Experiments upon the Relative Effect of Burners for Fuel and Illuminating Gases.

Thesis.

Herbert S. Kimball.

1891.

Experiments upon the Relative Effect of Burners for Fuel and Illuminating Gases.

It has been suggested that a non-luminous gas would eventually be the only gas distributed. This idea is based upon the facts, that its cost of manufacture is cheaper than that of illuminating gas, and that it may be used as a fuel and as an illuminant.

Others say that luminous gas will not be replaced, even when gaseous fuel has become general, for they claim that a luminous gas may be burnt as a fuel with the same cost as a non-luminous gas. Their assumption is based on the fact that a luminous gas, as now made, contains much more heat than the non-luminous gas of the present time.

My work has been to make a comparative examination of burners for illuminating and heating effects, using the gases that are manufactured in Boston.

The illuminating gas of the city consists of a mixture of coal gas and carburetted water gas.

The fuel gas is practically a non-luminous gas. It consists principally of hydrogen and carbonic oxide; a little coal gas is mixed with it, also mercaptan. This latter compound, a sulph-hydrate, possesses a disagreeable odor, which allows the detection of the gas if any should happen to escape.

The composition of the gases is shown by the following analyses, which were made by me, using the Hempel gas apparatus.

Analyses of Gases.

Symbol	Name	Illuminating Gas at M.I.T.	Illuminating Gas at South End Works	Fuel Gas
CO_2	Carbonic acid gas	2.8 %	1.8 %	2.3 %
C_2H_4 ect.	Ethylene ect.	11.8	8.4	.5
O_2	Oxygen.	1.2	.9	0
CO	Carbonic oxide	17.8	6.6	30.5
CH_4	Methane	26.0	31.7	5.5
H	Hydrogen	33.9	42.3	53.2
N ect.	Nitrogen ect.	6.5	8.3	8.0
Total		100.0	100.0	100.0

About one half of the experiments were made at the Institute. Through the kindness of the Messrs. Addicks of the Boston Gas Light Company I was allowed the use of the photometer-room and apparatus at the company's works;

where I made the most important experiments.

My investigations are divided as follows:-

Part I, Gas as an Illuminant.
Part II, Gas as a Fuel.

Part I, Gas as an Illuminant.

Division A, Using Illuminating Gas.

In this division I tested the efficiency of burners for illuminating gas found upon the market.

For the tests made at the Institute I used the photometer room of the Physical Department, which is provided with a Bünsen photometer. The Methven burner was used as my standard; and in order that I might know the exact light that it gave I tested it by a standard candle burning at the rate of 120 grains per hour. The results of the tests are as follows:-

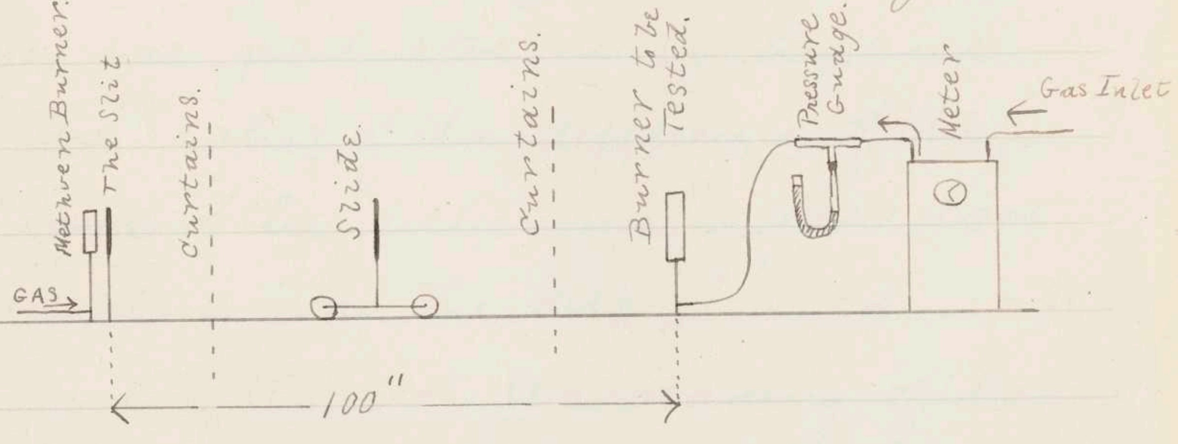
No. of Test.	Illuminating power.
1	1.97 candles
2	1.99 "
3	2.01 "

These results are so near 2 that I considered that no great error would be caused from this source if the illuminating power of the Methven power was taken as 2 candles, that is, it gave twice as much light as a standard candle burning at the rate of 120 grains per hour.

I used both a wet and a dry meter, the former being of larger capacity than the latter. Both meters were correct, the dry meter was a new one and was tested by the makers. The wet meter had been in the department for some time and the water level had been adjusted.

In order that the pressure at the point of ignition might be determined I placed a water pressure guage between the meter and the burner. A T joint was used as a connector. The difference of level of the water in the arms of the U shaped tube gave the pressure at the point of ignition, in terms of inches of water.

This sketch shows the arrangement.



Before making a test I cleaned the chimneys and allowed the Methven burner to come to its normal rate of burning and adjusted the height of the flame. The burner to be tested was kept burning some little time before making the test. When all was ready the extra lights were extinguished and the reading of the meter taken upon the second. The pressure of the gas was noted at the beginning and at the end of each test. I set the slide ten times in each test and noted the readings. Their mean when multiplied by 2, i.e. the standard was 2, gave the illuminating power of the burner. The scale was graduated in inches and in the "ratios of the difference of the squares of the distances". This last graduation was the one I used. At the end of the test the reading of the meter was taken; and by the time the consumption of gas per hour was figured.

The efficiency is obtained by dividing the illuminating power by the consumption of gas per hour. The result is the efficiency or the "candle per foot per hour".

I will give first the results of tests of the more simple burners.

Bray, 4 foot, low pressure. Union Slit

Gas per Ho.	Illuminating Power.	Pressure at Point of Ignition.	Efficiency or Candle per ft.
5.380 Cu.ft.	15.82 candles	1.5"	2.8+
4.38	13.92	1.1	3.2

Bray, 6 foot, low pressure, Union Jet.

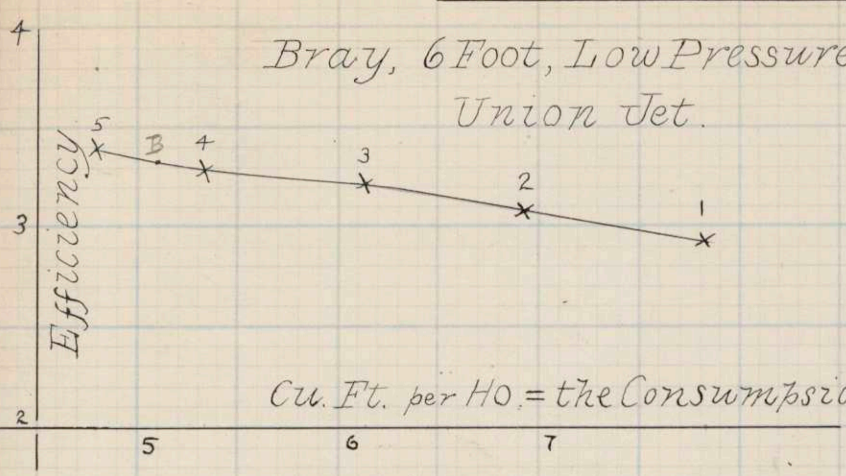
Gas per Ho.	Illuminating Power.	Pressure.	Efficiency or Candle per ft	
7.834 Cu.ft.	23.00 candles.	1.8"	2.93	(1
6.930	21.4	1.3	3.09	(2
6.139	19.8	1.15	3.22	(3
5.325	17.5	1.0	3.28	(4
4.785	16.2	0.8	3.38	(5

On page 9 a curve is plotted, where the ordinates are the efficiency and the abscissae the consumption of gas per hour. It will be noticed that the efficiency

Curves.

