Fuel Economy In Sugar Factories

By

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FUEL ECONOMY IN SUGAR FACTORIES.

BY SAMUEL L. JODIDI, PH. D.

A sugar factory works rationally not merely when it produces good sugar and obtains a high yield per 100 parts of beets, but also when it works economically, i. e., if the expenses for fuel, employes, limestone, etc., are minimized. Among these expenses those for fuel are doubtless the most considerable, and, although science and technics give sufficient means to control the work in the boiler house and to put it upon a rational basis, this phase is not seldom neglected during the campaign, but this causes a waste of fuel.

In the following are the results obtained during the last campaign in a sugar factory in this country, of 600 tons daily capacity. In its boiler house were altogether fourteen boilers: Eight high-pressure boilers with 105-125 pounds steam pressure for engines, and six low-pressure boilers with 45-60 pounds steam pressure for boiling purposes. One boiler of the high-pressure line had also connection with the low-pressure line and was able to produce steam of low pressure in case the factory needed more boiling steam. All boilers of both lines had the same heating surface of about 150 square meters each. The grates were also of the same size, namely $6' \times 6' = 36$ square feet. The chimney draught observed was 1″ water level. Pennsylvania soft coal, the analysis of which will be given later, was used as fuel.

It is agreed that no one can produce sugar in the factory, and the problem is considered to be solved satisfactorily when the sugar is extracted from the beets in such a manner that the losses are as small as possible. The same may be said with reference to the fuel. The heat cannot be produced in a boiler house. But when the energy—which was stored up in the plants by the sun some centuries or millenniums ago, and has remained in the fuel built up from the plants of that time by their decomposition—may be extracted in form of heat, as fully as possible, and the losses minimized, it is evident that such a boiler house works rationally.

In order to determine what "rational work" in a boiler house means, we ought to answer, above everything else, the question: What percentage of carbon dioxide is it possible to obtain, theoretically, in the burning of coal in the air? This is necessary because it will enable us to ascertain the figures we must try to attain. Now, according to Avogadro's law of 1811, in equal volumes of any gases an equal number of molecules is contained, or a molecule of any gas is always the same volume. The complete combustion of carbon in oxygen takes place according to the equation $C + O_2 = CO_2$ (equation I), in which $CO_2 = 2$ volumes (liters or cubic meters, etc.) of carbon dioxide and the molecule $O_2 = 2$ volumes (liters or cubic meters, etc.) of oxygen, according to the above-mentioned law.

In the burning of carbon with two or any volumes of oxygen result two or the same volumes of carbonic acid. However, the air consists not only of oxygen, but also of 79.08 volumes of nitrogen, which does not take part in the process of combustion. So that 20.92 volumes of oxygen contain 79.08 volumes of nitrogen; then two volumes of oxygen contain $\frac{79.08}{20.92} \times 2 = 7.56$ volumes of nitrogen. Adding this to both parts of the equation I we have: $C + O_2 + 7.56$ volumes $N = CO_2 + 7.56$ volumes $N = 9.56$ volumes of gas of combustion (equation II), in which $N =$ nitrogen. This equation expresses that in the burning of carbon in an amount of air necessary for its complete combustion, there results a gas consisting of 2 volumes of carbon dioxide and 7.56 volumes of nitrogen. Expressed in percentage ratio we find:

9.56 vols. of combustion gas contain 2 vols. of carbon dioxide.
100.00 vols. of combustion gas contain x vols. of carbon dioxide.

$$x : 2 = 100 : 9.56;\ x = \frac{2 \times 100}{9.56} = 20.92 \text{ per cent of carbon dioxide.}$$

Further:

9.56 vols. of combustion gas contain 7.56 vols. of nitrogen.
100.00 vols. of combustion gas contain y vols. of nitrogen.

$$y : 7.56 = 100 : 9.56;\ y = \frac{7.56 \times 100}{9.56} = 79.08 \text{ per cent of nitrogen.}$$

In words: If carbon would burn completely to carbon dioxide in an amount of air that is theoretically just sufficient, then a gas would result containing 79.08 per cent of nitrogen and 20.92 per cent carbonic acid, i. e., containing just the same per cent of nitrogen as our atmosphere, and as great a percentage of carbonic acid as the atmosphere contains of oxygen. Thus 20.92 is the highest percentage of carbon dioxide which is theoretically obtainable in the perfect combustion of carbon in the air; and these figures we ought to try to attain in our boiler houses, or to approximate them as nearly as possible.

However, in practice we are never able to furnish a combustion gas with such high contents of carbon dioxide. If for the combustion of coal the exact amount of air that is required by the theory should be used, the resulting gas would contain carbon monoxide as well as carbon dioxide, i. e., the combustion would not be complete.

Experience has shown that the most perfect combustion takes place if from one and a half to two times the amount of air that the theory requires be employed. Accordingly, changing equation II, we have: $C + O_2 + O + 7.56$ volumes $N \times 1\frac{1}{2} = CO_2 + O + 7.56$ volumes $N \times 1\frac{1}{2} = 14.34$ volumes of combustion gas (equation III), in which $O = 1$ volume (liter or cubic meter) of oxygen. Expressed in percentage we have:

14.34 vols. of combustion gas contain 2 vols. of carbonic acid.
100 vols. of combustion gas contain z vols. of carbonic acid.

$$z : 2 = 100 : 14.34;\ z = \frac{2 \times 100}{14.34} = 13.95 \text{ per cent of carbonic acid.}$$

In other words: If for combustion of carbon, one and a half times as many volumes of air be employed, as the theory requires, the resulting gas would contain 13.95 per cent of carbonic acid.

In a similar manner we find: $C + O_2 + O_2 + 7.56$ volumes $N \times 2 = CO_2 + O_2 + 7.56$ volumes $N \times 2 = 19.12$ volumes of combustion gas (equation IV). This, expressed in percentage, gives:

19.12 vols. of combustion gas contain 2 vols. of carbonic acid.
100 vols. of combustion gas contain u vols. of carbonic acid.

$$u : 2 = 100 : 19.12;\ u = \frac{2 \times 100}{19.12} = 10.46 \text{ per cent of carbonic acid.}$$

In words: If for combustion of carbon, two times as many volumes of air be employed as the theory requires, the resulting gas would contain 10.46 per cent of carbonic acid. It follows, from equations II, III and IV, that as long as a combustion gas contains from 10 to 21 per cent of carbonic acid—to be exact, from 10.46 to 20.92—the combustion must be considered as a favorable one, and the nearer to 20.92 the better.

But on the other hand: How many pounds (kilograms or tons) of air are necessary for the complete combustion of 1 pound (kilogram or ton) of carbon? And further, how many pounds of air per pound of carbon were actually used in the sugar factory in question?

Equation I expressed by weight gives: $C + O_2 = CO_2$. Since carbon (C) and oxygen (O) have the atomic weights 12 and 16 respectively, this equation means that in order to burn to carbonic acid,

12 pounds of carbon need 32 pounds of oxygen, or 1 pound of carbon needs $\frac{32}{12}$ pounds of oxygen.

