NATURAL AND ARTIFICIAL DRAFT.*

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My subject to-night falls naturally into two parts, in the first of which we will consider the properties of Natural Draft, and my remarks on this will repeat in part a similar presentation of the same subject which I have given elsewhere.

NATURAL DRAFT.

We see in nature the fire burning on the open ground, making its own natural draft produced by the current set up by the ascending heated gas of lighter density rising therefrom. If the wind blows against the fire it is greatly kindled and the heat becomes intensified, but when the air is quiet again, the combustion becomes more sluggish. Hence primitive man no doubt imitated the wind with his lungs or by fanning. The discovery of confining the heat up a vertical tube to make a better combustion we can also suppose to be within the limits of this period, although the uses made of these applications were not based upon any scientific study or knowledge of the causes producing these effects in the way we are endeavoring to understand and apply such principles more intelligently in our discussion here this evening.

The term "natural draft" as in general use at the present time we understand to refer to the draft produced by the tube or chimney unaided by any other means and for a while we will confine ourselves to this restriction of our subject. The importance of a good draft is becoming more appreciated as the demands for greater steaming and the closest economy in generating, are found to depend ultimately upon the ability of the chimney.

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Nearly every treatise pertaining to chimneys and natural draft will be prefaced with the following statement: "The natural draft obtainable from a chimney depends upon the column of gas inside the chimney being lighter than the air outside." This, however, is not altogether the sole cause in producing draft, as a wind blowing over the chimney produces considerable suction without the inside air or gas being heated at all; in fact, I have tested chimneys where I have obtained a slightly higher draft pressure than the temperatures and height figured to be possible. As there is always some wind in nature, this supplemental aid to the scientific quantity of draft that we have produced by heat, is of importance and of considerable value, many localities thus favored obtaining a draft equivalent to perhaps 25 or 50 ft. more of chimney height; nevertheless, as the wind is such an uncertain element we have to fall back in foresighting our calculations to what may be reliably obtained from an assumption of height and temperature conditions for producing a given draft by the stack.

There are only two dimensions to be determined, the height and the area, and we will consider first the matter of selecting the chimney height. A proper height is of the greatest importance as this produces the dependable pulling force. This force must be sufficient to overcome friction through the grates, and this quantity varies according to design and percentage of air opening.

Through the coal, which depends upon its depth, quality, tendency to clinker and the intelligence of the firemen.

Through the boiler, which is more or less according to its general type and bafflings.

Through the flues and chimney, which is affected by their size and shape as whether square or round and the crooks and turns and whether of brick or iron, the former making for more resistance.

Consideration for the adequate draft to cover these factors is no simple matter, but nevertheless should be squarely met.

The providing a good height of stack to produce a strong, vigorous draft involves some expense, but this expense can be offset by the use of fewer boilers at a less cost for a smaller building, as well as in the saving for foundations and piping.

It is becoming generally appreciated that there is also a con-

siderable economy in running with fewer boilers, due more or less to the following causes:

First.—There is less expense for banking same at night, as it costs no more to bank at night a highly developed boiler than for one running under or at normal rating.

Second.—With an intensity of fire the gases are more completely burned to CO_2 . A low flue temperature does not indicate that the gases were completely burned, and in fact it generally shows that they were not, as well as having an excess of air.

Third.—The better circulation set up and this more rapid circulation of steam making for better boiler efficiency. I remember in my reading of an interesting account of a discussion on this matter. I think it was before the New York Railroad Club by some English engineers, going into the matter of heat transference from the fire to water in passing through iron plate or boiler tube, in which they maintained that experiments had absolutely proved that there was a better transference of heat to ebullating water than to still water, and abroad they have carried this out logically in firing special boilers to heat the water for the steam making boilers to enter as near their steam making point as possible.

Fourth.—Although aside from any use of the Economizer there is generally a greater gain to be had from an intensive furnace, it is apparent that the economizer value is increased greatly in bringing to a conclusion the all around efficiency to be had from intensive firing by reducing the heat in the flue down to the lowest point allowable to sustain draft, thereby making for practically as perfect utilization of the heat that is to be had.

Fifth.—Less smoke produced. A good draft is necessary to the successful operation of any stoker, hence given the same co-operation to ordinary grates, less smoke will also result if combined with some intelligence that the firemen does not blanket the whole of his fire with green coal at a single operation.

Should some one rise to prove the opposite, I would be prepared to say that where experience has been found against attempting such heavy coaling and overrating (forcing, if you please) and where better economy was found to be had by running more, rather than fewer boilers, that such cases will usually be found where a poor draft exists, requiring more boilers to be used to get a larger grate area to spread the coal on thinner.

