unchanged. This curious result is to be ascribed mainly to the mobility of the air at this great height. The particles of oxygen could penetrate the flame with comparative ease, thus destroying its light, and making atonement for the smallness of their number by the rapidity of their action.

I find, indeed, that by reducing the density of ordinary atmospheric air to one half, we nearly double the mobility of its atoms." With reference to the opposite step of *compressing* the air, Dr. Frankland showed twenty-five years ago "that the quantity of a candle consumed in a given time is, within wide limits, independent of the density of the air; and the reason is, that though by compressing the air we augment the number of active particles in contact with the flame, we, almost in the same degree, diminish their mobility and *retard* the combustion. One of the most interesting facts established by Dr. Frankland is, that by *condensing* air around it, the pale and smokeless flame of a spirit lamp may be rendered as bright as that of coal gas, and, by pushing the condensation sufficiently far, the flame may actually be rendered *smoky*, the oxygen present being too sluggish to effect the complete combustion of the carbon."

Causing the flame to be smoky is diametrically opposite to the effect desired in a boiler furnace. Yet Mr. C. W. Williams, the well-known able and practical writer on "The Combustion of Fuel," argues in favour of *condensing* the air, and strongly condemns the heating and consequent expansion of the air beforen entering the furnace; chiefly on the ground that "its already unwieldly volume is still further increased," and that "no natural draught would be equal to the volume of air were it doubled by heating to 512 deg."

After considering the deductions of Professor Tyndall and Dr. Frankland, the writer has the temerity to believe, such a high authority as Mr. Williams notwithstanding, that preliminary heating of the air for combustion, especially if it could be accomplished by heat which would otherwise be wasted, is highly desirable, for seeing that if it were practicable to heat the air before entering the furnace, to the temperature at which it afterwards passes up the funnel, say 500 or 600 deg. F., an addition of nearly 50 per cent. would, with a corresponding addition to the heating surface, be made to the evaporative power of the fuel. Some part at least of this benefit might surely be secured.

The author has just finished a careful comparison, for economy of fuel, between two ordinary furnaces using cold air, and two similar furnaces, doing same duty, but supplied with air at 445 deg. F. (tin melts reluctantly in the current of air entering ash pit). Newcastle (N.S.W.) co-operative coal from the same cargo was used for each furnace, and the gases escaped in each case at about 900 deg. F.

The actual saving of coal in favour of the hot air supply has been each week 9·75 per cent., and 9.8 per cent., but these furnaces, although intended to do exactly the same work, also did 3 per cent. more work. Consequently the *real* saving in fuel is about 12·7 per cent. Theoretically the saving should, of course, be greater, but 10 per cent. is well worth having.

The activity of the atoms of oxygen while passing through the fire must be very greatly exalted, as the air at that temperature would be expanded, say, 4 times, and when leaving the boiler the air would still be expanded to double its volume.

It appears to the writer that Mr. Williams's objection to the "increased volume" caused by heating the air must be limited in application chiefly to the time during the mere *introduction* of the air into the furnace, for the cold air must be heated instantly on entry, at the expense of the "high temperature necessary in the furnace." The difficulties attending the "increased volume" of the heated air must therefore be the same both while *in* and *after leaving* the furnace, whether the air be admitted cold or hot.

A considerable number of instances on record might be quoted of benefit claimed to have attended the application of heated air to boiler furnaces.

As it is evident that the character of the operations which take place in the furnaces are chiefly governed by the quantity and manner of air supply, a crude but inexpensive and perhaps original method of estimating the air supply for ordinary furnaces working with natural draught may now be noticed. Of course the quantity of air to be admitted into the furnace must be calculated entirely from the weight of fuel consumed, regardless of the area of grate surface. No empirical rules based on the velocity of draught due to a given height of and temperature in the funnel can prove satisfactory, owing to the widely varying degrees of obstruction to the draught between the furnace and funnel offered by different boilers.