Now, we know that our atmosphere consists not merely of oxygen, but also of nitrogen, namely, 100 parts of the atmosphere contain 23.1 per cent by weight of oxygen and 76.9 per cent by weight of nitrogen. In consequence,

1 pound of carbon needs theoretically $\frac{32}{12} \times \frac{100}{23.1} = 11.54$ pounds of air in order to burn to carbon dioxide.

The figures 11.54 pounds of air we have calculated for 1 pound of carbon. But in the sugar factories, coal, as ordinarily used, contains, besides carbon, also moisture, ash, sulphur, etc. It is evident that 1 pound of coal needs for its combustion a different quantity of air from carbon. This we now proceed to calculate.

In the sugar factory in question, in the last campaign, Pennsylvania soft coal, the composition of which is given below, was used:

Water (moisture).	Ash.	Sulphur.	Carbon.	*Hydrogen.
1.44	9.14	0.57	78.10	4.8

Of these constituents only carbon, hydrogen and sulphur unite with oxygen. According to this analysis, in 100 pounds of coal are contained 78.10 pounds of carbon,

*[(Oxygen + Nitrogen) 5.95 by difference.]

4.8 pounds of hydrogen and 0.57 pound of sulphur. As we have already learned above, 1 pound of carbon needs for its combustion 11.54 pounds of air; consequently 78.10 pounds of carbon need $11.54 \times 78.10 = 901.27$ pounds of air. The second constituent, hydrogen, unites with oxygen according to the equation $H_2 + O = H_2O$. Since hydrogen has the atomic weight 1, this equation means that 2 pounds of hydrogen (H) need for their combustion 16 pounds of oxygen (O), or 1 pound of hydrogen needs 8 pounds of oxygen. In order to get the quantity of air necessary for 1 pound of hydrogen, we ought to multiply the amount of oxygen by $\frac{100}{23.1}$ (see page 5), i. e.,

1 pound of hydrogen uses $8 \times \frac{100}{23.1} = 34.63$ pounds of air. Consequently, 4.8 pounds of hydrogen use $34.63 \times 4.8 = 166.22$ pounds of air.

Finally, the third constituent, sulphur, unites with oxygen according to the equation $S + O_2 = SO_2$, and, as sulphur (S) has the atomic weight 32, this equation means that, for their combustion.

32 pounds of sulphur need 32 pounds of oxygen, or 1 pound of sulphur needs 1 pound of oxygen, corresponding to $1 \times \frac{100}{23.1} = 4.33$ pounds of air.

Consequently, 0.57 pound of sulphur uses $4.33 \times 0.57 = 2.47$ pounds of air.

Adding the results calculated for carbon, hydrogen and sulphur, we find: $901.27 + 166.22 + 2.47 = 1{,}069.96$. Thus we have found that, for their combustion,

100 pounds of our coal theoretically need 1,069.96 pounds of air, or 1 pound of our coal theoretically needs 10.70 pounds of air.

Consequently, 10.70 pounds of air are the least amount of air necessary for the combustion of 1 pound of our coal. However, modern technics has as yet no means fully to utilize in one run all the oxygen contained in the air. This is the reason that in practice we must use from 150 to 200 per cent of the air theoretically calculated. The ratio of the air theoretically necessary for 1 pound of coal to that of 1 pound of carbon is then $\frac{10.70}{11.54}$. This ratio we shall use in the succeeding pages.

Let us see how much air was used in the boiler house of the sugar factory in question. The examinations of the flue gases * made in the period between the 4th and the 15th of November, 1904, gave the following results:

The composition of the flue gases:

Date.	What Time.	Low-pressure Boiler No.	High-pressure Boiler No.	Carbonic Acid, CO_2, Per Cent.	Oxygen, O. Per Cent.	Carbonic Oxide, CO. Per Cent.	Nitrogen, N. Per Cent.
Nov. 4......	10 o'clock	......	No. 5	5.4	11.6	0.0	83.0
Nov. 4......	11 "	No. 11	.....	2.2	16.6	0.0	81.2
Nov. 4......	12 "	No. 11	.....	2.8	15.2	0.0	82.0
Nov. 4......	1 "	......	No. 5	5.6	12.2	0.0	82.2
Nov. 4......	1½ "	No. 11	.....	3.2	15.0	0.0	81.8
Nov. 4......	2 "	......	No. 5	5.8	11.8	0.0	82.4
Nov. 4......	3 "	No. 11	.....	2.0	16.5	0.0	81.5
Nov. 4......	4 "	......	No. 5	4.8	13.0	0.0	82.2
Nov. 4......	5 "	No. 11	.....	3.0	15.5	0.0	81.5
Nov. 4......	6 "	......	No. 5	4.9	12.8	0.0	82.3
Nov. 5......	8 "	......	No. 5	4.5	13.1	0.0	82.4

*All the gas analyses given in the table were made by means of the Orsat apparatus. Occasionally the quantity of carbonic acid ascertained by means of this apparatus was controlled by means of Stammer's burette and Scheibler's apparatus and found to correspond. For very accurate analyses it is advisable to use Hempel's apparatus. But for technical gas analyses the Orsat apparatus is more convenient, because it enables one to work more rapidly, is handier and is sufficiently accurate. In order not to disturb the work in the boiler house during the campaign, low-pressure boiler No. 11 and the high-pressure boilers Nos. 5 and 4 were appointed for observing and examining purposes, and the gas samples were drawn directly from the boilers, namely, between the draught damper and the flue.