Speaking of forcing, the use of any chimney is to force the fire. So every fire not left to smoulder or burn on the open ground is a forced fire. If you considered your boiler merely as a large kettle of some unknown size, whatever you could get out of it would be the capacity it was good for. Suppose you could get twice as much performance, or more than before, from any kettle, you would not consider you had caused any strain or injury nor would you; hence the word "forcing" in the sense of working beyond or close to its safe usage as would be in mind by the use of the word applied similarly to an engine does not exist. So long as the limit of safe pressure is never exceeded, the safe output of steam is unlimited.

It has come about in practice that the purchaser wishing to produce 1000 boiler h.p. that the builders generally furnish him 10,000 sq. ft. of heating surface or 10 sq. ft. per horsepower, as it is a safe measurement to use with a very ordinary draft. But whether the purchaser obtains 1000 h.p. or twice that, out of the size he has bought, is purely a matter of supplying heat enough and that is practically limited only by the draft strength to burn the requisite coal on the grates. As stated before, conditions may make it otherwise, as with a definite chimney draft installed, the efficiency may be better below the builder's rating, at rating, or above rating.

So where a person is planning a new chimney, his course for determining the size should include consideration of the following:

FOR THE HEIGHT.—1. The local advantages of the situation, as to exposure to wind and its general climatic dependence. As a general statement a high elevation at start for the foundation is an advantage, still it is not necessarily so, as sometimes a valley situation may be so placed that it may have an unusually strong current of wind drawn through same and seldom troubled with cross winds which would cut off the sweep above the chimney, but ordinarily the valley location demands a higher chimney to protect the plant against the loss of draft it would have, were it not hemmed in.

2. The placement distance of the furthest boiler or boilers, relative to the stack.

3. Type of boilers and grates.

4. Quality and depth of coal.

It is universally taught that "draft" varies as the square

root of the height, but this use of the word "draft" applies only to the capacity which is more a matter of area, as I will show later. The prime thing is a proper height, as it is this factor—adequately ascertained—that gives you the assurance of a provision for the essential force or pull to run your plant at a reduced expense for boilers, for their setting, piping and size of house, and with a better economy to boot. I wish you to note the distinction between draft pressure and draft capacity; the word "draft" is used too indiscriminately to either function and is unscientific as well as confusing.

Chimneys give a draft pressure in direct proportion to their height, thus 200 feet gives twice the pressure of 100 feet and the pressure is the same for all chimneys having the same height whether the area varies between them as 1 or 50 sq. ft. in section; hence, if I have figured it for you on a reasonable assumption of 450° in your flue gases and tell you it is 0.6 of an inch with a stack 100 ft. high when the outside air is 60° , then you will know that to obtain 0.9 of an inch that 150 feet height would be required regardless of any area, and for 1.2 inches the height must be 200 feet and so on. Afterwards selecting the area to suit the volume from the expected amount of output.

This factor 0.6 of an inch per 100 ft. of height the writer believes is a safe basis, as in the winter time the outside air is colder, making for a still better result, and while in the summer it would be somewhat less by the outside air being hotter than the assumed 60° , yet the heating system is off so that the work will be usually somewhat less, and in addition you have two likely forces that will most always make the draft better than this given factor, namely, the assistance of the wind and more frequently hotter leaving gases.

Many papers have been written on the subjects of chimneys and drafts, generally developing abstruse or speculative theories. The most helpful and practical that I have come across was in a recent article by T. F. J. Maguire, which gave definite measures of draft resistances. (See Table I.)

Loss of draft in boiler setting he measures as 0.3 of an inch to Water Tube boilers, increasing to 0.4 of an inch with 50 per cent. overload. Of course he intends this to be used with some judgment in application to the special boiler in mind, as to its construction and bafflings. The writer believes Horizontal Return Tubular boilers will be found to require the same allowance

and the Manning and Vertical types half of this or 0.15 of an inch. You do not have to take any multiple of the factor by the number of boilers.

Loss of draft in breechings. Maguire allows 0.1 of an inch per 100 ft. of length to circular iron flues and 0.05 of an inch for each right angle turn. If squares or rectangular shape, increase the above 25 per cent. For brick flues increase the above 30 per cent. The writer would allow for the stack travel the same as for the breechings.

The supplying of these reliable factors for fixing chimney dimensions on an intelligent basis to meet the duty that will be required is of great service.

Let us see how the application of such factors would apply to a concrete case where we assumed we wished to burn 25 lbs.

TABLE I.—DRAFT PRESSURE REQUIRED IN FURNACE.

Kind of coal.	Pounds of dry coal burned per square foot of grate per hour						
	15	20	25	30	35	40	45
	Draft in inches of water						
Eastern bituminous coals.....	.12	.16	.20	.27	.34	.42	.52
Western bituminous coals.....	.15	.20	.25	.33	.42	.52	.65
Semi-bituminous coals.....	.15	.20	.28	.37	.48	.60	.80
Anthracite buckwheat, No. 1 and larger.....	.45	.70	1.00				
Anthracite buckwheat, No. 2 and No. 3.....	.75	1.30					

of soft coal under Horizontal Tubular boilers with two right angle turns in the breeching.

