Gasifier efficiency

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The gasifiers that were used in the iron industry from the later half of the 19th century had, one could say, borrowed their design and construction from the furnaces. They were stout brick ovens, with thick, well insulated walls.

When at the end of 19th century producer gas begun to come in use for powering stationary internal combustion engines, and thereby mechanical designers took over designing the gasifier, it became somewhat more machine-like. They were however exceedingly careful with applying a steady heat-insulating masonry in the gasifier vessel. Of course, even in those days there were reoccuring attempts at eliminating the troublesome, heavy, and fragile masonry with refractory brick, and making the hearth from iron. Two circumstances was however standing in the way for their practical usefulness. Primarily, in those days there were still no alloys that were sufficiently heat resistive, and surrounding the hearth with a water mantle, from which the generated steam was led back to the gasifier, created too much steam addition and too low hearth temperature. Furthermore, for powering combustion engines, fuel consumption per hp-hour was of decisive importance. Due to the large heat loss from the non-masonry gasifier compared with the ones with masonry, fuel consumption per hp-hour became too big. The non-masonry gasifier could not compete with masonry gasifiers.

From around 1910 almost all use of producer gas for motor use ceased, due to the low pricing on oil fuels. The diesel motors ruled the market.

The gasifier has however at various occasions with shortage on fluid fuels again become used for powering combustion engines. But in those cases it has always been the case of powering various mobile motors, automobiles, buses, railway carriages, tractors, smaller boats and such. For these purposes, small size, small weight, and robustness against vibrations and bumps been decisive, while fuel consumption, due to the usually low fuel price, been put aside. No concern was taken for gasifier heat losses and efficiency and have therefore gone to excess in lack of heat insulation. Those who were around at the turn of the century[1] have had reason to be surprised at that the gasifiers in use today, with their complete lack of insulation, have performed as well as they actually have.

This is explained by two circumstances, both caused by the properties of the fuel.

The fuel that has been used, charcoal, regardless if it has been pre-charred, or formed within the gasifier, has compared to earlier used fuels, coke and anthracite, a very large reaction ability. The porosity of charcoal offers the reaction a very large surface, and thereby decreased heat losses compared to gasifiers for coke and anthracite.

If one on top of that use a dry fuel, dry wood, dry charcoal, insulation often only results in an increased temperature for the produced gas, whose heat then is cooled away before the gas reaches the motor.

One must however, not view the problem in this simple way. One must instead ask oneself how the saved heat losses can be put to use. With increased experience and rising prices on producer gas fuel, the issue on heat losses in gasifiers begun to attract attention. In the publication Gengas, as well as in Teknisk tidskrift, a thesis by dr-ing Lutz has been summarised, in which this question is the main issue. In Gengas nr 6 as well as in Teknisk tidskrift civ.ing.[2] Rolf Steenhoff reported about some experiments regarding the same thing.

[1] i.e. 1900 — JP
[2] Master of Engineering

Before taking on the main issue, I would like to stay for a moment at these authors' statements.

Lutz, his referrer in Teknisk tidskrift eng. G.V. Nordenswan, as well as Steenhoff points out the lack of insulation. Steenhoff even speaks about 'the peculiar fact that the heat balance problem so far seem to have been neglected by the manufacturers.'

As I have explained this is not really a neglection, but a stepping away from older observing of the heat balance problem, due to altered economical conditions, different usage and demands for small size, lightness, and robustness.

However, this does not prevent that a time has come when the old technicians demand for good heat balance is met by the youngers woes over the present gasifier's bad heat balance. For me, it cannot be anything but a joy that that time now has come, and that the principles for which I so long has been the only spokesman suddenly appear as young experimenters' new won experiences.

There are though in Lutz' in many respects meritorious thesis a few errors and inconsequences, which ought to be pointed out.

He puts forward that both the gas, and gas-air mixture, heat value need be raised for achieving more power from the motor. I would like to point out that the gas heat value have little to do with the heat value of the gas-air mixture or motor power. Since it confuses things, it is unfortunate. Motor power depends upon fuel-air mixture heat value. But fuel-air mixture heat value does not depend upon gas heat value, but rather upon the gas' need for combustion air to form a reaction equivalent mixture. Its is not unusual that a gas with high heat value gives a fuel-air mixture with lower heat value than the reference gas.

