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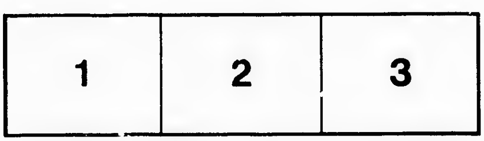
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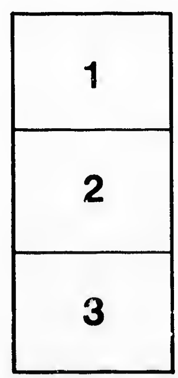
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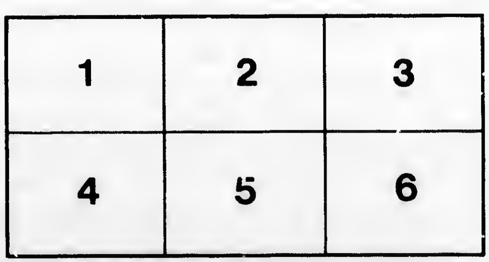
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CANADIAN

HAND-BOOK

OF

STEAM

AND

ELECTRICITY

ADAPTED TO THE REQUIREMENTS OF PERSONS IN CHARGE OF THE OPERATION OF STEAM AND ELECTRICAL APPLIANCES.

BY WM. THOMPSON.

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PREFACE

THE information contained in the following pages has been specially prepared with a view to meeting the requirements of persons desirous of qualifying themselves to undertake the successful management of electrical and steam appliances. The preparatory chapters are devoted to a concise explanation of the foundation principles of mathematics, a knowledge of which is absolutely essential to the study of electricity and engineering. In the succeeding chapters the student is lead by gradual stages to a more complete acquaintance with these subjects, and is equipped with knowledge sufficient to enable him to pursue his researches to any further extent within the compass of his ability and opportunities.

THE AUTHOR.

INDEX TO ENGINEERS' MANUAL

INDEX TO ELECTRICAL CALCULATIONS

ERRATA.

Page 15: Sixth line from top reads, "Divide $100 \div \frac{3}{4} = 400 \div 4 = 133\frac{1}{3}$;" should read, "$100 \div \frac{3}{4} = 400 \div 3 = 133\frac{1}{3}$." Eighth line from bottom reads, "$\frac{7}{8} \div \frac{3}{4} = \frac{7}{8} \div \frac{4}{3} = \frac{7 \times 4}{8 \times 3} = \frac{28}{24} = 1\frac{1}{6}$;" should read, "$\frac{7}{8} \div \frac{3}{4} = \frac{7 \times 4}{8 \times 3} = \frac{28}{24} = 1\frac{1}{6}$."

Page 61: Second line from bottom reads,

$$\frac{A\ N}{P\ T} \times 100 = \frac{5^2 \times .7854 \times 2}{2.5 \times .5} \times 100 = \frac{.393}{1.25} = .3144 \times 100 = 31.44\%;$$

should read,

$$\frac{A\ N}{P\ T} \times 100 = \frac{.5^2 \times .7854 \times 2}{2.5 \times .5} \times 100 = \frac{.393}{1.25} = .3144 \times 100 = 31.44\%.$$

Page 78: Second line from bottom reads, "16,272 total area of boiler $\div$ 30,753, number of stays required;" should read, "16,272, total area of boiler $\div$ 307 = 53, number of stays required."

COMMON FRACTIONS.

A FRACTION is one or more of the equal parts into which a unit, or that which is considered as a whole, may be divided.

[NOTE.—Thus a two foot rule is divided into $\frac{1}{64}$, $\frac{1}{32}$, $\frac{1}{16}$, $\frac{1}{8}$, $\frac{1}{4}$, and so on, and consequently this style of numeration is constantly occurring in mechanical engineering.]

The terms of a fraction are styled and distinguished as the Numerator and the Denominator.

The numerator of a fraction indicates the number of parts of the unit considered or taken.

The denominator indicates the number of parts into which the unit is divided.

To express a fraction is to indicate by figures the number of parts in the numerator and denominator respectively above and below a horizontal line.

Thus $\frac{1}{8}$, $\frac{1}{4}$, $\frac{1}{2}$.

Common Fractions are known as Simple, Compound and Complex.

A simple fraction is a fraction whose numerator and denominator consist of simple numbers.

Thus $\frac{1}{64}$, $\frac{1}{32}$, $\frac{1}{8}$, $\frac{1}{2}$.

A compound fraction is a fraction whose value is not fully expressed, but must be arrived at by computation.

Thus $\frac{1}{2}$ of $\frac{1}{16}$, $\frac{1}{8}$ of $\frac{3}{4}$, etc.

A complex fraction is one which contains a fraction in the numerator or denominator, or in both. Its value must be found by computation.

Thus $\dfrac{\frac{1}{2} \text{ of } 6}{\frac{2}{3} \text{ of } 1}$ $\quad \dfrac{\frac{1}{2} \text{ of } \frac{1}{10} \text{ of } 4}{\frac{1}{2} \text{ of } 6}$

The numerator or figures above the line correspond with the dividend, and the denominator or figures below the line with the divisor.

The chief principles relating to fractions are:

1. Multiplying the numerator by any number multiplies the fraction.

2. Multiplying the denominator by any number divides the fraction.

3. Dividing the numerator by any number divides the fraction.

4. Dividing the denominator by any number multiplies the fraction.

5. Multiplying both numerator and denominator by the same number does not affect the value of a fraction.

6. Dividing both numerator and denominator by the same number does not affect the value of a fraction.

Giving us the important general principle that any change in the numerator produces a corresponding change in the value of the fraction, and any change in the denominator produces an opposite change in the value of the fraction.

COMMON DENOMINATOR.

A common denominator is a denominator which is common to two or more fractions.

Rule: To find a common denominator to two or more fractions, multiply together all the denominator and the product will be the common denominator.

Example: Find common denominator of $\frac{1}{2}$, $\frac{2}{3}$, $\frac{3}{4}$, $\frac{15}{16}$ = The denominators multiplied together, as $2 \times 3 \times 4 \times 16 = 320$, which becomes the denominator common to the whole of these fractions.

This rule often entails a lot of work, consequently I prefer to reduce denominators to their simplest form and multiply together the final quotient and the divisors, which will give the common denominator in lowest form.

Example: Find the common denominator of

$$\frac{5}{6},\ \frac{7}{8},\ \frac{15}{32},\ \frac{2}{3},\ \frac{4}{5}$$

Reduce denominators to lowest form, thus:

$$\begin{array}{r|l} 3 & 6\ .\ 8\ .\ 32\ .\ 3\ .\ 5 \\ \hline 2 & 2\ .\ 8\ .\ 32\ .\ 1\ .\ 5 \\ \hline 4 & 1\ .\ 4\ .\ 16\ .\ 1\ .\ 5 \\ \hline & 1\ .\ 1\ .\ 4\ .\ 1\ .\ 5 \end{array}$$

Then by multiplying final quotient and divisors together, thus, we get

$$5 \times 1 \times 4 \times 1 \times 4 \times 2 \times 3$$

Since, however, single units do not in any way effect results we write it

$$5 \times 4 \times 4 \times 2 \times 3 = 480 \text{ C. D.}$$

Rule: To reduce two or more fractions to equivalent fractions having a common denominator, divide the common denominator by the denominator of the given fraction, multiply the quotient so found by their numerators, and write the results over the common denominator.

Reduce to equivalent fractions having a common denominator.

$$\frac{5}{6},\ \frac{7}{8},\ \frac{15}{32},\ \frac{2}{3},\ \frac{4}{5}$$

Since we have just found the common denominator of these fractions to be 480 we place it thus

$$\frac{400\quad 420\quad 225\quad 320\quad 384}{480}$$

and proceed as in rule to divide the common denominator by the denominator of the first of our fractions, $\frac{5}{6}$, which equals $480 \div 6 = 80$. Proceeding again as by rule, we multiply this product by the numerator, 5, thus $80 \times 5 = 400$, which result we place in first position above the common denominator. Proceeding similarly with the other fractions in our example, we get a series of fractions having a common denominator and equivalent to the fractions from which we started computation.

ADDITION OF FRACTIONS.

Addition is the process of finding the sum of two or more fractions.

Principle involved : Fractions to be added must be reduced to equivalent fractions having a common denominator.

Rule : To find the sum of two or more fractions having different denominators, reduce the given fractions to equivalents with a common denominator. Add the numerators so found, and if their sum is greater than the common denominator divide the numerator by the common denominator and the result will be the sum of the given fractions.

Find the sum of $\frac{5}{16} + \frac{7}{8} + \frac{3}{4} + \frac{1}{2}$.

Proceeding as before we find the common denominator to be 16, thus

$$\begin{array}{r|l} 4 & 16 . 8 . 4 . 2 \\ \hline 2 & 4 . 2 . 1 . 2 \\ \hline & 2 . 1 . 1 . 1 \quad = 16 \end{array}$$

Proceeding exactly as before we find the equivalent fractions having a common denominator to be expressed thus :

$$\frac{5 + 14 + 12 \times 8}{16 \text{ C. D.}} = \frac{39}{16}$$

Adding these numerators together, as in rule, we get the fraction $\frac{39}{16}$. Now dividing the numerator 39 by the denominator 16 we get $39 \div 16 = 2\frac{7}{16}$, then our question may be expressed thus :

$$\frac{5}{16} + \frac{7}{8} + \frac{3}{4} + \frac{1}{2} = \frac{5 + 14 + 12 + 8}{16} = \frac{39}{16} = 2\frac{7}{16}$$

This principle underlies the whole subject of addition, and needs no further demonstration.

SUBTRACTION OF FRACTIONS.

Subtraction of fractions is the process of finding the difference between two fractions.

Principle involved : Fractions, to be subtracted, must be reduced to equivalents with a common denominator.

Rule : To find the difference between two simple fractions, reduce the fractions to equivalents having a common denominator and subtract the numerators, and reduce the result to its simplest form.

Find the difference between $\frac{7}{8}$ and $\frac{15}{16}$.

Proceeding as already described in addition of fractions, we get

$$\frac{15}{16} - \frac{7}{8} = \frac{15 - 14}{16} = \frac{1}{16}.$$

It will be observed that the process is exactly similar to the process of addition, and exceedingly simple, requiring practically no explanation w .en we have mastered the principles.

MULTIPLICATION OF FRACTIONS.

Multiplication is the process of finding the product of two factors, one or both of which may be fractions.

Rule: To multiply a fraction by a fraction, multiply the numerators together and also the denominators, and reduce to simplest form.

Multiply together $\frac{1}{2} \times \frac{1}{2}$. Proceeding as per rules and multiplying the numerators together and the denominators likewise, we get

$$\frac{1}{2} \times \frac{1}{2} = \frac{1 \times 1}{2 \times 2} = \frac{1}{4}.$$

Following out the principle set forth in clause 6 of our introduction, multiply together

$$\frac{4}{5} \times \frac{5}{6} \times \frac{7}{8} \times \frac{9}{16}.$$

Following out this principle we proceed by a process of cancellation to reduce to simplest form, thus

$$\frac{\not{4}}{\not{5}} \times \frac{\not{5}}{\underset{2}{\not{6}}} \times \frac{7}{\underset{2}{\not{8}}} \times \frac{\overset{3}{\not{9}}}{16} = \frac{21}{64}$$

By applying this system of cancellation, based upon the principle set forth in clause 6, you will observe we materially shorten the process of calcula:ion without in any way affecting the result.

Rule : To multiply a fraction by an integer or an integer by a fraction,

1. Divide the denominator of the fraction by the integer and place the result under the numerator, and reduce to simplest form, or

2. Divide the integer by the denominator of the fraction, and multiply the result by the numerator, or

3. Multiply the numerator of the fraction by the integer and place the result over the denominator. (See clauses 1 and 4 of principles).

Example (employing 1st method) :

Multiply $\frac{27}{32} \times 8 = 32 \div 8 = 4$ —— $\frac{27}{4} = 6\frac{3}{4}$.

Example (employing 2nd method) :

Multiply $\frac{27}{32} \times 64 = 64 \div 32 = 2 \times 27 = 54$.

Example (employing 3rd method) :

Multiply $\frac{5}{8} \times 8 = \frac{40}{8} = 5$.

It will be observed that the first of these methods can only be employed when the integer can be divided into the denominator an equal number of times, and the second when the denominator can be divided into the integer similarly, and the third method can be used at any time, but when either of the other methods can be used, lengthens the process, as is evidenced by calculation in this case. Employing method 1 and embracing principle 6, calculation would have been made as follows :

$$\frac{5}{\not{8}} \times \not{8} = 5.$$

DIVISION OF FRACTIONS.

Division of fractions is the process of finding the quotient when either dividend or divisor is a fraction or mixed number, or when both dividend and divisor are fractions or mixed numbers.

Rule : To divide a fraction by an integer, divide the numerator or multiply the denominator of the fraction by the integer. The result will be the quotient. (See principles, clauses 2 and 3).

Example : $\frac{27}{32} \div 9 = \frac{3}{32}$.

Rule: To divide an integer by a fraction, multiply the integer by the denominator of the fraction and divide the product by the numerator, or divide the integer by the numerator and multiply the quotient by the denominator.

Example (by 1st method):

$$\text{Divide } 100 \div \tfrac{3}{4} = 400 \div 4 = 133\tfrac{1}{3}.$$

Example (by 2nd method):

$$30 \div \tfrac{3}{4} = \tfrac{10}{4} = 10 \times 4 = 40.$$

Rule: To divide a fraction by a fraction, multiply the numerator of the dividend by the denominator of the divisor and set down the product as a new numerator, then multiply the denominator of the dividend by the numerator of the divisor and set down the product as the new denominator—reduce new fraction to simplest form, or

Invert the terms of the divisor and proceed as in multiplication of fractions.

Example: Divide $\frac{7}{8} \div \frac{3}{4}$ (following 1st rule). Since numerator of dividend is 7 and denominator of divisor 4, we get $7 \times 4 = 28$, which becomes new numerator or dividend.

Since denominator of dividend is 8 and numerator of divisor 3, we get $8 \times 3 = 24$, which becomes new denominator or divisor and giving $\frac{28}{24} = 1\frac{4}{24} = 1\frac{1}{6}$, that is, $\frac{3}{4}$ is contained in $\frac{7}{8}$ $1\frac{1}{6}$ times.

Employing 2nd method:

$$\tfrac{7}{8} \div \tfrac{3}{4} = \tfrac{7}{8} \div \tfrac{4}{3} = \frac{7 \times 4}{8 \times 3} = \tfrac{28}{24} = 1\tfrac{1}{6}.$$

Again employing 2nd method and applying clause 6 of principles:

$$\tfrac{7}{8} \div \tfrac{3}{4} = \frac{7 \times \overset{1}{\cancel{4}}}{\underset{2}{\cancel{8}} \times 3} = \frac{7}{6} = 1\tfrac{1}{6}.$$

It occasionally occurs in computation of formula that a fractional part of a fraction requires to be divided by a fraction or a fractional part of a fraction.

Rule: To divide a compound fraction by a compound fraction, first reduce the compound fraction to a simple fraction, and then follow rule laid down for dividing a fraction by a fraction.

Example: Divide $\frac{1}{2}$ of $\frac{7}{8}$ by $\frac{3}{4}$ of $\frac{15}{16}$.

To reduce compound fractions $\frac{1}{2}$ of $\frac{7}{8}$ × $\frac{3}{4}$ of $\frac{15}{16}$ to simple fractions, proceed as in multiplication of fractions.

Then $\frac{1}{2}$ of $\frac{7}{8} = \frac{1}{2} \times \frac{7}{8} = \frac{7}{16}$, and $\frac{3}{4}$ of $\frac{15}{16} = \frac{3}{4} \times \frac{15}{16} = \frac{45}{64}$; then question becomes a simple matter, since we proceed exactly as in division of fractions from this point.

Since dividend $\frac{1}{2}$ of $\frac{7}{8} = \frac{7}{16}$,

Since divisor $\frac{3}{4}$ of $\frac{15}{16} = \frac{45}{64}$,

$$\text{we get } \frac{7}{16} \div \frac{45}{64} = \frac{7}{\not{16}} \times \frac{\overset{4}{\not{64}}}{45} = \frac{28}{45}$$

DECIMAL FRACTIONS.

A DECIMAL fraction is one whose fractional units are tenths, hundredths, thousandths, etc.

[NOTE.—The denominator of a decimal fraction is not expressed as in common fractions; instead of expressing the fractions $\frac{1}{10}$, $\frac{1}{100}$, $\frac{1}{1000}$, they would be decimally expressed as .1, .01, .001.]

The decimal point is the character (.). It signifies the decimal when placed on the left of the fractional units expressed, and separates the integer from the decimal, as it is on the right of the former and on the left of the latter.

Decimal places consist of the number of figures on the right of the decimal point.

The value of each place is shown in table of decimal notation

DECIMAL NOTATION.

Hundred Millions	Ten "	Millions	Hundred thousand	Ten "	Thousands	Hundreds	Tens	Units	Decimal point	Tenths	Hundredths	Thousandths	Ten thousandths	Hundred thousandths	Millionths
4	0	1	2	3	5	4	0	9	.	4	7	8	3	4	2
9th	8th	7th	6th	5th	4th	3rd	2nd	1st		1st	2nd	3rd	4th	5th	6th
Integers										Decimals					

[NOTE.—It will be observed that the integers are numerated from right to left, and the decimals from left to right. Thus the figures on the left of the decimal point express the number of units or integers, and those on the right of the decimal point the number of tenths or decimal parts of a unit.]

A pure decimal is one in which no integer or common fraction is expressed.

Thus .5, .125, .0625.

A mixed decimal is one which contains an integer and a decimal.

Thus 4.5, 3.125, 84.0625.

The chief principles of decimal notation are:

1st. Annexing ciphers to a decimal does not effect its value. Thus, if a cipher be annexed to the decimal .1, it would then be .10, and changed from tenths to hundredths, but the fractional units are increased tenfold; hence no change in value takes place.

2nd. Prefixing a cipher to a decimal fraction and moving decimal point to the left decreases the value of the decimal tenfold, or is equivalent to dividing by 10.

3rd. Moving the decimal point to the right one point increases the value of the decimal tenfold, moving two points one hundred-fold, etc.

4th. Moving the decimal point to the left one point decreases the value of the decimal tenfold, moving two points hundred-fold, and so on.

5th. The numerator of any decimal is the number of fractional units it contains, and its denominator is 1 followed by as many ciphers as there are places after the decimal point.

[NOTE.—Thus, in the decimal .125 the numerator is 125, and since there are three places after the decimal point, the denominator is 1 followed by three cyphers, and fraction is read $\frac{125}{1000}$.]

It is important to the reader that the principle of decimal notaion be thoroughly understood, since our scientists almost without exception adopt the metric system and express their formula and observations by decimal notation, and since micrometer gauges, calipers and rules are now in universal use, it is just as important that the principles of conversion of common fractions to decimal fractions and vice versa be equally well understood.

ADDITION OF DECIMALS.

Addition of decimals is the process of finding the sum of two or more decimals, and becomes an easy process once principles of decimal fractions are well understood.

Rule: To find the sum of two or more decimals, so place the decimals that the figures of same order shall fall in same column. Then add as in simple addition, placing the decimal point in the result between the integer and decimal.

Find the sum of 1.0625, .45, 87.5, .0007.

Proceed thus,

```
 1.0625
  .45
87.5
  .0007
-------
89.0132 = Total.
```

SUBTRACTION OF DECIMALS.

Subtraction of decimals is the process of finding the difference between two decimals.

Rule: To find the difference between two decimals, place the less decimal or subtrahend under the greater decimal or minuend, so that the figures of any order or denomination in the subtrahend shall fall under those of the same order or denomination in the minuend. Subtract as in simple numbers, placing the decimal point in the result between the integer and decimal.

Example: Find the difference between .6504 and 75.9735.

Process as by rule:

```
75.9735 (minuend)
  .6504 (subtrahend)
-------
75.3231 (difference)
```

Example: Find the difference between .00785 and .625.

Process:

```
.625
.00785
------
.61715
```

MULTIPLICATION OF DECIMALS.

Multiplication of decimals is the process of finding the product when either the multiplier or multiplicand, or both, are decimals.

Rule: To multiply an integer by a decimal, or vice versa.

Set the factor containing the least number of figures as a multiplier and other factor as the multiplicand, proceed as in simple numbers. Point off as many decimal places in the product as are contained in BOTH FACTORS. If the product does not contain so many places, PREFIX ciphers to supply the deficiency.

Example: Multiply 147. by.75, proceed as per rule.

```
  147.
   .75
 -----
  7 35
102 9
 -----
110.25
```

Since both factors contain but two places to the right of the decimal point, we require to point off this number in product.

Example (2): Multiply .75 by .625.

```
.625
 .75
-----
 3125
4375
-----
.46875
```

Since both factors contain five decimal places we point off this number in product.

Example (3): Multiply .0625 by .075.

```
  .0625
   .075
 -------
   3125
  4375
 -------
.0046875
```

Since both factors contain seven decimal places and product but five, we require to prefix two ciphers, and set decimal point to the left.

DIVISION OF DECIMALS.

Division of decimals is the process of finding the quotient when either the dividend or divisor or both are decimals.

Rule: To find the DECIMAL QUOTIENT when the divisor and dividend are both whole numbers, and the divisor is greater than the dividend, or when the divisor is not contained in the dividend an exact number of times.

Add as many ciphers to the dividend as there are decimal places required in the quotient, divide as in simple numbers, and point off from the RIGHT of the quotient as many decimal places as there have been ciphers added to the dividend, and USED, prefixing ciphers to the quotient if necessary.

Example: Divide 75 by 1506 to 4th decimal place.

Process as per rule:

```
1506)750000(.0498
     6024
     -----
     14760
     13554
     -----
      12060
      12048
      -----
         12
```

Since we wish to extend to fourth decimal place only, we annex to dividend four ciphers and proceed as in division of simple numbers, and get 498. Since, however, we annexed four cyphers to the dividend, and therefore require four decimal places in the quotient, we must prefix one cypher, and quotient will then read .0498, proving that the factor 1506 is contained in the factor 75 .0498 times, or that 75 is 0498% of 1506.

Example (2): Divide 743 by 125.

```
125.)743.000(5.944
     625
     ----
     1180
     1125
     ----
      550
      500
      ---
       500
       500
       ---
```

Here we have an example where two whole numbers are to be divided an exact number of times. Since we find the divisor is contained in the dividend 5 and a fractional times, we add to the dividend a cypher and bring this down and annex to the right of the remainder, as in division of simple numbers, repeating this process until there is no remainder. We then proceed to ascertain the number of ciphers annexed to the dividend, and point off a corresponding number of places in the quotient, counting from the right. In example the 125 is contained in 743 exactly 5.944 times.

Example (3): Divide .9735 by 50.

```
50).97350(.01947
    50
    ---
    473
    450
    ---
     235
     200
     ---
      350
      350
      ---
```

Here we divide a decimal by a whole number, proceeding exactly as before, and since the decimal contains four places to the right of the decimal point, and we require to add a cipher so as to have no remainder, we necessarily require quotient to contain five decimal places, and have to prefix a cipher to the quotient to bring about this result.

To divide when both divisor and dividend are decimals, and the divisor contains more decimal places than the dividend—

Rule: Add ciphers to the dividend until it shall have as many places as the divisor; then proceed as in simple numbers.

Example : Divide .125 by .0515.

```
.0515).12500000(2.4270
    1030
    ----
     2200
     2060
     ----
      1400
      1030
      ----
       3700
       3605
       ----
         950
```

This is an example of the application of principle 1. While we annex to the dividend a cipher we in no way change its value, and since we find .0515 to be contained in .125 two and a fractional times, we proceed by process already illustrated to extend to the fourth decimal place.

To divide when both divisor and dividend are decimals, and the dividend contains more decimal places than the divisor—

Rule : Divide as in simple numbers, and point off from the right of the quotient as many decimal places as the decimal places in the dividend are greater in number than those in the divisor.

Example : Divide .5000 by .125

```
.125).5000(4.0
      500
      ---
      000
```

The application of both these rules is demonstrated in previous example. Since, however, we want to make the principle clear, we repeated in another form. The writer wishes especially to impress on the student the great importance of thoroughly mastering the principles of calculation contained in these exercises in common and decimal fractions. A thorough knowledge of the principles involved is of immense benefit in computing much of the formula we shall at a later date meet with ; in fact, unless our knowledge of these principles is thorough we cannot hope to properly appreciate all the good things that the scientist has prepared for us.

There remains for illustration yet what concerns many of us, i.e., the principles involved during the conversion of common to decimal fractions and vice versa, which I will briefly illustrate before closing this number.

Since the denominator of a simple fraction is always larger thau the numerator, to reduce or convert a common fraction to its equivalent decimal fraction we have to follow one of the rules already laid down for the division of decimals, dividing the numerator by the denominator and adding ciphers as required.

Example: Reduce $\frac{15}{16}$ to a decimal fraction.

```
16)150000(.9375
   144
    60
    48
    120
    112
      80
      80
```

Since we had to add to dividend four ciphers, we place the decimal four places to the left, counting from the right, hence

$\frac{15}{16}$ reduced to decimals = .9375.

Example: Reduce .9375 to common fractions.

Since the numerator is 9375 and the denominator 1, with as many ciphers added as there is decimal places in the numerator, then fraction will be set thus $\frac{9375}{10000}$, which we reduce to simplest form:

$$\frac{\overset{5}{\cancel{9375}}}{\cancel{10000}} = \frac{\overset{5}{\cancel{1875}}}{\cancel{2000}} = \frac{\overset{5}{\cancel{375}}}{\cancel{400}} = \frac{\overset{5}{\cancel{75}}}{\cancel{80}} = \frac{15}{16}$$

PRACTICAL MEASUREMENTS.

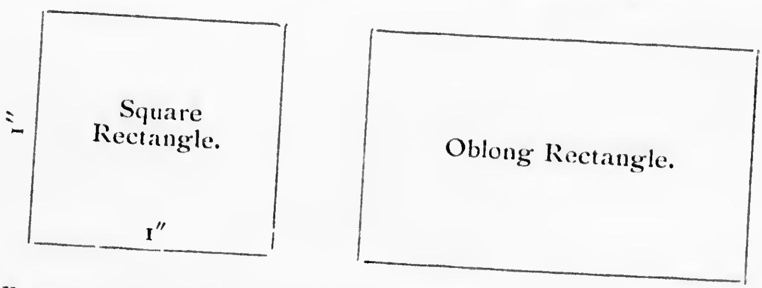
THE practical measurements herein referred to and treated as being of especial benefit to engineers, are distinguished as measures, of surface, of volume and of capacity.

MEASURES OF SURFACE OR SQUARE MEASURE.

SURFACE is that which bears reference to length and breadth only, depth or thickness not being considered.

The AREA of a surface is the number of square feet, inches or yards, etc., that such a surface contains.

A RECTANGLE is a surface which has four right angles.



Rule : To find the area of a rectangle or square, multiply the given breadth by the given length, and the product will be the area.

Rule : To find the required length of either side of a rectangle or square, divide the given area by the given length of known side.

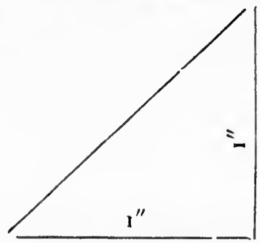
Example : Find the length of a surface whose area is 95 sq. in. and breadth 5 in.

$$95 \div 5 = 19 \text{ in.} = \text{length required.}$$

IRREGULAR OR TRIANGULAR MEASUREMENTS.

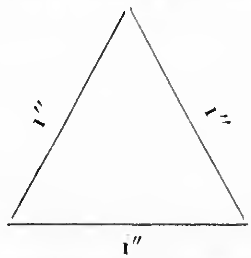
A triangle is a surface having three sides and three angles.

An Isoceles triangle is a triangle having two equal sides.



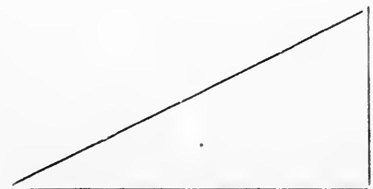
ISOCELES TRIANGLE.

An Equilateral triangle is a triangle having three equal sides.



EQUILATERAL TRIANGLE.

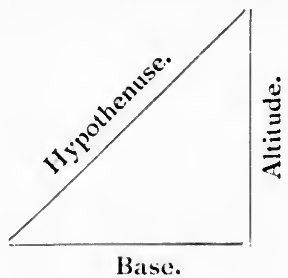
A Scalene triangle is a triangle which has no two sides equal to each other.



SCALENE TRIANGLE.

The base of a triangle is the line which intersects the other two lines at the point greatest distant from the vertex.

The lines representing the base and altitude are perpendicular to each other, and if a triangle be placed vertically, the base will be the side on which it appears to stand.



