

frictional resistance of the combustion gases through the smoke tubes and flues of these boilers was very low indeed, but notwithstanding this advantage it was not practicable to keep a full head of steam with natural draught, and the stoking was fairly heavy, as it is mostly bitumenous coal that is used in this plant, which has a tendency to cake in the fires and impede the passage of air required for combustion. It was decided to instal a fan 12ft. diameter x 5ft. 6in. in width, driven by a 16in. diameter x 12in. stroke vertical enclosed engine, fitted with forced lubrication. The fan is capable of handling 130,000 cubic feet of hot gases per minute working under normal conditions, and may, when the capacity of the factory is increased and sudden demands for steam occur, be speeded up to handle 160,000 cubic feet per minute. Two of the chimneys have been dismantled, the two remaining, into which the fan discharges, have been reduced in length. The change from natural to suction draft in this plant, as in the others described, has resulted in an ample steam supply, and increased capacity of the factory with considerable economy in fuel.

Many other cases could be quoted of steam boiler installations in Australia which have had suction fans fitted to produce accelerated draught, where the results in increased steaming capacity and fuel economy are similar to those already referred to.

In a paper on mechanical draught for steam boilers, by J. Crawford, Manchester, the writer states that he has installed over seven hundred induced draught fans in Lancashire alone, and many of them take the place, so far, as draught is concerned, of the most lofty and well-designed chimneys that could possibly be erected. This is a strong testimony, coming as it does from such a keen seat of steam engineering as Lancashire, in favor of the use of suction draught in preference to chimney draught.

Mechanical or accelerated draught under perfect regulation is a most important factor in the efficient working of steam boilers, as by its means the distribution of the air passing through the fire, over the fire, or at the fire bridge, can be regulated to ensure efficient combustion with a minimum quantity of air, and it permits of the arrangement of the fire bridges, deflectors, wing walls, or other system of baffles, to ensure a thorough mixing of the combustion gases before they fall below the temperature of ignition, for it is only by means of fairly high velocities of the gases of combustion, combined with efficient baffles, that thorough mixing can be obtained. The air supply is the one controllable factor in the working of a boiler furnace, and this can be readily secured by means of accelerated draught, but we cannot any longer trust to our experience and common sense to determine this important factor in boiler management.

Professor Unwin, in his "James Forrest" Lecture, in 1895, said he believed that in good and large installations at least it will come to be considered as necessary to have an instrument for accurately recording the C.O._2 in the combustion gases, as to have a pressure gauge to indicate the steam pressure. Since that date, much attention has been given by chemical engineers to the design and equipment of a reliable C.O._2 recorder, with the result that there are about half a dozen reliable instruments now being manufactured. In a recent paper on "Economy of Fuel," read by Mr. J. W. Bragg, before this Association, a detailed description of an excellent type of C.O._2 recorder is given, with instructions for manipulating it, the Author had an opportunity of seeing a number of these in operation in England, and was much impressed by their sensitive indication of any change in the quantity of C.O._2 in the combustion gases.

As the Author had not the opportunity of hearing Mr. Bragg's paper read, he would like, with permission, to put on

record his conviction that, if we as Engineers, are to make satisfactory progress in dealing with boiler efficiencies and fuel economies in the future, we must call to our assistance the expert chemist so that complete analysis of the combustion gases can be made, for that is the only rational way to determine what conditions are necessary in the working of a furnace to obtain the best results. The C.O.₂ recorder is to some extent to the boiler what the steam indicator is to the steam engine. By the use of the latter the engineer can tell if the steam distribution in the cylinders is satisfactory, and by the former if the most efficient conditions of combustion are being maintained, and it may safely be predicted that in the near future they will be installed in all up to date boiler plants, where fuel economy and boiler efficiency are valued. It should be noted that the C.O.₂ recorder indicates simply the C.O.₂ in the flue gases, and while useful as affording a constant check on the steadiness of work, the records to be of proper practical value, should be supplemented by frequent complete analysis of the gases, more especially when there has been a change in the class of fuel in use. In every case the results of an analysis should be considered in conjunction with the special conditions prevailing at the time, in order that a correct deduction may be made.