Lutz also points at the slowness of water dissociation in the gasifier, and presents numbers for 1 100°C, whose value I cannot judge. He says later though, that the temperature in the gasifier is 1 200 to 1 300°C. Reaction speed is above all a function of temperature. Therefore, the numbers for 1 100°C are without value for the reasoning, which in other aspects too is not entirely unassailable. On top of this, a decrease of gasifier losses implies a higher temperature in the gasifier, and by that a better chemical equilibrium and increased reaction speed.

Lutz' pessimistic view is rather surprising, since all his striving concerns decreased heat losses in the gasifier in order to make use of the energy. I the later half of his thesis he has however reached a more optimistic standpoint. He declares that due to decreased heat losses in the gasifier, temperature rises. Some of the recaptured heat can be used for dissociating water. He also presents a diagram, over performed experiments, fig. 13, p. 73, Teknisk tidskrift, Automobil- och motorteknik 1941.

In one of the cases, gas temperature heat is returned to the gasifier. Lutz states for example that one get the same heat value for the gas at 22 % moisture without, as for 30 % moist with, heat exchanger. This conclusion is qualitatively correct, but quantitatively erroneous. The evaluation cannot be based on m^3 gas but must be based on the heat value in the gas, per kg wood. Certainly, the amount of gas is larger with heat exchanger than without. This only puts the curves a little closer to eachother, and makes the difference in fuel moist somewhat lesser. This small erroneous comparison pervades throughout the thesis. But the experiments confirms that the correctness of the technique being used in an early stage, and that is the main thing.

Lutz has also used an insulated gasifier, which has given the same results. They show that heat householding in the gasifier is most important for the gasification process, and that the gasifier through better heat economy can be improved significantly. He also declares that 40 to 50 % moist in wood is within reach.

Steenhoff has performed experiments with an insulated gasifier and points out that no degrading from heat has occurred. 'This is is due to that the increased water dissociation (water-gas reaction) consumes a large portion of the heat, which is prevented from reaching the surrounding air, and so the captured heat in the end comes to the motor's use in the form of better gas quality.' He further says: 'In order to prevent the temperature in the charcoal gasifier at efficient insulation to rise too high, one is probably forced to add larger amounts of water in order to absorb the oxidation heat.'

All this new discovery is old, forgotten knowledge.

Steenhoff also declares that 'watergas reaction cannot take place until a certain amount of oxidation heat has been released and the temperature in the reaction zone still supersedes 1 000°C. Water addition in future mixed gas

gasifiers therefore ought to be thermostat controlled.'

This thermostat control is an excellent idea. But neither that is new. On old times gasifiers, in which steam being fed to the gasifier was produced by vaporising water with the gas heat, in a vaporising device, the amount of water was adjusted so that it would take a certain time until the water was heated enough for a significant amount of steam was fed to the gasifier. One could call this a sort of primitive thermostat. But it worked very well.

Steenhoff, as mentioned, finally states that the car gasifiers heat balance problem has been neglected.

One has reason to agree with that conclusion. There is good reasons to return to the technology from the turn of the century. I have touched the reasons for the neglect earlier. But without doubt, the time has come to seriously address this problem. In this situation it may be of some interest, to with the practical results as background, look at how the question stands theoretically.

An erroneous opinion prevails about the importance of steam or water in producer gas production, whether steam is added or in downdraft gasification comes with the fuel as moist. To begin with, one must point out, that when Lutz speaks about the slowness of water dissociation, he confuses the concepts. Chemists have found that reaction durance for steam dissociation and carbon dioxide reduction to carbon monoxide are about the same at identical temperature in the reaction vessel. This is an important fact. In one Mole[3] carbon, i.e. 12 kg carbon, 97 600 kcal is chemically bound. If this carbon is combusted to carbon monoxide, 68 200 kcal is tied in carbon monoxide. The remaining 29 400 kcal have been released and heated the produced gas, which has been generated by the carbons combustion with air, to about 1 200 to 1 300°C. This gas heat is lost in the cooler.

Of 97 600 kcal in the carbon, 68 200 kcal is left in the gas. The gasifier efficiency is therefore, if we consider a *lossless* gasifier

$$\eta = \frac{68\,200}{97\,600} = 0.70$$

or 70 %. This is a rather low efficiency.

Let us now examine the efficiency for a *lossless* gasifier, if we add water.

