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# NOTES ON THE APPLICATION OF MECHANICAL OR ACCELERATED DRAUGHT TO STEAM BOILERS TO INCREASE THEIR EFFICIENCY AND STEAMING CAPACITY.

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One of the conspicuous features in the field of mechanical engineering at the present time is the widespread and active movement in search of better economy and efficiency and the reduction of the smoke nuisance in the working of tseam-generating plants. A perusal of the current technical literature on this department of mechanical engineering will serve to indicate the extent and scope of the movement, and enable the reader to form an opinion on the various systems and appliances recommended by experts and inventors, with a view to increase the efficiency and economy, and at the same time reduce the smoke nuisance, in steam generating plants. It seems unnecessary in the present state of mechanical science to urge at length the advantage of mechanical or accelerated draught, as against natural or chimney draught, for coping with the demands that are constantly being made on engineers by steam users and shipowners for higher efficiency and economy, combined with minimum weight, in their boiler plants. While these notes are not intended to be historical, the author proposes to make brief reference to the various systems, and to describe more fully the system of induced or suction draught as applied to land boilers and the means of producing it. It may prevent any misapprehension if the meaning intended to be conveyed in these notes by the term "mechanical or accelerated draught—produced by fan or otherwise" be clearly stated. It means a draught of greater intensity than is usually obtained from a chimney 150 to 200 feet in height, when worked under normal conditions, viz., the temperature of combustion gases entering chimney at from 450 to 500 degrees Fahr.

From the results of tests carried out on boilers worked with mechanical or accelerated draught, it may be accepted as proved beyond reasonable doubt that accelerated draught, if properly worked, can increase the steaming capacity of a boiler from 15 to 20 per cent., without reducing the efficiency, and that it may be driven from 25 to 35 per cent. greater capacity with only a moderate drop in efficiency. It should, however, be noted that there are many boiler tests recorded where high efficiency has been obtained with moderate natural draught, but in most of these instances the boilers have been worked at low rates of evaporation per square foot of heating surface, and with ample area of fire-grate surface to permit of the fuel being burned efficiently.

Mechanical or accelerated draught may be produced by the following methods:—

1. Steam jets or exhaust in the chimney, as in locomotives, fire engines, and portable engines. In the boilers of locomotives, where the chimney is very short, the use of the steam blast to produce an intense accelerated draught has been one, if not the most important, factor in the development of the modern powerful locomotive, and has made it possible to burn the quantity of fuel per square foot of grate surface necessary to evaporate sufficient water to produce ample steam for the engine when pulling heavy loads or travelling at high rates of speed. In some recent tests made by the Pennsylvania Railroad Company with their testing plant at St. Louis, a passenger engine, travelling at the rate

of 56.38 miles per hour and developing 1621 I.H.P., required a draught in the smoke box equal to 6.59 inches water gauge to produce the necessary rate of combustion, viz., 118lbs. of coal per square foot of grate surface per hour. To obtain the same intensity of draught with an ordinary chimney, it would require to be something over 1,200 feet in height. The boiler efficiency calculated from the temperature of the furnace and of the gases leaving the tubes was fairly satisfactory, considering the rate at which the boiler was being driven.

| | |
|---|---|
| Coal burned per hour ... | 5,760lbs. |
| Coal burned per minute .. | 96lbs. |
| Temperature in furnace .. | 2,500deg. Fahr. (estimated) |
| Temperature leaving Tubes | 689deg. ,, ,, |

Estimated quantity of air used per lb. of coal, 18.

Temperature of air, 60 deg. Fahr.

$$\text{Efficiency } \frac{(2500^\circ - 689^\circ) \times 100}{2500^\circ} = 72{\cdot}44 \text{ per cent.}$$

deducting 7 °/₀ for radiation losses $72{\cdot}44 - 7 = 65{\cdot}44$ °/₀, which seems a fairly satisfactory figure considering the rate of driving and the very short time allowed for the transmission of heat from the furnace to the water.

Coal burned per min., 98lbs. × 18lbs. = 1728lbs. air.

Volume and time occupied by gases from furnace to chimney exit:—

$$1728 \times 13.5 \text{ c.ft.} = 23328 \text{ c.ft. air per min.}$$

Volume air entering tubes per min:—

$$\frac{23328 \times 2160 + 461}{60 + 461} = 114{\cdot}600 \text{ cubic feet.}$$

Velocity of air entering tubes per second:—

$$\frac{114600}{7{\cdot}5 \times 60} = 255 \text{ ft. per second.}$$

Velocity leaving tubes—

$$\frac{23328 \times 689^\circ + 461}{60 + 461} = \frac{\overset{\text{Cubic feet}}{51491}}{7{\cdot}5 \times 60} = \overset{\text{per second}}{114\text{ft.}}$$

Mean velocity—

$$\frac{255 \times 114}{2} = 184{\cdot}5\text{ft. per sec.}$$

Length of Boiler tubes, 18.75 ft.

