

German ideas on improvements of wood gasifiers

Summary in *Teknisk Tidskrift* of a thesis by H LUTZ
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English translation, 2000, JOACIM PERSSON

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The German authorities' interest in producer gas has become significant during the war, and among other things, a research institute 'Gasschlepper-Entwicklung' has been established, led by dr-ing H LUTZ. Herein is given a short summary on some of the views and findings published by him in *ATZ*. They solely concern wood gas, but the article may also be of interest for charcoal gas.

The best gasifiers of present standard types gives, with pine wood of 15 % moist content, a gas with a heat value of 1275 kcal/m³, which renders a heat value for the air-gas mixture of about 610 kcal/m³. This is significantly less than the corresponding value for common fluid fuels and explains the lesser mean pressure for producer gas power. It is of course of interest to increase the heat value of the gas and thereby also the mean pressure in the motor.

1 Theoretical views on improving gas heat value.

Modern wood gasifiers work satisfactory on wood from practically all kinds available, once cut up in a proper manner and sufficiently dry. The latter is very important. At present, the best gasifiers have an upper limit on acceptable moist content at about 30%, but already at 20% a steep and increasing degradation of the gas' heat value and thus the motor power can be noted. An increase of the upper limit on fuel moist is from the practical viewpoint desired, be-

cause one can't always count on well dried fuel being available and no practical fast methods to determine the moist content exist.

Moist impact on gasification.

The water in the fuel has great influence on the process of gasification. It must be vaporised by heat from the combustion zone. The heat need U_1 per kg fuel for this vaporisation can approximately be expressed by the formula:

$$U_1 = 6,25 \cdot m \text{ kcal}, \quad (1)$$

where m is fuel moisture in %.

The steam formed in the fuel tank passes the gasification zone, and it is a common misconception that the steam there is dissociated into hydrogen and oxygen. Some people even believe that extremely moist wood in this way would give gas with particularly high heat value, i.e. high motor power. The dissociation of steam however takes a certain reaction time to reach significant levels. Fig 1 — from Clement and Adams — gives a hint on this. As shown steam, in the presence of charcoal, needs to stay in the high temperature zone of 1100° for 0.5 sec. to reach a level of merely 20 % dissociation. The contact time in a vehicle gasifier is however far less; 1 m³ gas passes for example the combustion chamber in the Imbert gasifier on 0.2 sec.¹

¹ Really? 0,2 sec for a particle to travel through the gasifier, rather than a whole m³ sounds more reasonable. — JP 2000

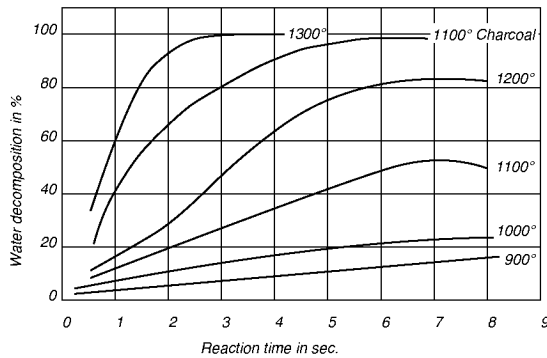


Figure 1: Dissociation of steam

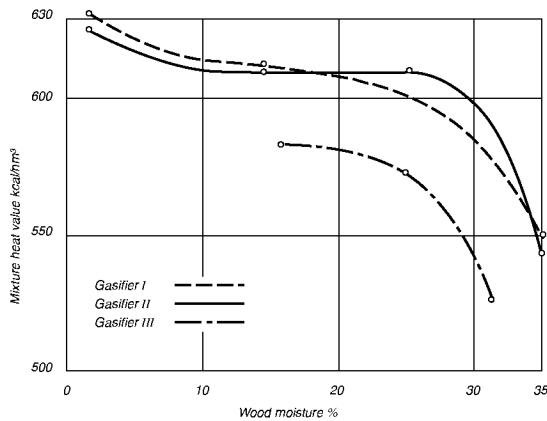


Figure 2: Mixture heat value as a function of fuel moisture for three different gasifiers.