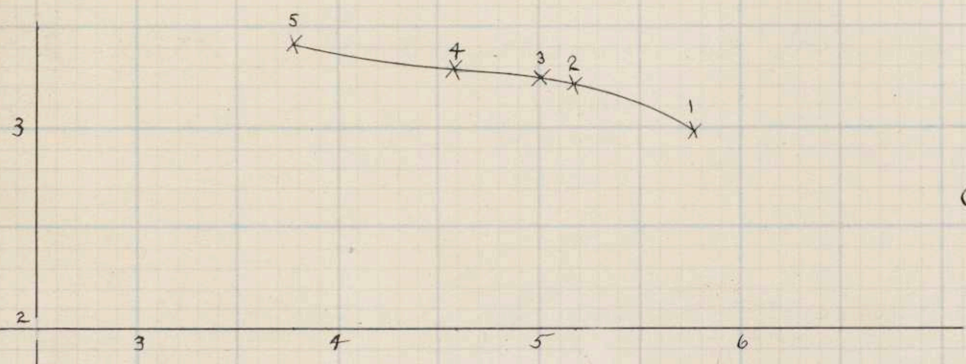
Showing the change of Efficiency with the Consumpsion of Gas.

Bray, 6 Foot, Low Pressure. Union Jet.



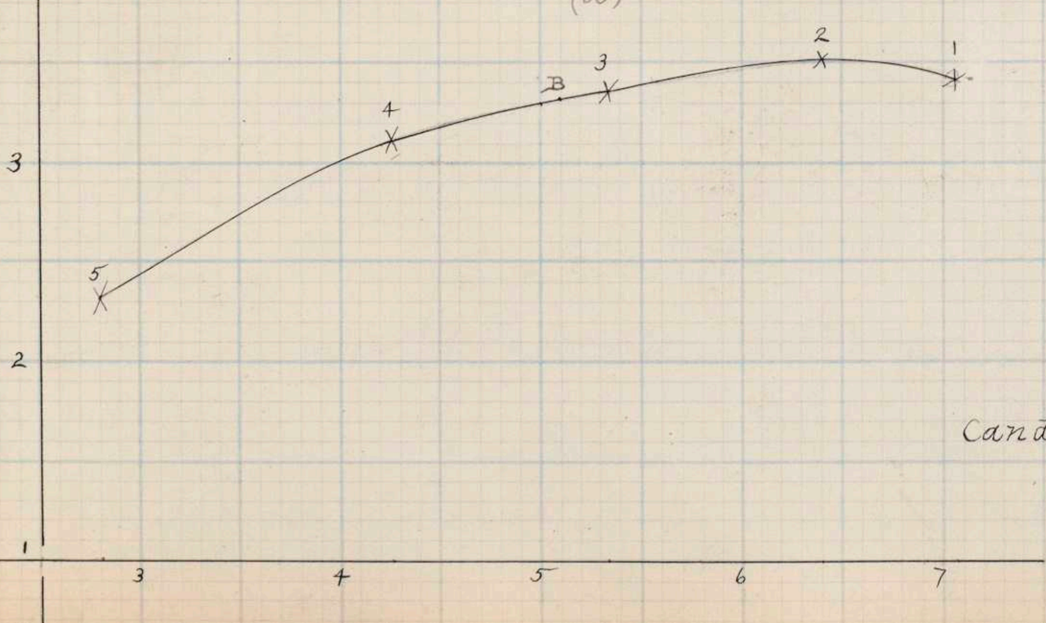
Candle Power 16.70

Bulb Fish-Tail Burner,



Candle Power 16.25

Common Argand Gas Burner. (a)



Candle Power 16.50

increases as the consumption of gas decreases.

The "candle power" can be computed from the curve. This quantity is based upon a consumption of 5 cubic feet per hour. Measure the ordinate corresponding to the abscissa 5; and multiply this number by 5. This result is the candle power, which is placed upon the plot to the right.

Jackson Pillar Burner. Special Check.

Pressure.	Illuminating Power.	Gas per Ho.	Efficiency.
1.45"	15.92 Candles	4.903	3.3 –
1.2	15.12	4.308	3.5

Jackson Pillar Burner. Regulating Valve.

Pressure.	Illuminating Power.	Gas per Ho.	Efficiency.
1.2"	17.56 Candles	4.872 cu.ft.	3.6
0.85	14.8	3.984	3.7+

During the last test an excellent light

was obtained and this test shows the highest efficiency of any of these simple burners.

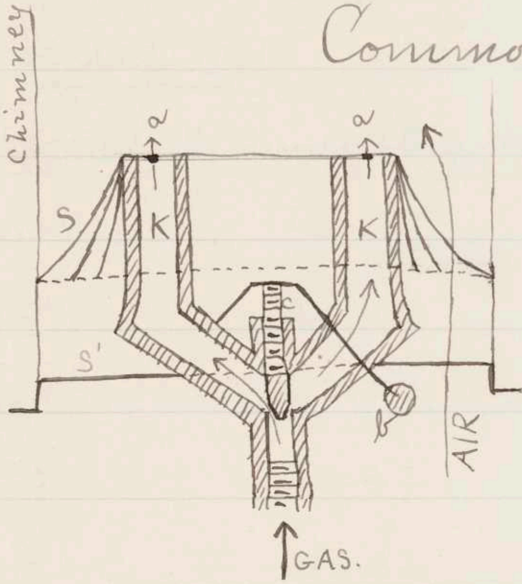
Bulb-shaped Fish Tail Burner.
[With screw regulator]

Pressure.	Illuminating Power.	Gas per Ho.	Efficiency
1.35"	17.24 Candles	5.77 Cu ft	2.99
1.3+	16.62	5.18	3.21
1.33	16.32	5.01	3.25+
1.45	15.10	4.590	3.29
1.5	12.90	3.78	3.41

On page 9 a curve is drawn for this burner. It efficiency increases with the decrease of consumption of gas. This burner compared with the Bray, 6 foot, low pressure, by their curves, is not quite so good as the Bray.

In this fish tail burner the decrease of consumption was obtained by screwing down the regulator, while in the other common burners the consumption was changed by turning the cock on the outlet pipe of the meter.

Common Argand.



A sketch of the burner is shown, which represents a cross section through the center. The gas enters, as shown, from the bottom and passes into the annular space K. From here it goes out of the holes a, a, and is consumed. The flame is circular in shape. The arm b turns the screw c which regulates the flow of gas.