Then, $\frac{18{\cdot}75}{184{\cdot}5} = 0{\cdot}1$ of a second as the time occupied by the gases in passing through the tubes. The cubic capacity of combustion space in firebox is estimated at 250 c.ft.

Then, $\frac{11460}{60} = 1910$ cubic feet per second,

and $\frac{250}{1910} = 13$

of a second as the time the gases of combustion are in the firebox before entering the tubes. The total time occupied by the combustion gases from their formation in the furnace to their exit from the smoke tubes was $0{\cdot}1+0{\cdot}13=0{\cdot}23$ of a sec. This is a very short period of time for the combustion to take place in the furnace and the gases to give up their heat to the water in the boiler through the heating surfaces. This is a striking example of the efficiency and steaming capacity that can be obtained by accelerated draught, for in this instance there is—

(a) Moderate excess of air for combustion.

(b) High velocity of air through fuel.

(c) High velocity combustion gases through tubes.

These are factors which make for the highest possible efficiency.

A second test made on a freight engine developing 512 I.H.P., the draught in the smoke box was .88 in. water gauge, or equal to that produced by a chimney about 160 ft. in height. The fuel was burned at the rate of 22lbs. per square foot of grate surface per hour, and the efficiency was 78.44 per cent.—a very satisfactory figure. The time occupied by the combustion gases from their formation in the furnace to their exit from the smoke tubes was about 0.42 of a second.

Tests made by Mr. Aspinall on a locomotive in 1893 showed that when running at speeds from 47 to 50 miles per hour, the draught registered at the following points was as under:—

| | | | |
|---|---|---|---|
| Chimney .. .. .. | 15in. | water gauge | vacuum |
| Smokebox.. .. .. | 7in. | ,, | ,, |
| In furnace .. .. | $3\frac{1}{2}$in. | ,, | ,, |
| Ashpit .. .. .. | $0\frac{1}{2}$in. | ,, | pressure |

The effective draught was 4in. water gauge or approximately equal to a chimney 730 ft. in height. If the water gauge in the smokebox be taken, which includes the draught necessary to overcome the friction of the gases passing through the tubes, it would require a chimney about 1,270 ft. in height to produce the draught obtained in these tests. Mr. Aspinall says "no trouble is experienced with leaky tubes when working with intense suction draught and high rates of combustion."

2. Steam jets under the firegrate, or through hollow firebars, and also over the top of fire. Where accelerated draught is produced in this way the results of numerous tests by various makers have generally indicated a decided improvement in the boiler efficiency, and a marked reduction in the volume of black smoke issuing from the chimney.

3. Blowing air by means of under-grate blowers or fans into the ashpit. This system is usually named auxiliary forced draught. It has not so far as the Author knows been much used for either marine or land boilers. The objection against its use are said to be liability to blow holes in the fire, and causing back draught in the furnace.

4. Blowing air by means of fans into a close stokehold or fireroom. This system finds its greatest application in warships and their auxiliaries, and to a lesser extent in the mercantile marine. The air pressure generally ranges from

$\frac{3}{4}$in. to 4in. water gauge, the former in large full powered vessels with a fair height of chimney, the latter in torpedo boats and topedo destroyers. There is a good deal of data published in the technical press on the working and efficiency of this system, to which the writer begs to refer the members for further information. It may, however, be of interest to refer to a recent example of what may be termed "intense accelerated draught" on the torpedo destroyer "Mohawk," which attained the extraordinary speed of 34.24 knots—nearly 40 miles per hour—on trial. The boilers of this vessel were fired with oil fuel at the rate of 71lbs. per minute for each boiler. The volume of air supplied to each boiler was close on 20,000 cubic feet, or 120,000 cubic feet for the six boilers. The air pressure was 4in. water gauge, or equal to that produced by a chimney about 730 ft. in height.

5. Blowing air into closed ashpits and on top of fires, through specially arranged valves and perforations in fire-doors, the air being heated by air-heaters in up-take on its way to the furnaces—"Howden's System." The system is extensiely used in the mercantile marine, and has greatly increased the steaming capacity and efficiency of marine boilers. This system seems so much appreciated in the mercantile marine that it is doubtful if any up-to-date steamers are now built without it, or some other equally efficient system.

It may be of interest to refer to the forced draught installation of the turbine s.s. "Lusitania" and "Mauretania," as they are probably the largest installations carried out up to date. On the speed trials of the "Mauretania," the fans—32 in number, 66in. diameter—supplied 900,000 c.ft. of air per minute, at a pressure in the ashpit of $\frac{3}{4}$in. water gauge. The height of the funnel is given at 130 feet. The total draught may therefore be taken at 1.5in. water gauge, or equal to that produced by a funnel about 275 ft. in height.

