Gas Efficiencies

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The very condensed article on gas efficiencies found below is largely taken from a thesis by Mr. John Waldron, carried out under the writer's direction last spring

To the uninitiated, the term gas refers to a commodity which is to be taken more less for granted, as a part of one's heritage, in the same way as we often think of heat, light, sunshine, etc. As we look a little farther into the subject, we find (usually from our gas bills) that gas is divided into two general divisions, artificial and natural, and, secondly, that which concerns us more vitally, the fact that gas is an expensive commodity.

The industrial man who depends upon gas as a heating medium (and most of them do) soon becomes a student of the properties of gas. He finds that the profits of his business are a function of his gas costs, and when the equation does not lean in the right direction, he wonders whether he is using the right type of gas; which brings us to the question, how many different kinds of industrial gas are there?

We find that there are a number of different types of gas, classified as to origin, analysis and properties. In the following table are listed the most important industrial gases, with their volumetric analyses and gross heating values, which properties we shall consider later. In this list we have arbitrarily listed Pennsylvania natural gas as a fair example of a rather variable article of commerce.

Character of Gas	H_2	CH_4	C_2H_4	C_2H_6	N_2	CO	CO_2	O_2	B.T.U.
Oil gas	32.0	48.0	16.5	....	3.0	....	....	.5	846
Coke-oven gas	50.0	36.0	4.0	....	2.0	6.0	1.5	.5	603
Carb. Water gas	40.0	25.0	8.5	....	4.0	19.0	3.0	.5	575
Water gas	48.0	2.0	....	....	5.5	38.0	6.0	.5	295
Blast furnace gas	1.0	....	....	....	60.0	27.5	11.5	....	91
Pintsch gas	12.1	45.4	35.7	....	3.0	.6	.7	2.0	1500
Producer gas	10.2	3.8	.2	....	55.2	25.6	5.0	....	148
Natural gas (Pa.)	....	67.6	....	31.3	1.1	....	....	....	1000

In every branch of industry today the watchword is efficiency. We constantly hear the terms, personal efficiency, engine efficiency, boiler efficiency, and in gas work the by-word is furnace-efficiency. By "efficiency," no matter what the application, is meant a ratio of the energy or work taken out of a system to that put in. Efficiency approaches 100% as a limit, but never reaches it, because in all applications there are certain unavoidable losses. In a furnace this may be due to faulty design. A portion of the loss may be due to radiation or many other causes. If we should test a furnace with several different gases, we would find that the efficiency would vary with the gas used. Hence back of furnace efficiency we have gas efficiency. This may be considered on two bases, first from the standpoint of thermal efficiency, and second from the standpoint of cost.

When we burn a gas, the products of combustion are gaseous and are capable of absorbing and carrying away as waste heat some of the heat of combustion. The amount of heat which a gas can carry away as sensible heat increases with the temperature, and is known as the thermal capacity of the gas. The difference between the heat of combustion of a gas and the thermal capacity of the waste products of combustion is the heat which can be utilized in the furnace, neglecting, of course, the losses by radiation, etc. The proportion of the heat utilized to that applied is what we call the thermal efficiency of a gas. The greater the flame temperature for such work the greater will be the proportion utilized. Hence in general we may say that the higher the flame temperature of a gas the greater will be the efficiency of the gas. Flame temperature is decreased by a high percentage of inerts in a gas. These inerts also carry away a considerable quantity of waste heat, and the combination of the two result in low efficiencies. The principle inerts in industrial gases are nitrogen, carbon dioxide and water vapor.

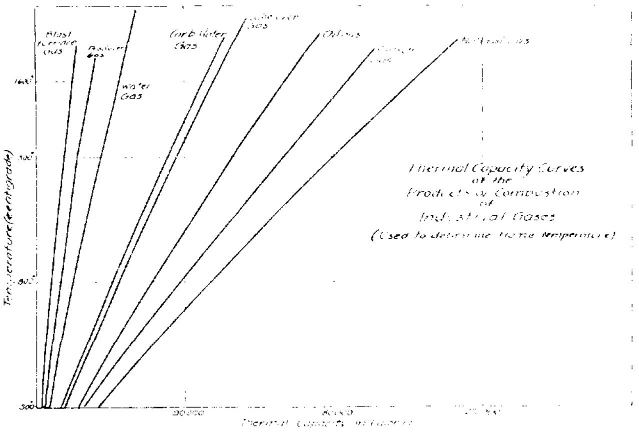
Another factor which influences efficiency is the quantity of air used to support combustion. Since practically four-fifths of the air entering a furnace is nitrogen, an excess of air will seriously effect the efficiency of the gas. On the other hand, if there is not enough air present to completely burn the gas, the heat of combustion will be low, and the efficiency will show the fact. Practice has shown that the best results are secured by maintaining an excess of approximately one-third the theoretical amount required.