The writer measures the actual draught—or, rather, partial vacuum—in a furnace by introducing a piece of iron gas-pipe, say ½ in. dia., and long enough to reach through a hole in the furnace front to about the centre of the furnace. On the outer end of the iron pipe a bend is formed, and a piece of glass tube attached—part of an old water-gauge glass. The open lower end of the glass tube being sealed in a little water, the height to which the water is raised within the tube then being measured, the rate at which the air will enter the furnace may easily be calculated from the following table. By multiplying the sum in square inches of the apertures supplying air to the furnace by the corresponding figures :—

Height of Water in Glass Tube.	Velocity of Air in Feet per Second.	Cubic Ft. of Air Passed p. Sq. Inch of Aperture p. Hr.	Lbs. Wt. of Air Passed p. Sq. Inch of Aperture p. Hr.
1/16th inch	12·8	320	23·7
1/8th „	18·4	460	34·
3/16th „	23·	575	42.6
1/4th „	26·4	660	48·9
5/16th „	29·6	740	54.8
3/8th „	32·24	806	59·7
7/16th „	35·	875	64·8
1/2 „	37·36	934	69·2

These figures have been calculated with a coefficient of 8/10th of the theoretical velocity and discharge; on the assumption that the air would be admitted into the furnace through perforated plates, the thickness of plate, and the diameter of the hole, being about equal. The temperature of the stoke-hole is assumed to be about 75 deg. F., or 13·5 Cubic feet of air weighing one pound.

In this way, the quantity of air admitted *above* the fire may easily be estimated and adjusted, and with a little more trouble the supply of air passing through the fire may also be indirectly calculated. If the front of the ash pit is closed by an ordinary thin sheet iron damper plate, fitted with a sliding door, adjusted so that say a vacuum equal to a head of $\frac{3}{16}$ inch of water is formed under the furnace bars, and at the same time say $\frac{3}{8}$ inches of vacuum is found above the fuel in the furnace. The weight of air entering through the damper plate is then found by multiplying the number of square inches in the adjusted aperture by the corresponding figures in the table, viz., 42·6. It is evident that exactly the same quantity of air is at the same time passing through the fire. If the damper plate is then entirely removed, and the vacuum in the furnace again noted, and found to be, say, $\frac{5}{16}$ of an inch, then the same number of square inches being multiplied by the corresponding figures—54·8—must give the weight of air entering through the ash-pit.

The velocity at which the air enters the ash-pit could, no doubt, be most readily ascertained by one of Casella's Anemometers, but these instruments are expensive and probably difficult to procure in the colonies.

If a large supply of air is drawn through a very restricted ash-pit, a vacuum may be formed under the fire bars,—after the damper plate is removed—of say, perhaps, $\frac{1}{16}$ of an inch, which must be deducted from the vacuum observed in the furnace, before the calculation is made; but in ordinary cases this correction is not necessary.

Take the case of an ordinary furnace, say 3 feet in dia., by 6 feet long, and a thin open fire and good draught, burning say 450 lbs. of coal per hour; 20 lbs. of air being admitted per pound of coal. The air must thus pass under the dead plate, through about 3 square feet of cross section, at the rate of about 11 lineal feet per second, or equal to a vacuum of about $\frac{1}{32}$ of an inch of water.

The sum of the spaces between the fire bars usually amounts to about $\frac{1}{3}$ of the total grate area. A velocity of the air of about 6 feet per second,—or equal to a vacuum of $\frac{1}{100}$ of an inch of water—would thus suffice to admit the full supply of air. But a very great obstruction is offered to the passage of the air immediately after, just *at the top of the bars*; where the spaces are almost covered by the fire and debris, which apparently reduces the available area for the admission of air to from $\frac{1}{4}$ to $\frac{1}{7}$ of the sum of the apertures between the bars. Hence the increase in steaming power usually attending the use of thin fire-bars, giving as much air space as possible.

The total quantity of air to be admitted to a furnace, having been decided on, a brief consideration of the manner in which it may be introduced remains.

The whole of the air, from 18 to 24 lbs. weight, for the the combustion both of the coke and the volatile matter, and for the dilution of the carbonic acid, may evidently be admitted through the fire, if it is sufficiently open; or, the proportion of air passing through the fire may be restricted to about one-sixth part,—producing carbonic oxide, and the volatile gases—the remaining $\frac{5}{6}$ of the air being admitted above the fire for the combustion of these gases. Any intermediate proportion between these extremes in the supply of air through or over the fire may obviously be adopted.

In ordinary practice the supply of air passing through the fire is regulated almost entirely by the demand for steam, and by the state of the fire; which, if thin and clean, rapidly burns into holes which may admit a large surplus of air; or, on the other hand, the grate may be almost hermetically sealed, either by clinker and ash, by a thick fire which has been ground small by constant slicing, or by heavy charges of small caking coal.