The chimney is supported by the frame work of wire, lettered S and S'.

The air is drawn up under the chimney, as shown by the arrow, and passes through ~~the~~ the flame work S, and then comes in contact with the flame.

Tests on the Common Argand Burner.

Series (a)

Pressure.	Illuminating Power.	Gas per Ho.	Efficiency.	
1.05"	24.24	7.140	3.4- }	(a
1.05	24.12	7.068	3.41 }	(1
0.9	22.50	6.440	3.5 }	
0.9	22.42	6.396	3.51 }	(2
.6	18.02	5.352	3.36	(3
.4	13.38	4.269	3.13	(4
.25	6.48	2.796	2.32	(5

Series (b)

.95	24.30	7.249	3.4-
.75	19.94	5.760	3.4+
.5	13.86	4.41	3.1+
.25	7.04	2.98	2.4-
.1	1.54	1.706	0.9

The regulation of the consumption was made, in both series, by the cock at the outlet of the meter.

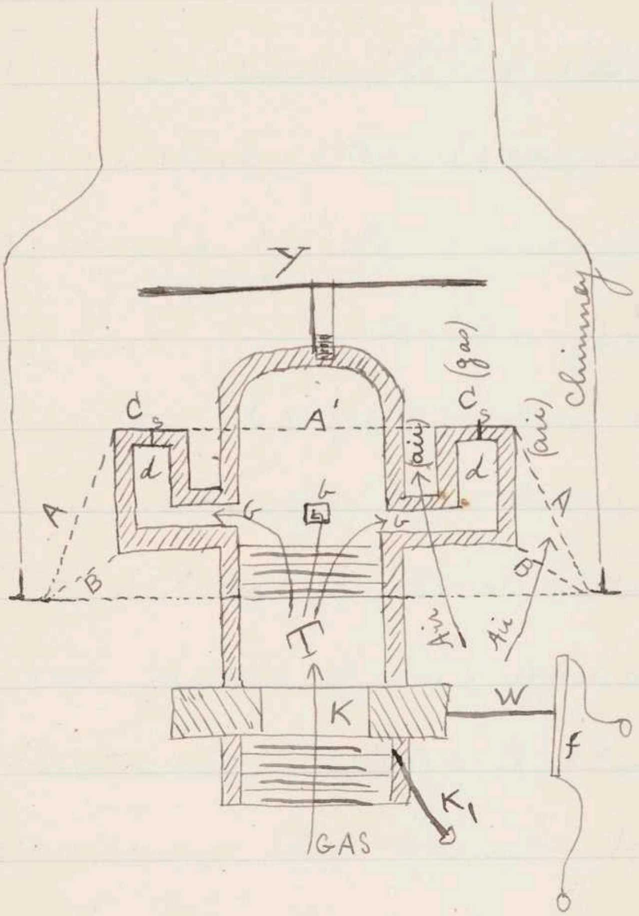
A curve the Common Argand, series (a), is plotted on page 9. It is to be noticed that the efficiency decreases with the decrease of consumption of gas, a fact just opposite in the common burners shown by the first two curves.

We can conclude from these curves that it is not economy to use two argand burners burning low and consuming together the same amount as that of an argand burning bright; because the total light given out by the two argands is less than that of the one argand, even when the consumption is the same in both cases.

On the other hand with the common burners two $3\frac{1}{2}$ "foot burners" is better than one 7 "foot burner". The consumption is the same but as the efficiency of $3\frac{1}{2}$ feet per hour is larger than the efficiency of 7 feet per hour, it follows that more light can be obtained from two small burners than from one big one, using the same amount of gas.

If the curve of the Bray, 6 foot, low pressure, Union Jet were plotted in the same plot as the curve of the common argand, they would cross at about the point marked B. Or, in either burner when the consumption is 5.1 cuft per hour the efficiency is the same, i.e., 3.32.

Royal Argand Burner.



This sketch is a crosssection of the burner. The gas enters as shown by the arrow, through the valve K, which is moved by the arm W and the lever f. The gas passes into the space I, and from here it passes through the three pipes marked b b b. These pipes lead into an annular space d. The gas passes from d through the holes s to the flame.

A, A' and B are screens through which the air for combustion is drawn.

The arrow bearing the legend "air" shows how the air is distributed. It should be noticed that air surrounds the flame on two sides, thereby causing quite complete combustion

Y is a circular piece which spreads the flame. K_1 is a screw which allows more air to enter.

the screen A' does not pass through the top part of the space T but is drawn dotted so as to show that it surrounds the space T.

I made two sets of tests on this burner. In the first series the flow of gas was regulated by the valve at the burner. When the valve was closed a little the pressure arose; and kept rising as the consumption of gas was made less by closing this valve.

In the second series the regulation

was made by the outlet cock on the meter. Here as the amount of gas was lessened the pressure fell.

Tests on the Royal Argand Burner.

Pressure at Ignition.	Illuminating Power.	Gas per Ho.	Efficiency	
0.8"	29.81 Candles	7.956 cu.ft.	3.74	(1
0.8	29.46	7.926	3.7+	
0.955	26.16	7.540	3.47	(2
0.955	26.06	7.560	3.4	
1.5	11.75	7.568	2.13	(3
1.49	11.95	5.616	2.1	

Series (b)

.905"	32.66	8.409	3.88	(1
.905	32.42	8.352	3.9 -	
.7	22.52	7.224	3.12	(2
.6	17.24	6.624	2.60	(3
.5	12.12	5.660	2.14	(4
.255	4.84	3.762	1.28	(5

On page 20 two curves of the preceding tests are plotted.

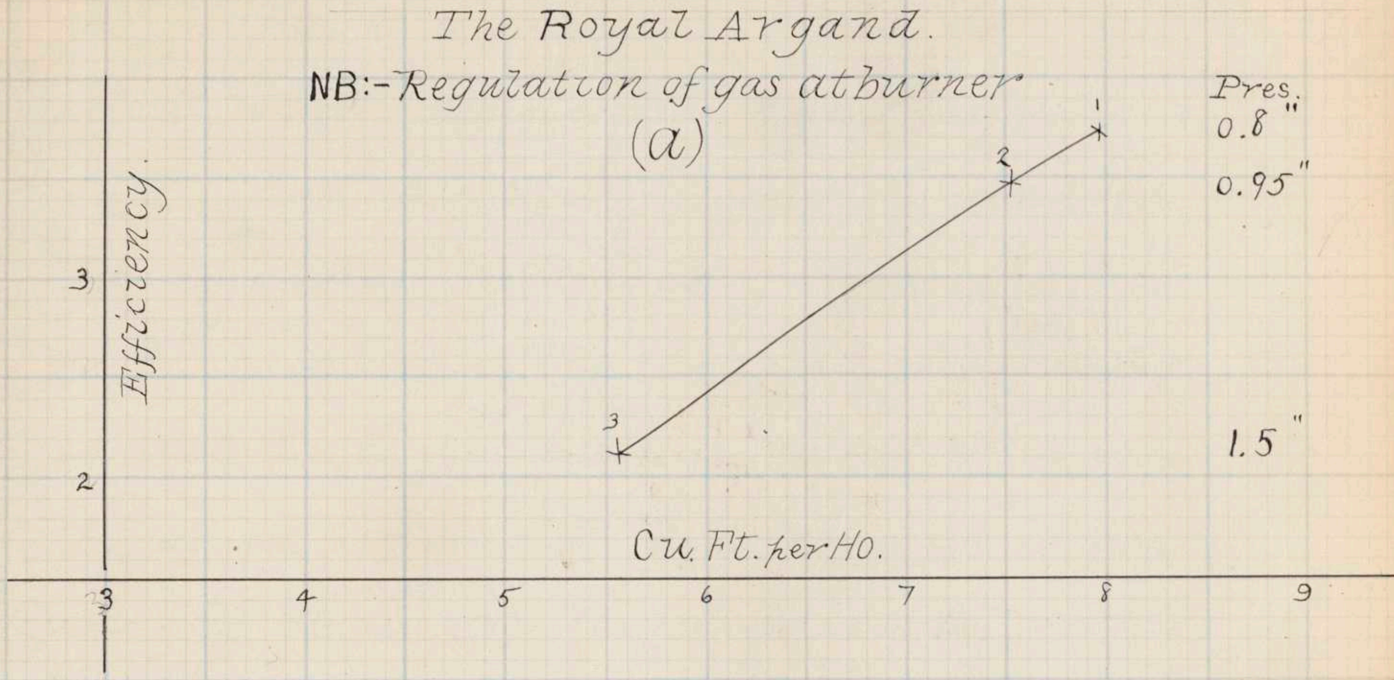
The comparison of these two curves is interesting. From these curves it is shown which is the better way to regulate the flow of gas.

