 7 of air the best explosions resulted, and it was found that maximum temperature and pressure, which Mr. Clerk maintains indicate complete ignition, occurred in $\frac{1}{20}$ of a second after the light was applied, and that the maximum temperature was only $1,800^{\circ}$ C., instead of a calculated $3,800^{\circ}$ C. Having known also that the high temperature immediately after ignition would prevent complete union of the gases, led to the conclusion that the phenomena observed in the engine were not due to the slow ignition, but rather to the fact that the gases only gradually united as their temperatures sufficiently decreased.

However, although this latter theory may serve as a partial explanation, it does not seem to be the real reason, for these results

* CLERK—Theory of the Gas Engine.

are noticed more in engines in which the explosive mixture is weak in gas, the temperature therefore comparatively low, and its effect on the combination of the gases small.

The matter therefore requires further investigation.

Otto at first thought it important to have the mixture in the engine stratified so that a part rich in gas should be first ignited, which would readily ignite the rest. It has, however, been shown that this is entirely unnecessary, and that as good results are obtained in well mixed mixtures. It should, however, be borne in mind that ignition is more easily effected in a mixture rich in gas than one poor in gas, so that care should be exercised to place the igniters in such a position as to be in contact with fresh gas and not with the burnt gases from the previous explosion.

The distribution of heat in the Clerk engine was as follows, as may be calculated from data already given on assuming that gas produces on complete combustion 505,000 foot pounds. (Since there is only .0761 cubic feet of gas present per cubic feet of mixture, the heat evolved will be .0761 x 505,000 = 38,430 foot pounds.)

	Foot pds.	Heat units per cent.
Work done by 1 cubic foot of the mixture	= 6,851	17.83
Mechanical equivalent of heat discharged with the exhaust (= {656-17} x .075 x 1,389.6 x .169) = 11,253	= 11,253	29.28
Mechanical equivalent of heat passing through the sides of the cylinder (by subtraction)	= 20,326	52.89
Totals	38,430	100.0

That is, for every 100 heat units given off by the explosive mixture, 29.28 are given off in the exhaust, 52.89 are lost in heating the water in the jacket, and only 17.83 are converted into useful work.

EFFICIENCY OF THE GAS ENGINE.—The efficiency of the cycle is measured by the ratio of the work done by the gas to the total quantity of heat supplied.

Referring to Fig. 8, since BC and DE are adiabatics the work of expansion will be

$$W_{DE} = \frac{v_D p_D}{k-1} \left\{ 1 - \left(\frac{v_D}{v_E} \right)^{k-1} \right\}$$

and the work done on the fluid during compression is

$$W_{CB} = \frac{v_C p_C}{k-1} \left\{ 1 - \left(\frac{v_C}{v_B} \right)^{k-1} \right\}$$

and Q, the total heat supplied in foot pounds, is given by

$$QA = C_v (T_D - T_C).$$

Where p, v, T are respectively the absolute pressures, volumes and temperatures at the points indicated by the subscripts; k is the ratio of the specific heats of the gas; C_v is the specific heat at constant volume, and A is the reciprocal of Joule's equivalent.

But $v_D = v_C$ and $v_B = v_E$ and $p_D T_C = p_C T_D$.

Hence the efficiency E is given by

$$E = \frac{\frac{v_D p_D}{k-1} \left\{ 1 - \left(\frac{v_D}{v_E} \right)^{k-1} \right\} - \frac{v_C p_C}{k-1} \left\{ 1 - \left(\frac{v_C}{v_B} \right)^{k-1} \right\}}{\frac{C_v}{A} (T_D - T_C)}$$

$$= \frac{\frac{A v_C p_C}{k-1} \left[\frac{T_D - T_C}{T_C} \right] \left[1 - \left(\frac{v_A}{v_B} \right)^{k-1} \right]}{C_v (T_D - T_C) (k-1)} = 1 - \left(\frac{v_A}{v_B} \right)^{k-1}$$

ACTUAL CONSTRUCTION OF THE ENGINE.—Engines such as the Otto, Fig. 7, are made single acting, and are of very simple construction. The cylinder is of cast iron and has a water jacket cast on to it, which, in the performance of the engine, is supplied with a stream of water.

The cylinder has no head in the crank end, and no crosshead is required, as the piston, being made of an extreme length, serves the purpose of guides. The volume of the cylinder and volume of clearance are usually so proportioned that the pressure, after compression, is about 35 pounds per square inch above the atmosphere.

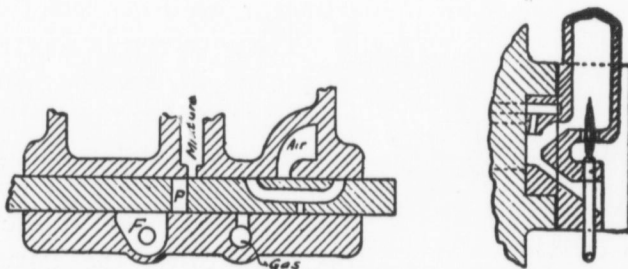


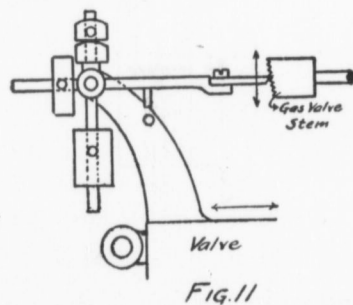
FIG 10

The gas and air are admitted as shown in the figure, the inlet valve being of rectangular shape and operated through the horizontal shaft, driven from the crank shaft by means of a bevel gear and

pinion; reducing the velocity in the ratio of two to one. A large section of the valve is shown in Fig. 10. The spaces marked "gas" and "air" are respectively connected with the supply of gas and the atmosphere; as shown in the figure, admission is taking place, the gas and air passing into the valve, mixing as they go, and the mixture is passing into the cylinder. The valve remains open for one full outward stroke of the piston, during which it moves over enough to the left to close the parts at the end of the stroke, so that compression may occur in the cylinder on the in-stroke of the piston. The valve now continually moving over to the left, brings a port, P, in contact with a flame which burns at F, and this port, carrying the flame with it, passes over till it communicates with the cylinder and ignites the mixture. In the valves a small hole is drilled from the port P to the inner face of the valve, which comes into communication with the cylinder just after P has passed away from the flame F. This small hole conducts the compressed gas from the cylinder to the flame in P, and the pressure in this port is thus raised very high on account of combustion of the gases, so that the flame shoots forth, igniting the whole mixture in the cylinder as soon as the valve reaches the proper position.

In all gas engines the gas is admitted through two valves before entering the engine, and is not in communication with the slide valve until the outer valve is opened.

This outer valve is placed directly at the end of the gas pipe and is operated usually through the governing mechanism, so that in case the engine runs above normal speed this valve will not be opened, and consequently a fresh charge will not be admitted to the cylinder, although a charge of air is of course drawn in at each fourth stroke.



The governor for this type of valve is shown in Fig. 11, and scarcely needs any explanation. It is a pendulum governor, and when the speed is normal, hangs in such a position as to open the gas valve at each stroke of the inlet valve, the governor being attached to the latter. If, however, the speed is excessive, the weight flies out, and the small lever being drawn down misses the valve and a charge of gas is not admitted, and consequently no explosion occurs for the succeeding stroke of the piston.

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INLET VALVES.—In some cases, however, and they are not few, the inlet valve is of the kind known as the “poppet” valve shown in Fig. 12. In most of these cases the velocity ratio between the crank shaft and valve motion is obtained by means of a spur-gear and pinion. The pinion is keyed to the crank shaft and a pin is put on the gear wheel, to which a rod is attached, and which consequently has the motion of the connecting rod of an engine. The end of this rod striking against the end of the valve, causes it to open, and it closes of itself by means of a spring.

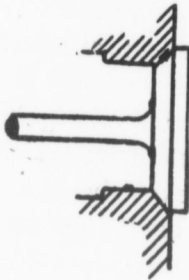


FIG 12

OUTLET VALVES.—All outlet valves seem to be somewhat similar in construction, being principally of the “poppet” type, and are operated by means of a cam placed on the slow moving shaft, the details of the arrangement depending on the peculiarities of the engine. Fig. 13 shows the Otto arrangement. In both the cases of the inlet and outlet valve they are arranged to be open for one full stroke and should then close rapidly if of the “poppet” type, in order that the valve may fit properly in its seat. Poppet valves have now been adopted in the Otto engine as made in Philadelphia.

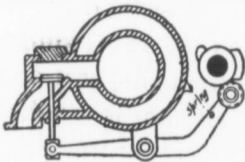


FIG 13

GOVERNORS.—Governors are sometimes arranged to operate the exhaust, and sometimes to operate the inlet valves.

A means of governing the outlet valve is by sliding the cam along the shaft so that it does not come into contact with the lever connected to the valve when the speed is too great. The cam may be fastened to the shaft by means of a feather, which will make the cam revolve and will still allow motion endwise. One type of governor for the inlet valve has already been explained. In case of the latter (poppet) type of valve, the governor often merely controls the end of a small lever attached to the operating rod for the valve, the lever operating a valve on the main gas pipe as in the case of the governor in Fig. 11. When the speed of the engine is too great the lever is lifted clear of the valve and no gas is admitted.

It may at first be thought that the governing of the outlet valve would have no effect, but when the pressure of exhaust is noticed it will be readily understood that if the cylinder be full of gas at high

pressure there will be no opportunity of getting fresh gas in for ignition unless this gas is released.

IGNITERS.—There are three kinds of igniters, one of which has already been mentioned, and which consists of a tube in which the gas is allowed to burn, the flame being made to communicate at certain definite times with the explosive gas in the cylinder.

Another type similar to this in some respects is the hot tube igniter which seems to be quite frequently used. A tube of platinum or some such substance is placed in such a position that the explosive charge may communicate with the outside of it, but the tube having an end in it the charge cannot get inside. On the inside of the tube a gas flame burns continually and keeps the tube at white heat. The tube is kept away from the explosive mixture until the time for the explosion comes, when the valve allows the two to communicate and the charge is fired. This igniter has some advantages in that there is nothing about it to leak or get out of order, but it is found that the excessive heat soon destroys the tubes and makes the scheme somewhat expensive.

Another kind is the electric igniter, which consists of some method of making a spark in the explosive gas at the required time of ignition. This method seems to be an excellent one, as it does away with all the hot tubes in the other igniters, all that is required being a fairly large battery, several large gravity cells being often used and an induction or spark coil. The igniter may be operated by a crank on the slow moving shaft to which is fastened a rod, the end of which has a lineal motion and may be so adjusted as to bring the points into contact as desired.

COOLING WATER.—The water for the water-jacket is always forced in at the bottom of the jacket, and allowed to run off at the top after it has been considerably heated in cooling the cylinder. The supply may be either taken from some convenient source, as the water works service, or a circulating tank may be provided, in which case the bottom of the tank should be level with the bottom of the jacket, the same water being used over and over. Very little water is required, and a half-inch pipe seems to be sufficient for the supply in a small engine.

WORKING FLUIDS.—The working fluids are various. Illuminating gas seems to have the preference on account of its convenience, although it is the most expensive.

A quality of gas known as "water gas," made by blowing steam over red hot coal or coke, is also used and is found to be very good.

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Carburetted air is used in gasoline engines. The gas is produced by drawing air over the surface of gasoline, having a specific gravity of about 0.65 to 0.67. Air treated in this way has an equal heating power to coal gas, and the great objection to the use of gasoline seems to be in the danger of explosion in the storage tank.

A gas quite generally used in self-contained gas engine plants is made by the Dowson process. A jet of steam from a small boiler is blown through an injector, where it is mixed with air, and the mixture is then passed over red hot coke or anthracite coal. The gas is then led through scrubbers into a storage tank. The calorific value of this gas is about one-fourth that of coal gas.

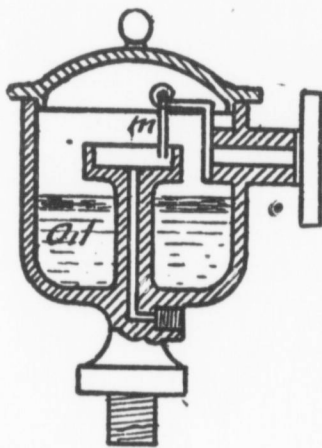


FIG 14

OILING.—All gas engine cylinders must be well oiled, and various methods are adopted to accomplish this. The apparatus used in the Otto engine is shown in the Fig. 14. The wheel *i* is driven by the engine and is supported on a shaft having on its inner end a crank on which hangs loosely a pin, *m*. As *i* revolves the end of the pin dips into the oil in the large vessel, then rises up to the inner vessel, where the oil is wiped off and runs down inside the tube to the piston. In many cases ordinary lubricators are used, the only requirement being that the supply of oil must be positive.

RESULTS OBTAINED IN PRACTICE.—

Results of tests made on the gas engine show that it compares favorably with other prime movers:

In a series of tests made by the Society of Arts, in 1888, on several engines, the consumption of coal gas was about 20 cubic feet per I.H.P. per hour, as shown in the following tests: In an Atkinson engine in which the expansive stroke was longer than the compressive stroke, the consumption was but 19.2 cubic feet. A trial made on the Crossley-Otto engine at the same time showed 20.8 cubic feet per I.H.P. and 24.1 cubic feet per B.H.P., showing a mechanical efficiency of 86 per cent. The speed of the engine was 160 revolutions per minute, and it developed 17.12 I.H.P., or 14.74 B.H.P. The amount of cooling water used in the jacket was 713 lbs. per hour, which was raised 71°.8F. in temperature. Thus of the total heat

developed 22 per cent. was converted into useful work, 43 per cent. given up to the cooling water, and 35 per cent. went off in the exhaust. The equation to the expansion curve of the diagram was $pv^{1.435} = \text{constant}$, and that of the compression curve $pv^{1.38} = \text{constant}$ approximately. The temperature of the exhaust was $2,130^{\circ}\text{F.}$, gas after compression was $1,060^{\circ}\text{F.}$, and the maximum was $3,440^{\circ}\text{F.}$ all absolute.

A simplex engine tested in 1889 showed a consumption of 21.55 cubic feet per H.P. per hour of town gas (607 heat units per cubic foot), and 88.03 cubic feet of Dowson gas (150 heat units), the jacket water used in the latter case being over 8 per cent. more than in the former.

REPORT OF A TEST OF A SEVEN HORSE-POWER ENGINE.*—Working capacity of the cylinder .2594 cubic feet, clearance volume .1796 cubic feet.

Temperature of gas supplied	62° .2F.
“ “ “ exhaust	774° .3F.
“ “ entering water	50° .4F.
“ “ exit water	89° .2F.
Pressure of gas in inch of water	3.06
Revolutions per minute (average)	161.6
Explosions missed per minute	6.8
Mean effective pressure, pds. per sq. in.	59
Horse power indicated	4.94
Work per explosion, foot pounds	2,204
Explosions per minute	74
Gas used per I.H.P. per hour, cubic feet	23.4
	Per cent.
	of heat
	received.
Heat Units.	
Transformed into work	22.84
Taken by jacket water	49.94
“ exhaust	27.22

COMPOSITION OF GAS.

	By volume.	By weight.
CO ₂	0.50%	1.923%
C ₂ H ₄	4.32	10.797
O	1.00	2.279
CO	5.33	15.419
C H ₄	27.18	38.042
H	51.57	9.021
N	9.06	22.273

On the tests above quoted the gas engine converts about 20% of the energy of the fuel into work, while the steam engine converts only about 15%, and more often 10%, of the energy of the fuel into work.

In ordinary working of engines using Dowson gas the consump-

* Journal Franklin Institute, Feb., 1890.

tion of anthracite coal is about 1.3 lbs. per I.H.P. per hour, and Messrs. Crossley, in England, guarantee on 300 H.P. engines using this same gas but 1 lb. coal or $1\frac{1}{3}$ lb. of coke per I.H.P. per hour, which is considerably superior to the steam engine.

Gasoline engines are on a par with steam engines using 6 pounds of coal per H.P. per hour, for the gasoline engine consumes about $\frac{1}{10}$ gallon gasoline per H.P. per hour, which, at 8 cents per gallon, brings the cost down to $\frac{8}{10}$ cent, corresponding to a consumption of 6 pounds coal when coal is at \$3.00 per ton.

This shows a very decided advantage for the gas engine, more especially when it is remembered that if the gasoline be employed no attendance is required, and there is no loss either when starting or stopping the engine.

On the other hand, although gas engines developing 320 H.P. have been constructed, yet they do not seem to be in general use, and the steam engine is used wherever considerable power is required.

Although the gas engine is, comparatively, very efficient, yet, as has been pointed out previously in this paper, very great losses result from the high temperature of the exhausted gases and from the amount of heat carried off by the water-jacket, and there is still room for improvement in these respects.

Another point requiring attention is the devising of a means of causing explosions to occur at each stroke instead of every fourth stroke. The present method requires very heavy fly-wheels and excessively large cylinders, which of course contribute considerably to the loss in the jacket.

CONCRETE AS MADE ON THE TRENT CANAL DURING THE SEASON OF 1896.

BY H. F. GREENWOOD, M. CAN. SOC. CIVIL ENGINEERS.

Before beginning the paper proper, it might be well to mention when and how concrete has been utilized on the great canal works of Canada. These will be taken somewhat in the order in which they were built.

In the first enlargement of the Welland Canal, the foundations of the locks were generally made of concrete and timber. Concrete was used very extensively in foundations, when the Lachine Canal was enlarged, and also in the locks along the Ottawa River. The canals along the St. Lawrence River, between the head of the Gallops Rapids and the foot of the Cornwall Canal, have concrete and timber foundations in all their locks, some of these bottoms containing as much as 2,000 cubic yards of concrete. Then the Sault Ste. Marie lock advanced concrete a step by showing its utility as a material for backing walls. It was also used in foundations and culverts at the same place. But the Soulanges Canal is really the pioneer as regards concrete for walls. Here the entrance piers (about 1,100 feet in length) at the head of the canal are made of crib-work as high as the level of low water mark. After these cribs had properly settled, a wall of concrete eight or nine feet high was built upon them. Besides being very substantial, this has proven a success and looks quite as well as masonry. When the work on this canal was let, alternative bids were asked for masonry throughout, and for concrete walls faced and coped with cut stone. Which of these kinds of work will be used the writer cannot say.

This brings us to the Trent Canal structures which were built wholly of concrete, no stone-work being used at all. The concrete works constructed during the season of 1896 were on the Peterborough-Lakefield Division, of which the writer has charge. This division consists of sections Nos. 1 and 2, with a firm of contractors for each section.

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The work on section No. 1 consisted of one lock, and the concrete in connection with two dams which were in the course of construction across the Otonabee River, for the purpose of raising it to the proper level for navigation.

The concrete works on section No. 2 consisted of the following:—Pivot piers and abutments for two swing bridges, abutments for one high level bridge, these latter abutments being 33 feet above the bottom of the canal, concrete in connection with a pipe culvert which conducts a creek under the canal, and concrete walls in two water-tight embankments.

The writer proposes to give, as briefly as possible, a description of the methods used and the precautions taken in constructing some of these works.

The specifications state that the contractors shall supply at their own cost, all plant, labor, moulds and materials necessary for the satisfactory execution and completion of the works, with the exception of the cement, which is supplied by the government.

SAND AND GRAVEL.—Extreme care was used in selecting the materials for concrete. The sand and gravel for section No. 1 were hauled in the winter, and were not at all difficult to find, as the conical and hog's-back hills in the vicinity are formed of these materials. Yet to find them free from clay, and to get coarse, sharp and well-proportioned sand caused some delay. The contractors sub-let this to the surrounding farmers and local men with teams at so much per cubic yard delivered on the works. Samples were brought to the engineer's office by these people, and it was some weeks before the proper kind of sand was obtained. The well-intentioned sub-contractor thought that what he dug out should go into his sleigh-box and none be wasted. So it was necessary to put an inspector at the pit to see that earthy matter, very fine sand and clayey gravel were all rejected, as it would be much more difficult to detect these after the material had been hauled to the works.

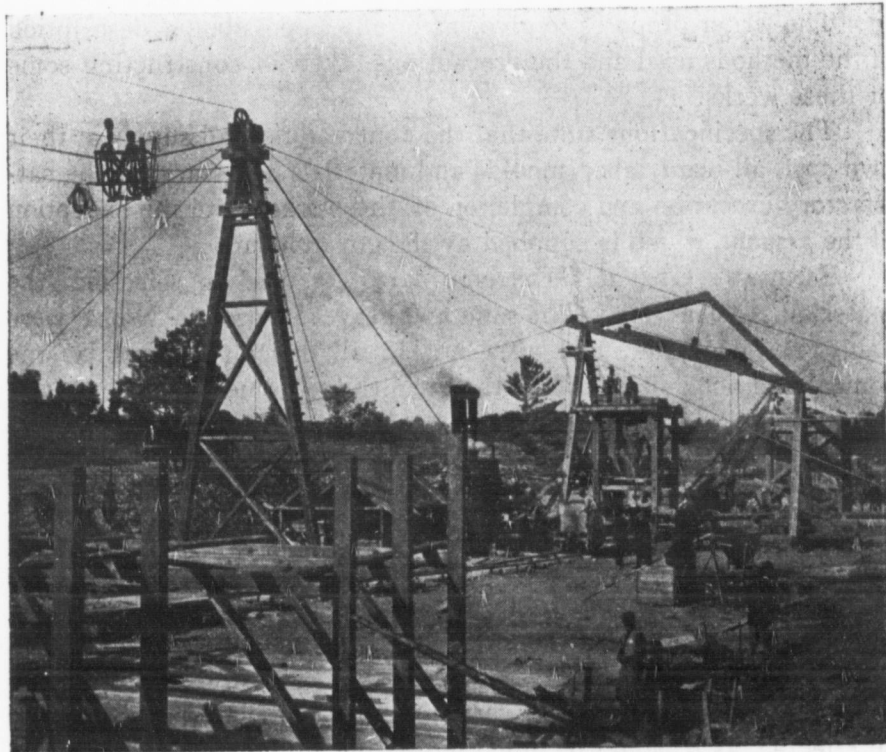
On section No. 2 the sand and gravel were obtained in a similar way; and, as the work progressed, delivered by dump-wagons at the side of the mixing platforms. These self-dumping wagons were of advantage to the contractors for this purpose, as they carried large loads and saved delay in emptying. Hauling the material as it was required saved moving it a second time; but unless the contractor had his own teams and wagons he could not be sure of a constant supply.

The following table is the result of sifting samples from two different grits:—

	Residue on 400.	R. on 900.	R. on 2,500.	Passed 2,500.
1st sample.....	19%	51%	22%	7%
2nd sample.....	8	42	38	12

Both of these have given good results.

CEMENT.—The cement for the season was let by contract, to be delivered in cars at the railway siding nearest the work, where it was



CONCRETE MIXER

handed over to the contractor. One of our Canadian firms, the manufacturers of the Star brand, secured the contract, but they were not able to keep the works supplied and also satisfy the demand from outside customers. The consequence was that after a time they supplied us with the Condor and Josson brands of Belgian cement. All cements were subjected to the following tests:—Color: the cement to

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be of a uniform quality and of a light gray tint, after being made into thin cakes and exposed to the air, and in no case must it show yellowish blotches. Weight: the specific gravity to be not less than 3.1. Tensile strength, per square inch of section, to be as follows: neat cement after three days 250 lbs., seven days 400 lbs., twenty-eight days 550 lbs. Fineness: All cement to be ground of such a fineness that 90% of it passes through a sieve of 10,000 holes to the square inch. Soundness: this was determined by Faijas apparatus. All pats when subjected to a moist heat of 110° Fahr. and warm water, to show no signs of blowing, for 24 hours after the tests were begun. All the above mentioned brands gave good satisfaction, but the Star brand was found to be more finely ground than the other cements. Unlike the other brands, it was supplied in "jute" sacks which were found by the contractors to be more easily handled when using the mixing machine; but the writer considers that there is more waste, as a certain amount remains in the sacks when emptying them. Six samples of cement were taken from each car as soon as it arrived in Peterborough, and these had to pass the following tests, viz., sifting, specific gravity, and blowing, before the car could be sent to the contractor's siding, where it remained until the three-day test for tensile strength had been made. If this proved up to standard, the car-load could be transferred to the cement-shed erected by the contractor close to the railway siding.

BROKEN STONE.—The specifications called for this to be free from earthy matter and to pass through a two-inch ring. The crusher used on each section was well adapted for the work it had to do. On section No. 1 they used a "Blake" jaw crusher to break the selected stone from the excavated limestone strata. On section No. 2 a "Gates" crusher of coffee-mill type was used, and there the stone were principally hard heads from the fields, or boulders from the excavation. The jaw crusher on section No. 1 run by steam, crushed about 150 cubic yards per day, while with the machine on section No. 2 electricity was used and a cubic yard of broken stone was obtained in 3½ minutes.

MOULDS.—The moulds for shaping the face of the lock walls were made by placing braced rectangular frames every five feet apart, and arranged so as to extend across that part of the lock for which they were intended. When they were in place, three-inch planed plank with half-inch lap joints were spiked to the vertical pieces and thus formed the face of the wall. Moulds of unplanned boards, made

like very long doors and placed end to end on edge, formed the back of the wall. These moulds, the same height as the proposed steps, were braced from the face of the excavation.

The moulds for the concrete, placed in front of the timber dams, were made in a similar way. In order to avoid sharp edges, mouldings with radii of from two to four inches were placed at all exposed angles less than 120 degrees.

For the bridges, the water-tight embankments, etc., the moulds were formed of scantling and plank placed in the same way as the moulds for the face walls of the lock, but were held in position by braces from the surface of the ground. Nearly all the face walls of bridges were built to a batter; whereas those of the locks were built plumb. In the high level bridge, the moulds at the back were held in position by iron rods passing from front to rear of the wall.

METHODS OF MAKING CONCRETE.—On section No. 1 the concrete for the lock was mixed by machinery and that for the face of the dams by hand.

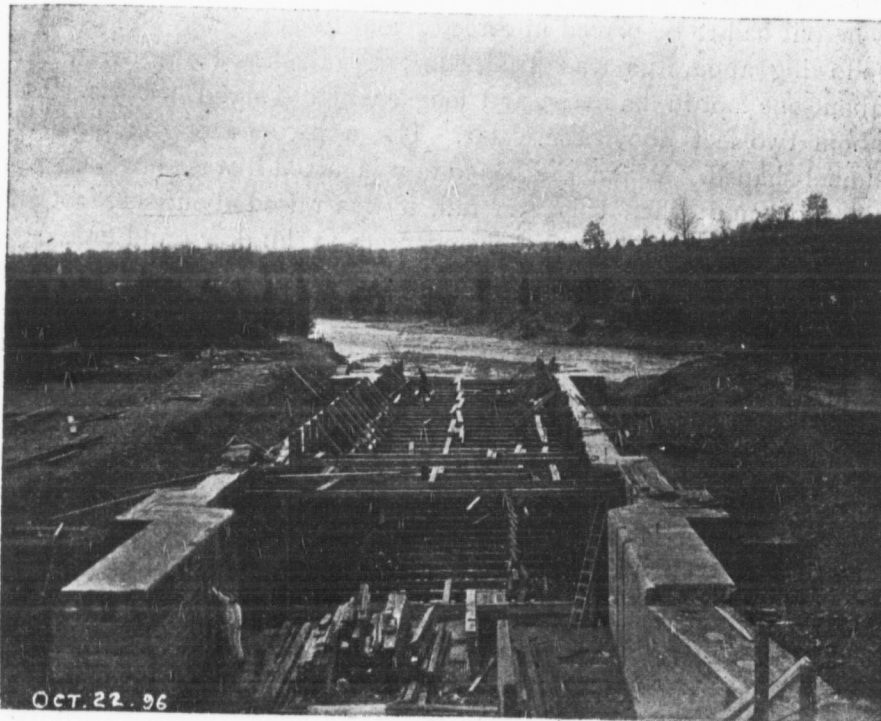
The mixing machine consisted of a cubical sheet-iron box revolving on its diagonal axis about six feet above the ground. This box was held up by a frame-work which also supported a platform above the box, and let into this platform was a hopper for receiving the materials. In the rear of the mixer was the crusher with a carrier leading from it into a large box hoisted on posts, to receive the broken stone. The stone was let out of this box, by a small sliding door, into a car that held one cubic yard of stone. The stone was then taken by car and dumped into a large oak box, holding $1\frac{1}{4}$ yards, placed near the mixer. The cement which had been deposited on a platform close at hand was dumped in upon the stone. Then the sand and gravel, brought in from the sand pile by another car, was dumped in last and about filled the box. The box was then hoisted and the contents dumped into the hopper. A barrel on the platform of the hopper was kept filled with water by a force pump at the river bank, and from this barrel a graduated tub was filled to the required height. When everything was ready the door of the cubical box was opened, and, when the slide door of the hopper was shot back, the tub of water was poured in as the materials were falling through into the mixer, which was then closed and revolved. It was found necessary to strike the mixer with mallets to keep the materials from sticking to the sides. After about sixteen or seventeen revolu-

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tions, the mixer was stopped and the concrete dropped into a box on a flat car beneath. It was then conveyed to the cableway, hoisted and run into the lock where, for the foundation, it was dumped, spread out in a layer of eight or ten inches and well rammed. For the walls the face was formed of mortar of proportion two to one, and two to five inches in width, as the case required, placed against the face mould, and this mortar was backed up by concrete in eight to ten-



CONCRETE LOCKS, SHOWING MOULDS

inch layers, well rammed. Where bolts were built into the concrete, for the purpose of holding the wallings or iron casings, a three to six inch square turn was made on the end imbedded, which gave the bolts an L-shaped appearance; the other end of these bolts had a nut and washer on them. This arrangement was continued throughout, and a three-inch layer of mortar properly smoothed over formed the coping. By this process a cubic yard was manufactured every five minutes. The best ten hours' mixing was 140 cubic yards.