It is somewhat beyond the scope intended for these notes to refer to the "chemistry of combustion," as that can be better done in a separate paper. A brief reference should, however, be made to indicate the nature of the problem to be handled in burning the semi-bituminous and bituminous coals of the southern, western, and northern collieries of New South Wales. The general analysis of coal from these districts is given as under:—

	Southern.	Western.	Northern.
	per cent.	per cent.	per cent.
Hygroscopic Moisture . .	0.97	1.87	1.92

Volatile Hyd. Carbon. . .	23.10	31.49	35.09
Fixed Carbon	65.26	52.62	54.08
Ash	10.67	14.03	8.91
Coke	73	64	62

Taking the round average at 65 per cent carbon and 35 per cent. vol. hyd. carbon, we get the following approximate figure for the air supply necessary for the combustion of the fixed carbon, and the vol. hyd. carbon.

Cubic feet of air required for the combustion of the fixed carbon in 1 ton of coal:—

$$2240 \times .65 \times 11.6 \times 13 = 219,565 \text{ cubic feet.}$$

This large volume of air required for the exclusive use of the coke on the firebars, must therefore be passed upwards from the ashpit. For the gaseous part of the fuel, D. K. Clark, in his work on combustion, has shown that each cubic foot of coal gas requires absolutely the oxygen of 10 cubic feet of air for efficient combustion. We may, for our argument, assume that from 9,500 to 10,500 cubic feet of gas is produced from each ton of bituminous coal and requires

$$\frac{9500 \times 10500}{2} = 10000 \times 10 = 100,000 \text{ cubic feet of air.}$$

Then, $219,565 + 100,000 = 319,565$ cubic feet as the minimum quantity absolutely required for the combustion of each ton of coal. There must be added to this amount the volume of excess air beyond what is chemically required to ensure good combustion. This excess air is variously given as 100 per cent. to 125 per cent. for natural draught and 50 per cent to 60 per cent. for mechanical draught.

The following example will serve to indicate the conditions to be observed to obtain efficient combustion with bituminous coal:—Firegrate 4ft. wide x 5ft. 6in. long—22ft. area. Rate of combustion, 25lbs. per sq. ft. F.G. equals 550 lbs. per hour equals 9.166 lbs. per minute. The fires to be

charged, say, every eight minutes equal to 9.166×8 equals 73.33lbs. per charge. Assuming the average depth of fire to be 12in., and that it is kept fairly free from ashes and clinker: then as the fuel next the firebars must be nearly exhausted, and that on the surface at nearly its full calorific value. The mean calorific value may without sensible error be taken at $\frac{0 \times 12}{2} = 6$ in. in depth = $\frac{22 \times 6}{12} = 11$ cub. feet or equal to about 605lbs. of coal of full calorific value. The ratio of the weight of fuel put on each charge to that in the furnace is $\frac{605}{77.33} = 8.25$ to 1.

This ratio of weight of incandescent fuel in furnace to that put on when charging should ensure the gas being distilled from the fresh charge with only a moderate reduction in the furnace temperature. Immediately the fresh charge is put in the furnace a large volume of gas will be generated, requiring an equivalent volume of air for its combustion, and at the time this takes place the fresh charge of fuel spread over the surface of the fire impedes the passage of air through it, thereby reducing its volume. Thus the smallest quantity of air is passing through the fire into the furnace when there is the largest generation of gas. It is therefore necessary to make provision for passing air into the furnace through some other channel to ensure good combustion. When the fresh charge is put into the furnace the rate of combustion of the coke or solid carbon portion is checked until the distillation of the coal gas from the fresh charge is nearly completed. The time taken to effect this is controlled by several factors, amongst which are moisture in coal, size or mechanical nature of it, and the condition of the fire as to depth and temperature immediately before the charge is put on. It may be taken at three minutes to illustrate this example:—

Weight of gas distilled of charge,—

$$73.33 \times .35 \text{ equals } 25.66 \text{ lbs.}$$

Volume of gas per charge,—

$$2240 : 25.66 :: 10000 : 114 \text{ cub. ft.}$$

Volume air,—114 x 10 equals 1140 cubic feet.

$$\text{,, ,, per min. } \frac{1140}{3} = 380 \text{ cubic feet.}$$

$$\text{,, ,, allowing 50 per cent. excess} = \frac{380 + 380}{2} \\ = 570 \text{ cubic feet.}$$

The area of perforations in the furnace fronts and fire bridge to permit this volume of air to pass through will depend on the draught or suction over the top of the fire measured in inches of water. If we assume a suction of a little over $\frac{3}{8}$ th in. water, this is equal to a velocity of about 2500 feet per min. Then $\frac{570}{2500}$ cubic feet = .228 square feet effective area of perforations of openings.