Date.	What Time.		Low-pressure Boiler No.	High-pressure Boiler No.	Carbonic Acid, CO_2. Per Cent.	Oxygen, O. Per Cent.	Carbonic Oxide, CO. Per Cent.	Nitrogen, N. Per Cent.
Nov. 5......	9	"	No. 11	.....	2.9	15.3	0.0	81.8
Nov. 5......	10	"	......	No. 5	5.0	13.6	0.0	81.4
Nov. 5......	11	"	No. 11	.....	2.7	14.9	0.0	82.4
Nov. 5......	12	"	......	No. 5	4.6	13.6	0.0	81.8
Nov. 5......	1	"	No. 11	.....	2.6	16.4	0.0	81.0
Nov. 5......	2	"	......	No. 5	4.8	15.2	0.0	80.0
Nov. 5......	4	"	......	No. 5	5.4	13.4	0.0	81.2
Nov. 5......	3	"	No. 11	.....	3.8	14.8	0.0	81.4
Nov. 5......	5	"	No. 11	.....	2.8	15.6	0.0	81.6
Nov. 6......	10	"	No. 11	.....	3.0	15.5	0.0	81.5
Nov. 6......	11	"	......	No. 5	4.1	14.4	0.0	81.5
Nov. 6......	12	"	No. 11	.....	3.4	14.9	0.0	81.7
Nov. 6......	1	"	......	No. 5	3.8	15.4	0.0	80.8
Nov. 6......	2	"	No. 11	.....	3.2	15.3	0.0	81.5
Nov. 6......	3	"	......	No. 5	6.2	11.6	0.0	82.2
Nov. 6......	4	"	No. 11	.....	3.6	15.1	0.0	81.3
Nov. 6......	5	"	......	No. 5	6.4	11.8	0.0	81.8
Nov. 7......	10	"	No. 11	.....	5.8	12.8	0.0	81.4
Nov. 7......	11	"	......	No. 5	7.6	11.4	0.0	81.0
Nov. 7......	12	"	No. 11	.....	7.5	12.0	0.0	80.5
Nov. 7......	1	"	......	No. 5	7.4	12.1	0.0	80.5
Nov. 7......	2	"	No. 11	.....	8.6	12.0	0.0	79.4
Nov. 7......	3	"	......	No. 5	7.0	12.4	0.0	80.6
Nov. 7......	5	"	......	No. 5	7.0	12.4	0.0	80.6
Nov. 7......	6	"	......	No. 5	7.8	11.1	0.0	81.1
Nov. 8-9....	9	"	......	No. 5	6.0	14.6	0.0	79.4
Nov. 8-9....	10	"	......	No. 5	9.2	9.4	0.0	81.4
Nov. 8-9....	11	"	......	No. 5	8.5	10.5	0.0	81.0
Nov. 8-9....	1	"	......	No. 5	7.6	12.4	0.0	80.0
Nov. 8-9....	2	"	......	No. 4	4.5	16.3	0.0	79.2
Nov. 8-9....	3	"	......	No. 4	6.5	13.1	0.0	80.4
Nov. 8-9....	5	"	......	No. 4	8.2	11.2	0.0	80.6
Nov. 8-9....	6	"	......	No. 4	6.4	13.9	0.0	79.7
Nov. 9-10...	7	"	......	No. 4	6.2	13.4	0.0	80.4
Nov. 9-10...	9	"	......	No. 4	7.4	12.0	0.0	80.6
Nov. 9-10...	11	"	......	No. 4	6.8	12.8	0.0	80.4
Nov. 9-10...	1	"	......	No. 4	7.3	11.6	0.0	81.1
Nov. 9-10...	3	"	......	No. 5	8.0	12.2	0.0	79.8
Nov. 9-10...	5	"	......	No. 4	8.3	11.7	0.0	80.0
Nov. 10-11..	7	"	......	No. 4	9.6	9.5	0.0	80.9
Nov. 10-11..	9	"	......	No. 5	10.0	9.1	0.0	80.9
Nov. 10-11..	11	"	......	No. 4	8.3	10.2	0.0	81.5
Nov. 10-11..	1	"	No. 11	.....	7.8	12.2	0.0	80.0
Nov. 10-11..	3	"	......	No. 4	9.0	10.6	0.0	80.4
Nov. 10-11..	5	"	No. 11	.....	6.8	14.0	0.0	79.2
Nov. 11-12..	8	"	......	No. 4	11.6	6.8	0.0	81.6
Nov. 11-12..	10	"	No. 11	.....	6.8	13.8	0.0	79.4
Nov. 11-12..	12	"	......	No. 4	10.3	9.9	0.0	79.8
Nov. 11-12..	2	"	No. 11	.....	7.4	12.6	0.0	80.0
Nov. 11-12..	4	"	......	No. 4	11.2	8.6	0.0	80.2
Nov. 11-12..	6	"	No. 11	.....	8.0	12.0	0.0	80.0
Nov. 11-12..	7	"	......	No. 4	10.6	8.8	0.0	80.6
Nov. 12-13..	8	"	......	No. 4	9.9	9.6	0.0	80.5
Nov. 12-13..	10	"	No. 11	.....	7.8	12.6	0.0	79.6
Nov. 12-13..	12	"	......	No. 4	9.4	10.0	0.0	80.6
Nov. 12-13..	2	"	No. 11	.....	5.4	14.3	0.0	80.3
Nov. 12-13..	4	"	No. 11	.....	6.8	12.6	0.0	80.6
Nov. 12-13..	6	"	......	No. 4	7.4	12.3	0.0	80.3

Date.	What Time.	Low-pressure Boiler No.	High-pressure Boiler No.	Carbonic Acid, CO_2. Per Cent.	Oxygen, O. Per Cent.	Carbonic Oxide, CO. Per Cent.	Nitrogen, N. Per Cent.
Nov. 13-14..	12 "	......	No. 4	5.6	14.2	0.0	80.2
Nov. 13-14..	1 "	......	No. 4	4.3	16.3	0.0	79.4
Nov. 13-14..	2 "	......	No. 4	6.0	13.2	0.0	80.8
Nov. 13-14..	3 "	......	No. 4	7.8	11.2	0.0	81.0
Nov. 13-14..	4 "	......	No. 4	8.0	11.4	0.0	80.6
Nov. 13-14..	5 "	......	No. 4	11.1	8.3	0.0	80.6
Nov. 15.....	10 "	......	No. 4	8.0	12.0	0.0	80.0
Nov. 15.....	11 "	......	No. 4	12.7	5.3	0.0	82.0
Nov. 15.....	1 "	No. 11	.....	10.0	7.9	0.0	82.1
Nov. 15.....	2 "	......	No. 4	9.7	9.9	0.0	80.4
Nov. 15.....	4 "	No. 11	.....	6.4	13.6	0.0	80.0
Nov. 15.....	5 "	......	No. 4	8.5	10.5	0.0	81.0
Nov. 15.....	6 "	No. 11	.....	7.7	11.8	0.0	80.5

In the first place, it is noticeable that no one of the analyses shows contents of carbon monoxide. This proves that in the boiler house in all cases a considerable surplus of air was used. In the second place, it is striking that all the analyses of the high-pressure boilers, with only one exception, showed a composition much more favorable than the analyses of the low-pressure boiler.

In the first three days (on the 4th, 5th and 6th of November) the flue gases had the following average composition:

	% CO_2	% O	% CO	% N
November 4, 5 and 6—Boiler No. 5..	5.1	13.1	0.0	81.8
November 4, 5 and 6—Boiler No. 11..	3.0	15.5	0.0	81.5

Thus in every 100 liters of the flue gases of the high-pressure boiler No. 5 were contained 5.1 liters of carbon dioxide and 13.1 liters of oxygen. Taking into consideration that the weight of 1 liter of carbonic acid and of oxygen equals 1.966 grams and 1.43 grams, respectively, we have: $5.1 \times 1.966 = 10.03$ grams of carbonic acid, of which $\frac{10.03 \times 12}{44} = 2.74$ grams of carbon and

$\frac{10.03 \times 32}{44} = 7.29$ grams of oxygen. Further, 13.1 liters of oxygen $= 13.1 \times 1.43 = 18.73$ grams of oxygen. Consequently, in 100 liters are contained 2.74 grams of carbon and $7.29 + 18.73 = 26.02$ grams of oxygen. Thus 2.74 grams of carbon united with 26.02 grams of oxygen, corresponding to $\frac{26.02 \times 100}{23.1} = 112.64$ grams of air, or 1 pound (gram) of carbon united with $\frac{112.64}{2.74} = 41.11$ pounds (grams) of air; or 1 pound of our coal used $41.11 \times \frac{10.70}{11.54} = 38.12$ pounds of air.