The concrete on section No. 2 was all mixed by hand, and here the proper proportions of cement, sand and gravel were thoroughly mixed together on the platform and spread out. Clean water was now added and the mass well worked with hoes. Broken stone was then spread over this and the whole turned over twice. It was then put into barrows, wheeled and dumped into the work, where the layers were well rammed, and the face of the wall treated as on section No. 1. The concrete along the face of the dams on section No. 1 was made and put in place in a way similar to that on section No. 2, except where it had to be placed in three or four feet of water, and then the following apparatus was used, viz.: a galvanized sheet-iron tube about one foot in diameter, and long enough to stand, when vertical, about two feet above the water. The upper end of the pipe was funnel-shaped. When the concrete was mixed it was shovelled into the tube, and, when this was full, it was raised about one foot and moved about. This allowed the concrete to slip down and more was added. Thus the concrete was put in without becoming saturated, as after the tube was once filled its contents did not come into contact with the water until it had left the bottom of the tube when it was in the place intended in the wall. After a few days an examination showed that this concrete was quite satisfactory.

On section No. 1 a portion of the stone was much finer than the size called for, and consequently less gravel was required. After several trials it was found that the following proportions were most suitable, viz.: One part cement, two parts sand, two and one quarter gravel and seven of broken stone. On section No. 2 there was a less proportion of finely broken stone, and hence it will be seen that more gravel had to be used. The parts here taken were: cement, 1; sand, 2; gravel, $3\frac{1}{2}$, and broken stone, 7.

REMOVAL OF MOULDS.—The moulds for the smaller walls were not removed until after five or six days, and those of the higher, and, consequently, heavier walls, were kept on for several weeks.

After the removal of these moulds, the walls present a very fair appearance, although there were occasional small projections, where the plank had drawn apart and mortar had worked in; but these were easily removed with the edge of the trowel. The outlines of the plank were left visible and gave one the impression of masonry courses. Where there were pine knots in the plank an impression of these knots was left on the wall; and these spots were found not to

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have hardened like the rest of the surface. However, a wash of water and cement, with which the faces of nearly all the walls were treated, remedied this.

ADVANTAGES.—About 11,000 cubic yards of concrete works were built during the season, and in the same classes of work the cost was not over two-thirds that of masonry. Its advantages are cheapness, expediency, the utilization of the ordinary laborer instead of the skilled mason and stone-cutter ; and, besides these, the stone is more easily found. The use of this class of stone has a tendency to beautify the surrounding country, as the farmer is paid to remove those objectionable stone-piles one so often sees dotted over his farm.

HYDRAULIC MINING IN BRITISH COLUMBIA.

AN ADDRESS DELIVERED BEFORE THE SOCIETY BY
J. W. TYRRELL C.E. (*Tor. Univ.*), M. CAN. SOC. C.E.

MR. PRESIDENT AND GENTLEMEN :

I am afraid there may be some disappointment in expecting a paper from me to-day, as I have not been able to find time to prepare one. However, I have here a plan of a placer mining proposition in British Columbia, upon which I have been, and am still working, and shall be very pleased indeed to give as full an explanation of the proposition as I can, and shall be glad to answer any questions which may be asked in connection with it.

As you will see by the title on the map, the name of the property is the Bridge River and Lillooet Gold Mine of the District of Lillooet, British Columbia. The claim or rather claims (for there are a number of them consolidated) are situated on the Bridge River, seventeen miles above its junction with the Fraser, to which it is tributary. The central feature of the claims is a large horse-shoe bend in the river, which itself flows in a deep gorge through banks of gravel about 450 feet in height. At the upper end of the horse-shoe the river strikes a protruding point of rock, which diverts its course and causes it to flow around to the north, thence easterly, then southerly through a narrow gorge between two rocky bluffs, and thence again to the eastward. It is expected that the bed of this horse-shoe bend, which is a broad gravel flat, will prove the richest part of the mine. The Bridge River is well known to be one of the richest gold-bearing streams in British Columbia. Through the narrow canyons which exist on the upper portion of the river it flows at the rate of five or six miles an hour; but when it strikes this protruding point of rock, which is about 350 feet in height, and which is commonly known as the "Hog's Back," the river is suddenly diverted and its current is very greatly reduced, from about five or six miles an hour to three or three and a quarter; so that, its velocity being checked, it will naturally

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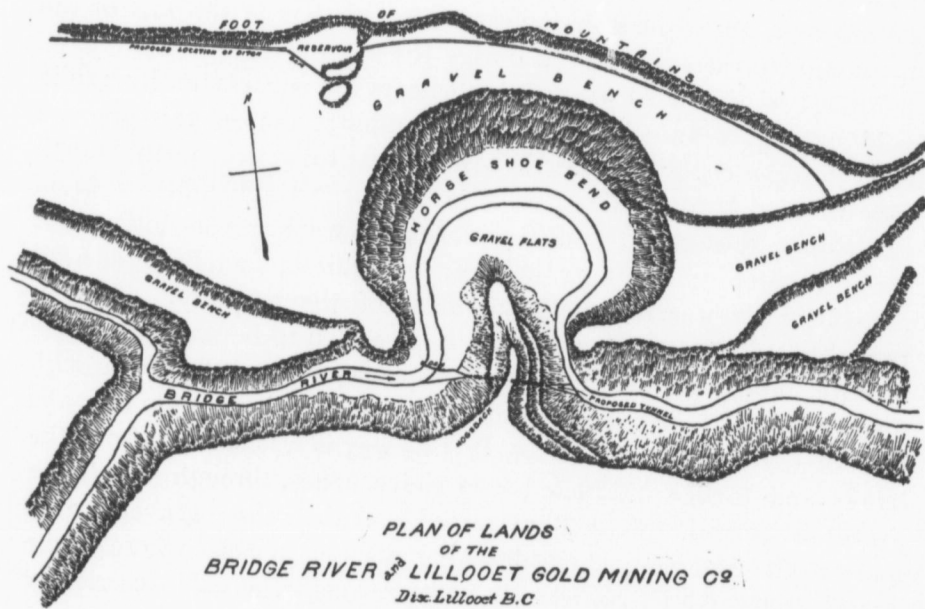
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deposit in the bed of the stream whatever gold it carries. It cannot do otherwise. This accounts for the rich gold deposits which have been found in the horse-shoe bend, as much as \$140 to the cubic yard having been taken from portions of it.

Bed rock has not been reached at all as yet. The richest deposits of gold in these placer mines are usually at bed rock below the gravel; so that it is expected something very rich will be found at the bottom. Sufficient prospecting has, however, been done on the property to prove beyond any question that it is rich in gold, but it has not yet



been prospected thoroughly. They now propose to sink a number of shafts and prospect holes so as to be able to determine with comparative accuracy the value of the whole property. This it is quite possible to do in the case of these placer mines. For instance, along the face of the banks of the river, which are about 450 feet in height, one can cut channels from top to bottom and ascertain the exact percentage of gold at various elevations down the face of the bank. You can readily see by taking a section from north to south through the horse-shoe along those banks in a couple of places, and again, along the face of those steep banks from east to west, that you will get cross-

sections which should give a fair average, and in that way a close estimate can be readily formed of the value of the whole property. If they determine to go into the matter more thoroughly, as some companies do whose claims are less favorably situated, they can sink shafts from top to bottom of the beds; but, of course, such shafts would be much more expensive than open channels in the face of the banks.

The whole property, I may say, lies in a deep valley between mountains which attain heights of five and six thousand feet on either side. The line marked "foot of mountains" is the foot of a range of mountains about six thousand feet in height. The southern boundary of the map approximately indicates the position of the foot of the mountains to the south of the Bridge River.

One of the most essential elements to success in hydraulic gold mining is an abundant water supply; and in this we are most fortunately situated. We are able to intercept the north fork of the Bridge River at a point about three miles west of the Company's claim, and thus bring a whole river down over their property to wherever it may be required, and have a head of 450 feet for working the lower beds of the property. As you probably understand, these gravel beds are all to be washed by jets of water brought down through this open canal and thence through open pipes, and discharged through what are called giants into the face of the banks; the gravel in this way is washed out from the banks and thence conducted into sluice boxes, through which the gravel is passed, the gold extracted and the refuse gravel carried away to the most convenient dumping place. In cases where ample dumping ground is not conveniently available, a cable carrier or elevating machinery is necessary in order to dispose of the great quantity of refuse gravel. In this case I do not think anything of the kind will be necessary. This mining location is most favorably situated in respect to the disposal of the refuse gravel; the channel of the river, as you see, is about 450 feet in depth. By commencing operations at the lower end of the property and working west or up stream, they will be forming a dumping ground as they advance with the work; as they wash the gravel from one place it will be transferred to a position a few hundred feet to the east of its original place, until the upper end is reached. There is probably enough gravel in these beds to furnish the company with all they can do for the next forty years, and that even with a very large supply of water. The

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Company has already secured 5,000 miner's inches of water, which is more than is being used by any mining company in British Columbia at the present time.

In order to dry the rich auriferous gravel bed in the bend of the river, it is proposed to construct a tunnel through the point of rock called the "Hog's Back," then dam the river and turn the stream through the tunnel. It is hoped in this way to be able, without much difficulty, to work the gravel to the bed rock, however deep that may be. It is said to be from thirty to forty feet below the bed of the river.

The total area of the claims of the Company amounts to 719 acres, and the total number of cubic yards of gravel amounts to about 366,000,000.

I may say that right at the grass roots on top of these high benches, which are 450 feet above the river bed, by prospecting in a number of places, an average of ten cents per cubic yard has already been found, and in one place, at the base of the gravel bank, as much as \$140 to the cubic yard. As to getting down to bed rock, we have not done that as yet.

The property is situated about eighty miles from the railway; Ashcroft is the nearest station. For sixty miles there is a good stage road kept up by the Government of British Columbia; the remaining twenty miles is pack trail.

It is estimated that about \$78,000 will be sufficient to equip the mine ready for hydraulic operations.

The course of the proposed water channel will be along the foot of the mountains to the north of the property. It is estimated that the water can be brought from a point three miles distant from the property, to where it may be required, for from twelve to fifteen thousand dollars. As compared with some of the other placer mines of British Columbia, this is a very small sum. The famous Cariboo Mine had to bring the bulk of its water supply for a distance of eighteen miles; and even after going to the great expense of bringing it that distance through extensive fluming and ditching, the supply was found to be insufficient, and other ditches had to be made, at great cost.

At this property there are probably 15,000 miners' inches available, although we are only bringing in 5,000 inches, that being considered ample. If necessary, the whole north fork of the Bridge River is available for use in working the mine.

The property is situated immediately to the west of the lands of the Indian Reserve, which are known to be highly auriferous as well, but on account of being held by the Indians they are at present not available for mining purposes. The lines of etching on the map represent different steps in the benches, each one being from fifty to one hundred feet lower than the upper one, the elevation of the highest bench being about 450 feet above the river bed in the horseshoe.

There is very little rock found on the property, only at three or four points; one at Gibson's Bluff, on the west side of the horse-shoe, again in the centre of the horse-shoe, where it is proposed to build the tunnel, and on the east side of the horse-shoe a bluff also occurs; but the remainder of the property is all gravel. It has evidently been of ancient river deposit, as one can clearly see from an elevation of three or four thousand feet. I took the trouble to climb up through the snow, although it was up to my waist, and, being without snowshoes, I had to simply wallow through it to get up. I reached an elevation of about 3,000 feet on the south side of the property, and from there got an excellent view of the whole claim; and it was quite clear that the ancient bed of the north fork of the Bridge River had been along the foot of the mountains to the north of the claims. This was particularly shown by a great slide of rock existing immediately to the west of the property. There had, in by-gone ages, been an enormous slide which had probably thrown the north fork of the river out of its original channel and caused it to flow in its present one. The confluence of the two streams had in former years, I believe, been somewhere in the vicinity of the horse-shoe itself. The former existence of the river to the north of its present position, along the foot of the mountains, would account for the existence of the great auriferous gravel beds.

I might say that the whole property is beautifully timbered. I never saw more lovely forests than occur right here on these high bench lands; they are as level as the floor, and the whole property is really a lovely park. The trees are all fir and pine, and there is no fallen timber at all. There is any quantity of timber for the construction of flumes, dams, tunnel-lining, or any other purpose. There is no building stone in the district, the rock found being of a soft nature.

I do not know that there is much more I can say, though I will be very pleased to endeavor to answer any questions that any gentleman present may feel disposed to ask.

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MR. TYRRELL—Two hundred feet to the inch. The total length of the claims from east to west is about two miles.

MR. YEATES—How is it they are able to get that much frontage? Is that sub-divided?

MR. TYRRELL—Yes. There are about ten leaseholds consolidated into one. The property was originally taken up in the names of these ten parties, and it was transferred or assigned by them to the Bridge River and Lillooet Gold Mining Company. The frontage limit of one claim is 1,500 feet, with an area of eighty acres, 1,500 feet along the river and going back sufficiently far to make up eighty acres. In some cases the mountains are so close that we could not get eighty acres in a claim, and they had to be reduced to whatever they might happen to be.

MR. DUFF—What is the quantity contained in the miner's inch?

MR. TYRRELL—That is a question that I had occasion to look up a good deal, for this reason: that a miner's inch varies in almost every country, and almost with every mining company. The miner's inch is really not a thoroughly established unit. In British Columbia, however, it is defined by statute, so that it is a fixed quantity there, and it is this: The quantity of water that will pass through half an opening one inch vertical by two inches horizontal, cut through an inch board having a head of seven inches above the centre of the opening.

In some places it is the quantity of water that will pass through an opening one inch square, with a head of six inches, and in some places the thickness of the board is one, two and three inches, so that that of course affects the discharge a good deal.

MR. BAIN—What will be found per cubic yard to pay for working?

MR. TYRRELL—About two cents a cubic yard has been found in many cases to pay for working; three cents will pay very well, and anything over that proportionately greater. It depends a good deal on the character of the gravel. If the gravel is found to be cemented, as it is in some mines, three cents would not pay at all. In the famous Horse Fly Hydraulic Mine, of the Cariboo District, the gravel is cemented a good deal, and they are now putting in stamp mills to crush it; so that probably twenty-five cents a yard would only about pay them in that case. The engineer of that company claims that he can crush the gravel at the cost of twenty cents per cubic yard.

In this mine there has been no cemented gravel found, and the three cents a cubic yard would pay handsomely. Two cents would pay working expenses.

MR. PIPER—What is the weight of a cubic yard of gravel?

MR. TYRRELL—I think it runs just about a ton.

MR. MITCHELL—With the exception of the Hog's Back, did you find any rock on the river?

MR. TYRRELL—Further up the north fork there are rocky bluffs. There is some along the river bank, but, excepting at the points I have mentioned, no rock shows on this property.

MR. MITCHELL—The indications would be then that there would be no auriferous gravel found to the west of the horse-shoe, where you say the slide of rock occurred?

MR. TYRRELL—Gold-bearing gravel is found further up the stream than the horse-shoe. I have not been up there myself, but I have been informed by prospectors and free miners who have been working up there that rich gravel beds do exist further up.

MR. MITCHELL—But not on this claim?

MR. TYRRELL—The whole of the bed of the stream is gold-bearing. Chinamen were working on a portion of the river bed east of the horse-shoe at the time I visited the mine, and they had to be ejected. They were making handsome dividends.

MR. WILKINSON—How is the gold found deposited in the gravel? In the free state?

MR. TYRRELL—In the free state in small nuggets about the size of a finger-nail—thin, flaky nuggets. No doubt some fine gold does exist, but what they have obtained so far in their prospecting has altogether been of the coarse description.

MR. McMILLAN—Does the size of the gravel increase as you go up the river bed in this case? Does it start off small and increase in size as you go up?

MR. TYRRELL—No; I don't know that there is any marked difference in the nature of the gravel. It appeared to be pretty uniform all the way up the banks, except in the river bed. The bottom of the river itself is formed of boulders, the finer gravel having washed down and worked its way between the boulders. The bed of the river itself is essentially a mass of boulders, and in that way forms a natural sluice-box to catch whatever gold the river carries. Some of the boulders would probably have to be handled with derricks.

MR. WEBSTER—Is all the mining of the Cariboo hydraulic?

MR. TYRRELL—A great portion of it.

MR. WEBSTER—They do not find out where all this gold comes from?

MR. TYRRELL—No; that is a question to which men are devoting all their energies. I was rather anxious to find the place where it all came from, when I was out there. (Applause.)

MR. STULL—About how much water is necessary for the treating of the gravel?

MR. TYRRELL—One miner's inch will treat all the way from two to ten cubic yards of gravel in twenty-four hours, depending on the character of the gravel, the grade of the sluice-boxes and the magnitude of the work generally; but an average is about three and a half cubic yards of gravel for one miner's inch per day of twenty-four hours. In the Cariboo Mine at the present time, according to the statement of their engineer, Mr. Hobson, they claim to be handling ten cubic yards of gravel per day, with one miner's inch, by the use of the most modern hydraulic machinery.

MR. STULL—What pressure do you get in bringing the water down?

MR. TYRRELL—We have a head of four hundred and fifty feet.

FOUNDATION FOR A TWENTY-ONE STORY BUILDING.

BY T. KENNARD THOMSON, C. E. (*Tor. Univ.*)
M. AM. SOC. C. E.

The most novel foundation for a high building ever constructed in New York, or at least the one containing the most unique features, is that for the new 21-story building for the Commercial Cable Company, south of and adjacent to the New York Stock Exchange. The new building has a frontage on Broad Street of 45 feet, and about 56 feet on New Street. The distance between the two streets is nearly 160 feet, covering the sites of four old buildings.

The essential features which made these foundations so entirely different from anything heretofore attempted, was the requirement that there should be a cellar and a sub-cellar below the curb, which necessitated an excavation over the entire lot to a depth of 20 feet below the level of the ground water. The water in the ground here flows freely at an elevation several feet above mean high water in the bay.

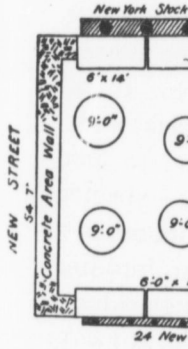
The foundation contractors had to give heavy bonds as a guarantee that they would make the cellar water tight, the methods of securing this result being left to their judgment, and they probably paid more for engineering assistants than any contractor ever paid for a job of this magnitude.

The contract was signed during the last week of January, 1896, and work was at once started. Three of the old buildings had been removed, while the fourth, a small, but shaky brick structure, next to the Stock Exchange, was not vacated until the first of May. It was decided to sink a series of rectangular caissons along each side of the lot, having a space of about six inches between them, which spaces were to be filled in by some means not then determined upon. There were 21 of these rectangular caissons which carried the side walls and columns, the smallest being 6 by 14 feet, and the largest 9 by 18

feet. The steel columns were later on, 18 cylindrical columns.

The building was to enable the steel columns to be rolled and shipped to the shop.

As soon as the steel columns were shipped, a



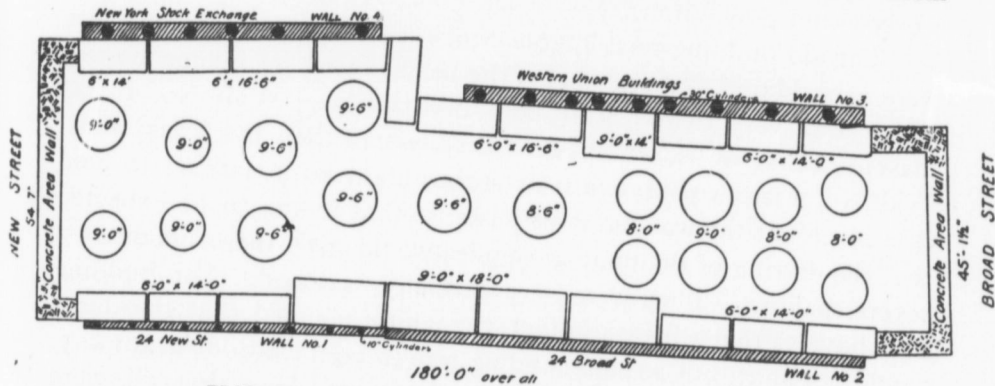
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feet. They all had an air chamber 7 feet high, and about 27 feet of steel cofferdam on top. The ends were also enclosed as described later on, making the whole lot water tight. In addition, there were 18 cylindrical caissons inside of the lot, to carry the intermediate columns.

The first thing done was to get up rough plans of these caissons, to enable the bridge companies to make their bids, and while they were preparing their estimates, the plans were elaborated, so that the steel could be ordered at once, and before the steel could be rolled and received from the mills, the detail plans were ready for the shop.

As some of these caissons weighed from 14 to 15 tons when shipped, a powerful travelling derrick was required to move them



PLAN OF LOT, SHOWING DISTRIBUTION OF CAISSONS

from the trucks to their position for sinking. This traveller was a stout wood frame affair, about 15 feet wide, 25 feet long, and 20 feet high, having a mast and boom at each of the four corners, and a vertical steam boiler for each boom, which was capable of lifting at least 20,000 pounds. A heavy timber trestle, strong enough to carry a railroad train, with two rails 13 feet apart, was designed to carry this derrick from one end of the building site to the other, and as the New Street end was about seven feet higher than the other, the trestle was made a few feet higher than New Street, allowing the trucks to drive on at this end, and giving plenty of room, about 10 feet, below for working.

The first actual work done on the ground was to drive 68 piles, from 30 to 36 feet long, to carry this temporary trestle. These piles were driven to hard pan, which was as far as they would go. Six-

teen piles, one-third the length of these, were driven to support the two air compressors for the caissons.

The lot had previously been excavated to the level of the adjoining cellar floors, and in many places below the foundations of the adjoining walls of three buildings, so that it was possible to shove a foot rule or pencil under these walls. As the two buildings on the south had restaurants in the cellar, the floors of which were directly on the quicksand, it was not surprising that the glasses rattled, and that there were frequent protests from the scared tenants and their patrons whenever the pile driving was going on. Although the contractors had authority to keep on driving, they preferred to lose a little money for the sake of causing as little annoyance as possible, therefore they suspended work from 11 a.m. to 2 p.m., lunch time, and worked on a public holiday.

The old building next to the Stock Exchange and wall No. 1 were very dilapidated and shaky, the bricks being set in lime mortar, which was very little better than dry powder. Wall No. 1 had masonry cellar walls, which were even worse than the brick work. Wall No. 2 was a party wall, six stories high, with nothing to hold it in place but the wooden floor joists, so that it was to be expected that the driving of the temporary piles would give these buildings a severe shaking. They were very carefully watched. The building may have settled a little; in fact, the janitor claimed that the doors would not shut, but as this building was to be pulled down anyway, it did not matter. No further damage was done, but all were relieved when the pile driving was finished.

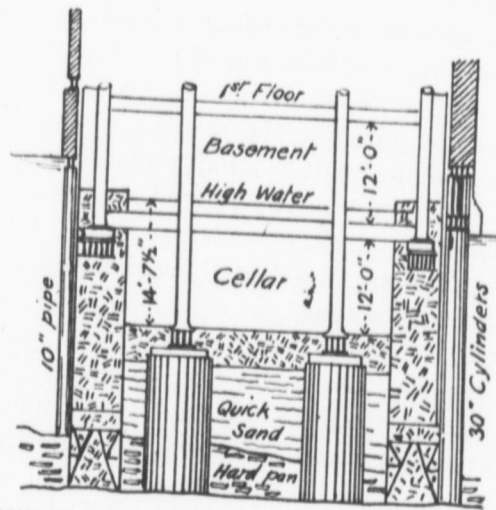
In the meantime, it was decided that it was absolutely necessary to underpin wall No. 1, and Mr. Breuchaud, of the firm of Arthur McMullen & Co., invented an ingenious method of doing this permanently, and without taking up valuable space by clumsy wooden shores, as is usually done, which would have to be moved several times.

He cut a horizontal hole in the wall about 4 feet long and 10 feet above the ground. Into this he placed two 12-inch eye-beams, and then made a vertical cut in the wall about two feet wide from the eye-beams to the bottom. Into this recess he placed 5 foot sections of 10 inch gas pipe, and by means of a 60-ton jack between the top of this 10-inch pipe and the bottom of the eye-beams, and the aid of a water-jet, the 10-inch pipe was forced down 5 feet, when another section was added, and so on, until 34 feet of pipe had been used, until the bottom was resting on hard pan; the jack was then

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removed, and the pipe filled with concrete, and new brick work built over it in place of the poor stone wall. Nine of these pipes were used under the 56 feet of wall.



SECTION, SHOWING UNDERPINNING IN ADJOINING WALLS

Wall No. 2, although well built, barring lack of foundation, was so top heavy, not being properly bonded to any other wall, that was decided to tear it down and build a new one. This was done, the side of the house was boarded and tar-papered until the first six caissons had been sunk, when a good concrete foundation was put in 6 or 7 feet below the old foundation, giving a solid bearing for the new brick wall.

The only adjacent wall then accessible, which was apparently able to stand up by itself, was wall No. 3, part of the Western Union Building, a heavy 8-story brick structure, resting on three rows of piles, which were supposed to have been driven to rock, so the first caisson was placed against this wall, and the sinking was started; but before it had penetrated ten feet, the principal or outside row of piles under wall No. 3 was found to be encroaching on the ground of new building, and had to be cut off to allow the caisson to sink. It was then discovered that some of these piles were only 8 feet long, instead of 35 feet, and that they all stopped short from 10 to 20 feet above rock. It was evident that it would be unsafe to proceed with the caisson work until this building had also been underpinned; therefore, the air was let off, the air chamber and the space was filled with water, to pre-

vent drawing any material from under the Western Union building, and it was over one month before the work of sinking could be started again.

The method of underpinning this building was similar to that adopted for wall No. 1, but inasmuch as the weight was so much greater, the cylinders were made 28 inches inside diameter, instead of 10 inches, and after they had been forced down to hard pan by two 60-ton jacks, the jacks were removed, and an air lock put in their place, which permitted pumping the water out and sending a man down to excavate the hard pan to solid rock. The cylinders were finally filled with concrete, properly capped, and built into the wall; but before this had been accomplished wall No. 2 had been pulled down, the first six caissons stretched along the wall as fast as they arrived, and sunk two at a time.

These caissons are strong steel boxes, having no bottom, but a roof or deck, seven feet above the bottom or cutting edge. The sides extend two feet above this deck, and had horizontal angles to connect to similar angles in the cofferdam, the connection being made by bolts every four inches. Rope gaskets soaked in white lead were placed between the angles, to prevent leaks. The sides and ends of the cofferdams were shipped separately, and bolted on in 5-foot vertical sections, with rope gaskets in the vertical as well as horizontal joints. As a rule, there were five sections, five feet high, bolted on as the caisson sank, making 34 feet from the cutting edge to the top of the cofferdam, which was, as near as possible, one foot above the water line.

To the deck of all caissons were bolted two three-foot shafts, with rope gaskets, one shaft for removing the material, and one for the use of the men. These shafts were added at the same time as the cofferdams were, and the space between the shafting and the sides of the cofferdams was packed with well rammed concrete until there was from 15 to 20 feet of concrete above the roof or deck, the aim being to stop the concrete just below where the iron base for the columns was expected to come, the rest of the cellar walls being built after the columns were in place.

The cofferdams were so designed that four feet of each end could be taken out to make the concrete cellar walls continuous. Both excavating and man shafts had of course air locks, the air being supplied through a hole in the man shaft. As the excavating lock was very heavy, weighing about 5 tons, and would be too high in the air if all the shafting were put on before sinking started, only about ten feet of

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shafting was placed under this lock until the caisson had sunk as far as it could, when the air lock was removed, and more shafting added generally it was necessary to remove the excavating lock once only, but in some cases it had to be done several times, and when this was being done, a wooden door was placed under the roof, and puttied with clay, the pressure of the air in the working chamber preventing the heavy door from falling.

The pressure of the air was, of course, regulated by the depth of water outside, and was kept slightly greater than the calculated amount. If the pressure was not high enough, the water would rush into the caisson, and if too high, the air would blow out, and suddenly decrease the pressure, and allow the water to enter through the "blow out." The maximum pressure required on this work was from 15 to 20 pounds per square inch, which is not supposed to be enough to hurt a man in good health, with no organic trouble. The friction on the sides was very great, running from 150 to 450 pounds per square foot of exposed surface of the sides of the caissons and cofferdams, and when this was added to the upward pressure exerted by the compressed air, the sum was greater than the weight of the steel and concrete, so pig iron was piled up on top of the concrete sometimes to the extent of a hundred tons.

There were generally from four to six men working in the air chamber, in eight hour shifts, filling the buckets, which held nearly one-half a cubic yard, and were pulled out and emptied by the travelling derrick. As soon as the cutting edge was well bedded in the hard pan, the sinking stopped, and the excavation was carried on below the cutting edge to rock; the rock was quickly cleaned off, and concrete dropped through the lock, rapidly shovelled and well rammed in place.

It is very difficult to make concrete hold water, but as it was essential that no water should find its way under the cutting edge, up through the caisson into the cellar, a thin layer of mortar was laid on the concrete, about six inches above the cutting edge, and on this good stout canvas was spread, with edges lapping several inches, and covered with a few inches of mortar, after which the concrete was continued to within four inches of the deck, the remaining space being rammed full of mortar. Only Portland cement was used on this job. It can be readily imagined what a difficult thing it is to fill up the deck all around, and gradually back out through a three foot shaft. The shafts were finally filled as high as the outside concrete,

and the upper sections removed with the air locks to the next caisson. The rectangular caissons having all been sunk by this means, with the spaces between them ranging from 2 to 12 inches, it was necessary to devise some means of closing these spaces, in order to have a water tight wall before digging the cellar. Stock ramming was tried, and found very successful. This consisted of driving down a three-inch pipe to the hard pan, dropping pellets of clay into it, and then forcing the clay out at the bottom by means of a pile driver acting on a long rod or piston; after a certain amount of clay had been forced through, the pipe was drawn up a little, and more clay sent down, and so on, making a compressed clay wall from hard pan to the surface. In some cases the clay was forced horizontally along the caisson ten feet away from the pipe. The pipes were generally put down in two positions between the caissons, and held the water out even better than had been hoped. Part of the clay was afterwards removed to make place for a permanent brick filling.

