Technical and Bibliographic Notes/Notes techniques et bibliographiques

The Institute has attempted to obtain the best original copy available for filming. Features of this copy which may be bibliographically unique, which may alter any of the images in the reproduction, or which may significantly change the usual method of filming, are checked below.

L'Institut a microfilmé le meilleur exemplaire qu'il lui a été possible de se procurer. Les détails de cet exemplaire qui sont peut-être uniques du point de vue bibliographique, qui peuvent modifier une image reproduite, ou qui peuvent exiger une modification dans la méthode normale de filmage sont indiqués ci-dessous.

- [ ] Coloured covers/ Couverture de couleur
- [ ] Covers damaged/ Couverture endommagée
- [ ] Covers restored and/or laminated/ Couverture restaurée et/ou pelliculée
- [ ] Cover title missing/ Le titre de couverture manque
- [ ] Coloured maps/ Cartes géographiques en couleur
- [ ] Coloured ink (i.e. other than blue or black)/ Encre de couleur (i.e. autre que bleue ou noire)
- [ ] Coloured plates and/or illustrations/ Planches et/ou illustrations en couleur
- [ ] Bound with other material/ Relié avec d'autres documents
- [ ] Tight binding may cause shadows or distortion along interior margin/ La reliure serrée peut causer de l'ombre ou de la distorsion le long de la marge intérieure
- [ ] Blank leaves added during restoration may appear within the text. Whenever possible, these have been omitted from filming/ Il se peut que certaines pages blanches ajoutées lors d'une restauration apparaissent dans le texte, mais, lorsque cela était possible, ces pages n'ont pas été filmées.
- [ ] Additional comments:/ Commentaires supplémentaires:

- [ ] Coloured pages/ Pages de couleur
- [ ] Pages damaged/ Pages endommagées
- [ ] Pages restored and/or laminated/ Pages restaurées et/ou pelliculées
- [x] Pages discoloured, stained or foxed/ Pages décolorées, tachetées ou piquées
- [ ] Pages detached/ Pages détachées
- [x] Showthrough/ Transparence
- [ ] Quality of print varies/ Qualité inégale de l'impression
- [ ] Includes supplementary material/ Comprend du matériel supplémentaire
- [ ] Only edition available/ Seule édition disponible
- [ ] Pages wholly or partially obscured by errata slips, tissues, etc., have been refilmed to ensure the best possible image/ Les pages totalement ou partiellement obscurcies par un feuillet d'errata, une pelure, etc., ont été filmées à nouveau de façon à obtenir la meilleure image possible.

This item is filmed at the reduction ratio checked below/
Ce document est filmé au taux de réduction indiqué ci-dessous.

10X 12X 14X 16X 18X 20X 22X 24X 26X ✓ 28X 30X 32X

The
to th

The
poss
of th
film

Orig
begi
the
sion
othe
first
sion
or il

The
shal
TINU
whic

Map
diffe
enti
begi
righ
requ
met

The copy filmed here has been reproduced thanks to the generosity of:

Library of the Public
Archives of Canada

The images appearing here are the best quality possible considering the condition and legibility of the original copy and in keeping with the filming contract specifications.

Original copies in printed paper covers are filmed beginning with the front cover and ending on the last page with a printed or illustrated impression, or the back cover when appropriate. All other original copies are filmed beginning on the first page with a printed or illustrated impression, and ending on the last page with a printed or illustrated impression.

The last recorded frame on each microfiche shall contain the symbol —► (meaning "CONTINUED"), or the symbol ▼ (meaning "END"), whichever applies.

Maps, plates, charts, etc., may be filmed at different reduction ratios. Those too large to be entirely included in one exposure are filmed beginning in the upper left hand corner, left to right and top to bottom, as many frames as required. The following diagrams illustrate the method:

L'exemplaire filmé fut reproduit grâce à la générosité de:

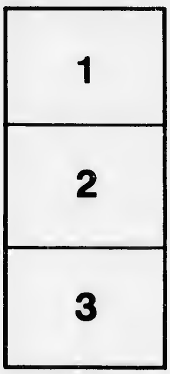
La bibliothèque des Archives
publiques du Canada

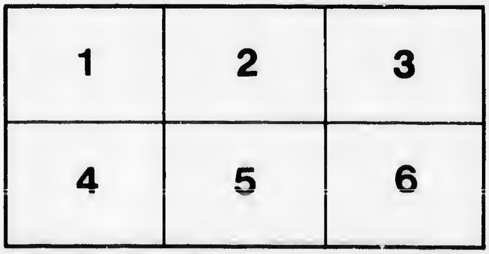
Les images suivantes ont été reproduites avec le plus grand soin, compte tenu de la condition et de la netteté de l'exemplaire filmé, et en conformité avec les conditions du contrat de filmage.

Les exemplaires originaux dont la couverture en papier est imprimée sont filmés en commençant par le premier plat et en terminant soit par la dernière page qui comporte une empreinte d'impression ou d'illustration, soit par le second plat, selon le cas. Tous les autres exemplaires originaux sont filmés en commençant par la première page qui comporte une empreinte d'impression ou d'illustration et en terminant par la dernière page qui comporte une telle empreinte.

Un des symboles suivants apparaîtra sur la dernière image de chaque microfiche, selon le cas: le symbole —► signifie "A SUIVRE", le symbole ▼ signifie "FIN".

Les cartes, planches, tableaux, etc., peuvent être filmés à des taux de réduction différents. Lorsque le document est trop grand pour être reproduit en un seul cliché, il est filmé à partir de l'angle supérieur gauche, de gauche à droite, et de haut en bas, en prenant le nombre d'images nécessaire. Les diagrammes suivants illustrent la méthode.





ADVANCE PROOF—(*Subject to revision*)

This proof is sent to you for discussion only, and on the express understanding that it is not to be used for any other purpose whatever.—(*See Sec.* 40 *of the Constitution.*)

Canadian Society of Civil Engineers.

INCORPORATED 1887.

TRANSACTIONS.

N. B.—This Society, as a body, does not hold itself responsible for the facts and opinions stated in any of its publications.

TRANSMISSION AND DISTRIBUTION OF POWER BY COMPRESSED AIR.

By John T. Nicholson B. Sc., M. Can. Soc. C. E.

The intention of this communication on the subject of the transmission and distribution of power by means of compressed air is mainly twofold. In the first place, to lay before this Society the fact, which has now been plainly proved by the experiments on the Paris installation, that the utilisation of energy by means of air under pressure is a more economical, convenient, and secure method than any other yet known. Secondly, and as a consequence of this statement, to present a prècis of the theory of the whole subject as founded on recent experimental results, so that the necessary data may not be wholly lacking from the records of this Society, when its members are called upon (as it is the author's belief that they shortly will be) to enter upon this department of engineering work.

Reference must be made incidentally to the importance (from the politico-economical point of view) of the encouragement of small industries in great manufacturing centres; and an attempt will be made to estimate the commercial feasibility of a scheme to supply and distribute power by air compression in Montreal; where, unlike Pari competition with electricty as an energy-transformer may be expected to be very severe.

Until quite recenly it has been supposed that energy transmission by the agency of air is of necessity an extremely wasteful process, the idea of its ever being able to compete with electricity for instance having hardly entered anyone's thoughts This wide-spread notion has now, however, been traced to its true source, by the eminent engineer, Professor Riedler of Berlin, and its erroneus nature completely demonstrated by the valuable and extensive experiments made by him and Professor Gutermuth on the 5,000 H.P. plant now at work in Paris. In illustration of the kind of evidence on the strength of which such views are commonly held on this subject, we may refer to Riedler's treatise on "New Experiences with the Power Supply of Paris by Compressed Air," where on page 37 it is stated that the usual efficiency of small mining plants is 10 per cent. to 15 per cent.; and that even with such compressors as those used at the St. Gothard Tunnel and by Sturgeon in Birmingham, three-fourths of the power is lost before the air reaches the mains even. And yet the feasibility of the economical transmission of power by compressed air has been criticised by the results of such inherently bad installations as these. It is as if the efficiency of the steam engine were to be judged by considering the economical value of one using forty or fifty instead of fourteen or fifteen lbs. of water per H.P. per hour. Is it not, on the other hand, altogether surprising that with the common occurrence of such extremely bad results, the system should have in any case survived? Had it not been for the inherent vitality and power of this method it must certainly have perished under such ill usage.

The recent adoption of the two great improvements of compression by stages and the use of a preheater before expansion have enabled Riedler to state definitely as the results of his experiments, that with even the ill made motors used in the small industries in Paris an efficiency of 50 per cent. is obtained, and with the old steam engines of larger power which are commonly used, 80 per cent. of the work of compression at the central station is developed in the motor; and that it is actually possible by using all the latest improvements in compressors and motors and with a very insignificant expenditure of fuel in the preheater easily to obtain just as much work at the motor as is supplied at the distant compressors, or in other words to leave a practical working efficiency of 100 per cent.

Such a result as this is quite unattainable by any other mode of power transmission; and is due simply to the fact that on this system alone is it possible to insert a charge of energy at the working point with no sacrifice to convenience and at an almost insensible cost.

Without further comment or comparison at present, let us pass on to investigate the theory of this surprising (practical) result.