Furnace draft for 25 pounds soft coal.....	0.2
¹ H. R. T. boiler	0.3
50 feet of steel breeching	0.05
Rectangular shape 25 per cent. additional.....	0.0125
Two right angles	0.1
Round brick chimney 150 feet.....	0.15
Brick surface 30 per cent. additional.....	0.045
Total draft required	0.8575

¹ Resistance increases with velocity, if therefore 25 pounds per square foot would develop a considerable amount above rating, add a third to the boiler resistance. In the above it would therefore be 0.4 for the H. R. T. instead of 0.3 for its normal. This addition of increase will probably cover the flue resistance as well.

Or approximately 0.9 of an inch, and as we can get 0.6 of an inch of pressure per 100 feet of height, then a 150 ft. stack should provide the total pressure needed. Notice that this stack height is indifferent to any size or amount of horsepower output, except as more boilers would require allowance for longer flue travel which would be very slight.

I would like the opinion of others on this showing, because if general practice is shown to coincide, it will be of much value and equally so if more reliable quantities can be established. I know at the outset that some will claim to have a 150 ft. chimney and cannot burn at this rate, and if so, the cause may be found due to excessive area absorbing the heat needed to produce the expected draft pressure or to some other accountable reason.

It may be pointed out that no allowance for economizer draft effect has been listed. But as the straight open-passage type of economizer has generally a greater free area than the flue, it can be reckoned on its length as for flue distance. Further, you must know that the top layers on the coal bed make for a greater proportional resistance, so an economizer saving 10 per cent. of coal, would ease the fuel resistance to produce the same output of steam, thus practically offsetting any effect of its own resistance, while the owner is 10 per cent. of coal in pocket with a proportionate draft pressure needed to accomplish the same output. This has proved universally true through a period of over half a century, so that the exceptions are now known to be due either to its faulty installation or fault in the design and size of the economizer selected.

Until further tests have been made to determine the actual pressures required for the usual run of commercial qualities of coal depths on grates, these figures may be treated with some caution, yet faulty as they may be, they will prove in the main quite trustworthy as a deviation will probably be found to be offset by some other, so if the boiler makes more friction, the coal perhaps will prove less. Hence, I believe determining your chimney height on a basis of such quantities, better than making a vague guess as it is generally being done now, and no one will welcome corrections to the foregoing calculations more agreeably than myself, knowing a true schedule would be of the greatest value to every power producer.

You observe the size of plant and number of boilers, except

as they effect the flue distance, have no consideration in this matter of height determination. That there is no definite height to correspond with a given size of horsepower will be seen if a stack of sufficient height to suit a 1000 h.p. plant is arranged as in Fig. 1.

FIG. 1.

That the same height should be equally sufficient with a proportional increased area for 2000 h.p. arranged as in Fig. 2.

As the length of pull to the furthest boilers is no greater a demand than that for the single 1000 h.p., so too, the same height would be satisfactory to 4000 h.p. of boilers arranged as in Fig. 3.

FIG. 2

As the gases travel about 70 feet a second, a distance of 20 feet more or less is negligible in the flue resistance as is the fact of using an Economizer, presuming the Open Tube style is used with a free area equivalent or greater to the flue giving a straight-way passage. The prime requisites therefore for determining the proper draft pressure are the coal depth and the boiler type.

FOR THE AREA.—The size of the plant determines the area. The boiler horsepower of the output should not be considered in determining the height as we have just seen and as is mistakenly being done now, with rare exception, but it is the sole basis for determining area.

The selection of a suitable area to a chimney is as frequently a guesswork dimension as for selecting the height. Some have a pet rule of making it proportionate to the grate surface, regardless of the fact that if twice as much coal is burned in one case as in the other, it would call for twice the flue area, because having

FIG. 3.

double the amount of gas volume of the other. Others figure up all the tube area in their Horizontal Return Tubulars or Manings or measure up the outlets of the water tube, etc.

As to build to good height costs so much more in proportion than for area, it is a common fallacy to curtail on the former and increase the latter. Thus for 1500 h.p. the owner provides himself with a stack of a height suitable for only 1000 h.p. and uses an area good for two or three times this amount and wonders why, after putting up a stack "said to be good for perhaps 3000 h.p." he has difficulty in getting 1500 h.p. and has to have recourse to artificial aid. The theoretical area required for 1000 h.p. of boilers with a stack only 100 feet high is but 7 square feet under ordinary conditions. In my own practice, I usually allow

20 sq. ft. for a single 1000 h.p. boiler installation as being ample for this amount of horsepower at normal running and also as allowing for the reasonable increased growth of plant and overload. For two or more thousand horsepower I reduce this area allowance about 10 per cent., increasing the reduction on very large plants to perhaps 20 per cent., keeping 16 sq. ft. as well within a safe limit per 1000 h.p. where the plant becomes several thousand. For smaller plants, say, 500 h.p., for instance, I would allow 12 sq. ft. which is then more than three times the theoretical area on the moderate basis of a height of 100 feet.