In like manner we have: In every 100 liters of the flue gas in the low-pressure boiler No. 11 were contained 3.0 liters of carbonic acid and 15.5 liters of oxygen; 3.0 liters of carbonic acid consist of $3.0 \times 1.966 \times \frac{12}{44} = 1.61$ gr. of carbon and $3.0 \times 1.966 \times \frac{32}{44} = 4.29$ gr. of oxygen. Besides this, 15.5 liters of oxygen $= 15.5 \times 1.43 = 22.16$ gr. of oxygen. Consequently in 100 liters of the flue gas were contained 1.61 gr. of carbon and $4.29 + 22.16 = 26.45$ gr. of oxygen. Or 1.61 gr. of carbon united with 26.45 gr. of oxygen corresponding to $\frac{26.45 \times 100}{23.1} = 114.5$ gr. of air; 1 lb. (gram) of carbon united with $\frac{114.5}{1.61} = 71.12$ lbs. (grams) of air; 1 lb. of our coal used $71.12 \times \frac{10.70}{11.54} = 65.94$ lbs. of air.

Now, what quantity of air per pound of coal was used in the following days?

During the last five days together the flue gases were of the following average composition:

	% CO_2	% O	% CO	% N
Nov. 10-11, 11-12, 12-13, 13-14 and 15—				
Boiler No. 5	10.0	9.1	0.0	80.9
Boiler No. 4	9.1	10.2	0.0	80.7
Boiler No. 11	7.4	12.5	0.0	80.1

In 100 liters of the flue gas in boiler No. 5 were contained 10.0 liters of carbonic acid and 9.1 liters of oxygen, or $10.0 \times 1.966 = 19.66$ gr. of carbonic acid, of which $19.66 \times \frac{12}{44} = 5.36$ gr. of carbon and $19.66 \times \frac{32}{44} = 14.30$ gr. of oxygen. Besides, 9.1 liters of oxygen $= 9.1 \times 1.43 = 13.01$ gr. of oxygen. Thus in 100 liters are contained 5.36 gr. of carbon and $14.30 + 13.01 = 27.31$ gr. of oxygen; consequently 5.36 pounds (or grams) of carbon united with 27.31 pounds (or grams) of oxygen corresponding to $27.31 \times \frac{100}{23.1} = 118.23$ lbs. of air. Or 1 lb. of carbon used $\frac{118.23}{5.36} = 22.06$ lbs. of air. Consequently, 1 lb. of our coal used $22.06 \times \frac{10.7}{11.54} = 20.45$ lbs. of air.

In like manner we find: In 100 liters of the flue gas in boiler No. 4 were contained 9.1 liters of carbon dioxide and 10.2 liters of oxygen corresponding to 4.88 gr. of carbon and 27.60 gr. of oxygen. Or

4.88 pounds (grams) of carbon used 27.60 pounds (grams) of oxygen.

1 pound (gram) of carbon used 5.66 pounds (grams) of oxygen, corresponding to 24.50 pounds of air.

1 pound of our coal used $24.50 \times \frac{10.7}{11.54} = 22.72$ pounds of air.

Similarly we have: 100 liters of the flue gas in boiler No. 11 contain 7.4 liters of carbonic acid and 12.5 liters of oxygen corresponding to 3.97 gr. of carbon and 28.45 gr. of oxygen. Consequently:

3.97 pounds (or grams) of carbon used 28.45 pounds (or grams) of oxygen.

1 pound (or gram) of carbon used 7.17 pounds (or grams) of oxygen, corresponding to 31.04 pounds (or grams) of air.

1 pound of our coal used $31.04 \times \frac{10.7}{11.54} = 28.78$ pounds of air.

In order to have the figures in the above calculation presented more clearly, they are summarized as follows:

	Pounds of Air.
1 lb. of carbon uses theoretically for its combustion....	11.54
1 lb. of our coal uses theoretically for its combustion..	10.70
1 lb. of our coal ought to use, according to the best practical experience, from about........................	16 to 21
1 lb. of our coal used actually in the first three days in boiler No. 5....................................	38.12
1 lb. of our coal used actually in the first three days in boiler No. 11....................................	65.94
1 lb. of our coal used actually in the last five days in boiler No. 5....................................	20.45
1 lb. of our coal used actually in the last five days in boiler No. 4....................................	22.72

1 lb. of our coal used actually in the last five days in boiler No. 11 .... 28.78

So we observe that in the first three days, when I did not regulate the air necessary for burning, in the high-pressure boiler No. 5, about four times as great a quantity of air was used as theory requires, and about two times as great a quantity as the best practical experience till now demonstrates; and in low-pressure boiler No. 11 was used six times the quantity of air required by theory, and from three to four times the air required by the best practical experience.

These figures changed essentially in the last five days, during which the air necessary for burning was regulated by me.

In low-pressure boiler No. 11 only from one-third to one-half more air was used than the best experience proves, and in the high-pressure boilers No. 4 and No. 5 the quantities of air used for burning agree very nearly with the best practice.

Here I wish to note that during the campaign the grate in boiler No. 4 was shortened, i. e., two feet was covered with fireproof brick, so that the grate surface was 6 feet by 4 feet, equals 24 square feet (instead of 6 feet by 6 feet). It follows from the figures mentioned that, although the combustion gases in boiler No. 4 were more favorable than in boiler No. 11, yet their composition was not generally better than in boiler No. 5. In consequence, it was not deemed advisable to shorten the grates in the other boilers.

At all events, it is evident that the greater the overplus of air penetrating the grates from the outside and passing up the chimney, the greater is the loss of heat in the boiler house. Let us ascertain, in the first place, the amount of calories which one kilogram of our coal is able to furnish, and, in the second place, determine the losses of heat caused by the overplus of air passing up the chimney. The coal under consideration has the following composition:

Moisture.	Ash.	Sulphur.	Carbon.	Hydrogen	Oxygen + Nitrogen. (by difference.)
1.44	9.14	0.57	78.10	4.8	5.95

According to Dulong the heating value of a coal equals

$$\frac{8{,}080\,C + 28{,}800\left(H - \frac{O}{8}\right)^{*} + 2{,}500\,S = 600\,W}{100},$$

in which C, H, O, S and W represent the percentage of carbon, hydrogen, oxygen, sulphur and moisture. Substituting in this formula the values found by the analyses, it becomes:

$$\frac{8{,}080 \times 78.1 + 28{,}800\left(4.8 - \frac{5.95}{8}\right) + 2{,}500 \times 0.57 - 600 \times 1.44}{100} =$$

7,485 calories. Now, of this quantity of heat a part is lost by the hot gases passing up the chimney.