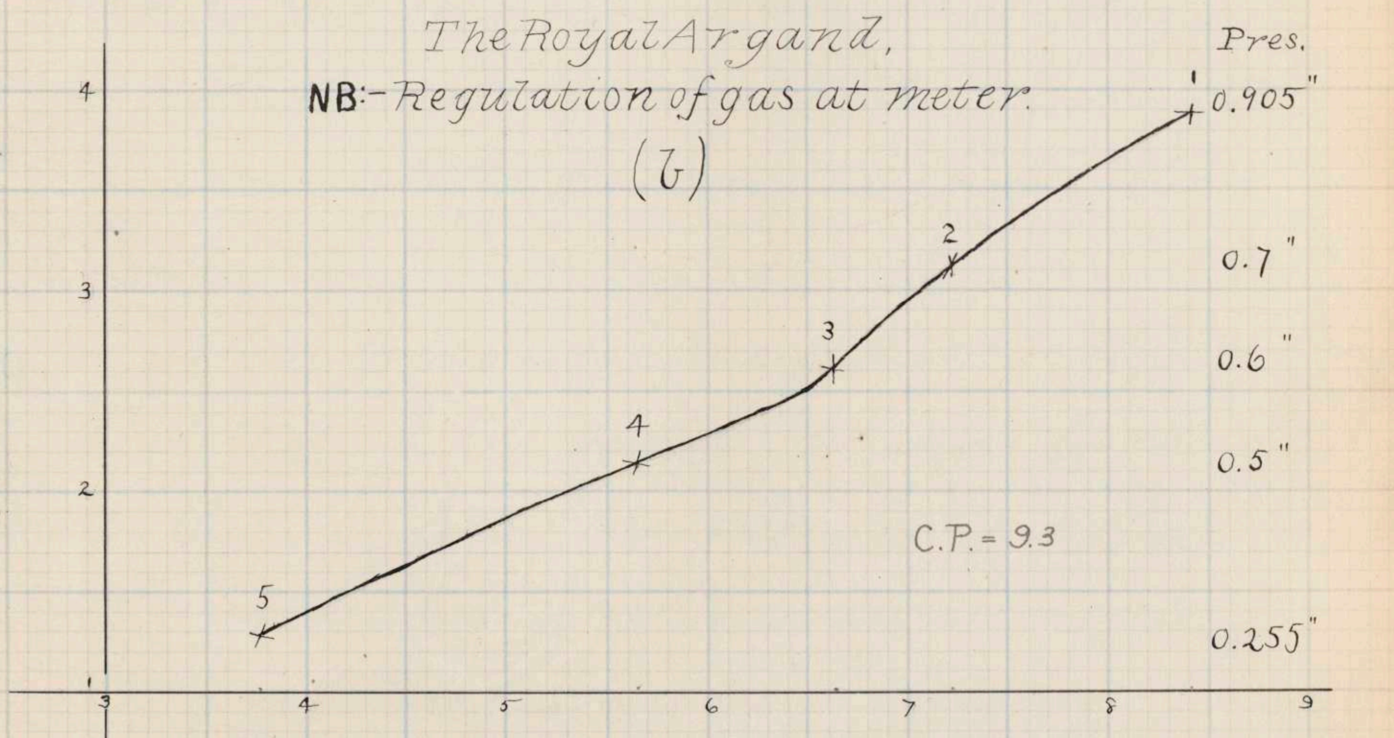
Find from the curves the consumption of gas corresponding to the same efficiency.

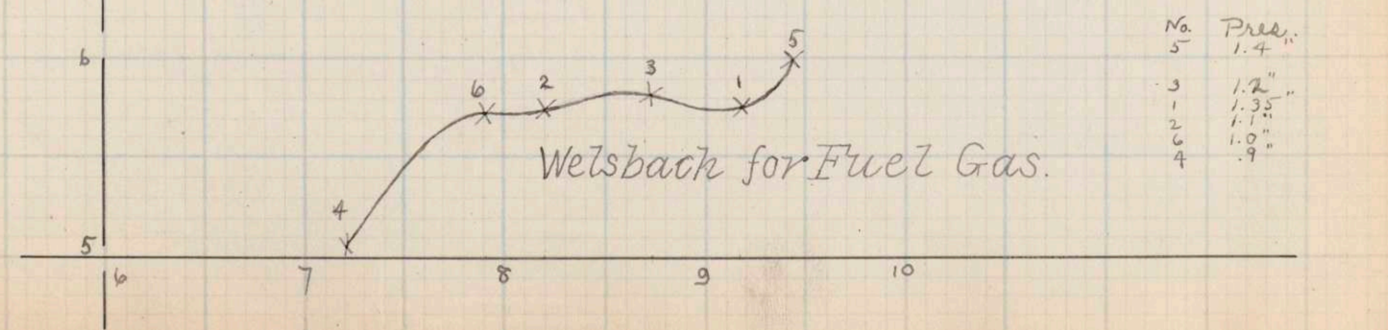
Efficiency.	Gas consumption (a)	(b)
2.2	5.69 cu ft per ho.	5.77
2.5	6.12	6.49
2.8	6.51	6.83
3.0	6.80	7.06
3.5	7.57	7.76
3.7	7.90	8.07

For the same efficiency series (a) gives the lower consumption of gas, and then follows, that the regulation of gas in the Royal Argand burner should be made at the valve at the burner.

Curves, continued.