Rule : To find the area of a triangle, multiply the base by one-half the altitude, and the product will be the area.

Rule to find either the altitude or base of a triangle, area, and one side being known : Divide the area by one-half the given dimension, and quotient will be required dimension of other side.

Example : Find the required length of the base of a Scalene triangle whose altitude is 6 inches and area equals 36 inches.

$36 \div$ by one-half altitude $= 36 \div 3 = 12''$, required length of base.

CIRCULAR MEASUREMENT.

A circle, as geometrically defined, is a plain figure bounded by a curved line, all parts of which are equally distant from the centre.

The circumference of a circle is the curve which bounds it.

The diameter of a circle is a straight line that passes through its centre.

The radius of a circle is a straight line that joins the centre to a point in the circumference.

[Note : Referring to this, it follows that the radius is one-half of the diameter.]

Rule : To find the circumference ofa circle, the diameter being given, multiply the given diameter by 3.1416, and the product will be the circumference.

Rule : To find the diameter of a circle, the circumference being given, multiply the given circumference by the decimal .3183, and the product will be the diameter.

Rules : To find the area of a circle, the circumference, radius or diameter being known,

Multiply the circumference by one-fourth the diameter, and the product will be the area ;

Or, multiply the square of the radius by 3.1416, and the product will be the area ;

Or, multiply the square of the diameter by .7854, and the product will be the area.

Example : Find the area of a circular bolt 3.1416 inches in circumference.

Circumference × .3183 equals dia.
3.1416 × .3183 = 1″ diameter,
1 ÷ 4 = .25 = one-fourth dia.
3.1416 × .25 = .7854 sq. in. area.

Example : Find the area of a circle whose radius is one-half inch.

Radius squared × by 3.1416=
.5 × .5 = .25 × 3.1416 = .7854 sq. in. area.

Example : Find the area of a circle whose diameter is 1 inch.

Diameter squared × .7854=
1 × 1 = 1 × .7854 = .7854 sq. in. area.

A review of these examples will prove clearly to the student why constant .7854 is used in formula when it is necessary to find area of any circle, and needs no further comment.

MEASURES OF VOLUME OF SOLID BODIES OR CUBICAL MEASUREMENTS.

Cubical measurement includes length, breadth and thickness being taken into consideration.

The process of finding the cubical contents of a solid body is similar to finding the area ; in fact, area multiplied by thickness will give cubical contents.

MEASURES OF CAPACITY AND CUBICAL CONTENTS OF SQUARE AND CYLINDRICAL BODIES.

Measures of capacity embrace measurements of barrels, tanks, bins, boxes, cylinders, etc., etc.

The liquid gallon of the United States contains 231 cubic inches.

The Imperial or British gallon contains 277.274 cubic inches.

A cubic foot of water contains approximately 6.25 Imperial gallons and weighs 62.5 pounds avoirdupois at 62° F. under atmospherical pressure.

Rule : To find capacity of a square tank, dimensions of which are known, multiply length by breadth and product by depth, and result will be cubical contents.

Example : Find the number of Imperial gallons of water a rectangular tank will contain, inside measurement of tank being : length 20 feet, width 15 feet, depth 3 feet 6 inches.

$$\text{Formula : } \frac{\text{Length} \times \text{width} \times \text{depth} \times 1728}{277.27} = \text{Imperial gallons.}$$

```
       20' = length.
       15' = width.
      ----
      100
      20
     ----
      300
       3.5 = depth.
     ------
     1500
     900
     ------
   1050.0 = cubical contents in cu. feet.
   1728   = cubic inches in one cu. foot.
  -------
     8400
    2100
   7350
  1050
 ---------
1.814,400 = cubic inches =
1.814.400 ÷ 277.27 = 6543.8 Imp. gallons,
```

or, when absolute correctness is not required, short method formula as follows may be adopted.

Length in feet × width in feet × depth in feet × 6.25 = Imp. gallons.

$$20' \times 15' \times 3'\,6'' = 1050 \times 6.25 = 6562.5 \text{ Imp. gals.}$$

Example (2): How many gallons (U. S.) of oil will cylindrical oil tank hold whose internal dimensions are: Depth 4 feet 6 inches, diameter 3 feet.

Formula:

$$\frac{\text{Diameter squared} \times .7854 \times \text{depth} \times 1728}{231} = \text{U. S. gallons.}$$

3′ × 3′ = 9′ × .7854 = 7.0686 = area in sq. feet—7.0686
4.5 depth.
31.80 cap. in cu. ft.
1728
54950.4 cap. in. cu. in.

54950.4 ÷ 231 = 237.9 gallons oil.

Example (3): It is required to fit a tank into a recess 6 ft. wide and 14 ft. 6 in. long. Tank to be made of 3 in. plank and contain 5000 Imperial gallons of water. What height should tank be so as to allow sides to project 6 in. above the water line?

First find exact internal measurement of tank, then exact quantity of water contained in each inch of depth; divide required quantity of water by this product, and add 6. Result will be required height.

Dimensions of recess are given as 6′ × 14′ 6″. Since, however, tank is to be constructed of 3 in. plank, twice this thickness must be deducted to get internal measurement of tank,

∴ 6′ − 6″ = 5′ 6″ internal width of tank.
14′ 6″ − 6″ = 14′ internal length of tank.
14′ × 5′ 6″ = 11.088 sq. inches.
11.088 ÷ 277.27 = 39.99 Imp. gals. per inch.
5000 ÷ 39.99 = 125 inches to water line.
(125 + 6) ÷ 12 = 10′ 11″ height of tank.

Example (4): A tank 1 ft. 9 in. deep, 2 ft. long and 4 ft. wide, is found to contain 70 Imperial gallons of oil. How far from the top is the oil, and what is capacity of tank when full?

Since one gallon of oil is equal to .16 cu. ft., we can here materially shorten our calculation by working decimally.

First find how many cubic feet 70 gallons are equal to by multiplying by .16.

$$70 \times .16 = 11.2 \text{ cu. feet,}$$

and as the tank is 2 feet by 4 feet, its base will equal 8 sq. ft.

Then divide 11.2 cu. feet by 8 sq. feet to get height of oil.

$$11.2 \div 8 = 1.4 \text{ feet height of oil.}$$

The tank is given as being 1.75 feet high,
and the oil is 1.40 " "
then oil is 0.35 feet from the top.

0.35 feet × 12 = 4.2 inches distance from top of tank to oil.

To find capacity of tank when full, we first find cubical contents of tank in feet and then divide by .16.

$$1.75 \times 2 \times 4 = 14 \text{ ft., cubical contents of tank.}$$

$$14 \text{ feet} \div .16 = 87.5 \text{ gallons of oil in tank when full.}$$

Example (5): If one cubic foot of coal weighs 84 pounds, what weight of coal will a car contain 30 feet long, 6 feet wide and 5 feet deep?

First find cubical contents of car in feet, then multiply by weight per cu. ft. Result will be total weight of coal.

$$\therefore\ 30 \text{ ft.} \times 6 \text{ ft.} \times 5 \text{ ft.} = 900 \text{ cu. feet.}$$

$$900 \times 84 = 75600 \text{ pounds of coal.}$$

Example (6): How many cubic feet of steam will a cylinder contain, 18 in. × 36 in., with 5 per cent. clearance, and how many cubic feet will be used per hour if engine runs 75 revolutions per miuute.

First find cubical contents of cylinder, including clearance, then multiply by strokes per minute, and this product by 60. Result will be number of cubic feet of steam consumed per hour.

18 in. × 18 in. × .7854 = 254.47 sq. in., area of cylinder.

254.47 × 36 in. = 9160.92 = cubical contents of cylinder without clearance.

9160.92 ÷ 95 × 100 = 9653.6 cu. in. = contents of cylinder, clearance included.

9653.6 ÷ 1728 = 5.58 cu. feet.

5.58 × 75 × 2 = 837 cu. ft. steam per minute.

837 × 60 = 50.220 cu. ft. of steam used per hour.

PRACTICAL RULES WORTH REMEMBERING.

The diameter of a circle × by 3.1416 = the circumference.
The circumference of a circle ÷ by 3.1416 = diameter.
The radius af a circle × by 6.283185 = circumference.
The circumference of a circle ÷ 6.283185 = radius.
The square of the radius of a circle × 3.1416 = the area.
The square of the diameter of a circle × 0.7854 = the area.
The square of the circumference of a circle × 0.07958 = the area.
The circumference of a circle × 0.159155 = the radius.
The square root of the area of a circle x 1.12838 = the diameter.
A semi-circle is ½ of a circle, or 180 degrees.
A quadrant is ¼ of a circle, or 90 degrees.
A sextant is ⅙ of a circle, or 60 degrees.

EVOLUTION.

Evolution is the process of finding the root of any number, and is of frequent occurrence in engineers' calculations.

The most important and only cases which I shall refer to is the process of finding the square or cube root of any number.

Example (1): Find the square root of 1521. In formula this is written $\sqrt{1521}$.

```
       15.21(39
        9
     ---------
69. |  621
    |  621
       ---
       ...
```

Beginning at the right hand figure 1, count two figures to the left and mark the second as shown in the example, take the figures to the left of this mark 15 and find what number multiplied by itself will give fifteen; there is no number that will do this, since $3 \times 3 = 9$ is too small and $4 \times 4 = 16$ is too large; we therefore take the one that is too small, viz., 3, and place it in the quotient, placing its square 9 under the 15 marked off in the number and subtract, and bring down the next two figures 21, making new dividend 621. To get the new divisor multiply the quotient 3 by $2 = 6$, and place as a trial divisor at the left of the dividend 621; find how many times this is contained in the dividend, discarding the last figure on the right; 6 is then contained in 62 nine times. Since we cannot pass this point, we place 9 in the quotient and also in the divisor; then we multiply the whole divisor 69 by this number (9) and place the product under the dividend and subtract. Having no remainder, root is now complete and found to be 39.

If we require proof of this we simply square the number, thus :

$$39 \times 39 = 1521$$
$$\text{then } 39^2 = 1521$$
$$\text{and } \sqrt{1521} = 39$$

Example (2) : Find the square root of 366.

```
        3.66(19.131126
           1
      --------
      29 | 266
         | 261
      --------
      381 | 5.00
          | 3 81
      ---------
     3823 | 1 1900
          | 1 1469
      -----------
      38261 | 43100
            | 38261
      -----------
      382621 | 483900
             | 382621
      ---------------
     3826222 | 10127900
             |  7652444
      -----------------
     38262246 | 247445600
              | 229573476
              -----------
                17872124
```

In this example we proceed to mark off as before and get as our quotient the whole number 19, but since there is still a remainder our root cannot be complete; we proceed as before, but since there remains no more figures in the dividend we annex to new dividend two ciphers and place a decimal point in the quotient to the right of the nineteen. Then proceeding as before we get our trial divisor by doubling present quotient $19 \times 2 = 38$ and place to the left of the dividend 500. 38 is contained in 50 once we therefore place a 1 in the quotient to the right of the decimal point and annex to the new divisor, multiplying as before and subtracting, we proceed in an exactly similar manner until we have no remainder or until decimal begins to repeat itself or is extended sufficiently to answer our purpose.

Example (3): Find the square root of 15227.56.

	1.52.27.56(123.4
	1
22	.52
	44
243	827
	729
2464	9856
	9856
	....

In a decimal quantity like the foregoing, the marking off differs from the previous examples. Instead of counting twos from right to left begin at the decimal point and count twos towards the left and towards the right. Note: when the first two figures to the right of the decimal is brought down we must place a decimal point in our quotient before extending it.

Briefly, the process of finding the square root of a whole number may for the guidance of the student be described as follows:

First mark off in twos commencing from the right. Then find the number whose square is next less than the figure or figures on the left of the number as the case may be, place this figure in the quotient and its square under the figure or figures already marked off on the left of the number, subtract and annex to the right the next two figures of the number; this then becomes a new dividend. To secure a new divisor, double the quotient by multiplying by 2 and place on the left of the dividend as a trial divisor; find how many times this is contained in the dividend, discarding the right hand figure, place this result in the quotient and also in the new divisor and multiply by same number, placing product under dividend and subtract as before; continue the operation for a new divisor. Bear in mind, however, you must always place two figures to the right of the new dividend.

It will occasionally occur as in our first two examples that the product of the trial divisor multiplied by the new divisor will exceed the dividend. In this case take the next lowest term and proceed as described.

TO FIND THE CUBE ROOT.

Example (1): Find the cube root of 1331.

```
                 1.331(11 Ans.
                 1
31        300 | 331
           31 |
          331 | 331
                ...
```

First mark off three figures from the right towards the left of the number, and we have 1 left. Now, 1 cubed equals one. Place the cube of 1 under the one of the number and subtract. There is no remainder. Bring down the next three figures as a new dividend. Next multiply the one placed in the quotient by 3, and place the product well to the left, as in the example. Next multiply this 3 by the quotient figure 1, and place the result, 3, to the right of where the 3 was placed and to the left of the dividend, and add two ciphers to it, as shown in the example.

This 300 is called the trial divisor. Now see how often it will go into the dividend 331, which we find to be once. Put 1 in the quotient to the right of the one already there, and place 1 also to the right of the number 3 at the extreme left of the example. Now, multiply this number 31 by the figure last placed in the quotient, and place the result under the trial divisor 300 and add. This now gives us the correct divisor, which we multiply by the last figure placed in the quotient and place result under and subtract from the dividend. There being no remainder, our root is now complete, and we find $\sqrt[3]{1331} = 11$.

Example (2): Find the cube root of 80677568161.

Process:

		80,677,568,161(4321 Ans.
		64
123	4800	16677
	369	
	5169	15507
1292	554700	1170568
	2584	
	557284	1114568
12961	55987200	56000161
	12961	
	56000161	56000161

The process to the second figure of the answer is a reproduction of last example.

TO FIND THE THIRD FIGURE OF THE ANSWER.

Multiply the 43 in the quotient by 3, equals $43 \times 3 = 129$; put this well out to the left as before. In the middle column of figures you will see the figures 369 and 5169; add these together, and to their sum add the square of the last figure in the quotient—that is in the present case 3. Then

$$\begin{array}{rr} & 369 \\ & 5169 \\ 3 \times 3 = & 9 \\ \hline & 5547 \end{array}$$

This number, with two ciphers added, is our new trial divisor 554700. It goes into the dividend 1170568 twice. Place 2 as the third figure of the quotient, and place 2 to the right of the number 129 on the left. Multiply 1292 by this number 2 and place the result, 2584, under the trial divisor and add. Result, 557284 is now the correct divisor. Multiply this number by 2 and place underneath dividend and subtract. Bring down the next three figures. We now have 56000161 as a new dividend.

TO FIND THE FOURTH FIGURE OF THE ANSWER.

Multiply the quotient 432 by $3 - 432 \times 3 = 1296$, and place this number to the left. Again in the middle column we have the figures 2584 and 557284; add together and add the square of the last figure in the quotient.

$$\begin{array}{rr} & 2584 \\ & 557284 \\ 2+2= & 4 \\ \hline & 559872 \end{array}$$

This number, with two ciphers annexed, 55987200, is our new trial divisor, and is contained in the dividend once. Add one to the quotient, also to the number on the left. Multiply and subtract as before. And since we have no remainder our root is now complete, and $\sqrt[3]{80677568161} = 4321$.

There is another method of extracting the cube root which to the student may be simpler and process clearer, since it has the advantage over method just described that when the student has mastered the process of working out the first figure of the quotient he has the rest at his command, as the process is but a repetition, and is the same for four figures as for two.

Find the cube of 1728.

$$\begin{array}{lr|l} & 1 & 1.728(12 \\ & & 1 \\ \cline{3-3} & & 728 \\ 3 \times 10^2 & = 300 & \\ 3 \times 10 \quad \times 2 = & 60 & \\ 2^2 & = 4 & \\ \cline{2-2} & 364 & 728 \\ \cline{3-3} \end{array}$$

First we mark off the number into quantities of three figures as in previous examples, and selecting the next lowest cube for the first figure of our quotient in the case 1, which is put down in the quotient and as a divisor. The cube of 1 is placed under the dividend and subtracted and next period 728 brought down as a new dividend. Now take the number in the quotient and add a cipher to it, making it 10, square this and multiply by constant 3; we then get $3 \times (10^2) = 300$ which is our trial divisor; for the next line multiply 10 by the constant 3 and multiply the product 30 by the figure placed in the quotient from the trial divisor $30 \times 2 = 60$; place this 60 below the 300 already obtained and add, to the sum of these numbers add the square of the last figure of the quotient, thus, $300 + 60 + 2^2 = 364$. This is now our correct divisor. Multiply by the last figure of the quotient, place underneath the dividend and subtract; being no remainder our root is complete.

APPLICATION OF FORMER STUDIES TO MECHANICAL AND ELECTRICAL ENGINEERING.

Since both numerical and algabraical formula will now be constantly used, it is absolutely necessary that students should endeavor to obtain facility in reading and solving formula generally.

The following signs must therefore receive particular attention, and be committed to memory.

$+$ is read plus, and means that the number following it is to be added to the number before it; thus, $4 + 3$ is 7.

$-$ is read minus, and means that the number after it is to be subtracted from the number before it; thus, $5 - 2$ is 3.

$\times$ is read multiplied by, and means that the number before it is be multiplied by the number following it; thus, 3×3 are 9.

$\div$ is read divided by, and means that the number before it is to be divided by the number following it; thus, $6 \div 3 = 2$.

$=$ is read equal to, and means that the quantity after it is of same value as quantity before it; thus, $7 \times 3 = 21$.

9^2 is read as 9 squared, and means that the number is to be multiplied by itself; thus, $9^2 = 9 \times 9 = 81$.

9^3 means same number cubed; thus, $9 \times 9 \times 9 = 729$.

$\sim$ is read the difference between any two numbers, and means the less number is to be subtracted from the greater.

( ) are called brackets, and mean that all the quantities within them are to be put together first; thus, $5(4-2+3\times 9)$ means that 2 must be subtracted from $4=2$, and $3\times 9=27+2=29$, and then this 29 is to be multiplied by $5=29\times 5=145$.

NOTE—When no sign is placed between a quantity and a bracket or a letter, it means that the quantity within the bracket is to be multiplied by the quantity outside. Thus in the foregoing the quantity within the bracket $=29$ is to be multiplied by 5, the quantity outside.

SIGNS THAT REPRESENT ROOTS OF NUMBERS.

The sign known as the radical sign is common to all numbers, and is expressed thus, $\surd$ or $\sqrt{}$. When it is required to express the square root of a number we simply put this sign before it, as $\surd 25$, but if the number for which we desire the square root of is made up of two or more terms then we express the square root by the same sign in front, but with a line as far as the square root extends, as $\sqrt{15+10}=5$, or $\sqrt{5(2+3)}=5$.

The cube root is expressed in a similar manner, but with a small 3 in the elbow of the sign, as $\sqrt[3]{}$; all other roots in exactly same manner; as $\sqrt[5]{}$ $\sqrt[6]{}$ and so on.

In mechanical text books the power and root are often combined and expressed thus $4^{\frac{3}{2}}$. This is read as the square root of 4 cubed. Therefore, the numerator represents the power and the denominator the root. In this case the square root of $4=2$, and 2 cubed equals 8.

The commonest form in which this is met with in engineering calculations is when the cube root of a number is squared, as $27^{\frac{2}{3}}$ which is read cube root of 27 squared. The cube root of 27 is 3 and 3 squared equals 9, which is the value of $27^{\frac{2}{3}}$.

One of the most frequently occurring errors in algabraic calculations is the misunderstanding of the proper use of the multiplication sign in algabraic quantities and formula, and requires special mention here. For instance, we have the quantity $25 - 10 \times 2$. It is a common error to say $25 - 10 = 15$; this multiplied by 2 equals 30. This is entirely wrong, as a moment's reflection will prove to the student, as it clearly reads 25 minus 10×2, and the first step should be to multiply $10 \times 2 = 20$; then, $25 - 20 = 5$, which is correct, and not 30, as at first appears.

The student requires to remember the following rule, which applies in all cases:

Multiplication and division signs CONNECT the numbers together between which they occur; plus and minus signs SEPARATE them.

For simplicity and accuracy, it is a good rule when working with complex formula, to first get rid of bracket signs, and then multiplication signs; the operation of computation of formula then becomes an easy task.

SAFETY VALVE CALCULATIONS.

ALL boilers should be fitted with two safety valves, one of which should be a lock-up valve, and set by the Boiler Inspector under whose immediate control it is.

The Canada Steamboat Act provides that every safety valve must have a lift equal to at least one-fourth of its diameter ; the openings for the passage of steam to and from the valve must each have an area not less than the area of the valve, as must also all waste steam pipes, etc., and the area of a safety valve must equal one-half inch for each square foot of grate surface in or under the boiler.

LEVER TYPE.

Find the diameter of a safety valve required for a boiler whose grate bars are 5 feet long and furnace 3 feet wide.

We first find number of square feet of grate surface ; then divide by 2, which gives area of valve in inches ; square root of area divided by .7854 equals diameter,

$$\text{then } \frac{L \times W}{2} = A$$

$$\text{and } \sqrt[2]{A \div .7854} = D.$$

Where L equals length of grate bars,
W equals width of furnace,
A equals area of valve in inches,
D equals required diameter of valve.

$$\frac{5 \times 3}{2} = 7.5 \text{ sq. inches.}$$

$$7.5 \div .7854 = 9.549.$$

Square root of 9.549 equals 3.09 inches ; then required diameter of valve is 3.09 inches, say 3⅛ inches.

Example (2): What weight is required to be placed 2 inches from the end of a safety valve lever to equal a boiler pressure of .50 pounds to the square inch, the diameter of valve being $3\frac{1}{8}$ inches, the distance from fulcrum to valve 6 inches, and total length of lever from fulcrum 16 inches? The weight of valve and stem is 15 pounds, and effective moment of 'ever 80 inch pounds.

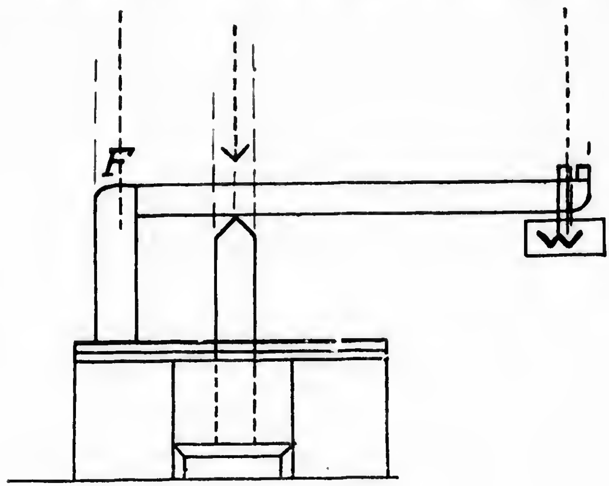


Fig. I

Since the steam pressure within the boiler and consequently pressing against the lower face of the valve and trying to unseat it, equals so many pounds per square inch, we must first find the area of the valve in square inches, to ascertain the whole force tending to raise the valve, but since the weight of the valve, spindle and lever acts downwards and against the upward pressure of the steam, we must make allowance for this, and the remaining force is that which we have to counteract by weight.

In diagram No. 1 F is the fulcrum, V is the point where pressure is exerted, W is the weight, FV is 6 inches, VW is 10 inches, and FW is 16 inches.

The principle of the lever is: The weight or force multiplied by its distance from the fulcrum is equal to the weight or pressure on the valve multiplied by its distance from the fulcrum,

$$\text{or, } W \times FW = V \times FV.$$

But the steam pressure has, in addition to the actual weight of W, also to overcome the moment of the lever, which is found by weighing the lever and finding how far its bal incing point is from F; then this distance multiplied by its weight is the effective moment of the lever, which we will call A.

$$\text{Then } W \times FW + A = V \times FV;$$

that is, the total force at work keeping the valve down is equal to the force or pressure endeavoring to lift it off its seat.

In accordance, then, with these principles, we get the following rules:

(1) Find the area of the valve and multiply it by the pressure per square inch.

(2) From the product take the weight of the alve and stem; the remainder is the V of the formula.

(3) Multiply "the remainder by the distance trom the fulcrum to the valve," FV, then subtract the moment of the lever, and divide by "the distance from the fulcrum to the weight," FW, found by adding "the distance from the fulcrum to the valve" to that "from the valve to the weight."

$3.125 \times 3.125 \times .7854 = 7.67$, area of valve.

$7.67 \times 50 = 383.50$, pressure against valve.

$383.5 - 15 = 368.5$, effective upward weight.

368.5×6 FV $= 2211.0$, effective moment lifting lever.

$2211 - 80$ (effective moment of lever acting downwards) $= 2211 - 80 = 2131$.

$2131 \div 16 = 133.2$, required weight of W.

NOTE: For extreme accuracy it is necessary to take note of the weight of the valve and its parts, and also of the moment of the lever, but in a great many cases this is entirely omitted. Then a question of this kind becomes simplified thus:

$$W = \frac{\text{area} \times \text{pressure} \times FV}{FW}$$

TO GRADUATE A SAFETY VALVE LEVER.

We have a safety valve 4 inches in diameter, and spindle presses against a point in the lever that is 4 inches from the fulcrum; how far must a weight of 120 pounds be placed from the fulcrum to equal a boiler pressure of 60 pounds to the square inch, when the valve weighs 8 pounds and effective moment of the lever is 50 inch pounds. Also give the graduation marks on the lever for 40 and 50 pounds pressure with the same weight.

$$\text{Formula } V = \text{area} \times \text{pressure} - 8.$$

$$FW = \frac{V \times FV - 50}{W}$$

In this question we require to find distance, FW. We first find area of valve; multiply this by pressure per square inch, and then subtract weight of valve and parts bearing downward to get total effective upward pressure; this equals V of formula. Now multiply total upward pressure by distance fulcrum to valve and subtract effective moment of lever; result, divided by weight, equals distance fulcrum to weight.

$4 \times 4 = 16 \times .7854 = 12.5664$, area valve.

$12.5664 \times 60 = 753.98$, total pressure.

$753.98 - 8 = 745.98$, V, total effective pressure.

$745.98 \times 4 = 2983.92$, total moment of valve.

$2983.92 - 50 = 2933.92$, total effective moment of valve.

$2933.92 \div 120 = 24.45$ inches distance FW.

Since the distance $FW = 24.45$ inches for a pressure of 60 pounds to the square inch, we can find what distance represents a pressure of 10 pounds by dividing this distance by 6, the number of times 10 is contained in 60.

$$24.45 \div 6 = 4.07.$$

Then for each additional 10 pounds pressure we require to move the weight a distance of 4.07 inches further from the fulcrum, and to find the distance from the fulcrum equal to a pressure of 40 pounds, this distance multiplied by $4 = FW$; therefore,

$$FW \text{ at 50 pounds pressure} = 4.07 \times 5 = 20.35 \text{ ins.}$$
$$FW \text{ at 40 pounds pressure} = 4.07 \times 4 = 16.28 \text{ ins.}$$

Required to find distance from fulcrum to valve, boiler pressure being 50 pounds to square inch; diameter of valve, 4 inches; weight of valve and spindle, 10 pounds; distance valve to weight, 12 inches, and weight 150 pounds; moment of valve lever, 40 inch pounds.

Formula:

$$FV = \frac{VW \text{ x } W + \text{moment}}{V}$$

$4^2 \text{ x } .7854 = 12.5664$ square inches.

$12.5664 \text{ x } 50 = 628.32$, total pressure.

$628.32 - 10 = 618.32$, total effective upward pressure, or V.

$12 \text{ x } 150 = 1800$ pounds.

$1800 + 40 = 1840$, total weight acting downwards at V.

$1840 \div 618.32 = 2.975$ inches distance FV; or distance FV is nearly 3 inches.

SUMMARY.

To find effective moment of lever, multiply weight of lever by distance from its balancing point or centre of gravity to fulcrum, and divide by distance from centre of valve stem to fulcrum. Result will be effective moment of lever in inch pounds, or the weight required to raise valve off its seat with nothing but lever holding against steam.

To find actual effective weight of ball, divide weight of ball by distance from fulcrum to valve stem, and multiply quotient by distance from ball to fulcrum.

To find length of lever, add together effective moment of lever and weight of valve and stem, and subtract from total pressure acting upwards against valve. Divide remainder by weight of ball, and multiply quotient by distance from stem to fulcrum.

TO FIND weight of ball, add together the effective moment of lever and weight of valve and stem, and subtract this sum from total pressure against valve at blowing-off point. Multiply remainder by distance from fulcrum to stem, and divide quotient by length of lever from fulcrum to weight.

TO FIND diameter of valve to blow off at given pressure, add together effective moment of lever, weight of valve and stem, and effective weight of ball. Divide this sum by gauge pressure, and result will be required area of valve.

Square root of area divided by .7854 equals diameter.