The caissons were sunk on an average 35 feet to rock; on top of the rock lay from 2 to 14 feet of hard pan, while nearly all the rest of the material up to the surface is quicksand. It might be stated here that nearly all of the lower part of New York rests on quicksand, which very few architects seem to be aware of.

Having two water-tight walls along the sides completed, the next thing was to produce these walls to the vault or area line under the streets, and to close the ends, as this portion does not carry any of the weight of the building, and all that was required being a temporary water wall down to the hard pan, and a permanent water-tight wall and retaining wall down to the sub-cellar floor, it was decided to drive a patented sheet piling to answer the first purpose, and build a concrete wall against this for the second purpose. These sheet piles were made of three pieces of plank, each $2\frac{1}{2}$ x 12 inches, and about 40 feet long, well bolted together, making a pile $7\frac{1}{2}$ x 12 inches. The centre plank forms a three-inch groove on one edge, and consequently a three inch tongue on the other.

As the piles were driven very carefully so as to keep the tongue in the groove of the next one all the way down, they held back the water and material until the concrete retaining or area walls were finished. Of course these sheet piles were strongly braced with heavy timbers, as the cellar was being excavated.

While all this was going on, the 18 cylindrical caissons in the interior of the lot were also being sunk. These were 8 feet, 9 feet, and

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9 feet 6 in. in diameter, there being six of each size. They were shipped in two sections; the bottom, or permanent section, containing a 6½ foot air chamber, was 16 feet high, and the top, or temporary section, 18 feet high. There was not room to place any concrete over the deck before sinking, as the interior columns are below the cellar floor. The space over the deck was filled with water, and a timber frame carrying four "crabs" or winches was placed on top, and the wire ropes passed through sheaves attached to the frame, and others attached to eye-beams on the ground, which was held down by pig iron, etc. By placing several men at each crab, the 16-foot section was pulled down in about 12 hours, or as fast as the material could be dug out and removed from the caisson. If the caisson sank faster than the material was removed, as sometimes happens, the men would not have sufficient working room in air chamber. By working quickly, the water did not cause enough trouble to require using compressed air for the first section, but by the time the top or temporary section had been added, the water had risen enough to necessitate using air for second section. The air chamber was cleaned out and filled with concrete the same as the rectangular caissons. The contractors were obliged to sink the cylinders before excavating the cellar or closing the ends, in order to allow the erection of the columns and girders, the weight of which prevented any danger of the new cellar walls being forced in by the overloaded foundations of the adjoining buildings, which was a decided advantage, as well as saving in time for the frame working.

After the cellar had been dug out, and four feet of concrete placed in the floor, the top 18 feet of the circular cofferdams was cut in two vertically, and the horizontal bolts taken out at the bottom, leaving no obstruction above the floor except the column and girders.

It might be well to state here that while this is by no means a typical case of New York foundations, it should be. Unfortunately, there are very few foundations so carefully put in. One reason is that engineers very seldom have control, although the features are chiefly engineering. In many cases competent engineers are not employed, or if consulted, are not heeded. Of course there are exceptions, but they are few and far between. This applies to the whole building, as well as the foundations.

It seems a pity that in a place like lower New York, with rock so comparatively near the surface, and a thick layer of treacherous quicksand overlying it, that "sky scrapers" should be allowed whose foundations do not go to rock.

ON SNOWSHOES FROM THE BARREN LANDS.*

BY J. W. TYRRELL, C.E. (*Tor. Univ.*),
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On the morning of the 6th of November, after a stay of seventeen days at Fort Churchill, our party was ready to set out for the south. We had secured the services of one dog-team with driver, and an Indian guide to accompany us to York Factory, the next Hudson Bay Company's post, about one hundred and seventy miles farther south, but about two hundred miles by the circuitous autumn route.

Our team consisted of six Eskimo dogs, and they were attached tandem fashion to a sled twelve feet long and a foot and a half wide. This sled was of the regular Eskimo type, with runners formed of sticks hewn down to the dimensions of about two inches by six inches, curved up slightly and rounded in front. The platform of the sled was formed of slats laid across the runners, to which they were securely lashed by sealskin thongs; and, lastly, the shoeing of this peculiar conveyance consisted of mud, put on in a soft state, and, when properly formed, was allowed to freeze, after which it was glazed over with a coating of ice.

Upon this sled was loaded our provisions, blankets, etc., all securely lashed on within a canvas wrapper. Our guide, whose name was Jimmie Westasecot, was a large, fine-looking Cree Indian of about middle age, who bore the distinction of being the most famous hunter and traveller in all the country. Our party now consisted of ten; my brother and myself being warmly dressed in the deerskin garb of the Eskimo, whilst the rest of the party wore the white blanket suits of the traders, and, with the exception of poor little Michel, whose feet, having been frozen during the former part of our journey, were still entirely too sore to allow him to walk, each man was provided with a pair of snowshoes.

*An account of Mr. Tyrrell's explorations in the Barren Lands with map of the route will be found in the proceedings of the Ontario Land Surveyors' Association, 1896.

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Thus provision was made for the transport of all necessary supplies; but we were obliged to provide for Michel also. Here a fortunate opportunity was presented. Mr. Matherson, who had a boat load of supplies lying on the coast, rather more than half-way down to York, had determined to accompany us with other teams as far as his cache, and offered to take him that far, and we expected by that time our load would be sufficiently light to take him ourselves. Mr. Lofthouse, the Missionary, also had goods at the boat, and added one more team to the expedition, making a total of fifteen men and five teams.

After taking farewell of our kind friends we marched from the Fort in single file, forming into a long serpentine train, winding our way to the southward across the broad frozen Churchill river, which, during the severe frosts of a few days previous, had become sufficiently frozen to allow us to cross in safety.

At the outset of the march, though our party had greatly improved physically during our stay at Churchill, we were still far from being strong, but we were anxious to push homeward as early as possible. Because of our physical condition it was thought best not to make forced marches at the outset, and the wisdom of this resolve was clearly proven before our first day's tramp was ended. On the afternoon of our first day's march my knee gave out, and within an hour or so every step caused me excruciating pain, and it was with the greatest effort that I managed to hobble along after the train until evening. We travelled about twenty-one miles during the day, on an easterly course, across open plains and snow-covered lakes, little timber being met with until we reached the "Eastern Woods," where it was decided to camp. Upon the open plains we had found the snow hard and in good condition for travelling, so that our teams had trotted along with their heavy loads with little difficulty, and but few administrations of the ponderous lash. The snowshoe travel was also comparatively easy for those whose legs were sound; but the moment we entered the woods the snow was light and soft, and travelling became much more difficult, making it necessary to send one ahead to break the way.

The snowshoes used by Jimmie, our guide, were about five feet long and eighteen inches wide, whereas those used by the rest of our party varied from three to three and a half feet in length and from ten to twelve inches in breadth. Though we purchased the shoes from the Hudson Bay Company at Churchill, they were made by

the Chipewyan Indians. Their shoes are not made symmetrically, but are constructed with great bulges on their outer sides, and are formed of two pieces of wood, tied together at both ends, and held apart in the middle by cross-bars, whilst the toes of the shoes are turned up with a sharp curve.

Having reached the shelter of the "Eastern Woods," and concluded our first day's march, a camping place was chosen.

The drivers of the teams at once proceeded to unharness the dogs, make beds for them of spruce boughs, and give them their daily meal of seal blubber or fish.

The other members of the party busied themselves by clearing away the snow, cutting down brush and fire wood, and building the camp. Our camp consisted simply of a wind-break of brush built three or four feet high of a crescent or "U" shape, and in such a position as to best afford shelter from the cutting wind. The snow was then cleared from this space and several inches of spruce boughs strewn in its place, and a good fire kindled in front.

Next thing was to prepare for supper. Our appetites, to be sure, were all ready, so bacon and biscuits were hauled out, whilst frying pans and tea-kettles were produced, and placed with their contents upon the fire. Fresh water had been found by cutting through the ice of a creek close by, and so nothing was lacking. Our simple meal was then heartily enjoyed, after which preparations were made for the night. Socks, duffles and moccasins—wet with perspiration from the day's march—were hung up before the fire to dry; robes and blankets were brought from the sleds and spread about the camp, and upon them our tired party soon assembled to enjoy a rest and smoke beside the fire before turning in for the night. My brother and I, who shared the same blankets, chose a middle position in the camp, our own men occupying the space to our left, whilst Mr. Matherson and his men occupied the space to our right. The night, though cold, was beautifully calm and clear, so that when the big dry sticks of wood were thrown from time to time upon the fire, showers of sparks ascended until they found hiding places among the dark branches of the overhanging spruce trees.

Camp fire stories and gossip were indulged in for an hour or so, and then about nine o'clock, several big logs were again thrown upon the fire, and each man rolled himself up in his blanket and lay down to sleep. There was little sleep for me, however, because of my knee, which gave me great pain during the night.

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Upon the next morning camp was called at five o'clock, and under the still star-lit sky all hands rolled out into the keen, frosty morning air. A fire was soon kindled, breakfast prepared and partaken of, sleds loaded, teams harnessed, snow-shoes examined and put in order, and at the first streak of dawn our tramp resumed.

It was yet dark in the woods, and to most of us there was no more indication of a trail in one place than in another; but our veteran guide, "Jimmie," who possessed all the sagacity of the ideal red man, led the way, and what the rest of us had to do was merely to follow his tracks. Soon we merged from the Eastern Woods, and, getting into a more open country, we turned our course towards the south, crossing broad plains dotted here and there by stunted scattered trees and ice-covered ponds.

As we travelled my leg caused me great pain, so that it became impossible for me to keep up with the train. I hobbled along as well as I could for a time; but finding that I was seriously retarding the progress of our march, arrangements were made to give me a lift for a while upon one of the sleds.

Peter and Louis were also becoming lame from the effect of their snowshoes, but were not seriously crippled. (For the benefit of any who may not be aware of the fact, I will explain that there are various forms of lameness commonly produced by the prolonged use of snowshoes. In thus travelling certain leg muscles which are only accustomed to perform light service are brought into vigorous use, and are very liable at first to become strained and cause much annoyance).

During our second day from Churchill a band of twenty or thirty deer were seen. Some of us were in no mood or condition to hunt; but Jimmie, our guide, and Mr. Matherson, went off in pursuit of the band, while our train pushed on. Several times during the afternoon we crossed the tracks of both deer and hunters, but when we came upon the big tracks of our guide we saw the first signs of success. He had evidently wounded a deer, and was giving him a hot chase, for the Indian strides were right upon those of a cariboo, and to one side of the trail spatters of blood could be seen on the snow. Toward evening our train came up with Mr. Matherson and Jim, who had had a long but fruitless run after the deer, but nothing could be seen of the guide. He had evidently entered the race to win, and had resolved to run his game to the ground; for, some time after camp had been made for the night in a thin patch of woods,

Jimmie walked in with a haunch of venison on his shoulder. He had wounded his deer early in the afternoon, but had been obliged to run him many miles before he could again come up with him. He had slain his victim a considerable distance from camp, and lest the carcase should be devoured by wolves in the night, a team was harnessed and Jimmie himself and one other man started off for the meat, which some hours later during the night they brought into camp. As we had had very little fresh meat for some time past, supper of venison steak was very much appreciated.

During the day's march numerous wolf and several Polar bear tracks had been crossed, but the cariboo were the only animals that were seen.

The next, our third day's tramp, was a short one, not in actual miles travelled by some of the party, but in distance made upon our course. It was, however, a big day's sport, for, during the day, no less than eight deer were shot. Unfortunately for my brother and myself, we were not able to take part in the chase, for by this time, though I was beginning to recover, my brother was as badly crippled as I had been, and for a time had to be hauled on a sled.

At about the close of the day, a little deer which Mr. Matherson had been following, and at which he had been practising for some time with my brother's rifle, stood and looked at him with innocent amazement, at a distance of about 300 yards from our train. Probably the cause of Mr. Matherson's wild shooting was the cross-wind which was blowing strongly at the time, but, however, he gave up in disgust and returned the rifle to my brother, asking him to try a shot. My brother said it was useless for him to try, as the deer had now run still farther away, and he himself had only one leg to stand on. However, dropping upon his knee, he fired one shot, and down dropped the deer, much to the astonishment of Mr. Matherson.

Several of the best haunches of venison secured during the day were loaded upon the sleds, but it was not thought wise to over-load the teams by trying to carry too much. The bulk of the meat was cached where it was killed, to be picked up by the Company's team upon their return trip and taken to Churchill, where it was much needed.

Our third camp was made in a strip of wood upon the bank of Salmon Creek, and to our Indians is doubtless memorable as being the place at which they had the big feed, for it took three suppers to satisfy them that night. With my brother and myself, the hours of

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darkness had ceased to give us repose, for our knees were so painful we could not sleep, but only turned restlessly from side to side, until the return of dawn. Happily for us all, the weather had continued to be fair, and not extremely cold since the commencement of our journey, and this was particularly fortunate on account of poor Michel, who would doubtless have suffered, had he been obliged to ride upon a sled all day during extreme weather. As it was, we were able to keep him fairly comfortable—bundled up in deer skin robes and blankets.

Upon the fourth day of our journey, meeting with no deer, we made about twenty-seven miles—a good march, considering the loads of our teams and the condition of our party. This brought us to the banks of Owl River, a stream two or three hundred yards in width, and situated in a straight line, about midway between York and Churchill. Here, at half past five o'clock, being then about dark, we camped.

At dawn the next morning we were again marching southward, with the expectation of that day reaching Stony River, where William Westasecot, a brother of our guide, was encamped, and the place at which our parties were to separate.

Three more deer were shot during the day, making a total of twelve so far for the trip—most of them being the victims of the Indian guide. About four o'clock in the afternoon, we arrived at Stony River, but there was no Indian camp to be seen, and for a time we saw no signs of the proximity of any human being. We turned down the river, and ere long came upon the tracks of a solitary hunter. These Jimmie knew to be the tracks of his brother, and by following them a mile or two into a dense evergreen wood, we came upon the camp. It was a solitary tepee situated in the heart of a snow-clad thicket of spruce trees and scrub, so dense that a bird could scarcely fly through it.

The Indian lodge or tepee was built of poles placed closely together, and arranged in the shape of a cone. The cracks between the poles were chinked tightly with moss, with which the tepee was then covered, excepting a foot or so at the top, where a hole was left for a chimney. An opening, made in the wall as a doorway, was closed by a heavy curtain of deerskin; and, as we lifted it, in the centre of the lodge, upon a square mud-covered hearth raised a few inches above the surrounding clay floor, a smouldering wood fire burned, from which the circling smoke ascended and found its way

through the chimney, whilst the old Indian rose from his seat and extended a welcome to enter. Deerskin cushions were offered, and as we seated ourselves more wood was piled on the fire.

William, the Indian, was a much older man than his brother, our guide, for his long flowing locks were already whitened with age, though he still appeared strong and athletic. His squaw and two sons completed his household, and to each one we handed a piece of tobacco. Pipes were then lighted and information sought and obtained of the Indian. We found that he had only seen and killed one deer for some weeks past, and was now almost out of food, and entirely out of ammunition. We supplied him with the latter, and told him where within a day's travel he might supply himself with the former.

We learned from him that the great Nelson River, which we expected to reach within two or three days, was still quite open; but he told us where, some miles up the river, we would find a large boat in which we might cross. It was arranged also that Eli, William's elder son should accompany us to York and assist by hauling a flat sled.

Whilst my brother and I and our guide were thus interviewing the Indian, our own camp was prepared a short distance away, and having completed plans for the morning we bade farewell to the red man, and losing the track by which we had come, had to struggle back through the thicket.

The next morning, being the 11th of November, the separation of our parties was arranged. The route of Mr. Matherson's party henceforth lay off to the eastward, whilst our path still led to the southward, toward the banks of the Nelson River. A place was prepared upon our own dog sled for crippled Michel, our team of six dogs was harnessed, and the flat sleds, including one for Eli, were then loaded with all that the dogs were unable to haul. Our supplies had by this time diminished to the extent of about two hundred and fifty pounds so that even with the additional weight of a man, our loads were lighter than at the outset of the journey.

Loads being thus readjusted, and our feet being harnessed to snow-shoes, we bade farewell to our friends from the Fort, as well as to those of the forest, and made a new start on our journey.

The weather had now become very mild, making the snow soft and even wet in some places. This made travelling very heavy for the team, causing the ice glazing to melt from the sled, and the mud

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shoeing to wear and drag heavily upon the track. My brother and I still suffered much pain from our knees, but with considerable difficulty we managed to keep up with the rest of the party, and after making a small day's march, camped for the night in a spruce wood on the bank of a small stream called by the Indians, White Bear Creek. On the following morning camp was called early. The weather had turned slightly colder during the night, making the prospects for travel more favorable. We started down stream upon the ice of the creek, and then across country through a thick spruce woods, to Duck Creek, where we found a second Indian camp. It was occupied by two Cree Indians and their families.

From one of these Indians we were able to purchase an additional dog, and the price asked was a new dress for one of the squaws; but as we had no dress goods with us, the best we could offer was that the dress should be ordered at the Hudson Bay Company's store at York, and delivered at the first opportunity. After several pipes of tobacco had been smoked, the offer was accepted, and with seven dogs in our team our journey was resumed—the creek being followed till it led us out to the low, dreary coast at the mouth of the Nelson. Here, having left the woods several miles behind, we were exposed to the full sweep of a penetrating south-west wind, and although on the coast of Hudson's Bay no water was yet to be seen. We are accustomed to thinking of a coast as being a definite narrow shore line, but to the inhabitants of the Hudson's Bay region, the word conveys a different meaning. There the coast is a great mud and boulder flat several miles in width, always wet, and twice during the day flooded by the tide. At this time of the year the mud flats were covered by rough broken ice and drifted snow, but above high tide mark the surface of the country was level and the walking good. For several hours we tramped southward down the coast with the cutting wind blowing in our faces. Towards noon we began to look longingly for some place of shelter, where we might make a fire to warm ourselves and prepare some lunch, but we pushed on until the afternoon was well advanced without finding a shrub or stick to afford shelter or fuel. A consultation was held, and the result was that our course was altered and shaped for the nearest woods several miles inland. A rapid tramp followed, and when the woods were again reached, the shelter and refreshments were both heartily enjoyed.

The great advantage of travelling on the open plain is that there

the snow is driven hard and hence the walking is much better than in the woods. Nevertheless, when the weather is rough, as it was on this occasion, the heavy walking is preferable to travelling in the open country in the teeth of a storm.

For the remainder of the day we tramped southward within the shelter of the woods, and, at about the time of sunset, made camp on the south bank of the stream known as Sam's Creek, in a lovely snow-laden evergreen bush—an ideal Canadian winter woodland picture. From this beautiful, but chilling scene our tramp was continued the next morning at daylight. The low shore of the Nelson was again reached and followed, until about noon a decided change in the character of the land was observed. A boulder clay bank commenced to make its appearance, and this as we advanced rapidly reached an elevation of twenty-five or thirty feet; and, as we proceeded farther up the river, became higher and higher and more thickly wooded. The change was a great relief from the level, dreary, treeless coast.

We were now well within the mouth of the great Nelson River, and could already, through the rising steam from the water, dimly see the dark outline of the opposite shore.

Considerable ice was found to be coming down the river, and on this account we could not help feeling some anxiety as to crossing; but we were within a few miles of the boat of which we had been informed, and it seemed probable that we might yet cross the stream before nightfall. At half-past three o'clock in the afternoon we found the boat drawn up in the mouth of Heart Creek, where William, the old Indian, had told us it was. It was a large, heavily-built sail boat, capable of carrying our whole outfit in one load, but, unfortunately, the keel was deeply imbedded in the sand and there securely frozen. The only way to free it was to chop it out, and to this task as many hands were set as could find room to work. We only managed, however, to get the boat loosened as the shades of night fell about us. We were then obliged to seek a place to camp. The river bank had here become very high and precipitous, but a short distance up the gorge we discovered a scattered grove of evergreens, and a camp was made beneath them.

During the night the wind, which had been blowing for two days past from the south-west, gave place to a gale from the north-west. Moreover this unwelcome guest did not come alone, but brought with it a driving snow-storm, which lasted all night. The gale shrieked

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through the trees, and threatened havock with our fire and blankets, and by daylight the snow which accompanied it had almost buried our party.

Such was our condition on the morning of the 14th, and such the first chilling view that greeted us; but we soon pulled ourselves out from the snow-drifts, and, after a good deal of searching, found sufficient dry wood to kindle a fire, with which a scanty breakfast was prepared. I say a "scanty breakfast," for this being our ninth day from Churchill, our supply of provisions was about exhausted; but we were now only one day's march from York, and so lack of provisions troubled us but little. After breakfast, notwithstanding the roughness of the weather, all hands at once proceeded to the boat, and by a united effort just managed to drag it out to the edge of the shore ice; but there, the tide being low, there was no water to float it, so we had to await the flood tide, which would not be up till about noon. Meanwhile, the boat was loaded where it rested upon the sand, and at twelve o'clock, being lifted by the water, a canvas was hoisted, and through a dense fog which rose from the river, we sailed up the shore in order to reach a narrow part of the river, and avoid broad shoals, which existed off the shore opposite to us. Having sailed about three miles up the river, along the shore, to the vicinity of Flamboro Head, our course was altered, and we steered into the fog for the south shore, about two miles distant. It was intensely cold, but, as there was a good breeze, our craft sped swiftly away on her course. Some floating ice was met with, but successfully passed, and for a time it seemed as if our crossing would soon be effected; but suddenly there loomed out of the mist, right ahead, a dense field of ice, broken and rafted and hurrying down with the current.

By putting our helm hard to starboard, and quickly dropping our canvas, we barely managed to keep clear of the ice, but what was now to be done? The south shore was still hidden by the dense fog, and nothing could be seen in that direction but the adjacent field of ice. On the north shore the dark outline of Flamboro Head could still be seen through the mist, and it was resolved thence to beat our retreat. We were, however, unable to sail against the wind, but taking to the oars, after a prolonged struggle we managed with great difficulty in a half-frozen condition to regain the place from which we had started.

Once more on land the camp was made, and a fire kindled, at which to thaw our stiffened limbs, and await our opportunity to cross

the river. The fog continued during the remainder of the day, preventing us from making a second attempt, and so we camped for the night.

By the next morning the fog had cleared away, revealing a dismal sight. On the south side, the river was frozen over, and the ice firmly set for a mile or more from shore, but the channel of open water north of this was running full of heavy ice, thus making our crossing more perilous, and as it was impossible to effect a crossing on foot, we were obliged to await a change in the condition of the river. Not the least unpleasant circumstance in connection with this waiting was that our provisions were now exhausted.

However, the men were sent out to hunt, and returned in the evening with nine ptarmigan, with which a good "bouillion" was made for supper. Besides this, Eli, the Indian boy, gave us some comforting information as to the existence of a fish cache of his father's not far distant. With this consolation and the resolve to send for the fish in the morning, we rolled up in our blankets and were soon dreaming of better times at home.

The next morning saw no change in the condition of the river, so two men and the dogs were sent after William's fish cache and other four of the men went off hunting, whilst the rest of the party remained in camp, collected wood, and kept the fire burning.

We had nothing to eat until evening, when the sledding party returned with a little bag and can of pounded dried fish, two or three gallons of seal oil, and some seal blubber for the dogs, all of which, though not exactly luxurious, we were exceedingly glad to receive. Later, two of the hunters returned with several ptarmigan and one or two rabbits, and last of all, some time after dark, the remaining two—Jim and our noble guide—walked into camp carrying the carcass of a deer. We had now sufficient provisions for several days, and they were divided equally with the party.

Without narrating in detail the incidents of the following days, it will be sufficient to state that for ten long days, this weary wait on the bleak, cold banks of the Nelson was continued. From time to time the men were sent out to hunt, but, except as above mentioned, were obliged to return without success.

On the morning of the 19th the guide and Jim, provided with rifles, blankets, axes and snowshoes, started off up the river, determined to find deer if there were any in the neighborhood, and also to investigate the possibilities of crossing the river further up.

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Four days of bitterly cold weather passed, the thermometer varying from 12 to 25 below zero, and then empty-handed, they returned. Food had again become scarce with us, and a fox which had been trapped was eagerly devoured.

On the evening of the 22nd, though the mercury indicated 22 below zero, the channel of the river above us was observed to be less thickly blocked with ice than where we were encamped, so it was resolved, if possible, to haul the boat a mile or two farther up stream and there to launch and measure our strength with the floe.

No time was lost, but all hands, excepting Michel, who was still unable to walk, engaged in the work. The boat, which had been kept chopped free from the ice, was launched, and by means of a long line we managed to tow it about half a mile up the shore, but then the ice became so dense that to prevent the boat from being crushed, it was necessary to haul it out on the shore. About a mile farther up was the point we desired to reach, so we were obliged to haul our boat along the shore. It was all we could manage, but by about nightfall we had gained the object in view. Then, by the light of the moon, we proceeded to move camp to the boat, so that in the morning, if it were possible to cross the river, we might be ready.

Next morning, the weather being bitterly cold, and a fog rising from the water, the prospects for boating were not the most pleasant, but we were resolved to effect a crossing if possible.

We towed the boat half a mile still farther up the river, until the Seal Islands were reached. Here, awaiting a favorable condition of the ice, we pushed out into the stream and commenced the struggle.

Every man was armed with an oar, a pole or an axe, and all of these were vigorously applied in forcing our way through the ice and the current. For a time we made fair progress, but were soon caught in the grip of the ice-pack, and hurried down with the stream toward the sea.

After considerable strenuous effort we regained open water. This struggle was repeated several times, but finally we succeeded in reaching, as we supposed, the stationary ice of the shore; but were sorely disappointed to find that it was only a jam in the middle of the channel.

We were now in a dilemma. It was impossible to tow around either end of the jam, and we were being carried to sea.

Finally we concluded to portage across the island of ice and

launch on the other side. Accordingly the boat was unloaded and our goods safely carried across; but the ice, we found, would not carry the boat, so we were obliged to cut a channel right through the island the full width of the boat. The boat was then hauled through, re-loaded, and again pushed out into the flowing pack, which, in spite of all our endeavors, carried us far down toward the mouth of the river.

At length we succeeded in getting within thirty feet of the solid south shore ice, but we were again nipped in the floe and carried helplessly downward until, it seemed as if after all we were going out into the bay.

We used every effort to free the boat, but all of no avail. At last, however, civil war among the floes caused a split and brought us deliverance. A few rapid strokes and our old craft bumped the solid ice.

Our bowsman, Francois, quick as a flash sprang ashore with the end of the tow-line, whilst the rushing ice again caught our boat and bore it downwards. Francois held on to the tow-line, but the tug of war was going against him. Finally, anchoring himself against a hummick of ice he succeeded in holding us fast until others sprang out to his assistance.

All hands quickly disembarked, but as there was still a full mile of rough ice, liable to break adrift at any time, lying between us and the shore, no time was lost in exultation; and although the rough ice made travelling difficult, we soon found ourselves on *terra firma* again, rejoicing that the Nelson was at last to north of us.

As we were all much chilled from our exposure in crossing the river, a fire was at once made in the edge of the woods, around which, with feelings of deep satisfaction, our party assembled.

A little of the pounded dried fish still remaining was fried on a pan, with seal oil, which, although not very palatable, was eaten with considerable relish.

After partaking of our light refreshments and the stiffness had been thawed from our limbs, snowshoes were again adjusted, and, with a "Hurrah for York," our tramp continued.

One more camp was made, and on the following day, being the 24th of November, at about eleven o'clock in the morning, we reached York Factory.

Here we were kindly received by the officer of the Hudson's Bay Company, Dr. Milne, a young Scotchman. Our men were given

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lodgings and rations in one of the many vacant houses of the Fort, whilst my brother and I were shown into the Doctor's bachelor quarters and allowed to occupy the room of Mr. Mowat, the assistant trader, who was absent from York at the time. Here we were able to have a bath, which added greatly to our comfort. With travellers in the north, particularly during the winter season, the practice of performing daily ablutions is quite unheard of. This is not due to neglect, but is rather an enforced custom, due to the painful effects produced by the application of ice-cold water to the skin. During the previous summer and autumn my brother and I adhered to the habit of daily washing our hands and face, until our skins became so cracked and sore that we were forced to discontinue.

Besides Dr. Milne, Mr. Macpherson, a servant, and Mr. Mowat were the only white residents of York.

Mr. Mowat had, only a few days before our arrival, been sent off with two Indians as a relief party to look for the Company's autumn mail, which was now more than six weeks overdue. The mail should have come down the Hays River from Oxford House, two hundred and fifty miles distant, before the close of navigation; but as nothing had yet been heard of it, or the party, grave fears were entertained as to their safety.

As to York Factory, it is one of those places of which it may be said "the light of other days has faded." In the earlier days of the Hudson's Bay Company it was an important centre of trade, and the port at which all goods for the interior posts were received, and from which the enormous harvests of valuable furs were annually shipped. In 1886, when I formerly visited York, there was a white population of about thirty, besides a number of Indians and half-breeds, in the employ of the Company; but as the local supply of furs had become greatly diminished, the staff of servants had been dismissed or removed, until York was now almost a deserted village.

One of the first duties receiving our attention upon reaching York, was the placing of poor crippled Michel in the doctor's hands. His frozen feet, still fearfully sore, were carefully examined and attended to. As he was now in good hands, it was thought advisable to leave him, so with as little delay as possible, preparations were made for the continuance of our journey.

Our faithful guide, "Jim," could now go no farther, so we were obliged to secure the services of another, which we did, and found him to be another brother of Jim's, called Charlie.

After fitting up two dog-teams and procuring necessary supplies, we were ready for our twelve days' trip to Oxford House. Through the kindness of the doctor we were offered the assistance of a third team for two days, which we gladly accepted, as we were somewhat overloaded.

The rations were divided equally, and consisted of 1 lb. bacon, $1\frac{3}{4}$ lbs. flour, $\frac{1}{4}$ lb. sugar and $\frac{1}{8}$ lb. tea per man per day. This was to carry us through the trip or we must suffer the consequences.