Efficiency on the cost basis is nothing more or less than a comparison of the cost of a given quantity of utilizable heat as produced by the different types of industrial gases. In making calculations we assume as our unit the "therm" (100000 B. T. U.).

By using these calculated values for abscissae and temperature as an ordinate, we obtain a curve giving the thermal capacity of the products of combustion of the gas at any temperature. If now we know the heat of combustion of the gas, and locate it on the curve, the temperature corresponding to the value will be the flame temperature of the gas.

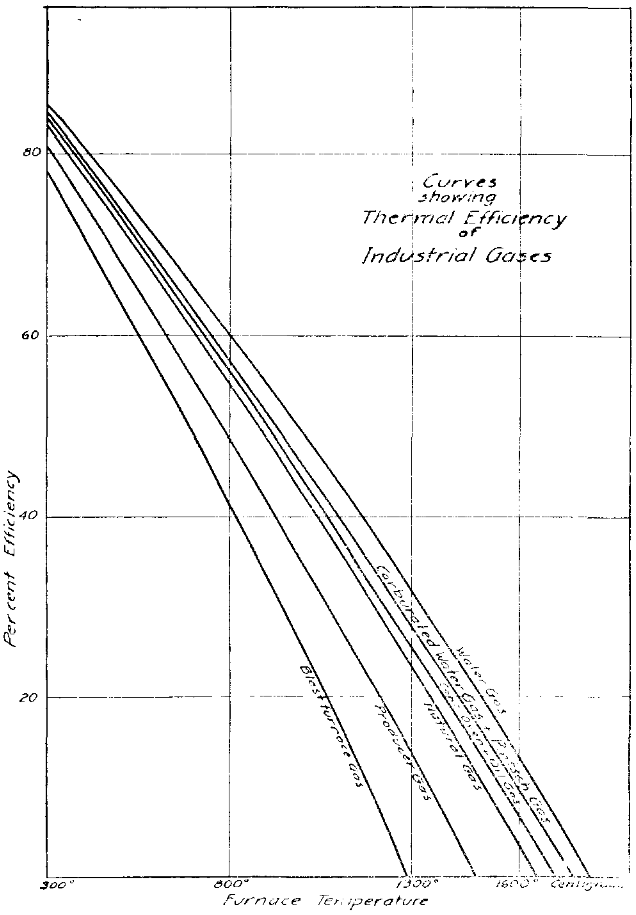
The curve shows the heat of combustion for gram-molecular volumes. By multiplying these values by the fraction of a gram-molecular volume of the constituent in question and taking the sum of the products, we obtain the heat of combustion.

H_2	$.48 \times 58330 = 27998$	calories
CH_4	$.02 \times 192160 = 3843$	calories
CO	$.38 \times 68000 = 25840$	calories
Heat of combustion	57681	calories



The ordinate on the curve for water gas corresponding to this abscissa is 1850°C. On the next page is a set of curves for all the gases with which we are dealing. The flame temperature found as above are as follows:

Oil gas	1710 C. or	3100 F.
Coke-oven gas	1710	3100
Carb. water gas	1700	3092
Water gas	1850	3362
Blast furn. gas	1260	2300
Pintsch gas	1750	3182
Producer gas	1460	2660
Natural gas	1610 C.	2984 F.



Our next step will be to derive a set of curves showing the efficiency of our list of gases. In this calculation we shall neglect all losses by radiation and consider the entire heat of combustion as utilizable except that part carried away by the products of combustion. We shall calculate the thermal capacity of the products of combustion at 200, 800, 1300, and 1900, or take the values directly off the curves which we have just considered. The utilizable heat at any of these temperatures is the difference between the total heat of combustion and the thermal capacity of the products of combustion for that temperature. The per cent efficiency is obtained by multiplying by 100 the quotient of the utilizable heat, divided by the total heat of combustion.

To show the calculation more clearly, we will tabulate all of the data, including the thermal capacity figures for water gas. We shall then be able to draw an efficiency curve for this gas. Similarly curves are obtained for the other gases.

EFFICIENCY OF WATER GAS

Analysis			Heat of Combustion	O_2 used
H_2	.48	Vol.	27998 calories	.24 Vol.
CH_4	.02	Vol.	3843 calories	.04 Vol.
N_2	.055	Vol.		
CO	.38	Vol.	25840 calories	.19 Vol.
O_2	.005	Vol		—.005 Vol.
CO_2	.06	Vol.		
		Total	57681 calories	.465 Vol.
				5
			Theoretical air required	2.325
			1.3 excess	.775
			Theoretical nitrogen	1.860
			Nitrogen in gas	.055
			Total N_2	2.69 Vol.