The system of compressor air main preheater and motor is diagramatically represented in Fig. 1 where a is the compressor driven either

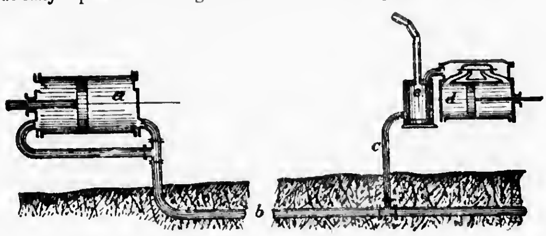


Fig. 1

by steam or water power; b is the air main leading from the central power generating station to the distributing mains; c represents a branch main taken off to run a motor d, and which, before supplying air to the motor, passes through a small heating stove or preheater e.

Compressors.

Considering the action of the compressors first: figure 2 is a diagram supposed to have been taken from air compressor a and given for the purpose of comparing the amounts of work done when one pound of air is compressed adiabatically and also isothermally.

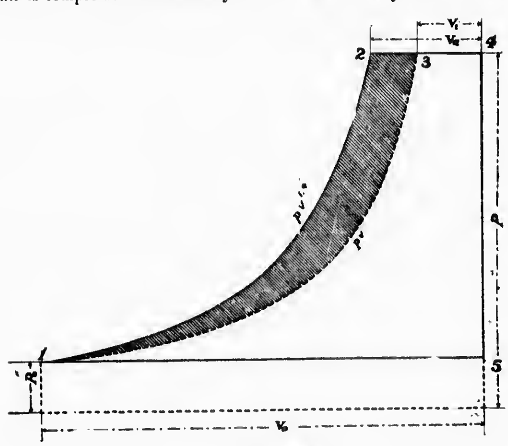


Fig. 2

If no heat be removed from the air during compression, it expands along the curve 1 2, whose equation is $p v^{\gamma}$ = constant and the work done is

$$\frac{p v^{a} - p_o v_o}{\gamma - 1}$$

this is spent in increasing the intrinsic energy of the air; the temperature rises from T_o to

$$T = T_o \left(\frac{p}{p_o}\right)^{\frac{\gamma - 1}{\gamma}} \qquad (1)$$

where $p\ v_a\ T$ and $p_o\ v_o\ T_o$ are the pressures, volumes and absolute temperatures of the air at the points 1 and 2 respectively

When the exhaust opens, the temperature of the air falls to that of the reservoir, which is T_o; the air gives up heat of the amount $K_p\,(T - T_o)$, while the piston does the work $p\,(v_a - v_i)$ to keep up the pressure; the state of the gas is then represented by point 3. During stage 3, 4, the piston delivers the pound of air at constant pressure and temperature; work of amount $p\,v_i$ being done. Part of the work done by the piston was, however, effected by the atmospheric pressure on the other side; so that the whole work supplied through the piston rod of the compressor is

$$\frac{p\,v_a - p_o v_o}{\gamma - 1} + p\,v_a - p_o v_o = \frac{\gamma}{\gamma - 1}\,(p\,v_a - p_o v_o) \quad \text{..........(2)}$$

this may be put in the form

$$\frac{\gamma}{\gamma - 1}\,c(T - T_o) \quad \text{..............................(3)}$$

and as $K_p = \frac{c\,\gamma}{\gamma - 1}$, we see that the whole work done in the adiabatic compression and delivery of one pound of air is equal to the heat generated during* stages 1 2 and 2 3, abstracted during stage 2 3, and lost in the reservoir when, as is usually the case, this is of large dimensions. Inserting the value of T from expression (1) in (3) we obtain for the work of adiabatic compression and delivery in the compressor:

$$W_{ca} = c\,T_o\,\frac{\gamma}{\gamma - 1}\left[\left(\frac{p}{p_o}\right)^{\frac{\gamma - 1}{\gamma}} - 1\right] \quad \text{...................(4)}$$

When, on the other hand, compression takes place at constant temperature the work done by the piston is $p_o\,v_o\,log_e\,\frac{v_o}{v_i}$. During delivery a further amount $p\,v_i$ is done; and subtracting the work $p_o\,v_o$ due to the back pressure, as in the last case, we obtain $p_o\,v_o\,log_e\,\frac{p}{p_o}$ for the work of isothermal compression and delivery of one pound; or

$$W_{ci} = c\,T_o\,\log_e\frac{p}{p_o} \quad \text{.......................... (5)}$$

Referring again to Fig. 2, the cycle is now 1345 instead of 12345, and the work done is seen to be much less, owing to the fact that the pressure of the air is kept down by abstracting heat as fast as it is generated, so that the state of the working substance is represented by the curve $p\,v$ = a constant. It is obvious then that, if the air is to be transferred to some distant point before doing work in the motors, the most economical way of compressing it is the isothermal mode; and this has long been acted on in practice by the use of cooling jackets round the cylinder and even in the piston. For the purposes of a central compressing station, however, this is far from an efficient plan; and is only to be recommended for mining plants where the injection of a spray of cold water is impossible owing to its impurity or to great undesirability of any additional mechanism.

Even with the very best forms of spray injectors now in use, the equation to the curve of compression is altered only from $p\,v^{1.4}$ to $p\,v^{1.2}$ instead of $p\,v$ = a constant. This is illustrated in Figs. 3 and 7, the latter of which shows a combined high pressure and low pressure card taken from an air compressor by Messrs. Riedinger & Co. in Augsburg, Germany, who are now in the foremost rank of constructors of this class of machinery.

---

* This might also have been inferred by observing that the intrinsic energy of the air is the same at 1 and 3, and that therefore the whole of the work done by the piston during 1, 2, 3, must have been abstracted as heat. This work

$$\frac{p\,v_a - p_o v_o}{\gamma - 1} + (p\,v_a - p\,v_i) \text{ however is equal to}$$

$$\frac{p\,v_a - p_o v_o}{\gamma - 1} + (p\,v_a - p_o v_o) \text{ since } p\,v_i = p_o v_o.$$

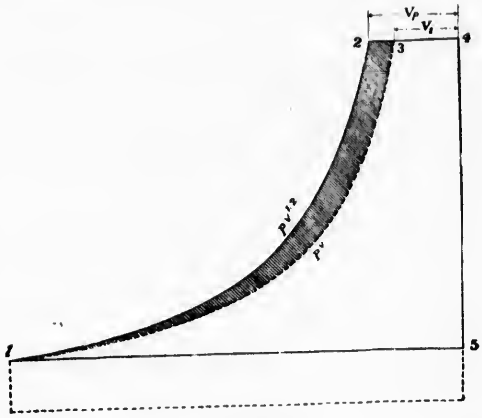


Fig 3

The most successful way of preventing the accumulation of heat in the compressors is to do the work in two (or more) stages. This is accomplished by allowing the air after its pressure has risen a certain amount to flow through an intermediate receiver of sufficient capacity to cool it almost down to the temperature of the atmosphere, so that when drawn into and compressed to the final amount in a second or high pressure cylinder its state is again represented by a point on the isothermal of atmospheric temperature. A theoretical diagram, illustrating this case, is given, viz.: Figure 4.

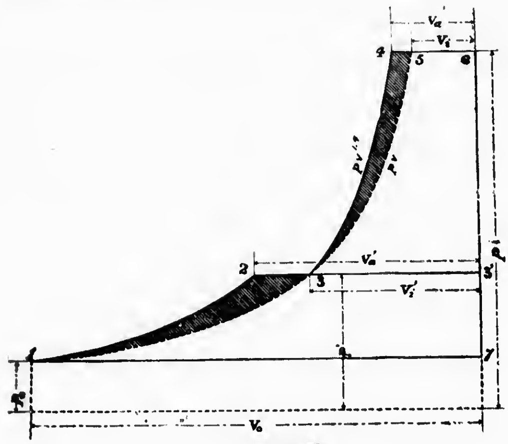


Fig. 4

Here the curve 1 2 is adiabatic, the cooling being supposed very slight, from 2 to 3 heat is abstracted in an intermediate receiver, called an intercooler, until the temperature falls to T_o; Line 33' or 3'3 represents the delivery of the air at a pressure p_i into the high pressure cylinder, in which a further adiabatic compression up to the pressure p takes place, as shown by curve 3 4. The part 4 5 and 5 6 needs no further explanation being of the same nature as already explained in connection with Fig. 2. Riedler has applied this plan to the new installation of ten thousand horse power in Paris with very great success, but as to the originator of the idea nothing seems to be known. Professor Elliott in his admirable paper on compound air compressors (read before the British Association at Cardiff), mentions his having seen an installation working in this way at the Newbattle Collieries near Edinburgh, built as an experiment by Mr. Morrison, the manager; and Professor Unwin, in his communication to the Institute of Civil Engineers, on this subject, states that the Newark Iron Works, Conn., constructed compound compressors with an intercooler as early as 1881.