On Tuesday morning, the 28th of November, the second stage of our sledding journey was begun. The dog-sleds now used were flat, somewhat the shape of a large toboggan, this type being better suited to the woodland travel, where the snow is soft and deep.

The condition of our party on leaving York was vastly different from what it had been on leaving Churchill. Our two hundred mile tramp had hardened our muscles, so that with the ten days' rest on the banks of the Nelson, and a four-days' rest at York, we were now in first-class walking trim.

Our first day's tramp was on the ice of the Hays River, which at times was so rough that we were obliged to take the shore. The banks, as we passed, were well wooded with spruce and a few poplar trees, while the adjoining country was of a low, rolling character.

Our course on the second day led through the woods to the north of the river, and by many winding ways we tramped on, following the track of our guide, who we soon found was a very inferior man to his brother, but as track-breaking was now more difficult work than it had been on the harder snow of the open country, his duties were rather more laborious. On this account one of our own men often broke the track, and the guide, merely giving directions as to our route, followed after. During the day's march much of the country passed through had been burnt over some years previous, and was covered with wind-falls and a scrubby second-growth. But little standing timber remained, and in many places the cold, cutting west wind, having little to break its force, almost froze our faces.

On the morning of the third day our assisting team from York, leaving its load with us, returned to the Fort. A readjustment of our loads was then made, and with two remaining teams heavily loaded, we pushed on, though now more slowly.

The problem of getting home had now apparently resolved itself into one of leg endurance, and so, with little variety in the cold wintry woodland scene, we continued the tramp.

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At about noon on the 1st of December we were pleased to meet Mr. Mowat, returning with a long-looked-for mail and party, all safe. The great delay in the arrival of the mail had been caused by one of the Indians becoming seriously ill soon after leaving Norway House, and having to return to that post. When he had sufficiently recovered to again take to his canoe, he and his companion started on, reaching Oxford House in safety, but too late to proceed further by canoe. They were therefore forced to wait and complete their journey on snowshoes, and were already on their road when Mr. Mowat met them. Thinking that the mail packet might possibly contain letters for my brother or myself, Mr. Mowat kindly consented to open it, but nothing was found for us. We had expected to have been home before this time, and having little idea as to what way we would return, we had not been able to leave our friends any certain address. After a brief halt we pushed on, and each party now had the advantage of the track made by the other.

The temperature now remained pretty steady at about 25° below zero; but, with the exertion of the tramp during the day and the shelter of the blankets and the warmth of the camp fire at night, we managed to keep pretty comfortable.

About sixteen miles beyond a large stream known as Fox River, an old ox track was reached. This in earlier days had been travelled by oxen and Red River carts, and over it hundreds of tons of freight had annually been hauled; but now it was so grown up with trees that it often required the skill of the guide to keep it. This track lead directly to Oxford, so that from this point onward it was our road, unless when lakes were met with, and then their surface was the preferable track.

Since leaving the banks of the Hays River, no timber of any value had been seen. The wood had all been black spruce of a very scrubby character, but now poplar, birch and jack-pine were occasionally to be seen.

On December the 5th the temperature ran down to forty degrees below zero—fine, cool weather for travelling and sleeping under a spruce tree. In this temperature we found difficulty at times to keep warm, and as we gathered about the camp fire at night, we found ourselves roasting and freezing simultaneously, reversing our positions occasionally, only to reverse the process. Our meals were served on hot pans, but were sometimes frozen before they could be disposed of.

During the afternoon of the 4th and the morning of the 5th of December we crossed Deer Lake, 27 miles in length, and at either end of the lake we found camps of Indians. From one of them we purchased some fine whitefish, which they were catching through the ice, but losing little time, the old ox track was again discovered, and our tramp continued through the woods. By this time our guide, Charlie, had become pretty badly used up by the march, so that he was no longer able to keep the lead, but our own men managed to keep the track and Charlie hobbled along behind.

During the evening of the 6th and the morning of the 7th of December we crossed a succession of thirteen small lakes and some flat open plains, but on the afternoon of the latter day saw a marked change in the character of the country. With the exception of two or three isolated patches, we had seen nothing in the shape of timber of any value since leaving Churchill, but now we had reached a heavy forest of white spruce, jack-pine, poplar and birch trees, and the change was a very pleasing one.

For a distance of six or eight miles we tramped through this heavy forest, and then, just at night-fall, reached the shore of Buck Lake, an extension of Oxford Lake. Unfortunately my brother's feet had become very sore during the day, so that he had been obliged to walk with only one snow-shoe. On this account we had fallen several miles behind the leaders of the party, and when we arrived at the shore of the lake nothing could be seen of our outfit; and, because of darkness and the hard surface of the snow, it was difficult to follow their track. At times we were obliged to go on our hands and knees in order to do so.

On reaching the shore we knew not which way to turn, but by the aid of a paper torch we soon discovered the tracks into the woods, which, owing to the deep snow, we were now able to follow. A quarter of a mile farther and we were again at the edge of the woods, where, to our glad surprise, and but a short distance ahead, flashed out the lights of Oxford House.

A few minutes later we were the guests of Mr. and Mrs. Isbister, one of the most hospitable old couples it has ever been my good pleasure to meet. Mr. Isbister was the local agent of the Hudson's Bay Company, and was a thorough old-time Canadian, one of those men filled with reminiscences of early Canadian life in the north, and whose many stories are a delight to the listener.

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commenced for our journey to the next post, Norway House, one hundred and fifty miles farther on. Some delay was here occasioned in getting dogs, but at length three miserable, half-starved teams were secured, and, with a new guide and drivers, we set out on the third stage of our winter journey. Without narrating the many little incidents by the way, which were very largely a repetition of those of the former part of the trip, I need only say that, after a six days' tramp with the thermometer in the neighborhood of 40 degrees below zero, we arrived safely at Norway House, an important Hudson's Bay Company post, situated at the northern extremity of Lake Winnipeg. I should have said that two of the dog teams procured at Oxford had been intended to haul my brother and myself, and for a time they did so; but the poor animals were in such a wretched condition from the effects of former hard work, that we preferred to walk most of the time, and before we reached Norway House considered ourselves fortunate that we escaped without having to haul the dogs.

Having reached Norway House the difficulties of our journey, so far as my brother and myself were concerned, were practically ended. Sufficient good strong dogs were here available to admit of us traveling in carryalls for the remaining four hundred miles still separating us from West Selkirk, the northern terminus of the railway, but of course our Indians had to stick to their snowshoes. It was here decided to divide our party and send the three western men—assisted by the team of Eskimo dogs which had accompanied us the whole six hundred miles from Churchill—on foot up the valley of the Saskatchewan River, that being their most direct route. In taking it they would reach their several homes within about the same distance that we would have to travel in reaching Selkirk, namely, four hundred miles. Arthur Owman, the driver from Churchill, chose to go up the Saskatchewan with the western men, so that of our original party there only remained the two Iroquois, Peter and Louis, to accompany my brother and myself. With the least possible delay, four good dog teams, as many drivers and a guide, were procured from Mr. Macdonald, the Hudson Bay Co.'s factor, who showed us much kindness, and two days before Christmas the last and longest division of our journey was begun.

My brother and myself were now warmly rolled up in robes and blankets and lying in our carryalls. Our supplies and baggage were all loaded upon the two remaining sleds, and with a driver

trotting along beside or behind each team, the guide running before, and the two Iroquois sometimes before and at other times behind, we travelled on an almost due south course over the ice along the shore of Lake Winnipeg. About the same time that we started for the south, the other section of our party set out across the lake to the westward for the mouth of the Saskatchewan River, the course of which they were to follow to their homes.

Our teams, of four dogs each, consisted chiefly of fine, powerful animals, and we soon found that there was no further necessity of my brother or me exerting ourselves more than we desired. The teams travelled all day, and indeed day after day, at a rapid trot, sometimes breaking into runs, so that it gave the Indians all they could do to keep up with them. Halts were made once during the morning, at noon, and once during the afternoon to rest the dogs; and in the evening camp was made on the shore in the woods as on the earlier parts of our journey. Some parts of our road were very rough and lumpy, making the footing bad for both men and dogs. It also made travelling scarcely less disagreeable to us who rode, for as our carryalls rattled and bumped over the lumps, we, lying upon our backs without room enough to move, received the full benefit of every bump.

But taking rough and smooth together, we travelled on, making an average of about forty miles per day, and some days making as much as forty-six or forty-seven miles. When we had made about half our distance to Selkirk, and were in the neighborhood of a fishing station at the mouth of Berens River, poor Peter, the Iroquois, played out, but being fortunate in meeting a man who was teaming fish to Selkirk, we secured a passage for Peter, and ourselves pushed on. When we had made about another hundred miles, Louis, the remaining Iroquois, also became crippled; but again arrangements were made to have him driven in with a horse and sleigh, and without delay we pushed on. As the force of gravitation increases inversely as the square of the distance, so our anxiety to get in increased as the end of our journey drew nearer, and at length, after a long and rapid trip which occupied ten days, on the evening of the 1st of January, 1894, under the light of the street lamps of the little town, our teams trotted up the streets of West Selkirk, and thus our canoe and snowshoe journey of three thousand three hundred miles was completed.

I need hardly say that the telegraph office was soon found and messages despatched to our anxious friends, who for six months past had not been able to hear from us.

AIR COMPRESSORS.

BY H. V. HAIGHT, GRAD. S.P.S.

No one who is at all interested in engineering can fail to be impressed with the importance of the applications of compressed air. Though some of its uses have been known for hundreds of years, and though it has been used in mining, tunnelling and similar work for a long time, yet it is only lately that compressed air has begun to receive the attention that it deserves. As evidence of its recent development we might point to the compressed air journal, *Compressed Air*, which has been published since the beginning of 1896, and to the fact that, since the beginning of the present year, the *Engineering Magazine* has devoted to compressed air a special department of its index of technical literature. One can hardly pick up a technical journal without seeing some reference to the uses of compressed air; and, even the newspapers have given descriptions of the pneumatic street cars now running in New York City. We have been somewhat behind European countries in our recognition of the possibilities of compressed air. For over ten years there has been in operation in Paris a pneumatic system of power-distribution, and for some time street cars run by compressed air have been in operation in France and Switzerland.

While the uses of compressed air are receiving so much attention, not much appears to be generally known regarding the methods of compressing air. This paper is intended to present in concise form some of the information regarding air compressors which is scattered through various books, periodicals and catalogues.

The most common form of air compressor is the direct-acting piston compressor. The air cylinder of the Air Brake Pump shown in Fig. 4 will serve to illustrate the action of compressors of this kind. On the down stroke air is drawn in above the piston through valve I, while at the same time the air below the piston is compressed and forced out through valve D¹. On the up stroke air is drawn in at I¹ and forced out through D.

Air at very low pressures, such as the blasts used in blowing fires, cleaning grain, ventilating buildings and mines, etc., is furnished by bellows, rotary blowers, or fans, but these machines are not generally classed as air compressors, and both in theoretical treatment and design they are usually very different from the kind first mentioned.

The most common method of driving a compressor is by direct connection to a steam engine, the two pistons being on the same rod, as shown in Figs. 4, 13, 14, 15, etc. Other methods of driving are by direct connection to a water-wheel, as in Figs. 21 and 22, or by belting or gearing, from a shaft to which power is furnished from some source. (Figs. 10, 11 and 18.)

USES OF COMPRESSED AIR.

In order to get a fair idea of the requirements of a well-designed compressor, we should understand some of the uses to which compressed air is put, as a design which would be correct under one set of conditions might be quite unsuitable under other circumstances. There are some two hundred distinct uses of compressed air, not including those in which it merely produces rotary motion in general, the compressed air motor taking the place of a steam engine, electric motor or some other means for furnishing power. Hence, we must necessarily limit ourselves to a few of its uses, and we will choose such uses as will best illustrate the different requirements in the design of air compressors.

One of the earliest uses of compressed air of which we have any record, is in connection with work done under water, in diving apparatus, bridge caissons and tunnels. The pressures used are generally low, from 10 to 25 pounds per square inch. It is difficult for men to work under high pressure. In the construction of the gas tunnel under the East River and Blackwell's Island, at New York, the pressure in the tunnel was 48 pounds. The pressure was so great that the workmen could remain only two hours at a time in the tunnel, and several of them died from the effects of it. It is evident that a compressor for this service should be *reliable*. It should be simple, strong, portable, capable of working under a considerable range of pressures, or of being run at a high speed in an emergency. All these points would probably be considered more important than steam economy.

Next to its use for work under water, one of the earliest uses of

compressed air, and one which still employs probably one-half of the compressed air that is used for mechanical purposes, is in driving rock drills and other machinery in mining and quarrying, or in the construction of canals and tunnels. The pressures used vary from 50 to 100 pounds per square inch—60 pounds being a common pressure. The requirements of a compressor for this service will, of course, vary considerably with the location, altitude, transportation facilities, etc. We might say, in general, that economy of steam and durability are the most important requirements. Mines are often situated at a considerable distance from a source of supplies, so that coal is dear, and repairs are troublesome and expensive. In the case of a coal mine, however, steam economy would have little weight, except, perhaps, as far as it affected the size of boilers necessary to supply the steam. For high altitudes, the compression cylinder must be made larger for the same power capacity. Where water-power is available, of course the compressor would require to be designed to suit the hydraulic conditions.

In some large cities, notably in Paris, there are large central stations, with pipe systems running to all parts of the city, for the purpose of supplying compressed air for numerous purposes. In large plants of this kind the greatest attention can be paid to the production of compressed air at the lowest power cost.

The automatic air brakes on railroad trains are operated by compressed air furnished by the air-brake pump, placed on the locomotive. The fact that these "pumps" have been in use a number of years, that there are about 30,000 of them in service, and that other designs have been tried and discarded, makes it probable that the design is the one which is the most suitable under the circumstances; and yet they use steam in the most wasteful manner that one could imagine. The air-brake pump uses nearly ten times as much steam for the same service as would be required by the best modern air compressor, and yet it is "the one compressor whose extravagant waste of steam is fully condoned by the circumstances surrounding its employment." The pump is very simple, and is always ready for service, and the steam used is mostly that which would otherwise be blown off at the safety valve of the locomotive while stopping at stations or running down grade.

Air at a comparatively low pressure—from two to four pounds per square inch—is used in blast furnaces. The machines which furnish the blast are called blowing engines, and are very similar to

ordinary air compressors, except that no attempt is made to cool the air during compression. Fig. 31 shows the construction of the air cylinder of a blowing engine.

Air at a very low pressure is also used in the systems of pneumatic tubes for the transfer of mail matter and other parcels. In Philadelphia, where a line of tubes has been installed, the pressure at the main station is seven pounds, and at the sub-station, half a mile away, it is four pounds. The compressor at the main station furnishes power for both the outgoing and the return tubes. In New York City, the pneumatic despatch tubes of the Western Union Telegraph Company are operated partly by direct pressure and partly by vacuum.

In the pneumatic switch and signal systems it has been found advisable to use air at a low pressure. Ten pounds is the pressure used in some cases.

Mining locomotives are often run by compressed air, carried in strong tanks under high pressure. The high pressure is necessary on account of the comparatively small reservoir which the locomotive can carry. The pressures used vary from 350 to 700 pounds per square inch. The compressor must, of course, be designed for this high pressure. As we will see later, compression in two or more stages is almost absolutely necessary for high pressures. In some cases these compressors take air from the general mine service at 80 pounds, and compress to the pressure required by the locomotive.

Compressed air is also used for running street cars. As the reservoirs of these cars must necessarily be small, and the cars must make long trips, the pressures used are sometimes very high, 2,000 pounds per square inch being used in some cases. Even this does not represent the highest pressures used, as the cars are sometimes charged from a large stationary reservoir, in which air is stored under a higher pressure.

Very high air pressures are also used in connection with dynamite guns. The pressure actually used in the gun is about 1,000 pounds per square inch, but in order that several shots may be fired without running the compressor, it is necessary to store the air at a considerably higher pressure—2,000 pounds or more. It will be readily seen that the requirements of a compressor for this service are in many respects quite exceptional, but we shall refer to this more fully when describing a compressor recently built for this purpose.

Air compressors are used on board ship for different purposes.

In this case one very essential requirement is economy of space. On men-of-war the compressed air is used in dynamite guns and for propelling the Whitehead torpedo, in both of which a pressure of about 1,000 pounds per square inch is used. It has lately been proposed to use compressed air on men-of-war for many other purposes also, such as running pumps, operating turrets, etc. On board the ships which carry meat from Australia, compressed air refrigerating machines are in use. The air is compressed in one cylinder to about fifteen atmospheres, thoroughly cooled, and then expanded in another cylinder to about five atmospheres. The exhaust is used for cooling and is then compressed again. This system is known as dense-air refrigerating.

If we examine the question of the design of an air compressor or an air compressing plant, we shall see that in this, as in almost every engineering problem, the underlying principle is economy. We must not, however, consider the matter in any narrow sense, but must take into consideration all the circumstances which bear on the question, giving to each its proper weight. Advantages must be set against disadvantages in order to arrive at a combination which will, on the whole, be the least expensive, considering the results to be obtained.

THEMODYNAMICS OF AIR COMPRESSION.

The changes which occur in the properties of the air contained in the cylinder of an air compressor, may be represented graphically by plane curves, taking as co-ordinates any two of the independent properties of the fluid. The curve most commonly employed, is the one whose co-ordinates are pressures and volumes. With these co-ordinates, we are able to compare our results with the diagrams drawn by an indicator. It is usual to assume that air follows the laws of perfect gases, as expressed by the equation

$$pv = RT$$

The adiabatic equation is

$$pv^k = \text{Const.}$$

And the isothermal is

$$pv = \text{Const.}$$

The values usually taken for the constants are :

$$p_a \begin{cases} = 14.7 \text{ pds. per sq. inch.} \\ = 2,116.8 \text{ pds. per sq ft.} \end{cases}$$

$$R = 53.22$$

$$T = t + 461$$

$$k = 1.41$$

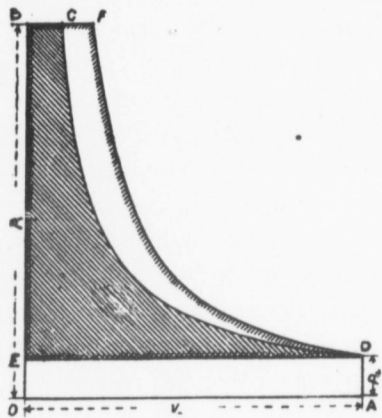


FIG. 1.

Fig. 1 represents an ideal diagram, without clearance or valve resistance. We shall assume that the curve of compression is of the form $pv^n = \text{Const.}$, where the value of n will depend upon the degree of cooling during compression.

During the process ED air is drawn in at atmospheric pressure and does the work on the piston

$$p_a v_a$$

During the process DF this air is compressed to the receiver pressure p_1 , the work done being

$$\frac{p_1 v_1 - p_a v_a}{n - 1}$$

During the process FB this air is expelled at constant pressure, the work done being

$$p_1 v_1$$

The total work of compression and delivery of one pound of air is

$$\begin{aligned} U &= \frac{p_1 v_1 - p_a v_a}{n - 1} + p_1 v_1 - p_a v_a \\ &= \frac{n}{n - 1} (p_1 v_1 - p_a v_a) \\ &= \frac{n}{n - 1} p_a v_a \left(\frac{p_1 v_1}{p_a v_a} - 1 \right) \\ \text{Now } \frac{v_1}{v_a} &= \left(\frac{p_a}{p_1} \right)^{\frac{1}{n}} \end{aligned}$$

Inserting this in the above equation we get

$$U = \frac{n}{n - 1} p_a v_a \left[\left(\frac{p_1}{p_a} \right)^{\frac{n-1}{n}} - 1 \right] \quad (1)$$

$$\text{But } p_a v_a = RT_a$$

Inserting this we get for the work of compression and delivery of one pound of air

$$U = \frac{n}{n - 1} RT_a \left[\left(\frac{p_1}{p_a} \right)^{\frac{n-1}{n}} - 1 \right] \quad (2)$$

Since p_1 and p_a occur as a ratio we may take them in any convenient units, such as pounds per square inch or atmospheres, instead of in pounds per square foot.

During compression the temperature rises and the final temperature may be obtained from the equation

$$\frac{p_1}{p_a} = \left(\frac{T_1}{T_a} \right)^{\frac{n}{n-1}}$$

$$\text{Whence } T_1 = \left(\frac{p_1}{p_a} \right)^{\frac{n-1}{n}} T_a \quad (3)$$

The temperature of the compressed air usually falls, in the receiver and pipes, to the initial temperature T_a , the heat given out being

$$\begin{aligned} Q &= C_p (T_1 - T_a) \\ &= C_p \left[\left(\frac{p_1}{p_a} \right)^{\frac{n-1}{n}} - 1 \right] T_a \end{aligned} \quad (4)$$

Adiabatic Compression.—Equation (2) becomes

$$U = \frac{k}{k-1} R T_a \left\{ \left(\frac{p_1}{p_a} \right)^{\frac{k-1}{k}} - 1 \right\} \quad (5)$$

When the initial temperature is 60° F. this becomes

$$U = 95,630 \left[\left(\frac{p_1}{p_a} \right)^{0.29} - 1 \right] \quad (6)$$

Inserting the value of $\left(\frac{p_1}{p_a} \right)^{\frac{k-1}{k}} = \frac{T_1}{T_a}$ from (3) in equation (5) and

putting $\frac{k-1}{k} R = \frac{C_p}{A}$ equation (5) reduces to $U = \frac{C_p}{A} [T_1 - T_a]$

That is to say, the whole work of the adiabatic compression and delivery of one pound of air is equal to the heat generated during compression and given out when the air cools down, at constant pressure, to its original temperature.

Isothermal Compression.—If the compression follows the isothermal line DC (Fig. 1)

$$\text{Work of atmospheric pressure} = p_a v_a$$

$$\text{Work of compression} = p_a v_a \log_e \frac{p_1}{p_a}$$

$$\text{Work of delivery} = p_1 v_1$$

$$\text{But } p_1 v_1 = p_a v_a = \text{Const.}$$

∴ Work of isothermal compression and delivery of one pound of air is

$$U = p_a v_a \log_e \frac{p_1}{p_a} \quad (7)$$

$$= RT_a \log_e \frac{p_1}{p_a} \quad (8)$$

When the initial temperature is 60° F. this becomes

$$U = 27,710 \log_e \frac{p_1}{p_a} \quad (9)$$

Two Stage Compression.—Air is often compressed in two or more stages, passing through an intercooler on its way from one cylinder to the next, and having its temperature reduced nearly to the initial temperature. Assuming that the intercooler is very large and that the temperature of the air can be reduced to the initial temperature in passing through it, we have the processes as shown in Fig. 2.

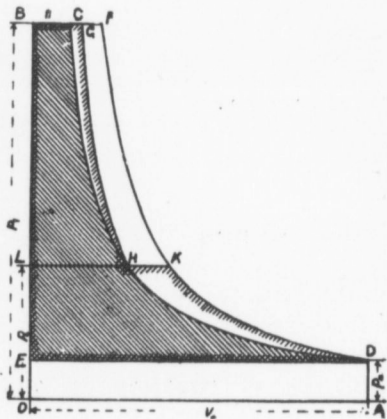


FIG. 2.

During the process ED air is drawn in at atmospheric pressure. From D to K it is compressed in the first cylinder to the pressure p_c . In the process KL it is forced out into the intercooler. During the process LH it is drawn into the second cylinder, during HG it is compressed, and during GB it is delivered at the pressure p_1 . The work of compression and delivery of one pound of air is

$$U = \frac{n}{n-1} RT_a \left[\left(\frac{p_c}{p_a} \right)^{\frac{n-1}{n}} + \left(\frac{p_1}{p_c} \right)^{\frac{n-1}{n}} - 2 \right]$$

Equating the first differential to zero we get the value of p_c which will make the work a minimum

$$p_c = \sqrt{p_a p_1} \quad (10)$$

Inserting this value in the above equation we get

$$U = \frac{2n}{n-1} RT_a \left[\frac{p_1^{\frac{n-1}{2n}}}{p_a^{\frac{n-1}{2n}}} - 1 \right] \quad (11)$$

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Three Stage Compression.—By a similar method we get the minimum work of three stage compression to be

$$U = \frac{3n}{n-1} RT_a \left[\left(\frac{p_1}{p_a} \right)^{\frac{n-1}{3n}} - 1 \right] \quad (12)$$

Mean Effective Pressure.—From equations (1) and (7) we may obtain the value of the mean effective pressure for the process. Dividing by v_a we get

$$\text{Adiabatic - M. E. P.} = \frac{k}{k-1} p_a \left[\left(\frac{p_1}{p_a} \right)^{\frac{k-1}{k}} - 1 \right] \quad (1a)$$

$$\text{Isothermal - M. E. P.} = p_a \log_e \frac{p_1}{p_a} \quad (7a)$$

Tables have been calculated and may be found in books on compressed air, giving the mean effective pressure of both adiabatic and isothermal compression to different pressures. They are very useful for making calculations of the power required by a compressor or in comparing the actual work of compression with the ideal.*

Efficiency.—The work of isothermal compression is taken as the standard in determining the efficiency of compression. It represents the ideal and unattainable, but still the only rational standard. The excess of work over that of isothermal compression represents the work uselessly expended in overcoming valve resistance and in heating the air during compression. This heat is lost when the temperature of the compressed air falls to the initial temperature, as it usually does before the air is used.

Dividing (8) by (2) we get the efficiency of single stage compression, under the assumed conditions

$$E_1 = \frac{\log_e \frac{p_1}{p_a}}{\frac{n}{n-1} \left[\left(\frac{p_1}{p_a} \right)^{\frac{n-1}{n}} - 1 \right]} \quad (13)$$

For two stage compression, dividing (8) by (11) we get

$$E_2 = \frac{\log_e \frac{p_1}{p_a}}{\frac{2n}{n-1} \left[\left(\frac{p_1}{p_a} \right)^{\frac{n-1}{2n}} - 1 \right]} \quad (14)$$

*The writer has found the tables in "Compressed Air" by Frank Richards to be very useful.

For three stage compression, dividing (8) by (12) we get

$$E_3 = \frac{\log_0 \frac{p_1}{p_a}}{\frac{3n}{n-1} \left[\left(\frac{p_1}{p_a} \right)^{\frac{n-1}{3n}} - 1 \right]} \quad (15)$$

The following table gives the values of E_1 , E_2 and E_3 for adiabatic compression to several pressures.

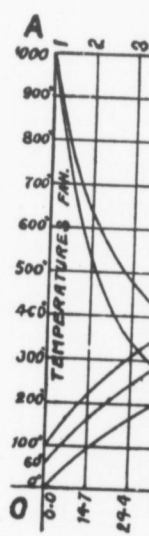
Gauge pressure.	$\frac{P_1}{P_a}$	E_1	E_2	E_3
29.4	3	85	92	..
58.8	5	78	89	..
88.2	7	74	86	..
132.3	10	70	84	..
205.8	15	66	82	..
499.8	35	57	76	84
1014.3	70	51	72	81
2041.3	140	45	68	78

Effect of Clearance.—If we assume that the air in the clearance expands according to an exponential curve, having the same value of the exponent as the compression curve (which cannot be far wrong), then the air in the clearance acts as a cushion, storing and giving out energy. Then no more power will be required to compress and deliver the same quantity of air, but the capacity of the compressor cylinder will be lessened by the length of E L, Fig. 17, to the whole length of the diagram. This makes it necessary to compress in stages, when high pressures are desired. In compressing to 35 atmospheres (about 500 pounds gauge) for instance, if there were a clearance of even *one per cent.*, the air in the clearance would expand and fill over 30 per cent., of the cylinder, reducing the capacity by that amount.

Equations (2), (5), (6), (8), (9), (11) and (12), giving the work in foot pounds per pound of air compressed, will still apply, but if we wish to make use of the equations giving the mean effective pressure, we must either (1) reduce the M.E.P. by the ratio of E L to the whole length of the diagram, or (2) use the M.E.P. determined by this equation with the actual quantity of air compressed.

Pressure-Temperature Curves.—Some very interesting curves are given by W. L. Saunders, C.E., in connection with his paper on "Compressed Air Production." These are shown in Fig. 3. There are, in fact, two distinct diagrams. The curves starting from the corner A show the relative volumes at different pressures in

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atmospheres or by gauge (taking the initial volume as unity.) The curves starting from the corner O show the temperature at different pressures during adiabatic compression, the initial temperature being given.

For example, suppose air to have been compressed to seven atmospheres, as shown at the top of the diagram, or 88.2 lbs. gauge,

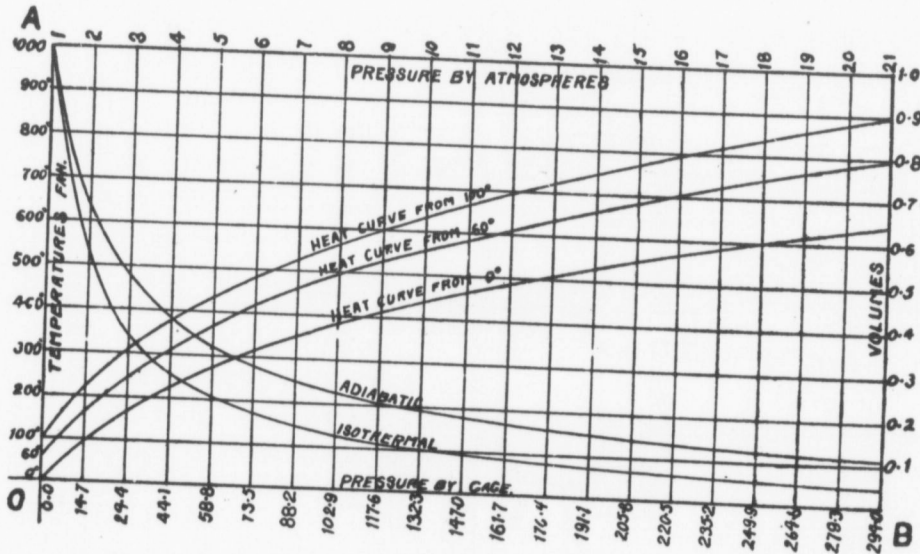


FIG. 3.