[3] 1 Mole equals 1000 mole

The reactions will be as follow, if we again count with 1 Mole carbon. A portion of the carbon, say x portion, combusts to carbon dioxide. Then $x \cdot 97\,600$ kcal is released.

The remaining carbon, $(1-x)$ parts of 1 Mole, combusts to carbon monoxide. Thereby $(1-x) \cdot 29\,400$ kcal is released. Some of the heat released from the carbon combustion can then dissociate water. We assume that of 1 Mole carbon, y Mole water (1 Mole = 18 kg water) dissociates. Then $y \cdot 68\,400$ kcal is bound.

The added water has transformed into steam. For this heat has been required.

The gas emanating from the gasifier has a high temperature. We use this gas heat for vaporising water. All the heat leaving the gasifier as gas heat, we return to the gasifier as steam heat. Call temperature heat Q_{gas}, and steam heat Q_{steam}, where thus $Q_{steam} = Q_{gas}$.

We get the balance

$x \cdot 97\,600 + (1-x) \cdot 29\,400 - y \cdot 68\,400 - Q_{gas} + Q_{steam} = 0$

or $x \cdot 97\,600 + (1-x) \cdot 29\,400 - y \cdot 68\,400 = 0$

For this we have sacrificed 97 600 kcal, while in the gas we get, as chemically bound energy

$$(1-x) \cdot 68\,200 + y \cdot 68\,400$$

The efficiency is then

$$\eta = \frac{(1-x) \cdot 68\,200 + y \cdot 68\,400}{97\,600}$$

Let us now assume that no carbon dioxide is formed, i.e. $x = 0$.

The balance equation then becomes $29\,400 = y \cdot 68\,400$ or $y = \frac{29\,400}{68\,400} = 0.43$.

This implies that for each kg carbon,

$$0.43 \cdot \frac{18}{12} = 0.64 \text{ kg steam is added.}$$

The efficiency is then

$$\eta = \frac{(1-0) \cdot 68\,200 + 0.43 \cdot 68\,400}{97\,600} = 1.00$$

i.e. 100 % efficiency.

We take the other borderline case, and assume that all the carbon combusts to carbon dioxide, i.e. $x = 1$.

The equilibrium equation is then $97\,600 = y \cdot 68\,400$ or $y = \frac{97\,600}{68\,400} = 1.427$.

This implies that for each kg carbon

Saturation temperature °C	45	50	55	60
Kg steam per kg coal	0.20	0.21	0.32	0.45
Thereof dissociated kg	0.20	0.21	0.32	0.34
Or in %	100	100	100	76
Analysis:				
CO_2	2.35	2.5	4.4	5.1
CO	31.6	30.6	28.1	27.3
H_2	11.6	12.35	15.45	15.5
CH_4	3.05	3.0	3.0	3.05
N_2	51.4	51.55	49.05	49.05
Lower heat value kcal/m^3	1 517	1 502	1 506	1 487
m^3 gas per kg kol	3.79	3.75	3.76	3.82
Total heat in the gas kcal	5 749	5 633	5 653	5 680
Efficiency with respect to 1st column	1	0.98	0.98	0.99
Heat value per m^3 gas-air-mix kcal	657	653	648	646
Motor power with respect to 1st column	1.00	0.99	0.99	0.98

Table 1: Glow layer 106 cm. Fuel consumption 1 120 kg/h. Fuel:coal. *(Unclear to me wether coal or charcoal was used for fuel. The original source is not available. — Transl. note.)*

$$1.427 \cdot \frac{18}{12} = 2.15 \text{ kg water is added.}$$

Efficiency becomes

$$\eta = \frac{(1-1) \cdot 68\,200 + 1.427 \cdot 68\,400}{97\,600} = 1.00$$

or 100%.

We see from this that water addition is a powerful mean to increase efficiency for an *ideal lossless* gasifier.

There are however no lossless gasifiers. Every gasifier has heat losses of various kinds.

Nor can we decide that carbon will be combusted to carbon monoxide or carbon dioxide, and that the added water will dissociate.

The proportions of carbon monoxide, carbon dioxide, dissociated water, and non-dissociated water will stabilise according to the laws of chemical equilibrium.

But the direction of the water's effect in the real gasifier will be the same as for the lossless, ideal gasifier.

While a real gasifier with dry charcoal perhaps has an efficiency of 60 %, the gasifier with water addition, carried out properly, give a efficiency of 80 to 85 %.