If the efficiency of a compressor working isothermally, and which therefore wastes no energy in useless heating of the air, to be afterwards lost in the mains, be denoted by 100, then the efficiency of what we shall call Case I, a simple adiabatic compressor, will be found to be 74½. This is obtained by finding the ratio of the areas 1345 and 12345 in Fig. 2, which represents the case in question, or we may find it analytically by evaluating

$$\frac{W c i}{W c a} = \log_e r \Big/ \frac{\gamma}{\gamma - 1}\left[r^{\frac{\gamma-1}{\gamma}} - 1\right]$$

where $r = p/p_o$ ....(6)

In this case r being 7

$$\eta_1 = \frac{1{\cdot}9459}{3{\cdot}5[7^{\cdot 286} - 1]} = 0{\cdot}744$$

Case II. For a simple compressor with spray injection, the efficiency is (see Fig. 3) 84½ °/₀ or

$$\eta_2 = \frac{W c i}{W c p} = \frac{\log_e r}{\frac{n}{n-1}\left[r^{\frac{n-1}{n}} - 1\right]} = \frac{1{\cdot}9459}{6[7^{\cdot 166} - 1]} = 0{\cdot}85 \text{ ....(7)}$$

if $n = 1 \cdot 2$.

Case III. Similarly in the case of two stage adiabatic compression the efficiency obtained from Fig. 4 is 86.2 °/₀. The pressure (p_1) in the intercooler is to be chosen so as to make the work done in the two cylinders a minimum. This work is expressed by

$$W_{2ca} = c T_o \frac{\gamma}{\gamma - 1}\left[\left(\frac{p_1}{p_o}\right)^{\frac{\gamma-1}{\gamma}} + \left(\frac{p}{p_1}\right)^{\frac{\gamma-1}{\gamma}} - 2\right] \text{ ....(8)}$$

which being differentiated and equated to nothing gives for the value of the receiver pressure $p_1 = \sqrt{p_o\, p}$.

In that case (8) becomes

$$W_{2ac} = c T_o \frac{2\gamma}{\gamma - 1}\left[\left(\frac{p}{p_o}\right)^{\frac{\gamma-1}{2\gamma}} - 1\right] \text{ ....(9)}$$

Hence $\eta_3 = 0 \cdot 862$ as above.

Case IV.—Lastly, taking the case of three stage compression with spray injection, which would only be resorted to for the largest plants: we can obtain an efficiency as per Fig. 5, of 95.5 °/₀.

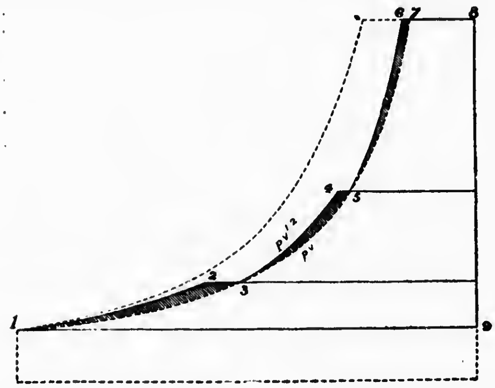


Fig. 5

Analytically, determined it is

$$\eta_4 = \log_e r \Big/ \left(\frac{3n}{n-1}\left[r^{\frac{n-1}{3n}} - 1\right]\right) = \frac{1.946}{18[7^{\cdot 056} - 1]} = 0{\cdot}95 \text{.........(10)}$$

That these efficiencies are not mere figures deduced by analytical special pleading, and which are utterly distant from practical results, is evinced by examination of the annexed cards taken from actual compressors. The first, Figure 6

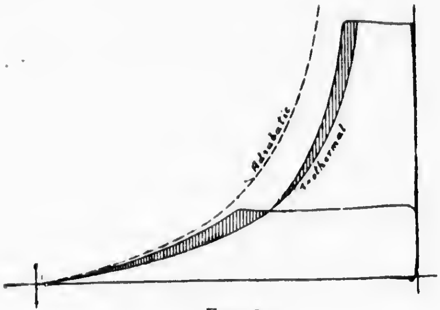


Fig. 6

is from Riedler's first two stage compressor, made on trial for the Paris installation by altering a Cockerill machine. It gives a ratio of actual work to isothermal work of 0·9.

The other, Figure 7

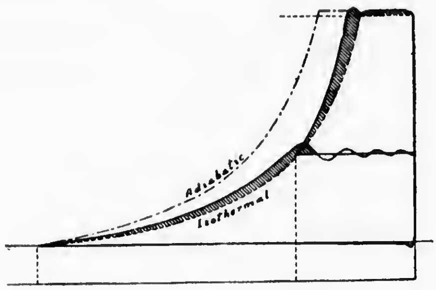


Fig. 7

is taken from an experimental two-stage compressor built by Messrs. Riedinger to the designs of Mr. Lorenz. Its figure is 0·91.

These results show how nearly the cycle of a well designed compressor, with correctly proportioned valves, first-class valve gear, and good jet injection, will approach to the theoretically predicted card.

Figs. 8 and 9, taken from Riedler's "Kraitversogung," show dia-

Fig. 8

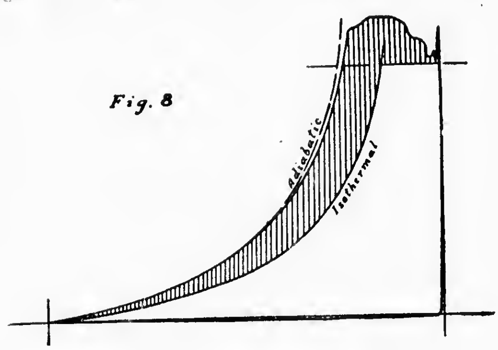
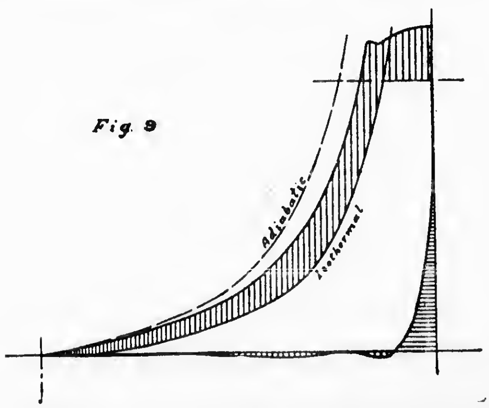
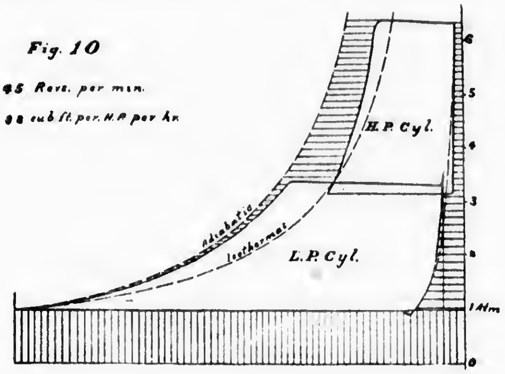
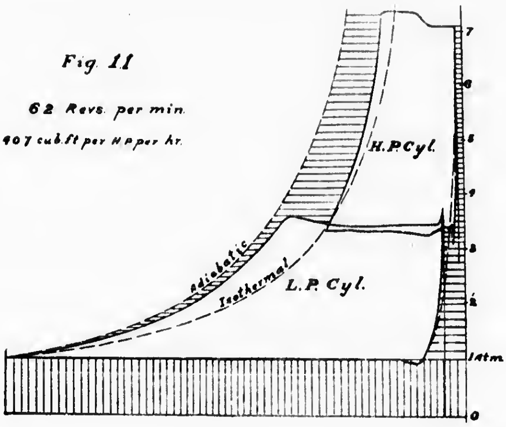


Fig. 9



grams from the older machines of Paxman & Cockerill. The inefficient cooling and ill proportioned valve gear are the causes of the large amounts of lost work shown. Their efficiencies are 0.6s and 0.728 respectively.





Figs. 10 and 11 are diagrams from one of the 2000-horse-power compressors, which have been working at the new Central Station at Quai de la Gare, Paris, since the spring of 1891.

LOSSES IN THE MAIN FROM LEAKAGE AND FRICTION.

The general opinion has hitherto been that long distance power transmission by compressed air involves of necessity great losses from leakage and fluid friction in the mains. This view can, however, no longer be held in the face of the experimental results obtained with the Paris supply pipes. The tests carried out there by Gutermuth and Riedler are the most exhaustive and on the largest scale ever attempted. By permission of the authorities in the French Capital, trials for leakage and friction were conducted and repeated with lengths of pipes varying from two to ten miles, the diameter being about one foot.

The amount of leakage from the mains was determined by allowing them to stand under pressure, and observing the amount of fall on the gauges as time went on. As the mean result of several experiments it appeared that 2,330 cubic feet of air at atmospheric pressure were lost by leakage per mile per hour. This amounts to 8 per cent., as the main was one foot in diameter and the pressure 7 atmospheres absolute; so that the pressure fell to 6.44 atmospheres at the end of the hour. If the velocity of the air be increased from 1.46, at which rate it would have moved to pass a mile of pipe in one hour, to 30 feet per second, its usual velocity; then the air, instead of being one hour, would only remain 3 minutes in the mile of main, and the loss is reduced to 0.4 per cent. This loss will cause a fall of pressure of about 0.41 pounds per square inch per mile.

This surprisingly good result is an evidence of the extremely efficient joints fitted on the Paris pipes. These pipes are of cast iron with plain ends, and are jointed by means of three cast iron rings and four bolts acting on two elastic packing rings.

Better results even than these can certainly be obtained with new mains equally well laid, for the results given by Riedler include several unknown losses such as the pneumatic clock system supply, and that to some small motors which could not be stopped.