6. Blowing air into or through underfed stokers. There are several types of underfed stokers in use. Air is forced by a fan through tuyeres, at the sides of the opening and up through the bed of coal. These furnaces burn efficiently most classes of coal. The heat on the top part of the furnace is intense, so that a want of care in cleaning may result in serious injury to the furnace. With the plunger type, its positive action can force the fires to meet increased demands for steam . It is important in connection with the working of these stokers that the coal should not contain too much moisture.

7. Blowing air into base of chimney through an air injector. This system of producing accelerated draught was tried in the French Navy, in 1876. The air pressure in the injector varied from 2.12in. to 10.2in. water gauge. At the higher air pressure the accelerated draught produced was sufficient to burn the coal at the rate of 41 lbs. per square foot of grate surface. This system was found to be more economical than the steam jet in the funnel, but was set aside in favor of the induced or suction system, which required less power to produce a similar intensity of draught.

8. Drawing the combustion gases from the furnace by means of suitable fans, the air being heated in the up-take on its way to the furnace—"Ellis and Saves Induced or Suction Draught." This system has been used to a considerable extent in the mercantile marine, and to a moderate extent in warships. It has its most extensive application in land boiler installation, the air heater being generally omitted, and seems the most natural way of producing accelerated draught. It has also the merit of being readily adapted to any existing boiler installation, as it does not require any special furnace fitting.

In a recent paper read before the Iron and Steel Institute on May 10th, 1907, by A. C. Capron, the "Ellis and Eaves" system of induced or suction draught is described, and the results of several evaporative tests given. Test No. 2 was made on an ordinary Lancashire boiler worked with both systems of draught—natural and suction.

Lancashire Boiler, 8.0in. dia x 28.0in. long, H.S., =900

| | DRAUGHT. | |
|---|---|---|
| Coal burned per sq. ft. of | Natural. | Ellis & Eames. |
| grate surface per hour .. | 28.5lbs. | 30lbs. |
| Calorific value of Coal .. | 14,000 B.T.U. | 13,000 B.T.U. |
| Water evaporated per hour | 6,724lbs. | 10,180lbs. |
| ,, ,, per lb. of coal | 6.68lbs. | 9.42lbs. |
| ,, ,, from & at 212deg. | 8.07lbs. | 10.45lbs. |
| ,, ,, per sq,ft. of heating surface per hr. | 7.47lbs. | 11.3lbs |
| Efficiency .. .. .. | 55 per cent. | 77 per cent. |

These figures show an increase in the steaming capacity with accelerated draught. of 51.4 per cent., and a saving of 29.4 per cent. in coal.

There are a number of evaporative tests recorded in the paper showing the high efficiency obtained by this system as applied to Marine, Lancashire, Stirling, and Babcock boilers. A test made in determine the maximum rate of evaporation obtainable from a 9.0in. x 30.0in. Lancashire boiler gave an average of 18.642 lbs. per hour=16 lbs. of water per in. H.S. per hour. The boiler efficiency of this test is not given, but another test on a similar boiler gave an efficiency of 71 per cent., and an evaporation of 10.3 lbs. of water per lb. of coal, when being driven at the rate of 11.2 lbs. of water per square foot heating surface. A full report of this valuable paper is given in "Engineering," May 24th, 1907. It is well worthy of a careful perusal by those interested in obtaining high efficiency and economy in steam boiler plants.

In view of the importance of fuel economy in the production of steam, and other industrial operations requiring coal, it seems advisable in these days of keen competition to investigate every system of working boilers and furnaces that promises increased efficiency and economy in existing plants, a reduction in the number of boilers in new plants, while maintaining the same efficiency, and the use of cheaper grades of fuel without loss of steaming capacity or efficiency.

The Author has had some experience in the application of accelerated suction draught—produced with fans—and ventures the opinion that there are few existing steam boiler plants worked with natural draught, that would not be greatly increased in steaming capacity and efficiency by the use of accelerated draught, the advantages of which may be briefly stated as follows:—

1. Effective regulation and control of steam under extreme variations of load, demands for steam, conditions of firing, and the use of different kinds of fuel.
2. Increase of steaming capacity of existing plants 20 per cent. to 30 per cent., without reducing their efficiency.
3. Reduction of smoke nuisance.
4. Ability to burn efficiently coals of cheaper grades.
5. Steaming capacity independent of atmospheric conditions.
6. Immediate response to sudden increased demand for steam.
7. Less labor required in stoking, as the fires do not require so much working.