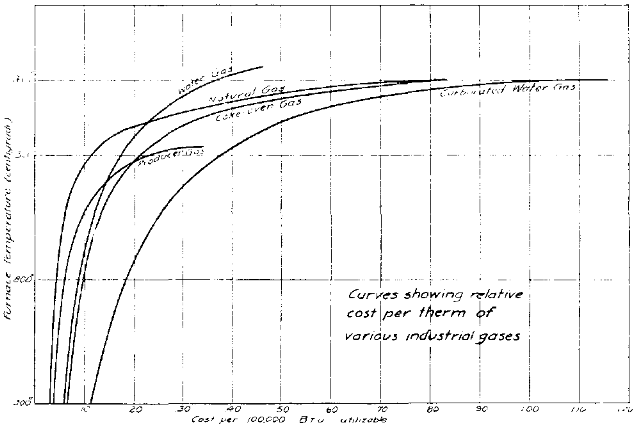
THERMAL CAPACITY

Waste gas	300°	800°	1300	1600°
CO_2 .46 vol.	1341	3987	6999	8889
H_2O .52 vol.	1313	3602	6262	8157
N_2 2.69 vol.	5587	15435	25958	32598
Total	8241	23024	39219	49641
Utilizable	49440	34657	18462	8040
Efficiency	85.71%	60.08%	32.00%	13.94%

From these values we can graphically represent and compare the efficiencies of the common industrial gases. Next we want to get some sort of a comparison on the cost basis. The chief difficulty here is to get some accurate costs. We find that the price of most artificial gas is a function of the cost of coal, which varies with the season, locality and many other factors. We can assume a price per ton of coal and base our calculations upon this premise. The prices of water gas, producer gas, and coke-oven gas, are here based upon coal at $5.00 per ton.

Furthermore we find upon investigating prices, that some of the gases which we listed above are back-numbers today on account of cost considerations. The gases in question are Oil gas and Pintsch gas. Oil gas is being displaced by the crude oil itself which is sprayed into the furnace. Pintsch gas was formerly compressed and carried on passenger trains for lighting purposes, but it has lately been almost universally displaced by electricity.

The price of water gas, carborated water gas, producer gas, and coke oven gas are taken from a pamphlet published by The United Gas Improvement Company of Philadelphia.



As we said before, we shall calculate the cost of 100,000 B. T. U. of utilizable heat at different temperatures and plot curves for each gas. As our data for utilizable heat is in gram-calories, we must first convert it over into British Thermal Units. The cost of a Therm is expressed by the following equation:

$$\text{Cost} = \frac{100000 \text{ cost per M ft.}}{\text{B. T. U. per cu. ft.} \times 1000}$$

As before, we will tabulate our values and then plot curves accordingly.

COKE-OVEN CAS—PRICE 33c/M

Utilizable heat in	300°	800°	1300°	1600°
B. T. U. per cu. ft.	488.30	328.13	153.31	40.42
Cost per Therm	7.76c	10.05c	21.52c	81.67c

CARBURETED WATER GAS—PRICE 60c/M

Utilizable heat in	300°	800°	1300°	1600°
B. T. U. per cu. ft.	474.76	323.15	157.50	50.89
Cost per Therm	12.63c	18.56c	38.10c	117.9c

WATER GAS—PRICE 15c/M

Utilizable heat in	300°	800°	1300°	1600°
B. T. U. per cu. ft.	248.2	174.0	92.7	40.4
Cost per Therm	6.04c	8.62c	16.9c	37.17c

NATURAL GAS (PA.)—PRICE 30c/M

Utilizable heat in	300°	800°	1300°	1600°
B. T. U. per cu. ft.	994.15	650.7	276.45	35.94
Cost per Therm	3.09c	4.61c	10.85c	83.27c

PRODUCER GAS—PRICE 5.2c/M

Utilizable heat in	300°	800°	1300°	1600°
B. T. U. per cu ft.	128.55	77.16	21.15	None
Cost per Therm	4.04	6.74	24.58	

Using the cost in cents as an abscissa and the corresponding temperature as an ordinate we can plot curves for each of the above gases. No cost data was available for blast furnace gas, on account of it being a "waste" product, so we will have to omit it from our set of curves.

What do our curves mean? In the main they tell an excellent story for water gas. From the point of view of temperature of combustion, thermal efficiency, and cost efficiency, water gas seems to cocupy a most favorable position. Our curves show natural gas to be the cheapest, but with its uncertain supply, it bids fair to be displaced by water gas installations. For general purposes, carbureted water gas is to be preferred on account of its luminiferous qualities; municipalities are now looking forward to mixed gas installations which will carbonize gas coal and then use the coke to make water gas. The two resultant gases are mixed and makes a high grade fuel very economically.

The chief value of such curves is in the ability we have to pick the right gas for the temperature we are using. For example if we are debating between water gas and producer gas, we can see at a glance that producer gas is the more economical under 1200′C. and for temperatures above 1200′C. water gas is the better fuel.