TO FIND pressure at which a boiler will blow off, add together effective moment of lever, weight of valve and stem, and effective weight of ball. Divide this sum by area of valve in square inches. Result will be gauge pressure at which safety valve will act.

FUNDAMENTAL PRINCIPLES OF ELECTRIC ENERGY.

COMMON UNITS OF MEASURE.

The units commonly met with by engineers in the study of the principles underlying the generation, transmission and use of electricity are the volt, ampere, ohm and watt.

In diagram No. 1 A is a dynamo or electric battery, and the source of electric energy, and the purpose of which is to produce a difference in potential between the terminals B and B_1. This difference in potential is measured in volts, and we say that between the terminals B and B_1 there exists an electric potential or pressure of so many volts, written symbolically (E.M.F.)

Let us now suppose that a difference in potential exists between B and B_1, and that B is the point of higher pressure; if we connect B and B_1 together by a substance capable of conducting electricity, there will be a flow from B to B_1. This flow of electricity is known as a current and measured as amperes.

The rate at which current will flow from B to B_1 when joined together by a conductor as at C depends upon following conditions: 1st, upon the difference in pressure or electric potential between B and B_1; 2nd, upon cross section or area of conductor

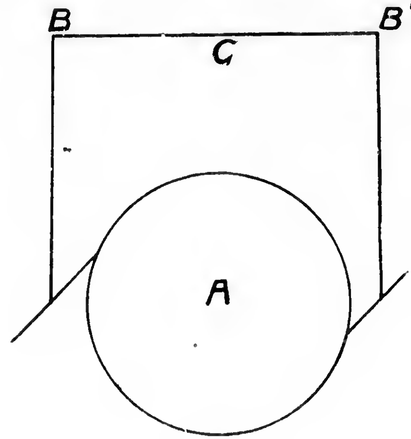


Fig. I

C, and upon length of C and nature of material of which C is composed; or, in other words, we may say that the rate at which current will flow through conductor C depends upon the difference in pressure and upon resistance offered by C to current.

Therefore, the greater the difference in potential the greater the current.

When a current flows through a conductor there is a loss in potential or voltage caused by the resistance of the conductor. This resistance is measured in ohms, and consequently a conductor is said to have a resistance of so many ohms.

When a difference in potential exists between B and B_1, but no connection between them, there is no flow of current through the dynamo or generator A, and therefore no work will be done by it. But if conductor C is connected to terminals B and B_1, current will at once begin to flow, and A will be compelled to do work to keep up the flow. The rate at which this work will be done will depend upon difference in potential between terminals B and B_1, and upon quantity of current flowing through the circuit. This then becomes the electrical energy or rate of doing work, and the electric unit of work or energy is the watt, and, in accordance with above, equals the volts multiplied by the amperes, or by the potential in volts multiplied by current in amperes.

The watt, then, is the product of one volt and one ampere, and in energy or work is equal to $\frac{1}{746}$ h.p., or 746 watts are equivalent to the mechanical force necessary to raise 550 pounds one foot high in one second, or 33,000 pounds one foot high in one minute.

The kilo-watt, as the name implies, equals 1,000 watts.

The symbols commonly used in formula to represent the units above described are as follows :

E. or E.M.F. equals electro motive force or volts.

C., the current or amperes.

R., the resistance or ohms.

W., or watts, represents the electrical energy.

K.W. represents kilo-watts.

SPRING-LOADED SAFETY VALVES.

THE questions of most importance to the practical working engineer regarding spring-loaded valves are : Size of steel from which the spring shall be made ; required inside and outside diameter ; compression required to have given effect.

A standard spring, if made of the best square steel, contains an area of .25 of a square inch, the inside diameter is exactly two inches and outside diameter three inches ; it contains thirteen complete coils, and measures exactly eleven and one-half inches in length. The working load is assumed at 600 pounds, one-sixth of its breaking load when hardened to a temper just sufficient to break it; at this load it should deflect exactly one inch.

Example (1): A safety valve 4 inches in diameter has a spiral spring made of square steel 3″ diameter outside and .25″ thickness of steel; what will be the pressure per square inch?

Formula:

$$\frac{12{,}000\ S^3}{d} = \text{whole pressure on valve.}$$

Where S = thickness of steel in inches,

d = diameter of spring from centre to centre of steel,

12,000 = constant used for square steel,

8,000 = constant used for round steel.

$$\text{Then, total weight} = \frac{12{,}000 \times .5^3}{2.5} = 600 \text{ pounds.}$$

Diameter of valve is given as 4 inches. Area of valve then $= 4^2 \times .7854 = 12.5664$ square inches. ∴ pressure per square inch $= 600 \div 12.5664 = 47.7$.

The foregoing is the fundamental principle to connect the loading of the spring valve with that of a direct weighted valve, and from it may be obtained both the proper thickness of steel to be used and the proper inside and outside diameters of the spring.

Example (2): What must be the outside diameter of a spiral spring for a safety valve 5″ in diameter? The pressure to be carried is 50 pounds, and the diameter of the steel is ¾ inch.

Formula:

$$d = \frac{8000S^3}{W}$$

Where d equals as before the mean diameter of the spring, S thickness of steel, W the whole weight on the valve, then

$$d = \frac{8000 \times .75^3}{5^2 \times .7854 \times 50} = \frac{3360}{981.75} = 3.42 \text{ inches.}$$

This, however, is only the mean diameter, or the diameter from centre to centre of steel. Therefore, the diameter of the steel must be added to this to get the outer diameter.

$\therefore$ outer diameter $= 3.42 + .75 = 4.17$ inches.

Example (3): The diameter of a spring loaded safety valve is 5 inches, gauge pressure 60 pounds, and mean diameter of a spiral spring 5 inches, what must the area be for square steel, also the length of each side, the area and diameter for round steel, and the inside and outside diameter of each spring.

The Steamboat Inspection Act adopts the Board of Trade rule for the determination of the required size of steel under the following formula:

$$\frac{\sqrt[3]{w \times d}}{c} = s$$

s = Side or diameter of steel in inches.

w = Load on spring in pounds.

d = Diameter of spring from centre to centre of steel.

c = 12,000 for square steel.

c = 8,000 for round steel.

Then we require to multiply total load in pounds by mean diameter in inches, and divide by either constant 12,000 or 8,000, as the case may be, and cube root of quotient equals diameter of steel.

First find what w of formula represents, by multiplying area of valve by pressure per square inch.

$$\therefore w = 5^2 \times .7854 = 19.635 \text{ sq. in. area.}$$

$$19.635 \times 60 = 1178.1, \text{ total weight.}$$

$$1178.1 \times 5 = 5890.5.$$

Then $\frac{\sqrt[3]{5890.5}}{12000}$ = diameter for square steel.

and $\frac{\sqrt[3]{5890.5}}{8000}$ = diameter for round steel.

$5890.5 \div 12,000 = .49$, and $\sqrt[3]{.49} = .788$ inches length of each side for square steel.

$.788 \times .788 = .62$ square inches area of square steel.

$5890.5 \div 8000 = .736$, and $\sqrt[3]{.736} = .9$ inches diameter of round steel.

$.9^2 \times .7854 = .63$ square inches area of round steel.

For a spring constructed of square steel our dimensions then become:

Mean diameter of spring (i.,e., from centre to centre of steel) . . . . = 5 inches
Outside diameter of spring equals 5 inches plus size of steel . . . . = 5.788 inches
Inside diameter of spring equals 5 inches minus size of steel . . . . = 4.212 inches
Size of steel . . . . = .788 inches
Area of steel must contain . . . . .62 sq. in.

And for a spring constructed of round steel, dimensions are as follows, viz.:

Mean diameter of spring . . . . 5 inches
Outside diameter of spring is 5 in. + .9 . . . . = 5.9 inches
Inside diameter of spring is 5 in. − .9 . . . . = 4.1 inches
Diameter of steel wire . . . . = .9 inches
Area of steel must contain . . . . .63 sq. in.

With a standard spring before us it is easy to determine the required sectional area of any steel spring when fundamental principles of this formula are understood.

As we are given the whole of the dimensions of a standard spring made of spring steel, we can determine the sectional area of a square spring by the following process:

As given weight is to required weight so is given sectional area to required sectional area.

For example, let us compare our determination of sizes for a square spring with a standard spring; our question then becomes:

As 600 : 1178.1 :: .25 : required area.

Then $1178.1 \times .25 = 294.5$.

$294.5 \div 600 = .49$, sectional area of spring at a load of 1178.1 pounds.

$\sqrt[2]{.49 \div .7854} = .788$ required size of steel to comply with standard spring. All other dimensions of the spring will change in same proportion.

With spiral springs then there is to the practical operating engineer the important question of determining the increase in pressure by compression or the decrease in pressure by reducing the compression, or the change similar and corresponding to the graduation of a lever safety valve.

The formula for this is $\frac{W \times d}{S^4 \times G} \times n =$ total compression.

Where W is the total weight pressing upwards against the valve in pounds

d = mean diameter of spring

S is thickness of steel in sixteenths of an inch

G is constant 30 for square steel

G is constant 22.8 for round steel

n is number of coils in spring.

Example (3): A spring loaded safety valve 5 inches in diameter is set for a gauge pressure of 90 pounds, but owing to weakness of boiler, pressure must be reduced to 60 pounds; the outer diameter of spring is five inches and spring is made of ⅝ inch steel with 15 coils; what compression must be given to produce required pressure starting with spring slack?

$$\frac{W \times d^3}{S \times G} \times n = \frac{5^2 \times .7854 \times 60 \times 4\tfrac{3}{8}^3 \times 15}{10^4 \times 30} = 4.932$$ inches, total compression required.

From this formula may be deduced the number of coils required, so that a given pressure shall require a given compression, or the load on the valve with a given compression, the diameter of coil or thickness of steel, if the other quantities are given.

The most important of these to the engineer is the determination of the number of coils required; the change in pressure by a given change in compression, and also the determination of the total weight bearing down against the valve or the weight required to lift it off its seat when dimensions of spring and compression are known.

To determine the number of coils required to balance a given pressure with a given compression, we construct from above formula the following:

$$C \div \frac{W \times d^3}{s^4 \times G} = N.$$

Where W, d^3, s^4, G and N have same values as in last formula, and C equals compression in inches, result will be required number of coils.

To determine pressure at which valve will blow off, with a spring of given dimensions and given compression.

Formula:

$$\frac{s^4 \times G}{a \times d^3 \times N} \times c = P,$$ pressure at which safety valve will blow off.

a equals area of valve in inches.

To determine total weight holding the valve in place, with a valve of given dimensions and given compression.

Formula:

$$\frac{s^4 \times G}{d^3 \times N} \times c = W,$$ total weight holding valve down.

Reference has been made to every safety valve requiring a given orifice or opening to allow of free passage of steam, so that increase in boiler pressure shall not take place. It is at the same time just as important that area of valve should not be too great to allow the free discharge of steam.

For steam above 10 pounds pressure above the atmosphere, the weight of steam that will escape into the atmosphere through an opening one square inch in area is, in 70 seconds, just equal to the pounds in the absolute pressure of the steam per sq. inch.

Example: To what height must a 5 inch safety valve rise from its seat to allow steam to escape at the rate of 9,200 pounds per hour, if the pressure on the boiler is 75 pounds per sq. inch above the atmosphere.

Since the weight of steam that will escape per square inch in 70 seconds is equal to gauge pressure plus atmospherical pressure, we proceed to find the weight of steam escaping from one sq. in. per hour.

Gauge pressure, 75
Atmosphere, 15
90, absolute pressure.

Then as 70 : 60 :: 90 : to the weight of steam escaping per minute.

Then, $\frac{60 \times 90 \times 60}{70} = 4628.5$, pounds of steam per hour per sq. in.

Then as 4628.5 : 9,200 :: 1 sq. inch to required area,

$\frac{9200}{4628.5} = 1.98$ square inches of escape required.

Then if required area is divided by circumference of valve in inches, result will be distance valve will be required to raise from its seat to allow the escape of 9,200 pounds of steam into the atmosphere.

```
3.1416                  15.708)1.98000(.126 of an inch lift.
     5                         15708
15.7080 = circumference.        41920
                                31416
                               105040
                                94248
                                10792
   .126
      8
 1.008 = Lift must be ⅛ of an inch.
```

From this, weight of steam escaping into the atmosphere from any orifice may be determined.

OHM'S LAW.

As stated in our last, and following out the principles therein set forth, the current in a conductor varies directly as the pressure or potential at the terminals, and inversely as the resistance of the conductor. From this then we get the following formula:

(1) $$C=\frac{E}{R}$$

This is known as Ohm's law, and is in continual use in the study of formula underlying the principles of electrical engineering.

In equation 1 we have formula for C, when both E and R are known. It consequently follows that we require but a simple transposition in the terms of our algebraic equation to find any of the quantities E, R or C when any two of them are known.

(2) Thus $$R=\frac{E}{C}$$

which simply means that the resistance is equal to the electromotive force (E M F) divided by the current, and

(3) $$E=R\ C$$

meaning that the E M F is equal to the resistance multiplied by the current.

From these equations it will be readily seen that if any two of the quantities E, R or C are given, the third may be found from one of the three equations, and that they are all based on the same law.

The energy in an electric circuit is equal to the pressure or potential at the terminals of the conductor multiplied by the current flowing through the conductor or circuit, and can be expressed in formula as follows:

(4) $$W \text{ or watts}=E+C$$

Here we have a simple formula for the purpose of finding the electrical energy of a circuit or generator when E and C are known.

But it frequently occurs that we must find W when any two of the units E, R or C are known. In equation (3) we have $E=R\ C$.

With this information before us let us substitute this value of E in (4) ; we then get

$$W \quad (R\,C) \times C \text{ or}$$

$$C^2 \times R = \text{watts}$$

Again in equation (1) we have

$$C = \frac{E}{R}$$

Substitute this value of C in equation (4), and we get

$$W = \left(\frac{E}{R}\right) \times E \text{ or}$$

$$\frac{E^2}{R} = \text{watts}$$

Following out then the general principles laid down, we get these formula for the determination of the electrical energy in any circuit when any two of the units E, R or C are known, or in other words the capacity of any circuit or dynamo to do work.

In our mechanical studies we establish the important fact that the energy cannot be destroyed, and that it will occur either as mechanical force or heat, or both.

And when an electrical current is passed through a wire or conductor a certain amount of electrical energy is lost as such, but makes its appearance as heat. Consequently the amount of heat generated must be equal to the electrical energy lost, and must therefore be measured in watts.

Formula : $W = C^2\ R$ is the formula generally used for the computation of heat generated in a circuit. If the resistance of a circuit and current flowing is known it is only necessary to multiply the resistance of the circuit by the square of the current to find electrical energy lost in transmission and appearing as heat.

STRENGTH OF BOILERS.

A STANDARD boiler, constructed in accordance with the Canada Steamboat Act, is assumed to have a maximum working pressure of one hundred pounds to the square inch and be forty-two inches in diameter, and, if made of best refined iron plate, shall be at least one-quarter inch thick, made in the best manner.

If boiler is made of steel, a maximum working pressure of one hundred and twenty-five pounds to the square inch is allowable; diameter and thickness of plate as above.

The tensile strength of the material for iron is to be taken as 48,000 pounds per square inch of section with the grain, and 42,000 pounds per square inch across the grain, and for steel 60,000 pounds per square inch. And when boiler and all joints are constructed in best manner, four may be taken as a factor of safety.

From the foregoing standard it at once becomes apparent that the required thickness of plate varies directly with the diameter of the boiler, and the safe working pressure varies inversely with the diameter.

From this we might construct the following formula to obtain the safe working pressure of any boiler:

$$\frac{TS \times 2T}{D \times FS} = P$$

Where TS = tensile strength of material,
2T = twice thickness of plate in inches,
D = diameter of boiler in inches,
FS = factor of safety,
P = safe working pressure.

It becomes evident, however, that since plate must be somewhat weakened by having holes drilled or punched in it to receive the rivets by which the plates are fastened together, and that the rivets themselves must have a direct effect on the strength of the seam, it is necessary first to determine the strength of the punched plate at the joint as compared with the solid plate, and also the strength of the rivets as compared with the solid plate.

The well-known axiom that the strength of a chain is its weakest link is borne out here in a remarkable degree, and the weakest part of a boiler is certainly the strength of that boiler.

Consequently, before we can determine the safe working pressure of a boiler, its required diameter or required thickness of plate, we must first determine strength of all rivetted seams.

It is self-evident that the strength of any section of plate must be its width multiplied by its thickness, multiplied by the weight required to break it.

For example, let us assume we have a piece of boiler plate one inch in width and one-quarter inch thick, and that it broke when a weight equal to 48,000 pounds per square inch of section had been applied to it. We should require to exert a force equal to $1'' \times .25'' \times 48000 = 12000$, which is the greatest possible strength we may expect to get per sectional inch of this plate.

Suppose, now, we drill a hole in the centre of this plate, we clearly reduce its sectional area and consequently its strength. Obviously, then, both the pitch of the rivets and their diameter must be taken into consideration in computing strength of plate at seams as compared with the solid plate, and we might say that width of plate in inches minus diameter of rivets, multiplied by number, and difference multiplied by thickness of plate in inches, multiplied by tensile strength of plate per square inch of section, will equal strength of plate at joint, or

$$p - (d \times n) \times T \times TS = s;$$

and since we want to know what percentage of strength punched plate bears to solid plate, we may modify this formula and get the formula required by Board ot Trade Rule :

$$\frac{(p-d) \times \text{[illegible]}}{P} = \text{percentage of strength of plate at joint as compared with the solid plate.}$$

We now have found the strength of plate when prepared for the rivets, and must now consider the strength of the rivets employed to fill up these holes, so that the operation of making the seam may be completed.

As already seen, the plate has been weakened by having had holes made in it. We now proceed to fill up these holes with rivets, and I need hardly point out that if the strength of the plate is greater than the strength of the rivets, and the boiler loaded to the strength of the plate, the rivets will give out by shearing across. We endeavor to get as strong a joint as possible, and for this purpose put in as many rivets as practicable in a seam. Suppose, however, we put the whole of the rivets in one row, we have reduced the plate area, and the stronger our rivet section becomes the weaker becomes the sectional area of the plate at the joint.

Therefore it is customary to divide the rivets into two, three or more rows, as by doing this the same strength of rivets is retained and the rivets are pitched a reasonable distance apart, enabling a fair percentage of strength to be obtained in the plate.

Then, if we knew the shearing strength of rivets per square inch of section, we may say that $d^2 \times .7854 \times Ss$ = shearing strength of rivet when only one row of rivets is used. Then $d^2 \times .7854 \times Ss \times N$ = shearing strength of rivet when two or more rows are employed.

Where d^2 = diameter squared,
$.7854$ = constant,
Ss = shearing strength of rivets,
N = number of rows of rivets.

Then,

$$\frac{d^2 \times .7854 \times Ss \times N \times 100}{p \times T \times TS} = \text{percentage of strength of rivets as compared with solid plate.}$$

Since both shearing and tensile strength of plate may be considered as equal, we may cancel these and proceed to get strength of rivets by formula adopted by Board of Trade :

Where

$$\frac{a \times N \times 100}{P \times T} = \text{percentage of strength of rivets as compared with solid plate.}$$

Where a = area of rivets,
N = number of rows,
P = pitch in inches,
T = thickness of plate in inches.

From these two formulae, then, may be ascertained both the strength of plate and rivets as compared with solid plate, and it follows that the least of these percentages is the strength of the joint.

NOTE : When rivets are exposed to double shear, percentage of strength obtained from foregoing formula may be multiplied by 1.75.

Example (1): Find the strength of plate at the joint as compared with solid plate if the rivets are ½ inch in diameter and pitched at 2½ inches.

$$\frac{P-d}{P} \times 100 = \frac{2.5 - .5}{2.5} \times 100 = 80\%,$$

strength of plate at joint as compared with solid plate.

Example (2): Suppose that pitch and diameter of rivets in a double-rivetted joint are same as in example No. 1, and thickness of plate equals half an inch, what will be the strength of rivets as compared with solid plate ?

$$\frac{a}{P}\,\frac{n}{T} \times 100 = \frac{5^2 \times .7854 \times 2}{2.5 \times .5} \times 100 = \frac{.393}{1.25} = .3144 \times 100 = 31.44\%,$$

strength of rivets as compared with solid plate.

As a rule it is understood that diameter of rivets may be same thickness as plate, but with thin plates this rule will not hold good, as in the present case it is evident that strength of rivets at joint is far too weak, and it would simply be absurd to construct a joint on these proportions. To increase strength of rivets we must either decrease pitch or increase diameter of rivets. It is considered good practice to have the percentage of strength at the joint or seam 70% of the strength of the solid plate. We can therefore decrease the percentage of strength of the plate by increasing the diameter of the rivet to ¾ of an inch, and at the same time increase the strength of the rivets.

Then,

$$\frac{P - d}{P} \times 100 = \frac{2.5 - .75}{2.5} \times 100 = 70\%,$$

percentage of strength of plate at seam as compared with solid plate, and

$$\frac{a \quad n}{P \quad T} \times 100 = \frac{.8834}{1.25} \times 100 = 70\%,$$

strength of rivet as compared with solid plate.

It will be readily seen that the most economical joint is one in which the plate and rivet sections are equal in strength. As already pointed out, if one section is stronger than the other it creates a decided disadvantage, as the weakest part of a joint must be its strength, and in a case like the foregoing we might with advantage put half the difference between the strength of the section on to the weakest section.

The easiest way to arrive at this, then, is to equate the formula for the rivet section to that for the plate section :

$$\frac{P - d}{P} = \frac{d^2 \times .7854 \times n}{P \times T}$$

We can now, by a simple transposition of formula, find a pitch that will give equal percentages :

$$P = \frac{a \times \text{No. in one pitch}}{T} + d.$$

Example: What pitch will the rivets of a double rivetted seam have to be so as to secure an equal percentage of strength in rivets and plates at the joints, shell plate being half inch and diameter of rivets ¾ inch?

$$\frac{d^2 + .7854 \times 2}{.5} + .75 = \frac{.8834}{.5} = 1.76 + .75 = 2.50 = \text{pitch.}$$

Proof:

$$\frac{2.50 - .75}{2.50} \times 100 = 70\%.$$

$$\frac{.75^2 \times .7854 \times 2}{2.5 \times .50} \times 100 = 70\%.$$

I will again repeat these two most important formulæ, and recommed the student to commit them to memory:

$$\frac{\text{(Pitch minus diameter of rivets)} \times 100}{\text{Pitch}}$$

equals percentage of strength of plate at joint, as compared with solid plate, and

$$\frac{\text{(Area of rivets x No. of rows)} \times 100}{\text{Pitch x thickness of plate}}$$

equals percentage of strength of rivets, as compared with the solid plate.

APPLICATION OF OHM'S LAW.

An examination of the preceding article on Ohm's law establishes three important rules, viz.:

1. The current varies directly with the electromotive force or potential, and inversely with the resistance.
2. The resistance varies directly with the electromotive force, and inversely with the current.
3. The electromotive force varies directly both with the current and resistance.

For practical operating engineers, these rules, based on Ohm's law, are the fundamental principles underlying most electrical calculations. It is important that the principles be thoroughly understood, and I regret that, in a work of this kind, full details cannot be given, for want of space. Before proceeding to an exposition of these principles by mathematical problems, I wish particularly to point out to my readers the desirability of their acquiring literature dealing with fullest details of Ohm's law.

Bearing in mind the fact that these articles are written especially for engineers operating electric plants, I shall content myself with giving principles and formula especially adapted to their requirements.

It may be well to mention that whatever is included in a circuit forms a portion of it. Be it the generator itself, convertors, meters, or any apparatus in connection with the generation or transmission of an electric current, and the resistance of both line and apparatus, must necessarily be included in resistance of circuit.

The resistance of a generator is nearly always referred to as internal resistance, and that of the outer circuit or line as external resistance, to distinguish between them, and the two resistances added together from the total resistance of the circuit, or the R of the formula.

Example (1): An electric generator having an internal resistance of 5 ohms and an E.M.F. of 50 volts, sends a current through a line of copper wire whose resistance is 25 ohms; what is the current?

$$C=\frac{E}{R}, \text{ then } 5+25=30 \text{ ohms total R, and}$$

$$\frac{50}{30}=1.66 \text{ amperes.} \qquad \text{(Rule 1.)}$$

Example (2): A difference of potential (E.M.F.) of 110 volts is maintained in an electric circuit, and a current of 250 amperes is the result. What must be the resistance of the line?

$$R=\frac{E}{C}, \text{ then } \frac{110}{250}=.44 \text{ ohm.} \qquad \text{(Rule 2.)}$$

Example (3): A generator having an internal resistance of 1 ohm sends a current of 50 amperes through a circuit having an external resistance of 2.5 ohms? What is the electromotive force of the generator?

$$E = R\ C, \text{ then } 1. + 2.5 = 3.5 \text{ ohms total } R,$$
$$\therefore\ 3.5 \times 50 = 175 \text{ volts.}$$

PORTIONS OF CIRCUITS.

All portions of a single circuit must of necessity receive the same current, but the electromotive force, or what is usually styled difference of potential, or drop in potential, and resistance, may vary to any extent in different sections of the circuit.

Example (4): A generator maintains a constant E M F of 110 volts between its terminals. The terminals are connected to and current is passed through a series of four coils, one having a resistance of 50 ohms, one 25 ohms, one 12.5 ohms, and one 6.25 Paying no attention to the resistance of the conductors between these coils, what is the E M F between the terminals of each coil?

A solution of this problem can best be reached by application of principle laid down in rule 3, viz.: That the electromotive force varies directly with the resistance and with the current.

In this case we wish to find E M F at given points on the line, when R alone of coil is known. The total R of the four coils is 93.75 ohms; calling the coils 1, 2, 3, and 4, and the difference of potential at their terminals E^1, E^2, E^3, E^4, we get the proportion.

As

$$93.75 : \begin{matrix} 50 \\ 25 \\ 12.5 \\ 6.25 \end{matrix} :: 110 \text{ volts} : \begin{matrix} E^1 \\ E^2 \\ E^3 \\ E^4 \end{matrix}$$

Then working out the problem by regular rules of proportion, we get

$$\begin{aligned} &E\ M\ F \text{ of } E^1 = 58.7 \text{ volts.} \\ &E\ M\ F \text{ of } E^2 = 29.3 \quad '' \\ &E\ M\ F \text{ of } E^3 = 14.7 \quad '' \\ &E\ M\ F \text{ of } E^4 = \ \ 7.3 \quad '' \end{aligned}$$

An examination of the problem will also prove to the student the theory of the statement that all portions of a single circuit must receive the same current. Taking, for example, total resistance of line at 93.75 ohms, and E M F at terminals of generator at 110 volts, and applying rule No. 1, we get

$$C = \frac{E}{R} \text{ or } \frac{110}{93.75} = 1.17 \text{ amperes.}$$

Applying the same principles to the coils, E^1, E^2, E^3 and E^4, we find that current at terminals of each is the same.

Example (5): Suppose the same external circuit was connected to a generator having a resistance of 10 ohms. The E M F of the 50 ohm coil has been found to be 60 volts, what is the E M F at the terminals of the generator, and what would be the E M F of the generator on open circuit.

The total R of our coils has been found to be 93.75 ohms, and by rule 3 we demonstrate that, as the resistance of the coil is to the total R of the circuit, so is the E M F at the terminals of the coil to the E M F at the terminals of the generator,

Or, as $50 : 93.75 :: 60 : x$,

and $\therefore$ $x = 112.5$ E M F at terminals of generator.

By following rule 1, we find the current at the terminals of coil No. 1 to be

$$\tfrac{60}{50} = 1.2 \text{ amperes.}$$

The total resistance of the circuit is the internal resistance of the generator = 10 ohms; the resistance of the conductors, of which no account has been taken, and the resistance of the four coils = 93.75 ohms.

$$10 + 93.75 = 103.75 \text{ ohms, total R of line.}$$

Then to find required E M F of generator to maintain a current of 1.2 amperes through a resistance of 103.75 ohms, we must apply rule 2.

$$E = R\ C,$$

or $1.2 \times 103.75 = 124.5$ volts, required E M F of generator.

STRENGTH OF BOILERS.

Having determined the strength of the boiler at the joints, we next require to determine safe working pressure, thickness of plate, tensile strength per sectional inch, etc.

A standard boiler is said to be 42 inches in diameter and have a safe working pressure of 100 pounds per square inch, if constructed in best manner of iron plate one-quarter inch thick, having a tensile strength of 48,000 pounds per sq. inch of section.

From this, then, we can construct the following formula to determine the safe working pressure of any boiler:

$$\frac{TS \times 2T \times \% \text{ strength of joint}}{D \times FS} = P,$$

and from this we require but a slight transposition to construct a formula to determine either the diameter or thickness of plate required to conform to this standard, and

$$\frac{D \times P \times FS}{TS \times \%} = 2T \div 2 = T, \text{ and}$$

$$\frac{TS \times 2T'' \times \%}{P \times FS} = D.$$

This formula refers to any boiler, no matter whether constructed of iron or steel, 48,000 pounds being taken as the tensile strength for iron, and 60,000 pounds being taken as the tensile strength for steel, and four being taken as a factor of safety in each case when boiler is constructed in best manner.