Previously to the large scale and careful work of Gutermuth and Riedler, the only experiments on the subject of loss of pressure by friction of air flowing in long pipes were those of Arson (v. P.I.C.E. Vol. 63), of Devillez on pipes up to 5 inches diameter, and of Stockalper on the 6 and $7\frac{1}{2}$ inch pipes supplying the drills in the St. Gothard Tunnel.

Taking these older results and those obtained at Paris together it appears that they agree fairly well, provided the co-efficient of friction be supposed to diminish as the size of the pipe increases. Unwin has discussed in four papers (Vols 43, 63, 93, and 105) in the Proceedings of the Institution of Civil Engineers the question of the loss due to friction of air flowing in long pipes. For the coefficient of friction he gave, using D'Arcy's formula, in 1880,

$$\zeta = 0.0027 \left(1 + \frac{3}{10d} \right)$$

[vide also "Encyc. Britt." (IX) "Hydromechanics"]: and for the pressure p_s at the supply end of a length of main L, of diameter d, when the initial velocity is u_1 feet per second; he obtained

$$p_s = p\sqrt{\left[1 - \frac{\zeta u_1^2 L}{222900d}\right]} \text{.....................(11)}$$

If we choose to insert the value of ζ as depending on the diameter, then we put for ζ in expression (11) the value

$$.0023\left(1 + \frac{3}{10d} \right);$$

where Unwin's formula has been slightly altered to suit the experimenta results obtained by Riedler and Gutermuth: which gave for pipes 1 foot in diameter $\zeta = 0.003$. Putting then in equation (11) this value for ζ and 5280 for L we obtain

$$p_s = p\sqrt{\left[1 - \left(\frac{u_1^2}{18350d} + \frac{u_1^2}{61160d^2}\right)\right]} \text{............(12)}$$

If it be allowed that one steam horse power will compress 360 cubic feet of air at atmospheric pressure up to 7 atmospheres absolute (the new Paris compressors do from 407 to 440) then the volume passing any point in the mains will be $\frac{1}{70}$ cubic feet per second for each horse power. We must therefore have

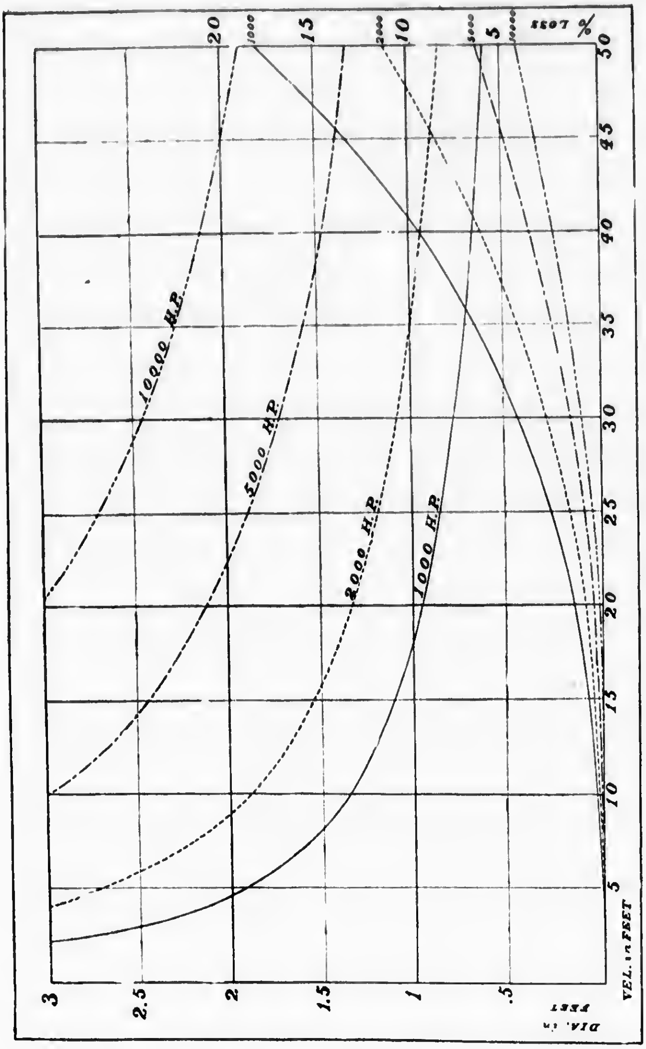
$$\frac{\pi}{4} d^2 u_1 = \frac{H}{70}$$

$$\text{or } u_1 = \frac{H}{55d^2} \text{ ....(13)}$$

Inserting this in (12) we have

$$p_s = p\sqrt{\left[1 - \left(\frac{H^2}{3025 \times 18350d^5} + \frac{H^2}{3025 \times 61160d^6}\right)\right]} \text{... (14)}$$

which is in a convenient form for calculating the sizes of mains: where the diameter must be fixed by the relative rate at which first cost increases and running expenses diminish as the pipe gets larger.



Curves of percentage-loss of pressure in mains

In figure, curves have been drawn co-ordinating the sizes of main required with various initial velocities for 1,000, 2,000, 5,000, and 10,000 horse power.

The lower curves show the loss of pressure per mile in percentage of the original pressure for all the cases. Taking, *e. g.*, the 10,000 H. P curves we find that with an initial velocity of 45 feet per *sec.* and a consequent diameter of 2 feet for the main, the percentage loss of initia pressure is 3.3 *per* cent. per mile.

MOTORS.

The air having now arrived at the motors may be allowed to expand adiabatically, *i.e.*, without addition of heat, or it may be warmed during expansion by a spray injection; or again it may be worked in two stages and warmed in an intermediate receiver of sufficient capacity. The best mode of using the air, however, is to pass it through a heating stove or preheater, and begin expansion in the motors with air at as high a temperature as is convenient, the expansion afterward taking place along the adiabatic curve. If the motor be large enough to warrant the necessary primary outlay, it should indeed be heated twice, being delivered by the high pressure cylinder at a pressure of two or three atmospheres, again passed through a heater and expanded in a large cylinder until its pressure falls to that of the atmosphere.

Consider then, Case I, Figure 12, a simple motor with no preheater, no injected spray, *i.e.*, adiabatic expansion.

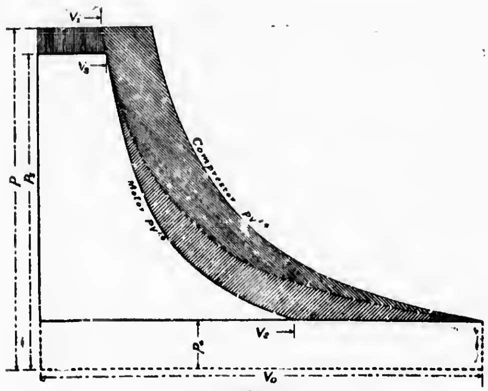


Fig. 12

The air enters the motor from the mains at pressure, volume, and temperature, denoted by p_s v_s T_o. It does work of amount

$$p_s\,v_s + \frac{p_s\,v_s - p_o\,v_e}{\gamma - 1} - p_o\,v$$

$$= \frac{\gamma}{\gamma - 1}\left(p_s\,v_s - p_o\,v_e\right) \ldots (15)$$

$$= \frac{\gamma}{\gamma - 1}\,c(T_o - T_e) \ldots (16)$$

As before $T_e = T_o\left(\frac{p_o}{p_s}\right)^{\frac{\gamma-1}{\gamma}}$ ....(17)

so that, expressed in terms of p_s, p_o, and T_o the work done during adiabatic expansion in the motor is

$$W_{ma} = c\,T_o\,\frac{\gamma}{\gamma - 1}\left[1 - \left(\frac{p_o}{p_s}\right)^{\frac{\gamma-1}{\gamma}}\right] \ldots\ldots (18)$$

If the motor were as good as possible, so that the air expanded isothermally, heat being added from the store in the atmosphere, it would do the work.

$$W_{mi} = c\,T_o\log_e\frac{p_s}{p_o} \ldots\ldots (19)$$

The efficiency of the simple adiabatic motor is therefore :

$$\eta = \frac{W_{ma}}{W_{mi}} = \frac{\frac{\gamma}{\gamma - 1}\left[1 - \left(\frac{p_o}{p_s}\right)^{\frac{\gamma-1}{\gamma}}\right]}{\log_e\frac{p_s}{p_o}} \ldots\ldots (20)$$

In this case p_s and p_o are 6.5 and 1 respectively, so that

$$\eta = \frac{3.5(1 - .154^{.286})}{1.8718} = 77\%$$

This is illustrated by diagram No. 12, where the white card is that expected from the motor; the shaded areas show the losses in compressor, mains, and motor respectively.

If there were no fall of pressure in the mains, expression (18) would be changed to

$$W_{ma} = c\,T_o\left[1 - \left(\frac{p_o}{p}\right)^{\frac{\gamma-1}{\gamma}}\right] \ldots\ldots (21)$$

so that the air gains in volume by its fall in pressure, the effect due to pipe friction being to make the rate of expansion in the motor less. The ratio of the works done in two perfect motors working one with and the other without loss by pipe friction is

$$\frac{\log_e\frac{p_s}{p_o}}{\log_e\frac{p}{p_o}} \ldots\ldots (22)$$

If $p = 7$ and $p_s = 6.5$ this ratio is $\frac{1.8718}{1.9459} = 0.964$.