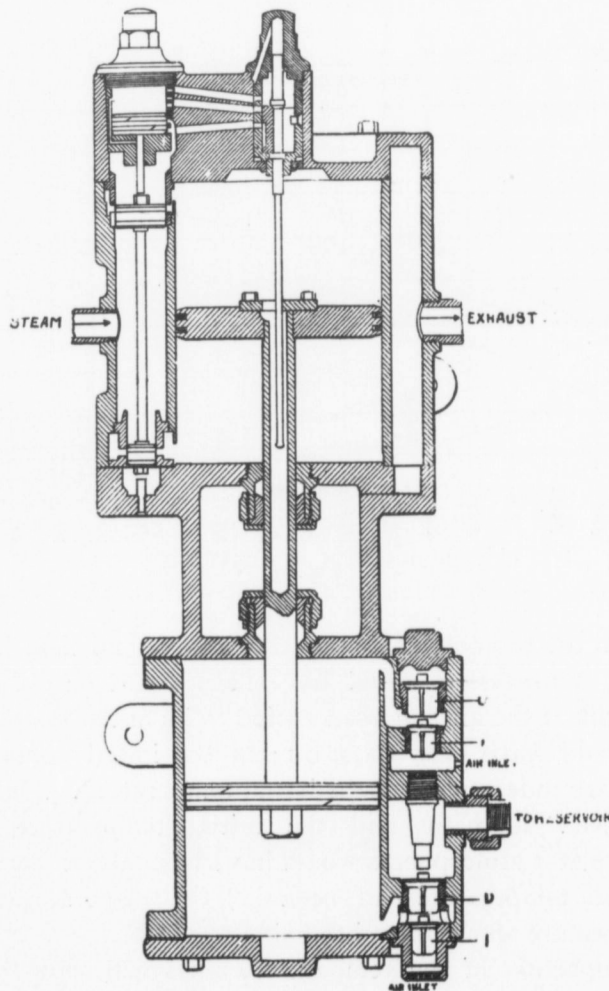
as shown at the bottom; then the volume, had no heat been given out during compression, would have been about 0.25 of the initial volume, while if the air had been cooled to its initial temperature the volume would have been about 0.14 of the initial volume. These quantities are independent of the initial temperature. Had the compression been adiabatic and the initial temperature 0° F., the temperature at 7 atmospheres would have been about 350° F., while if the initial temperature had been 60° , the temperature at 7 atmospheres' pressure would have been about 454° F.

An inspection of the temperature lines will show that a high initial temperature corresponds to a high temperature throughout compression, and also to a rapid rise of temperature during compression. This shows the advantage of a low initial temperature.

We can also see the advantage of a low initial temperature from equations (2) (8) and (12). It will be seen that the work of compression varies directly as the absolute temperature. If the tempera-

ture of the air which is available for compression is 39° F. or $461 + 39 = 500^{\circ}$ by the absolute scale, then every five degrees which this air becomes heated before compression begins represents a loss of one per cent. In the winter there is often a difference of 50 degrees

Fig. 4. AIR PUMP.



between the air outside the engine room and the air inside of it, so that a saving of ten per cent. might easily be made by a proper attention to the air supply. In almost every form of air compressor the air has a chance to become heated during admission to the cylinder by coming in contact with hot metal. To make matters

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worse, the air is often forced to flow in thin streams over the heated metal. There is evidently a chance for considerable improvement in this particular. This is a loss, however, which is not shown by the indicator, so that very little attention is paid to it, and manufacturers of compressors calmly assume that it does not exist.

REMOVING THE HEAT OF COMPRESSION.

Compressors are often divided into classes, which differ from one another in the methods employed for removing the heat imparted to the air during compression. One classification is into "wet" and "dry" compressors. With "wet" compressors water is used in the cylinder during compression to keep down the temperature. Wet compressors are sub-divided into *injection* compressors, in which water is admitted to the cylinder in a spray, and *water piston* compressors, where a body of water moves back and forth with the piston and compresses the air. Figs. 25 and 26 show the compression end of a water piston compressor made by the Humboldt Engineering Company, Kalk, near Cologne, Germany.

In "dry" compressors the whole cooling effect on the air *during compression* must come from the walls of the cylinder and piston. The dry compressor is the kind more commonly used. There is no firm on this continent, so far as can be learned, which regularly manufactures wet compressors, and a great many firms in England and other European countries make only dry compressors. The wet compressor is the earlier type, and it is still used extensively in some places, notably at the power plant in Paris, where there are compressors of 2,000 H. P. each, in which water is injected into the cylinder. In Germany also the wet compressors seem to find considerable favor.

There is, without doubt, considerable to be said in favor of using water in the cylinder during compression. When water is properly introduced in a fine spray, the temperature is kept down throughout compression and the heat loss is very small. In compressing adiabatically to five atmospheres (58.8 pounds gauge) the lost work, due to the heating of the air, is 27 per cent. of the work of isothermal compression. W. L. Saunders, C.E., in his paper on "Compressed Air Production," says that in the old Ingersoll Injection Compressor this loss was reduced to 3.6 per cent., and he quotes a description of a compressor of an European type in which it was reduced to 1.6 per cent. The description given is as follows: "Engine, two vertical cylinders, steam jacketed, with Meyer's expansion gear; cylinders,

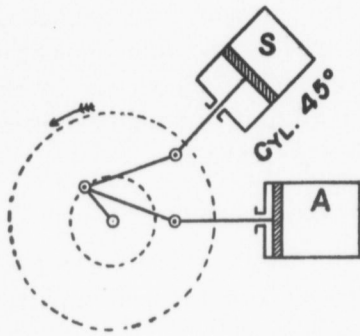


FIG. 5

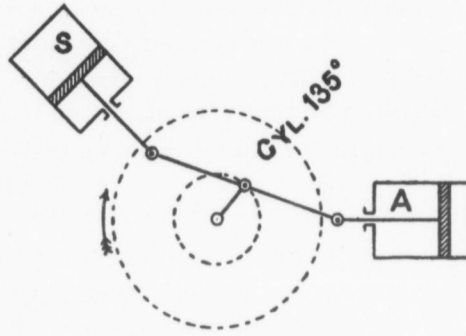


FIG. 6

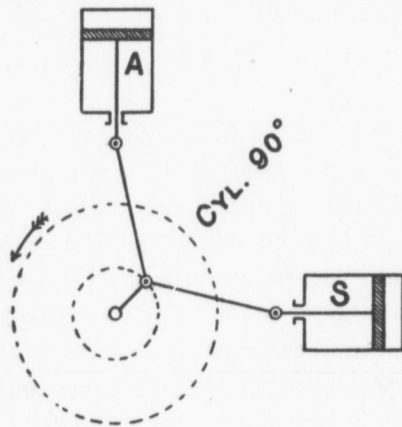


FIG. 7

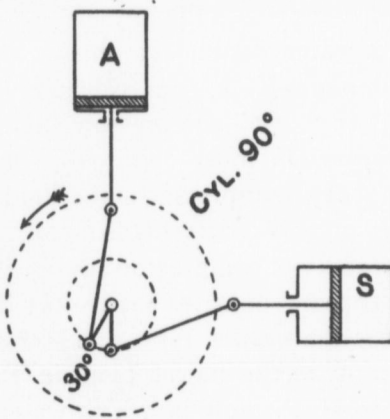


FIG. 8

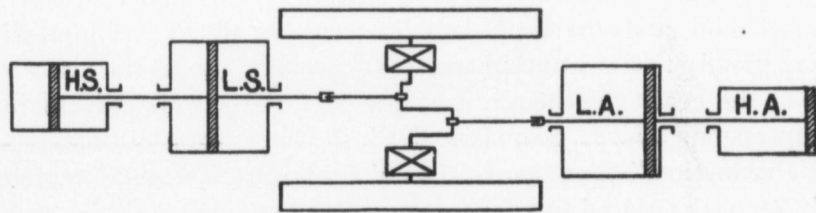


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16.9 inches diameter, stroke 39.4 inches; compressor, two cylinders, diameter of piston 23 inches; stroke 39.4 inches; revolutions per minute, 30 to 40; piston speed 195 to 260 feet per minute; capacity of cylinder per revolution, 20 cubic feet; diameter of valves, viz., four inlet and four outlet, $5\frac{1}{2}$ inches; weight of each inlet valve, 8 lbs.; outlet, 10 lbs.; pressure of air, 4 to 5 atmospheres. The diagrams taken of the engine and compressor show that the work expended in compressing one cubic meter of air to 4.21 effective atmospheres (61.9 pounds per square inch gauge pressure) was 38,128 lb. (it appears to mean meter-pounds; the pound is of course not a measure of work). According to Boyle and Mariotte's law (that is, for isothermal compression) it would be 37,534 lb., the difference being 594 lb., or a loss of 1.6 per cent."

For adiabatic compression, the lost work would have been 28 per cent. of the work of isothermal compression. The temperature of the air on entering the cylinder was 50°F., on leaving, 62°F. The mechanical efficiency was $85\frac{1}{2}$ per cent.

The thermal efficiency of this compressor was remarkably high, the more so when we consider that the calculation from the area of the indicator cards includes in the 1.6 per cent., the losses due to valve resistance also. It should be noted, though, that the friction loss of 14.5 per cent. is quite large, and that the low piston speed would require the machine to be very large and heavy in proportion to its capacity.

The results of experiment and experience all go to show that by the proper use of water in the cylinder during compression the temperature of the air can be kept down and the loss of work due to heating of the air can be reduced beyond what can be expected of mere surface cooling. Other advantages that are claimed for "wet" compressors are as follows:—

- (1) Increased volume of air per stroke, due to the clearance spaces being filled with water.
- (2) Cold cylinder, preventing the air admitted from becoming heated before compression begins.
- (3) Low temperature of air immediately after compression, thus causing the moisture of the air to be condensed in the receiver.
- (4) Low temperature of cylinder and valves, thus maintaining the packing.

In order to be efficient as a cooling device, water must be

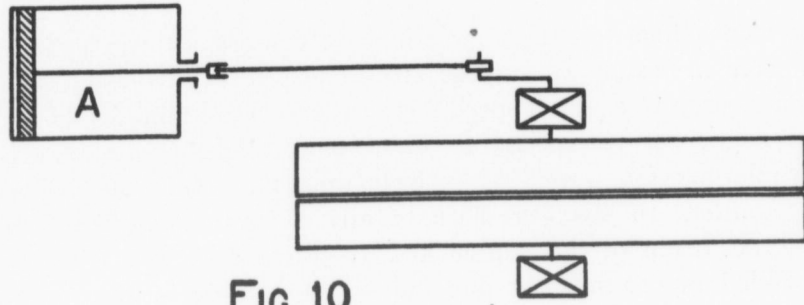


FIG. 10

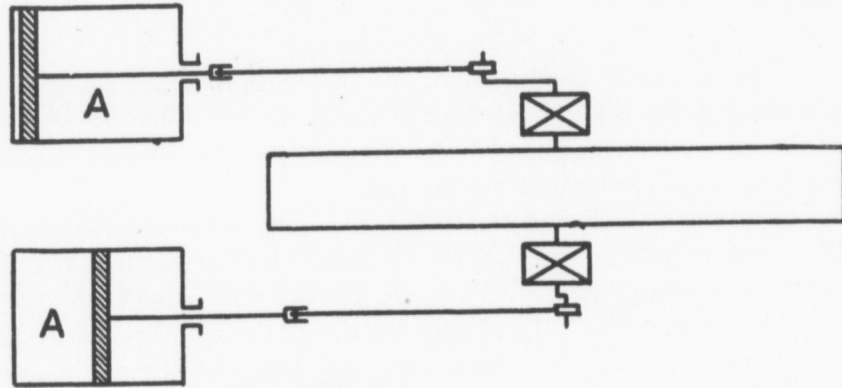


FIG. 11

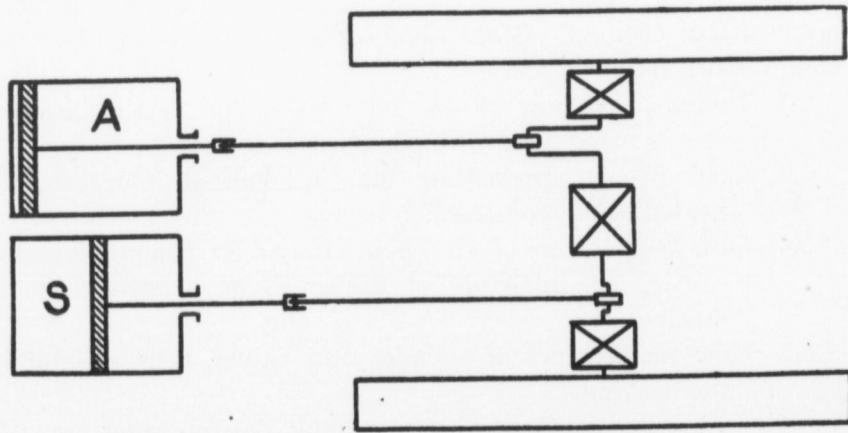


FIG. 12

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injected *during compression* in a *fine spray*. Water and air are both poor conductors of heat, so that in order to cool the air its particles must be brought in *contact* with the water. When water is admitted with the air through the inlet valves, it falls at once to the bottom of the cylinder and can have little effect during compression. With water piston compressors the result is much the same; the surface of the water becomes heated and it is then of little further use. It would not be as good as that much surface of cast iron. Cast iron and water have about the same capacity for heat at equal volumes, but cast iron is about eighty times a better conductor than water. When water is used in the cylinder but does not keep down the temperature of the air, then the air will take up moisture and the air delivered will contain much water. The pressure of this water vapor will also increase the work of compression. Other objections to water in the cylinder, besides these two, are as follows:

- (1) Impurities in the water act on the surfaces exposed to it.
- (2) The presence of water causes difficulty in lubricating the cylinder.
- (3) Mechanical complications connected with the water pump and the difficulty of injecting the right quantity of water.
- (4) Loss of the power required to move the water in the cylinder.
- (5) Absorption of air by the water.
- (6) The presence of the water limits the speed of the compressor, because of the danger of breaking the cylinder-head.

Of these objections the most serious is that of the increased wear of the working parts. Even when pure water is used the cylinders wear to such an extent as to produce leakage and require re-boring. The limitation of speed is also of considerable importance. This does not so much affect injection compressors, as they may approach dry compressors in speed; but the hydraulic or water piston compressors are subject to the laws which govern piston pumps, and are limited to a piston speed of about 100 feet per minute. The slow speed of hydraulic piston compressors makes a very heavy and expensive construction necessary. Dry compressors may be run at a piston speed of nearly 500 feet per minute, and injection compressors at over 400 feet per minute.

There is one other method of removing the heat of compression, though it can hardly be called a method of removing the heat *during compression*. It is by compressing the air in two or more stages and

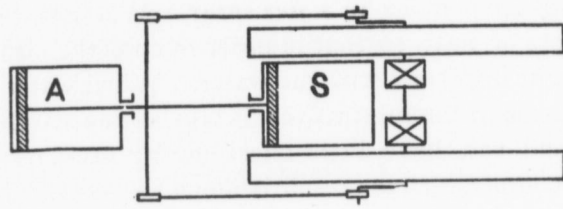


FIG. 13

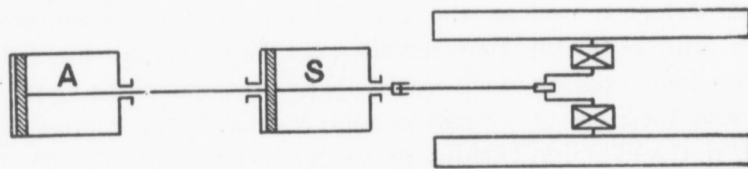


FIG. 14

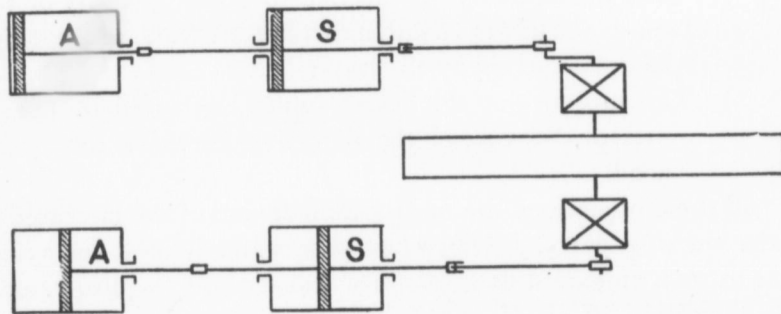


FIG. 15

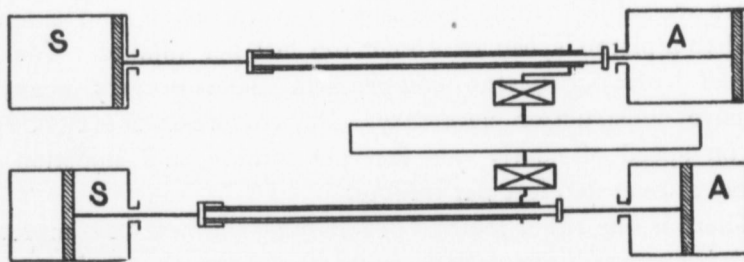


FIG. 16

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cooling it between the stages. This method can be made quite efficient, for the intercooler can be made of sufficient capacity to cool the air to the initial temperature. The possible saving is shown by the table previously given of the theoretical efficiency of single-stage, two-stage, and three-stage compression to various pressures. The greatest saving by compounding is effected when compressing to high pressures. It is when compressing to high pressures that the other advantages of compounding, viz., the reduction of the terminal strains and the clearance losses, are the most marked.

This method of cooling may be, and usually is, combined with some other method of cooling. The Norwalk tandem compound compressor shown in Fig. 20 has both water jackets and intercooler. The Riedler compressors used at the power plant in Paris are two-stage compressors with spray injection.

To sum up we may say: Good spray injection will give the highest thermal efficiency; but other considerations make the presence of water in the cylinder undesirable. Water used in the cylinder, except as a spray, is objectionable. Surface cooling by water-jacketed cylinders is not particularly efficient, but has many advantages. Compression in two or more stages, combined with one of the previous methods of cooling, gives excellent results.

VARIOUS EFFICIENCIES.

Let U = work of compression, as calculated from the indicator cards of the steam cylinder.

And U_1 = work of compression, as calculated from the indicator cards of the air cylinder.

Then $\frac{U_1}{U} = E_m$ may be taken as the *mechanical efficiency* of the compressor, including, of course, the friction of both steam and air ends; that is, in reality, E_m is the combined mechanical efficiency of both steam engine and compressor.

U and U_1 may be taken in foot pounds per pound of air compressed. It is more usual to take the work per cubic foot of free air compressed; but in that case we must take both pressure and temperature into account also.

Let U_2 = work of isothermal compression of one pound of air. (See equations (8) and (9).

Then $\frac{U_2}{U_1} = E_c$ may be taken as the *efficiency of compression*. It

includes losses due to imperfect valve action, to leakage, to clearance, to heating of the air during admission, and to the rise of temperature during compression. All of these losses except the last may be kept small by good construction. The imperfect action of inlet valves causes throttling during admission, which increases the work of the stroke and decreases the quantity of air admitted. The extra work is represented by the area of the card between the atmospheric line M N, and the admission line A F, Fig. 11. The loss of capacity is represented by the ratio of A K to the whole length of the diagram, A L. This loss of capacity is not necessarily a loss of efficiency, but calculations of efficiency are often made on the basis of the volume of the cylinder, and we must then take the loss of capacity into account. The loss due to imperfect action of the dis-

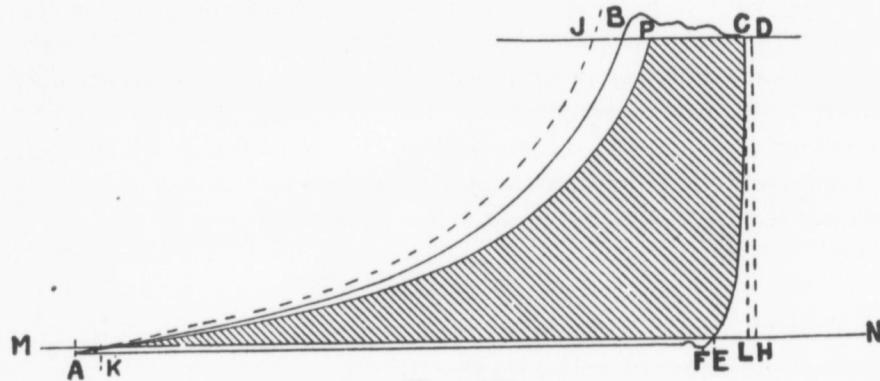


FIG. 17

charge valve is represented by the area of the air-card above the line J.D., representing the receiver pressure, (See Fig. 17). Leakage should not cause any appreciable loss in a well-constructed compressor. It is to be noted, however, that leakage will reduce the apparent work of compression, as calculated from the cylinder capacity, and hence will give a higher apparent efficiency—although the real efficiency is less. The loss due to clearance is almost wholly a loss of capacity. It must, of course, be taken into account when the work of compression is calculated from the cylinder capacity. The loss of capacity due to clearance may be conveniently included with the loss due to throttling during admission, the total volumetric efficiency being represented by the ratio of K E to the whole length of the diagram.

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the beginning of the compression stroke may, as previously indicated, be of considerable importance. This loss may be made small by taking the air from as cool a place as possible and by exposing it as little as possible to hot surfaces during admission. A point just below the eaves on the north side of the building is generally a good place from which to draw the air. The pipe conveying the air to the compressor should preferably be of wood, brick or earthenware, in order to be non-conducting. The inlet valve passages should be short and direct, and the openings should have a large area compared to the area of metal next to them, so that only a small portion of the air may come in contact with the hot metal. Keeping the walls of the cylinder cool will help to prevent the air which has entered the cylinder from becoming heated before compression begins. This loss is not shown by the indicator cards and hence is often neglected. It could be determined by measuring the quantity of air compressed. Where this is not possible we should at least make some reasonable allowance for it, basing our judgment on any actual results obtainable, modified by the conditions in the given compressor. The largest loss included under E_c , that due to the rise of temperature during compression, is discussed under the head of *Removing the Heat of Compression*. Equations (10), (11) and (12) give the theoretical efficiency of adiabatic compression, where this loss is the only one included. We may determine this loss separately, if we wish, by calculating the exponent of the compression curve on the indicator card and inserting the value of n in equation (10).

To sum up, we may say that the total efficiency of the compressor, $E_m E_c$, is made up of two factors, the *mechanical efficiency* E_m , represented by the ratio of the indicated work on the air piston to the indicated work on the steam piston, and the *efficiency of compression* E_c , represented by the ratio of the isothermal work of compression to the indicated work on the air piston, both quantities being calculated for the same *mass* of air. This mass may be a pound of air or it may be the mass of a cubic foot of air under given conditions of temperature and pressure. When the actual work of compression per cubic foot of *free* air is calculated on the assumption that a cylinderful of free air is compressed per stroke, then the resulting efficiency must be multiplied by the *volumetric* efficiency of the compressor and by the efficiency represented by the ratio of the absolute temperature of the free air to the absolute temperature of the cylinderful of air. The product of these three factors will then be E_c .

Not many complete and reliable tests of air compressors have been made in this country, so that the figures given below refer chiefly to European compressors.

Prof. Unwin gives the two following tables. The figures are of special interest as showing the marked improvements which have been made in compressors. The compressor used at the St. Gothard tunnel in 1872 is interesting historically, as it was then that Prof. Colladon first introduced spray injection. It is to be remembered that E_m represents the mechanical efficiency, E_c the ratio of the useful work to the actual work of compression, and $E_m E_c$ represents the total efficiency.

Type of compressor.	p_1 , atmos.	Lost work in % of useful work.	E_c
Colladon, St. Gothard	6	105.0	0.448
“ “	6	92.0	0.521
Sturgeon	3	94.3	0.515
Colladon	4	38.15	0.722
Slide valve compressor	5	49.3	0.670
Paxman	42.7	0.701
Cockerill	6	40.2	0.713
Riedler—two-stage	6	12.07	0.892

Other and more extended experiments gave the following results:—

Compressor.	Steam work per hr., ft. pds.	Wt. of air compress'd.	Steam work per lb. of air.	$E_m E_c$	E_m	E_c
Paxman (Sturgeon)	1,980,000	20.24	97,830	0.551	0.85	0.648
Cockerill (Dubois-Francois)	1,980,000	22.94	86,340	0.624	0.85	0.735
Riedler (two-stage)	1,980,000	28.06	70,550	0.764	0.87	0.898

In a duplex *geared* steam driven compressor described in *Engineering* of 1894, the I. H. P. of one steam cylinder was 81, and the I. H. P. of the corresponding air cylinder was 69, giving $E_m = 85\%$. As all the power is transmitted through two crank shafts and a pair of gears, we should expect the friction to be large.

The *American Machinist* of April 23, 1896, gave a report of a test of a duplex, three-stage, high-pressure compressor for furnishing compressed air at 2,000 pounds pressure for a pneumatic gun battery. Fig. 29 shows the general arrangement of this compressor. The mechanical efficiency, E_m , was 81.5%. The efficiency of compression, E_c , was 78.9%. This gives for the efficiency of the whole machine $81.5 \times 78.9 = 64.4\%$. The theoretical value of E_s for three-stage

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adiabatic compression is 78.1%, so that the efficiency of compression came very close to the theoretical value, the loss from imperfect valve action being somewhat more than made up by the cooling effected by the jackets. The efficiency of single stage adiabatic compression to 2,000 pounds is only 45%. Both of these efficiencies are remarkably good, considering the extremely high pressure, and indeed the total efficiency of 64.4% is probably as high as in many compressors which compress to 100 pounds instead of 2,000 pounds.

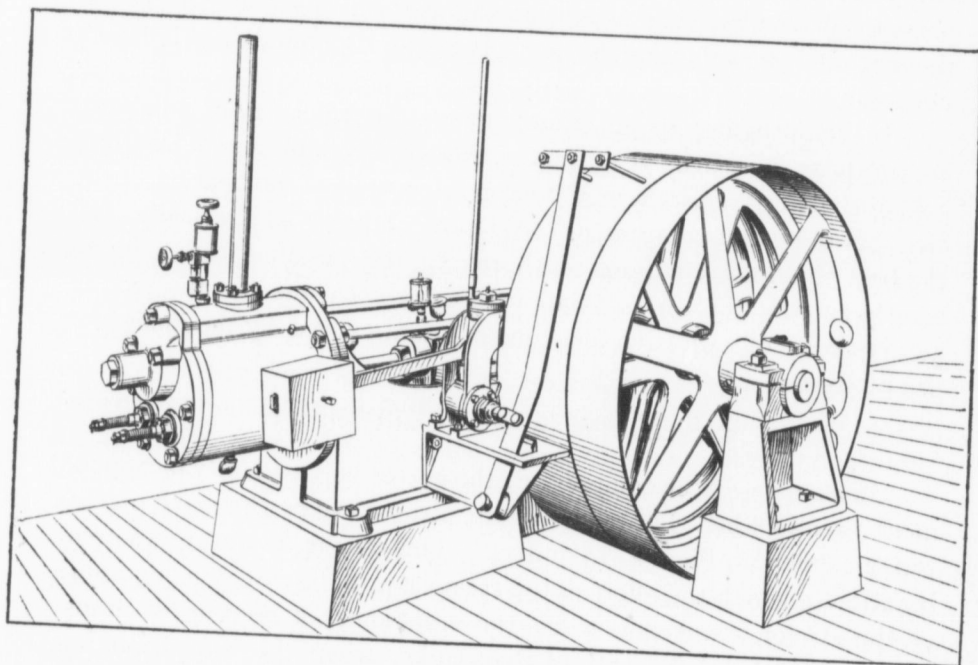


FIG. 18.

The mechanical efficiency of some kinds of "dry" air compressors is very high. It is stated that tests made by Professor Jacobus for the World's Fair judges showed a friction loss in a 300 horse-power compressor of less than five per cent.

There is still another efficiency which, while it cannot properly be said to pertain to the compressor, is of much greater practical importance. This is the efficiency of the steam end of the compressor. Many of the smaller compressors have common slide valves without cut-off, and even with good boilers and piping it is not to be

expected that they will require less than six pounds of coal per horse-power-hour. Even in those compressors which have a Meyer cut-off with hand-adjustment, the steam cards are not such as to lead one to expect a very good steam economy; and they would probably require from three to four pounds of coal per horse-power-hour. Builders will furnish compressors of what Mr. Frank Richards calls the "five-C type," the Corliss Cross Compound Condensing Compressors, and guarantee that the coal consumption shall not exceed two pounds per horse-power-hour. With the two-stage Riedler compressors, driven by triple expansion engines, which are used in Paris, the net fuel consumption during a test was 1.3 pounds per I. H. P. per hour.

In compressing to 80 pounds gauge the efficiency of adiabatic compression E_1 , is over 75%; that is, there is a possible loss of less than 30% of the work of isothermal compression, due to the heating of the air. As the worst compressor could not compress adiabatically, and the best could not compress isothermally, the possible loss by inefficiently cooling the air is small, compared with the possible 200 or 300 per cent. of excessive fuel consumption, caused by the inefficient use of steam.

EQUALIZATION OF POWER AND EFFORT.

In a steam-driven compressor, the power will evidently be applied most directly when the steam and air pistons are on the same piston-rod, as shown in Figs. 4, 13 and 14. This results, however, in a combination in which the effort of the steam is greatest at the beginning of the stroke, at the time when the resistance of the air is almost nothing; while at the end of the stroke, when the expansion has greatly reduced the steam pressure, the air pressure is a maximum. To make matters worse, the cushion due to clearance in the air cylinder acts *with* the steam at the beginning of the stroke.

Various methods have been employed for equalizing the effort of the steam and the resistance of the air throughout the stroke.