Example (1): Find the safe working pressure of an iron boiler, made in best manner, joints having a sectional strength equivalent to 70% of solid plate; boiler being 42 inches in diameter and having plate ⅜ of an inch thick.

$\frac{TS \times 2T \times \%}{D \times FS} = P = \frac{48{,}000 \times .75 \times .70}{42 \times 4} = 150$ pounds, safe working pressure.

Same boiler in steel would become :

$\frac{60,000 \times .75 \times .70}{42 \times 4} = 187.5$ pounds per square inch safe working pressure for steel.

Example (2) : Find the required thickness of plate (steel) required in a boiler five feet in diameter, to carry a safe working pressure of 100 pounds to the square inch, sectional strength of a triple rivetted joint being 70°/₀ of strength of solid plate.

$$\frac{D \times P \times FS}{TS \times \%} = 2T,$$

$$\frac{60'' \times 100 \times 4}{60,000 \times .70} = 2T =$$

$\frac{24,000}{42,000} = .571 \div 2 = .285$ inches, or nearly $\frac{5}{16}$ inch, required thickness of plate.

Example : What diameter should a boiler be when constructed of iron made in best manner and with ½ inch plates, working pressure to be 200 pounds per square inch, joints and rivet sections having a tensile strength equal to .70% of strength of solid plate,

$$\frac{TS \times 2T \times \%}{P \times FS} = D = \frac{48,000 \times 1. \times .70}{200 \times 4} = \frac{33,600}{800} = 42 \text{ inches.}$$

Same boiler constructed in steel :

$$\frac{60,000 \times 1. \times .70}{200 \times 4} = \frac{42,000}{800} = 52.5 \text{ inches.}$$

Example : Find the strain per sectional inch on a boiler 42 inches in diameter, having ¼ inch plate and having a working pressure of 100 pounds per square inch.

Formula :

$TS = \frac{P \times D}{2T} = \frac{100 \times 42}{.5} = 8400$ pounds strain per sectional inch of plate.

STEEL FURNACES AND FLUES.

The Canada Steamboat Act provides that the external working pressure to be allowed on plane circular steel furnaces and flues when subjected to such pressure, when the longitudinal joints are welded or made with a butt strap, shall be determined by the following formula: 90,000 × the square of thickness of plate in inches ÷ (length in feet + 1) × diameter in inches equals the working pressure per square inch, provided it does not exceed that found by the following formula:

$$\frac{8{,}000 \times T''}{D''}$$

T″ thickness in inches.
D″ diameter in inches.

The length to be measured between the rings, if the furnace is made with rings.

Example: Find the working pressure of a circular flue 36 inches in diameter, 6 feet long and made of ⅜ inch steel plate.

$$\frac{90{,}000 \times \frac{3}{8}^2}{(6+1) \times 36} = \frac{90{,}000 \times .1406}{7 \times 36} = \frac{12654}{252} = 50 \text{ pounds working pressure.}$$

$$\text{Check: } \frac{8{,}000 \times T''}{D''} = \frac{8{,}000 \times .375}{36} = 83.3 \text{ lbs.}$$

The collapsing pressure of a plane circular furnace tube is found by the following formula:

$$\frac{806{,}300 \times T^2}{D.\ L} =$$

When T equals thickness of plate in inches.
D equals diameter of flue in inches.
L equals length of flue in feet.

Example: What is the collapsing pressure of a furnace tube whose diameter is 36 inches, length 6 feet and thickness of plate ⅜ inch?

$$\frac{806{,}300 \times .1406}{36 \times 6} = \frac{113{,}365.78}{216} = 524.84.$$

CORRUGATED STEEL FURNACES AND FLUES.

Steel flue furnaces, when new, corrugated and machine made, and practically true circles, the working pressure is found by the following formula, provided that the plane parts at the ends do not exceed six inches in length, and the plates are not less than $\frac{5}{16}$ of an inch thick and furnace made in one length.

$$\frac{12{,}500 \times T''}{D''} = \text{working pressure.}$$

And for corrugated iron furnaces made similarly the following formula can be used:

$$\frac{10{,}000 \times T''}{D''} = \text{working pressure.}$$

Example: Find the working pressure allowable on a corrugated steel furnace flue 42 inches wide, 7 feet long and $\frac{3}{8}$ thickness of plate,

$$\frac{12{,}500 \times .375}{42} = 111.6 \text{ pounds.}$$

Find the working pressure allowable on same furnace constructed in iron.

$$\frac{10{,}000 \times .375}{42} = 89.3 \text{ pounds.}$$

DIVIDED AND SHUNT CIRCUITS.

A conductor from one terminal of a generator may be divided into any number of divisions or branches. Each branch or division may vary in resistance, and they may all unite on reaching the other terminal.

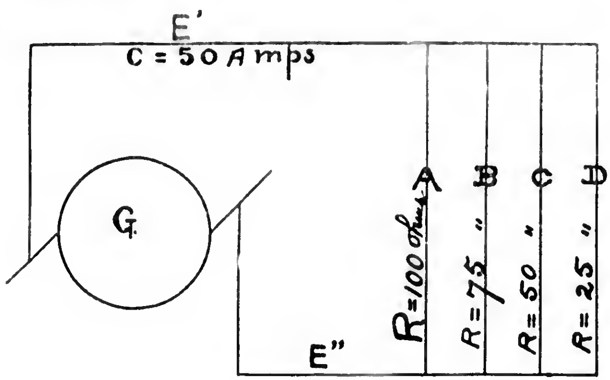


FIG. 2.

Example 6: A portion of the circuit connected with generator G in Fig. 2 consists of 4 parallel conductors, A, B, C and D. R of A=100 ohms; B=75 ohms; C=50 ohms, and D=25 ohms, what will be the ratio of current passing through the circuit which will pass through each conductor.

According to Rule 1 the current passing through each of the conductors A, B, C and D will be inversely proportionate to its resistance.

$$\therefore \text{As } A : B : C : D :: \tfrac{1}{100} : \tfrac{1}{75} : \tfrac{1}{50} : \tfrac{1}{25}$$

Or to simplify:

As A : D 100 : 25
B : D :: 75 : 25
C : D :: 50 : 25

That is, that the ratio which current passing through conductor A bears to current passing through conductor D is the same as the ratio that the resistance of conductor A bears to R of conductor D, and so on for all the other conductors.

Example 7: Supposing the current passing through terminals of generator, and consequently through circuit, to be 50 amperes, what amount of current will pass through each of the branches, A, B, C and D, in foregoing problem.

To determine the amount of current that will pass through parallel circuits of different resistances, take the resistance of each branch in ohms as a denominator, having 1 as a numerator. Reduce the fractions to a common denominator and add together the new numerators. Take the sum of the numerators as a new common denominator, and the single numerators as new numerators, and new fractions will express proportional currents passing through portions of circuit as units of one.

$$\text{Then } \tfrac{1}{100}\ \tfrac{1}{75}\ \tfrac{1}{50}\ \tfrac{1}{25}\ \frac{3\ .\ 4\ .\ 6.\ 12}{300}$$

And sum of numerators equals 25, using this as per rule $\frac{3\ .\ 4\ .\ 6\ .\ 12}{25}$

∴. current passing through branches expressed in units of one must equal: $A=\frac{3}{25}$; $B=\frac{4}{25}$; $C=\frac{6}{25}$; $D=\frac{12}{25}$.

Total current passing through circuit is given as 50 amperes.

Then current passing through $A=\frac{3}{25} \times 50=6$ amp.
" " " " $B=\frac{4}{25} \times 50=8$ amp.
" " " " $C=\frac{6}{25} \times 50=12$ amp.
" " " " $D=\frac{12}{25} \times 50=24$ amp.

It will be observed in Fig. 2 that current passing through circuit first passes through conductor E^1, and when parallel branches are reached four paths are provided for its passage, when it again unites on conductor E^{11}.

It is quite evident that the more paths there are provided for the passage of the current the less resistance will be offered.

This brings up a problem as to resistance offered by the parallel branches of a circuit as compared with a single conductor.

It is quite clear that we cannot summarize or add the resistances of each parallel branch together. If branch A had only been provided, then resistance of A would have been the resistance of that portion of the line, but addition of other branches clearly reduces resistance of each branch to flow of current by providing another path for its passage.

In divided circuits the resistance of the combined branches is expressed by the reciprocal of the sum of the reciprocals of the resistances.

Example 8: Find the resistance of the combined branches, A, B, C and D, as set forth in foregoing examples.

The reciprocal of resistance is conductance expressed usually as Mhos, a derivate of the word Ohms.

The reciprocal or conductance of the four branches then is:

$$\tfrac{1}{100}+\tfrac{1}{75}+\tfrac{1}{50}+\tfrac{1}{25}=\tfrac{25}{300} \text{ or } \tfrac{5}{60} \text{ Mhos.}$$

The resistance of the combined branches is as 5 : 60 = 12 ohms.

Application of Rule 3 to this problem proves that the E M F on each of branches is equal 600 volts.

R of A =	100	ohms	and	C =	6	amps.	E	M	F 600	volts.
R of B =	75	"	"	=	8	"	"	"	600	"
R of C =	50	"	"	=	12	"	"	"	600	"
R of D =	25	"	"	=	24	"	"	"	600	"

And combined resistance of A, B, C, D = 12 ohms combined. C = 50 amps. E M F 600 volts.

Perhaps a clearer method of arriving at the combined resistance of parallel circuits is to use the formula

$$R=\frac{R \times R^1}{R+R^1}$$

Which is based on the principle that the combined resistance of two parallel circuits can be found by multiplying their resistances together and dividing the product by the sum of their resistance.

By this method, combining A and B we get $\frac{100 \times 75}{100 + 75} = 42.8$ ohms.

Combining C and D we get $\frac{50 \times 25}{50 + 25} = 16.7$ ohms.

Then combining these two products we get $\frac{42.8 \times 16.7}{42.8 + 16.7} = 12$ ohms combined R of branches A, B, C and D.

If the whole of the branch circuits were of uniform resistance, then formula could be very much simplified by using formula

$$R = \frac{R}{N}$$

When the resistance of one branch is divided by the number of branches the quotient will be the combined resistance of all the branches.

Example 9: What would be the combined resistance of four parallel branches each having a resistance of 100 ohms?

$$\frac{100}{4} = 25 \text{ ohms.}$$

STRENGTH OF STAYS AND FLAT SURFACES.

We require here to find area and number of stays required, area of surface supported by one stay, and the pressure that may be allowed against any flat surface.

The greatest stress per square inch of section of an iron stay allowed is 6000 lbs. Then calling this the T. S. (tensile strength) of our formula, the total stress on a stay may be found by the following formula:

$$\text{Stress (S)} = a \times T\,S$$

Example: Find the stress allowable on a direct stay $1\frac{1}{4}$ inches in diameter when the stress allowable equals 6000 pounds per square inch section.

$S = a \times T\,S = 1.25^2 \times .7854 = 1.2271$ square inches of section.

$1.2271 \times 6000 = 7362.6$ total stress allowable on stay.

Example, the stays of a boiler are $1\frac{1}{4}''$ in diameter and placed 12 inches apart, what should be the working pressure of the boiler if the stress allowable per square inch section of stay is 6000 pounds.

Rule: First find the stress the stay is capable of supporting, then divide the result by the area held up by each stay and the quotient with the pressure allowable on the boiler.

$1.25^2 \times .7854 = 1.2271$ square inches section of stay.

$1.2271 \times 6000 = 7362.6$ total stress allowable on stay.

Since the stays are 12 inches apart or 12 inches from centre to centre of stay, each stay must support a section of plate equal to 12 inches squared.

Then $12 \times 12 = 144$ square inches area, supported by each stay. Then $7362 \div 144 = 51.1$ pounds pressure allowable on the boiler.

Rule to find required diameter of stay: Area of section in square inches held up by each stay multiplied by pressure on boiler divided by stress allowable per sectional inch on stay equals required area of stay.

$$\sqrt[2]{area \div .7854} = \text{diameter}.$$

Example: Find the required diameter of a direct stay when allowable stress on stay is 6000 pounds per square inch of section and stays are 15 inches apart with boiler pressure at 75 pounds per square inch.

$15 \times 15 = 225$ square inches of surface supported by stay.

$225 \times 75 = 16{,}875$ pounds stress on each stay.

$16{,}875 \div 6000 = 2.81$ square inches required area of stay.

$\sqrt[2]{2.81 \div .7854} = 1.9$ diameter of stay required.

Example: the stays of a boiler are $1\frac{1}{2}$ inches in diameter and capable of sustaining a stress of 8,835 pounds, what distance must they be pitched apart to sustain a working pressure of 60 pounds to the square inch?

Rule: $\frac{8835}{60}$ = area of section, and square root of area of section equals pitch or distance from centre to centre of stays.

$8835 \div 60 = 147.2$ area of section to be supported in square inches.

$\sqrt{147} = 12.125$ length of each side of section of plate, or required pitch of stay $= 12\frac{1}{8}$ inches.

Proof: $12.125^2 \times 60 = 8,820$.

[Note.—This result would have been exact had fractional parts of an inch been worked out.]

We now have rules for three of the most important determinations relating to stays:

1st. Determining the total weight or stress that a stay is capable of supporting.

2nd. Determining the required diameter of a stay when total weight to be sustained is known.

3rd. Determining the area of surface a stay of given dimensions is capable of supporting under known conditions.

To practical operating engineers these questions are of great importance; I will therefore repeat the examples under conditions which may be expected to be met with in ordinary practice.

Example: The stays on a flat surface are 12 inches apart centre to centre, and through corrosion, have eaten away to 1 inch in diameter. The pressure per square inch on the boiler is 60 pounds, what is the strain per square inch section of stay and to what pressure should the strain be reduced to give a stress of 5,000 pounds per square inch section of stay.

$12 \times 12 = 144$ square inches held up by each stay.

$144 \times 60 = 8640.$ pounds held up by each stay.

$1^2 \times .7854 = .7854$ square inches sectional area of stay.

Then stress per square inch section of stay equals:

$$8640 \div .7854 = 11.000$$

This is clearly sufficient to break the stay and render the boiler unsafe.

$5000 \times .7854 = 3927$ pounds weight that stay is capable of sustaining.

$3927 \div 144 = 27.27$ pounds safe working pressure.

And therefore to comply with conditions named that strain on stay must not exceed 5000 pounds per square inch of section, boiler pressure must not be allowed to exceed 27.27 pounds per square inch.

Example: The stays of a boiler are 10 inches apart, and one of them breaks, throwing more stress on the four surrounding stays. The stays are 1⅛ inch in diameter, and the boiler pressure is 50 pounds per square inch, what extra stress will be placed per square inch of section of stays if area supported by each has been increased by ⅓, and what must the boiler pressure be reduced to so that stress per square inch section of stay shall not exceed original stress.

Stress held by each stay equals—

$$10 \times 10 = 100 \times 50 = 5000 \text{ pounds.}$$

Sectional area of stay equals—

$1.125 \times 1.125 \times .7854 = .994$ square inches, stress per square inch of section before the break $= 5000 \div .994 = 5030$ pounds.

Then stress per square inch of section after the break =

$$5030 + \tfrac{1}{3} \text{ of } 5030, \text{ or } 5030 + 1676.66 = 6706.66 \text{ pounds.}$$

Stays before break supported $10 \times 10 = 100$ square inches of surface, and after the break they are called upon to support ⅓ more, or 133.33 square inches.

Original stress per square inch section of stay $= 5030 \div 133.33 = 37.7$ pounds per square inch, to which point pressure must be reduced so that original stress on stays may be maintained.

Example: What is the total pressure on the flat bottom of a boiler 18 feet 6 inches long by 6 feet wide, the pressure of the steam being 30 pounds per square inch, and the depth of water 10 feet 5 inches. Find also the required number of stays 1½ inches in diameter, and what diameter they must be pitched apart when the stress per square inch of section of stay shall not exceed 6000 pounds.

Take a column of water 1 foot high and 1 square inch in area as weighing .434 pounds.

10 feet 5 inches equals 10.416 feet.

∴ $10.416 \times .434 = 4.51$ pounds pressure per square inch through weight of water.

Then $4.51 + 30 = 34.51$ total pressure per square inch on bottom of boiler. The boiler is 18′ 6″ by $6' = 18.5 \times 6 = 113$ sq. feet area.

$113 \times 144 = 16272$ area of boiler in square inches.

$16272 \times 34.51 = 561,546.72$ pounds total weight bottom of boiler is called upon to support.

Area of stay equals $1.5^2 \times .7854 = 1.767$ square inches.

$1.767 \times 6000 = 10602$ pounds weight that one stay is capable of holding up.

$561,546.72 \div 10602 = 53$ nearly number of stays required.

Or we might say since each stay is capable of supporting 10602 pounds, $10602 \div 34.51 = 307$ square inches area of plate each stay can support.

16272 total area of boiler $\div 307 = 53$ number of stays required.

$\sqrt{307} = 17.5214$ inches distance from centre to centre of stay.

DROP IN POTENTIAL AND SIZE OF LEADS FOR MULTIPLE ARC CONNECTIONS.

SUBSIDIARY leads or branch leads are taken from larger sized mains of constant E.M.F., or from terminals of generators with constant E.M.F. to supply current to one or more lamps, motors or other appliances requiring a constant E.M.F.

There is a drop of potential in the leads to be provided for so that the appliances may have to work at a reduced E.M.F. The E.M.F. of the leads is known, and the required E.M.F. of the appliance to be supplied with current, also its resistance, and a rule is required to calculate the size of wire in the lead to secure proper results.

The resistance of the leads supplying any lamp or appliance for a desired drop within the leads is equal to the reciprocal of the current of the lamp or appliance multiplied by the desired drop in potential expressed as volts. This principle is based on the fact that the drop in potential in portions of circuits varies with the resistance.

Example 10: A 110-volt lamp having a resistance of 220 ohms is to be placed 50 feet distant from a main having a constant E.M.F. of 115 volts. What must be the resistance of the line to maintain a constant E.M.F. of 110 volts at the lamp?

The lamp current is found by the formula:

$$C = \frac{E}{R} = \frac{110}{220} = .5, \text{ or } \tfrac{1}{2} \text{ ampere.}$$

The reciprocal of the current then is $\frac{2}{1}$. This multiplied by desired drop 5 volts $= \frac{2}{1} \times 5 = 10$ ohms, required resistance of leads.

For two or more lamps in parallel similar rules are applied.

In this case the E.M.F. of the terminals or main leads, the factors of the lamps, and their distance from the point of connection with the main leads require, to be given.

Example 11: A pair of subsidiary leads are to be run a distance of 150 feet from main leads, and to carry current for ten 50-volt lamps having a resistance of 100 ohms. The main leads have a constant E.M.F. of 55 volts. What is the resistance required in subsidiary leads, and what size of wire B & S gauge?

The combined R of lamps is found by formula:

$$R = \frac{R}{N}$$

Then $\frac{100}{10} = 10$ ohms, combined resistance of 10 – 100 ohm lamps in parallel, $\frac{50}{10} = 5$ amperes current to be supplied to lamps. The reciprocal of $5 = \frac{1}{5} \times 5 = 1$ ohm resistance required by line. Length of lead 150 ft. x 2 = 300 ft., total length of line. Required resistance 1 ohm ÷ 300 = .0033 ohms per foot, equivalent to No. 14 gauge wire as per table.

Or this may be worked out on the principle that the resistance of the leads is equivalent to the combined resistance of the lamps multiplied by the percentage of drop and divided by 100 minus the percentage of drop; which we can express in formula thus, using x as representing the required quantity:

$$x = \frac{R \times \%}{100 - \%}$$

The percentage of drop is found by dividing required drop in E.M.F. by initial E.M.F. on mains, and $\frac{5}{55} = 9\%$. The required resistance of the leads then is $\frac{100}{10}$ = combined R of lamps.

$$\frac{10 \times 9}{100 - 9} = \frac{90}{90} = 1 \text{ ohm, required R of leads.}$$

STRENGTH OF BOILERS.

The Steamboat Inspection Act, 1882, ss. 4, provides "that the areas of diagonal stays are found in the following manner:"

Find the area of a direct stay needed to support the surface, multiply this area by the length of the diagonal stay, and divide the product by the length of a line drawn at right angles to the surface supported to the end of the diagonal stay; the quotient will be the area of the diagonal stay required.

Example: Find the area required in a diagonal stay supporting 1 square foot of surface, boiler pressure being 75 pounds per square inch, length of diagonal stay 12 feet and length of line 9 feet, stress allowable per square inch of section on direct stay being 6,000 pounds.

```
  12
  12
 ---
 144 square inches surface supported.
  75
 ---
 720
1008
----
10800 total stress on direct stay.
```

10,800 ÷ 6,000 = 1.71 square inches, required area of direct stay.

```
1.71 area of direct stay.
  12 length of diagonal stay.
```

20.52 = 20.52 ÷ 9 length of line = 2.27 square inches, required area of diagonal stay.

When the tops of combustion boxes or other parts of a boiler are supported by solid rectangular girders, the following formula may be used for the purpose of finding the working pressure to be allowed on the girders, assuming that they are not subjected to a temperature greater than that of the steam and are supported by hanging stays.

Formula

$$\frac{C \times d^2 \times T}{(W - P)\ D \times L} = \text{working pressure.}$$

Where W = width of combustion box in inches,
P = pitch of supporting bolts in inches,
D = distance between the girders from centre to centre in inches,
L = length of girder in feet,

d = depth of girder in inches,
T = thickness of girder in inches,
C = 500 when girder is fitted with one supporting bolt,
C = 750 when fitted with two or three,
C = 850 when fitted with four.

The working pressure for the supporting bolts and plate between them is determined by rules for ordinary stays already referred to.

The pressure allowed on plates forming flat surfaces is found by the following formula :

$$\frac{C \times (T+1)^2}{S-6} = \text{working pressure per square inch.}$$

Where T = thickness of plate in sixteenths of an inch,
S = surface supported in square inches,
C = 100 ; but when the plates are exposed to the impact of heat or flame, and steam only is in contact with the plates on the opposite side, C must be reduced to 50.

Example : Find safe working pressure of a flat-bottomed boiler whose stays are pitched 15 inches apart and thickness of plate is ½ inch.

$$\frac{C + (T+1)^2}{S-6} = \frac{100 \times (8+1^2)}{225-6} = \frac{8100}{219} = 37 \text{ lbs. safe working pressure.}$$

To find required thickness of plate we must reconstruct the formula :

$$\frac{S-6 \times P}{C} = (T+1)^2 \text{ and } \sqrt{T+1} = T.$$

Example : Find the required thickness of plate for a flat-bottomed boiler, whose stays are pitched 12 inches apart and steam pressure is 50 pounds per square inch, and depth of water in boiler is 7 feet. Also, what must be the diameter of stays if they are not allowed to carry more than 6,000 pounds per square inch of section ?

Pressure due to water $= .433 \times 7 = 3.031$ lbs.
Pressure due to steam $= 50.$

Total pressure per square inch $= 53.$ lbs.

Then

$$\frac{S - 6 \times P}{C} = \frac{(144 - 6) \times 53}{100} = \frac{7314}{100} = 73.14.$$

And $\sqrt{73.14} = 8.55$. $8.55 - 1 = 7.55$ or $\frac{15}{32}$, required thickness of plate in sixteenths or thirty-seconds of an inch.

Stays are pitched 12 inches apart, and therefore must support a surface of $12 \times 12 = 144$ square inches.

$144 \times 53 = 7{,}632$, total weight each stay is called upon to support.

$7632 \div 6000$ stress allowed per square inch of section of stay $=$ 1.272 square inches, required area of stay.

$\sqrt{1.272 \div .7854} = 1.25$ (nearly), required diameter of stay.

It sometimes occurs that the stays of a boiler are to be fixed with cottars, and it is necessary to know what size the end of the stay must be swelled to so as to have the same strength as the stay. For this purpose the following formula is used:

$$D = \left(1 + \frac{.08}{N} + \frac{.4}{\sqrt{N}}\right)d$$

Where d = diameter of stay in inches.

D = increased diameter.

N = depth of cottar in terms of its width; that is, if cottar is ½ an inch wide and 1½ inches deep, N would be 3, since depth of cottar is 3 times the width.

Example: The stays of a boiler are to be fixed with cottars ½ an inch thick and 2 inches thick, the diameter of stay being 1½ inches, what size must the end be made so as to have uniform strength with stay?

$D = \left(1 + \frac{.08}{4} + \frac{.4}{\sqrt{4}}\right) \times 1.5 = (1 + .02 + .2) \times 1.5 = 1.83$ required diameter of end of stay.

EXAMPLE 12: In Fig. 3 we have represented a pair of mains on which we have to connect four groups of lamps, consisting of five lamps each connected in multiple. The lamps have each a resistance of 200 ohms. The E.M.F. of the terminals to which leads are connected is 110 volts, and it is desired to allow a drop in potential of 10 volts, to be divided equally between each of the four groups of lamps. What must be the resistances of the four sections of wire?

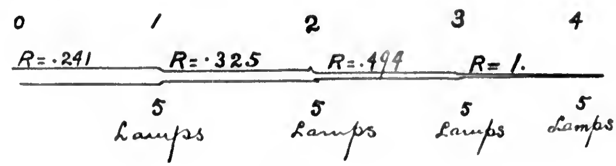


FIG. 3.

Commencing at group 1, we have an E.M.F. of 107.5 volts, at group 2 105 volts, at group 3 102.5 volts, and at group 4 100 volts, with a uniform drop of potential of 2.5 volts between each of the groups. Commencing the calculation at the extreme end of lead, or at group 4, we have 5 lamps connected in parallel, each with a resistance of 200 ohms. Then combined R of group 4 = $\frac{200}{5}=40$ ohms, and a total current of $\frac{100}{40}=2.5$ amperes. The required R of section 3 to 4 then is $\frac{10}{25}\times 2.5=1$ ohm.

Taking now group 3, calculating by similar methods, and bearing in mind the fact that the combined resistances of the whole of the groups must be the same, since the number of lamps in each group are equal, total current of group 3 then is

$$\frac{102.5}{40}=2.56 \text{ amperes,}$$

And since the current required for group 4 must pass through the wire supplying group 3, we get:

Current of group 4 = 2.5 amperes,
" " " 3 = 2.56 "
Total current wire 2-3 = 5.06 "

The required R of section 2 to 3 then is equal to $\frac{100}{506} \times 2.5 = .494$ ohms.

Taking now group 2 and calculating in exactly similar manner, $\frac{105}{40} = 2.62$ amperes, and $2.62 + 2.56 + 2.5 = 7.68$, total current pass-

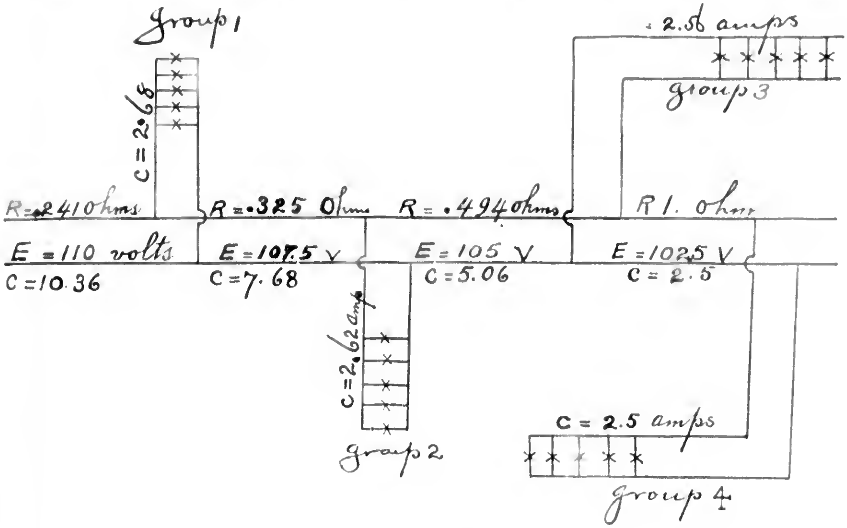


FIG. 4.

ing on wire section 1 to 2. $\frac{100}{768} \times 2.5 = .325$ ohms, required R sections 1 to 2.

Group $1 = \frac{107.5}{40} = 2.68$ amperes, and $2.68 + 7.68 = 10.36$, total C passing on wire section 0 to 1. $\frac{100}{1036} \times 2.5 = .241$ ohms, required R sections 0 to 1.