Hence the necessity for an unceasing watch on the state of the fire, and the difficulty of regulating the supply of air entering above the fire in even proportion to the quantity entering *through* the fire. It is clearly desirable that the fire should be as much as possible maintained in a uniform condition, which cannot be the case with heavy charges of fuel at long intervals.

Michael Reynolds in his book "Locomotive Engine Driving," truly says, that "The secret of first-rate firing is to fire *frequently, and a little at a time*."

Whether much or little air be admitted either through or after the fire, the first object is to mix it thoroughly with the furnace gases, and it would appear that this object can best be attained by admitting the air *in small jets, at a high velocity across the current of the flame*, although, for the sake of convenience, the air is usually admitted either at the bridge, or more frequently through the furnace door or front.

The most economical thickness of an ordinary fire of the Newcastle Co-operative coal appears to be not less than 12 inches, or virtually as thick as it is possible to work the fire, so long as it remains clean.

The effect of admitting air through the furnace doors is marked. Recent experiments with one of a range of Cornish boilers (now under the care of the writer), shewed an increase of temperature (registered by a pyrometer in the outer flue of the boiler—indicating the temperature of the passing gases after a run of 60 feet from the furnace) with varying admission of air above the fire up to 80 square inches of aperture, or 4 square inches per square foot of grate. Each boiler is 7 feet dia., and 27 feet long, with 20 square feet of grate in a corrugated furnace and flue 3ft. 8in. dia.

About 400 lbs. of coal are burnt per hour with a vacuum in the furnace equal to $\frac{3}{8}$ths of an inch of water. (The chimney, 120 feet high, gives a draught of $\frac{3}{4}$ths of an inch.) With the 80 square inches of opening above the fire, about 12 lbs. of air will be admitted per pound of coal consumed, or enough chemically for the complete combustion of the coal, though at the same time at least as much air would be admitted through the fire.

The pyrometer is a very simple affair, merely a small stiff iron tube, 28 feet long, carried on bearers through the centre of the flue. One end of the tube is firmly fixed, and a long pointer rests against a knife edge on the other end of the tube. The long arm of the pointer travels over a quadrant scaled 100 deg. F. to 3 inches. The scale was standardized up to 600 deg. F. by a thermometer. The temperature indicated will be the average obtaining throughout the flue. This little arrangement is extremely sensitive, the slightest alteration in the admission of air, or in the state of the fire being almost instantly responded to. The increase of temperature shewn in the outer flue, when 80 square inches of aperture is suddenly opened above the fire, averages about 60 deg. F., with a fire either of coal or coke. When the apertures above the fire are suddenly closed again, the pointer usually drops as rapidly as it had risen previously. The temperature indicated with ordinary firing ranges from 750 deg. to 800 deg. F., usually standing at or near 760 deg. F. The highest temperature noted with a clean fire of round coal and hard firing was 850 deg. F.; but with a clean coke fire 1050 deg. F. has been registered, indicating probably a long flame of C.O., and shewing that the temperature in the outer flue is *not* in proportion to the rate of evaporation, nor to the value of the fuel as the coke possessed only about $\frac{4}{5}$ths of the evaporative power of the coal. The 12lbs. weight of air admitted in excess above the fuel, and finally leaving the boiler at about 500 deg. F. must carry off sufficient heat to evaporate about $1\frac{1}{2}$lbs. of water, or 20 per cent. of the duty of the boiler. Yet the weight of water evaporated per pound of coal only falls off about 3 per cent., thus shewing that more perfect combustion must have been attained, although the resulting increase of heat generated cannot all be abstracted from the larger volume of less highly-heated gases travelling more rapidly past the heating surface of the boiler. This effect of the admission of an excess of air to the furnace in distributing the heat more evenly over the heating surface of a boiler is sometimes utilized with advantage in the case of boilers that prime badly, by setting the furnace door ajar. Some sacrifice of economy of fuel may follow owing to the difficulty of abstracting the heat from large volumes of gases at comparatively low temperatures, as the rate of conduction is in proportion to the difference in temperatures between the source and the recipient of heat. With ordinary strength of draught, a square foot of heating surface near the smoke-box end of a boiler tube evaporates only about $\frac{1}{16}$ as much water as a square foot of the fire-box, although the differences between the temperatures in the furnace, and in the tube respectively, and the temperature of the boiler are only about 3 to 1. The increase of air pressure in the furnace accompanying most systems of forced draught must tend to localize the heat, and to increase the evaporation effected by the furnace. While increased chimney draught, and consequent vacuum in the furnace, must tend to distribute the heat, and equalise the percentages of the total work done by the furnace tubes—or other heating surfaces respectively. A high furnace temperature being undoubtedly necessary in order to secure complete combustion, it would therefore appear that any successful attempt to raise the temperature in most ordinary furnaces would prove beneficial, especially when it is borne in mind that in the case of internally fired tubular boilers—as estimated by Peclet, and corroborated by recent American experiments—*half* of the available heat is at once abstracted, as radiant heat, by the plates of the furnace. There is usually besides this the drain on the furnace temperature of heating, say, at least, 10 lbs. weight of air per pound of coal, above the quantity chemically necessary, to say 1500 deg. F.; which would be equal to the evaporation of over 3 lbs. of water. It is true that $\frac{2}{3}$ of this heat is afterwards returned to the boiler through the tubes; but the restitution of heat is too late to assist combustion.