Assuming the entering air to be at normal temperature and the co-efficient of flow through the perforations at .6, the actual area of openings works out—

$$\frac{\text{sq. ft.}}{6} \quad \text{sq. ft.} \quad \text{sq. ft.} \quad \text{sq. order.} \\ \frac{.228 \times 10}{6} = .36 = .36 \times 144 = 51.84 \frac{51.84}{22} = 2.35 \text{ sq.}$$

With accelerated draught there need be no difficulty in regulating the air supply, as the intensity can be regulated by speeding the fan to suit the class of coal, the depth of fire, and the quantity of air required to be passed through or over the fire, or at the fire bridge: all that is necessary is to fit suitable ashpit doors and valves to control the quantity required. The adjustment of the doors and valves and the intensity of draught required to produce the best results can best be regulated by mechanical means and by having a C.O.2 recorder installed, the indications of which are read in the light of fairly frequent full gas analysis.

Centrifugal fans for producing forced or accelerated draught were first brought into use about the year 1827, when

Edwin Stevens arranged a fan for forcing air into the ashpit of a steamer in America. The demand for accelerated combustion does not, however, seem to have been urgent in those early days of steam engineering, as very little progress or development of the system is recorded. It is only during the last quarter of a century that the question has received close attention from engineers, and its development at the present time is very marked, as evidenced by the number of steamers fitted with an installation and also the number of land boiler plants that are being installed in various countries. There are quite a number of different designs of fans in use for producing accelerated draught, the difference being mainly in structural details rather than in the principle of working. It should be noted that the blades or vanes in the wheels of the centrifugal fan vary greatly in shape as made for different purposes and by different designers, and that, although centrifugal fans have been in use for more than two centuries, engineers are not yet in agreement as to the best proportions and form of the working parts. Many tests have been made to determine the capacity and efficiency of different types of fans. Those made by Mr. Bryan Donkin in 1893-4, which included eleven different designs and shapes of blades, showed that the one with straight blades and perfectly plain inlets gave the highest mechanical efficiency. In some experiments made by Heenan and Gilbert in 1896, a slightly higher efficiency was obtained by curving the blades or vanes forward in the direction of motion to form an angle of about 25 degrees, with the tangent of the circle (at point of contact) forming the inlet of fan. There are several other types of fans fitted with from 24 to 64 shallow concave blades or vanes, which are claimed by the makers to give high efficiencies and large outputs with smaller size impellers. The author regrets he has not any data or the results of actual tests made with these fans, to enable a comparison to be made between them and the simpler form.

The fans of the different makers can, no doubt, be driven at a speed to give the stipulated output. The author would, however, repeat the caution given by a well-known author that "most manufacturers overrate the capacity of their fans and under-estimate the horse-power required to drive them." It seems, therefore, advisable when installing an accelerated draught plant to carefully specify the conditions under which the plant is to work, and stipulate for a test of capacity and the horse-power required under actual working conditions.

Formula for speed and output of fans.—When a fan is working within its capacity, it will be found that the tip speed is approximately that which a body would attain by falling through a height of air column corresponding to the water gauge column at which the fan is intended to work:—

For air at 82 degrees Fahr., humidity 80 per cent.:

h = velocity head of air in feet.

H = pressure difference in inches of water W.G.

$$h = \frac{\text{density of water} \times H}{12 \times \text{density of air}}$$

At 82 degrees Fahr.:

$$h = \frac{62.21 + 1}{12 + 0.072} = 72.77 \text{ ft.}$$

Velocity of air in feet per second:

$$\begin{aligned} V &= \sqrt{64.32 + 72.744} \\ &= \sqrt{H} = 67.2 \sqrt{1} = 68.2 \text{ ft. per sec.} \\ &= 68.2 + 60 = 4,092 \text{ ft. per min. say } 4,000 \text{ ft.} \end{aligned}$$

to maintain a pressure of 1 inch water gauge.

In order that the pressure in the fan housing shall be equal to that corresponding to the tips of the floats or vanes, neither the velocity through the inlet nor the radial velocity at the inlet must be greater than the velocity of rotation of the points of floats at the inlet. Hence the maximum number of cubic feet of air discharged by a fan against a pressure

corresponding to the velocity of the tips of the floats is equal to the product of the velocity of the parts of the floats at the inlet multiplied by the area of the inlet, or by the area through which the air passes radially at the inlet, if it be smaller than the area of the inlet.

For an ordinary standard type of fan blower for forced draught, the author has found by actual test that the following formula gives fairly reliable figures for fan output:—

A = output capacity in cubic feet of air per min.

r = ratio obtained by dividing the diameter of inlet by the diameter of fan wheel.