8. Permits the products of combustion to be reduced from 250 deg. to 300 deg. Fahr. before entering chimney, by means of economisers, air-heaters, or other forms of heat extractors.
9. Permits of baffle arches and bridges being arranged to ensure an effective mixing of the products of combustion.
10. Permits a greater depth of fire in furnace, which ensures the air being brought into more intimate contact with the fuel, thereby producing a higher furnace temperature with less excess air.

As accelerated draught can be produced by either steam jets or fans, the selection of the system to be used in any special case should be based on a careful consideration of the cost of installation, its applicability to the case in hand, and the efficiency and economy in working.

For land boilers the Author inclines to the opinion that the suction draught system will be found the most efficient, easiest to control, and the least costly to work, and in cases where boiler plants have outgrown their original capacity, and require to have more boilers connected up to the same flue and chimney area, its application will be found to greatly improve the efficiency of combustion and permit of the boilers being worked to their most economic steaming capacity.

The following descriptions of some boiler plants which have been changed from natural to suction draught will serve to indicate the scope there is for its wider application:—Plant No. 1 originally consisted of six multitubular boilers with a chimney 6ft. 6in. diameter at top, by 135 ft. in height. To meet an increase in the capacity of the factory, three locomotive boilers were added with a chimney 4ft. 3in. diameter, x 110ft. in height. The output of the factory was further increased, so that two more multitubular boilers were installed with a chimney 4ft. diameter x 85ft. in height, making eleven boilers in the enlarged plant. The heating and firegrate surface in the eleven boilers were ample for the maximum amount of steam required to run the factory, but with the chimney draught available, the capacity and efficiency were considerably reduced by frequent stoppages on account of low steam pressure. It was therefore decided to instal a suction draught fan of ample capacity, to allow for future extensions and for sudden increased demands for steam. The fan is of the ordinary standard type, 10ft. diameter x 4ft. 6in. in width, driven by a 12in. x 12in. engine, capable of handling 80,000 cubic feet of hot gases per min., at a water gauge of 1½in. The fan inlet was connected to the main flue, into which all the boiler flues were led, and the outlet was connected to the 6ft. 6in. x 135ft. chimney, a bye-pass being arranged for natural draught when raising steam. The results obtained by the change from natural to suction draught were most satisfactory. A full head of steam pressure can be steadily maintained: the working capacity of the factory was increased from 20 to 25 per cent., the fuel consumption much reduced, the labor of the firemen stoking the coal burning fires much lightened, and two of the chimneys were dispensed with.

Plant No. 2 originally consisted of seven locomotive boilers with a chimney 5ft. 6in. diameter x 130ft. in height. Four additional boilers were installed to meet the demand for increased steaming capacity. Another chimney was also installed to meet the demand for increased steaming capacity. Another chimney was also installed 4ft. 6in. diameter x 90ft. in height, and the diameter of the 130ft. chimney was increased to 6ft. 3in. With the available draught there was much difficulty in keeping steam, even with favourable weather conditions. When, however, the weather conditions were unfavourable, it was next to impossible to keep a full head of steam, and there were frequent stoppages of the factory on that account. It was decided to instal a suction draught fan to handle 70,000 cubic feet hot gases per minute as a minimum, and from 85,000 to 100,000 as a maximum. The fan is 11ft. diameter x 3ft. 6in. wide. It is driven by a 16½in. diameter x 12in. stroke vertical engine. The 4ft. 6in. x 90ft. chimney was dismantled, and the 6ft. 3in. one shortened to about 70ft. in height. The result of the change from natural to suction draught resulted in plenty of steam to keep the factory going at maximum capacity, and a marked reduction in fuel consumption. This fan will handle in the near future about 95,000 cubic feet of hot gases per minute, and the 6ft. 3in. diameter x 70ft. chimney will be ample for carrying off the discharge from the fan.

No. 3 Plant consists of twelve boilers with a chimney 8ft. internal diameter at top x 145ft. in height. The draught measured by water gauge at base of chimney was from ·7in. to ·8in., which, with careful handling of dampers, was sufficient to maintain a full head of steam fairly constant, when the weather conditions were favourable, but when unfavoruable and with some classes of coal, it required a good deal of stoking and hard work at coal fires to keep the full steam pressure. A fan 10ft. diameter x 4ft. 6in. wide, driven by a 10in. diameter x 12in. stroke engine was installed, with the result that there is no difficulty in keeping a full head of steam, and the capacity of the factory can be increased from 20 to 25 per cent. with the same boiler plant when occasion arises. The fuel economy produced by the change to suction draught has been very satisfactory.

Plant No. 4 consists of sixteen boilers and four chimneys, each about 6ft. internal diameter x 125ft. in height. The