If the chimney is above 100 feet in height, the theoretical 7 sq. ft., requirement is still less, and as I say, I never take less than 16 sq. ft. of area, which is more than double the theoretical for 100 ft. high, I consider that it is ample allowance for any overload, as well as safe, and I have never found any difficulty in practice by its application.

The smallest allowable area should give the best draft, as were we to increase 20 sq. ft. per 1000 h.p. to 30 sq. ft., it would mean in a travel of 150 ft. distance up the stack, assuming this height, together with a flue length of 30 ft. to reach its port, that we have added 645 sq. ft. of surface to be warmed to the same temperature of the gases with exposure to radiation loss, as well as increasing the air leaks caused by the chimney suction through flue seams and the porous bricks of this added surface. All of this excess surface put on by unneeded area is therefore making for a great detriment to the pulling force of the stack so essential for keeping down the plant investment as well as for its economy.

On the same basis of conditions as for the 100 ft. stack to be used for determining the draft pressure, we find that 69 cubic feet will be passed per second per each square foot of area.

Assuming then our boiler horsepower requires as much as 4 pounds of coal per horsepower and while theoretically 12 pounds of air is needed to burn a pound of coal we will use 20 or plus the pound of coal involved,—21 pounds of gas or 84 pounds gas per boiler horsepower. So as calculation shows, we have therefore for 1000 boiler horsepower with a short stack of only 100 feet high, the startlingly small area of 7 sq. ft. actually needed. If the surface friction needs to be set off, surely 25 to 50 per cent. is ample allowance, and then as you think the plant may run above rating, or increase in the future, use your judgment as to

further percentage of increase to same; but do bear in mind that excess area beyond reasonable future requirements does not assist at all in pulling the needed air through the coal heaped on the grates.

Surely 4 pounds of coal per horsepower and 21 pounds of gas per pound of fuel are reasonably large factors, so if requiring actually only 7 sq. ft. per 1000 h.p., why such tremendous excess areas are invariably allowed, is a puzzle. I suppose it is done because it is cheaper to provide more area than the needed height and therefore we see something like a 2000 h.p. or more area with an inferior height provided to be used for only 1000 h.p. and proving in such cases that where the short stack height is a fault to begin with, it is made worse by hitching it together with an undue area. In actual practice the writer has found several stacks work close to their theoretical area capacity, as for instance at Lawrence, Mass., a chimney 128 feet high above grates with flue area of 9 sq. ft. took care of 6 Manning boilers in a satisfactory manner, developing 780 h.p. whereas the usual chimney tables recommend this size for approximately only 300 h.p.

The movement of air follows the law of gravity, $V = \sqrt{2gh}$. So the difference in capacity between stacks respectively 100 and 200 feet high would, therefore, be in proportion to their square roots, as 10 is to 14, which is small for such a great difference, so I ignore it altogether and taking an area that I know to be right to the smaller, which is 7 square feet theoretically and increasing this to 20 square feet for use in practice per 1000 h.p., for any height of chimney, I know it must be even more safe if there is a greater height than 100 feet. So I believe this is the largest area for best results and using any greater factor than 20 sq. ft. can only be detrimental to the draft force.

While I do not wish to deter those who have time and the disposition to figure a given chimney problem with accuracy, yet I believe the factors, 0.6 of an inch pressure per 100 feet of height and the area factor at 20 sq. ft. per 1000 h.p. for all heights, will be welcomed by many as safe quantities to work to in selecting the two required dimensions of a new chimney.

If you must add something for "good luck" put it on the height, as you stand to lose less on this, as the excess area will only come useful in a long distant future when the plant has

grown to it, as the 20 sq. ft. basis for area is nearly three times the theoretical and it provides sufficiently for all needs of reasonable increase.

I have seen too many plants handicapped by strained proportions for a great future, whereas when the future did arrive, it was entirely a different mill or a problem altogether dissimilar to any initial conception. In following the mill development for twenty years in New England, it has inclined me to believe that if I had the making of any new power plant layout, it would be my purpose to plan for the highest economy for the immediate needs, not extending farther perhaps than the next five years. This burdening a new plant to struggle under heavy fixed charges and loss in operating until the work develops to meet the initial undue proportion, is as bad as buying a man's suit for a boy because you know he is going to grow to it some day. Make things of right proportions to get the best economy for what you need now, and when success brings ample capital you can then easier afford to throw away the old plant, if you like, and start out with another up-to-date outfit. In our conceit at any present time, we lay out big schemes for additional future boilers of the same kind in a great shed of a building and what is found generally ten or fifteen years later, is a collection of big and little units, different makes, different piping systems, etc., with the same thing seen in the engine room and elsewhere.