Therefore we find we require, to meet conditions as set forth in our problem, a wire varying in resistance and consequently in area, as shown in Fig. 3, and where

R of section of wire			0 to 1 =	.241	ohms,
"	"	"	1 to 2 =	.325	"
"	"	"	2 to 3 =	.494	"
"	"	"	3 to 4 =	1.000	"

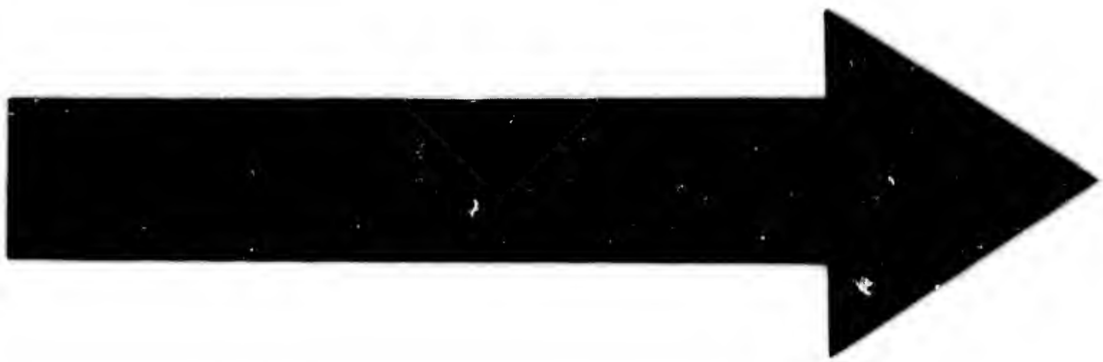
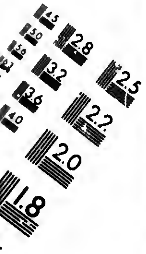
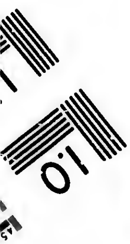


IMAGE EVALUATION
TEST TARGET (MT-3)

6"


2.8
2.5
3.2
2.2
3.6
2.0
1.8


1.0

These resistances, divided by twice the length of one side of lead, will equal R per foot required on lead.

Fig. 4 shows the whole of the results of our previous problem in detail, and at the same time it will be seen from diagram that this method of computation can be applied to almost any system of distribution on the two-wire principle, and need not here have further reference.

CALCULATION OF WORK DONE BY PUMPS.

Rule : To find the contents of the pump when full, find the area of the cylinder in inches, multiply by length of stroke in inches, and result will be capacity of pump in cubic inches of water each stroke.

Rule : To find capacity of pump per hour, first find contents of cylinder each stroke, then multiply by strokes per minute, and then by 60 ; result will be capacity of pump per hour in cubic inches ; to reduce to cubic feet divide result by 1728.

Example : Find the contents of a boiler feed pump, stroke being 24 inches and diameter of cylinder 6 inches.

Formula : $D^2 \times .7854 \times L = \text{contents}$; $6^2 \times .7854 = 28.2744$, area in cubic inches ; $28.2744 \times 24 = 678.5856$ cubic inches, contents of pump cylinder when full.

Example : Find the capacity per hour of a boiler feed pump in cubic feet, diameter of piston being 4 inches, stroke 6 inches, and pump making 75 strokes per minute.

$4^2 \times .7854 = 12.5664$ square inches, area ;

$12.5664 \times 6 = 75.3984$ cubic inches, contents per stroke ;

$75.4 \times 75 = 5655$ cubic inches per minute ;

$5655 \times 60 = 339300$ cubic inches per hour ;

$339300 \div 1728. = 196.35$ cubic feet of water, capacity per hour.

DETERMINING THE REQUIRED SIZE OF BOILER FEED PUMPS.

This question, as practical engineers will know, covers a wide range of subjects, and it is particularly hard to lay down a hard and fast rule adapted to every condition of service. It might be assumed that the quantity of water accounted for as being used within the cylinder of an engine would be a nearly correct basis on which to arrive at the required capacity of the pump. This, however, for many reasons, is so far from being correct that I have decided not to refer at length to this method of calculation.

Clearly, a boiler feed pump should have ample capacity for all calls that are likely at any time to be made upon it, and with the quantity of water we may be called upon to evaporate per minute or hour before us, we are enabled to arrive at a fair approximation of the required capacity of the pump. Even this must be coupled with a good deal of practical common sense, and provision must at all times be made for leakage on the boiler and its accessories, and leakage and slip within the pump itself.

Example: Find the required capacity of a boiler feed pump for three boilers whose furnaces are 3 feet by 6 feet, coal consumption 15 pounds per square foot of grate surface per hour, and evaporation equal to 10 pounds of water per pound of coal.

6 feet
3 feet
18 square feet surface in each boiler
15 pounds coal consumed per hour
90
18
270 pounds of coal per hour each furnace
3
810 pounds, total coal consumed per hour
10
8100 pounds of water evaporated per hour
$8100 \div 62.5 = 129.6$ cubic feet of water per hour
129.6
4 factor of safety
518.4 cu. feet of water per hour for safety, after allowance for slip, leakage, etc., required capacity of pump.

What must be the diameter of a double-acting duplex steam pump making 100 strokes per minute and having a stroke of four inches to comply with above requirements?

$518.4 \div 60 =$ 8.64 cu. feet per minute;
$8.64 \div 100 =$ .0864 cu. feet per stroke;
$.0864 \times 1728 = 149.3$ cu. inches, required contents of pump;
$149.3 \div 4 =$ 37.325 cu. inches, required area of cold water piston;
$37.325 \div .7854 =$ 47.5, and
$\sqrt{47.5} =$ 6.88 inches, required diameter of pump piston, or say, 6⅞ inches.

Then, to safely comply with the conditions set forth, we shall require a duplex steam pump making 100 displacements per minute, with a 4-inch stroke and a cold water piston diameter of 6⅞ inches.

MISCELLANEOUS QUESTIONS.

To find extra pressure required to discharge water from a given orifice:—

Formula:

$$\frac{T^2\ D^4}{2000000\ d^2\ B^2}$$

Where T = travel of plunger in feet per minute,
D = diameter of plunger in inches,
d = diameter of delivery valve,
B = breadth of opening or lift in inches.

Example: The cold water piston of a pump is 4 inches in diameter and has a travel of 150 feet per minute. The delivery valve is 2½ inches in diameter and has a lift of ¼ of an inch. What extra pressure is required to discharge the water?

$$\frac{T^2\ D^4}{2000000\ d^2\ B^2} = \frac{150^2 \times 4^4}{2000000 \times 2.5 \times .25^2} = \frac{5760000}{781250} =$$

$$5760000 \div 781250 = 7.37 \text{ pounds.}$$

To find velocity at which water will travel through the discharge pipe of a pump. The velocities are in inverse proportion to the area, or what amounts to the same thing, the velocities are in inverse proportion to the square of the diameters.

Then for the purpose of determining the ratio of velocity between any two pipes we may construct the following formula :

$$\frac{D^2}{d^2}$$

Where D equals diameter of plunger, d equals diameter of pipe. And when the speed of the plunger is known the velocity of the water in the discharge pipe may be determined by formula :

$$\frac{D^2 \times T}{d^2} = V.$$

Where D = diameter of plunger in inches,
T = travel in feet,
d = diameter of discharge pipe in inches,
V = velocity of discharge in feet per minute.

Example : The plungers of a pump are 10 inches in diameter and have a travel of 100 feet per minute. At what velocity will the water travel through a discharge pipe 2 inches in diameter ?

Then

$$\frac{D^2\ T}{d^2} = \frac{10^2 \times 100}{2^2} = \frac{10000}{4} = 2500 \text{ feet per minute.}$$

The work done due to the energy of motion of a moving body is represented by the formula :

$$\frac{W\ V^2}{64}$$

Where W equals the weight, V equals velocity in feet per second.

Example : The piston of an hydraulic ram is 12 inches in diameter ; water in feed pipe has a velocity of 2,000 feet per minute ; feed pipe to ram is ¾ inch. What is the energy of ram per pound of water used ?

Velocity in feet per second equals

$$\frac{2000}{60} = 33{\cdot}33{\cdot}$$

It has already been shown that the velocity of water in pipes depends upon the areas or diameters squared ; consequently $12^2 \div .75^2 = 144 \div .5625 = 256$. That is, 256 is the ratio of velocity of water in feed pipe as compared with the velocity of the water in the ram. Therefore, if the water in the ram moves at the rate of 1 foot per second, the water in the feed pipe must move at the rate of 256 feet per second, and the amount of work done is the same in each case. The difference in areas causes the ram to move only $\frac{1}{256}$ the speed of the pump, and what the ram loses in speed it must gain in force, since energy is indestructible, and the pressure exerted by the ram must be 256 times greater than that in the pipe to make up for loss in speed.

Energy of motion in pipe then equals

$$\frac{W\ V^2}{64} = \frac{1 \times 33.33^2}{64} = 17.35 \text{ ft. lbs.}$$

Then the work done by ram per pound of water used equals $17.35 + 256 = 4441 - 60$ foot pds. per pound of water used.

The pressure due to velocity is found by dividing the square of the velocity in feet per second by the constant 148.3.

Example : The piston of an hydraulic ram is 6 inches in diameter ; velocity of water in a ½-inch feed pipe equals 2,500 feet per minute. What is the work done by the ram per pound of water used, and what is the pressure per square inch due to velocity, and if the energy of the water had been turned into heat what would be the rise in the temperature of the water ?

Velocity of water in feed pipe per second equals

$$\frac{2500}{60} = 41.33,$$

and $6^2 \times .5^2 = 36 \div .25 = 144$, ratio of velocity in ram as compared with feed pipe ;

$\frac{W\ V^2}{64} = \frac{1 \times 41.33^2}{64} = 26.69$ foot lbs. energy of motion per pound of water in feed pipe ; $26.69 \times 144 = 3843.36$ foot pounds per pound of water used by ram; $V^2 = 1708.16$, and pressure due to velocity in pipe equals

$$\frac{1708.16}{148.3} = 11.51 \text{ pounds per square inch.}$$

Then the pressure on the ram must equal $11.51 \times 144 = 1657.44$ pounds per square inch.

The mechanical value of a British Thermal Unit (B T U) is equivalent to raising 1 pound 772 feet high in one minute, or what is the same thing, raising 772 pounds one foot high in the same period of time; therefore a raise of 1° F. in the temperature of a pound of water equals 772 foot pounds of energy.

$$\frac{26.69 \text{ energy per pound of water in feed pipe.}}{772}$$

equals .0345° F. increase of temperature of water in feed pipe.

Then

$$\frac{3843.36}{772} = 4.98° \text{ F. rise of temperature in ram.}$$

Then if the whole of the energy of the ram had been expended in heat it would have given off sufficient heat to have raised the temperature of each pound of water 4.98° Fahrenheit.

REQUIRED SIZE OF LEADS IN CIRCULAR MILS.

A MIL is $\frac{1}{1000}$ of an inch, and written decimally .001. The area of a circle $\frac{1}{1000}$ of an inch in diameter is termed a circular mil, and a great many wire tables express the area of the cross section of a wire in circular mils written symbolically C. M. Rules for the sizes of wires as met with in engineering practice for given resistances are often based on circular mils, and include a constant for the conductivity of materia. of which wire is composed. From this, then, we can construct a formula for the calculation of the resistance of wire of whatever material composed, so long as we know the specific resistance of the material.

Commercial copper wire of 90% purity, one foot long and one C. M. in cross section, is said to have a resistance of 10.79 ohms at 75° F. (approximate). In accordance with the rule that the resistance of a circular conductor varies inversely with the square of its diameter and directly with its length, we can construct the following well-known formula for the determination of resistance of copper wire:

$$R = \frac{10.79 \times L}{d^2}$$

Example (10): A commercial copper wire one-half an inch in diameter has a specific resistance of 10.79, what is the resistance per foot?

½ inch = .500 mils.

$.500^2$ = .250,000.

10.79 ÷ .250,000 = .000043 ohms per foot.

Example (11): A copper wire 5,000 feet long, with a cross section of 8,000 C.M., what is its resistance?

$$\frac{10.79 \times 5,000}{8,000} = 6.743 \text{ ohms.}$$

The required cross section of a wire in C. M. is equal to its length divided by its resistance and multiplied by 10.79, or

$$\text{C.M.} = \frac{\text{L}}{\text{R}} \times 10.79$$

The required cross section of a pair of leads in C.M. for a given drop is found to be equal to the product of the length of leads multiplied by number of lamps (in parallel) by 21.58 by 100, minus the percentage of drop, and the whole divided by the resistance of one lamp hot multiplied by the percentage of drop allowed.

$$\text{C.M. or } d^2 = \frac{\text{L} \times 21.58 \times \text{N} \times 100 - \%}{\text{R} \times \%}$$

or what is the same thing,

$$\text{C.M.} = \frac{10.79 \times 2 \times \text{L} \times \text{N}}{\text{R}} \times \frac{100 - \%}{\%}$$

Example (12): Ten lamps are to be placed in multiple at the end of a double lead 100 feet long. The resistance of each lamp when hot being 220 ohms, what must be the sectional area of the wire if a drop of 5% is allowed on E.M.F.?

$$\frac{21.58 \times 100 \times 10}{220} = 98 \times \frac{100 - 5}{5} = 1872 \text{ C.M}$$

Based on this and following out the principles laid down in Ohm's Law, the following formula is often given as a ready means of determining the required size of wire for house or secondary incandescent circuits:

$$\text{C.M.} = \frac{21.58 \times \text{L} \times \text{N} \times \text{C}}{\text{L v}}$$

Where C.M. = Area in circular mils.
" L. = Length of one side of lead.
" N. = Number of lamps.
" C. = Current required by each lamp.
" L v = Number of volts per lamp loss in line.

When lamps or groups of lamps or other appliances are placed at different distances from the generator, apply principles laid down in example; or, roughly stated, determine first the size of wire required for each lamp or group, as if on independent circuits, starting from the dynamo, then combine all wires running in same direction.

DETERMINATION OF THE MEAN PRESSURE THROUGHOUT THE STROKE WHEN USING STEAM EXPANSIVELY.

Considering recent advances in modern engineering and improved appliances at hand, an article on this subject is perhaps superfluous. There are, however, such important principles involved and such useful information obtainable, that the author feels justified in referring to the subject at short length. Since a large proportion of my readers are operating simple non-condensing engines, the author will deal particularly with this class, and the principles involved can then be readily applied to compound engines of any type.

The engines to which many of us were first introduced had what is styled a fixed "cut-off," which took effect at almost any point between start and finish of piston travel, according to the views the engineer held on the question of working steam expansively. And speed was controlled by means of a throttling device, arranged to reduce or raise the pressure against the piston as occasion required. This type in modern practice is nearly obsolete, and we have in its stead what is termed an automatic "cut-off" engine, arranged to take steam at beginning of stroke at full boiler pressure, and regulating its speed by means of a variable "cut-off"—that is, initial pressure against piston on admission remains constant and varies only as pressure on boiler varies; —and this pressure is maintained against the piston as it travels within the cylinder to a point of the stroke varying in direct proportion as the load on the engine varies.

Theoretically, then, if we had no cut-off until admission valve closed at the end of the stroke, the pressure of the steam against the piston would remain the same, and a diagram representing the operation could be drawn as represented in Fig. 5, within the letters, A, B, C, D, and the pressure against the piston can be readily ascertained by a simple process at any point of the stroke, and the mean, initial and terminal pressures would at all times be equal, and the mean effective pressure would be initial pressure minus back pressure, and could be equally as readily determined.

Let us now suppose that when the piston has reached a point equal in distance to one-third of its travel, the admission valve closes and cut-off takes place; the piston then travels the remaining two-thirds of the distance by the expansive force of the steam

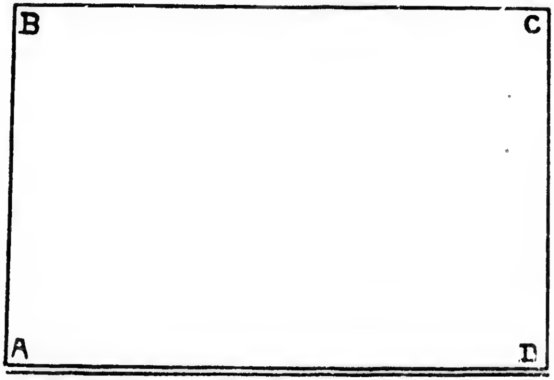


FIG. 5.

already admitted, and supposing that expansion would take place under isothermal conditions, that is, that the temperature of steam remained constant, it is clear that as expansion increases pressure decreases, consequently the terminal pressure of the steam will be very much less than the initial pressure, and that at any point in the stroke between one-third and the end, the pressure will be less than the point immediately before and higher than the next succeeding point. If, then, we know the initial pressure of our steam and the point of cut-off, and can by any means determine the pressure at the respective points of the stroke, we can by finding the mean of these pressures thus determine the mean pressure on the piston. For this purpose, then, we re-arrange Fig. 5 as illustrated in Fig. 6, and divide this into any even number of points, taking care that one of these points shall coincide exactly with and intersect point of cut-off.

To do this we first divide the cylinder into an equal number of parts by subtracting the numerator from the denominator of the point of cut-off expressed as a fraction, and if the result is an even

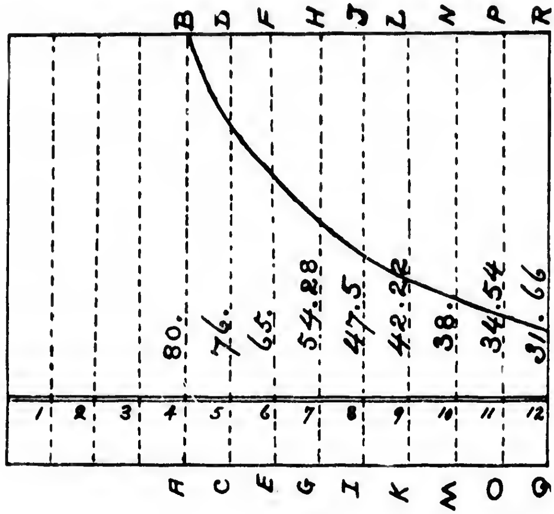


FIG. 6.

number above six, the denominator of the fraction is the number of equal parts into which the cylinder can be divided so that one of the ordinates will exactly intersect the point of cut-off.

Example: With steam cut off at $\frac{3}{15}$ of the stroke, what number of parts must the cylinder be divided into?

As per rule, $15 - 3 = 12$—an even number above six—therefore cylinder must be divided into 12 equal parts. It will, however, very frequently be found that when the numerator is subtracted from the denominator that either an odd number or an even number less than six is the result. In either case, double, treble or quadruple both the numerator and the denominator, and if this does not answer, increase fraction until you get a fraction giving the desired result.

Example: Suppose steam is cut off at $\frac{1}{3}$ stroke, into how many equal parts must cylinder be divided?

Proceeding as per rule, $3 - 1 = 2$, an even number less than six, which will not answer.

$\frac{1}{3} \times \frac{2}{2} = \frac{2}{6}$, which is still too low; we continue the process until we reach

$\frac{1}{3} \times \frac{4}{4} = \frac{4}{12} = 12 - 4 = 8$, an even number higher than 6, and cylinder can then be divided into 12 equal parts.

Fig. 6 then represents a cylinder, and we proceed to divide into 12 equal parts, with cut-off taking place at $\frac{1}{3}$ of the stroke. Each of the dotted ordinates in this diagram then represents the position of the piston expressed in $\frac{1}{12}$ths of piston travel. Point of cut-off, or $\frac{1}{3}$ of stroke, will equal 4 of these parts, and the pressure of steam at 1st, 2nd, 3rd and 4th positions of piston remains constant.

When piston is in position, A, B, at 4, cut-off takes place, and at Q, R, exhaust valve opens. If steam then was expanding under true isothermal conditions, the lines, c, d, e, f, g, h, etc., show the gradual decreasing pressures of the steam due to expansion and pressures represented by letters, A, B, Q and R, show the total value of the steam during expansion.

To find the pressure of the steam at any one of the positions of of the piston during expansion, multiply absolute initial pressure of steam by number of ordinate at point of cut-off, and divide this result by the number of ordinate at which pressure is desired.

Example : With steam admitted at 80 lbs. gauge pressure, find the pressure at each of the ordinates in diagram.

$80 + 15 = 95$, absolute pressure.

$95 \times 4 = 380$, value of steam previous to cut-off.

Then pressure at	C D	$=\frac{380}{5}=$	76.	pounds.
" " "	E F	$=\frac{380}{6}=$	65.	"
" " "	G H	$=\frac{380}{7}=$	54.28	"
" " "	I J	$=\frac{380}{8}=$	47.5	"
" " "	K L	$=\frac{380}{9}=$	42.22	"
" " "	M N	$=\frac{380}{10}=$	38.	"
" " "	O P	$=\frac{380}{11}=$	34.54	"
" " "	Q R	$=\frac{380}{12}=$	31.66	"

To find total value of steam during expansion we require to find area of space enclosed by A, B, Q and R.

For this purpose we adopt the Simpson rule, which is : To the first and last ordinates add four times the sum of the even ordinates and twice the sum of the odd ordinates ; one-third of this sum equals the area.

Then 4 or A B =			95	pounds.
5 or C D =	76	x 4 =	304	"
6 or E F =	65	x 2 =	130	"
7 or G H =	54.28	x 4 =	217.12	"
8 or I J =	47.5	x 2 =	95	"
9 or K L =	42.22	x 4 =	168.88	"
10 or M N =	38	x 2 =	76	"
11 or O P =	34.54	x 4 =	138.16	"
12 or Q R =			31.66	"
		3	1255.82	
Value during expansion,			418.60	"

Before expansion,	380	pounds.
During "	418.60	"
Value during whole stroke,	798.60	"

If now, we divide by number of ordinates used, we get mean pressure against the piston throughout the stroke.

$$798.60 \div 12 = 66.55 \text{ pounds.}$$

If the engine piston was running against a perfect vacuum, then mean pressure throughout the stroke would be the mean effective pressure on which to calculate power developed by any engine in doing work, but this rarely, if ever, happens; therefore the absolute back pressure against the piston must be deducted, and we get

Mean pressure − back pressure = mean effective pressure.

Example: Find mean effective pressure on the piston of a non-condensing engine when mean pressure is 66 pounds per square inch and back pressure two pounds above the atmosphere.

$2 + 15 = 17$ pounds absolute back pressure, and $66 - 17 = 49$ pounds mean effective pressure of steam on piston.

When principles of calculation are understood, formula for calculation can be considerably shortened by use of logarithms.

1st. The hyperbolic logarithm of the ratio of cut-off increased by 1 and multiplied by terminal pressure equals mean pressure.

2nd. The hyperbolic logarithm of the ratio of cut-off increased by one and multiplied by initial pressure, and result divided by ratio of cut-off, equals mean pressure.

3rd. Second rule minus absolute back pressure equals mean effective pressure throughout the stroke.

Example of Rule 1: Cut-off takes place at $\frac{1}{3}$ of stroke; the ratio of cut-off therefore is $3 \div 1 = 3$, and the hyperbolic logarithm of 3 is 1.09861,

$\therefore\ 1.098 + 1 \times 31.6 = 66.39$ pounds, mean pressure.

Example of Rules 2 and 3:

$$95 \times \frac{1.098 + 1}{3} = 66.4 \text{ pounds, mean pressure.}$$

$$95 \times \frac{1.098 + 1}{3} - 17 = 49.4 \text{ pounds, mean effective pressure (M.E.P.)}$$

In addition to finding the mean pressure by process of calculation, we require also to find the mechanical efficiency gained by cutting off steam in comparison to steam being admitted during the whole of the stroke. This can be found by dividing the mean pressure by the terminal pressure absolute. Then 66.4 ÷ 31.6 = 2.098 ; or expressed briefly, the mechanical efficiency is the hyperbolic logarithm of the ratio of cut-off plus 1.

Finally, on this subject, we want to find the co-efficient of efficiency or a number expressing the practical efficiency of the steam, including the effect of expansion as compared with the duty of the same steam without cut-off or expansion and loss by back pressure.

Rule :

$$\frac{\text{Mean effective pressure} \times \text{Length of stroke}}{\text{Absolute pressure} \times (\text{Length of admission} + \text{Clearance})} = \text{The co-efficient of efficiency.}$$

Example : Find the co-efficient : Gauge shows 80 pounds ; stroke 12 inches, cut-off taking place at $\frac{1}{3}$ of stroke, and mean effective pressure is shown to be 49 pounds, piston having $\frac{1}{4}$ inch clearance.

$$80 + 15 = 95, \text{ absolute pressure.}$$

$$\therefore \frac{49 \times 12}{95 \times (4 + .25)} = \frac{588}{403.75} = 588 \div 403.75 = 1.45 \text{ co-efficient.}$$

THREE-WIRE SYSTEM.

In the three-wire system the lamps are really arranged in sets of two in series. The two outer wires have double the potential of the lamps, and since, owing to the lamps being in series, one-half the current only is required as compared with multiple arc two-wire system ; therefore, to carry one-half the current with twice the difference in potential or double the E.M.F., a conductor with one-quarter the area of cross-section suffices.

Dynamos are frequently set in series in large buildings, and their terminals wired out on the three-wire system to save copper. Since each of the wires is but one-quarter the size of the wires in the ordinary two-wire system, it remains clear that the weight of copper required on the three-wire system is but ⅜ of that required on ordinary two-wire systems. The formulæ already laid down for two-wire work apply to three-wire calculations as regards size of mains, if denominator of formula be multiplied by 4.

$$\text{C M or } d^2 = \frac{21.58 \times L\ N \times (100 - \%)}{R \times \% \times 4}$$

This formula gives required cross-section of mains in circular mils, using commercial copper wire as a conductor.

ALTERNATING CURRENT SYSTEM.

In alternating systems we have two sets of mains to deal with, primary and secondary, both of which have different E. M. F.'s.

Theoretically, the rules deduced from Ohm's law are not correct as applying to this system of generation, because calculations must be made to allow for conversion from primary to secondary current. The ratio that the primary E.M.F. bears to the secondary E.M.F. is expressed by dividing the primary E.M.F. by the secondary E.M.F., and is termed ratio of conversion. Thus,

$$\frac{\text{E primary}}{\text{E secondary}} = \text{Ratio of Conversion.}$$

The current in the primary is equal to the current in the secondary divided by the ratio of conversion.

Example: On an alternating circuit whose primary E.M.F. is 1,000 volts and secondary E.M.F. 50 volts, there are 500 lamps, each having a resistance of 50 ohms, what is the primary current and what the secondary?

$\frac{1000}{50} = 20$, ratio of conversion.

$\frac{50}{500} = .1$, combined R of lamps.

$\frac{50}{.1} = 500$ amperes current on secondary.

$\frac{500}{20} = 25$ amperes current on primary.

Current being determined, rules deduced from Ohm's law apply exactly as shown for direct current calculations.

Example: An alternating generator has 4,000 feet of primary main attached with an E.M.F. across the terminals of the machine of 1040 volts; it is decided to allow a drop of 40 volts on the primary at the convertor. The secondary main has attached to it 750 16 c.p. lamps at an E.M.F. of 50 volts, each lamp having a resistance of 50 ohms. What is the resistance on the primary wire?

$1040 - 40 = \frac{1000}{50} = 20$, ratio conversion.

$\frac{50}{50} = 1$ amp., current each lamp.

$750 \times 1 = 750$ amps., total current on secondary.

$750 \div 20 = 37.5$ amps. current on primary.

$\frac{1}{37\frac{1}{2}} \times 40 = 1.06$ ohms resistance on primary.

To obtain the required size of primary mains in circular mils, calculate by formula for two-wire direct current, and divide the result by the square of the ratio of conversion. Or

$$C\ M = \frac{21.58 \times L\ N \times (100 - \%)}{R \times \% \times R\ C^2}$$

Example: An alternating current generator has an E.M.F. across the leads of 1040 volts, and current is delivered 4,000 feet from station, E.M.F. at terminals being 1,000 volts; current consists of 1,000 lamps, having a resistance of 50 ohms each on a 50 volt secondary circuit. What should be the cross-section of the primary mains in circular mils, and what is resistance of same main to allow a drop of 40 volts as shown?

$$\frac{1000 = \text{E.M.F. at terminals of primary}}{50 = \text{E.M.F. on secondary}} = 20 \text{ R.C.}$$

$$40 \div 1040 = 3.84\% \text{ drop in potential.}$$

$$\frac{21.58 \times 4000 \times 1000 \times (100 - 3.84)}{50 \times 3.84 \times 20^2} = 108{,}079 \text{ C. M., required cross-}$$

section of primary main in circular mils.

Total current on secondary $= 1000 \times \frac{50}{50} = 1000$ amps.

$1000 \div 20 = 50$ amps. secondary current.

$\frac{1}{50} \times 40 = .8$ ohms resistance, primary main.

HORSE POWER CALCULATIONS.