Early Designs.—In many of the older compressors the power was applied through a crank shaft, the cylinders and cranks being set at various angles, as shown in Figs. 5, 6, 7 and 8, taken from W. L. Saunders' paper on Compressed Air Production. Fig. 5 shows the Rand and Waring; Fig. 6 the Davies; Fig. 7 the Frick, and Fig. 8 the Burleigh, old Ingersoll and De La Vergne designs. About the only remaining representative of the class in which the cylinders are

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set at an angle to one another is the De La Vergne refrigerating machine. It has a horizontal steam cylinder and two vertical compression cylinders. The connecting-rods of the steam cylinder and one compression cylinder are attached to the same crank. The crank for the other compression cylinder is on the same crank shaft, but at an angle of about 150° to the first one.

These angular positions involve expensive construction and unsteadiness. The indirect application of the power also causes a greater loss in friction.

Air Brake Pump.—In the Westinghouse Air Brake Pump shown in Fig. 4, the forces are equalized in a most ingenious manner. This is a direct-acting or straight-line compressor; that is, the two pistons are on the same piston-rod. Both cylinders are double-acting. As will be seen by the indicator diagrams, shown in Fig. 23, the steam is throttled at the beginning of the stroke, but the pressure rises during the stroke till at the end the steam is at full boiler pressure. At the beginning of the return stroke the back pressure is very high, but falls off during the stroke. The high back pressure at the beginning of the stroke is made necessary by the cushion of compressed air in the clearance of the air cylinder. It will be evident that this arrangement is even more wasteful of steam than that of using steam at boiler pressure for full stroke; but, as previously noted, there are other conditions which make the question of steam economy a minor consideration.

Straight Line Compressors.—There is, however, no very great difficulty in getting nearly uniform motion at the fly-wheel of a straight-line compressor of the crank and fly-wheel type, shown in Figs. 13 and 14. It is only necessary to have a heavy fly-wheel and heavy reciprocating parts. Then at the beginning of the stroke, when the steam is at full pressure, its energy will be spent chiefly in accelerating the heavy reciprocating parts, while towards the end of the stroke, when the power of the steam is diminished, these reciprocating parts will give out energy while being brought to rest. The heavy fly-wheel will greatly assist in obtaining a uniform motion, but as the transmission of energy to and from the fly-wheel causes a pressure of the cross-head against its slide, of the wrist-pin and crank-pin against their bearings and of the crank shaft against its bearings, it is evident that the less work the fly-wheel has to do the less work will be lost in friction. If we can arrange so that the fly-wheel will have but little work to do to steady the motion, we shall be able to make it lighter, which will also diminish the friction. On the other hand, the trans-

mission of energy from the steam to the reciprocating parts, and from them to the air, is direct and does not cause any side thrust. The fact that a great part of the power is thus transmitted

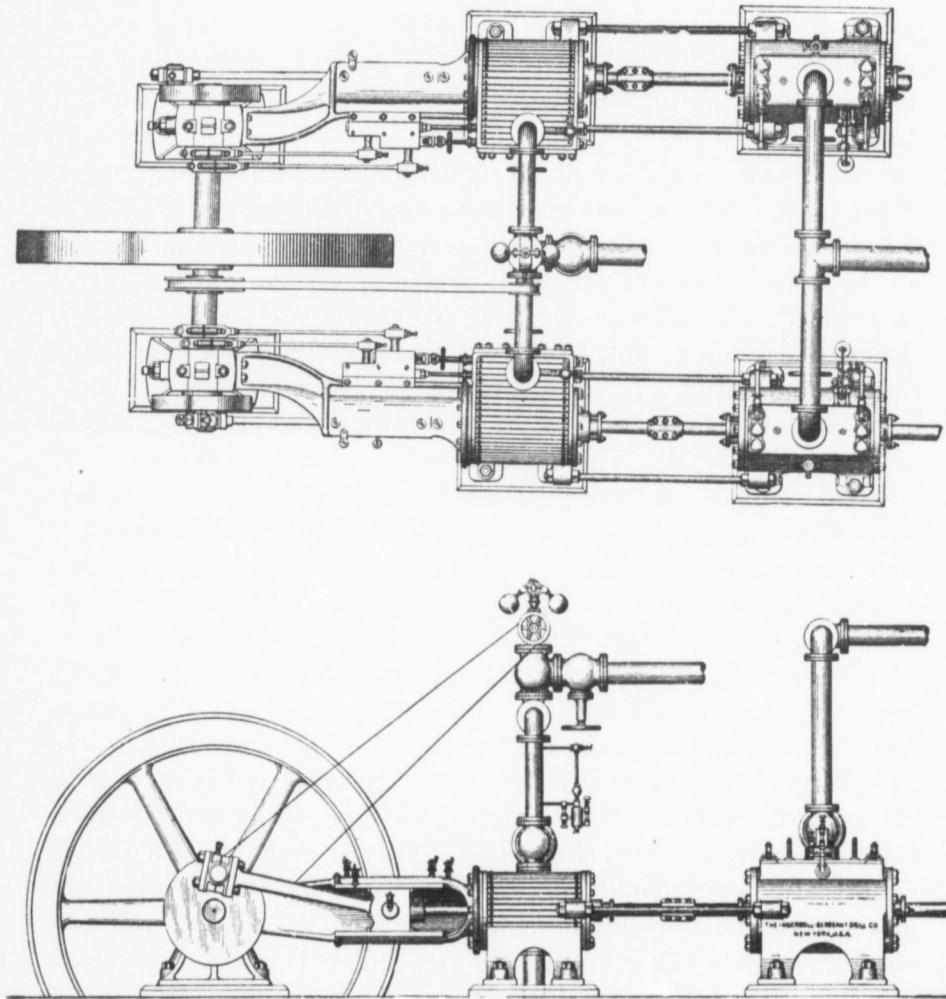


FIG. 19.

directly, instead of through a crank and crank-shaft, explains why it is that the friction of both steam and air ends of an air compressor is less than the friction of an ordinary steam engine.

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weight and velocity of the reciprocating parts necessary to give nearly uniform motion at the fly-wheel. Let us suppose the form of the steam and air indicator-cards to be known. From these we can determine the unbalanced force for any point of the stroke. This should, after allowing for friction, be equal to the product of the mass of the reciprocating parts and their acceleration due to the uniform motion of the fly-wheel. This product may be called the rate of change of momentum of these parts. Of course we can only equalize these for one point of the stroke, preferably for a point near the beginning or end of the stroke. We may increase the product of the mass and the acceleration by making the reciprocating parts heavier or by increasing the speed of the compressor. By increasing the speed we soon reach the greatest piston speed that is desirable. We may, however, increase the acceleration while keeping the piston speed constant, by shortening the stroke and increasing the angular velocity. The large angular velocity will also enable us to reduce the size of the fly-wheel.

Another way in which we may look at the question is this: The difference between the work done by the steam and the work done on the air up to any point of the stroke, should, after allowing for friction, be equal to the energy of the reciprocating parts at that point, due to the motion derived from the uniform motion of the fly-wheel. In this case as well we can only make these equal for one point in the stroke. We should probably choose a point near the centre of the stroke, where the energy of the reciprocating parts is a maximum. We can increase the energy at the centre of the stroke by making the reciprocating parts heavier, or by increasing the piston speed. Changing the length of stroke while keeping the piston speed constant, will have no effect on the energy at mid-stroke.

As we get somewhat different conditions for maximum by these two methods, it might be possible to equalize for two points in the stroke; that is, we might be able to make the unbalanced force, at the beginning or at the end of the stroke, equal to the rate of change of momentum at that point, and also make the excess work up to mid-stroke equal to the energy of the reciprocating parts at that point, the energy and the rate of change of momentum being both calculated from an assumed uniform motion at the fly-wheel.

As the unbalanced force at the beginning of the stroke and the excess work of the steam up to mid-stroke are both large, we are evidently driven to conclude that heavy reciprocating parts, high

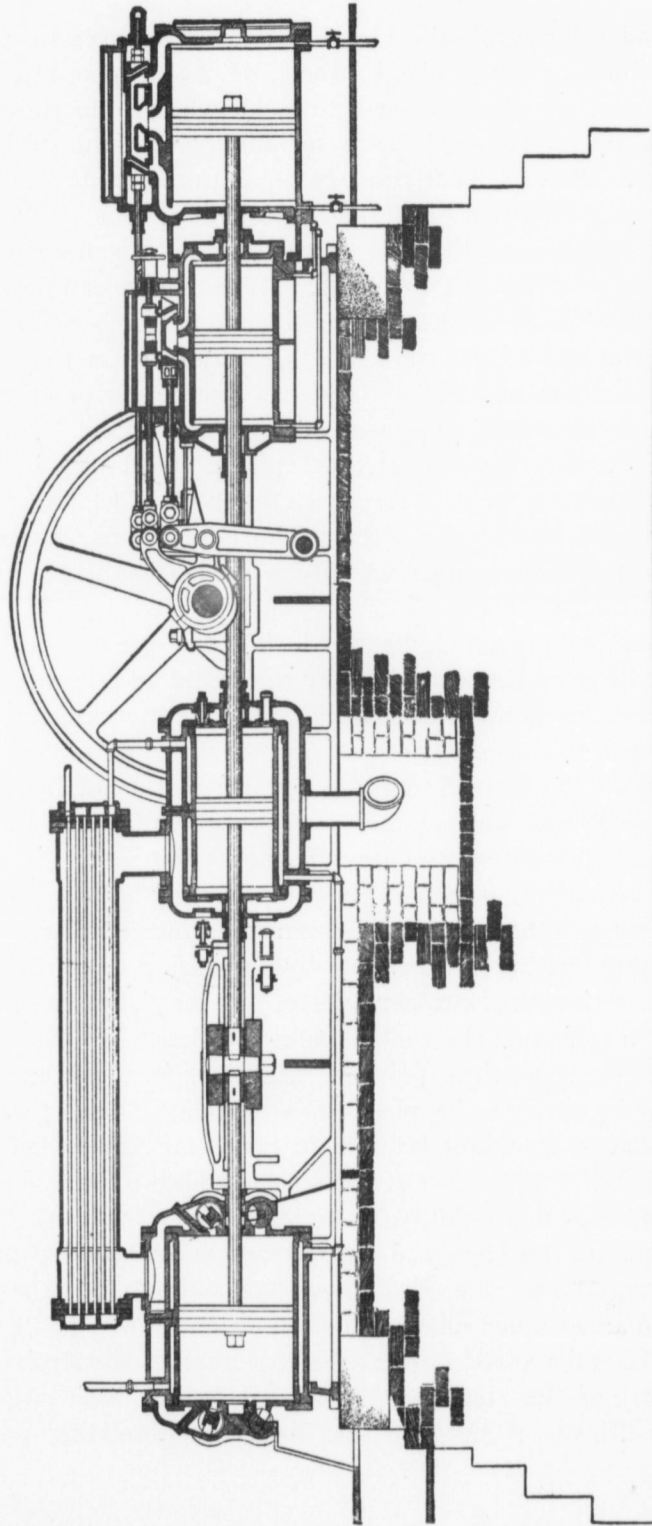


FIG. 20.

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piston-speed and short stroke are desirable. The high linear and angular velocities have the further advantages of allowing a smaller fly-wheel, of increasing the capacity of a compressor of given size, of decreasing the relative friction loss, and, up to a certain point, of increasing the economy of steam.

When, however, we consider the loss during compression due to the heating of the air, we see that a slow speed and a long stroke would be the most favorable condition for the removal of heat from the air. The long stroke will also make the loss of capacity due to clearance relatively less.

Duplex Compressors.—Another principle which is used in equalizing the effort of the steam to the resistance of the air, in order to secure uniform motion, is shown in the duplex compressor (See Figs. 11, 19, 22, 27, 36). This consists practically in two straight-line compressors connected to the same crank shaft. The angle at which the cranks are set is usually, though not always, a right angle. Fig. 15 will serve to illustrate the action of duplex compressors. Suppose all four pistons to be moving toward the right, then the steam in the upper steam cylinder, being at full pressure, is furnishing power to compress the air in the lower air cylinder, the upper air cylinder requiring but little power during that time, and the lower steam cylinder furnishing but little. This will continue till the lower pistons reach the end of their stroke to the right and start back toward the left, when the conditions will be reversed. If the effect of the reciprocating parts is small there will evidently be considerable energy transmitted through the connecting-rods, cranks and crank-shafts—causing pressure on the bearings and great strains in the crank-shaft. The result is that the crank-shaft must be large and that the friction will be excessive.

It is evident, however, that the power may be equalized in each half of the duplex compressor by the same method as in a straight line compressor. We shall then have the practical advantages of duplex construction without the excessive friction and great strains. The advantages referred to are as follows:—With the cranks set as they usually are, there is no dead centre. Each half of the compressor being complete in itself, one half may be installed or run without the other. Finally, a smaller fly-wheel may be used with a duplex compressor than with a straight line compressor under similar conditions, or with a fly-wheel of the same size the motion will be steadier.

Compound Compressors.—The maximum force in a compressor due to the resistance of the air may be considerably reduced by compounding, that is, by compressing the air in two or more stages. The ideal diagram of two-stage compression is shown in Fig. 2. The actual diagrams are considerably different, owing to valve resistance, clearance, and the limited capacity of the intercooler.

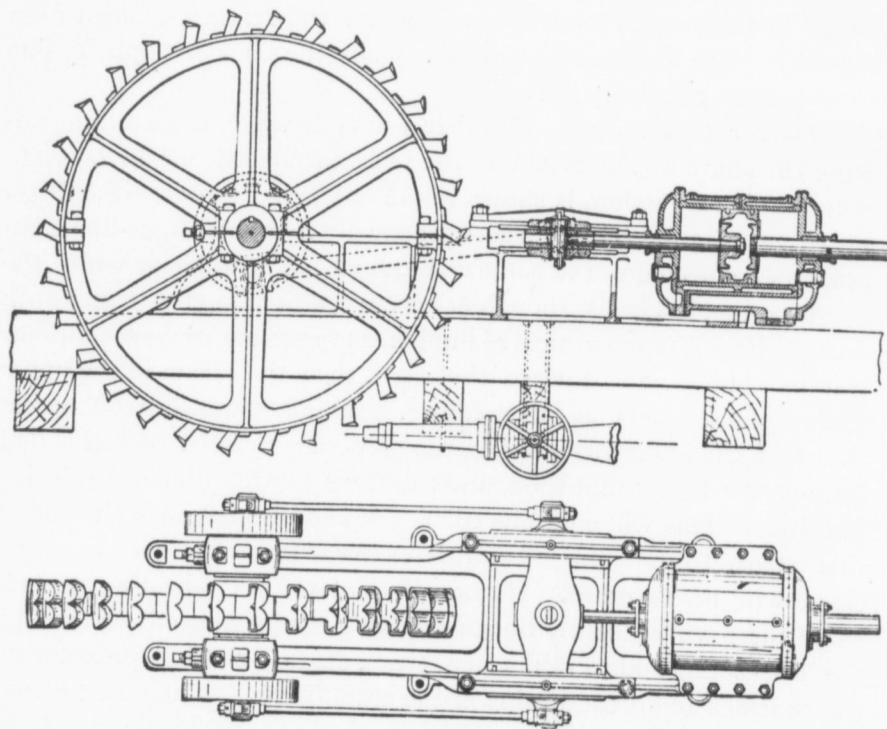


FIG. 21.

The condition for maximum efficiency under the ideal conditions was found to be $p_c = \sqrt{p_1 p_a}$ where p_a is the initial pressure, p_1 the final pressure and p_c the pressure in the intercooler. For this condition the capacity of the H. P. cylinder should be $\frac{p_a}{p_c}$ of the capacity of the L. P. cylinder.

When compressing to 100 pounds gauge, or 114.7 pounds absolute,

$$p_c = \sqrt{14.7 \times 114.7} = 41.1 \text{ pounds absolute} \\ = 26.4 \text{ pounds gauge.}$$

Then the capacity of the H. P. cylinder should be $\frac{14.7}{41.1} = .36$ of

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Fig. 24.

the capacity of the L. P. cylinder. These figures represent average practice fairly well. The pressure in the intercooler is usually higher than 26.4 pounds, but this may be explained by the fact that the intercooler is often too small and does not reduce the temperature within 100° of the initial temperature.

Let us make some simple assumptions, which will enable the calculations to be made readily and with sufficient accuracy for the present purpose. Let us take the case of two-stage adiabatic compression to 100 pounds gauge, very large intercooler where the air is cooled to the initial temperature (say 60° F.), most efficient size of H. P. cylinder, same stroke for both pistons, clearance and valve resistance negligible. To be definite, suppose the area of the L. P.

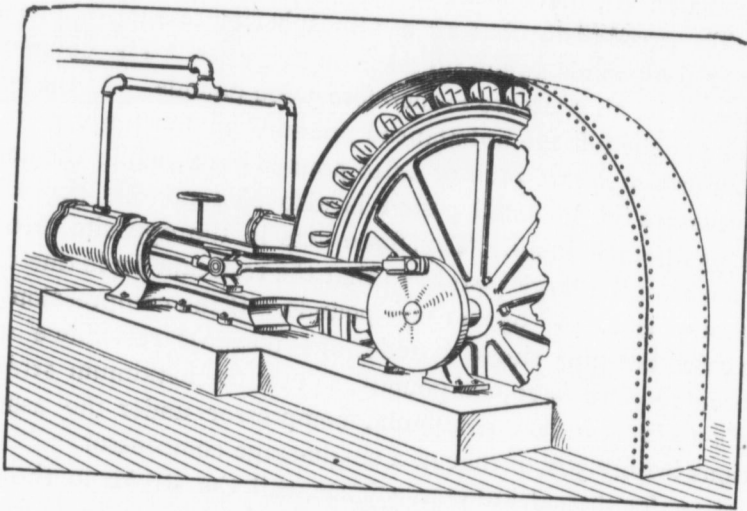


FIG. 22.

piston to be 100 square inches (corresponding to a diameter of 11.28 inches) and its stroke 17.28 inches. The capacity of the compressor, which depends solely on the capacity of the L. P. cylinder, will then be one cubic foot per stroke. The area of the H. P. cylinder will then be 36 square inches and its capacity 0.36 of a cubic foot.

The maximum strains and the work of alternate strokes will depend on the arrangement of cylinders and pistons. The three different arrangements in common use are the single-acting tandem, the double-acting tandem, and the double-acting cross compound.

The single-acting tandem compound arrangement is shown in Fig. 24.

The action is as follows: Air is admitted to the large cylinder through the hole A and the inlet valve B, situated in the piston C. On the stroke to the left this air is compressed and forced out through the valve D, through the pipe E, into the space F. At the same time air from this space is being drawn into the high pressure cylinder through valve G. On the stroke to the right the air in the H. P. cylinder is compressed and forced out through valve K. During the stroke to the right air is also being drawn into the L. P. cylinder through valve B. Each stroke is thus an admission stroke for one cylinder and a compression stroke for the other.

Let us first find the maximum resistance due to the air pressure. At the end of the stroke to the right the air pressure on the large piston is balanced, there being air at atmospheric pressure on both sides. The small piston has air at atmospheric pressure on one side and air at 100 pounds gauge pressure on the other. The unbalanced force due to the air pressure is therefore 3,600 pounds. At the end of the stroke to the left the unbalanced pressure on the large piston is 26.4 pounds per square inch or 2,640 pounds in all, while the unbalanced pressure on the small piston is also 26.4 pounds per square inch or 950 pounds in all. This force acts in the opposite direction to the force on the large piston, so that the resultant force due to the air pressure is $2,640 - 950 = 1,690$ pounds. If the compression had been carried out in a single cylinder the terminal resistance would have been $100 \times 100 = 10,000$ pounds, so that the maximum strain in a single-acting tandem compound compressor under the assumed conditions is only 36% of that in a single-stage compressor.

Let us, for the sake of convenience, call the stroke to the right the admission stroke and the stroke to the left the compression stroke (thinking of the *large* cylinder). The terminal resistance for the admission stroke is 3,600 pounds, while for the compression stroke it is only 1,690 pounds, not half as much. Now, the acceleration of reciprocating parts, due to a uniform motion of the fly-wheel, will be nearly the same at the ends of both strokes, and for economical working the steam pressure must be nearly the same in both cases, so that it would be practically impossible to equalize the forces so as to secure approximately uniform motion.

If the compressor is delivering air at some pressure other than 100 pounds per square inch, then the conditions will be as follows:—The diagram of the L. P. cylinder will remain unchanged, the pressure in the intercooler will be the same, the quantity of free air com-

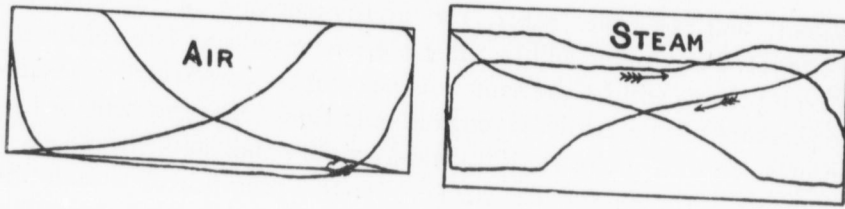


FIG. 23

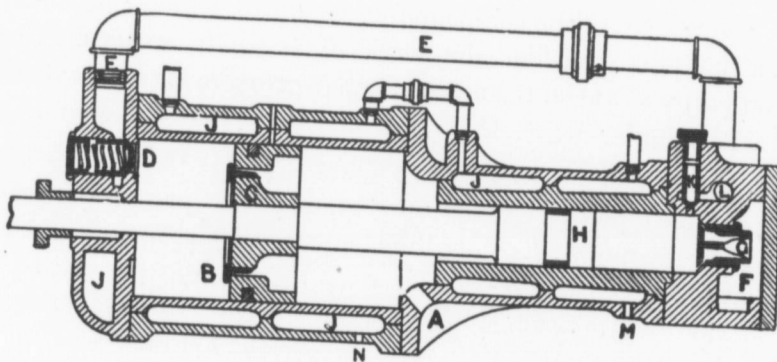


FIG. 24

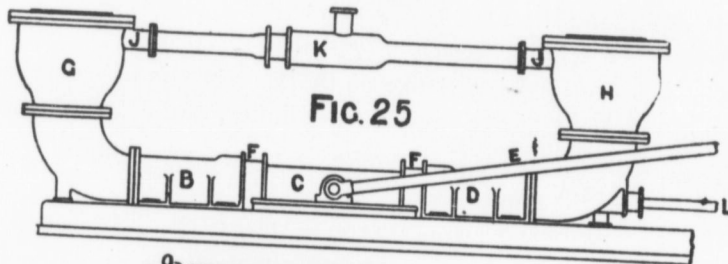


FIG. 25

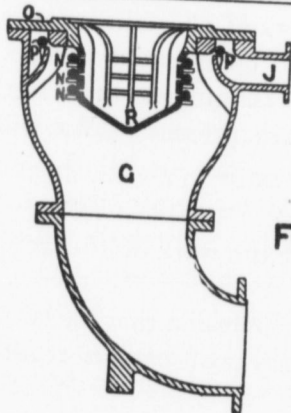


FIG. 26

pressed will be the same, the admission line of the diagram of the H. P. cylinder will be the same, and resultant force of the air on both pistons will be the same for the compression stroke. Besides the pressure of the air delivered, the only thing changed will be the compression line of the H. P. cylinder, which indicates the effort of the piston on the air for that stroke. If the pressure of the air delivered were 47 pounds instead of 100, then the terminal resistance of the alternate strokes would be equal, but even then the work of the admission stroke would be greater than that of the compression stroke, and moreover the compounding would then be inefficient.

Let us next consider the work of alternate strokes. From equation (1a) we can get the mean effective pressure for each cylinder.

$$\text{L. P. cylinder M. E. P.} = 3.45 \times 14.7 \left[\left(\frac{41.1}{14.7} \right)^{0.29} - 1 \right] = 17.6$$

$$\text{H. P. cylinder M. E. P.} = 3.45 \times 41.1 \left[\left(\frac{14.7}{41.1} \right)^{0.29} - 1 \right] = 49.2$$

Adding the back pressure (above the atmospheric pressure) to each of these, we get the M. E. P. of the compression stroke only to be

$$\text{Comp. stroke of L. P. cyl. - M.E.P.} = \dots\dots\dots 17.6 \text{ pds. per sq. in.}$$

$$\text{“ “ H.P. cyl. - M.E.P.} = 49.2 + 26.4 = 75.6 \text{ pds. per sq. in.}$$

We then have the work of the several strokes as follows:—

$$\text{L.P. cylinder ad. stroke} = \dots\dots\dots \text{ o ft. pounds.}$$

$$\text{comp. stroke} = 17.6 \times 100 \times 1.44 = 2,534 \text{ “}$$

$$\text{H.P. cylinder ad. stroke} = \dots\dots 26.4 \times 36 \times 1.44 = 1,369 \text{ “}$$

$$\text{comp. stroke} = 75.6 \times 36 \times 1.44 = 3,921 \text{ “}$$

Since the admission stroke of the L. P. cylinder corresponds to the compression stroke of the H. P. cylinder, and *vice versa*, we have:

$$\text{Total work of admission stroke} = 3,921 \text{ foot pounds.}$$

$$\text{“ “ compression “} = 2534 - 1369 = 1,165 \text{ “ “}$$

Hence, in this case the work of the admission stroke is over three times as great as that of the compression stroke. Let us examine the case where the air is not compressed at all in the second cylinder, but is delivered at 26.4 pounds pressure. We will then have:

$$\text{Work of admission stroke} = 1,369 \text{ foot pounds.}$$

$$\text{Work of compression “} = 1,165 \text{ “}$$

Even in this extreme case the work of the admission stroke is the greater.

We are driven to the conclusion that the two-stage, single-acting tandem arrangement is a very poor one as regards the equalization of power or effort.

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The next compound arrangement to be considered is the double-acting tandem. Fig. 20 shows a section of a Norwalk two-stage, double-acting tandem compressor, driven by a tandem compound steam engine. The action will be readily understood from the figure. After compression in the L. P. cylinder on the left, the air flows through the intercooler to the H. P. cylinder. The compressed air from the H. P. cylinder flows through the large pipe shown below the cylinder.

The work of alternate strokes and the resistance at corresponding parts in the alternate strokes are evidently equal, so that it will only be necessary to compare this case with the single-stage, double-acting

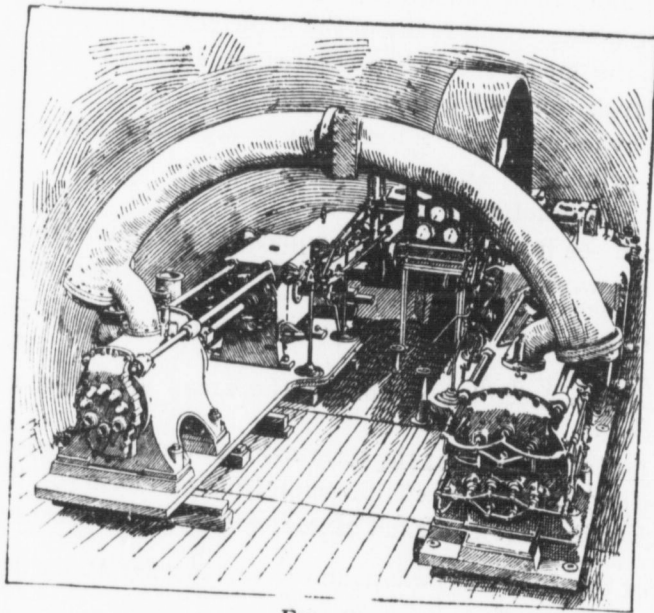


FIG. 27.

compressor. The terminal resistance of each stroke will be the sum of the terminal resistances in the previous case, or $3,600 + 1,690 = 5,290$ pounds. If the compression all took place in the large cylinder the terminal resistance would be 10,000 pounds, nearly twice as great. The work per stroke will be the same as in the cross-compound compressor to be considered next.

The third arrangement of compound compressors is the double-acting cross compound. Fig. 28 shows the general arrangement of a duplex cross compound compressor, driven by a cross compound

engine. L A and H A are the low pressure and high pressure air cylinders, L S and H S the low pressure and high pressure steam cylinders. C represents the intercooler and R the receiver, through which the air passes before entering the distributing pipes. The dotted lines indicate the path of the air through the machine. Fig. 27 shows a compressor of this design, as built by the Canadian Rand Drill Company.

The terminal resistance of the air in the low pressure cylinder L A is (in our assumed case) $26.4 \times 100 = 2,640$ pounds. The terminal resistance of the air in the high pressure cylinder H A is $(100 - 26.4) \times 36 = 2,650$ pounds, practically the same. Either of them is but a little more than $\frac{1}{2}$ of the corresponding terminal resistance of a duplex single-stage compressor of the same capacity.

From the mean effective pressures previously found we get the work per stroke for each cylinder, as follows :

$$\text{L. P. cylinder} = 17.6 \times 100 \times 1.44 = 2,534 \text{ foot pounds.}$$

$$\text{H. P. cylinder} = 49.2 \times 36 \times 1.44 = 2,441 \quad "$$

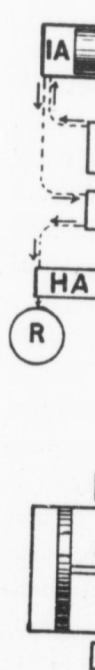
These also are practically the same.