Realizing the convenience of using the chimney tables in vogue, I hope my two factors of 0.6 of an inch per 100 ft. of height and 20 sq. ft. area per 1000 boiler horsepower will prove a simpler and better substitute, and when used with intelligent study and tabulation for the needed height for pressure, will make your future chimneys a better investment.

In regard to the character of the chimney construction in general use, the most efficient and handsomest, in the writer's opinion, is a well designed red brick or radial brick chimney with an inside core. The next selection would be such brick chimney without a core, following which would be a lined steel stack, with the unlined steel pipe the lowest in order. There is another advantage besides the better retention of heat, in having a core, as it can be taken out if more area is ever needed and in many cases this has been done.

Concrete chimneys are being built also, but some good en-

ineers are afraid of them as they claim that concrete is such a brittle substance that owing to wind vibration it will certainly in time open fissures through the thin shell, which will permit the entrance of moisture and combining with the sulphur gas destroy the reinforcing iron bonding the material.

To make my paper practical to those of my hearers who have chimneys already built, I would say that yours is a case of studying your conditions to see what you can best get from them and suggest that you try running your plant on as few boilers as possible. I believe the result will prove decidedly advantageous. You must have the engineer interested to give it a fair trial as it may mean a little better attention to fires to prove it out, because if you are troubled with weak natural draft you must break up the fires oftener and study closely to obtain more intelligent and more intensified firing.

In winter, if you are troubled with poorer draft than in summer, it is due to having the boiler room too tightly closed. If the firemen object to cold drafts from doors and windows, provide the air entrance from the top of the room.

Often the wind in certain directions, instead of assisting the draft makes for the contrary, which condition occurs when the wind is blowing in the direction towards the further boiler house door and this being kept open, the suction of air follows along in the same direction out through same, so that the end boilers nearest to the door have difficulty in getting their supply of air through the grates.

An unutilized excess of draft pressure is bad and the boilers should be fired as near the limit of draft as possible so as to prevent such excess, but there will at times be necessarily a considerable surplus pull by the wind producing a greater draft one time than another. That this excess draft is more common than otherwise is shown by the operation of the automatic regulation of dampers in the general run of plants, continually cutting off 25 to 50 per cent. and more of the available draft throughout the entire day. Of course as the plant is being run, the damper regulation makes for a great saving in preventing an undue excess of air through the grates, but the force should be put to work so far as possible to produce a more intense fire and by heavier coaling to run with fewer boilers.

In this matter of draft regulation, it is much better to have a

regulator that operates slowly than to have one so sensitive as to be opening and closing on a slight variation of pressure, thereby letting in an excess of air one minute, and then tightly closing, cutting off the air supply altogether which makes for another loss to follow by imperfect combustion.

If you have such a sensitive damper, it is not necessary to throw it out, just limit your range of damper opening, so that it does not shut tight or open to its fullest extent. The regulating damper should be as near the chimney as possible, and if it were placed at the top of the chimney, it would be better yet, as in times of closing, it would hold back that much more heat. As it operates now in many plants, when the damper is closed at the port, the brick lining or core begins to lose immediately its stored up heat and the chimney cools off, then when the demand for steam comes instead of an active chimney agent, it takes a bit of a while for it to recover its lost heat and give vigorous draft; meanwhile, the plant is held back that much more heat. The condition becomes worse where the regulation is applied to dampers in the boiler uptakes, as during the time of cut off the flues have cooled as well as the chimney.

It will not be denied that any sort of a chimney gives some draft, in fact, a fair draft as practice is to-day, but I maintain that the average draft is not up to what it might be and should be, hence we are generally using too many boilers and firing at a disadvantage for the best economy. New boilers are purchased to get thinner fires or artificial draft frequently installed that would be unnecessary if the chimney were properly worked out in the beginning.

THEORETICAL CAPACITY AND PRESSURE TO A CHIMNEY 100 FEET HIGH.

1. Assumed height = 100 feet.
 Assumed area = 1 square foot.
 Assumed gases = 450 degrees Fahrenheit.
 Assumed outside air = 60 degrees Fahrenheit.

2. The first step is to ascertain how high the 100 foot column of air will balance a column of gas at 450 degrees Fahrenheit.

The density of a gas varies in direct proportion to its temperature from absolute zero (461° below 0° Fahrenheit).

$$\begin{array}{l} 60 + 461 : 450 + 461 :: 100 : x, \\ \text{or} \quad 521 : 911 :: 100 : 175 \end{array}$$

3. Velocity or fall will be the difference between 100 feet and 175 feet or 75 feet.

And velocity is expressed by the familiar formula

$$V = \sqrt{2gh}$$

Calling g , which is the acceleration due to gravity 32, this formula becomes

$$V = \sqrt{64h} = 8\sqrt{h} = 8\sqrt{75} = 8 \times 8.66 = 69.28.$$

That is, for each square foot of area there will be 69.28 cubic feet emptied per second.