According to the analysis of the coal, in 1 kilogram of the latter are contained 781 gr. of carbon, of which, say, 2 per cent† fall through the grate into the ashes, so that there remain

$781 - \frac{781 \times 2}{100} =$ in round number 765 gr., for the formation of

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*Nitrogen may be neglected because it affects the result less than 1 per cent. Soft coal contains generally much less nitrogen than oxygen, and even in a very unfavorable case, if our coal contains 2 per cent nitrogen, we find:

$$\frac{8{,}080 \times 78.1 + 28{,}800\left(4.8 - \frac{3.95}{8}\right) + 2{,}500 \times 0.57 - 600 \times 1.44}{100} =$$

7,557 calories. Consequently, the difference equals 7,557 — 7,485 $= 72$ calories, or $\frac{72}{7{,}485} = 0.96\%$.

Similarly, for the sake of simpleness, it was above assumed that the air consists of 20.92 volumes of oxygen and 79.08 volumes of nitrogen, against which 0.04 volumes of carbon dioxide really contained in the air were neglected.

†Examinations of the combustible part of the ashes, which fell through the grate, made by me in a sugar factory of Germany, under similar conditions, give me the right to this assumption.

carbonic acid gas. In the first three days the combustion gases in boiler No. II were of the average composition:

% CO_2	% O.	% CO.	% N.
3.0	15.5	0.0	81.5

Three liters of carbonic acid weigh $3 \times 1.966 = 5.898$ gr. of carbonic acid corresponding to $5.898 \times \frac{12}{44} = 1.6085$ gr. of carbon.

In consequence, 1,6085 gr. of carbon furnish 3.0 liters of carbonic acid; 765 gr. of carbon furnish t liters of carbonic acid; $t: 3.0 = 765: 1.6085; \ t = \frac{3.0 \times 765}{1.6085} = 1{,}426$ liters $= 1.426$ cubic meters of carbonic acid.

The quantity of oxygen results from the proportion $3.0: 15.5 = 1{,}426: s; \ s = \frac{15.5 \times 1{,}426}{3.0} = 7{,}368$ liters $= 7{,}368$ cubic meters of oxygen.

The quantity of nitrogen results from the proportion $3.0: 81.5 = 1{,}426: r; \ r = \frac{81.5 \times 1{,}426}{3.0} = 38{,}740$ liters $= 38.740$ cubic meters of nitrogen.

Thus, 1 kilogram of coal furnishes 1.426 cubic meters of carbonic acid, 7.368 cubic meters of oxygen and 38.740 cubic meters of nitrogen.

In order to ascertain the quantity of heat that each gas carries up the chimney, the weight of the gas (i. e., volume × specific gravity) must be multiplied by the specific heat and by their rise of temperature. The temperature of the air entering the grates was 20° Celsius; that of the chimney gases is mostly between 200° and 300° C. Let us suppose their average temperature was 250° C.* Since the temperature of the escaping gases varies in different factories, I will calculate the losses for all the three temperatures. The rise in temperature is then 250 — 20 = 230°C., 300 — 20 = 280°C., 200 — 20 = 180°C.

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*This temperature could not be determined exactly in the absence of a pyrometer.

	Cubic Meters.	Weight of Cu. M. Kilogr's.	Sp. Heat.	Rise of Temp., Cels.	Cals.
At 250° C*, carbon dioxide carries away	1.426 ×	1.966 ×	0.217 ×	230 =	139.9
At 250° C., oxygen carries away	7.368 ×	1.43 ×	0.218 ×	230 =	528.3
At 250° C., nitrogen carries away	38.740 ×	1.26 ×	0.244 ×	230 =	2,739.4
Total	47.534				

Furthermore, the quantity of heat carried off by the water vapor must be calculated. The aqueous vapor proceeds from the combustion of hydrogen contained in the coal, from its moisture and from the air penetrating the grates. According to the analysis, the coal contains 4.8 per cent = 0.048 kilograms of hydrogen per kilogram of coal. One kilogram of hydrogen produces in burning 9 kilos. of water, consequently 0.048 kilogram of hydrogen produces $0.048 \times 9 = 0.432$ kilograms of water. The quantity of moisture in the coal is 1.44 per cent =

	Cubic Meters.	Weight of Cu. M. Kilogr's.	Sp. Heat.	Rise of Temp.	Cals.
*At 300° C, carbon dioxide carries away	1.426 ×	1.966 ×	0.217 ×	280 =	170.3
At 300° C, oxygen carries away	7.368 ×	1.43 ×	0.218 ×	280 =	643.1
At 300° C, nitrogen carries away	38.740 ×	1.26 ×	0.244 ×	280 =	3,334.9
At 300° C., water vapor carries away	0.881 kgms.		× 0.481 ×	280 =	118.7
		Total			4,267.0

Total loss equals 4,267.0 calories or $\frac{4,267.0}{7,485} \times 100 = 57.0\%$

					Cals.
At 200° C, carbon dioxide carries away	1.426 ×	1.966 ×	0.217 ×	180 =	109.5
At 200° C, oxygen carries away	7,368 ×	1.43 ×	0.218 ×	180 =	413.4
At 200° C, nitrogen carries away	38.740 ×	1.26 ×	0.244 ×	180 =	2,143.8
At 200° C., water vapor carries away.........	0.881 kgms.		× 0.481 ×	180 =	76.3
		Total			2,743.0

Total loss equals 2,743 calories or $\frac{2,743}{7,485} \times 100 = 36.6\%$

0.014 kilogram per 1 kilogram of coal. The amount of air entering the grates equals the amount of combustion gas — 47.534 cubic meters — as it follows from equation II. The quantity of water vapor per cubic meter of the air was found by me to be 9.16 grams. Consequently the total volume of 47.534 cubic meters contains $9.16 \times 47.534 = 0.435$ kilograms. So that the total quantity of water vapor per kilogram of coal $= 0.432 + 0.014 + 0.435 = 0.881$ kilogram. The quantity of heat carried away by the water vapor equals its weight $\times$ its spec. heat $\times$ rise of temperature, i. e., 0.881×0.481 (sp. heat) $\times$ 230 (rise of temp.) $= 97.5$ calories.

Adding to the losses caused by carbon dioxide, oxygen and nitrogen, we have $139.9 + 528.3 + 2{,}739.4 + 97.5 = 3{,}505.1$ calories. Since 1 kilogram of our coal furnishes 7,485 calories, the total loss expressed in percentage ratio gives $\frac{3{,}505.1}{7{,}485} \times 100 = 46.8$ per cent. These figures we have found for boiler No. 11 in the first three days.

In the same manner we may calculate for boiler No. 5. The average composition of its gases was:

% CO_2	% O.	% CO.	% N.
5.1	13.1	0.0	81.8

Now, 5.1 liters of carbon dioxide $= 5.1 \times 1.966 = 10.027$ gr. of carbon dioxide corresponding to 2.735 gr. of carbon. Thus 2.735 gr. of carbon furnish 5.1 liters of carbon dioxide; 765 gr. of carbon furnish x^1 liters of carbon dioxide. $x^1 : 5.1 = 765 : 2.735$; $x^1 = \frac{5.1 \times 765}{2.735} = 1{,}426$ liters $= 1.426$ cubic meters of carbon dioxide.