We can see from our general equations that the terminal resistance and the work per stroke for each cylinder should be the same, in our assumed case. The ratio of the piston areas is $\frac{p_a}{p_c}$ but this equals $\frac{p_a}{\sqrt{p_a p_1}} = \frac{\sqrt{p_a p_1}}{p_1} = \frac{p_c}{p_1}$, that is, the areas are inversely as the

terminal pressures, so that the terminal resistances are equal. Also, in calculating the work of compression from equation (6), there being the same weight of air in each case, the only difference is that we have $\frac{p_c}{p_a}$ for the L. P. cylinder, and $\frac{p_1}{p_c}$ for the H. P. cylinder. But

$$\frac{p_c}{p_a} = \frac{p_1}{p_c} \text{ so that the work per stroke is the same in each case.}$$

In single stage adiabatic compression to 100 pounds gauge the lost work is 36.7% of the work of isothermal compression, while for two-stage adiabatic, with perfect intercooling, the lost work is 16.5% of the work of isothermal compression. Hence the maximum possible saving by two stage compression is about 20%. The saving practically possible is considerably less, for the following reasons:—(1) The intercooler does not usually reduce the air to the initial temperature. (2) Considerable saving over adiabatic compression can be affected in single-stage compression, hence there is not so much lost work to be



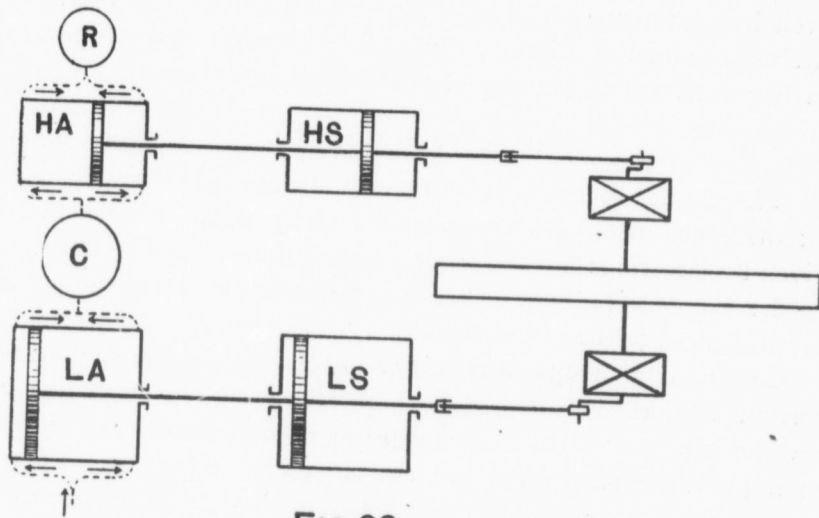


FIG. 28

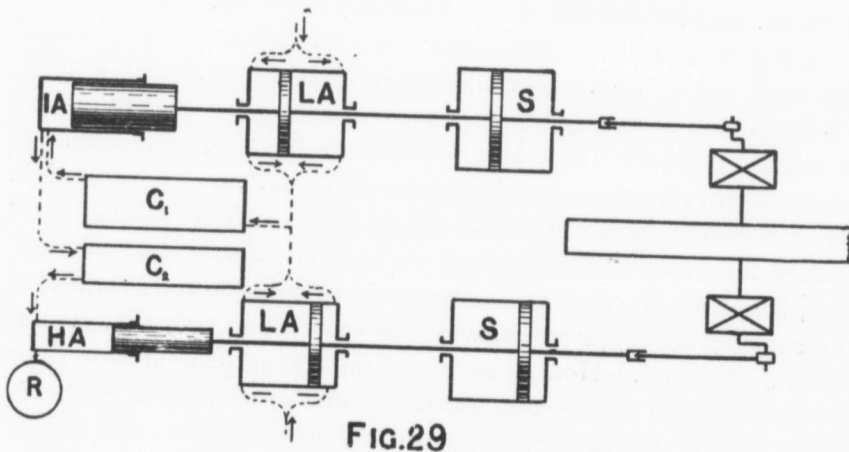


FIG. 29

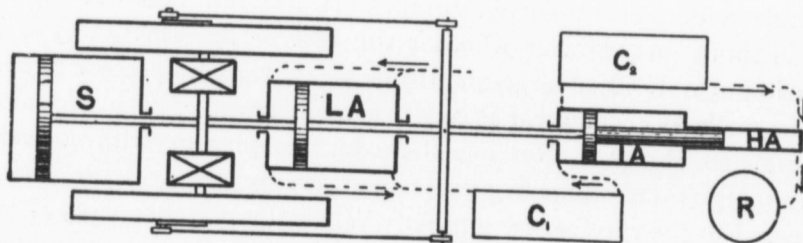


FIG. 30

saved by compounding. (3) The losses due to the extra valve resistance and extra friction, caused by the additional cylinder, will partly counteract the saving effected.

METHODS OF DRIVING.

The greater number of compressors in use are driven by steam, but there are also quite a number driven by water power, and a few driven by electric motors. According to the method of connecting to the driving power, the compressor may be classed as either belt-driven, geared or direct-connected.

In machine shops and other places where power can be conveniently taken by a belt from line shafting, some form of belt-driven compressor is in many respects most suitable, especially for small quantities of air or where the demand is irregular. They are very simple, and hence the first cost and the expenses for attendance and repairs are much lower than for an independent steam-driven compressor. A still more important advantage which may be claimed for them is that of economy of steam.

In the large railroad shops and other machine shops in which compressed air is used, the main engines are generally of a good Corliss type and are fairly economical. The average coal consumption might probably be taken as $2\frac{1}{2}$ pounds per H.P. hour. A common steam-driven compressor of moderate size, with a plain slide valve or a Meyer cut-off on the steam cylinder would require at least 4 pounds and probably 6 pounds of coal per H.P. hour. In addition to this, the irregular demand will necessitate considerable variations in the speed of the compressor, which is a condition very detrimental to steam economy. Hence we see that even after allowing for considerable losses of power in transmission by belting and shafting, the belt-driven compressor is more economical than the direct-connected steam-driven compressor, under the given conditions. The independent steam-driven compressor has one point of superiority in that it may be run whether the rest of the machinery is in operation or not. For large quantities of air the compressor engine may be made as economical as any other engine.

Fig. 18 shows a Rand belt-driven compressor with a belt-shifting regulator. This regulator operates by air pressure, being connected to the receiver by a pipe. When the pressure rises above a certain point the regulator shifts the belt over to the loose pulley. When the pressure falls a few pounds the belt is shifted back to the

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tight pulley and the compressor starts again. Fig. 10 shows a simple plan of the same machine, the regulator not being shown. For larger belt-driven machines the belt-shifting regulator cannot so well be employed. When necessary these may be unloaded by an automatic regulator, acting on the air valves. One type of straight line belt-driven compressors is like Fig. 21, but with a belt pulley in place of the Pelton wheel. The pulley is made heavy in order to act as a fly wheel as well. Another type of straight line belt-driven compressors has two belt pulleys, a crank between them and a single connecting rod. When this type is used for heavy duty two belts are employed to give a central pull on the crank. Fig. 11 shows the arrangement of a duplex belt-driven compressor. This type is more suitable than the straight line type for large quantities of air or high pressures, as the resistance is more evenly distributed throughout each revolution. Large compressors of this type are sometimes belted to a water wheel, such a combination allowing considerable latitude in the design of both water wheel and compressor.

For some purposes a connection by gearing is more suitable than belting. Gearing gives a more positive motion, gives a definite speed ratio, and is more suitable for transmitting a large force. Some electrically-driven compressors are geared, the pinion on the shaft of the electric motor meshing with a large gear which takes the place of the belt pulley on belted compressors. Large belt-driven compressors are sometimes made with a gear connection between the pulley-shaft and the crank-shaft. This permits the use of a smaller belt and gives a higher belt speed. The gearing ratio is usually two to one, the large gear being on the crank-shaft of the compressor. Water-power compressors are also sometimes geared, the pinion being on the turbine shaft, and the gear on the crank-shaft of the compressor. The writer knows of but one example of a compressor geared to a steam engine, and as there are a number of unique features about this compressor a short description of it will be given.

This compressor was built by the English firm of Arnold Goodwin & Son, Southwark, for a carpet-cleaning factory. It is a duplex compressor and consists practically of two engines with their cranks set at 90 degrees on one crank-shaft, and two compressors with their cranks set at 90 degrees on another crank-shaft, these two crank-shafts being connected by a pair of spur gears. The crank-shaft of the engines also carries a fly-wheel. The engines have cylinders 22 x 42 and are designed to run at 60 revolutions, giving a piston speed

of 420 feet per minute. The compressors have cylinders 26 x 42 and run at half the speed of the engines, the gearing ratio being two to one. Both steam and air valves are different from the kinds in ordinary use on compressors. The steam valves are piston valves, moved by a cam on the crank-shaft. The valve rod is held up against the cam by an auxiliary steam cylinder. The cut-off is at one-tenth stroke. The inlet valves of the air cylinders are $21\frac{1}{2}$ inches in diameter (the cylinders are 26 inches in diameter), and give an opening of 10% of the cylinder area. They are moved by the piston rods, which pass through the centres of the valves and open and close them at the turn of the stroke. The delivery valves are poppet valves, having a vertical lift, and are apparently without springs. Steam and air cards from this compressor are given in *Engineering* of Aug., 1894. An inspection of the air cards showed a considerably smaller volume of air for one cylinder than for the other, at the same pressures. A few measurements were taken and the following results obtained. There was very little throttling of the inlet, and yet the compression line did not leave the atmospheric line until about 10% of the stroke for one end (call it the head end) and 14% of the stroke for the crank end. It appears quite evident that the inlet valves close much too slowly. Taking the volume to the point where the compression line leaves the atmospheric line as the initial volume, the following results are obtained:

Pressure.	Vol. h. end.	Vol. c. end.	Vol. Iso.	Vol. Adia.
0	1.00	1.00	1.00	1.00
15	.60	.55	.50	.61
26	.45	.37	.35	.49
60	.26	.20	.20	.31
70 (Receiver P.)	.23	.18	.17	.29

There is no apparent reason for better cooling in one end of the cylinder than in the other, and even if there were, the compression line for the crank end lies nearer the isothermal than it is reasonable to expect from a simple water-jacketed cylinder. The most obvious conclusion is that the inlet valve for that end leaked.

The I.H.P. for one half was: steam cylinder 81 I.H.P., air cylinder 69 I.H.P., giving a mechanical efficiency of 85%. This is fairly high, considering that all the power is transmitted through two crank shafts and a pair of spur gears.

We have considered various arrangements of belted and of geared compressors. The third and by far the largest class comprises direct-connected compressors. The advantages of direct

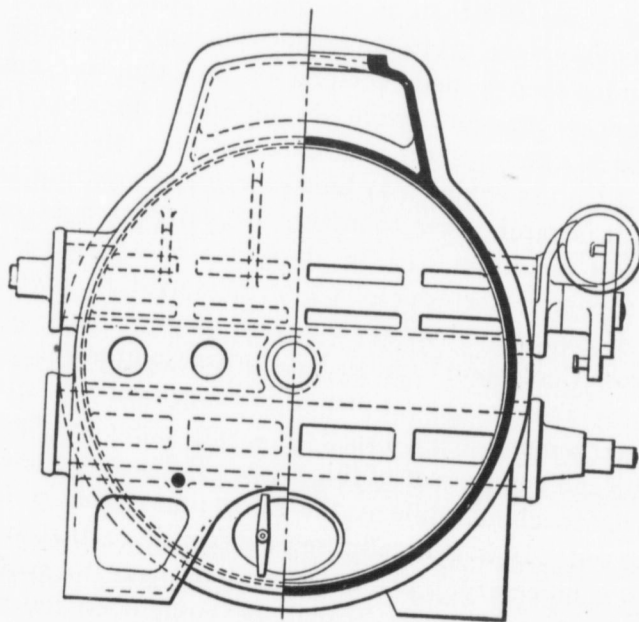
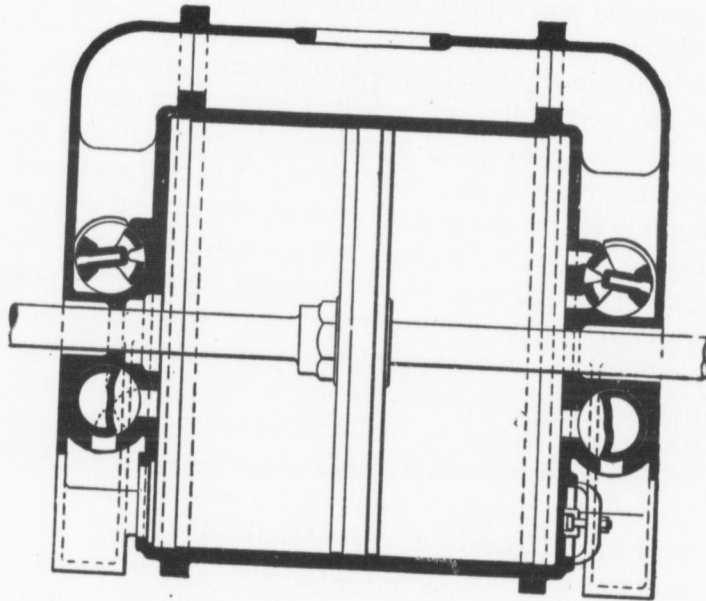


FIG. 31.

connection are simplicity, positive action and small friction losses. Direct-connected water power compressors (see Figs. 21 and 22) are, almost without exception, driven by Pelton wheels. This wheel is very simple and its form and its weight are such that it can be put in place of the belt pulley of a belted compressor and can furnish driving power and act as a fly-wheel as well. By choosing a suitable diameter of the wheel it is possible to have the best peripheral speed of the buckets for the given head and at the same time to have the best speed of rotation for the compressor. Fig. 21 shows an Ingersoll-Sergeant straight-line water-power compressor, and Fig. 22 shows a Rand duplex water-power compressor. The sheet iron casing around the Pelton wheel of the latter is merely to prevent the water from spraying over the machine.

We now come to the last and in many respects most important method of driving compressors, that of direct connection to a steam engine. Even if we do not include with them the 30,000 air-brake pumps used by the American railroads, the direct-connected steam-driven compressors probably still out-number all others. It has been previously pointed out that there is greater room for economy in the design of the steam end than in the design of the air end. Under ordinary conditions the greatest possible difference in the efficiency of compression between a poor compressor and the best compressor made is about 20 per cent., while the difference between the steam consumption per horse-power-hour of a common slide-valve engine and the best Corliss engine may be 200 or 300 per cent. of the latter quantity. It is natural then to make the description of the steam engine a most important part in the name of a compressor. For example, a compressor which is generally used to produce large quantities of compressed air at the lowest power cost is called the Duplex Cross Compound Condensing Corliss Compressor.

Figs. 13 and 14 show different arrangements of straight-line steam-driven compressors. Fig. 13 is a very common type. Fig. 37 shows the Rand compressor of this type. This arrangement makes a very compact machine, while at the same time giving a fairly long connecting rod. It is generally self-contained, so that little or no foundation is necessary. The cross-head is made to swivel at the centre so that no bending strain shall be brought on the piston-rod. In Figs. 20 and 21 there is shown a section of the cross-head at its point of connection to the piston rod, in which the pin of the swivel connection can be seen. The clearance can be adjusted by "taking up" the connecting rods or by moving the cross-head along the piston-rod.

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Fig. 15 shows the most common arrangement of the principal parts of duplex single-stage compressors. From the figure it is evident that a duplex compressor has ample room for a large fly-wheel, though whether a large fly-wheel is an advantage may be questioned. This compressor can not very well be made self-contained by putting all the parts on a box bed, as in Figs. 18, 20, 21 and 36. The frame is usually of the girder type, or partly of the girder type, but with tie rods between the cylinders, as in Fig. 19, which shows the Ingersoll-Sergeant duplex. Fig. 16 shows another arrangement for duplex compressors. The Blake and Knowles and the Clayton are about the only compressors of this type. The Blake and Knowles compressor of this type is a small compact affair designed for "racking off" beer. Fig. 36 shows the standard design of the Clayton compressor. Both firms mount this type on a box bed, making it self-contained.

Fig. 12 is shown as one of the oddities in compressor design. It is one of the types of the English firm of Schram & Co. As all the power is transmitted through the crank shaft, there is likely to be a considerable friction loss.

We now come to compound compressors. Of these there are but two general types, the tandem compound straight line and the cross compound duplex.

The air cylinder of a single-acting tandem compound compressor is shown in Fig. 24. There is usually an intercooler instead of the simple pipe E between the cylinders. The general arrangement is like Fig. 13, but with the two air cylinders in place of the one shown in the figure.

Fig. 20 shows a straight-line double-acting tandem compound compressor driven by a tandem compound engine. The construction will be readily understood from the cut. The whole machine is mounted on a box bed and is self-contained. The advantages of the tandem compound arrangement lie chiefly in the direct application of the power, and in the great momentum of the reciprocating parts.

Fig. 28 shows the general arrangement of the cross compound duplex. This is the kind generally used for producing large quantities of compressed air at a low cost. The engines are usually fitted with Corliss valves and run condensing, making the "five C" type, the Corliss Cross Compound Condensing Compressor. Fig. 27 shows a compressor of this type built by the Canadian Rand Drill

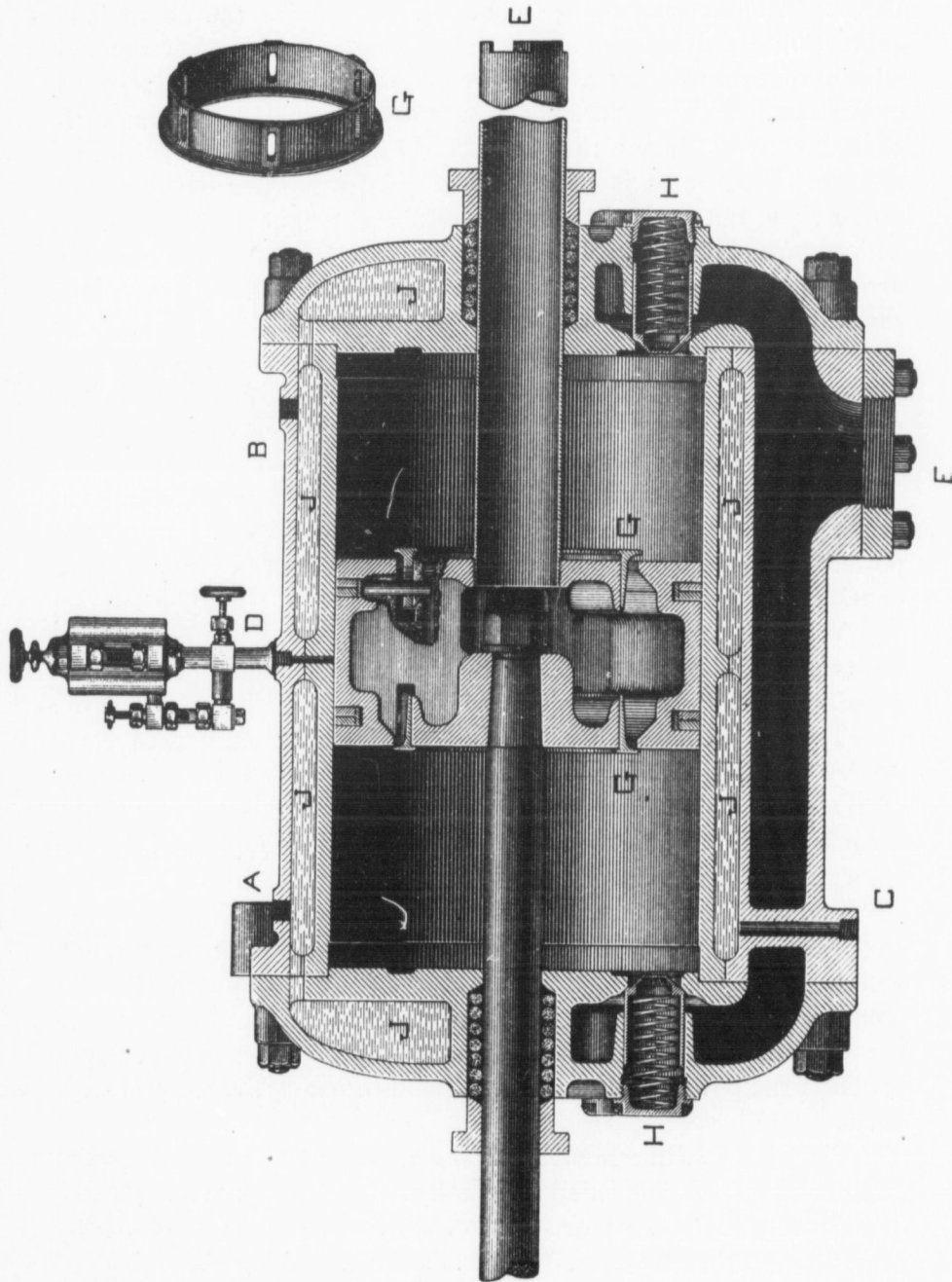


FIG. 32.

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Co. The intercooler of this compressor is the arched pipe extending across from one cylinder to the other. This contains a large number of small tubes through which cold water flows.

Fig. 9 shows another odd English design. It is manufactured by the firm of S. H. Johnson & Co. It will be seen that it consists of a tandem compound steam engine driving a tandem compound compressor, but it differs from Fig. 20 in having the power transmitted through a crank shaft.

Fig. 30 shows the general design of the Norwalk straight-line three-stage compressor. The dotted lines show the direction of air circulation through the machine. The intercoolers C_1 and C_2 , are simply diagrammatic, the actual intercoolers being on the top of the machine and extending nearly the whole length of it. It will be seen that the low pressure cylinder L A is double-acting, but that the intermediate cylinder I A, and the high pressure cylinder H A, are single-acting and compress on alternate strokes. This arrangement is open to somewhat the same objection as the single-acting tandem compound arrangement, shown in Fig. 24; that is to say, the resistance and the work of alternate strokes are not equal. In this case, though, owing to the low-pressure cylinder L A being double-acting, the proportional inequality will not be nearly so great, and is hardly worth considering when compared with the advantages of simplicity of construction, good cooling and ease of packing, secured by the single-acting arrangement. The Norwalk Co. kindly sent blue-prints and other matter relating to this compressor, from which the following description is compiled.

The steam cylinder S is 16 inches in diameter. The double-acting intake cylinder L A is $10\frac{1}{2}$ inches in diameter, the single-acting intermediate air cylinder I A is $6\frac{1}{4}$ inches in diameter, and the single-acting high-pressure cylinder H A is $2\frac{5}{8}$ inches in diameter. The common stroke is 16 inches. The clearance of L A is 3%, of I A it is 3.1%, and of H A it is 2.5%. This includes indicator pipes and rigging, which, in the case of the high-pressure cylinder, formed a considerable portion of the clearance. Blue prints of indicator cards show that the final gauge pressures were :

Low pressure air cylinder L A.....	72 pounds per square inch.
Intermediate air cylinder I A	410 " "
High pressure air cylinder H A.....	2,030 " "

Diagrams are given of the "Combined unbalanced pressures on the three air pistons, referred to the $10\frac{1}{2}$ inch air piston." These

show at a glance that the power and the effort of alternate strokes are not equal. A combined card for the three cylinders, with adiabatic and isothermal lines drawn, shows a very large gain over single-stage adiabatic compression.

Fig. 29 shows the usual design for three-stage duplex compressors. There are two double-acting steam cylinders, two double-acting low-pressure air cylinders, a single-acting intermediate air cylinder and a single-acting high pressure air cylinder. Considering one-half of this compressor by itself, it will be evident that the work and the resistance of alternate strokes are very unequal. On the forward stroke the pressure of the air in the single-acting cylinder assists the steam, on the return stroke it opposes it, hence there must, in any case, be considerable energy transmitted through the crankshaft, either to and from the fly-wheel or from one side of the compressor to the other. Taking the compressor as a whole, the work of alternate strokes would be most nearly equalized when the cranks were set at 180° , but then of course there would be a possibility of the compressor getting on the dead centre.

In the *American Machinist* of April 23, 1896, and in the *Journal of Electricity* (San Francisco) for December, 1895, there were descriptions of two compressors of this type which were designed and built in San Francisco for the pneumatic gun battery at Fort Winfield Scott. These compressors, from the excellence of their design and construction and from the unusual conditions of the service, present many features of interest.

There are two exactly similar compressors in the plant, and the description applies to either one of them. The cranks are set at 145° in order that the machine may be as nearly balanced as possible and yet be able to start from any position. The steam cylinders are high-pressure, non-condensing. They are twenty inches in diameter by twenty-four inches stroke, and are fitted with Meyer hand-regulation cut-off. The steam pressure usually carried in the boilers is 100 pounds, and the engines ran under full load when cutting off at $\frac{3}{8}$ stroke. "The low-pressure air cylinders are placed next the steam cylinders. They are double-acting, with pistons packed in the usual manner, by cast-iron rings sprung into place. The intermediate and high-pressure air cylinders are single-acting, with plungers. The intermediate plunger is packed with soft packing in the ordinary form of stuffing box. The high-pressure plunger is packed with sectional babbitt and brass rings. This has proved a

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very satisfactory packing for high pressures. It does not leak when properly made and the friction is not excessive. The valves are all of the poppet type, carried in bronze casings."

The arrangements for cooling are very thorough. The air cylinders and heads are water-jacketed, and water circulates in the intermediate and high-pressure rams.

Between compressions and after the final compression the air passes through large intercoolers, situated in cement tanks the foundation of the machine.

The American Machinist gives the following as the result of a test :

The I.H.P. of the steam cylinders was 351.6 horse-power. This was at 100 revolutions per minute, or a piston speed of 400 feet per minute. The combined I.H.P. of the air cylinders was 286.7 horse-power. This gives a mechanical efficiency of 81.5%. The pressure of the discharge of each air cylinder, as shown by gauges, was as follows :

Low pressure	75 pounds
Intermediate.....	375 "
High	2,000 "

TEMPERATURES.

	Temperature of suction	Temperature of discharge	Temperature by adiabatic compression	Difference
Low pressure cylinder	75°	320°	444°	124°
Intermediate pressure cylinder.	73	289	355	66
High pressure cylinder.....	69	358	392	34

The final temperature of single-stage adiabatic compression to 2,000 pounds is 1,769 degrees.

These figures indicate the relative amounts of heat abstracted by the jackets and coolers. The last column shows that the amount of heat removed by the jackets is about in proportion to the cylinder areas. The difference between the temperature of discharge and the temperature at the entrance to the next cylinder indicates the amount of heat removed by the intercoolers. The low temperature of the suction of the intermediate and high pressure cylinders shows that the intercoolers were very efficient.

It will be seen that many of the features in this compressor are such as would be adopted in any large and economical plant for furnishing air at a high pressure. This is more particularly the case with the air end. In the design of steam end, however, the usual

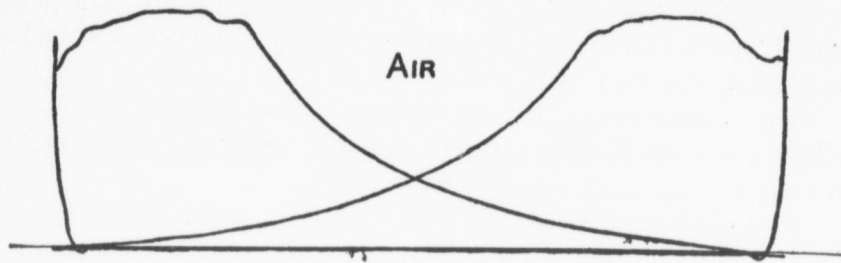


FIG.33

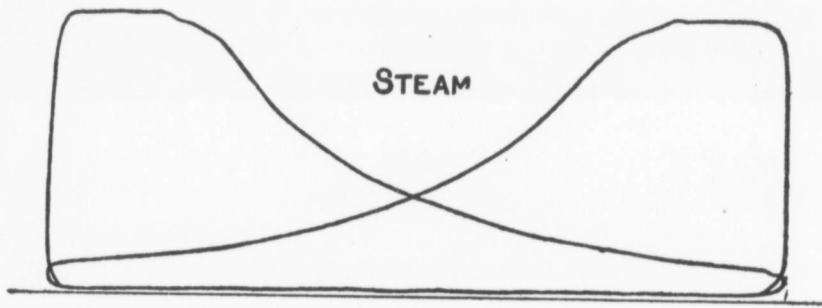


FIG.34

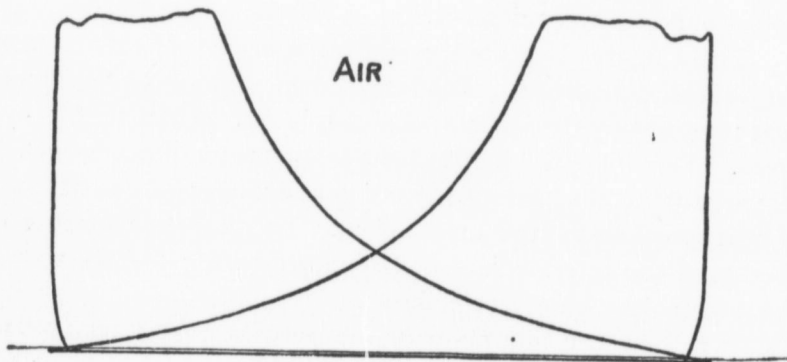


FIG.35

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construction would be compound condensing engines with Corliss valves. In this case though, solidity, simplicity and durability were the principal things desired, while economy of steam was made a minor consideration. Another important point to be considered was that the compressor should have a large capacity in a short time, that is, it should be able to run at a high speed without injury. How well this has been attained is shown by the fact that during part of the test the compressor was run at a piston speed of 568 feet per minute, without vibration or undue heating.

VALVES.

No paper on air compressors would be complete which did not devote some space to a consideration of their most important details—the valves.

With regard to the valves of the steam ends, it will only be necessary to point out the essential differences between the conditions in an air compressor and in an engine for ordinary purposes, such as driving mill machinery or dynamos. In driving dynamos, for instance, the speed must be constant, whatever the load, and the question of economy turns largely on the method of governing. The advantage of governing the cut-off over governing by throttling accounts for much of the superiority of Corliss valves and automatic expansion gear. In an air compressor, however, there is a definite amount of air compressed per stroke, and hence the speed of the compressor should vary according to the demand for air. A compressor is largely self-governing. When the demand is light the pressure in the receiver rises, the work of compression becomes greater, and the engine begins to run more slowly. When the demand is heavy the pressure falls and the machine speeds up again. The only governor that is absolutely necessary is one which will act when the speed rises to the highest safe limit, to prevent the machine from "running away." This might take place when the demand was very heavy or when a break occurred in the discharge pipe.