4. The weight of chimney gases at 450 degrees has been determined to be 0.045 pounds per cubic foot, hence:

$$69.28 \times 0.045 = 3.1176 \text{ pounds per second.}$$

$3.1176 \times 3600 \text{ seconds per hour} = 11,223 \text{ pounds gas per hour per one square foot of area.}$

We now have a practical, safe result to work with.

If we assume 84 pounds of gas per 1 boiler h.p. then $11,223 \div 84 = 133.6$ h.p. per square foot of chimney area.

1000 h.p. of boilers with stack only 100 feet high requires theoretically therefore only 7 square feet of area and if above 100 feet high, it would be of course less.

Now you can double this area in practice or triple it, but when some quadruple and quintuple this amount, it is time to halt as the increase adds nothing to the effectiveness but the reverse.

As to pressure:

A cubic foot of water weighs 62.37 pounds and one inch of this equals 5.2 pounds, so if we divide the pressure per square foot by this or multiply it by $\frac{1}{5.2} = 0.192$, we shall have the height of column of water which it will support in inches.

The weight per cubic foot of a gas at any temperature may be found, therefore, by dividing this constant product of the weight and absolute temperature by the given absolute temperature.

Air at 32° weighs 0.080728 pounds per cubic foot. Its absolute temperature is 493.2. The product of this weight and temperature is

$$0.080728 \times 493.2 = 39.8$$

So that to find the weight per cubic foot of air at any temperature it is necessary only to divide 39.8 by that temperature plus 461.2, *i.e.*, by the given absolute temperature and we can say, calling the density or weight per cubic foot D ,

$$D = \frac{39.8}{t + 461.2} \text{ or } D = \frac{39.8}{T}$$

The weight of a cubic foot of chimney gas, which is not simply heated air, but a mixture of nitrogen, carbonic acid gas, etc., would be about 0.084 of a

pound per cubic foot at 32° for perfect combustion of ordinary coal, and 24 pounds of air to the pound of fuel. Its weight per cubic foot or density at any other temperature would be

$$d = \frac{.084 \times 493.2}{t + 461.2} = \frac{41.43}{T}.$$

Density of air at 60 degrees = D = 0.0763

Density of gas at 450 degrees = d = 0.0454

.192 x 100 feet stack x (0.0763 - 0.0454) = 0.593 inches, practically 0.6 of an inch, and will be the same for all stacks 100 feet high when the gas and air temperatures are the same as the above, regardless of any difference in area or whether only one square foot or fifty.

ARTIFICIAL DRAFT.

So many favorable comments and demands were made for copies of my previous paper on natural draft which showed the wide-spread interest of intelligent students to secure tangible and more definite knowledge of that subject, that I am glad to have opportunity here to add some remarks and suggestions to the use of Artificial Draft as it is a subject of rapidly growing interest and importance, as natural draft is so varying in its action between different places—and in the same place—and in one hour with another, that no exact rules can be made in regard to it. Hence the broad empirical formulas for chimney sizes and the wide divergence in practice of heights and areas that are seen in use to handle similar amounts of boiler horsepower—being based on opinions and deductions more or less sound from the experience of their engineering advisers.

Utilization of forces in nature which are affected largely by the weather have an uncertainty of reliability—such as tidal power, wind-mills, water-falls, etc. When, therefore, the use of such a fluctuating force is made the sole reliance for the economical burning of fuel and with public service corporations to meet unflinching the growing demands of their patrons—the engineering talent is found perplexedly attempting to formulate definite rules or regulations to constantly changing firing conditions, which at best can only be general, or practically to make the best use of whatever draft is available at the time, so what measure of success is attained thereby is, of course, to their credit.

The never-failing interest on the subject of natural draft and

the more general realization of its elusive quality to be confined within any certain formula, is making for greater study of the advantages of artificial draft for producing a definite positive draft pressure for the right volume that will be suited at all times to precise needs. Combustion being a chemical action which is an exact science, it is possible to make definite experiments of the requirements of any fuel for its complete combustion and then maintain the same in constant everyday practice very closely if given the operating facilities that will reliably supply the conditions determined by the laboratory and experimental investigations.

The generalities of this subject have been well stated by Mr. C. E. Roehl in a discussion before the American Street and Interurban Railway Engineering Association where he said:

"Capacity is fundamentally a matter of rate of firing. Firing rates vary widely, whereas efficiencies with a given grade of fuel do not; therefore, it follows that it is only necessary to get coal into a furnace and burn it to cause the rate of steaming to vary very nearly in proportion to the rate of firing. The practical response of the rate of steaming to the rate of firing follows logically from the modern recognition that with boiler equipment actually in service at the present day, the limitation of the heat transmitting ability of the metal of the heating surface is not approached.