The quantity of oxygen is determinable by the proportion $5.1 : 13.1 = 1{,}426 : y^1$; $y^1 = \frac{1{,}426 \times 13.1}{5.1} = 3{,}663$ liters $= 3.663$ cubic meters of oxygen.

The quantity of nitrogen is ascertained by the proportion: $5.1 : 81.8 = 1{,}426 : z^1$; $z^1 = \frac{1{,}426 \times 81.8}{5.1} = 22{,}872$ liters $= 22.872$ cubic meters of nitrogen.

The amount of calories that each gas carries up the chimney is:

	Cubic Meters.	Weight of Cu. M. Kilogr's.	Sp. Heat.	Rise of Temp., Cels.	Cals.
At 250° C, for carbon dioxide	1.426 ×	1.966 ×	0.217 ×	230 =	139.9
At 250° C, for oxygen....	3.663 ×	1.43 ×	0.218 ×	230 =	262.6
At 250° C, for nitrogen...	22.872 ×	1.26 ×	0.244 ×	230 =	1,617.3
Total..................	27.961				

Let us now calculate the weight of aqueous vapor. Moisture per kilogram of coal there is 0.014 kilo water vapor; 0.048 kilogram of hydrogen furnishes in burning $0.048 \times 9 = 0.432$ kilo. water vapor. Aqueous vapor penetrating the grates with the air equals 27.961 (cu. m.) × 9.16 gr. = 0.256 kilo water vapor. Total, 0.702 kilograms of water vapor.

In consequence, the quantity of heat carried up the chimney by the water vapor is 0.702 (kilograms) × 0.481 (spec. heat) × 230 (rise of temp.) = 77.7 calories. Hence the total loss of heat carried up the chimney by all the gases together equals

$$139.9 + 262.6 + 1,617.3 + 77.7 = 2,097.5 \text{ calories, or } \frac{2,097.5}{7,485} \times 100 = 28.0 \text{ per cent.*}$$

In the last five days the losses may be calculated as follows:

In boiler No. 11 the flue gas was of the average composition:

% CO_2	% O.	% CO.	% N.
7.4	12.5	0.0	80.1

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*At 300° C. the losses are calculated as follows: For carbonic acid, 170.3 calories; for oxygen, 319.7 calories; for nitrogen, 1,968.9 calories, and for aqueous vapor, 94.5 calories. Altogether the loss up the chimney equals $170.3 + 319.7 + 1,968.9 + 94.5 = 2,553.4$ calories, or $\frac{2,553.4}{7,485} \times 100 = 34.1$ per cent.

At 200° C. the losses are calculated in like manner for: Carbon dioxide, 109.5 calories; oxygen, 205.5 calories; nitrogen, 1,265.7 calories, and aqueous vapor, 60.8 calories. Altogether the loss up the chimney equals $109.5 + 205.5 + 1,265.7 + 60.8 = 1,641.5$ calories, or $\frac{1,641.5}{7,485} \times 100 = 21.9$ per cent.

Thus we have: 7.4 liters of carbon dioxide equals $7.4 \times 1.966 = 14.548$ gr. of carbon dioxide, corresponding to 3.968 gr. of carbon.

Consequently, 3.968 gr. of carbon generate 7.4 liters of carbon dioxide; 765 gr. of carbon generate u^1 liters of carbon dioxide. $u^1 : 7.4 = 765 : 3.968$; $u^1 = \frac{7.4 \times 765}{3.968} = 1{,}426$ liters $= 1.426$ cubic meters of carbon dioxide.

The volume of oxygen is found by the proportion $7.4 : 12.5 = 1{,}426 : t^1$; $t^1 = \frac{12.5 \times 1{,}426}{7.4} = 2{,}409$ liters $= 2.409$ cubic meters of oxygen.

The quantity of nitrogen is found by the proportion: $7.4 : 80.1 = 1{,}426 : s^1$; $s^1 = \frac{1{,}426 \times 80.1}{7.4} = 15{,}435$ liters $= 15.435$ cubic meters of nitrogen.

The losses are calculable as follows:

	Cubic Meters.	Weight of Cu. M Kilogr's.	Sp. Heat.	Rise of Temp. Cels.	Cals.
At 250° C., for carbon dioxide	1.426 ×	1.966 ×	0.217 ×	230 =	139.9
At 250° C., for oxygen..	2.409 ×	1.43 ×	0.218 ×	230 =	172.7
At 250° C., for nitrogen..	15.435 ×	1.26 ×	0.244 ×	230 =	1,091.4
Total	19.270				

Now we proceed to calculate the quantity of aqueous vapor which passes up the chimney:

48 gr. of hydrogen produce in burning $48 \times 9 = 432$ gr. $=$ 0.432 kilograms of water vapor.

Moisture per kilogram of coal equals 0.014 kilograms of water vapor.

The quantity of water vapor entering the grates with the air equals $19.27 \times 9.16 = 0.177$ kilograms of water vapor.

Total, 0.623 kilograms of water vapor.

The amount of heat carried off by the water vapor equals 0.623 (kilograms) × 0.481 (sp. heat) × 230 (rise of temp.) = 68.9 calories. Hence the total loss of heat equals 139.9 + 172.7

$+ 1,091.4 + 68.9 = 1,472.9$ calories, or $\frac{1,472.9}{7,485} \times 100 = 19.7$ per cent.*

The calculation for boiler No. 5 takes place in the same manner. The composition of its combustion gases was as follows:

% CO_2	% O.	% CO.	% N.
10.0	9.1	0.0	80.9

Ten liters of carbon dioxide equal $10.0 \times 1.966 = 19.66$ gr. of carbon dioxide, corresponding to 5.362 gr. of carbon.

Now, 5.362 gr. of carbon produce 10.0 liters of carbon dioxide. 765 gr. of carbon produce x″ liters of carbon dioxide.

$$x'' : 10.0 = 765 : 5.362; \quad x'' = \frac{10.0 \times 765}{5.362} = 1,426 \text{ liters} = 1.426 \text{ cubic}$$

meters of carbon dioxide.

The quantities of oxygen and nitrogen are determinable by the following proportions:

$$10.0 : 9.1 = 1,426 : y''; \quad y'' = \frac{1,426 \times 9.1}{10.0} = 1,298 \text{ liters} = 1.298$$

cubic meters of oxygen; $10.0 : 80.9 = 1,426 : z''; \; z'' = \frac{1,426 \times 80.9}{10.0}$ $= 11,536$ liters $= 11.536$ cubic meters of nitrogen.

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*At 300° C. the losses are calculated in like manner, namely, for: Carbon dioxide, 170.3 calories; oxygen, 210.3 calories; nitrogen, 1,328.7 calories, and water vapor, 83.9 calories. Together all the gases carry off 1,793.2 calories, or $\frac{1,793.2}{7,485} \times 100 =$ 24.0 per cent.