Several authors agree that in well-arranged furnaces, with the natural draught, half the oxygen admitted passes away uncombined.

The loss caused by the admission of any considerable surplus of air to the furnace being so large, it is desirable to ascertain in what state of the fire the smallest proportion of oxygen is passed through unburned.

The repeated and careful analysis of the burnt gases from the boiler flue before referred to, in which the pyrometer was placed, revealed the somewhat unexpected result that *the amount of oxygen passing unchanged through the fire, in every case increased almost uniformily in proportion as the fire became dirty and choked.* After the fire had been recently cleaned, and with a thick hot fire of clean coke and a sharp draught, no air being admitted above the fire, the pyrometer indicating 1030 deg. F.; 20 per cent. of oxygen admitted was found to have passed through the fire unchanged. After the fire had run for four hours the percentage of uncombined oxygen rose to 30 per cent., and after six hours to 55 per cent. At the end of six hours a thick continuous and apparently almost impervious clinker had covered the bars, the production of steam being reduced to about one-fourth.

It is thus clearly desirable to maintain the fire *constantly* in a clean open condition, and to work with as much draught as possible, the thickness of the fire being regulated by the strength of draught available.

The following are average examples of the actual partial analysis:—

FIRE OF COKE, 14 INCHES THICK.

	1 hour after Cleaning.	$3\frac{1}{2}$ hours after.	6 hours after Cleaning.
Carbonic acid, including SO_2	16 per cent.	14.2 per cent.	9.3 per cent.
Carbonic oxide...	none.	traces.	0.4 per cent.
Oxygen ...	4 per cent. = 20 per cent. of total.	6 per cent. = 30 per cent.	10.9 per cent. = 54.5 per cent.
	20.	20.2	20.6
Tem. in flue ...	1030 deg. F.	800 deg. F.	650 deg. F.

FIRE 10 INCHES THICK, OF NEWCASTLE CO-OPERATIVE SMALL COAL.

	1 hour after Cleaning.	4 hours after.	8 hours after, fire very dirty.
Carbonic acid including SO_2	13.2	13.4	11.3
Oxygen ...	3.2 = 16 per cent. of total.	6.6 = 33 per cent.	8.0 = 40 per cent.
Carbonic oxide and moisture not estimated.			
	16.4	20.0	19.3
Tem. in flue ...	830 deg. F.	790 deg. F.	630 deg. F.

Fire 12 inches thick, of Newcastle co-operative round coal, 2 to 3 hours after cleaning, or average condition—

Carbonic acid, including SO_2	12.2	
Oxygen	7.5 = 37.5	of total.
	19.7	

On the following pages will be found an extract from a summary of some practical tests of the comparative evaporative powers of several kinds of fuel. The figures given are the averages of many closely-corresponding tests of each kind of fuel. The tests averaged about eight hours duration each. The fire was drawn about seven each morning, and a fresh fire started from weighed coal; the time, the register of feed meter, and level of water in the boiler being noted. At the conclusion of each trial the fire was allowed to burn entirely out, the water in the boiler then being pumped up—a trifle only—exactly to the mark. The nearly constant temperature of the feed water, after passing through a Green's economiser, averaged 168 deg. F. The accuracy of the water meter was frequently tested. The ash and clinker were weighed together; the soot and flue deposit *not* being included.

Extract from Summary of some Meter Tests of Evaporative Powers of Fuels at Auckland Sugar Refinery, July, 1885, to March, 1886.—EDWIN C. STABLES.