The total thermodynamic efficiency of the system or the ratio of the indicated work of the motor to that done on the simple adiabatic compressor (Case I) is then

$$0.77 \times 0.964 \times 0.744 = .554.$$

Allowing 0.85 for the mechanical efficiency of this prime mover driving the compressor, and 0.9 for that of the motor, we have $0.85 \times .554 \times .9 = .423$ for the total efficiency of the system. Or 42 per cent. of the work indicated in the steam engine is delivered on the brake at the motor.

Case II. With spray injection; but otherwise as in last case the work would be

$$W_{ms} = c\,T_0 \frac{n}{n-1}\left[1 - \left(\frac{p_0}{p_s}\right)^{\frac{n-1}{n}}\right] \quad \text{.....................(23)}$$

were n may be from 1.25 to 1.4.

Case III. In a compound motor the air is exhausted out of the first cylinder into a large receiver at atmospheric temperature, and is thus, or by mixing with a jet of spray, raised in temperature (nearly) to that at which it entered from the mains; which, if no preheater be used, will also be that of the atmosphere.

In this case the work done in the high pressure cylinder is

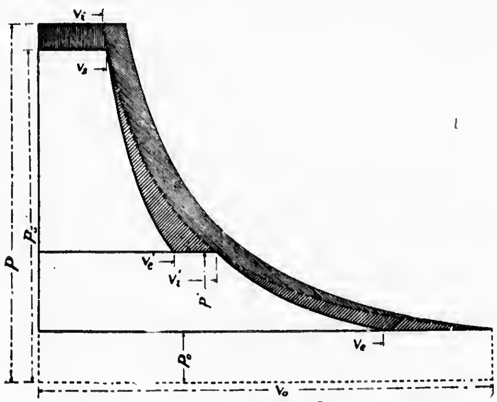


Fig. 13

$$\frac{\gamma}{\gamma-1}\,(p_s v_s - p' v_e') = c\,T_0 \frac{\gamma}{\gamma-1}\left[1 - \left(\frac{p'}{p_s}\right)^{\frac{\gamma-1}{\gamma}}\right]$$

That done in the low pressure cylinder is

$$\frac{\gamma}{\gamma-1}\,(p' v_s' - p_0 v_e) = c\,T_0 \frac{\gamma}{\gamma-1}\left[1 - \left(\frac{p_0}{p'}\right)^{\frac{\gamma-1}{\gamma}}\right]$$

The work done by both is

$$W_{m2i} = c\,T_0 \frac{\gamma}{\gamma-1}\left[2 - \left(\frac{p'}{p_s}\right)^{\frac{\gamma-1}{\gamma}} - \left(\frac{p'}{p_s}\right)^{\frac{\gamma-1}{\gamma}}\right] \quad \text{.........(24)}$$

If p' be taken equal to $\sqrt{p_s\,p_0}$ which gives maximum work in the motor and equal power developed in each cylinder; then

$$W_{m2a} = c\,T_0 \frac{2\gamma}{\gamma-1}\left[1 - \left(\frac{p_0}{p_s}\right)^{\frac{\gamma-1}{2\gamma}}\right] \quad \text{...............(25)}$$

If this two stage motor be supposed supplied from a three stage compressor working with spray injection (Case IV of compressors) the the total thermodynamic efficiency

$$\iota = \frac{\frac{2\gamma}{\gamma-1}\left[1 - \left(\frac{p_0}{p_s}\right)^{\frac{\gamma-1}{2\gamma}}\right]}{\frac{3n}{n-1}\left[r^{\frac{n-1}{3n}} - 1\right]} = \frac{7[1 - .154^{.142}]}{18[7^{.086} - 1]} = .796$$

and the total working efficiency $- .765 \times 796 = 0.61$.

Case IV. Let one pound mass of air arriving from the mains in the state $p_s v_s T_o$ be heated at constant pressure in a small stove to a temperature T_r, so that its volume increases to

$$v_r = v_s \frac{T_r}{T_o}$$

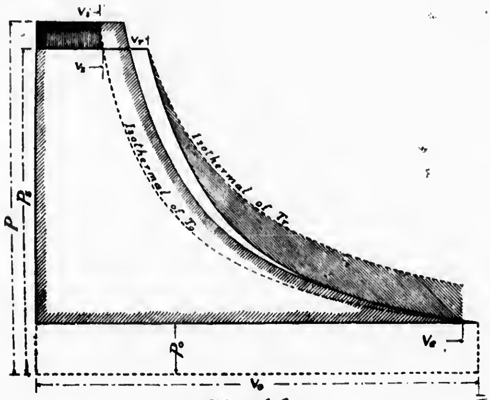


Fig. 14

If the expansion be adiabatic the work done in the high pressure cylinder is

$$p_s v_r + \frac{p_s v_r - p^1 v_r^1}{\gamma - 1} - p^1 v_r^1 = \frac{\gamma}{\gamma - 1}\left(p_s v_r - p^1 v_r^1\right)$$

$$= c\,T_r \frac{\gamma}{\gamma - 1}\left[1 - \left(\frac{p^1}{p_s}\right)^{\frac{\gamma - 1}{\gamma}}\right]$$

Let the air then exhaust into the low pressure cylinder passing through a second small heating stove on its way, and thereby being raised in temperature again to T_r.

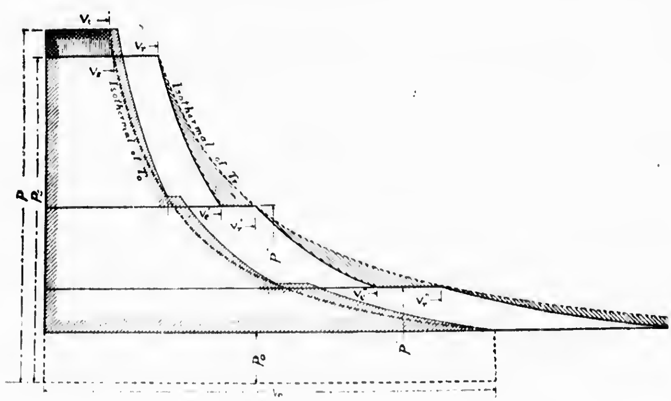


Fig. 15

The work done in the low pressure cylinder with adiabatic expansion down to the atmosphere will be

$$\frac{\gamma}{\gamma - 1}\left(p^1 v^1 - p_o v_e\right)$$

$$= c\,T_r \frac{\gamma}{\gamma - 1}\left(1 - \left(\frac{p_o}{p^1}\right)^{\frac{\gamma - 1}{\gamma}}\right)$$

and the total work when $p^1 = \sqrt{p_s p_o}$ is

$$W_{mgs} = c\,T_r \frac{2\gamma}{\gamma - 1}\left[1 - \left(\frac{p_o}{p_s}\right)^{\frac{\gamma - 1}{2\gamma}}\right] \qquad \text{.................. ....(26)}$$

So that the work done increases proportionately to the rise of absolute temperature. Diagram 15 illustrates a three stage motor.

The ratio of the work indicated here by the motor to that indicated in the compressing cylinder is

$$\eta_t = \frac{c\,T_r \frac{2\gamma}{\gamma-1}\left[1-\left(\frac{p_2}{p_s}\right)^{\frac{\gamma-1}{2\gamma}}\right]}{c\,T_o \frac{3n}{n-1}\left[r^{\frac{n-1}{2n}}-1\right]} \quad \ldots\ldots\ldots\ldots\ldots (27)$$

if $T_r = 400 + 461$ and $T_o = 60 + 461$, then

$$\eta = \frac{861 \times 7\,[1 - .154^{.142}]}{521 \times 18\,[7^{.09} - 1]} = 1.306$$

and the total efficiency of the system is

$$\eta_t = .765 \times 1.306 = .999$$

against this must be set a quantity of coal whic experiment has been found to be about 0.3 pounds per horse pow hour.

Without preheating, one horse power in the distant steam engine was found to give 0.61 horse power on the motor brake. With preheating to 400° F. we get 1.0 horse power. Hence we get 0.39 horsepower by an additional expenditure of 0.3 pounds of coal or

$$\frac{.3}{.39} = 0.78 \text{ pounds of coal per horse power per hour.}$$

It will be remembered that it was found advantageous in the compressor to keep down the temperature by abstracting heat during compression, which is delivered to natural reservoirs such as water or air at atmospheric temperature. Similarly we see that in the motor the most economical mode of doing work is to keep up to the isothermal curve as much as possible by adding heat during expansion from these same natural sources, water and the atmosphere, either by injecting a spray or by using an interwarmer at atmospheric temperature.