At 200° C. the losses are, for: Carbon dioxide, 109.5 calories; oxygen, 135.2 calories; nitrogen, 854.2 calories, and for water vapor, 53.9 calories. Together all the gases carry off 1,152.8 calories, or $\frac{1,152.8}{7,485} \times 100 = 15.4$ %.

The calculation of the losses is as follows:

	Cubic Meters.	Weight of Cu. M Kilogr's.	Sp. Heat.	Rise of Temp. Cels.	Cals.
At 250° C., carbon dioxide carries off	1.426 ×	1.966 ×	0.217 ×	230 =	139.9
At 250° C., oxygen carries off	1.298 ×	1.43 ×	0.218 ×	230 =	93.1
At 250° C., nitrogen carries off	11.536 ×	1.26 ×	0.244 ×	230 =	815.7
Total	14.260				

The calculation of the quantity of aqueous vapor passing up the chimney is executed as follows:

48 gr. of hydrogen furnish in burning 0,432 kilos. of water vapor; moisture per kilogram of coal equals 0.014 kilos. of water vapor; water vapor entering the grates with the air equals 14.26 (cu. m.) × 9.16 (grams) = 0.131 kilos. of water vapor; total, 0.577 kilos. of water vapor, which carries up the chimney 0.577 (kilos.) × 0.481 (sp. heat) × 230 (rise of temp) = 63.8 calories.

The total loss of heat that all the gases carry off equals 139.9 + 93.1 + 815.7 + 63.8 = 1,112.5 calories, corresponding to $\frac{1,112.5}{7,485} \times 100 = 14.9$ per cent.*

Let us recapitulate: In the first three days—as I only tried to ascertain the manner and quality of the work in the boiler house, and I did not regulate the air entering the grates—the loss of heat in boiler No. 11 was 46.8 per cent, at 250° C. (57.0% and 36.6% at 300° C. and 200° C., respectively); likewise the loss in boiler No. 5 was 28.0 per cent at 250° C. (34.1% and 21.9% at 300° C. and 200° C., respectively). These conditions were im-

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*At 300° C., the losses were found as follows: For carbon dioxide, 170.3 calories; for oxygen, 113.3 calories; for nitrogen, 993.1 calories; for water vapor, 77.7 calories; together, 1,354.4 calories, corresponding to $\frac{1,354.4}{7,485} \times 100 = 18.1$ %.

At 200° C., the losses were found: For carbon dioxide, 109.5 calories; for oxygen, 72.8 calories; for nitrogen, 638.4 calories, and for water vapor, 50.0 calories; together, 870.7 calories, corresponding to $\frac{870.7}{7,485} \times 100 = 11.6$ %.

proved essentially in the last five days, when I regulated the air necessary for burning, namely: In boiler No. 11 the loss of heat was 19.7 per cent at 250° C. (24.0% at 300° C., and 15.4% at 200° C.); likewise the loss in boiler No. 5 was only 14.9 per cent at 250° C. (18.1% at 300° C. and 11.6% at 200° C.).

In other words, per 100 tons of coal the loss in the first three days was 46.8 tons in boiler No. 11, and 28.0 tons in boiler No. 5; the loss became, instead, in the last five days, 19.7 tons in boiler No. 11, and 14.9 tons in boiler No. 5 These figures apparently show the great importance of a correct regulation of the air necessary for burning. The losses in boiler No. 4 were between those of the boilers Nos. 11 and 5.

I am sure that losses caused by false regulation of the air necessary for burning take place in some factories, and each sugar house that uses a great percentage of coal per 100 parts of beets has a very forcible reason in the first place to think of false regulation of the air, and should try to remove this fault. Certainly, during the campaign the factory administration has a great multiplicity of cares, in order to get sugar of good quality and as high a yield as possible, etc., so that it is hardly in a position to look occasionally in the boiler house. The management is usually satisfied if the steam gauges of the boilers show sufficient pressure, as is desired in the factory for the engines and for boiling purposes.

Whether or not the boiler house works economically is certainly a question of great importance, which a correct and qualified administration must and will try to answer. In order to work economically (supposing, above all, a correct construction of the boiler house plant) we should consider the regulation of the air entering the grates; in the second place the qualities of the fuel, feed water and steam.

First of all it is of importance that the grate be covered with coal on its whole surface as uniformly as possible, because on places where the grate is free from coal the air enters the grate unproductively, passing up the chimney as not being properly utilized, and increasing the waste of fuel. On the other hand, where the coal lies in too high layers, the entering of the air is more difficult, whereby the active grate surface is decreased. Only when the coal lies in uniform and medium layers has the entering air the greatest opportunity to come into close contact with the glowing coal on many places, whereby the oxygen of the air can be utilized in the best possible manner.

Many firemen customarily open the dampers regulating the draught wide, as soon as the steam pressure decreases, or they open the stokeholes in case the steam pressure and the glow on the grates increase too much. It is evident that these manipulations are incorrect, because lots of air thereby penetrates the grates, cooling the combustion gases as well as the boilers and the gas channels. It is, on the contrary, more suitable to regulate the air as equally as possible. A convenient way to reach this purpose is to place measuring scales along the chains, which must be equal and which must run on pulleys, in order to regulate the air inlet. The scales can be made in each boiler house from shelves painted black and divided by means of white lines into inches or centimeters. Before the beginning of the campaign the engineer ought to ascertain, and then to tell the firemen, what lines of the scale correspond to the end of the chain, if the damper is entirely open, half, quarter, etc. Besides the separate dampers in each boiler, a main damper ought to be placed where the flue discharges into the chimney, and in boiler houses with high— and low—pressure lines, two main dampers ought to be applied.

As we have learned in the preceding pages, the analysis of the flue-gases gives us an excellent and thoroughly reliable means to ascertain at any moment how many pounds or tons of air are used in burning one pound or ton of coal. Therefore, in the first days of the campaign, the engineer, together with an experienced chemist, has to control the work in the boiler house, and, above everything else, has to examine the regulation of the air necessary for burning. On the basis of several analyses, carefully made, they should determine in what position of the main and of the separate dampers the combustion gases have the most favorable composition, that is, the highest percentage of carbon dioxide without any carbon monoxide.*

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*The loss caused by presence of carbon monoxide can be figured in the following manner: For this purpose we have to use the thermal equations: $CO + O = CO_2 + 67{,}960$ calories (1); $C + O_2 = CO_2 + 97{,}650$ calories (2). These equations express that in burning 1 molecule of carbonic oxid to carbonic acid 67,960 calories are produced, and in burning 1 atom of carbon to carbonic acid 97,650 calories are generated. Equation (2) we can represent in two phases: $C + O = CO + x$ calories (a) and $CO + O = CO_2 + 67{,}960$ calories (b), where x indicates the quantity of

This determined, the firemen ought to be instructed to act accordingly. As soon as the firemen are accustomed to certain positions of the dampers they will find it to be unsuitable to shove the damper up and down often, and they will do so only in case it is fully expedient. For instance, only the separate damper of any boiler ought to be closed while its grates are cleaned from ashes and slag. Or, if the steam pressure in all the boilers rises too high, and the combustion is pretty brisk, then it is advisable to lower the main damper, etc. It is necessary, at any rate, positively to counteract the bad practice of many firemen to use a great surplus of air.