The power or force required to do a certain mechanical work is usually referred to as foot pounds. That is, one pound raised one foot high is called a foot pound, without reference to the time required to do the work. Therefore, if we want to find force or energy required to be expended to do a certain work expressed in foot pounds, we require to multiply the weight required to be raised by the distance in feet through which weight has to be lifted.

A horse power is fixed as the work performed in raising 33,000 pounds one foot high in one minute, or what is exactly the same thing, raising one pound 33,000 feet high in the same period of time. Here we have time required to do a certain work, and note of this must be taken in our calculations.

Then to reduce force exerted at the piston of a steam engine, and to express this force in horse power, we require to know effective pressure against the piston throughout the stroke, and distance travelled in feet by the piston per minute. And to do this use the following established rules :

1st. Find area of piston in square inches.

2nd. Find the total pressure in pounds on the piston by multiplying the area by the mean effective pressure per square inch.

3rd. Find the distance in feet traversed by the piston per minute by multiplying the length of stroke in feet by twice the revolutions per minute.

4th. Find the energy exerted by the engine expressed in foot pounds per minute by multiplying the total pressure in pounds against the piston by the travel in feet per minute.

5th. Find the horse power by dividing total foot pounds per minute by 33,000.

From this, then, we can construct the following simple formula:

$$\frac{A.N.P.S.^1}{33{,}000} = H.P.$$

Where A = Area of piston in square inches.
N = Number of strokes per minute (revolutions multiplied by two.)
P = Mean effective pressure per square inch.
S^1 = Length of stroke in feet.

Example : Find the horse power of an engine 9.5 inches by 12, running 280 revolutions per minute, mean effective pressure throughout the stroke being 35 pounds per square inch.

$9.5^2 \times .7854 = 70.88$ square inches area.

$$70.88 \times 35 =$$

```
   70.88
      35
  ------
   35440
  21264
 -------
 2480.80 total pressure against piston.
```

```
 280 revolutions per minute.
   2 strokes per revolution.
 ---
 560 strokes per minute.
   1 length of stroke in feet.
 ---
 560 feet travelled by piston per minute.
```

```
      2480.8 pressure on piston.
         560
      -------
     1488480
     124040
    ---------
     1389248.0 foot pounds per minute.
33000)1389248.(42.09 horse power.
      132000
      ------
       69248
       66000
      -------
       324800
```

We have in this formula two constants, .7854 constant multiplier to find area, and 33000 constant divisor to find horse power, consequently by dividing .7854 by 33,000 we get a constant multiplier as a result, and thus shorten our method.

$.7854 \div 33000. = .0000238$, which becomes a constant multiplier, and our formula then becomes $(d^2\ N\ P\ S^1) \times .0000238 = H.\ P.$

Example: Using this formula find horse power of an engine, dimensions, etc., as per last example.

```
          9.5=diameter of piston.
          9.5
         ------
         90.25=d²
           560=strokes per minute.
         -------
         5415 00
        45125
        --------
        50540.00
              35=mean effective pressure.
       ----------
       252700
      151620
      --------
      1768900
         .0000238=constant multiplier.
     ------------
     14151200
     5306700
    3537800
    ------------
    42.0998200=H.P.
```

CALCULATING HORSE POWER FROM INDICATOR DIAGRAMS.

An indicator diagram is practically a record of the action of the steam on the piston throughout the stroke of an engine, and if we are enabled to ascertain the area of the diagram, having the length of the diagram and scale of spring used before us, it becomes an easy task to find the mean effective pressure of the steam throughout the stroke.

The area of the diagram is easiest found by use of a small instrument called a planimeter, which should be set to a natural scale, that is, area of diagram should read in square inches. Knowing the area and dividing by length of diagram in inches, will give us height of a regular body of an equal area.

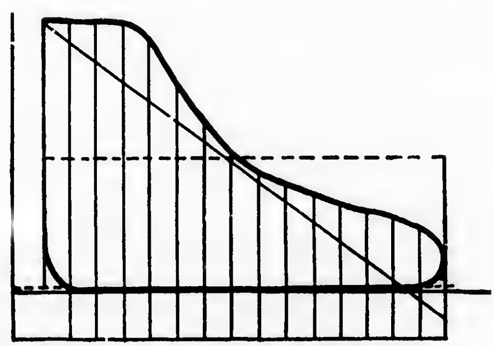


FIG. 7.

Fig 7 represents a diagram 3 inches in length, and the irregular body has an area of three square inches. If we reduce this area to a regular body with at least two of its sides equal, we get a diagram, as shown by dotted lines, exactly one inch in height ; multiplying this by scale of spring used, we get M.E.P. throughout the stroke. Therefore, we can construct a formula as follows to calculate M.E.P. from an indicator diagram :

$$\text{Area} \div \text{Length} \times \text{Scale of spring} = \text{M.E.P.}$$

The horse power calculation can be very much shortened by using what is known as an engine constant; that is, the power developed by an engine with M.E.P. of 1 pound per sq. inch, and is particularly useful where horse power calculations are being constantly made from same engine.

Abreviated the formula would then read:

$$\text{Engine constant} \times \text{M.E.P.} = \text{H.P}$$

Example: Using engine constant and M.E.P. find I.H.P. of a single cylinder engine $9\frac{1}{2}'' \times 12''$ running 280 revolutions per minute. Diagram measures 3 inches in length, and planimeter

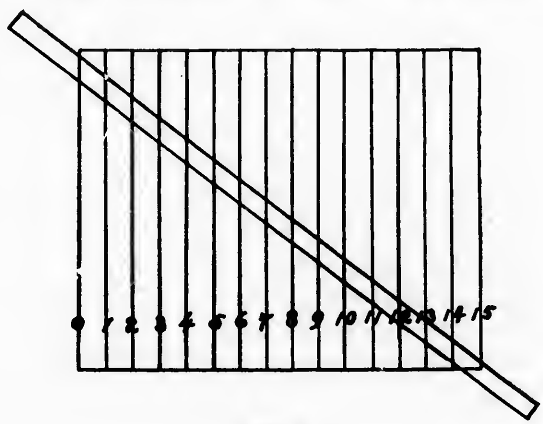


FIG. 8.

shows area to be 2.625 sq. inches, scale of spring used in indicator being 40 pounds per inch of compression.

First, find power developed by engine with a mean effective pressure of one pound per square inch:

$$9.5^2 = 90.25$$
$$90.25 \times 560 = 50540$$
$$50540 \times .0000238 = 1.2 \text{ H.P.}$$

Then power developed by this engine with steam pressure on piston equalling one pound per square inch of area is 1.2 H.P., which is our engine constant. Next find mean effective pressure shown by diagram :

Area ÷ Length = 2.625 ÷ 3 = .875 average height in inches.

.875 × 40 scale of spring used = 35. M.E.P.

Then 1.2 × 35 = 42. horse power.

In the absence of a planimeter, it becomes necessary to devise a method of arriving at area of diagram. To those engineers who are unacquainted with geometry this is sometimes difficult to do.

With every indicator is sent out a number of rules graduated in such a manner that the divisions between each inch correspond exactly with scale of spring used ; by the aid of these it becomes comparatively easy to subdivide into equal divisions. For instance, suppose we wish to divide Fig. 7 into 15 equal parts by using a graduated scale laid across diagram at an angle so that the divisions 1 and 15 shall exactly coincide with lines at each end of diagram, and marking off at each division on scale intervening by erecting at each of these points an ordinate at right angles with atmospheric line, we get 15 exact divisions. It now remains for us to ascertain the pressure represented in the centre of each of these divisions, and finding the mean pressure by adding the pressures together and by dividing the total by number of ordinates erected, we get total mean effective pressure calculation of H.P. It then becomes a simple repetition of examples already described. To convey meaning clearly Fig. 7 is reproduced in Fig. 8.

CORROSIVE AND SCALE-FORMING AGENTS IN BOILER FEED WATERS.

CHAPTER I.

WATER is universally conceded to be the greatest of all known solvents, consequently it never occurs in a state of purity as a natural supply. The foreign matter may be composed of either solids or gases, or both, and may be in suspension, mechanical or chemical solution with the water. By the term suspension is meant a state in which the foreign matter is present in the water in its original state, no matter how finely divided, and when it can be abstracted from the water by filtration, having the same properties as when it entered the water in the first place.

In boiler feed waters this usually consists of vegetable organic matter, finely divided clay, etc. The coarser and heavier the particles the sooner will they separate out and settle to the bottom of any receptable in which water may be contained. It is possible, however, to find water with foreign matter in suspension so minutely divided that it is impossible to detect them except by slight turbidity or characteristic coloring given to the water. I have in my laboratory samples of water taken from freshly drilled artesian wells in the vicinity of Montreal, containing particles of clay held in suspension so minutely divided that it took weeks for complete settlement to take place, and the slightest movement of the containing vessels would cause particles to again rise in the water, thus causing turbidity.

Matter in mechanical or physical solution, on the other hand, has entered into combination with the water and cannot be again abstracted except by means of a change of state or evaporation. For instance, to pure, distilled water add common salt; this at once dissolves, and until water is saturated, if salt was pure, no apparent change takes place in the appearance of the water itself, and if solution was passed through the finest possible filter, salt would still remain in solution, but if we carefully evaporate off the water, salt will finally remain in its original state, no evident change having taken place.

If to pure water (H_2O) we add oxide of sodium (Na_2O), soda at once combines with the water, or part of it, with generation of heat, a chemical reaction taking place in accordance with following equation:

$$Na_2O + H_2O = 2NaOH.$$

In this case one molecule of sodium oxide enters into combination with one molecule of water to form the new chemical compound, sodium hydro-oxide, which dissolves in the excess of water present, and remains in chemical solution; and if water was evaporated off, sodium oxide would not be recovered in its original state as an oxide, but in the state of sodium hydroxide.

The reader will note the difference here. On the one hand, addition of sodium chloride to the water made no apparent change in general appearance of water to the naked eye, and no heat was evolved, and on evaporation it was again recovered in its original state, and without any change in weight. In this case salt simply entered into mechanical solution with the water, due to the solvent powers of that menstrum, and is really but a physical change. In the other case sodium oxide first entered into chemical combination with a portion of the water (due to the chemical affinity of the one compound for the other) with evolution of heat, and excess of water present dissolved new chemical compound, which then remained in chemical solution. On evaporation solid sodium oxide would be found to have gained in weight in direct proportion with the number of molecules of water required for chemical change from the oxide to the hydroxide.

Changes of this description are constantly taking place, and it is with these we shall particularly deal at a later stage in these articles.

Not only do a great many solids dissolve in water to a greater or less extent, but many gases also dissolve very readily, and to these can be traced phenomenon occurring in some feed waters known as pitting, corrosion and grooving.

The first of these may be very properly described as corrosion, occurring in small spots on parts of a boiler, and is quite distinct from general corrosion, which wastes away an extended area of surface. Pitting is both annoying and generally very destructive, in some cases burrowing holes through the affected parts of a boiler as completely as if it had been drilled. This action was formerly and is to-day occasionally attributed to poor material used in construction, the theory being that weak spots exist and are attacked by corrosive agents found in the material itself. There remains practically no doubt but that a condition of affairs of this kind existing would have an effect on the boiler parts, and would facilitate the pitting action. An explanation of this kind falls very far short of a satisfactory answer, however, in either theory or practice, as it is applicable to very few cases.

Careful experiments made by leading chemists and a review of the whole subject go to prove quite conclusively that pitting occurs most frequently when gases are found dissolved in the water, oxygen and carbonic acid gas being the most active agents, and more especially when present together. These gases under certain conditions are very soluble in water, and in examining a water for boiler feed purposes require just as careful consideration as does dissolved solid.

Atmospheric air dissolves in water very readily, and contains at all times a certain percentage of carbonic dioxide, and here a very peculiar fact is to be noted that has an important bearing on the point before us. It is a well known fact that atmospheric air is composed of nitrogen and oxygen in mechanical combination, four of nitrogen to one of oxygen by volume, or very nearly 79 volumes of nitrogen to 21 of oxygen. When atmospheric air is dissolved in water these proportions are found to have changed said to be due to the greater solubility of oxygen in water.

It is worthy of note that water dissolves very unequal quantities of the different gases, and very unequal quantities of the SAME GAS, at different temperatures. One volume of water absorbs at the temperatures stated in the following table under atmospheric pressure equal to 30 inches of mercury, according to Bunsen, the following volumes of the different gases :

Degrees Fah.	Oxygen (O)	Nitrogen. (N)	Hydrogen (H)	Carbon Dioxide CO_2	Chlorine Cl	Sulphur Dioxide SO_2	Hydric Chloride H Cl
32°	.041	.020	.019	1.80		53.9	505
50°	.033	.016	.019	1.18	2.59	36.4	472
68°	.028	.014	.019	.90	2.16	27.3	441

While not altogether applicable to our point, it may be stated that as the pressure increases a correspondingly larger quantity of the gas is absorbed, and as the temperature increases the solubility of the gas decreases in many cases. (Carefully refer to table on this point.) It is, however, important to note that the pressure which determines the rate of absorption of a gas is not the general pressure to which the water or other absorbing liquid is exposed, but that pressure which the gas under consideration would exert if it were ALONE PRESENT in the space in which the absorbing liquid is in contact. It is necessary to bear this in mind to understand why atmospheric air absorbed by water differs in composition from ordinary air.

As I have said, atmospheric air consists of 79 parts of nitrogen and 21 parts of oxygen. In atmospheric air, acting under a pressure of 30 inches of mercury or one atmosphere, the oxygen exerts a partial pressure of $\frac{21}{100}$, and the nitrogen $\frac{79}{100}$. At 50° F, according to table, one volume of water at atmospheric pressure absorbs .033 volume oxygen and .016 volume nitrogen, supposing these gases to be in a pure state. Then under the partial pressures above indicated water cannot absorb at 50° F. more than $\frac{21}{100} \times .033 = .007$ volumes of oxygen and $\frac{79}{100} \times .016 = .013$ volumes of nitrogen.

Then, in $.007 + .013 = .020$ volumes of atmospheric air absorbed by water there are consequently .007 oxygen and .013 nitrogen, or in 100 volumes, 35 volumes of oxygen and 65 volumes of nitrogen. Atmospheric air then dissolved in water is seen to be very much richer in oxygen than is the air itself in its ordinary condition. This fact is in itself worthy of the most careful consideration, and explains clearly what is too often considered purely accidental phenomena.

Before proceeding to discuss what action takes place during the act of pitting, I wish to digress from the subject to point out to the reader that the capacity of water to absorb gases of fixed chemical compounds, such as carbonic dioxide (CO_2), sulphur dioxide (SO_2), and hydric chloride (HCl), must not be confounded with the behavior of atmospheric air. Thus hydric chloride must not be understood as being absorbed by water in the same proportions as its elements, hydrogen and chlorine. It is a complete gaseous chemical compound of itself, and combines as such; in other words, nitrogen and oxygen retain their own peculiar properties in atmospheric air, but just as soon as hydrogen and chlorine combine together to form hydric chloride, an entirely new chemical compound is formed, with quite different properties from the elements of which it is composed, and with entirely different degrees of solubility.

When water is strongly heated for a long time, atmospheric air is completely expelled, and at once resumes its normal composition; thus we have present a quantity of free oxygen, which is the cause of a great deal of our trouble. While the action of oxygen on iron is well understood, it is not easy to explain the action of gases producing pitting in a steam boiler, particularly to explain why isolated spots are attacked while surrounding metal remains unaffected. If we heat water gradually in a glass retort, open to the atmosphere, bubbles of gas or air expelled from the water are seen clinging to the sides and bottom ; and if we purposely scratch the inner surface of the glass, or in other manner create an imperfection of a similar nature, it presents a wonderful attraction for these little bubbles, more collecting there than at any other part of the retort. And so tenaciously do these bubbles cling to their selected places that it requires considerable agitation to remove them.

In steam boilers the same conditions prevail, and there remains but little doubt that these bubbles contain free oxygen and other gases in a favorable condition to act on the metal beneath. Temperature being high, they necessarily act with a great deal of rapidity. When the oxygen has combined with the iron of the metal, protoxide of iron (FEO) is formed, and a little excresence appears on the surface of the metal, due to the expansion of the iron by the addition of oxygen, and occupying more space than the iron acted upon. Subsequent expansion and contraction causes this small excresence to burst, and leaves a small pit or roughened surface, which readily attracts the gas bubbles, and the process is again repeated until finally a hole has been eaten a considerable distance into or completely through the part affected.

Chapter II.

When we understand what is taking place during the act of pitting, it becomes comparatively easy to suggest a remedy. What is required here is a substance on which the corrosive agent can exhaust itself; and probably the best remedy is a slight coating of lime scale, which can be easily obtained by the use of lime water or milk of lime.

This theory has not, however, been universally accepted as the true cause of pitting (although in the writer's opinion it appears very rational). The cause of this trouble has been attributed by many writers to electrolytic action set up between the impurities of the iron and the iron of the boiler itself, which, being electro-positive to the impurities, gradually disappears while the impurities remain to further the disintegrating action. In support of this theory it became a common practice to suspend zinc in boilers subject to pitting and corrosion, on the assumption that since zinc is chemically more powerful than iron, it would become electro-positive to the iron and thus protect the boiler against electrolytic action at the expense of its own metal. If such is the case, then it becomes very necessary for us to note what may be expected to take place when zinc is suspended in the boiler as suggested.

To get as clear an understanding as possible of this process, let us briefly illustrate what takes place in a voltaic cell, which is practically what we are converting our boiler into with zinc and shell as electrodes and water and its impurities as electrolytes. To this end let us examine the process known as electrolysis, taking for example a dilute solution of hydric chloride, subjected to decomposition by means of electrolysis in a glass vessel so that process may be noted. We find chlorine evolved at the positive pole and hydrogen at the negative pole, the gases being perfectly pure and unmixed. If, while the decomposition of the hydric chloride is rapidly proceeding, we examine the intervening liquid carefully, no apparent movement or disturbance of any kind can be perceived, and nothing in the shape of currents in the liquid or transfer of gas bodily from one pole to the other can be observed, and yet two portions of the hydric chloride separated by two to six inches are actually seen to evolve pure chlorine and pure hydrogen.

There seems but one method of explanation of this singular phenomenon, which is applicable to all similar cases of electrolytic decomposition, and that is to assume that each of the particles of hydric chloride intervening between the electrodes or poles, and by which electric current is conveyed, simultaneously suffer decomposition, the hydrogen travelling in one direction and the chlorine in the other. The neighboring elements being in close proximity to each other, unite to again form hydric chloride and destined to be again decomposed by a repetition of same change. Thus it is each particle of hydrogen may be made to t[illegible] in one direction by becoming successively united to each particle of chlorine between itself and the negative pole; and when it reaches the latter, finding no disengaged particle of chlorine for its reception it is rejected, so to speak, from the series and thrown off in a free state.

Exactly the same thing happens to the chlorine which is travelling in the opposite direction, consequently a succession of particles of hydrogen are thrown off at the negative pole and a corresponding succession of particles of chlorine at the positive. The power of the current is exerted with equal energy in every part of the liquid conductor, though its effects become manifest only at the terminals. The action is purely of an internal nature, and the metallic electrodes or terminals of the battery simply serve the purpose of completing the connection between the latter and the liquid to be decomposed.

Like hydric chloride, all electrolytes, when acted upon by electricity, are split into two constituents, which pass in opposite directions. Substances of the one class, such as chlorine, iodine, oxygen, etc., are evolved at the positive pole, and those of the other class, such as the metals and hydrogen, at the negative pole. It is, though, important to remark that oxygen salts, such as the sulphates and nitrates, when acted upon by the current, do not divide into acid and basic oxide, but into a metal and compound substance or group of elements. Thus sulphate of copper ($Cu\ SO_4$) does not split into SO_3 and $Cu\ O$, but into metallic copper (Cu) and sulphione (SO_4) sulphuric acid ($H_2\ SO_4$) dividing into the same compound and hydrogen. In a similar way it is seen that the part of the electrolyte passing to the negative pole may be a compound consisting of several elements. An illustration of this change is the commonly used sal ammoniac ($NH_4\ Cl$) which is decomposed in such a manner that the ammonium (NH_4) goes to the negative pole, when it is resolved into ammonia (NH_3), the pure hydrogen and the chlorine going to the positive pole.

We must, nevertheless, draw a distinct line between true and regular electrolysis and secondary decomposition brought about by the reaction of the bodies eliminated upon surrounding liquid or upon the substance of the electrodes. When, for example, potassium sulphate ($K_2\ SO_4$) is electrolysed, hydrogen appears at the negative pole together with its equivalent quantity of potassium hydroxide ($K\ OH$), because the potassium which is evolved at the electrode immediately decomposes a portion of the water there present. The chemical reaction takes place as follows:

$$K_2 + 2\ H_2\ O = 2\ K\ O\ H + 2\ H.$$

At the same time the sulphione ($S\ O_4$) which passes to the positive pole takes up hydrogen by decomposing the surrounding water forming sulphuric acid ($H_2\ SO_4$) and liberating oxygen according to following reaction:

$$SO_4 + H_2\ O = H_2\ SO_4 + O.$$

In like manner the sulphuric acid itself is resolved by the current into hydrogen and sulphione, which latter decomposes the water at the positive pole reproducing sulphuric acid and liberating oxygen just as if the water itself were directly decomposed by the current into hydrogen and oxygen. This explains a circumstance that was very puzzling to our early experimenters upon the chemical action of a voltaic battery. The true source of these compounds was traced by Davey in 1807, who, showed very clearly that they proceeded from impurities in the water, or the vessel which contained it, or from surrounding air. He redistilled water at a temperature below boiling, and found when marble cells were used to contain the water intended for decomposition hydric chloride appeared at the negative pole and sodium at the positive, but derived from sodium chloride present in the marble as an impurity. This manifestly proves that water in a pure state is not an electrolyte and is incapable of conveying current, but is enabled to do so if even a trace of saline matter is present.

We have now, I hope, clearly expounded the principles of the voltaic cell. Now, let us consider its practical application for the purpose we have in view. Suppose we have a wire conducting an electrical current ; cut this wire and place both ends in a cell containing water to which we have added some sulphuric acid to add to its conductivity. It will be observed that bubbles of gas are forming on the ends of the wires. These bubbles are simply hydrogen and oxygen obtained as already described. Let us now select for our poles, zinc and wrought iron, to get as nearly as possible the conditions existing within our boiler. If our zinc is pure no perceptible action will take place on immersion in the cold solution. We next immerse our wrought iron plate, and find chemical action is at once set up, hydrogen bubbles rising and metal gradually wasting away. Let us now connect the two wires from the source of electrical energy to the dry ends of our plates, and a complete change of conditions at once takes place.

The hydrogen will still be seen to rise from the wrought iron plate, but the plate itself will cease to dissolve. But the zinc plate will gradually disappear, and just as long as any part of it remains in contact with the water and in electrical contact with the iron, the iron will be protected from decomposition at the expense of the zinc. We can now, I think, perceive clearly the reason for the gradual wasting away of the zinc or positive pole. As the water is decomposed by the passage of the current, the oxygen is attracted to the positive pole, and being practically electrolytic, oxygen or ozone attacks the metals, very actively and destructively, and we find them more or less rapidly wasting away.

We have now before us information to enable us to understand the action of zinc in boilers, and can readily see that zinc can only be successfully used where certain conditions pre-exist. We must first have some solution that makes a good electrolyte, and next see that contact between zinc and shell of boiler is electrically good; further, we must be sure that galvanic action is set up within the boiler. I think it has been amply proven in engineering practice that galvanic action is set up within the boiler due to many causes, such as difference in temperature in different parts of the boiler, thereby causing a current, and generating electricity due to friction; also galvanic action is set up between the different kinds of metal used in and about a boiler, such as composite fittings and steel shell, etc. It is also quite possible to create galvanic action between different parts of the same boiler when a certain portion of the metal is homogeneous, while another is poorly made, due to bad iron, etc. In fact, galvanic action may be set up in a multitude of ways, and it is this very fact that makes the use of zinc in boilers, especially in fresh waters, rather to be condemned than approved, especially when action is not clearly understood. It has lately become a very common practice, especially in marine work, to purposely set up galvanic action within the boiler, by the aid of an external current, to prevent not only corrosion, but the formation of scale, and the system has met with a great deal of success, as it very properly would when conditions are favorable. Marine engineers are, however, exceptionally favored in this respect. Not only does their feed water contain a large quantity of saline matter, but also a certain proportion of free acid, making the solution within the boiler an excellent electrolyte; consequently they have only to see that contact between their zinc and iron electrodes is correct and galvanic action set up to secure good results.

The first essential required is a thorough knowledge of action of zinc in boilers, and secondly, a knowledge of conditions preexisting. Before leaving this subject I wish to point out to the reader that nothing but the purest zinc must be used. Ordinary commercial zinc contains many impurities, and especially must lead be absent. If lead is present it will be found after zinc has wasted away, a new condition of things will exist; the shell of the boiler will become electro-positive and the lead negative, and the cure becomes worse than the disease.

GENERAL CORROSION.

This form of corrosion is in some localities a very common one, and is a peculiarly difficult one to explain in a general way. It is largely due to the presence of free acids, which may be present in the feed water, or may exist as a result of the use of some of the vile nostrums sold as boiler compounds, prepared frequently by people who do not know the first requirements of the substance they sell, except that it will take off scale. When carbonates are absent, free sulphuric acid may be present, especially in mining districts, and chiefly derived from the oxidation of pyrites and sulphides. This acid is also often found in streams passing through manufacturing districts, owing to the refuse from dye works, galvanizing shops, chemical factories, etc., having been discharged into them.

Another fruitful source of free sulphuric acid is the use of kerosene, which is now so commonly used. Kerosene is produced by one of a series of distillations of petroleum, and in its first and crude state is a turbid liquid, having a strong odor and a bluish tinge. To remove these, the refineries give the kerosene a course of treatment with sulphuric acid. Part of this, together with impurities, precipitates as a heavy black sludge. The purified oil is next treated with caustic soda, to neutralize any free acid, and then washed with water. Like many other processes of a similar nature, work is not always well done, and free sulphuric acid remains in solution. The oil itself vaporizes very readily when in the boiler and passes off with the steam. The sulphuric acid being non-volatile, remains behind, and finally becomes sufficiently concentrated to attack the boiler, and corrosion sets in.

A very prolific source of corrosion is also caused by the presence of hydrochloric acid in the water. This is a very fruitful source of trouble in waters containing magnesium chloride in solution, and is often caused in waters containing other salts of magnesia by the use of compounds which reduce salts of magnesia to magnesium chloride. At all temperatures of present boiler practice, magnesium chloride decomposes in presence of water in accordance with following chemical equation :

Magnesium Chloride.		Water.		Magnesium Hydrate.		Hydrochloric Acid.
$Mg.\ Cl_2$	+	$2H_2O$	=	$Mg.\ O_2H_2$	+	$2H\ Cl.$

Reference has been made to the formation of magnesium chloride, and consequently the liberation of hydrochloric acid by the use of compound resolvents. A striking example of this is the practice of adding sal ammoniac, $N\ H_4\ Cl.$, to the feed water to dissolve carbonate of lime, the reaction in this case being :

Sal Ammoniac		Carbonate of Lime.		Chloride of Lime.		Carbonate of Ammonia.
$2N\ H_4\ Cl.$	+	$Ca\ C\ O_3$	=	$Ca\ Cl_2$	+	$(N\ H_4)_2\ Co_3.$

The final result is that a soluble salt added to a water containing an insoluble salt, the insoluble salt is rendered soluble, and consequently no precipitation takes place. Unfortunately, the reaction does not stop here; waters containing carbonate of lime invariably also contain carbonate of magnesia, and the following reaction is set up between the sal ammoniac and the carbonate of magnesia:

Carbonate of Magnesia.		Sal Ammoniac.		Carbonate of Ammonia.		Chloride of Magnesia.
$Mg. Co_3$	+	$2 N H_4 Cl.$	=	$(NH_4)_2 Co_3$	+	$Mg. Cl_2.$

This latter salt undergoes a secondary decomposition as follows:

Chloride of Magnesia.		Water.		Hydrate of Magnesia.		Hydrochloric Acid.
$Mg. Cl_2$	+	$2H_2O$	=	$Mg. O_2H_2$	+	$2H Cl.$

The action of hydrochloric acid differs materially from the action of the sulphuric acid, owing to the fact that it volatizes very readily, and as a vapor passes off with the steam; thus, not only will the boiler itself be attacked, but also the steam pipes, and even the engine. This acid, at temperatures higher than boiling, even in dilute solutions, attacks iron very readily, and is a fruitful source of corrosion and its companion troubles.

Vegetable acids, or, properly speaking, organic acids, while of a feebler nature, will attack iron to some extent, and particularly since these acids are derived from waters usually taken from swamps containing a great deal of vegetable organic matter with very little lime salts. In cold climates the water is also apt to contain a considerable quantity of free oxygen, which adds materially to the corrosive action of the acids present. The presence of the slimy organic precipitate common to waters of this class seems to add to, rather than retard, the work of corrosion.