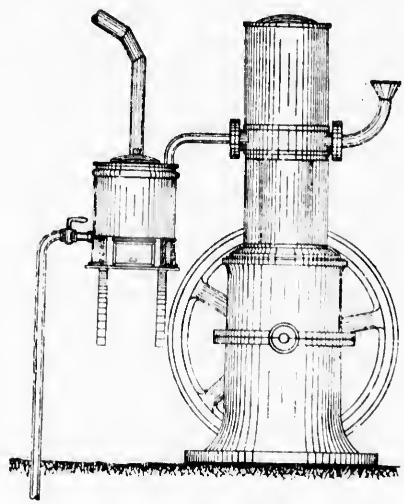


Fig. 16

1 H.P. MOTOR

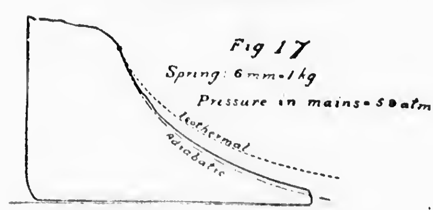


Fig 17

Fig 18

40 H.P. MOTOR

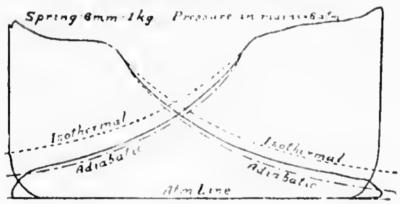
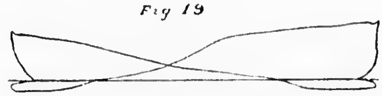


Fig 19



It has long been the custom in Paris to use a small stove through which the compressed air is passed before being used in the motors; such an arrangement is shown for a one horse motor to a scale of one inch to the foot, in Fig. 16, and an indicator card from the same in Fig. 17. It now appears that heat transmitted into air under pressure is extraordinarily efficient. It is almost wholly converted into mechanical effect. This would lead us to consider the highly interesting question of the theory of the preheater. The author prefers, however, to withhold this for the present, pending the completion of some experiments now being made on the subject at McGill College, by which he hopes to be enabled to fill in the necessary constants in the expressions obtained for the heat transferred into the fluid under given conditions of heating surface, temperature difference, velocity, and dryness of the air. Suffice it for the present to give the following practically realized data for a motor of one brake horse power:—the air can be heated from 60° up to 400° F., with a stove whose external dimensions are 8″ diameter and 12″ high at an expenditure of 0.44 pounds of coke screenings per hour; while for a motor of 40 horse power the preheater need only be 16″ diameter and 28″ high, and will require only 0.22 pounds of fuel per horse power per hour.

The possibility of the subsequent addition of energy at such an insignificant cost is a special characteristic of this system of energy transmission. Such a supplementing charge can indeed only be administered when compressed air is the working fluid; and by this means not only can the heat uselessly produced at the generating station and lost in the mains be made good; but, as has just been shown, more heat may be added than was originally lost, and the motor may at a very small expense, and without any additional trouble or inconvenience, give out more power than was spent on the compressor.

In reference to this point it may be stated that the air motors and preheaters in Paris are attended to,—perhaps more correctly stated are left unattended,—by waiters and domestic servants who have all manner of other employments. All they have to do is to turn on the air-cock, refill the lubricators, and put on a shovelful of fuel once or twice a day. As Prof. Riedler has remarked, the air motor appears to be even a more long suffering machine than the steam engine, which is so deservedly celebrated in this respect. With regard to the amount of preheating to be resorted to, this depends on the size of motor and the desired temperature of exhaust. If the motor is a large and powerful one it may be advisable to use two heaters, both a preheater and an interheater. For motors of 10 horse power and under, however, one will usually be sufficient. If the air enters without preheating it will be exhausted at temperatures from 10° to 25° F., in which state it may be used for cold storage or other similar purposes. This is largely the case in Paris, where in many restaurants and cafés, air motors drive the dynamos for lighting, and the escaping cold air is afterwards led into refrigerators for obvious purposes. Confectioners again use the motor during the day to drive the mixing and other machines, light their shops in the evening, and use the exhaust for making ice. The exhausting of clean cold air into a workshop is a great advantage in a hot climate. If, on the other hand, recourse is had to a considerable amount of preheating, the air will be exhausted at or even above atmospheric temperature: and with a large motor, enough warm fresh air may be obtained to serve in winter for heating and ventilation.

In concluding this part of the paper it will be well to recapitulate in brief the several efficiencies of the different parts and the combined efficiency of the whole system for one or two of the cases most likely to occur.

The mechanical efficiency of the compressing machine may be safely taken to be 0.86, the Paris installation compressors gave this result; and with the new 2000 horse compressors Riedler has obtained 0.9. A turbine will give from 0.75 to 0.8 for the same ratio.

The thermodynamic efficiency of the compressors is for a single stage compressor with spray injection 0.85, and for a two stage compressor 0.92.

The loss in the mains due to leakage and fall of pressure for a 5 mile transmission may be put at 3.8 per cent., so that the efficiency of the mains is 0.962.

The thermodynamic efficiency of a simple adiabatic motor without preheater is 0.77; of a two stage adiabatic motor 0.9; of a simpler preheated motor 0.8 to 0.9; and of a two stage preheated motor 1.1 to 1.3.

The total efficiency or ratios of the brake horse of the motor to the horse power used in the compressors for the two cases which we have to consider in estimating the financial possibilities of a pneumatic pov supply are therefore as follows:—

Case I. Turbines driving best compressors, power transmitted through 5 miles of main, largest air motor for factory, with two stage heater,

Easily possible: 0.92 x 0.96 x 1.25 = 1.1

Actually done: 0.90 x 0.96 x 1.16 = 1.0

Case II. Turbines driving best compressors, power transmitted and distributed by 7½ miles of main, medium sized simple air motor with preheater,

0.92 x 0.94 x 0.87 = 0.75.

Case III. Triple expansion steam engines driving best compressors at central station in or near city, power distributed in 5 miles of main and consumed in an average simple preheated motor,

0.92 x 0.96 x 0.87 = 0.76.

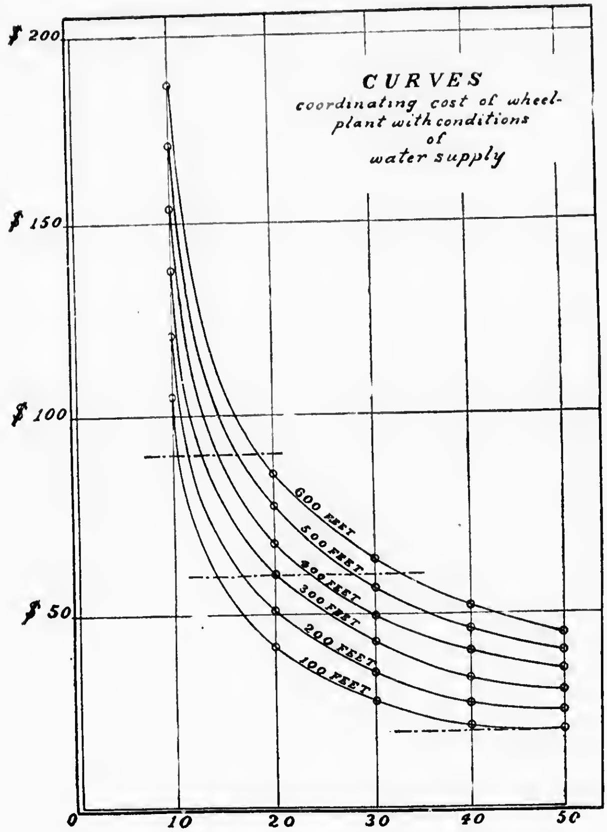
The mechanical efficiency of the turbine or steam engine is here left out, as it will be allowed for in the estimated cost of a horse power delivered to the compressor.

In entering upon the consideration of the commercial feasibility of a transmission and distribution scheme by compressed air, let us direct our attention to a concrete case, and postulate the conditions which obtain in the locality in question as regards cost of coal, nature and amount of available water and other power.

Referring, for example, to Montreal, let us take for granted that an abundant supply of water with a fall of, say, 20 feet can be obtained 5 miles from the city; and that all difficulties in connection with the utilisation of this power, such as frazil can be, as the author believes they can be, successfully overcome. This being the case, let us in the first place consider whether power can be supplied on a large scale to a mil owner at anything like the same price as he can make it for himself by burning coal in steam boilers and using the steam in a first class steam engine.

First then let us ascertain at what price per horse power per annum a pneumatic power supply company owning its water supply can afford to deliver to a consumer 5 miles away compressed air at a pressure of, say, 95 lbs. on the gauges.

From statistics and data given by Swain, Manning and Main, it appears that the cost of one H. P. on the wheel shaft, that is for dam, head and tail races, turbines and shaft, penstocks, gates and wheel-pit, for a 2,000 H.P. plant, varies from $17.00 with a fifty foot head, 100 foot distance from supply to discharge, to $153.00 with a ten foot head and a distance of 600 feet. (See Fig.)



In the case of the works now approaching completion at Austin, Texas, the figure, as kindly supplied me by Mr. Lea, of McGill College, is $14.00 for an average head of 57 feet and a distance from canal to river of 600 feet.

In the present case it has been assumed that the cost of one wheel H.P. is $90.00; which will allow, with a head of 20 feet, a distance from supply to discharge of about 700 feet, or, with a head of only 10 feet, a distance from river to canal of 100 feet.

It will probably be admitted that this is a somewhat high estimat for this location, where the average head may be expected to be from 20 to 30 feet, and the possibility of dispensing with a dam will allow for almost any reasonable length of supply and discharge canals. The fixed expenses on this capital sum are here taken at interest 5 per cent., epairs 1 per cent., depreciation, etc., 2 per cent., or a total of 8 per cent., which on $90.00 amounts to $7.20. The running expenses, including attendance, oil and waste, are taken at $0.75 per H.P., making a total annual expense per H.P., supplied at the turbine shaft of $7.95.