"Higher steaming capacity usually reduces labor charges and inevitably reduces investment charges. It reduces the labor charges because, as a rule, more coal per man is being fired and more steam per pound of coal is being obtained. Investment charges are reduced because greater power is obtained per boiler. Maintenance charges increase, but the increase is practically confined to the furnace and, except in very special cases, while an offsetting factor, it is not a ruling one.

"Moderate increase of evaporating rate, 100 or 150 per cent., or perhaps more, must be brought about. Installation of very large capacity city turbines has forced this and in isolated instances a good deal has already been accomplished. There seems little reason to doubt that the best which has at present been accomplished will in a few years become standard practice."

Another statement on this subject from the *Electrical Engineer*, London, is worth attention:

"It is frequently quoted that with mechanical draft a smaller excess supply of air than that demanded by theory is required than with natural draft. In all probability this arises from the fact that natural draft pressures, are, as a rule, considerably lower than those mechanically produced, and fires are worked with less thickness with the former, so that such a thorough and uniform mixing of the coal and coal and air does not take place as with the great pressure and thicker fires of the latter."

Artificial draft may be either of two systems or a combination of both, namely, the Induced Draft, Forced Draft or Balanced Draft.

The Induced Draft or Suction Draft has all the advantages of the natural chimney draft, with the additional assurance of providing almost any positive required draft pressure that will be needed and where the plant is in its infancy, it is frequently better to use an inexpensive induced draft than to incur the investment charge for a huge chimney against future needs which are indefinite, perhaps to a remote period. While generally the cost of the induced draft is 75 to 80 per cent. less than an equivalent chimney capacity, its proportionate expense is not fixed, as the greater the chimney height, the less the induced draft equipments cost in proportion and if foundations are particularly expensive for the chimney the relative difference in cost becomes greater in favor of the induced. By using powerful fans the outlay for boiler installations can be reduced at least 25 per cent., and in one case the company I represent cut it by one-half with great success. This saving would fully offset the expense for the highest standard of mechanical draft equipment—or put another way, chimney cost would be saved altogether.

The maintenance of the induced draft is very small. If the plant is large enough to warrant using Corliss type engines, the operating expense can be maintained at less than one per cent. of the steam produced. In ordinary moderate sized plants the expense for operating a well designed equipment would never be more than double this, or 2 per cent., which would be an extreme to produce an extraordinary pressure. The equipment stands up well with small risk of break-down and by attaching a pulley which can be operated by a belt from the main drive or to an electric motor, the plant is insured against shut-down without the expense for duplicate apparatus.

Mr. Wm. R. Roney, in his valuable paper before the American Society of Mechanical Engineers, stated that the operating costs on several induced draft plants installed by his firm averaged about one-half of one per cent. of the horsepower of the total steam output. As his paper was written many years ago, I hardly believe he would claim that to-day, although it would be as easy to do it to-day by simply attempting to equal the ordinary natural draft applied to plenty of boilers with ample grate area, but it would take nearly all of one per cent. of the horsepower output to meet the draft demand for the concentrated development embodied in the present larger boiler units, for to obtain double the draft pressure of former times requires three times the amount of power applied to the fan. Calling it to-day then, one per cent. of the steam output, it is still a trifling cost commensurate with its results, while allowing all the exhaust from the fan engine to be utilized in heating feed water, the actual cost to produce the one per cent. of total horsepower output disappears almost altogether in fact, can well be ignored.

The writer has been much impressed with the growing demand for mechanical draft systems from manufacturers who may have only 200 horsepower or even less. Formerly such parties would rush to their boiler maker for additional boilers and build costly foundations in an enlarged building, and then struggle to work in the necessary new flues and pipe connections—all at expense for money and time in delays. Now, an inexpensive fan makes their present plant meet their growing increase and by further supplementing the boiler heating surface with Economizer tubes, the steam output may be even doubled with no excessive heat waste up stack—all accomplished rapidly at moderate cost and within the limits of the present building. The boiler makers themselves are lending to the growth of artificial draft because owing to the competition among themselves, they know they can offer the purchaser a better trade per horsepower cost in the larger single units, which puts the buyer, however, to the expense of building a greatly higher chimney to obtain the expected rating or purchase the low-priced induced draft apparatus when he can then accomplish the rating with ease and even more.

Induced draft fans are usually provided with water-cooled bearings, to protect the babbit from melting down, but I have

known where induced draft fans have been used for eighteen years without any such water, in fact, the bearings probably can be kept sufficiently cool by small openings in the fan case around the bearing so that some cold air will always be drawn over same. This had better not be attempted with direct connected engine sets, as it would draw more or less gritty dust over the engine as well, which would work into its bearings and cross-head. A half inch water pipe, however, will furnish all the water generally necessary to the largest size of induced draft fan. In my practice, I regularly install such cooling system as it is a very simple safeguard to adopt.