The most common steam valve for a compressor of medium size is a slide-valve with Meyer cut-off, regulated by hand. A valve of this kind is shown on the H.P. cylinder of Fig. 20. Fig. 34 shows the steam cards from a straight-line compressor with Meyer cut-off. The steam cylinder was 20 x 24, and the air cylinder 22 x 24. The figures for the cards shown are: cut-off, $\frac{1}{4}$; steam pressure, 90; air pressure, 70; revolutions per minute, 50; mean effective pressure (average of two), 43.7.

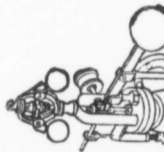
Another difference between an ordinary engine and the engine of an air compressor is shown by these cards. It will be seen that the amount of compression is very small. One of the principal effects of compression in a steam cylinder is to cushion the reciprocating parts. In an air compressor in which steam and air pistons are on the same piston rod, the cushioning is done very effectually by the compressed air in the air cylinder, hence there is not the same necessity for cushioning by steam.

The most common form of air valve is the poppet valve. Both suction and discharge valves of the high-pressure air cylinder in Fig. 20 are of this type. The discharge valves in Fig. 32 are also poppet valves.

The advantages of poppet valves are that they are very simple, have little tendency to leak, and are easily reground by hand if a slight leak should occur. They are entirely automatic, opening when the pressure on the face exceeds that on the back. This automatic action is particularly desirable for discharge valves, as the pressure of the discharge is variable, and hence a fixed point of opening would not be suitable.

Some objections to poppet valves are as follows: To insure prompt closing at all speeds, the springs must exert considerable force. In the case of inlet valves the throttling caused by the pressure of the springs, while hardly noticeable on the indicator-card, may cause quite a loss of capacity and a small loss of power. A throttling of eight ounces per square inch could hardly be seen on a card taken with a sixty spring, but yet it would cause a loss of 3.4% in capacity, and, at a discharge pressure of 100 pounds per square inch, a loss of about 1.2% in power. Another objection is that a large number of valves are necessary, on account of the small lift that can be allowed each one. A compressor of medium size would have from three to five inlet valves and two discharge valves for each end of each cylinder, making from ten to fourteen valves for each cylinder. The air, being forced to flow in thin streams over the metal, has a chance to become heated during admission, with consequent loss of power. Poppet valves nearly always chatter to some extent, and are liable to break and get into the cylinder, wrecking the machine. The defects of poppet valves are the most serious in the case of inlet valves, so that many makers who retain the poppet discharge valves have substituted some other form of inlet valve.

Corliss valves are used on the air cylinders of a number of com-



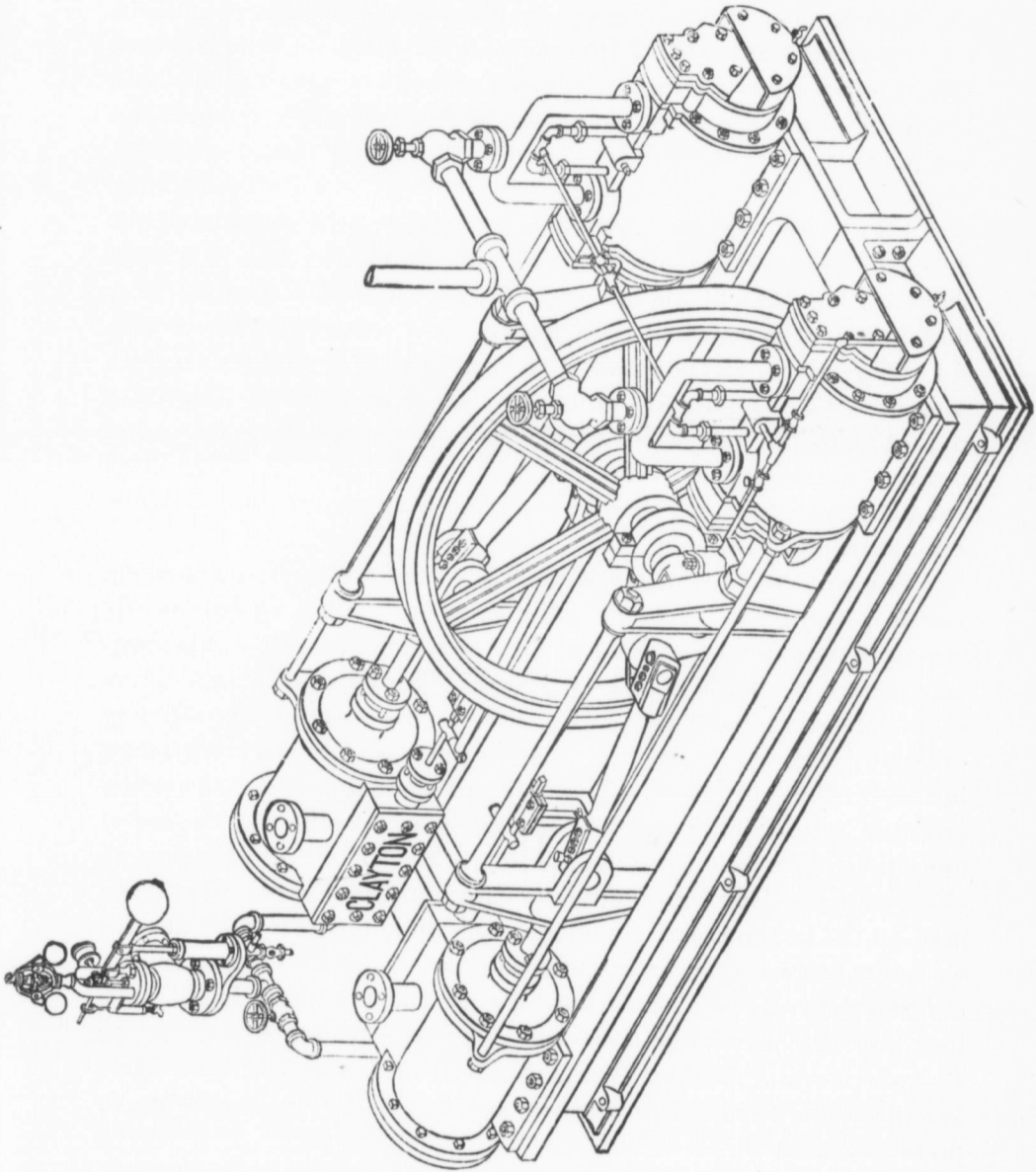


FIG. 36.

pressors. These can easily be used as inlet valves, because the proper point of opening and closing is fixed or very nearly so. But in the case of discharge valves some provision must be made to allow the valve to open at the time when the pressure in the cylinder is equal to the pressure on the other side of the valve. In the Norwalk Compressor shown in Fig. 20, Corliss valves are used on the L.P. cylinder. The pressure of the discharge from the L.P. cylinder of a compound compressor is fixed, so that in this case no special provision is necessary.

Fig. 31 shows two views of the cylinder of a blowing engine designed for a pressure of four pounds per square inch. It is built by the Philadelphia Engineering Works. The discharge valve is double ported to give a large opening with a small valve movement. As the double port increases the clearance it is not used for high pressures. The inlet valve of this cylinder is operated directly by a rod attached to the wrist plate. The discharge valve is closed positively, but is opened by air pressure, by means of an auxiliary cylinder and piston. These can be seen just above the upper valve-arm, in the end view, Fig. 31.

Some of the advantages of Corliss valves are the large opening, which permits the cylinder to be filled with cool air at nearly atmospheric pressure, and the positive movement, which enables the compressor to be run at a high speed. Their disadvantages lie in their well-known tendency to wear and become leaky, in the difficulty of repair, in the large clearance, and in the weakening of the cylinder heads by the long ports. The wear of the valve may be partially obviated by using it for low pressures only and by having the movement take place only when the pressure is nearly balanced on the two sides. In the Nowalk compressor (Fig. 20) the Corliss valves are used on the low-pressure cylinder only. In addition to this, the discharge valves have a pair of cams interposed between the eccentric rod and the valve-arm, so arranged that the valve stands still until the pressure is nearly balanced. In the compressors of the Philadelphia Engineering Works (Fig. 31) the discharge valve opens automatically when the pressure is balanced, and closes before much pressure comes on it.

Fig. 32 shows the air cylinder of the Ingersoll-Sergeant compressors. G G are the inlet valves, placed in the piston. They are without springs or mechanism of any kind, but are opened and closed by the motion of the piston. Their advantages consist in a large

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opening with very small throw, very slight throttling of inlet air, simplicity and durability, small clearance, and the saving of space in the cylinder head for water-jacketing. Some of their disadvantages are: The closing effort begins at mid-stroke, and increases as the square of the velocity. The air is admitted through a thin hot tube and a hot piston. A considerable leak might occur without its being detected, as it could not very well be heard. The valves are not easily accessible for inspection and repair.

Some peculiar air valves are shown in Fig. 26, which is a section of the air chamber of one end of the compressor whose air cylinder is shown in Fig. 25. The valves are simply rubber rings of circular section, lying in grooves and covering slits in the metal. The pressure of the air expands the rings and uncovers the slits. It will be seen that there are three inlet and one discharge valve. As this is a "wet" compressor the valves are not subjected to a very high temperature, which would soon destroy the rubber.

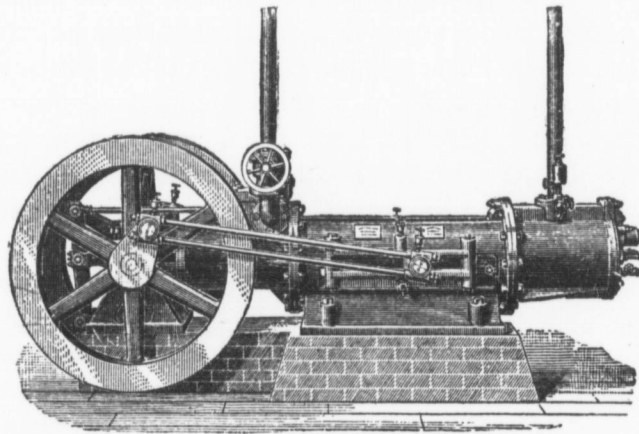


FIG. 37.

The last type of valve which we shall consider is the mechanically controlled poppet valve. This is the type of valve used on the Riedler compressor, where it has given such excellent results.

Fig. 35 shows an air card taken from a compressor with Riedler valves. The air cylinder was $27 \times \frac{1}{2}$, the speed 61 revolutions per minute, and the air pressure 78 pounds gauge. The mean effective pressure is 33.3 pounds per square inch.

The general principle of mechanically controlled poppet valves is to provide a means for taking the pressure of the spring or valve rod

off the valve, just before the pressure is balanced on both sides, in order to leave the valve free to open to its full extent when the air pressure on its face exceeds the air pressure on the back. At the proper time the valve is closed, either directly or by allowing a spring to press against it. The movement to operate the gear may be taken from a special eccentric or from the eccentric which operates the steam valve, either directly or through a wrist plate. A part of the mechanism for operating the valves can be seen in Fig. 27, at the end of the large cylinder on the right. This movement is operated from a special eccentric on the crank-shaft.

Objections urged against this type of valve are their complication and the necessarily slow closing, which must be either too early or too late.

With regard to the first, it may be said that the extra complication of the gear is counterbalanced by the fewer number of valves necessary, on account of the high lift which may be allowed. Both suction and discharge valves should close at a definite point, when the crank passes the dead centre, so that it should be possible to make the valve close at that exact point. It will also be evident that, as the piston velocity decreases up to the end of the stroke, the valve might begin to close quite early, without increasing the throttling or the velocity of the air through the valve. It will be seen that mechanically controlled poppet valves possess many of the advantages of ordinary poppet valves and but few of their disadvantages.

The writer wishes to thank the following firms for their kind assistance:

The Canadian Rand Drill Co., for several electrotypes.

The Rand Drill Co., New York, for blue-prints and an electrotype.

The Ingersoll-Sergeant Drill Co., for blue-prints, steam and air indicator cards, and electrotypes.

The Norwalk Iron Works Co., for a blue-print and an electrotype.

The Clayton Air Compressor Works, for an electrotype.

Fraser & Chalmers, Chicago, for blue-prints and air cards.

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MUNICIPAL ENGINEERING IN ONTARIO.

BY HERBERT J. BOWMAN, O.L.S., M. CAN. SOC. C.E.

In the Ontario "Municipal Act" it is provided that
"The Council of every county, township, city, town, and incorporated village may pass by-laws for appointing such Pound-keepers, Fence Viewers, Overseer of Highways, Road Surveyors, Road Commissioners, Valuators, Game Inspectors, and *other officers* as are necessary in the affairs of the corporation, or for carrying into effect the provisions of any Act of the Legislature or by-law of the Corporation, or for the removal of such officers; but nothing in this Act shall prevent any member of a corporation from acting as commissioner, superintendent or overseer, over any road or work undertaken and carried on, in part or in whole, at the expense of the corporation; and it shall be lawful for the municipality to pay such member of the corporation acting as such commissioner, superintendent or overseer."

The foregoing extract may suggest that in the past municipal engineers have not been of such frequent occurrence or importance as pound-keepers, etc., having been classed with the nameless "other officers" of corporations. In a great many of the smaller towns, although expending considerable sums on waterworks, drainage, road improvements, etc., no engineer is employed. A committee of the municipal council is given complete charge of certain work and proceed to carry their ideas into effect, or the whole matter may be left in the hands of the chairman, the other members of the committee being too busy or lacking in interest. If the chairman does not take personal charge of the work, he secures some other "practical" man to act as commissioner, superintendent or overseer, usually some ambitious carpenter or other mechanic, the proud possessor of a spirit level and a two-foot rule, and the work is proceeded with.

If, however, the work in hand is to be let by contract and the "practical" man does not feel equal to the emergency of preparing specifications, an advertisement is prepared after the manner of the following printed in a late paper :

The Town of ——— contemplate building, during the coming summer, Granolithic Sidewalks of four (4) feet and upwards in width, and will be pleased to receive suggestions and figures as to style of construction (specifications) and cost of same, from parties in that line of business.

Cheap and durable walks are what are wanted.

It is not necessary to point out the defects in such a method of carrying on public works, except to say that the chances are that the honest contractors will be beaten and good work will not be secured. Undertakings of greater importance, such as water-works and sewerage, are often advertised as open for tenders, each contractor to furnish his own plans and specifications, and the contract is awarded by a council composed, perhaps, of good business men, but men who know very little about the engineering questions involved.

The favored contractor is profuse in his thanks to the Council for recognizing the advantages (?) of his tender, and takes the first opportunity of confidentially informing this body that it is entirely unnecessary to go to the expense of employing an engineer to see that the specifications are carried out. In other cases, after the contract is signed and an engineer appointed, it is found that the specifications are vague and full of loop holes, so that a large bill of extras is piled up and the contract settled by an expensive law-suit. The fact is that, except perhaps in a few of the larger cities, there is room for much improvement in the matter of designing and constructing public works in the different municipalities in the province.

The remedy for this state of affairs, the writer is convinced, does not lie in the way of legislation, as in this democratic country no coercive measures can be adopted even if the end is for the common good. Public opinion will have to be educated up to put more reliance in permanent and responsible officers to take charge of the spending of public moneys. In this the rural municipalities are leading the way, for, through the working of the "Ditches and Watercourses Act" and the "Drainage Act," the township engineer has become a very useful officer, and in the matter of drainage is the recognized authority. Many of these men are engineers of experience and practically all are Ontario Land Surveyors, possessing the qualifications necessary for this work. However, when we come to look into the question of engineering for the larger villages and towns, we find that little attention has been paid by engineers in this country to this class of work. The bulk of the students in the engineering col-

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leges aspire to be Electrical or Mechanical Engineers, and the few who take up Civil Engineering are looking forward to railway or government work, in spite of the fact that all these are much overcrowded. In municipal engineering there are still openings, but the young engineer should be qualified in practice as well as theory, in short, must be a "practical" man, and not afraid to commence like any young lawyer or doctor in some out of the way place, and grow up with the country. For a while, no doubt, he may have a struggle to make both ends meet, and may have to take up some other work not exactly of an engineering character, but which will add to his knowledge of business and municipal affairs. For instance, a case has come to the writer's notice where a young engineer performed the duties of assessor where he was located in the early days of his career, and has since risen to the top of the ladder, being chief engineer of one of the greatest railway systems on this continent. The young municipal engineer, to succeed, must also be an Ontario Land Surveyor, and thus be in a position to locate all the disputed property lines in his neighborhood, as well as prepare plans for registration of new surveys and new roads, etc. During the year's apprenticeship to some practising surveyor, the college graduate will also add to the practical knowledge that he is assumed to have acquired in the vacations during the college course.

At present there is no organization in Ontario to bring municipal engineers together to read papers and discuss topics of mutual interest. The National Engineering Society, with headquarters at Montreal, does not fill this need and should not be expected to. A provincial organization seems to be necessary, such as the State Engineering Societies of Michigan, Illinois, Ohio, Indiana, Iowa, and other local engineering clubs. This society should have permanent headquarters in the provincial capital. It may be said that the Ontario Land Surveyors' Association already fills this need, and to a certain degree that is true, but many members of that association who are also engineers, have so far silently endeavored to keep purely engineering questions in the background. Now that the attempt to form a close corporation of engineers in Ontario seems to have been abandoned, we may expect more attention to be paid to the consideration of the advisability of enlarging the scope of the Ontario Land Surveyors' Association so as to include Municipal Engineering, and thus aid in securing to municipalities competent men to design and construct their different public works.

CRUSHING STRENGTH OF WHITE PINE.

BY A. H. HARKNESS, GRAD. S.P.S.

The tests, the results of which are given in the following tables, though not extensive enough to permit of any very definite conclusions being drawn, may prove of interest as serving to show the relative crushing strength of pine transversely and longitudinally placed, that is, with the load applied to the sides of the fibres, and with the load applied to the ends; also the effects of moisture on the longitudinal crushing strength.

The specimens used in the tests were cut from pieces of white pine about three and three-quarter inches square, and are from the heart wood of small trees. Although they were not all cut from the one piece, the material in them was so similar in quality that the different tests will admit of comparison.

The pieces from which the specimens were taken were purchased from a city lumber firm 21st October, 1896, and represent fairly the average quality of pine from which 4 x 4 inch scantling is cut. They were stored in the laboratory of the School of Practical Science until the tests were made.

The first table gives the transverse crushing strength tested on March 17th, 1897. The specimens were all cut in four-inch lengths from one piece, the specific gravity of which was 37.25, and which contained 12.2 per cent. of moisture calculated on the weight after being dried. This is about the normal amount of water contained in thoroughly seasoned wood protected from the weather. The loads required to produce a compression of three per cent. and of fifteen per cent. respectively, are given in table No. 1 in the fourth and fifth columns. The second column gives the thickness of the block, and the third the dimensions of the area subjected to pressure. Figs. (a), (b) and (c) show the different ways in which the blocks were placed

in the machine in regard to the position of the heart of the wood and the annual rings. The letters in the sixth column refer to these figures.

The maximum strength of the wood is sometimes reached before the block is compressed fifteen per cent. In fact the load begins to increase very slowly shortly after the three per cent. limit is reached, at perhaps about five per cent. compression. When the pieces are placed as in Fig. (a) the maximum load is always reached at a compression of less than fifteen per cent., the annual rings seeming to

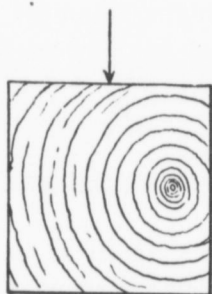


Fig. a

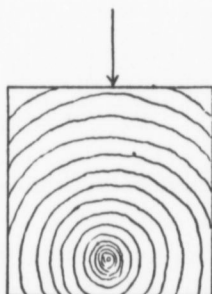


Fig. b

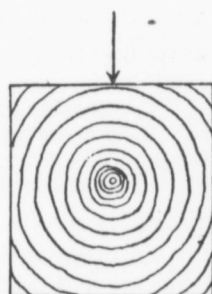


Fig. c

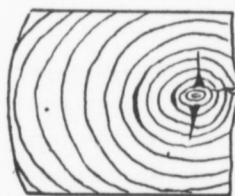


Fig. d

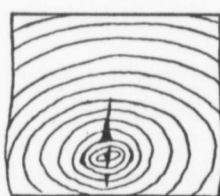


Fig. e



Fig. f

act somewhat like curved plates, the rings splitting apart and the side toward which they are convex bulging out, as shown in Fig. (d). When the blocks are placed as in Fig. (b) the rings simply become pressed closer together, and the load will continue to increase indefinitely. Failure is accompanied by splitting above the heart, which seems to act as a wedge, as shown in Fig. (d). When the heart is near the centre failure is accompanied by both splitting above and below the heart, and bulging out at the sides as in Fig. (f).

Table No. 2 shows the longitudinal crushing strength. The specimens were cut in eight inch lengths with the exception of the five marked with asterisks, which were each four inches long.

Those of which the crushing strengths are given in column A, were cut from the same stick as the four-inch pieces tested transversely, and were tested at the same time, March 17th, 1897. Those given in columns B, C and D were tested on December 21st, 1896; and were cut from the ends of three different sticks, which had been tested as long posts on December 16th, on which date the specific gravities and percentages of moisture were as given in the following table. As the pieces would have lost some moisture in the five intervening days, the values given for B, C and D are higher than the actual.

	A	B	C	D
Specific gravities	37.25	51	46	53
Percentage of moisture.	12.2	23		22.5

The percentage of moisture in C was not determined, but was probably about the same as in B and D.

A comparison of the results given in table No. 1 with those in column A, table No. 2, both sets of tests being made on specimens from the same piece of timber, shows that for well seasoned pine the longitudinal crushing strength is about ten times as great as the transverse strength to resist a compression of three per cent. Hence it is quite evident that in the case of a wooden column in order to develop its total crushing strength, it is necessary to have a capital to receive any wooden beams resting on it. The area of the top of the capital should be about ten times the area of the column, or the top of the capital should be over three times the diameter of the column on which it rests. The same thing applies to the cases of columns supported by timber placed horizontally. Of course in the case of long posts in which the full crushing strength of the cross section is not reached, the ratio between the area of the capital and the column need not be so great.

A comparison of column A in table No. 2 with the columns B, C and D, shows the very decided effect which the quantity of moisture in timber has on its crushing strength.

TABLE NO. I.

No. of Test.	Thickness in inches.	Breadth in in. by Length in in.	Load at 3% Compression in lbs. per sq. in.	Load at 15% Compression in lbs. per sq. in.	Manner of placing block.	Remarks.
1	3.73	3.75 x 3.97	435	524	A	
2	3.73	3.75 x 4.00	475	478	A	
3	3.73	3.75 x 4.00	556	579	A	
4	3.72	3.73 x 4.00	468	576	B	
5	3.73	3.70 x 4.00	537	645	C	
6	3.73	3.73 x 4.00	483	576	C	
7	3.74	3.74 x 3.98	455	551	A	Knotty and splintery.
8	3.73	3.73 x 3.98	499	613	C	
9	3.73	3.74 x 4.00	408	482	C	A pitch ring about heart.
10	3.72	3.72 x 4.02	516	618	C	
11	3.72	3.73 x 4.02	493	593	C	Large season crack.
12	3.73	3.75 x 4.03	458	510	C	Knotty and pitchy.
13	3.74	3.71 x 4.02	505	584	C	
14	3.73	3.74 x 4.00	406	475	B	Pitch ring.
15	3.75	3.75 x 4.05	486	486	A	Knot at each end.
16	3.74	3.77 x 4.02	538	638	C	Season cracks.
17	3.73	3.70 x 3.96	420	542	C	
18	3.73	3.72 x 4.00	435	555	A	
19	3.72	3.73 x 4.06	542	621	C	
20	3.73	3.73 x 4.02	413	413	B	
21	3.73	3.71 x 3.95	534	551	C	Gummy.
22	3.74	3.74 x 4.00	441	541	A	Gummy and shaky.
23	3.73	3.75 x 4.00	437	513	C	Pitch ring.
24	3.72	3.72 x 4.02	543	597	B	An enclosed knot.
25	3.72	3.74 x 4.02	440	563	C	
26	3.74	3.70 x 4.00	550	596	C	
27	3.73	3.70 x 6.00	489	600	C	
		Average	480	560		

TABLE NO. 2.

No.	Crushing strength per square inch.			
	A	B	C	D
1	5,110	3,641	3,598	3,513
2	4,746	3,982	3,562	2,948
3	4,848	4,391	4,078	3,043
4	5,317	4,096*	3,740*	3,332
5	4,934	3,883*	3,826*	3,947
6	5,050	4,426*		3,115
Average	5,001	4,069	3,761	3,316

TESTS ON THE TENSILE STRENGTH OF STEEL BOILER PLATES.

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The following table gives the results of tests of specimens cut from two plates of flange steel. Six specimens, marked A and B respectively, were cut from each plate, those with odd numbers lengthwise, or in the direction of rolling, and those with even numbers crosswise, or parallel to the rolls. The specimens were sheared from the plates and then planed to an uniform width of 2 inches, the metal injured by shearing being removed.

The tests were made on the 200,000 lbs. Riehle Testing Machine in the Laboratory of the School of Practical Science, the specimens being placed in the machine with a clear length of 15 inches between the jaws.

The Yield Point was determined by the drop of the beam, and was strongly marked, every specimen stretching considerably without any further increase in load.

An examination of the table will show that both plates were slightly stronger crosswise than lengthwise, but no general conclusions can be drawn from such a small number of tests.

Tests which were made at the Watertown Arsenal in 1885 on 48 steel plates, varying in thickness from $\frac{3}{16}$ inch to $\frac{3}{4}$ inch, one specimen cut lengthwise and one crosswise from each plate, indicated that the strength in each direction was substantially the same; in many of the plates it was almost exactly the same, in about half the others the strength lengthwise was a little greater, and in about half a little less than the strength crosswise. These conclusions have been confirmed by other tests.

The percentages of elongation in column 7 were calculated from the formula of the Committee of the American Society of Civil

Engineers,* who recommend that the percentage of elongation in 8 inches should be specified as a function of the ultimate strength of the test specimen, by the formula

$$\text{Per cent of elongation in 8 inches} = \frac{1.500.000}{\text{Ultimate strength.}}$$

Those in column 8 were calculated by Prof. Johnson's modification of the above formula.

$$\text{Per cent. of elongation in 8 inches} = \frac{1.800.000}{f - 10.000} - 10$$

Where f is the ultimate strength of the test specimen.†

These formulæ express Tetmajer's criterion, which is essentially, that if two steels whose ultimate strengths may vary within assigned limits are to be equally suitable for the purpose of construction, the coefficients of ultimate resilience shall lie within narrow limits.

If instead of the ultimate strength we take the elastic limit Tetmajer's criterion would require that the coefficient of elastic resilience shall be constant.

Let \mathcal{L} = the elongation in length l .

p . = stress per sq. inch at elastic limit.

s . = strain = $\frac{\mathcal{L}}{l}$

A = Area of cross-section.

E = Young's modulus.

K = coefficient of elastic resilience.

The resilience or the work done by the gradually applied stress

$$= \int p A d\mathcal{L} = Al \int p. ds.$$

By Hooke's law $p = Es$.

Hence the resilience = $Al \times \frac{1}{2} Es^2 = \frac{1}{2} ps \times Al$.

The coefficient of elastic resilience K or the work done per unit of volume = $\frac{1}{2} ps$, and depends only on the material.

If $l = 8$ inches the percentage of elongation in 8 inches = $\frac{100\mathcal{L}}{l} = 100s$ and $K = \frac{1}{200} p \times$ per cent. of elongation in 8 inches.

This would apply to the ultimate strength and elongation, and ultimate resilience if Hooke's law were true, and if the material continued to be homogeneous up to the breaking point. But in structural steel neither of these conditions hold.

Beyond the elastic limit there is no known relation between p and s by means of which the expression for the resilience may be in-

*Engineering News, July 16th, 1896.

†Digest of Physical Tests, Oct., 1896.

tegrated, and the determination of the coefficient of ultimate resilience must rest on direct observation of the material under test.

The Committee of the American Society of Civil Engineers also recommend that the specified per cent. of contraction in area shall be $\frac{2,800,000}{\text{Ultimate strength}}$.

The values specified by this formula have been calculated, and are given in column 9 for the purpose of comparison with the observed percentages of contraction in area.

	MARK.	Cross-section in inches.	Yield Point in pds. per sq. in.	Ultimate Strength in pds. per sq. in.	Per cent. of Elongation in 8 ins.	Per cent. of contraction in area.	$\frac{1,500,000}{f}$	$\frac{1,800,000}{f-10,000}$	$\frac{2,800,000}{f}$
Lengthwise.	1 A.....	2x 372	38,770	51,100	32'	59'5	29'3	33'9	55'
	3 A.....	2x 373	38,200	51,100	36'3	64'5	29'3	33'9	55'
	5 A.....	2x 373	39,400	53,550	30'5	55'3	28'	31'4	52'3
	Average.....		38,800	51,900	32'9	59'7	29'	33'1	54'
Crosswise.	2 A.....	2x 382	41,230	58,180	25'5	50'2	25'8	27'5	48'2
	4 A.....	2x 385	38,180	55,400	27'5	56'8	27'2	29'8	50'5
	6 A.....	2x 384	38,400	55,730	30'	51'3	27'	29'3	50'4
	Average.....		39,270	56,430	27'7	52'7	26'6	28'8	49'6
Lengthwise.	1 B.....	2x 362	41,000	51,800	28'1	54'0	29'	33'	54'2
	3 B.....	2x 365	40,550	51,900	28'1	53'5	29'	33'	54'
	5 B.....	2x 369	40,900	52,600	30'5	58'0	28'6	32'3	53'3
	Average.....		40,800	52,100	28'9	55'2	28'8	32'8	53'8
Crosswise.	2 B.....	2x 384	39,850	53,100	28'1	57'0	28'3	31'8	52'8
	4 B.....	2x 384	38,600	52,400	30'	57'5	28'7	32'5	53'4
	6 B.....	2x 383	38,800	52,900	28'8	57'5	28'5	32'0	53'
	Average.....		39,100	52,800	29'6	57'3	28'5	32'1	53'1