The compressors will cost considerably less than a steam engine of equal power: for although they cannot be said to be now in the market in this country (the highest type of modern first class compressor being here in question), yet this will be more than compensated for by the lack of air and circulating pumps, and the fact of there being no crank shaft to charge against the compressor, this having been already reckoned along with the cost of the turbines. The cost price of compressors may therefore be taken at $10.00 per gross H.P., and if we take the fixed expenses at:—interest 5 per cent.; depreciation 4 per cent., repairs 2 per cent., together 11 per cent., and the running expenses at 75 cts. per H.P., the total cost per H. P. per annum of compressors is $1.85.

The twelve inch cast iron mains with special flexible joints, as used in Paris, may be expected to cost $30.00 per ton; which is at the rate of $1.00 per running foot. Adding 25 cts. per foot for trenching and laying, we obtain a total of $33,100. or $16.55 per H. P., for 5 miles of 12 inch main. Taking interest 5 per cent., depreciation 3 per cent., repairs ½ per cent.; together 8½ per cent., the cost per H. P. per annum amounts to $1.40.

The total cost per annum to the Power Supply Company of one compressor horse power is

Water Power............................	\$7.95
Compressors............................	1.85
Mains..................................	1.40
or a total of	\$11.20

This includes 5 per cent. interest on the capital expended.

The capital expended up to this point by the company, including that upon dam, canals, penstocks, wheel-plant, compressors and mains, amounts to \$116.55 per H.P. Five per cent. on this sum amounts to \$5.82, which added to \$11.20 makes a total of \$17.03. If then the Supply Company charge the consumers at the rate of \$17.00 per H.P., they will secure themselves a revenue of 10 per cent. on their outlay.

For this sum of money the Supply Company do not supply to the consumer a quantity of air sufficient of itself to produce one H.P. But in order to effect this it is only necessary for the mill owner to fit as part of his motor plant, one or two heaters to supply the energy lost in transmission. The cost of the motor, including these heaters, may be expected to be less than that of a steam engine of the same power. But, taking the cost at \$12.50 per H.P., and reckoning on this, fixed expenses at the rate of 11 per cent., viz., 5 per cent. interest, 4 per cent. depreciation, 2 per cent. repairs; taking also \$5.00 as the cost of the motor house, with 10 per cent. as fixed charges, the total cost to the consumer of his own power plant is \$1.90 per H.P. per annum. To this must be added the running expenses as follows:—

One man at \$2.50............................	\$1.56
Oil waste and supplies........................	0.80
Coal for the two heaters at together 0.3 lbs. per H.P. hr. at \$4.00 per long ton.......	1.65
Total	\$4.01

The air discharged by the motors will be of sufficient amount and at such a temperature as to heat some portion of the mill; but for security we shall add a plant for heating alone of one-fifth the size of the original steam plant replaced by the air motor. This plant will cost about \$15.00 per H.P., so that the capital outlay will be \$3.00 per H.P. of power. Taking the fixed expenses at 12½ per cent. on \$3.00, that is \$0.38; the running expenses (viz.: coal at \$2.00; attendance, (one man at \$1.40 for 150 days say \$0.42) at \$2.42; the total cost of this heating plant per horse power of power plant will be \$2.80.

Adding together all the items of the mill owner's annual expenditure viz.:

Cost of air supply....................	\$17.03
Air Motors............................	4.01
Extra heating.........................	2.80
	\$23.84

We obtain a total of \$23.84 as the annual cost to the mill owner of his air supply, air motors, and steam heating plant.

With this we have now to compare the cost to him of steam engine and boilers of the same power.

Assuming with Mr. Main (Trans. Am. Soc. Mec. Eng., Vol. XI) that the consumption of coal per 1 H.P. per hour of a compound engine is 1.75 lbs. and of a high pressure engine 3.00 lbs., and allowing that 25 per cent. of the steam exhausted from the high pressure cylinder is taken from the receiver for heating purposes, we obtain a consumption for this combined steam power and heating arrangement of (1.75 × .75 = 1.31 + 3.00 × .25) 2.06 lbs. per horse power hour. The coal bill @ \$4.00 per ton will therefore amount to $\left(2.06 \times 10 \times 308 + \frac{4.00}{2240} =\right)$ \$11.35. For boiler attendance we must allow two men at \$1.50 and for the engine one man at \$2.50 for every 500 Horse Power or $\left(\frac{4.00 \times 308}{500} =\right)$ \$2.46 per H.P. per annum. With \$0.80

for oil and waste and no allowance for cost of feed or tax on condensing water, which are supposed to be supplied free by engine circulating pump, the running expenses amount to $14.61 per H.P. per annum.

The fixed expenses must be reckoned on the cost of boilers, engines and houses.

Boilers of the Babcock Wilcox type cost about $20.00 per H.P. and $5.00 for setting, together $25.00. With interest at 5 per cent., depreciation 5 per cent., taxes and insurance 2 per cent., repairs 2 per cent., together 14 per cent., this works out to $3.50 fixed expenses on boilers. The boiler, coal houses and chimney cost about $6.00 a horse power, which comes to $0.60 per H.P. per annum, if interest, depreciation and repairs be taken at together 10 per cent.

The first cost of a steam engine in the neighbourhood of 500 horse power is $10.00, with 25 per cent. for setting, $12.50. Taking the charges at 11 per cent., viz.: Interest 5 per cent., depreciation 4 per cent., repairs 2 per cent., the fixed cost of the engine will amount to $1.40, while the engine house costing $5.00, at 10 per cent., increases this by $0.50.

The total expense incurred by the mill owner for the production of power by steam is therefore :—

Fixed expenses.................	Boilers	$3 50
	Boiler house and Chimney..	0 60
	Engines.......................	1 40
	Engine house.................	0 50
Running expenses	Coal	11 35
	Oil and waste.................	0 80
	Attendance.........	2 46
		$20 61

per horse power per annum.

The cost of a horse power supplied by means of water and air was found to be $23.84, hence we see that so long as coal remains so abundant and cheap, and can be so cheaply transported by land and sea, other natural sources of energy will continue to be of an inferior value. The great transmitters of energy are indeed our railways and steamships, which transport at a rate infinitely cheaper than by any other means the enormous stores of mechanical energy accumulated in our coal fields; and that in any required amounts and to any distances, unhampered by the losses of power which inevitably accomplish every transformation.

The only chance for a commercially successful utilisation of water power in a neighbourhood well situated for coal supply is a case where the capital outlay for water plant can be reduced considerably below $90.00. As, for instance, by the accident of great head; such natural fitness that the supply and discharge canals may be short, or that a dam is not necessary. Then and then only can power be supplied to a distant mill by means of compressed air at a price which competes with the cost of production by steam at the mill or factory itself. If, for example, we take the capital outlay at $20.00 (a point shown on the diagram near the lower limit) instead of $90.00 for power delivered by the turbine shaft, then the annual cost to the mill owner of his air supply, air motors, and steam heating plant on the same scale as before is reduced to $15.34, or about two thirds of its former estimated cost, one-fourth less than the calculated cost of steam. It remains for experts on water utilisation in this district to examine whether a source of water power supply cannot be found, such that the initial outlay per horse power delivered to the compressors need not be more than $60.00; in which case, power can certainly be supplied on the pneumatic system at a cost less than that of steam even to a large factory working full time.

It will of course be observed that in these two estimates of transmitted power, it has been tacitly assumed that the horse power indicated by the motors was the same as that given to the compressors. Not merely can this be certainly secured *even on the motor brake* with such an insignificant expenditure of coal as that mentioned above; but, as has been actually effected with plant, far from being near the limit of that which is technically possible, an actual gain of work is possible, a working efficiency of 116 per cent. having been obtained.

Any other system of transmission, wasting as it must at least 25 per cent. of the energy supplied at the wheel shaft, at once raises the cost per horse power from our supposed $15.34 (when the capital outlay for water power is $20.00) to $20.45, or the same as that of steam.

Let us now turn to the case of an employer using a small amount of power, and we shall find, as is well known, that he must fall an easy prey to our central power supply company, even if he does not use his power intermittently, as is almost always the case.

We have seen that the air compressed at a water power station can be delivered to a city five miles away for $23.84, when the cost of water plant is $90.00 per horse power. If we increase the price to $25.00 we shall have allowed for about 5 miles of 9 inch mains in the city; and the supply of consumers at this rate allows the Power Company 10 per cent. on their capital outlay. We shall assume that a ten horse air motor gives out on its brake for a given quantity of air only 75 per cent. of the power used in compressing that air. Experiments made on the smallest motors of less than one horse power, commonly used in Paris gave this total efficiency at close on 50 per cent,, while larger machines, as a general rule, simply old steam engines with very small mechanical efficiency, gave 80 per cent. with but 90° F. preheating of the air and a coal consumption of $\frac{1}{5}$ pound per horse power per hour. Then our small consumer must pay $25.00 x $\frac{4}{3}$ = $33.33 for the air required to deliver him *one brake horse power;* not *one indicated* which he usually pays for.

If his motor and preheater cost him $33.00 per horse power, the fixed charge at 10 per cent. will be $3.30; and if he uses 0.2 pounds of coal, his running expenses will be $1.10 per horse power per annum when he works 3,080 hours a year. The total cost to this consumer of one brake horse power thus amounts to:—

Air..	$33 33
Fixed charges..................................	3 30
Running expenses..........................	1 10
	$37 73

$37.75. This assumes that he works at full power for 10 hours a day during 308 days. If he works only at ½ power, this price will bo reduced almost in proportion to the smaller power employed, as the air motors cut off automatically; and if he work intermittently, it will be reduced in the same manner, as he is only charged for the air which actually passes through his meter. For example, if his 10 brake horse power motor works 10 hours a day, his power bill will be $377 per annum. If he runs only five hours a day, the amount sinks to $210; and smaller quantities in the same proportion meted out with the precision of an ordinary gas meter. This estimate is based on an assumed necessary expenditure of $90.00 for wates and wheel plant. The author believes this to be a very high price for Montreal.