As a general rule, horizontal engines are preferred to very large fans if foundations can be had on the ground, but in elevated positions, the vertical type is preferred to avoid lateral vibrations.

The Forced Draft blows the air under the grates and the cost of operation is the same as for the induced draft, because, although it has a smaller fan, the weight of air to be moved in a given time is the same as the induced draft would have to handle if used at the other end.

There are different methods of regulating both forced and induced draft sets. Frequently an actuator is used to operate by means of crank levers, for regulating the fan speed by moving the governor. In my practice, I get precisely the same effect by simply inserting a pressure regulator in the steam supply to the engine.

Where forced draft is used in connection with a chimney draft which already is controlled at its port by an automatic damper regulator, another wire can be connected from it to operate a simple balanced valve in the steam supply to the forced draft so both the chimney damper and forced draft work in unison—such system is called *Balanced Draft*.

Whether Induced or Forced Draft is installed the engineer should study the operation of his fan engine and set his governor and cutoffs to suit the best uniform speed, because as the requirements are put up to the fan builders to meet the most maximum conditions contemplated, an ample sized engine with suitably adjusted cutoffs will be furnished to give ability to meet those extreme demands and too often the operator relies solely upon his regulator to take care of his load adjustment, with the result that the movement is constantly in motion, with the fan at one

moment working at its maximum and whooping the fires up so that the pressure gains for some time after the fan has slowed up. That the engineer should therefore make any new engine adjustment that may be needed to suit his normal conditions, should not require further argument. It would make for a marked improvement in economy and enable those in charge of the coaling to fire better under the more uniform draft conditions.

Speaking for New England, there are probably 10 Forced Draft fan systems installed to one of Induced Draft, indeed counting the various steam jet systems with same, I judge there are 50 forced fires to one artificial suction draft system. This is natural on account of the ease of installing the former, and its lower cost. Then, too, forced draft is better adapted for burning the fine grades of anthracite or buckwheat which pack on the grate so densely as to make too serious a demand for draft from any suction fan to be practical, whereas a strong underneath blast will keep the coal lifted and keep the particles in motion so the air is thoroughly mixed, producing a good fire with little smoke.

If the exhaust steam from the fan engine is blown into the air duct it will prevent clinker mass from forming and fusing on the grates. This has become quite a common practice and proves generally beneficial.

The forced draft usually makes a hot, dirty boiler room and frequently makes more arduous conditions of labor, as the heat tends to fly out upon them whenever doors are open. Then, too, the air blast seeks the weakest place of resistance in the fire and through such places produces holes letting in cold air to no good purpose. I think, however, there are considerable possibilities of economy with this system where firemen of superior intelligence are employed, as with carefully run fires, a thorough combustion can be obtained and the heat therefrom will be forced into effective contact with all parts of the heating surfaces.

The most common fallacy in regard to this use of forced draft is that it is a quick, inexpensive remedy where the present draft is inadequate. This proves true in some cases and in others, it will make for worse conditions than before.

The situations where it will benefit, speaking now as a draft remedy, will be where areas through flues and chimney are ample, although the height of the stack is too short to produce the necessary pulling force.

Whereas on the other hand, the case being one where the height and areas are both inadequate or outgrown, then the introduction of forced draft to such, requires a fierce blast to overcome the resistance ahead of the gases to reach the atmosphere and makes for such force against the boiler fronts as to become a source of danger to the men every time the doors are opened for coaling, also such a draft condition is injurious to the settings, as well as the fronts.

Forced draft, then, requires either a good draft at the other end, or paradoxically, no draft at all, but a short spacious path to out of doors. If any of you have forced draft in your plants which works too strenuously against the fronts and it is impossible to keep up steam with a lower air pressure, then you want to adopt the suggestions of providing easy vent after leaving boilers or improve chimney draft or adding the positive induced draft. But there is another remedy which might be worth trying if your boilers are of Water Tube Type, and that is, to remove the bafflings; your heat—as shown by the conditions of pressure around the front—is going to be just as efficiently brought in contact with the heating surfaces without assistance of the boiler bafflings in such cases.

Abroad intensive firing is being adopted on larger scales and in the development to achieve the highest results in some of the great electrical and industrial stations they are equipping their plants with huge thermal storage tanks in addition to their Economizers. These things are bound to follow in this country as progressive boiler builders realize that whatever helps the economical production of steam is to their advantage in keeping pace with their wide-awake competitors who are scientifically improving the efficiency of gas producers.

The prime movers of the plant have heretofore had the first place in attraction for study and development and thousands of dollars are spent to secure only a small economy which may be offset in the adjoining room by the firemen unnoticed. However, just as the public has had a surfeit of the moving signs on the Great White Way, so is coming the day when the owner will walk his visitor past the wonderful turbines into his boiler room and there throw out his chest with pride at its display of cleanliness, and its well-studied features to secure all the heat possible from the fuel by its most complete utilization.