Whole chapters might be written on the best methods of treating troubles of this kind, but I consider the best advice is to consult some one thoroughly trained in this particular subject, who is not only able to suggest a remedy, but can determine accurately the nature and the cause of trouble, and the slight expense incurred will never be regretted.

Chapter III.

Having discussed the presence of corrosive agents in solution, we now require to turn our attention to the presence of impurities likely to occur as dissolved solids and solids held in mechanical suspension, some of which are liable to form scale or encrustation.

The total solids contained within a boiler feed water may be in either one of two conditions, in mechanical suspension, as small particles, or in chemical solution; and water may contain impurities as per following table:

In mechanical suspension:	Organic matter	Animal. Vegetable.
	Inorganic matter	As sand, mud, etc.
In solution:	Organic matter	Animal. Vegetable.
	Inorganic matter	Scale forming. Non scale forming.

Matter in mechanical suspension, whether organic or inorganic, may be removed by filtration, but matter in chemical solution, as dissolved impurities, cannot be removed by mere filtration, but must receive treatment either by chemicals or heat, the aim being to get a precipitation whereby we have the impurities in condition first named.

I shall not attempt to deal with the whole of the chemical compounds that may at times be found in natural waters, but confine myself to those compounds of common occurrence with which we are all well acquainted. These may be classed as the oxides, chlorides, carbonates, bi-carbonates and sulphates, being the compounds formed by the union of the various acid radicles with the basic radicles or metallic elements, those most commonly found being silicon, aluminum, iron, calcium, magnesium, sodium and potassium.

Before proceeding to discuss the nature of the scale formed, or the action of these various compounds within the boiler, it is first necessary to briefly explain their presence in the water. One of the commonest and most important of these groups of salts, and a group with which we are most frequently called upon to deal, is the carbonates. They are very widely distributed, being found in considerable quantities nearly the world over. Carbonate of calcium is found in the well-known forms of limestone, marble, chalk, coral deposits, etc. Carbonate of magnesium occurs quite frequently as magnesite, and in combination with carbonate of calcium very largely as dolomite.

Carbonate of iron occurs less frequently, and not so largely diffused in nature as siderrite or spathic iron.

The carbonates of the alkaline bases, sodium and potassium, occur very largely in the alkaline districts, but being soluble at all temperatures found in boiler practice, do not play such an important part in engineering practice as scale-forming agents as do the carbonates of the alkaline earth.

The whole of the carbonates are formed by the union of carbonic dioxide (Co_2) with some one of the metallic oxids, such as calcium oxid (CaO), magnesium oxid ($Mg\,O$), sodium oxid (Na_2O), etc.

The usual chemical action taking place may be classed as a double one, carbon dioxide (Co_2) first combining with water (H_2O) to form carbonic acid (H_2Co_3). The metallic oxids just named enter into combination with carbonic acids as follows :

Calcium Oxid.		Carbonic Acid.		Calcium Carbonate.		Water.
$Ca\,O$	+	H_2Co_3	=	$CaCo_3$	+	H_2O.

and

Magnesium Oxid.		Carbonic Acid.		Magnesium Carbonate.		Water.
$Mg\,O$	+	$H_2\,Co_3$	=	$Mg\,Co_3$	+	H_2O.

In this case the bi-valent basic radicles of calcium and magnesium replace the hydrogen of the carbonic acid and the liberated hydrogen enters into combination with the oxygen of the metallic oxid; consequently from the combination of two chemical compounds, as shown in equation, two new compounds, consisting of either carbonates of calcium or magnesium and water, are formed. The combination between the oxide of sodium and carbonic acid is practically the same, with this exception: Sodium is a univalent metal, consequently has the power to replace only one atom of hydrogen. The chemical reaction for the production of sodium carbonate therefore is:

Sodium Oxid.		Carbonic Acid.		Sodium Carbonate.		Water.
Na_2O	+	H_2Co_3	=	Na_2Co_3	+	H_2O.

As a rule, out of all the scale-forming material found in feed waters, none occurs so frequently, nor yet in such large proportion, as does carbonate of calcium; next in order carbonate of magnesium may be said to occur. Carbonate of iron occurs in limited areas and never in large quantities.

The carbonates of calcium and magnesium are very slightly soluble in water, and very rarely exist as such in quantities exceeding two grains per imperial gallon, and it is very rarely that they are present in the water separately, as they usually exist in water together, and in this case the total held in solution never exceeds the maximum quantity of either which the water is capable of dissolving. This small quantity of dissolved solids would have but little effect in a boiler feed water, and draws our attention to a very important fact. If the carbonates of calcium and magnesium are, as stated, nearly insoluble in water, how is it that they predominate as scale-forming impurities and are so often found in chemical solution in boiler feed waters in such large quantities?

If we turn back to the article on dissolved gases, we shall find that many gases are very soluble in water, and it is this fact that plays such an important part in explaining the presence of insoluble carbonates.

Wherever organic decomposition or combustion is taking place, carbonic dioxide (CO_2) is being constantly evolved. This at ordinary pressures and temperatures exists as a gas, and is therefore a constant constituent of the atmosphere; it is also contained in the soil as a product of organic decay.

J. A. Wanklyn, in an excellent work on "Water Analysis," published in London, England, states that "in many natural waters there is more carbonic acid gas in some form or other than any other single foreign material." As already seen, carbonic dioxide is very soluble in water; some is absorbed by falling rain, and a still greater quantity as it passes through the soil. We have already noted the very wide distribution of the various carbonates in nature, and although the carbonates of lime and magnesia are nearly insoluble in water, they are very soluble in water containing carbonic acid.

The carbonates of lime and magnesia appropriate a portion of the carbonic acid equal in quantity to that already existing in combination with their oxids to form the carbonate, thus forming what is known in chemistry as a bicarbonate, according to the following equation:

Carbonate of Lime.		Carbonic Acid.		Bicarbonate of Lime.
$Ca\,Co_3$	+	$H_2\,Co_3$	=	$Ca\,H_2\,(Co_3)_2$.

and

Carbonate of Magnesia.		Carbonic Acid.		Bicarbonate of Magnesia.
$Mg\,Co_3$	+	$H_2\,Co_3$	=	$Mg\,H_2\,(Co_3)_2$.

Both the bicarbonates of lime and magnesia are very soluble in water, and the presence of carbonate of lime and magnesia in boiler deposits may then be explained as follows: The rain reaches the earth charged with a certain quantity of carbonic acid, and in passing through the soil takes up a still greater supply, and after passing through the earth rarely escapes contact with some of the carbonate rocks, which dissolve in it. After passing over these rocks and forming new solutions, the water again reaches the surface and forms the supply of our rivers, lakes or wells, from which we take our boiler feed supplies. These bicarbonates are very unstable salts, and are much more soluble in cold water than hot, owing to the fact that a rise in temperature drives off the excess of carbonic acid, and the bicarbonate is as a consequence reduced to the carbonate, in which condition it is nearly insoluble. When a temperature of 180° F. is reached, a large percentage of the carbonic acid is driven off, and the bicarbonate consequently suffers reduction to the carbonate, and at 290° F. the precipitation is complete. Thus we are readily enabled to account for the presence of the carbonate salts in boiler encrustation.

Next to the carbonates, the sulphates play an important part in feed waters. The sulphates of magnesium, sodium and potassium are all readily soluble in water, and although they play an important part in the treatment of boiler feed waters, need not be referred to here.

Probably no scale-forming salt has given more trouble or been more destructive to boilers than has sulphate of calcium. Sulphuric acids readily attack nearly the whole of the metallic oxids, and especially those under consideration, forming sulphates and water, thus:

Calcium Oxide.		Sulphuric Acid.		Calcium Sulphate.		Water.
CaO	+	H_2SO_4	=	$CaSO_4$	+	H_2O.

Calcium sulphate, or sulphate of lime, is found in nature widely distributed, occasionally in the anhydrous form as anhydrate, and much more commonly as the hydrate known as gypsum. When gypsum is heated to about 240° to 250° F., it loses a large portion of its water of crystallization and becomes what is known to us as plaster of Paris. This product is, as we know, capable of taking up another portion of water and "setting" to a close, hard stony mass. The anhydrous sulphate is nearly insoluble in water, but the hydrated form dissolves fairly readily and up to about 120° Fah.; as the temperature increases the solubility increases.

Above 212° F. solubility decreases very rapidly, and at 300° F. it becomes almost entirely insoluble. Unlike the carbonates, the presence of carbonic acid gas has no effect upon its solubility, its solubility being entirely due to the solvent power of the water itself. When the hydrated sulphate of lime precipitates it loses a portion of its water of crystallization, and when it reaches the boiler plate the balance, and it is consequently converted into the anhydrous state, and this change in crystalline form is largely the cause of precipitates containing sulphate of lime being bound into such hard compact masses and forming such a troublesome scale.

As already stated, sulphuric acid occasionally occurs in streams, etc. If bicarbonate of lime or magnesia are present, free acid will not exist until the salts of calcium and magnesium have been reduced from carbonates to sulphates. The same reduction takes place when water containing sulphuric acid is passed over limestone rocks, and since rain water has been shown by numerous chemists to contain traces of sulphuric acid, the presence of sulphate of lime is largely accounted for. The chlorides of the various metals under consideration are frequently present in feed water, especially sodium chloride, which is simply common salt. Since, however, the whole of the metallic chlorides we have occasion to refer to are easily soluble in water and do not form scale except in extreme cases, we do not require to refer to them at any length, particularly since we shall require to discuss them fully at a later stage, chiefly as to their effect on the scale-forming agents.

The oxides of silicon and aluminum are frequently found in scale, and when present in any quantity form a very troublesome scale. They are not easily soluble in water, but often occur in large quantities where muddy water is used without previous filtration.

CHAPTER IV.

CHEMICAL analysis of a boiler feed water not only enables the chemist to determine the quantity of foreign matter present, but also the condition or form in which it appears as an impurity; it also enables him to express with certainty an opinion as to the nature of scale that will be formed and quantity that may be expected, and thus judge as to the suitability or otherwise of a water for boiler feed purposes. For purposes of illustration I have chosen a number of characteristic samples of water, all of which have, in some respects at least, different properties.

No 1 is a sample of water from an artesian well in the eastern portion of the city of Montreal that shows an almost entire absence of lime and magnesia salts, but which is still strongly impregnated with impurities. A partial analysis shows this water to contain:

Total solids per imperial gallon	36.42	grains.
Made up as follows:		
Sodium chloride (salt)	2.32	"
Sodium sulphate	6.85	"
Alkaline carbonates and bicarbonates with traces of silica	27.25	"

The whole of the foreign matter contained in this sample of water consists of soluble salts in chemical solution, that is to say, salts that have a very high degree of solubility in water, and consequently precipitation of impurities as scale-forming agents cannot occur. Although this is positively a non scale-forming water, it cannot be classed as a good or even fair water for boiler feed purposes in its original form. A glance at its composition shows it to be strongly alkaline and liable to cut the boiler and boiler fittings. As a matter of fact, this is what occurred in actual practice, and users found it impossible to use the water satisfactorily until impurities had been neutralized by chemical treatment.

No. 2 is a sample of water from an artesian well used to supply the town of Montreal West, and may be classed as a fair boiler feed water. As will be seen, this water is very rich in dissolved solids, and also contains a fair percentage of scale-forming material. Partial analysis shows it to contain:

Total solids per imperial gallon	96.2	grains.
Made up as follows:		
Insoluble suspended matter................	1.00	"
Aluminia and peroxide of iron	.20	"
Carbonate of lime	5.20	"
Carbonate of magnesia	3.17	"
Sulphate of soda	13.49	"
Chloride of soda..........................	60.60	"
Alkaline carbonates and bicarbonates......	12.54	"

Here we have an example of water that actually contains scale-forming agents and at same time material necessary to prevent formation into hard scale when precipitated. This water showed in use results that might be anticipated from its composition, precipitating a heavy insoluble sludge at lowest part of boiler, and after boiler had been in use a short time water became both highly concentrated and strongly alkaline, although the boiler was only evaporating about 700 gallons of water per day; a sample of water drawn from the boiler three weeks after being put in use, analysis showed it to contain an enormous amount of dissolved solids held in solution, composition of impurities being as follows:

Total solids per imperial gallon...........	2796.36	grains.
Insoluble suspended matter...............	6.72	"
Chloride of soda......	1940.40	"
Sulphate of soda	425.28	"
Alkaline carbonates and bicarbonates.....	398.48	"
Hygroscopic water......................	25.48	"

So strongly alkaline had the water become that brass fittings on boiler were being attacked, and wherever a small leak occurred deposits formed on outside of boiler, which is a marked characteristic of the behavior of the soda salts. At no time, however, during the last four years has any scale been found, a heavy sludge precipitating, having the following composition:

Silica	6.44%
Aluminia and peroxide of iron	16.32%
Carbonate of lime	54.92%
Carbonate of magnesia	7.40%
Sulphate of soda	2.37%
Chloride of soda	10.80%
Carbonates of soda and potass	1.25%

The presence of the soluble soda salts in the sludge may be explained by remarking that the sludge was of such a consistency that a quantity of water had to be withdrawn at all times with the sludge. Until the composition of impurities contained within this water was known a great deal of difficulty was experienced in its use, particularly by foaming. The only treatment required, however, is to keep the water within the boiler from becoming too concentrated by frequent blowing off, and good results are now being obtained from its use.

Samples 1 and 2 mark distinct classes of feed waters. In No. 3 we have a sample of water of another type, an excellent water for boiler feed purposes, and used largely by both the Grand Trunk and Canadian Pacific railway companies, for use in the boilers of their locomotives. This sample was obtained from Brampton, Ont., and is supplied to the town by means of gravitation from a small lake situate a few miles north of the town. Analysis shows it to contain but a small quantity of dissolved solids and to be remarkably free from lime and magnesia salts, composition of impurities being:

Total solids per imperial gallon	6.00	grains.
Insoluble suspended matter	.40	"
Carbonate of lime	2.85	"
Carbonate of magnesia	.30	"
Chloride of soda	1.20	"
Sulphate of soda	.48	"
Alumina and peroxide of iron (traces).		

This is a type of feed water that tends to make engineers happy, and requires but occasional washing out to dispense with either chemical or mechanical treatment.

Samples No. 4, 5 and 6 show examples of scale-forming waters in various forms.

No. 4.—Sample from Walkerton, Ont., shows a water rich in lime and magnesia salts existing in solution in the water as bi-carbonates and precipitating as their respective carbonates :

Total solids per imperial gallon	21	grains.
Insoluble suspended matter	.80	"
Carbonate of lime	12.12	"
Carbonate of magnesia	6.66	"
Chloride of soda	1.20	"

Also traces of aluminia and peroxide of iron.

Sample No. 5.—Sample of water from artesian well in eastern portion of the city of Montreal :

Total solids per imperial gallon	43.7	grains.
Insoluble suspended matter	2.04	"
Carbonate of lime and magnesia	14.32	"
Sulphate of lime	12.65	"
Chloride of soda	9.38	"
Alkaline carbonates and bicarbonates	5.31	"

Sample No. 6.—Sample of water from factory at New Toronto, Ont:

Total solids per imperial gallon	141.6	grains.
Insoluble suspended matter	1.00	"
Alumina and peroxide of iron	.80	"
Carbonate of lime	27.48	"
" " magnesia	20.45	"
Sulphate of lime	37.36	"
Chloride of soda	54.60	"

A review of the impurities contained in these various samples shows very clearly how important this part of our subject becomes, and how widely different and varied in quantity are the impurities contained in the various feed waters throughout the country. I have said that when the nature of the impurities present is known that the effects resulting from the use of various waters for boiler feed purposes can be ascertained. This is well illustrated by the results obtained from the use of the various samples chosen for purposes of illustration from a large number of feed waters examined in my laboratory.

No. 1 and 2 I have already referred to at length. No. 3 is a class of water occasionally met with and predominating in some districts, and is a type of excellent water for the purpose indicated, and may be used without previous treatment with safety.

No. 4 is also a good boiler feed water, containing the whole of its impurities in such a condition that a physical change is all that is needed to render greatest portion of impurities insoluble, and consequently in such a condition that mechanical filtration will remove them from the water. As a matter of fact the users complain that while they had no scale in their boilers a very heavy scale formed in the heater, sample of which I received and analyzed with the following result:

Insoluble	.38%
Alumina and peroxide of iron	1.10%
Carbonate of lime	92.08%
" " magnesia	5.60%

Scale was light, very porous, and easily removed, and is a good example of the change taking place as set forth in last month's contribution on this subject when the water is sufficiently heated to drive off excess of carbonic acid and the insoluble carbonates of lime and magnesia are at once precipitated.

Sample 5 shows a type of water that has actually a double effect, a reaction setting up between the alkaline carbonates and the sulphates of lime and precipitating a sludge, balance of sulphate of lime bonding with carbonates of lime and magnesia and forming heavy scale.

Sample 6 shows a sample of water that belongs to a class that should not be used for boiler feed purposes if any other water can be obtained, and requires both chemical and mechanical treatment, scale formed from this water, as is to be expected from composition of impurities, being exceedingly hard, tenacious and troublesome.

Chapter V.

Having determined the nature of impurities contained in the feed water, it next becomes an important consideration as to what will be the nature of scale formed when impurities are precipitated, or what effect the water will have on boiler parts provided no scale-forming material is present.

It is quite obvious that a water containing such impurities as those in sample No. 1 described in last chapter cannot form scale except at very high degrees of concentration, or when water within the boiler has become completely saturated; then, of course, crystallization will begin, but crystals will again dissolve when unsaturated molecules of water are brought into contact with the crystals. This form of scale will never be met with except in cases of extreme ignorance or carelessness, and need not be discussed at any length. As will be observed, however, the whole of the impurities in this water are non-volatile in the presence of heat at temperatures met with in ordinary boiler practice, and consequently as water evaporates into steam impurities are left behind, and a gradual increase in density takes place. The impurities, being soluble in water, remain in solution, and water in boiler becomes more and more saturated. Impurities being alkaline in reaction, a very high degree of alkalinity is in course of time reached. While the alkalies do not, as a rule, attack iron very readily, they attack brass alloys vigorously, reducing the metallic elements and causing a great deal of trouble, and in many cases serious damage has resulted.

Another very important reaction that sets in in waters of this kind is the formation of magnesium chloride, as mentioned in earlier articles, and as a consequence, free hydrochloric acid is liberated, which, being very corrosive even when diluted, no part of the system from boiler to exhaust on engine is quite free from danger of corrosion from this source.

The conditions under which a boiler feed water is to be used plays a very important part in the treatment required and the effect a water will have on the boiler parts. For instance, where good water is scarce, or in plants where economy has been carefully studied, it has become a common practice to use surface condensers, draining condensed water to a hot well and returning therefrom to boiler, using over and over again. In thoroughly equipped plants loss by evaporation is very small and quantity of fresh water used small, consequently the water may be returned to boilers many times daily. Waters that are low in dissolved solids in the first instance deposit very little scale-forming material. Condensed water from hot well being practically a distillate from original water, contains no scale-forming agents, and is, in the absence of oil practically pure. This may, at first glance, be considered a very happy condition of things ; unfortunately, practice has shown it to be in many cases the reverse. Instead of scale forming, the boiler parts are very often found to have suffered from pitting and corrosion. Explanation of this condition appears difficult, and corrosion of boilers has often been charged to presence of organic acids, when, as a matter of fact, the purity of the water itself may be said to be responsible. When water is sent to hot well it is brought into contact with atmospheric air, and, being pure, readily absorbs or takes into solution some of the gaseous elements contained therein. Reference to my first article on this subject will readily explain the cause of pitting or corrosion due to the presence of free oxygen in the water.

We have already seen that the most troublesome scale-forming impurities held in chemical solution are the salts of lime and magnesia as usually met with in feed waters.

As conditions of use vary, so will nature of scale formed vary. Particularly is this the case with scale formed from the salts of magnesia. These salts in many cases are peculiarly unstable, and this fact is not sufficiently taken into account either by chemists or engineers. The carbonates of lime are, except in very exceptional cases, always accompanied by a certain proportion of the carbonates of magnesia. Personally, in my experience I have never found carbonate of magnesia entirely absent from a natural water when carbonate of lime was present. I have, as would naturally be expected, found carbonate of magnesia present when the entire lime was present as sulphate.

In examination of a boiler scale, it occasionally happens that the general appearance of a scale is such as would lead the engineer to suspect the presence of a strong bonding agent, such as sulphate of lime, while complete analysis shows the scale to be practically free from sulphates. While the carbonates of lime and magnesia form in presence of organic matter, and especially in high pressure boilers, hard compact scale in many cases, analysis of scale will show that the whole of the bases of these metals cannot be combined with carbonic anhydride. The reason for this is evidently the reducing of part of one of the compounds to an hydro-oxide. Since magnesia is the least stable of the two bases, it is the writer's opinion that the magnesium carbonate immediately in contact with the boiler plate is reduced from a carbonate to an hydrate, and carbonic acid gas liberated. When this occurs in presence of sulphate of lime a particularly obnoxious scale is formed.

A sample of scale sent to my laboratory was of a very troublesome nature, being hard and tenacious, and having very high power as a non-conductor of heat; while it was, according to sample, less than ¼-inch thick, still its construction made it extremely dangerous. Subsequent analysis proved it to have the following composition :

Silica	9.66%
Alumina and peroxide of iron	3.44%
Sulphate of lime	57.37%
Carbonate of magnesia	27.12%
Magnesium hydro-oxide	2.07%
	99.66%

In this case a portion of the magnesium carbonate through the action of heat had been reduced according to following equation :

$$Mg\,CO_3 + heat = Mg\,O + Co_2,$$

the oxide of magnesia thus formed then combining with water to form the hydro-oxide, which is only partially soluble in water.

$$Mg\,O + H_2\,O = Mg\,(OH)_2.$$

The hydro-oxide is extremely fine, and under conditions existing within the boiler forms a ready bonding material, and especially so in presence of sulphate of lime.

The carbonates of lime and magnesia, when precipitated at such a low temperature, form porous, easily-removed scale, having very low specific heat, consequently cannot be classed as equally dangerous with those scales of more compact construction. Some idea of nature of scale formed can be arrived at from a study of the physical and chemical properties of the following samples of scale analyzed in my laboratory.

The first is a sample of scale formed from water containing salts of both lime and magnesia, and both hard and tenacious, containing the following parts in 100 :

No. 1. Supplied from Montreal, Que :

Silica	1.56
Alumina and peroxide of iron	4.30
Carbonate of lime	26.95
Sulphate of lime	52.65
Carbonate of magnesia	14.20

No. 2. Sample of scale from New Toronto, Ont.—Shows a rather uncommon condition of scale forming. As seen by composition of scale, a large quantity of mud (greatest portion of which must have been held in mechanical suspension) was present; this, combined with sulphate of lime, formed a particularly troublesome scale. The composition of impurities in the water from which this scale was formed is illustrated in sample No. 6, preceding

chapter, and is worthy of remark for two important reasons: First, analysis of water shows very little alumina present, consequently very little mud was held in suspension, while scale shows a large quantity of alumina. This difference is accounted for by the fact that weather conditions had much to do with the presence of mud, and sample sent for analysis showed water under best possible conditions. Secondly, it will be observed that water contains both carbonates of lime and magnesia, while carbonate of lime is entirely absent from scale. This circumstance at first somewhat puzzled the writer, until he ascertained that the engineer in charge was using refined coal oil to remove scale. As is very often the case, oil contains excess of free sulphuric acid acquired during process of refining in sufficient quantity to reduce the whole of the carbonate of lime to sulphate, and also a portion of the carbonate of magnesia to sulphate of magnesia, which latter, being soluble in water, does not appear in the scale.

This sample of scale contains the following parts in 100:

Silica	3.98
Alumina, with traces of peroxide of iron	33.80
Sulphate of lime	53.52
Carbonate of magnesia	8.78

No. 3. Sample of scale from Walkerton, Ont.—Light, porous, and easily broken or removed, a typical type of carbonate scale formed at low temperatures. Composition:

Acid insoluble	.38
Alumina and peroxide of iron	1.10
Carbonate of lime	92.08
Carbonate of magnesia	5.60

Carbonate in presence of organic matter form in many instances very hard scales, degrees of hardness varying with nature of organic matter present.

No. 4.—Sample No. 4, received from London, Ont., is an excellent type of scale of this kind, being very hard and tenacious. The organic matter present in this case was largely composed of oil, which by action of heat has become carbonized, and although scale was not more than ¼ inch thick, it was of a very dangerous type. Composition :

Acid insoluble	.70
Alumina and peroxide of iron	.75
Sulphate of lime	2.33
Carbonate of lime	80.07
Carbonate of magnesia	9.91
Organic matter	6.04
	99.80

Another sample of scale with nearly the same composition, thicker, but much coarser in granular construction, due to difference in nature of organic matter, yielded on analysis :

Acid insoluble	.30
Alumina and peroxide of iron	.70
Sulphate of lime	3.32
Carbonate of lime	83.75
Carbonate of magnesia	6.20
Organic matter	6.01
	100.28

The loss occasioned by allowing such formations as above to remain on the sheets and tubes of a boiler is so important a factor in economy that it is almost impossible to estimate it. It has been stated on good authority that the formation of an incrustation $\frac{1}{16}$ of an inch in thickness will increase the fuel consumption 12% over a boiler working under similar conditions with clean shell and tubes. This statement is, however, obviously in error, since scale of different composition has different heat conducting powers, and loss must vary in accordance with composition of scale, as well as with variation in thickness. The fact remains that the incrustation formed within a boiler has a very much lower conductivity than has the plate of the boiler itself, even under most favorable conditions, so that loss is bound to occur if incrustation is allowed to accumulate ; and loss is not only loss of heat and consequently loss of fuel, but serious damage to boiler may occur. Such is the non-conducting power of many even very thin scales that plates are liable to become over-heated, while scale has a high non-conductivity, when interposed between boiler shell and water it has very low tensile strength; consequently, when plates become overheated, internal pressure forces the affected part outward, and boiler is badly damaged, even if serious explosion does not occur.

Chapter VI.

Having considered the scale forming properties of various impurities contained in natural waters, it naturally now requires our attention to be drawn to remedial measures. This we can only discuss in a general way, since conditions of use and impurities in feed waters vary so widely; it is obviously impossible to lay down any single method to suit all cases. Perfectly satisfactory results can only be obtained by individual examinations of each case, taking into consideration not only condition and nature of impurities in feed waters, but also the condition of service and style of boilers or other heating apparatus in use.

While we cannot lay down a rule and formula adapted to each case, we can, at least, intelligently discuss the nature of the reaction it is our desire to bring about, and in this way, I hope, enable the engineer to have reliable data at hand for his guidance.

As already pointed out during the early stages of these articles, the solid impurities contained in the feed water may be in either of two conditions—suspended mechanically, or held in solution. The first of these has quite as important a bearing upon final results as has the latter, and requires just as careful consideration. Since, however, matter held in mechanical suspension requires nothing but mechanical treatment or filtration to effect removal, the question does not involve any serious difficulty. The writer cannot impress too strongly, however, upon his readers the very great importance that this kind of impurity has upon formation of scale. It is comparatively easy in many districts, for various reasons, for the pumps to be continually delivering to the boilers varying quantities of finely divided clay, sand, etc., when water on surface of source of supply appears to be perfectly clear, and presence of such impurities is not even suspected until the engineer finds his boilers coated with thick scale of a most dangerous type. Where there is the slightest danger of anything like this occurring, engineers should insist upon a first-class filtering medium being placed between source of supply and boilers, and small first cost of a real first-class article of this kind will be amply repaid in a very short time.

The idea that any kind of water will do for boiler feed purposes so long as it is "wet" is far too prevalent. The presence of such impurities as are usually met with in mechanical suspension has a very important bearing on scale formation, especially so in the presence of salts of lime and magnesia, and the extraction of matter held in mechanical suspension in very many cases largely tends not only to reduce, but to actually prevent the formation of scale, and the first important requirement necessary for the building up of a good feed water is that it should be clean. As a matter of fact, insoluble matter in suspension should in no case be allowed to exceed .5 grains per gallon. If care and judgment are exercised a good filter can be easily secured, set up, and kept clean, and a very large proportion of the matter held in mechanical suspension removed.

Impurities in solution are of quite a different class, inasmuch as they cannot be extracted by mere mechanical filtration, since by being in solution in the water they will pass through the finest filter, and as a consequence before they can be extracted a change of state must take place, and they must be changed from soluble to insoluble salts, whereby they appear in condition first mentioned and in a position to be extracted by purely mechanical means.

Before proceeding to discuss how this can be brought about, I wish briefly to refer to my first article on this subject dealing with the application of electrical current for prevention of corrosion. A great deal has been claimed by various inventors and writers as to the adaptability of methods of this kind for preventing the formation of scale and effecting its removal after formation. In some instances remarkable success was attained, in many others complete failure resulted. The method has not been universally successful, nor can it be, for many reasons.