The cost of a horse power varies in Montreal from $60 to $120, rented to or supplied by consumers using from 3 to 25 horse power; so that on the lowest estimate these would save from $22 to $39 according to amount used, per horse power per annum, by a system o compressed air distribution.

Let us now inquire what can be done by generating power in a Central Station near the city, by means of first class triple expansion steam engines and first class compressors; and distributing the same to customers in a main of a length of two miles for each 2,000 horse power.

Without troubling the Society with details, the schedule of annual charges will run somewhat this:—

Fixed expenses,	Boilers..	$3 50
	Boiler and Engine houses and chimney	1 20
	Triple Expansion steam engines.........	2 23
	Compressors..................................	1 10
	Mains (12″ dia.)..............................	0 56
Running expenses,	Coal..	8 28
	Oil waste etc,..................................	1 00
	Attendance	2 46
		$20.33

The total cost to the Central Station Coy. of one compressor horse power is thus $20.33 which includes 5 per cent. interest on their expended capital of $71.37 per horse power.

This outlay is made up as follows:

High-Pressure boilers and setting...	$25.00
Houses and chimney............................	11.00
Triple engines and setting........................	18.75
Compressors..	10.00
Mains..	6.62
Total..	$71.37

Allowing 5 per cent. more on this, or $3.57, we have a total of $23.90; which is the price at which the Central Station Company can supply air for one horse power and secure at the same time 10 per cent. interest on their capital outlay.

The easy inference from this is that 500 consumers in this city, of an average of four horse power each, would, by forming themselves into a Central Power Supply Company, reduce their power bill by from 45 per cent. to 75 per cent.! It ought to be mentioned that the lower limit of saving just mentioned, assumes that the consumers' steam engines, which, without alteration, will serve equally as air motors, have a present value of $33.00 per horse power.

Regarding the question of heating in winter, there seems every possibility, in view of the successful system of steam distribution in New York, of being able to supply heat by laying mains to the city from the Central Power Station, and leading the exhaust from the steam engines in the same to be delivered to the workshops and houses in turn; and this at an enormous saving of fuel and expense to all concerned.

This would also be a most desirable scheme from the point of view of the elimination of smoke from our large cities.

The great benefit to small producers by such a great reduction in cost of power is obvious and need not at present employ our further attention.

Reference ought here to be made to many advantages apart from the question of cost which attend the adoption of the pneumatic system of power supply.

In the first rank we may place the elimination of 95 per cent. of the smoke which now renders manufacturing centres so obnoxious from an æsthetic point of view, and of the dangers and responsibility attending the use of steam boilers by unskilled persons, these being done away with or removed from the more crowded parts of the city. The possibility of running air motors in the centre of the city, where a supply of water for condensing or even feed is extremely expensive, is an obvious advantage.

The extreme handiness of the working medium and its suitability for use by technically unskilled attendants has already been adverted to. In this respect the air motor bears away the palm from the electric motor, the gas engine, and even the much enduring steam engine; all of which require a certain modicum of knowledge or experience. The repairs also of such a machine require only a knowledge of perfectly well understood mechanical details.

The use of the exhaust for either refrigeration, ventilation, or even heating renders the rejected air a beneficial by-product, instead of a nuisance, as the exhaust from a steam engine certainly is in summer.

The suitability of compressed air for the working of lifts ought not to escape mention; a cheapening of the first cost of at least 10 per cent. and of running expenses at the rate of 75 per cent. over other systems can be easily attained.

Tram cars worked by compressed air are now in use in Nantes, Brussels, Chester, and other places; they have there proved both serviceable and economical in spite of the fact that the power they use is generated in small compressing stations. A reservoir capacity with air at a perfectly safe pressure can be obtained with an ordinary sized car to do a return journey of 5 miles without any intermediate charging station; and the consequent removal of a dangerous overhead wire, such as is used on the electric trolley system, is not to be despised in a populous city such as this. The difficulty of snow could be overcome by having a car devoted to clearing the tracks alone; but this will be preferably effected by having a light overhead railroad, as the ruts in the streets caused by keeping a clean tramroad in winter are extremely unpleasant, not to say dangerous, to occupants of vehicles.

The convenience with which compressed air as a working agent could replace steam in a city already supplied with power by a number of small steam engines is sufficiently indicated when it is stated that all that is necessary to be done, without altering the engine in the slightest degree, is to uncouple it from the boiler and connect to the air main in the street with the interposition of a reducing valve and an air meter. The steam boiler may then be sold and the engine tender may devote nearly his whole time to other duties.

The low price of small motors may be referred to. They cost less in Paris than even steam engines, which are of course easily the cheapest of all small motors; and the introduction of good rotary patterns has rendered their availability for small industries still more marked.

We have concluded from the calculations above elaborated, and which are based upon results already obtained with the Popp system in Paris, easily improvable, that a great economy in the cost of power to small employers can be effected by the adoption of a scheme for the centralised production of mechanical energy and its distribution by the use of compressed air. The question now naturally arises: Is this encouragement of small employers a wise thing to aim at from the point of view of the whole community, or ought we not rather to repress and altogether annihilate them in order that all industrial work may be confined to large factories?

A complete answer to this far-reaching question will not here be attempted; but the following considerations may not be out of place.

Statistics show that three fourths of the mechanical power now used in the world has originated within the last thirty years; and it has also been computed that one hundred times more work is done by the aid of machinery at the present day than by the combined efforts of the whole human race. The work of this vast and terrible mechanical agency must of necessity ever increase and grow in amount; it cannot in the slightest degree be limited or discontinued without the instant decline and final cessation of our material civilisation.

We are therefore face to face with this enquiry:—Are we to confide to the capitalists the sole mastery and control of this enormous power, upon the wielding of which the very destinies of the race depend? Or ought not rather the vast stores of Nature's energy to be at the common disposal of all, as a beneficent working agent?

It truly appears to the author that the results of the long continued operation of the former alternative are at the very root of th great Labour questions with their accompanying Socialisms and Communisms which are now so momentous in all the countries of Europe, and are beginning to agitate even the New World.

Consider the conditions of life of the factory hand. When a young workman, he sees no prospect of ever being able to compete as an independent employer with the large establishments producing the commodities he helps to make; he accordingly never dreams as a rule of saving his earnings for the purpose of establishing himself in business; but on the contrary uses the same to minister merely to his pleasures, and frequents the society of men like himself who, naturally ill content with their conditions of life, indulge in noxious political talking, if nothing worse. This state of things is certainly not improved, when, as he advances in life, from which the freshness and gloss have now been removed, he sees nothing before him but his day of toil unrewarded save by his weekly wage.

It is far otherwise with a man who can be his own employer. He takes pleasure in, and works with diligence and foresight at, an occupation from which he anticipates a personal reward for his own industrious skill. His intelligence is quickened by the invention of better methods for the carrying on of his work and in the buying of his own materials and the sale of his own finished products. He will have an apprentice or two who ought, if they are not already members of his family, to live in his house, and who consequently, from personal esteem, will take as keen an interest in the business as he does himself. They know that they themselves will some day be small employers, so that no detail of the whole organization will escape their vigilance.

There is no reason why these people should not have high moral and political aims; if only a strong government attends to the just protection of their rights and property; and they can then have no possible grounds of complaint.

It would seem therefore not illogical to draw the conclusion that in a state where small industries flourish there will reign peace, contentment, order, and prosperity; that discord imported from without can find no root, while discontentment from within can never arise.

We all know that the factory hand is a much more common object than the contented small employer; and this is the direct result of the extremely unfavourable condition in which such small employers are placed as regards the obtaining of mechanical power. As a consequence they have to work with antiquated tools; for almost all the great technical improvements pass over without touching them, the first requirement for their application being the possession of motive energy; so that they shortly fall hopelessly behind in a race in which they are so heavily handicapped. How can it be otherwise when it is remembered that they must pay from 4 to 10 times more for power than the more fortunate capitalist does; and are at the same time encumbered with taxes and regulations by the authorities levied upon the possession of prime movers in the midst of populous cities?

Sooner or later it must come that the small employer will obtain for himself the advantages accruing from the economical use of power which are at present the monopoly of the capitalist alone.

The great technical advances recently made in electricity and in the use of compressed air evidently point to the speedy accomplishment of this desirable result. And in a very few decades we may confidently predict the removal from our manufacturing cities of all the wasteful and noxious gas-producing prime movers now used; in their stead the employment of more convenient and more economical secondary motors supplied from mains in the streets which lead the working fluid from well conducted and favourably situated power supply stations. When the time comes, compressed air as an energy medium will be found to be an irrepressible young giant demanding and exacting his due recognition.

My best thanks are due to Mr. Lea B. A. Sc. of McGill College for valuable help in connection with the estimates of cost; and to Mr. G. S. Smith, B. A. Sc. of McGill College for much careful assistance without which the preparation of this communication in the midst of a busy session would have been almost impossible.