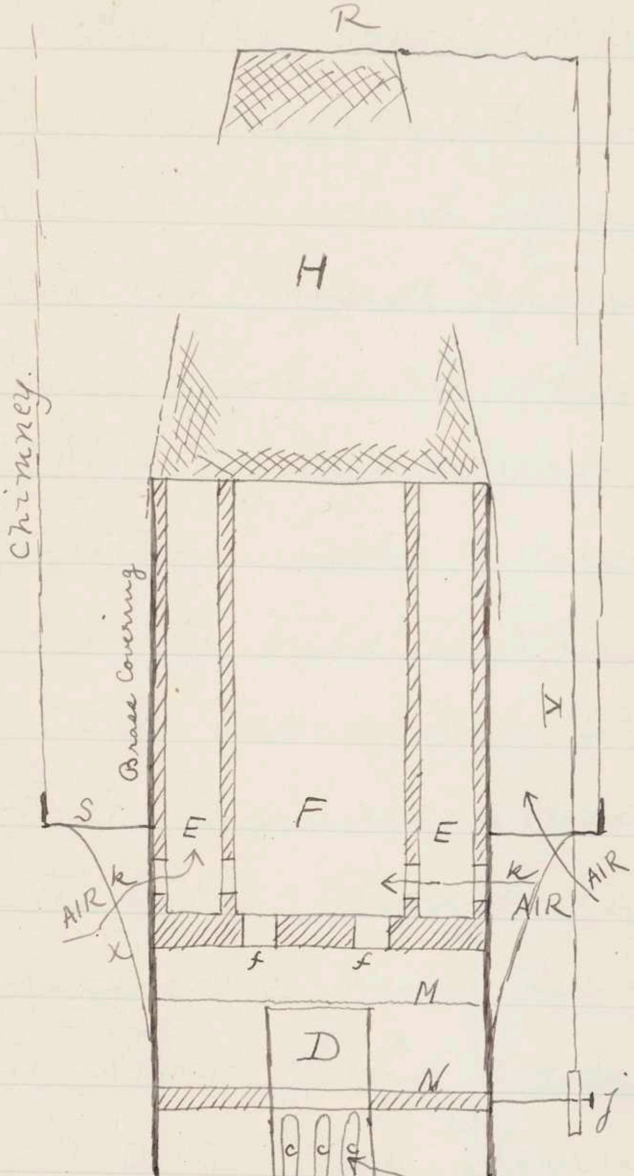




The reason that I give for this effect, which seems to be based upon the fact that as the pressure increases the efficiency increases, (keeping in each comparison the consumption constant), is that the higher pressure would cause the same volume of gas to have a greater velocity, than would a lower pressure and an equal consumption. The faster the velocity the more air would be drawn in, which would make the combustion more complete, causing the light to be brighter.

This opinion is somewhat different than that held about common burners i.e., that a low pressure is best, for it allows the gas to burn completely and preventing any from "blowing through".

The Welsbach Incandescent Burner



I have drawn a rough sketch of this gas burner.

D is a tube which screws on to the gas fixture; and the burner fits on this tube.

The part lettered E F E is a double-walled cylinder with a bottom. It is made of some fire resisting material. In the bottom are four holes f f (of which only two are shown). These holes open into the annular space E.

In the walls of the cylinder are four holes, near the bottom, marked k k and which open from the air into the inside space F. Only two of these holes are shown.

M is a wire screen; and N is a partition with a circular opening to allow the tube D to pass through.

c c c are slits in the side of the tube, while o o are small holes in partition in the tube. Through these holes the gas enters and their size regulates the flow of the gas.

a a a are openings near the bottom of the burner. These may be closed by a revolving cover.

The chimney is supported by the pieces S and x.

A very important part of the burner is the mantle H, which is made of material (principally zirconium) that is rendered incandescent by the ignition of the gas. This mantle is conical in shape; and is a fragile, gauze-like object. It is supported by a ring R and the rod V and is held in place by the screw j.

The gas enters as shown by arrow, passes through o, and draws in air through a and c. So that the air and gas become mixed as in a Bunsen burner. This mixture of air and gas pass through the screen M, through the holes f & the annular space E. More air is drawn in through K and mixes with the gas. Also air is sucked into F and up under the chimney. The combustion of the gas is well aided by the air. The heat being such that the mantle is heated to incandescence, and a very fine light is produced.

The burner is also provided with a shade.

I tested these burners as the others, the mantle being so arranged that it gave the best light.

These burners were tested under various conditions of pressure and consumption of gas. In order increase the consumption the holes o were enlarged. The photometer room at the Gas Works was supplied with a regulator and soby weights I could get the desired pressure. At the Institute, as I had no governor, the pressure depended on the pressure in the pipes.

Tests on Welsbach Incandescent Burner.

For Illuminating Gas.

Pressure at Point of Ignition	Illuminating Power	Gas per Hour	Efficiency. or "Candle per Ft"	No.	Remarks
1.8"	21.26 candles	3.828	5.5+	1.	}
1.8	20.88	3.795	5.5	2	
1.8	24.46	3.940	6.2	3	}
1.6	18.22	3.612	5.0+	4	
1.9	23.06	3.972	5.8	5	} Turned mantle around.
1.9	29.4	4.004	7.3	6	
1.65	.6.104	2.595	2.4	7	}
2.05	14.90	2.874	5.2	8	
1.5	26.24	3.558	7.4-	9	}
1.5	27.86	3.612	7.7	10	
1.6-5	25.52	3.549	7.2	11	
1.8-5	31.24	3.828	8.2-	12	}
1.8	32.70	3.924	8.3	13	
1.4	22.96	3.435	6.6	14	}
1.4	22.92	3.396	6.7	15	
1.4	41.46	4.626	8.9	16	}
1.4	39.24	4.578	8.6-	17	

Welsbach, [continued]

Pressure.	Illuminating Power.	Gas per Ho.	Efficiency.	No.	Remarks.
		cu. ft.			
1.4"	39.88 candles	4.668	8.5	18	}
1.4	39.98	4.660	8.6-	19	
1.45	43.42	4.740	9.2-	20	}
1.45	43.98	4.689	9.4-	21	
——	43.86	4.728.	9.3	22	
——	2.52	2.65	9.5	23	}
1.3	44.22	4.540	9.7+	24	
1.5	46.34	4.945	9.4-	25	
1.65	45.56	4.997	9.1	26	}
1.65	45.36	5.005	9.1	27	
——	35.	6.180	5.6	28	
1.15	35.30	5.670	6.2	29	}
1.15	35.36	5.674	6.2+	30	
1.	36.84	5.092	7.2	31	}
1.	36.18	5.014	7.2	32	
.7.5	35.52	4.56	7.1-	33	
1.7	45.0	5.040	8.9	34	}

Welsbach, [continued].

Pressure.	Illuminating Power.	Gas per Ho.	Efficiency.	No.	Remarks.
1.7"+	44.66 candles	5.148 cu ft	8.6	35	
1.75	44.74	5.184	8.6	36	
1.6.	44.22	4.920	8.9+	37	
1.6	43.84	4.964	8.8+	38	
1.7	43.16	5.229	8.3-	39	
1.7	42.82	5.184	8.3-	40	
1.65	42.16	5.100	8.2+	41	
1.5	43.50	4.88	8.9-	42	
1.5	43.8	4.920	8.9	43	
1.4	42.84	4.755	9.0	44	
1.55	43.36	5.064	8.6-	45	
1.4	32.02	6.471	4.9	46	Low pressure
1.2	35.34	5.85	6.0	47	& too much
1.	38.06	5.124	7.4	48	gas
0.9	37.10	4.87	7.6	49	
2.3	33.76	4.248	7.9	50	small
1.95	27.86	3.936	7.1-	51	holes
1.7	42.32	5.428	7.8	52	
1.65	43.28	5.33	8.1	53	
1.65	44.72	5.508	8.1	54	
1.5	43.50	4.884	8.9	55	

In the preceding tests on the Welsbach burner did not give the light that is claimed by the company. I thought perhaps that a higher pressure might bring up the efficiency, but with my small meter I was unable to get a two-inch pressure, the back-pressure in the meter cut down the pressure from the mains.