D = diameter of fan wheel.

N = number of revolutions per min.

r = 0.707.

$$1. \quad A = 650 \times D^2 \sqrt{1}$$

$$2. \quad A = D^3 \times N \times 0.5$$

$$3. \quad A = 1.38 r^3 \times N$$

These equations are used for both double and single admission fans, because in the case of the double admission fans one of the inlets has a pulley before it on one side and a bearing on the other, which impedes the flow into the fan, so that the double admission fan is very little, if any, larger in capacity than a single admission fan.

For a steel plate fan 10 feet dia. x 4 feet 6 inches in width, working at a W.G. of $1\frac{1}{2}$ inches, the capacity works out:—

$$1. \quad A = 640 \times D^2 \times \sqrt{1.5} \\ = 640 \times 100 \times 1.225 \\ = 78336 \text{ cubic feet per min.}$$

$$2. \quad A = D^3 \times N \times .5 \\ = 1000 \times 159 \times .5 \\ = 79500 \text{ cubic feet per min.}$$

$$3. \quad A = 1.38 \times .707^3 \times D^3 \times 160 \\ = .488 \times 1000 \times 160 \\ = 78000 \text{ cubic feet per min.}$$

For suction draught fans the same formula apply, but for a given water gauge the height of the corresponding column will be greater for furnace gases than for air, because the furnace gases have less density. The tip speed will, therefore, be greater for a given water gauge when handling furnace gases. The ratio according to the laws of falling bodies will depend on the square roots of the heights of the respective columns of gases—that is, the tip speed necessary to produce a given water gauge will vary inversely as the square root of the density of the gases in the two cases, and as the densities of furnace gases and air vary inversely as the absolute temperature, the tip speed necessary to produce a given water gauge will vary directly as the absolute temperature of the gas. Thus the speed to handle the same weight of furnace gases is determined by the formula :

$$V=4000\sqrt{i} \text{ for air at } 82^{\circ} \text{ Fah. for furnace gases at } 500^{\circ} \text{ Fah.}$$

$$V=4000 \sqrt{\frac{500+461}{82+461}+i}=5268 \sqrt{i}$$

$$V=5268 \times \sqrt{1.316}=5268+1.224=6,447\text{ft. per min.}$$

$$= \frac{6448}{31.316}=205 \text{ rev. per min when handling furnace gases}$$

as against about 130 revolutions per min. when handling air at 82° Fah.

Horse Power required to drive fan—

$$\text{Formula } \frac{\text{Volume} \times \text{W.G.}}{6352 \times .4} = \text{I.H.P.}$$

$$\text{Example } \frac{79000 \times 1.5''}{6352 \times .4} = 46.4 \text{ I H.P.}$$

The factor or co-efficient .4 allows for the engine and fan efficiency and sufficient surplus power in engine to drive the fan at about 30 per cent. increase above normal capacity.

A fan for suction draught, which has to handle gases of high temperature, should be simple in construction and arranged to run at a moderate speed of revolution. The im-

PELLER should be carefully balanced, the bearings efficiently lubricated, and fitted with water-cooling arrangements. The rotary member of the fan should be practically indestructible, designed to resist unequal expansion and sand blast action.

The main point to be observed in an efficient and economical installation is not to have the fan too small for the volume of air to be handled. Experiments have established the following laws for a constant resistance for the same fan:—

1. The air discharged varies as the speed.
2. The gauge reading varies as the (speed)²
3. The brake horse power varies as the (speed)³

That is to say, if a given size of fan be driven at double the speed, it will discharge double the volume of air and will require eight times the power to drive it.

No special reference need be given to the relative cost of producing a good draught by means of chimneys or fans, as that subject is fully dealt with in most of the steam engineering text books.

For a 200ft. chimney, the relative cost of producing a given draught is stated by Walter B. Snow as 35 to 1. In this connection it should be noted that a chimney 200 feet in height would be much more costly than a fan having equal discharging capacity.

In conclusion, the author would like to say that these scattered notes have been somewhat hurriedly compiled, but he hopes the references therein are sufficiently extensive to bring out a good discussion on one, if not the, most important subject in connection with steam engineering at the present time—viz., the application of accelerated draught to steam boilers to increase their efficiency and economy, and to assist in reducing the smoke nuisance. In this connection, he ventures to suggest to the Council that they might with much

advantage to the members follow the example of the English Institute of Marine Engineers by instituting a course of lectures on combustion, and purchase a flue gas analysis outfit and C.O.₂ recorder, so that practical demonstrations could be given to the members.