I have already pointed out that there are certain scales such as those formed from the carbonates of lime and magnesia that are not very compact, but porous and easily penetrated by the water, consequently the water easily reaches the boiler shell, and when brought into contact with a voltaic current decomposition of the water as an electrolyte sets in, and the hydrogen gas bubbles which form on the iron plate very soon form a thin film of hydrogen gas, interposed between the scale and the plate; as a consequence, scale having poor adhesive qualities soon peels off. Such a result cannot be obtained except in the presence of fairly pure carbonate scale.

Other scales such as are formed from carbonate of lime and organic matter, sulphate of lime, etc., are hard, compact, tenacious in their hold upon iron, and quite impervious to water. Under such conditions as these decomposition of the water cannot take place in contact with the plate, and consequently the thin film of hydrogen gas cannot form between the boiler and the plate.

The methods usually adopted to prevent the formation of scale are to render the scale forming impurities insoluble by physical or chemical changes, thus precipitating impurities either previous to or after reaching boilers. It will be readily seen that before treatment of this kind can be effective certain precautions must be taken.

First—precipitate so formed must be of such a nature that it will not harden or bind together into scale; next, chemical compounds added must also be of such a nature that they themselves will neither form scale nor yet attack the boiler parts, as with either of these it is quite possible to get, as a final result, a condition of affairs worse in effect than would result from impurities originally existing.

A process for softening water, originating from Scotland and known as the Porter-Clark process, may here be referred to as a very useful method for improving feed waters containing the soluble bi-carbonates of lime and magnesia.

This method consists essentially in adding to the feed water a quantity of lime water which first combines with free carbonic acid to form bi-carbonate of lime, and then combining with the excess of carbonic acid contained in the bi-carbonate thus formed as with the excess of carbonic acid already existing as bi-carbonate of lime and magnesia—this final reaction is represented by following equation (in the case of lime salts, a similar reaction taking place with magnesia.)

Lime Water.		Bi-Carbonate of Lime.		Carbonate of Lime.		Water.
$Ca(OH)_2$	$+$	$Ca(HCO_3)_2$	$=$	$2CaCO_3$	$+$	$2H_2O$

Both the carbonate of lime and magnesia are insoluble at 211° F., and nearly so at 60° F., so that the separation of the precipitate becomes mechanically possible.

As will readily be seen, however, care must be taken to add just the quantity of lime required to effect precipitation of the bi-carbonate, as carbonate or calcium hydro-oxide will pass on to the boiler and deposit lime on the boiler parts as evaporation proceeds, and if in any great excess, a worse scale will be formed than would have been formed if original matter had been allowed to deposit in the boiler. Moreover, since action of lime water is limited to excess of carbonic acid, free or combined with lime and magnesia as bi-carbonates, no reaction will set in between sulphate of lime and lime water, consequently use of this process is limited to waters rich in bi-carbonates, and may be easily detrimental if applied to waters containing much sulphate of lime, particularly if any excess is added, as then the whole of the essential requirements for the formation of a hard compact scale would be present.

It was originally my intention to show the reaction that would set up between a number of the many compounds on the market, but I find to do this, subject will become unreasonably long. I will then confine myself to a few of the most commonly used substances.

Possibly the chief of these is common hydrated carbonate of soda, or what is commercially known as "sal soda." This compound is largely used for softening water both of temporary and permanent hardness, reactions setting in with both bi-carbonate and sulphate of lime, as shown in equation :

Bi-carbonate of lime (soluble).		Carbonate of soda (soluble).		Carbonate of lime (insoluble).		Bi-carbonate of soda (soluble).
$Ca(HCO_3)_2$	+	Na_2CO_3	=	$CaCO_3$	+	$2NaHCO_3$

In this case the basic carbonate of soda absorbs or combines with the excess of carbonic acid combined with carbonate of lime and soluble bi-carbonate of soda, and insoluble carbonate of lime is formed. (Note, the reaction with the magnesia salts is similar.)

A reaction also sets in between the sulphate of lime present and the carbonate of soda ; thus :

Sulphate of lime.		Carbonate of soda.		Carbonate of lime.		Sulphate of soda.
$CaSO_4$	+	Na_2CO_3	+	$CaCO_3$	+	Na_2SO_4

Another commonly used and useful reagent is the tribasic phosphate of soda, which is in many cases to be recommended as a good reagent, its chief property being the ease with which the reaction sets in and the entirely unhardenable properties of the precipitate. With sulphate of lime the reaction is :

Tri-basic phosphate of soda.		Sulphate of lime.		Phosphate of lime.		Sulphate of soda.
$2Na_3PO_4$	+	$3CaSO_4$	=	$Ca_3(PO_4)_2$	+	$3Na_2SO_4$

The chief objection to use of chemical compounds of this type is their property of throwing precipitates down, which, if allowed to accumulate, become very troublesome, and, to overcome this, frequent efforts are being made to introduce compounds that will bring about a chemical change but leave the product solubie in water. A great deal may be said for and against use of compounds of this kind—particularly against.

Many compounds of this nature contain a compound known as "sal ammoniac," a sait known in chemistry as chloride of ammonia, or muriate of ammonia, and having the composition NH_4CL.

The reaction between the lime salts and ammonium chloride is a very distinctive one; taking, for instance, sulphate of lime, we get:

Sulphate of lime.		Sal ammoniac.		Chloride of lime.		Ammonium sulphate.
$Ca\,SO_4$	+	$2NH_4Cl$	=	$CA\,Cl_2$	+	$(NH_4)_2SO_4$

Both sulphate of ammonia and chloride of lime (note 1) are easily soluble in water, and a high degree of concentration would have to be reached before deposit of solid matter could take place; but, as I have already pointed out, natural waters containing lime salts, either sulphate or carbonate, nearly always contain magnesia in some form or other, and I may be pardoned for once more referring to the great danger attendant upon the use of sal ammoniac in presence of magnesia. Taking, for instance, magnesia as commonly present as bi-carbonate, a reaction between this salt and sal ammoniac would set up as follows:

Bi-carbonate of magnesia.		Sal ammoniac.		Magnesium chloride.		Bi-carbonate of ammonia.
$Mg\,(HCO_3)_2$	+	$2NH_4Cl$	=	$Mg\,Cl_2$	+	$2NH_4CO_3$

Magnesium chloride is very unstable, and in presence of heat at once breaks up into oxide of magnesia and hydro-chloric acid. The acid, being volatile, passes off with the steam, and plays havoc with steam pipes and engine valves; while magnesia salt is in even worse shape than it was originally, since oxide of magnesia is a very fine substance, entirely insoluble in water, and forming a ready bonding agent. Any compound containing even a small percentage of sal ammoniac should be looked upon with suspicion, unless magnesium salts are entirely absent from feed water.

NOTE.—$Ca\,Cl_2$ must not be confounded with the compound usually sold as a disinfectant under the name of chloride of lime, which is a mixture of chloride and hypochlorite of lime.

CHAPTER VII.

ANOTHER commonly met compound of a similar type is one containing large percentages of caustic alkalies, usually crude caustic soda. The reaction between sulphate of lime held in solution and caustic soda is similar to reactions already cited.

Sulphate of Lime.		Caustic Soda.		Calcium Hydro-Oxide. (Lime)		Sulphate of Soda.
$Ca\,SO_4$	+	$2Na\,OH$	=	$Ca\,(OH)_2$	+	$Na_2\,SO_4$

A similar reaction sets up between carbonate of lime and caustic soda. Water within the boiler soon becomes strongly alkaline and attacks brass and composite fittings very vigorously, also is very prone to foam; particularly is this the case if any saponifiable oil finds its way to the boilers. Compounds containing quantities of caustic soda in the absence of neutralizing agents can be with safety avoided.

Innumerable compounds have been introduced on the market containing organic acids, and some of these have good properties to recommend them. Chief among these are compounds containing "tannin" or tannic acid. Rogers' process for the prevention of formation of scale consists essentially in the use of sodium tannate, which is a very useful reagent when properly made and applied. A reaction sets in between carbonate of lime and sodium tannate whereby insoluble amorphous tannate of lime is precipitated and sodium carbonate is formed, which in time acts upon any sulphate of lime present, reducing it to a carbonate of lime, thus leaving it in a position to be acted upon by a fresh supply of sodium tannate. Such reactions as these have sound chemical reasoning to recommend them. Care should be taken, however, that an excess of acid is not present in the solution, or damage to the boiler will occur. If sodium tannate is at all pure and made by trained chemists the reaction should always leave sufficient alkali present within the boiler to counteract the injurious effect of free tannic acid.

It will be seen from the foregoing that boiler feed waters are subject to a wide range of impurities and in widely apart quantities, so much so that the use of no single boiler compound can be relied on to attain satisfactory results. Each particular case must have individual attention. Where methods of this kind have been adopted and practical experience has been brought to bear on the subject, wonderful success has been attained. This is evidenced by the almost remarkable success that has been attained by such men as Geo. W. Lord, whose compounds to-day stand so high in the annals of steam engineering that genuine compounds bearing this name are now accepted without question.

Treatment by chemicals aims to precipitate scale forming material as an insoluble, unhardenable sludge which can be easily separated from the water.

This method has very serious drawbacks, inasmuch as precipitation takes place within the boiler itself, and a thick pasty mass is liable to form directly over the fire box in certain styles of boilers of such a nature as to be quite as dangerous as the formation of the scale itself. We can then readily see that a successful method of dealing with scale forming waters demands both chemical and mechanical treatment—chemical treatment to precipitate scale forming agents, and mechanical treatment to extract this precipitate previous to delivering water to the boilers.

Every plant that makes any attempt at economy is provided with some means of heating feed water previous to delivering to boiler. The effect of this heater is to bring about a physical and chemical change on certain of the impurities contained by the water, and the presence of heat tends to aid precipitation and hasten the action of reagents; consequently all compounds should be fed into water gradually in sufficient quantity (previously determined) previous to water entering heater, when action will set in. Many of the manufacturers claim to extract the whole of the impurities at the heater by the simple addition of heat, while they are enabled, if a sufficiently high temperature can be reached, to cause precipitation of impurities. It is not quite as clear that this precipitate can be at once separated. Usually this precipitate passes over with the water to the boiler and is of an extremely fine nature whether chemical or physical means have been chosen to bring about precipitation. To prevent this a filtering arrangement, as shown in Fig. 1, is to be recommended.

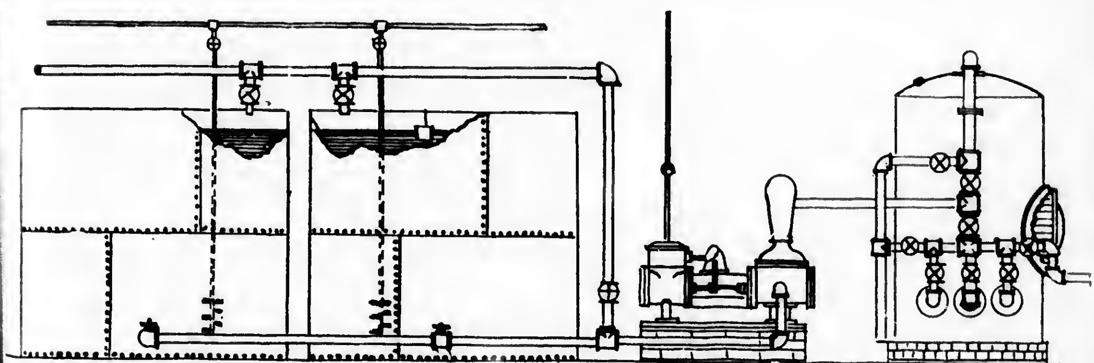


FIG. 1.

This arrangement is intended to use two tanks of required capacity into which a definite quantity of reagent has been added and the whole is heated to about 212° Fah. water being fed from each tank alternately to boilers, sufficient time being allowed to lapse to complete chemical reaction before water is passed through filter intervening between tank and boiler. While these tanks are a distinct aid to the efficient working of the filter, they are by no means an absolute necessity. Water could be passed directly from heater to pumps, thence through filter to boiler. With care in choice of a reagent a method of this kind ensures clean boilers and successful treatment of waters otherwise unfit for boiler feed purposes.

Since, however, in bad waters filter is liable to be given a great deal of work, it is absolutely necessary that sure and quick methods for cleaning of filters are provided, and engineer requires to fully satisfy himself on this point before undertaking installation of a purifying plant on this principle.

In waters liable to throw down heavy precipitates in the absence of a filtering medium, or in small plants where capital investment becomes excessive for filtering apparatus, great care should be exercised in the choice of boilers. Construction should be such that all precipitates will deposit on lowest and coolest part of

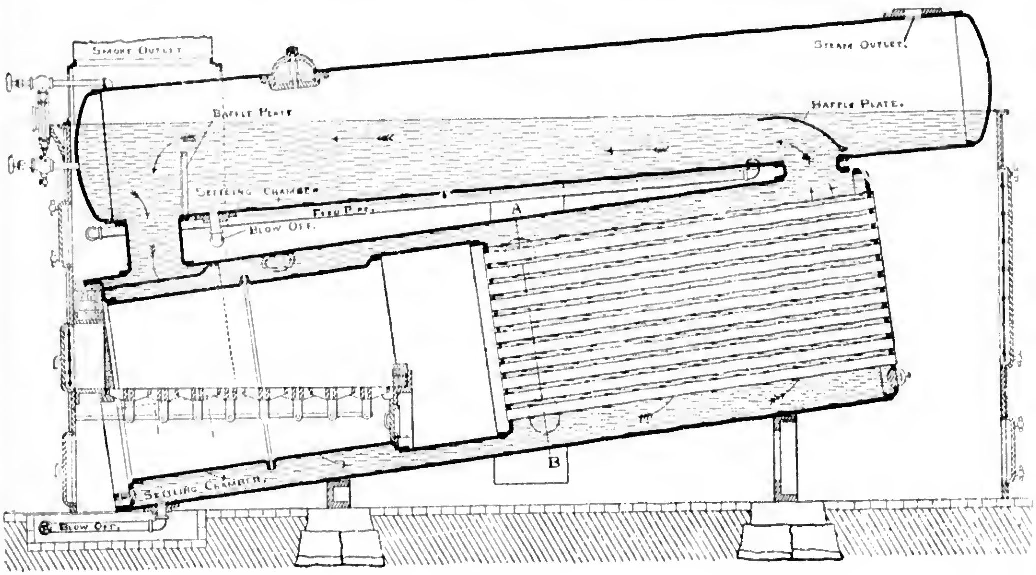


FIG. 2.

boiler at a point easily accessible and easily blown out. (See Fig. 2.)

This shows a type of boiler constructed with a view of securing precipitation of scale-forming impurities before water comes into actual contact with flues and plates of boiler exposed to high temperatures. Water containing the bi-carbonates of lime or magnesia or other salts that simply require heat to cause change of state from soluble to insoluble salts, being fed into the upper portion of boiler or portion used for steam drum, separation and precipitation would take place gravitating to lowest point or immediately behind baffle plate in front end of boiler, where blow-off is situated.

A type of boiler that has in the writer's experience given excellent satisfaction in this respect is illustrated in Fig. No. 3.

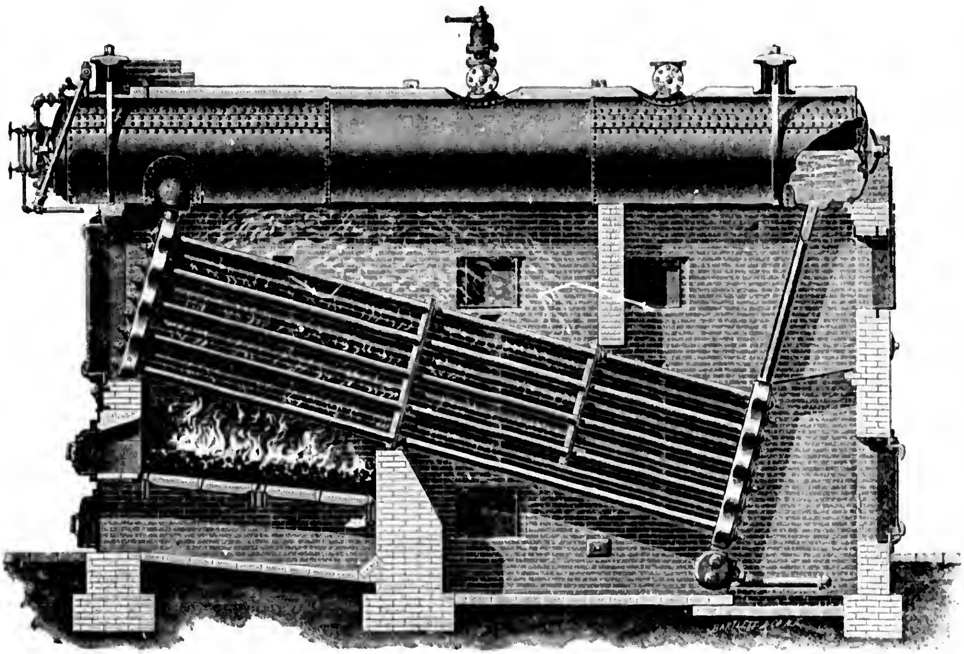


FIG. 3.

It will be noted that mud drum is provided at lowest point in this boiler, and placed in such a position that no actual contact with high temperature gases can occur; when waters have been treated as suggested, precipitate will follow current to lowest point and then settle. In this case mud drum acts as a receptacle for this precipitate, and being arranged in form indicated by cut, sludge or precipitate is concentrated in ready form for blowing out, and it has been the writer's privilege to have examined boilers of this type using waters that had been treated with chemical compounds and blow-off opened for a short time as occasion required to get rid of sludge, that were practically clean, although they had been in almost continuous use for nearly four months.

Both these boilers show distinctive types of mechanical arrangement designed to assist the water chemist in his work, and in closing these articles I wish to add my quota of thanks to the mechanical genius that enables this important question to be dealt with so successfully.

TABLE OF PROPERTIES OF SATURATED STEAM.

(From Peabody's Tables.)

Pres. lbs. per sq. in. above vacuum.	Temp. in deg. Fah.	Tot. in ht. units fr m w'tr at 32°.	Heat in liq'd frm 32° in units	Heat of vapor't'n or latent h. in h. u.	Den'y or wt. of cub. feet in lbs.	Vlm. of 1 lb in cu. ft.	Factor of equiv'l't evapor'n at 212°.	Total pressure above vacuum.
1	101.99	1113.1	70.0	1043.0	0.00299	334.5	.9661	1
2	126.27	1120.5	94.4	1026.1	0.00576	173.6	.9738	2
3	141.62	1125.1	109.8	1015.3	0.00844	118.5	.9786	3
4	153.09	1128.6	121.4	1007.2	0.01107	90.33	.9822	4
5	162.34	1131.5	130.7	1000.8	0.01366	73.21	.9852	5
6	170.14	1133.8	138.6	995.2	0.01622	61.65	.9876	6
7	176.90	1135.9	145.4	990.5	0.01874	53.39	.9897	7
8	182.92	1137.7	151.5	986.2	0.02125	47.06	.9916	8
9	188.33	1139.4	156.9	982.5	0.02374	42.12	.9934	9
10	193.25	1140.9	161.9	979.0	0.02621	38.15	.9949	10
15	213.03	1146.9	181.8	965.1	0.03826	26.14	1.0003	15
20	227.95	1151.5	196.9	954.6	0.05023	19.91	1.0051	20
25	240.04	1155.1	209.1	946.0	0.06199	16.13	1.0099	25
30	250.27	1158.3	219.4	938.9	0.07360	13.59	1.0129	30
35	259.19	1161.0	228.4	932.6	0.08508	11.75	1.0157	35
40	267.13	1163.4	236.4	927.0	0.09644	10.37	1.0182	40
45	274.29	1165.6	243.6	922.0	0.1077	9.285	1.0205	45
50	280.85	1167.6	250.2	917.4	0.1188	8.418	1.0225	50
55	286.89	1169.4	256.3	913.1	0.1299	7.698	1.0245	55
60	292.51	1171.2	261.9	909.3	0.1409	7.097	1.0263	60
65	297.77	1172.7	267.2	905.5	0.1519	6.583	1.0280	65
70	302.71	1174.3	272.2	902.1	0.1628	6.143	1.0295	70
75	307.38	1175.7	276.9	898.8	0.1736	5.760	1.0309	75
80	311.80	1177.0	281.4	895.6	0.1843	5.426	1.0323	80
85	316.02	1178.3	285.8	892.5	0.1951	5.126	1.0337	85
90	320.04	1179.6	290.0	889.6	0.2058	4.859	1.0350	90
95	323.89	1180.7	294.0	886.7	0.2165	4.619	1.0362	95
100	327.58	1181.9	297.9	884.0	0.2271	4.403	1.0374	100
105	331.13	1182.9	301.6	881.3	0.2378	4.205	1.0385	105
110	334.56	1184.0	305.2	878.8	0.2484	4.026	1.0396	110
115	337.86	1185.0	308.7	876.3	0.2589	3.862	1.0406	115
120	341.05	1186.0	312.0	874.0	0.2695	3.711	1.0416	120
125	344.13	1186.9	315.2	871.7	0.2800	3.571	1.0426	125
130	347.12	1187.8	318.4	869.4	0.2904	3.444	1.0435	130
140	352.85	1189.5	324.4	865.1	0.3113	3.212	1.0453	140
150	358.26	1191.2	330.0	861.2	0.3321	3.011	1.0470	150
160	363.40	1192.8	335.4	857.4	0.3530	2.833	1.0486	160
170	368.29	1194.3	340.5	853.8	0.3737	2.676	1.0502	170
180	372.97	1195.7	345.4	850.3	0.3945	2.535	1.0517	180
190	377.44	1197.1	350.1	847.0	0.4135	2.408	1.0531	190
200	381.73	1198.4	354.6	843.8	0.4359	2.294	1.0545	200

WATER BETWEEN 32° AND 212° FAHR.

Temperature Fahr.	Weight, lb. per cub. ft.	Temperature Fahr.	Weight, lb. per cub. ft.	Temperature Fahr.	Weight, lb. per cub. ft.
32°	62.42	123°	61.68	168°	60.81
35	62.42	124	61.67	169	60.79
40	62.42	125	61.65	170	60.77
45	62.42	126	61.63	171	60.75
50	62.41	127	61.61	172	60.73
52	62.40	128	61.60	173	60.70
54	62.40	129	61.58	174	60.68
56	62.39	130	61.56	175	60.66
58	62.38	131	61.54	176	60.64
60	62.37	132	61.52	177	60.62
62	62.36	133	61.51	178	60.59
64	62.35	134	61.49	179	60.57
66	62.34	135	61.47	180	60.55
68	62.33	136	61.45	181	60.53
70	62.31	137	61.43	182	60.50
72	62.30	138	61.41	183	60.48
74	62.28	139	61.39	184	60.46
76	62.27	140	61.37	185	60.44
78	62.25	141	61.36	186	60.41
80	62.23	142	61.34	187	60.39
82	62.21	143	61.32	188	60.37
84	62.19	144	61.30	189	60.34
86	62.17	145	61.28	190	60.32
88	62.15	146	61.26	191	60.29
90	62.13	147	61.24	192	60.27
92	62.11	148	61.22	193	60.25
94	62.09	149	61.20	194	60.22
96	62.07	150	61.18	195	60.20
98	62.05	151	61.16	196	60.17
100	62.02	152	61.14	197	60.15
102	62.00	153	61.12	198	60.12
104	61.97	154	61.10	199	60.10
106	61.95	155	61.08	200	60.07
108	61.92	156	61.06	201	60.05
110	61.89	157	61.04	202	60.02
112	61.86	158	61.02	203	60.00
113	61.84	159	61.00	204	59.97
114	61.83	160	60.98	205	59.95
115	61.82	161	60.96	206	59.92
116	61.80	162	60.94	207	59.89
117	61.78	163	60.92	208	59.87
118	61.77	164	60.90	209	59.84
119	61.75	165	60.87	210	59.82
120	61.74	166	60.85	211	59.79
121	61.72	167	60.83	212	59.76
122	61.70				

Freezing point of water at sea level . . . . . 32° F. Weight per cubic inch . .03612 lbs.
Maximum density . . . . 39.1° F. " " " " .036125 "
British standard for specific gravity . . . . 62° F. " " " " .03608 "
Boiling point under atmospheric pressure 212° F. " " " " .03458 "

TABLE SHOWING

NUMBER, DIAMETER, WEIGHT, LENGTH AND RESISTANCE OF PURE COPPER WIRE.

BROWN & SHARPE GAUGE.

No.	Diam. In mils	Circ'ulr mils (d2), 1 mil = .001 in.	W'g't Lbs. per 1000 ft	Length. Feet per lb.	Resistance of Pure Copper at 75° Fahrenheit. Ohms per 1000 ft.	Feet per Ohm.	Ohms per lb.
0000	460.000	211600.0	639.32	1.56	.051	19605.69	.0000798
000	409.640	167805.0	507.01	1.97	.064	15547.87	.000127
00	364.800	133079.2	402.09	2.49	.081	12330.36	.000202
0	324.950	105534.0	319.04	3.13	.102	9783.63	.000320
1	289.300	83694.0	252.88	3.95	.129	7754.66	.00051
2	257.630	66373.0	200.54	4.99	.163	6149.78	.000811
3	229.420	52633.4	159.03	6.29	.205	4876.73	.001289
4	204.310	41742.5	126.12	7.93	.259	3867.62	.00205
5	181.940	33102.3	100.01	10.00	.326	3067.06	.00326
6	162.020	26250.5	79.32	12.61	411	2432.22	.00518
7	144.280	20817.0	62.90	15.90	.519	1928.75	.00824
8	128.490	16509.0	49.88	20.05	.654	1529.69	.01311
9	114 430	13094.0	39.56	25.28	.824	1213.22	02083
10	101.890	10381.0	31.37	31.88	1.040	961.91	03314
11	90.742	8234.1	24.88	40.20	1.311	762.93	.05269
12	80.808	6529.9	19.73	50.69	1.653	605.03	.08377
13	71 961	5178.4	15.65	63 91	2.084	479 80	.13321
14	64.084	4106.8	12.41	80.59	2.628	380.51	.2118
15	57.068	3256.8	9.84	101.63	3.314	301.75	3368
16	50.820	2582.7	7.81	128.14	4.179	239.32	.5355
17	45.257	2048.2	6.19	161.59	5.269	189.78	.8515
18	40 303	1624.3	4.91	203.76	6.645	150.50	1.3539
19	35.890	1288.1	3.78	264.26	8.617	116.05	2.2772
20	31.961	1021.5	3.09	324.00	10.566	94.65	3.423
21	28.462	810.08	2.45	408.56	13.323	75.06	5.443
22	25 347	642.47	1.94	515.15	16.799	59 53	8.654
23	22.571	509.45	1.54	649.66	21.185	47.20	13.763
24	20.100	404.01	1.22	819.21	26.713	37.43	21.885
25	17.900	320.41	.97	1032.96	33.684	29.69	34.795
26	15 940	254.08	.77	1302.61	42.477	23.54	55.331
27	14.195	201.50	.61	1642.55	53.563	18.68	87.979
28	12.641	159.79	.48	2071 22	67.542	14.81	139.893
29	11.257	126.72	.38	2611.82	85.170	11 74	222.449
30	10.025	100.50	.30	3293 97	107.391	9.31	353.742

TABLE SHOWING THE DIFFERENCE BETWEEN WIRE GAUGES.

No.	Brown & Sharpe's.	Old English or London.	Stubs' or Birmingham
0000	·460	·454	·454
000	·40964	·425	·425
00	·36480	·380	·380
0	·32495	·340	·340
1	·28930	·300	·300
2	·25763	·284	·284
3	·22942	·259	·259
4	·20431	·238	238
5	·18194	·220	·220
6	·16202	·203	·203
7	·14428	·180	·180
8	·12849	·165	·165
9	·11443	·148	·148
10	·10189	·134	·134
11	·09074	·120	·120
12	·08081	·109	·109
13	·07196	095	·095
14	·06408	·083	·083
15	·05706	·072	·072
16	·05082	·065	·065
17	·04525	·058	·058
18	·04030	·049	·049
19	·03589	·040	·042
20	·03196	·035	·035
21	·02846	·0315	·032
22	·025347	·0295	·028
23	·022571	·027	·025
24	·0201	·025	·022
25	·0179	·023	·020
26	·01594	·0205	·018
27	·014195	·01875	·016
28	·012641	·0165	·014
29	·011257	·0155	·013
30	·010025	·01375	012
31	·008928	·01225	·010
32	·00795	·01125	·009
33	·00708	·01025	·008
34	·0063	·0095	·007
35	·00561	·009	005
36	·005	0075	·004
37	·00445	·0065	. .
38	·003965	·00575	.
39	·003531	·005	. .
40	·003144	·0045	. .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