Concerning the composition of the coal—whether bituminous (soft coal) or brown coal—I would say it is profitable to buy a coal as free from ash as possible. If, for instance, there is a choice of purchasing a coal containing either 5 per cent ash for \$4 a ton—to take a round figure—or a coal with 10 per cent ash for \$3.80 a ton, there can be no doubt that the first one is preferable. A simple consideration shows this.

In the first place the last mentioned coal contains 5 per cent more ash, which means 5 per cent less combustible substance, i. e., it has only the value $\$4.00 - 4.00 \times \frac{5}{100} = \$3.80$. Besides, as a coal richer in ash, it requires a more frequent cleaning of the

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calories which 1 atom of carbon furnishes in burning to carbonic oxide. Adding (a) and (b), we have: $C + CO + O_2 = CO + CO_2 + 67{,}960$ calories $+ x$ calories (3). Subtracting equation (2) from equation (3) and solving the resulting equation, we find that x equals 29,690 calories. So that 1 atom of carbon, or 12 kilos. of carbon, produce 29,690 calories in burning to carbonic oxid, hence 1 kilo of carbon produces $\frac{29{,}690}{12} = 2{,}474$ calories. On the other hand we know from equation (2) that 12 kilos of carbon produce 97,650 calories in burning to carbonic acid, therefore 1 kilo of carbon produces $\frac{97{,}650}{12} = 8{,}137.5$ calories. Consequently, 1 kilo. of carbon would lose $8{,}137.5 - 2{,}474 = 5{,}663.5$ calories, if all carbon would burn to carbonic oxid, and for each 1 per cent the loss equals $\frac{5{,}663.5}{100} = 56.6$ calories.

grates, consequently more work, and causes the cold air to enter the grates; furthermore, a part of the heat is lost by the hot ashes falling through the grates. The coal must be of medium size and accommodated to the construction of the grates. Similarly, it is more profitable to buy dry coal for a correspondingly higher price. For, apart from the fact that the real value of the coal is decreased by the weight of the moisture, a part of the available heat is unproductively used for the evaporation of the moisture. Since the heat of vaporization of water equals 600 calories, every per cent of moisture contained in a coal uses unproductively six calories of heat. This fact is important for factories using brown coal as fuel, because the latter is generally distinguished by a high content of moisture. Finally, coal should be procured that is as free from sulphur as possible, for sulphur burning to sulphur-dioxide corrodes the boiler plates.

As for the feed water, its temperature must be very uniform. If there is not sufficient condensed water from exhaust steam, the firemen usually supply the boilers with cold water. Apart from the fact that the feeding, sometimes with hot water, sometimes with cold water, is injurious to the boilers, causing an alternate expansion and contraction which may cause the boilers to leak, the formation of steam takes place irregularly under these conditions. In order to prevent this defect, a heater should be placed in the boiler house, heated by exhaust steam, through which the feed water must pass, and which, by means of inlet and outlet valves, can be heated to the temperature desired before going into the suction tank, from which the feed pump forces the water into the boilers.

The feed water should have as high temperature as possible. The boilers are thereby relieved of too forcible firing, and, on the other hand, tensions of the boiler plates are avoided. If there is not sufficient exhaust steam in the factory to heat the feed water, so that cold water must be used, the water can be heated by means of an "economizer," in case the combustion gases in the flue are sufficiently hot, and the draught in the chimney is strong enough. It is to be regretted that the "economizer" is known and used by very few factories. This appliance, consisting of a system of pipes, can easily be placed in the flue about 200 millimeters under its arch. The feed water forced by means of the pump through these pipes is heated by the combustion gases in the flue before it reaches the boilers. Should it be necessary to remove the economizer during the work, one needs only to close its valve in front of the flue, so that the feed water is forced directly from the suction tank into the boilers.

My notes in a sugar factory in Germany, having a daily capacity of 2,100 centweights of beets, show that the temperature of the feed water by such an economizer, of 44 square meters surface and 1.32 cubic meters volume, was increased about 40° C. It is evident that the hotter the gases are in the flue, and the slower the feed pump works, the more the feed water is heated by the economizer.

As already mentioned, the analyses of the flue gases in the high-pressure boilers show a more favorable composition than those in the low-pressure boilers, i. e., the fuel is utilized in the former more completely than in the latter. Another fact speaks also in favor of the high-steam boilers. Indeed, let us consider the following table:

Steam of 1 atmos. absol. press. has 100.0° C., requires 622.0 cals.
Steam of 2 atmos. absol. press. has 120.6° C., requires 628.3 cals.
Steam of 3 atmos. absol. press. has 134.0° C., requires 632.4 cals.
Steam of 5 atmos. absol. press. has 152.2° C., requires 637.9 cals.
Steam of 10 atmos. absol. press. has 180.3° C., requires 646.5 cals.

This table shows that:

Steam of 1 atmos. absol. press. req. 622.0 cals. for each atmos.
Steam of 2 atmos. absol. press. req. 314.1 cals. for each atmos.
Steam of 3 atmos. absol. press. req. 210.8 cals. for each atmos.
Steam of 5 atmos. absol. press. req. 127.6 cals. for each atmos.
Steam of 10 atmos. absol. press. req. 64.6 cals. for each atmos.

We thus observe that the higher pressure the steam has the fewer calories or—what is the same—the less coal it requires, and, consequently, the cheaper it is.

It could hardly be the intention of the writer of this article to fully exhaust so important a question as fuel economy in sugar factories, because it is not practicable in the limits of an article in a journal. For instance, the question of the losses caused by conduction or radiation* of heat was not touched upon at all. By

*These losses within the boiler house can be calculated as follows: By means of the thermal equations $(C, O_2) = 97{,}650$ calories, $(H_2, O) = 68{,}460$ calories and $(S, O_2) = 71{,}080$ calories we are able to figure the total quantity of heat which, say, one ton of the coal can furnish. Subtracting from this result the easily calculable losses occasioned by the escaping gases and hot ashes, there remains the available heat (a) which serves really this article, however, it was intended to call the attention of the interested circles to several most important points where considerable economy of fuel can be attained. From the data mentioned here, it follows that a factory works economically in the boiler house, if the following conditions are fulfilled: Correct regulation of air necessary for combustion, which is the most essential condition; escaping combustion gases of low temperature—the higher the chimney the lower can be the temperature of the gases; coal as free from ash, slag and sulphur as possible, to which the size of the coal and the construction of the grate must be carefully adjusted; feed water of uniform temperature and as hot as possible, and, finally, steam of high pressure for the engines.

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for the heating of the boilers. Knowing further the average temperature and the quantity of feed water with which the boilers are supplied as well as the temperature to which the water in the boilers is raised, one can easily determine the amount of available heat (b) used for the formation of steam only. Subtracting (b) from (a) gives rougly the loss of heat through conduction and radiation.