Description of Fuel.	Lbs. Feed Water @ 168 deg. F actually evaporated per lb of fuel (add ·045lbs to each quantity if from 212 deg. F.)	Gallons of Water @ 168 deg. evaporated per ton of Fuel.	Weight of Fuel to evaporate 100 gallons from 168 deg. F.	Normal rate of Evaporation in gallons per hour by one boiler.	Lbs. Feed Water evaporated per ea. sq. ft. of (600 sq. in.) heating surface in lbs per hour.	Coal burnt per ea. sq. foot of (20 sq. in.) grate-bar surface in lbs. per hour.	Percentage of Ash and Clinker. (Dry.)	Price per ton of Fuel in Stoke-hole.	Gallons of Water @ 168 deg. F. evaporated for £1	Value per ton of Fuel, compared with Co-operative *Round*, @ 23/3. A	Value per ton of Fuel, compared with Co-operative *Small* @ 16/3. B	Value per ton of Fuel, compared with Westport *Small*, @ 18/3. C
Co-operative *Round* Coal ... Newcastle, N.S.W. A	7·0	1568·	143·lbs.	297· Max. 377 with forced firing.	4·95	21·17	11·3	23/3	1348·	23/3	17/3	16/5¼
Co-operative *Small* ... ... B	6·6	1478·4	151·	249·	4·38	18·85	11 75	16/3	1819·	21/11	16/3	15/5¾
Ferndale *Round*... ... ... Newcastle, N.S.W.	7·2	1612·8	138·8	288·	4·8	20·0	9·3	22/3	1450·	23/11	17/8¾	16/10½
Ferndale *Small*	6·5	1456·	154·	243·4	4·05	18·65	9·23	16/3	1792.	21/7	16/-	15/3
Newcastle Coal Co.'s *Round* ...	7·2	1612·8	138·8	364·	6·07	25·3	9·	22/3	1450·	23/11	17/8¾	16/10½

Newcastle Coal Co.'s *Small* ...	6·6	1478·4	151·	243·	4·05	18·46	9·6	16/3	1819·	21/11	16/3	15/5¾
Bay of Islands, N.Z. *Round* ...	6·27	1411·2	159·4	335· Max. 411½	5·583	26·7	10·3	20/3	1392·	20/10	15/5	14/8½
Kamo—Top Seam ... ... Whangarei, N.Z.	5·6	1254·4	178.	252·	4·2	22·445	6·23	13/9	1824·	18/7¼	13/9½	13/1¾
Kamo—Lower Seam	5·25	1176·	190·	261·1	4·35	24·868	5·48	13/9	1710·	17/5¼	12/11¼	12/4
Whau-Whau *Round* ... ... Whangarei, N.Z.	4·86	1088·6	205·7	252·5	4·2	26·0	9·8	13/9	1583·	16/1¾	11/11½	11/5
Taupiri Unscreened ... ... (damaged by weather) Waikato, N.Z.	4·65	1041·6	215·	268·	4·46	28·8	3·32	16/3	1282·	15/5¼	11/5¼	10/11
Greymouth, N.Z., Coal ... (damaged by weather)	7·4	1657·6	135·	272·5	4·54	18·4	7·0	36/3	914·5	24/7	18/2¾	17/6
Round Coal, Westport, N.Z.... C	8·544	1913·85	117·	355·	5·916	20·75	2·0	23/3	1646·	28/3	21/0½	20/0½
Small Coal, Westport, N.Z. ... C	7·777	1742·	128·7	281·	4·6816	18·05	2·0	18/3	1909·	25/10	19/-	18/3
" Duckinfield *Small* " ... ... Newcastle, N.S.W.	6·6	1478·4	151·	275·5	4·59	20·875	11·9	16/3	1819·	21/11	16/3	15/5¾
J. & A. Brown's *Round* ... Newcastle, N.S.W.	7·17	1606·	139·4	319·	5·316	22·9	10·2	22/3	1443·6	23/9¾	17/7¾	16/10
Auckland Gas Co.'s *Screened Coke*, chiefly from Greymouth, N.Z., Coal ...	6·3	1411·2	158·7	323·2	5·386	25·75	8·8	15/3	1851·	20/11	15/6	14/9¼
Auckland Gas Co.'s *Small Coke* (average sample) ...	4·637	1038·68	215·65	213·8	3.563	23·05	8·5	10·3	2026·	15/5	11/5	10/10½
Best Rough Coke from own Retorts, from Co-op. N.S.W. Coal	6·95	1556·8	...	302·			13·1					