At the photometer room at the works of the Boston Gas Light Company I was able, through the aid of a governor, to obtain the desired pressure and keep it constant.

Of course the only function of the governor is to keep the pressure constant.

The photometer room at the works is similar to the one at the Institute, except that it is provided with a wet meter; and that the pressure guage is one that has a registering hand. Also I used two standard candles as my standard, and corrected for the rate of burning. The candles being mounted upon a scale and the time, by a stop watch, ~~the length of time~~ it took to burn 20 grains. From this the illuminating power was corrected, for the standard candle should burn 120 grains per hour.

Tests on Welsbach Burner, [continued]
[At the Works of the B. G. L. Co.]

Pressure.	Illuminating Power	Gas per Ho.	Efficiency	No.	Remarks.
1.7"	35.8 candles	5.623 cu ft	6.4	56	
2.1	31.7	4.124	7.7−	57	
2.4	41.1	5.047	8.1	58	
2.4	43.0	5.138	8.3	59	
2.4	43.0	5.124	8.4−	60	
2.4	41.1	5.145	7.9+	61	

Welsbach [continued].

Pressure.	Illuminating Power	Gas per Ho.	Efficiency	NO	Remarks
1.8"	29.5 candles	cu. ft. 5.700	5.2-	62	
1.85	38.9	4.509	8.6	63	
2.	44.06	4.707	9.4-	64	
2.	43.75	4.73	9.2	65	
2.-	25.62	3.918	6.5	66	
2	41.28	4.435	9.3	67	
2 -	44.7	4.554	9.8	68	
2 -	46.83	4.640	10.1	69	candle Power 50.5
2 -	46.57	4.670	9.1	70	
2 -	44.17	4.805	9.2	71	

Conclusions from the Tests of the Welsbach Incandescent Burner. [Illuminating Gas]

Test number 69 gives the best result, an efficiency of 10.1 or 10.1 candles to the cubic foot per hour. It gave an illuminating power of 46.83 candles and the gas consumption is only 4.640 cu. ft. per hr. The "candle power" figured upon the rate of consumption of 5 cu. ft. per hour is 50.5 which is the claim of the agents in Boston.

First I will show the faults of the other tests:-

Pressure over 2", in tests 57-61 inclusive the efficiency is not so high as in test 69. The consumption in No. 57 is too low, while in 58-61 it is too large.

In tests 8 and 50 the pressure is over 2", but in both the consumption is too low.

Low Pressure and Small Consumption, gave a fair efficiency. See 1-5 inclusive, and 9-15 inclusive, in which tests a very good light considering the small consumption of gas.

Pressure a little under 2" and Consumption of about 4 cu ft per Ho., or a little more, in which the efficiency is not so high as in test 69. See 16-22 inclusive, 5, 6, 48, 55, 24-26 inclusive, 33, 37, 38, and 42-44 inclusive.

In tests 27, 34-36 inclusive, 39-41 inclusive and 45 the pressure is quite low but efficiency might be better under different conditions.

Low Pressure and Large Consumption, gave quite a low efficiency, which shows that this method of burning is not right. See tests 46, 47, 48, 49 and 29-33 inclusive.

High Pressure and Moderate Consumption, give the best result. Tests 63-65 inclusive and 67-71 inclusive show clearly this conclusion. This set of tests is is not wholly the best, for I gradually increased the consumption, by enlarging the gas entrance holes, till the most efficient point was found, which is shown by test 69. The pressure in this set was kept at 2" by placing weights upon the governor. As the holes were made larger the pressure decreased and in order to keep up the pressure the weights were put on the governor.

In test 70 the holes were made a little larger than 69 which shows too much gas was admitted. In test 71 I made the holes a trifle smaller which made the efficiency higher than in No. 70 but not so good as in No. 69.

This burner, in order to produce the best light, must be adjusted. A pressure of 2" must be obtained at the point of ignition and the holes must be of the right size.

A pressure of 2", I believe; is always maintained in the pipes, and the size of holes may easily be adjusted. The brightness of the mantle is the judge of the burning of the burner; and increase or decrease the size of the gas holes until the brightest light is obtained.

If the pressure is too high it may be reduced by turning the cock on the fixture.

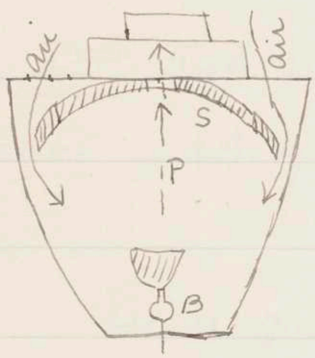
The reason that the pressure of 2 inches is the best, is that by this pressure, just the right amount of air is drawn in to make the best suited combustion of the gas.

I found it best to keep the air shutter open wide.

. This burner when compared with the preceeding burners shows that for the same consumption of gas a much better light may be obtained.

Baker Regenerative Burner.

[At the Works]



B is a common fish-tail burner, (bulbed shaped) which is placed in this globe. No air can get in at the bottom. the products of combustion pass up & through the chimney. On the way they heat the porcelain plate S. The air for combustion comes in as marked and is heated by the porcelain plate. This heating of the air causes the combustion to be better and the illuminating power is increased.

I tested this burner both with the regenerative attachment and alone.

Tests on the Baker Regenerative Burner.

Pressure.	Illuminating Power.	Gas per ho.	Efficiency
1st With the Regenerative attachment.			
1.65"	26.6 candles	cu. ft. 5.028	5.29
2nd Fish-tail burner alone.			
1.6-1.65	19.4	5.064	3.83

Or, a gain by the Baker Regenerative attachment of 27.6% in efficiency.

The tests on the Welsbach and Baker burners show that there is a more efficient way of burning gas than by the Argand and fish-tail burners.

Division B, Using Fuel Gas.

The description of this gas is given on pages 2 and 3; and in order that it may be used as an illuminant, an incandescent burner must be used.

Welsbach Incandescent Burner for Fuel Gas.

The burner part resembles a common Argand burner of a very small size, perhaps an inch in diameter. The mantle is supported over this burner. The mantle is smaller in size than the illuminating gas mantle and seems stronger. No chimney is used, but a glass globe surrounds the mantle. The gas is burnt without mixing the air with it, in fact the whole burner is simple and durable.

Tests on Welsbach Incandescent Burner. [Fuel gas].

The tests on this burner were made at the Works of the B. G. L. Co. The globe used had a strip or zone of ground glass at the top and bottom, while the large or middle zone was of plain glass.

The following table will show under what conditions the burner was tested.