We shall now look at how the matter stands if we use wood instead of charcoal.

If 1 kg dry wood is heated to 400°C, we get

Charcoal:	0.38 kg with 81 % carbon
Water:	0.24 "
Tar:	0.16 "
CO_2:	0.09 "
CO:	0.04 "
H_2:	0.04 "
Acetum:	0.05 "
Methanol:	0.01 "

This corresponds to 0.64 kg water per kg charcoal, or 0.80 kg water per kg pure carbon.

If the wood had not been dry, but originally contained 20 % moisture, the amount of water had become 1.3 kg for each kg charcoal, or 1.6 kg water for each kg pure carbon.

We find thus numbers for water content, which lies within the two previously mentioned limits.

But apart from carbon, there are in addition combustible substances in the form of tar, carbon monoxide, and hydrogen, plus that the pyrolysis of wood implies heat generation.

Wood of 20 % moisture should thus be of no risk to use in a gasifier.

From these theoretical observations it would be of interest to return to reality and compare theory with laboratory results. This is possible thanks to a couple of skillfully performed older test series recited here in table 1 and 2, apart from the two last rows in each table, which have been calculated by me from the test results.

Saturation temperature °C	60	65	70	75	80
Kg steam per kg coal	0.45	0.55	0.80	1.10	1.55
Thereof dissociated kg	0.395	0.45	0.49	0.57	0.62
Or in %	87.4	80.0	61.4	52.0	40.0
Analysis:					
CO_2	5.25	6.95	9.15	11.65	13.25
CO	27.3	25.4	21.7	18.35	16.05
H_2	16.6	18.2	19.65	21.8	22.65
CH_4	3.35	3.4	3.4	3.35	3.5
N_2	47.5	45.9	46.1	44.85	44.55
Lower heat value kcal/m^3	1 543	1 533	1 455	1 405	1 371
m^3 gas per kg coal	3.81	3.704	3.898	4.012	4.065
Total heat in the gas kcal	5 879	5 678	5 672	5 637	5 573
Efficiency with respect to 1st column	1.00	0.97	0.96	0.96	0.95
Heat value per m^3 gas-air-mix kcal	653	648	631	618	609
Motor power with respect to 1st column	1.00	0.99	0.97	0.94	0.93

Table 2: Glow layer 213 cm. Fuel consumption 574 kg/h. Fuel: coal. *(Unclear to me wether coal or charcoal was used for fuel. The original source is not available. — Transl. note.)*

Now, as mentioned earlier, many are of the opinion, that is gas heat value per m^3 decreases, it implies a degradation. This is however not necessarily true. With decreasing heat value follows generally a decreased demand for combustion air. Only if heat value per m^3 for reaction equivalent fuel-air mixture decreases with increased water levels, versus decreased heat value for the gas a degradation is present, showing itself in a decreased engine power. Likewise a degradation is introduced if with increased water levels a decreased gasifier efficiency follows.

If we first consider table 1, we find that the added water has been well dissociated. Furthermore we see that for an increase of 0.20 to 0.45 kg water per kg coal, the gasifier efficiency as well as motor power has stayed the same within test error limits.

Looking at table 2, we find that water dissociation has been low. The reason is not apparent from the test protocols. At an increase from 0.45 to 1.55 kg water per kg coal, gasifier efficiency however only decreased 5 % and motor power by 7 %. Had the water dissociated better, which ought to have been doable, possibly through increased load on the gasifier, surely neither efficiency nor motor power had decreased with increased water addition.

If we look at the analysis, the obvious relationship is apparent, that with increased water, more coal must be combusted to carbon dioxide and less to carbon monoxide to produce heat for water dissociation, while at the same time hydrogen levels increase. With increased water dissociation decreases also nitrogen levels while the coal in greater extent combusts with water oxygen instead of air oxygen. This tests thus confirms theory.

Also Lutz' and Steenhoff's experiments are explained by and confirms theory. Lutz' is however somewhat over-optimistic when he assumes 40 to 50 % wood moisture. Using wood like that is not necessarily worse than average moist wood. But the amount of water ought to supercede the theoretically dissociable, why superheated steam leaves the gasifier, and efficiency decreases. On the other hand, the gas heat value is not decreased thereby, since most of the steam condenses in the cooler.