No.	Pressure	Illuminating Power.	Gas per Ho. cu. ft.	Efficiency.
1	1.35"	52.8 candles	9.168	5.76
2	1.1	47.02	8.196	5.74
3	1.2	50.80	8.724	5.82
4	0.9	36.4	7.205	5.05
5	1.4	56.53	9.43	5.99
6	1.0	45.34	7.91	5.73

Test No. 5 shows the best efficiency,

but its consumption is the largest. Here the consumption depends on the pressure, and as the pressure increases the consumption increases.

On page 20, at the bottom, a curve is plotted, from which can be deduced that the general tendency is, that by increase consumption of gas the efficiency is increased. Point 1 seems to indicate otherwise but perhaps there may be something wrong with the test, very likely the mantle was not arranged so as to give its best light.

This form of illumination seems by these tests to be very desirable, as the light can be furnished for very small amount of money.

Comparison of the Preceding Burners, on a Money Basis.

Name of Burner	No. of Test	Kind of gas.	No. of Burners	Total Illuminating Power	Gas needed to burn 215 Hours.	Cost per 250 Ho.
Welsbach	69	Ill.	1	46.83 cand.	cu. ft. 1000	$ 1.00
Welsbach	3	Fuel	1	47.02	1760	.53
Common Argand	Series a Test a	Ill.	2	48.48	3070	3.07
Royal Argand	1 b	Ill.	1.43	46.83	2590	2.59
Jackson Reg.	2	Ill	3	44.4	2580	2.58
Baker Regen.	1	Ill.	1.76	46.83	1910	1.91

Illuminating Gas @ $1.00 per 1000 cu. ft.
Fuel gas @ .30 " " "
If the cost of fuel gas was 50 cts per 1000 cu ft, then the above would be 88 cts instead of 53 ct.

To figure this table every test is compared with the Welsbach for Illuminating gas:—

	Ill. power	cu ft. gas per ho	Test
1) Welsbach (ill.)	46.83	4.640	69
2) Welsbach (fuel)	47.02	8.196	3

Then 1000 ft of ill. gas in 1) will burn $\frac{1000}{4.64} = 215$ hrs.

1000 ft of fuel gas in 2) " " $\frac{1000}{8.196}$ hours

The amt of fuel gas to burn 215 ho will be —

$$\frac{1000}{1} \times \frac{8.196}{4.64} = 1760 \text{ cu ft.}$$

Then 1760 x 30 cts = 53 cts

This table is based on the fact that that the illuminating power is equal in every comparison. It will be noticed that they are not equal but near enough for this calculation.

The last column shows the cost for 250 hours. The amount of light being the same in each way of burning the gas.

The fuel gas is the cheapest as readily seen and the Welsbach with illuminating gas is next. Of course the price of a new mantle must be added to the cost of the gas, for the mantles gives out after 300-500 hours use. However the incandescent system is the cheapest.

Part II, Gas as a Fuel.

My experiments in this part consisted of determining the best kind of gaseous fuel for the use in a chemical laboratory.

The laboratories of the Institute are now supplied with illuminating gas, using the Bünsen burner and my work in this part was to show whether it was going to pay to change the kind of gas, to fuel gas, taking cost, time and throughness of work into account

I made these experiments at the gas works and under such conditions as they would be used in a laboratory.

My experiments consisted in heating a known amount of water, from a certain temperature to another degree of temperature; and noting the consumption of gas and the length of time.

The beaker or flask was mounted upon a stand, a wire gauze protecting the glass, and a thermometer was suspended in the water.

The burner for illuminating gas was a Bünsen burner; and for fuel gas the same burner with the air supply closed and holes for the gas admittance made a little larger

The hottest part of the flame was placed at the bottom of beaker or flask.

The gas was metered and the pressure was noted.

By these means a comparison could be made between illuminating gas and fuel gas, as both had the same work to perform and under the same conditions.

Heating Water in a Beaker.

(1)
By Illuminating Gas.

No.	Pressure.	Gas.	Time.	Amt of Water.	Temp. Before	Temp. After
1	1.7"	0.569 cuft	$7\frac{1}{2}$ min	300 cc	19.3°C	91.0°C
2	1.7"	0.570	$7\frac{5}{12}$	300	24.0	90.0
3	1.7"	0.571	$7\frac{7}{12}$	300	18.2	90.0

This set is not efficient as some of the others. Very likely the flame was not placed in the most efficient point.

4.	1.7"	0.430 cuft	$5\frac{5}{6}$ min	300 cc	23.6°C	90.0°C
5	1.7"	0.470	6	300	24.7	90.0
6	1.7"	0.440	$5\frac{1}{2}$	300	25.0	90.

The results in this set are better than the preceeding set. Its average is:—

1.7" 0.446 cuft $5\frac{7}{9}$ min 300cc 24.4°C 90.0°C

The loss by evaporation is between 4 and 5cc, and this should taken in to account when figuring the amount of heat given to the water.

(2) By Fuel Gas.

The Bünsen burner with the air holes closed by paper was used.

No.	Pressure.	Gas. cu.ft.	Time	Amt of Water.	Temp. Before	after.
1	1.7"	.960	11 1/12 min	300 cc	21.0°C	89.0°C
2	1.7"	.889	11 1/2	300	22.0	89.+
3	1.7"	.890	11 1/2	300	22.4	89.+

The flame in above tests was a little yellow. Nos. 2 and 3 agree so throw out No. 1.

4	1.7"	.870 cu.ft.	11 1/3 m	300 cc	24.0°C	90°C

In test No. 4 I made pin holes in paper covering air holes and this made some of the yellow disappear

5	1.7"	.811 cu.ft	10 m	300 cc	24.5°C	90.0°C

In No. 5 the pin holes were enlarged and got a fine blue flame.

6 No results for I enlarged the air holes too much which caused the flame to puff.

No. 5 shows that a little air is better than no air, for it makes better combustion; thereby using less gas and doing the work in a less time.

In order that fuel gas will do the same work as illuminating gas and in the same time, more gas must be admitted, as the following experiments show.

No.	Pres.	Gas. cu ft	Time.	Amt of Water.	Temp Before	after.	Remarks.
1	1.7"	1.010	6 11/12 m	300cc	23.5°C	91.0°C	Flame has yellow tinge.
2	1.7	1.030	7	300	22.5	91.0	made holes in paper. Still little yellow
3	1.7	1.000	6 5/6	300	22.3	91.0	Large holes for air
4	1.7	1.020	6 11/12	300	22.4	90.0	Larger still and yet little yellow
5	1.7	1.015	6 11/12	300	23.0	90.0	air holes closed
6	1.7	1.010	6	300	25.5	90.0	gas holes made larger & a little air admitted.
7	1.7	1.030	6	300	22.0	90.0	More air till a blue flame
8	1.7	1.015	6	300	22.0	91.0	Same as 7.

This series differs from that on page 46, in that, that at the beginning the gas holes were enlarged and in Nos 6, 7 + 8 the gas holes were again made larger. The average of this series is best made by taking the mean of tests 6, 7 and 8. which is as follows:-

Pres.	Gas cu.ft	Time	Amt water.	Temp Before	after
1.7"	1.018	6 m	300 cc	23.1°C	90.0°C

The mean of Series on page 47 is

1.7	.883	$11\frac{4}{9}$	300	22.8	90.0

When the above figures are compared it shows that the first used the more gas but did it in almost half the time.

The average of illuminating gas on page 45 will be repeated:-

1.7	.446	$5\frac{7}{9}$	.300	24.4	90.0

If this is compared with the first mean on this page it is seen that both did approximately the same work in about the same time. The consumption of fuel gas is $\frac{1.018}{.450} = 2.26$ times that of illuminating gas.

Relative Cost.

1018 cuft Fuel gas @ 30¢ costs $.31

@ 50¢ " .51

450 " Illuminating Gas @ $1.00 costs $.45

@ 1.25 " .56

At the present rates in Boston, i.e., Fuel gas @ 50 cts per 1000 cu ft and Illuminating Gas @ $1.25 per 1000 cu ft., the difference is not so marked, but when the price reaches 30 cts per 1000, and this figure will be obtained in a year or so, the price for the same amount of heat will be less by using fuel gas.

Heating Water in a Flask.

Used the same apparatus with the exception of a beaker a flask was used.

(1) By Illuminating Gas.

Pres.	Gas (cu. ft)	Time	amt of Water	Temp. Before	Temp. After
1.74"	.410	~	300	20.2°C	90.0°C
1.74	.435	5 1/6 m	300	22.0	90.0
1.74	.425	5 1/6	300	22.0	90.0

The average is:–

Pres.	Gas (cu ft)	Time	amt of Water	Before	After
1.74"	.423	5 1/6 m	300 cc	22.0°C	90.0°C

(2)

By Fuel Gas.

Just enough air was admitted to make a blue flame.

Pres.	Gas.	Time	Amt of Water.	Temp. Before	After.
1.72"	.905	$5\frac{1}{4}$m	300cc	24.0°C	90.0°C
1.72	.850	$4\frac{11}{12}$	300	25.5	90.0
1.72	.860	5	300	27.0	90.0

The average is:-

1.72"	.871 cu.ft.	$5\frac{1}{18}$m	300	25.5°C	90.0°C

Comparing the averages of the tests on the flasks I finds it takes to do approximately the same work $\frac{.871}{.423} = 2.06$ times as much fuel gas as illuminating gas.

By comparing the cost the fuel gas would be cheaper, even more so than in the case of the beaker.

It should be noticed that a little air gives better results and a small air hole should be placed in every burner.

Fletcher Burner.

The vessel containing the water is placed quite near the burner. I used an agate-wear kettle. The principle of the experiment is the same as in the preceeding tests.

(1) Illuminating Gas.

Pres	Gas	Time	Water.	Temp Before	after.
	cu.ft				
.95"	1.650	$4\frac{1}{3}$m	$\frac{1}{20}$ cu.ft	24.7°C	95.0°C
.96"	1.700	$4\frac{1}{2}$	$\frac{1}{20}$	24.0	96.0

Its average:-

	cu.ft				
.955"	1.675	$4\frac{5}{12}$m	$\frac{1}{20}$ cu.ft	24.4°C	95.5°C

(2) Fuel Gas.

Air holes closed with paper & wax.

Pres.	Gas.	Time	Water	Temp Before	after.	
	cu.ft					
.95"	2.750	7m	$\frac{1}{20}$ cu.ft.	25.0°C	95.0°C	
.95	2.800	$7\frac{1}{6}$	$\frac{1}{20}$	26.0	95.0	
.98	2.650	$6\frac{3}{4}$	$\frac{1}{20}$	27.0	95.0	air holes made in paper
.96	2.775	7	$\frac{1}{20}$	24.0	95.0	Larger air holes

The average

	cu.ft				
.96"	2.744	$7\frac{3}{16}$m	$\frac{1}{20}$ cu.ft	25.5°C	95°C

Some Gas-Engine Calculations.

Messrs. Rose and Moseley for their thesis made experiments on Clerk's gas exploding apparatus. Among the gases used were illuminating and fuel gases.

Their results are as follows from which I figured the mean effective pressure.

To find the mean effective pressure per sq. in., which forces the piston forward, multiply the area of the card (in sq. ins.) by the spring (80) and divide by the length of the card (1.25").

Number	Mixture. Parts		Area between Max. and 2 seconds beyond, by plan		Mean Effective Pressure	
	Gas	Air	Illuminating	Fuel	Illuminating	Fuel.
					lbs per □"	lbs per □"
1	1	4	.94 sq. in	.75 sq. in	60.16	48.00
2	1	5	.94	.71	60.16	45.44
3	1	6	.91	.65	58.24	41.60
4	1	7	.86	.61	50.04	39.04
5	1	8	.82	.53	52.48	33.92
6	1	8	.80			
7	1	9	.77	.09		
8	1	9	.77			
9	1	10	.75			
10	1	10	.74	.06 approx		
11	1	11	.71			
12	1	11	.71	.04 approx	45.44	
13	1	12	.54			
14	1	12	.63			
15	1	13	.45			
16	1	14	.45			
17	1	15	.04			

Spring = 80

Length of Card = 1.25"

Test No. 12 was found to be of the best efficiency for illuminating gas.

In order obtain the efficiency divide the area by fraction which represents the amount of gas in the mixture.

As in No 12.

$.71 \div \frac{1}{12} = 8.52$ the best for illuminating gas.

as in No. 4

$.61 \div \frac{1}{8} = 4.88$ the best for fuel gas.

Notice No. 12 (ill. gas) and No. 2 (fuel gas) have the same mean effective pressure; and for No. 12 $\frac{1}{12}$ is gas, while in No. 2 $\frac{1}{6}$ is gas. This shows that it take twice as much fuel gas as illuminating gas. The comparison is correct for the mixtures are so put in to the apparatus, that in the case of Nos. 2 and 11, No. 2 has just twice as much gas as No. 11.

But while No. 11 is the most efficient for illuminating gas, No. 2

is not the most efficient for fuel gas. It happens that No. 4 is the most efficient for fuel gas and that it takes less gas than No. 2.

No. 4 is $\frac{1}{8}$ gas and its M.E.P. is not so large as No. 2.

Therefore if the initial pressure of the gas is to be the same, a cylinder based on No. 2 for fuel gas, would have to be just twice as large, as the cylinder of an engine for illuminating gas based on No. 12, in order that the total pressure and work would be the same. If the initial pressure is to be greater in fuel gas engine than in an illuminating the cylinder need not be twice as large, but then power will be consumed in compressing the gas.

Of course if the cylinder is twice as large, the M.E.P. will be one half of what is given; but as the cylinder is twice as large the total pressure will be the same.

Compare the most efficient mixtures of both gases, No. 12 for illuminating, and No. 4 for fuel and we get a better result. $\frac{3}{2}$ as much fuel gas as ill. gas.

If the initial pressure is to be the same in both kinds of engines, the cylinder must be

$$\frac{45.44}{39.04} \times \frac{3}{2} = 1.74 \text{ times as large}$$

in area to give the same work as an illuminating gas engine.

From this it will be seen that fuel gas will run an engine cheaper than illuminating gas; but the first cost will be more in case of the fuel gas engine.

This thesis has been in the main a test of burners, not so much to test the burners alone, but tests that will show the relative effect of the burners for fuel and illuminating gases.

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Massachusetts Institute of Technology,
May 1891.