The number goes for the *entire* gasification space; in the tight high temp. zone with its extreme gas velocity the reaction time is thus significantly less. The conditions for dissociating water molecules is therefore very unfavourable.

To investigate this the research institute has examined the most well-known German wood gasifiers' function at various fuel moistures. Fig. 2 displays the results from testing of three such models. The tendency of all the three curves are that fuel-air mixture heat value decreases with increasing fuel moisture. — The curve points show the mean values for 10 hour tests on full load with pine fuel; subtests gave similar

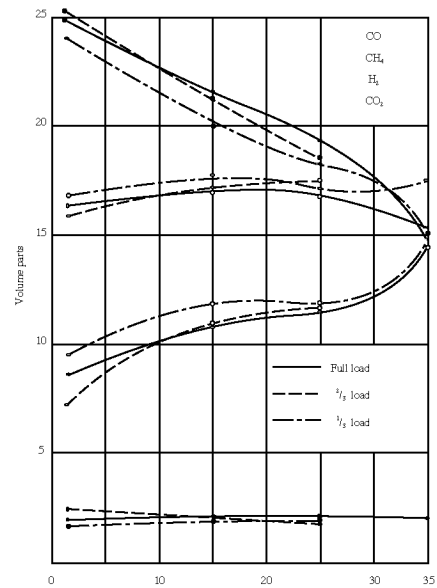


Figure 3: Gas composition at different fuel moisture levels.

results.

To gain a high specific motor power one should then use as dry fuel as possible. A test with a 4-cyl Ford BB motor at 1800 rpms, fed with an Imbert gasifier, gave the following confirming results:

Wood moisture %	Motor power hp
2	26.5
10	24.6
15	23.4
20	22.2
25	21.0
30	19.7

Up to a moisture of 25 % the power loss is a linear function of the fuel moisture, beyond that the drop is steeper. (For the interval 0—30 % moist the test results can be described with the equation formula $N : N_0 = 1 - 0.009m$, where N_0 is the 'water free' power and m is the moisture in % — *Ed. note*)

Gas composition at various moistures is of particular interest, and is shown in fig. 3. While the CO-level

displays steeply falling levels at increasing moisture, and the CO₂-levels displays a corresponding increasing tendency, the H₂-levels are almost and CH₄-levels completely constant. For almost fully dry wood (2 % water) the hydrogen level is only about 1 % lower than the highest measured level. 1 % hydrogen is generated from dissociating 21 g water, i.e. 2.1 % of the fuel weight or $\frac{1}{7}$ of the present ‘moist water’ at 15 % fuel moisture (at a load of 2.62 nm³/kg). Dissociation of water in the fuel is thus insignificant, which confirms the reasoning above.²

So where does all the hydrogen from water free fuel come from? Some of the hydrogen may stem directly from the distillation and some from tar cracking in the combustion zone. Furthermore, large amounts of water is generated from gasification in the form of super-heated steam — according to our own tests, up to 30 % of the dry fuel weight. Even dry fuel thus supplies enough water to, as much as the reaction time allows, explain the formation of the measured levels of water dissociation gases. 22 % ‘gasification water’ is enough for forming about 10.4 % hydrogen, through dissociation.

From this it is obvious that fuel moisture is only an unnecessary ballast which by its heat need has a negative effect on gasification. Wood water must not only be vaporised with heat consumption according to (1), but must also be super-heated to a temperature of up to 1 200—1 300° when passing through the hearth. For the latter process, heat U_2 per kg fuel is required:

$$U_2=0.0048 \cdot m(t-100) \quad (2)$$

where m is wood moisture in % and t the temperature in °C to which super-heating is taken. Through addition of the equations (1) and (2) we get the heat need for fuel moisture as:

$$U_m = m(5.77 + 0.0048t) \text{ kcal/kg fuel} \quad (3)$$

²E HUBENDICK disagreed on this, see his reply in the article about gasifier efficiency. — JP 2000

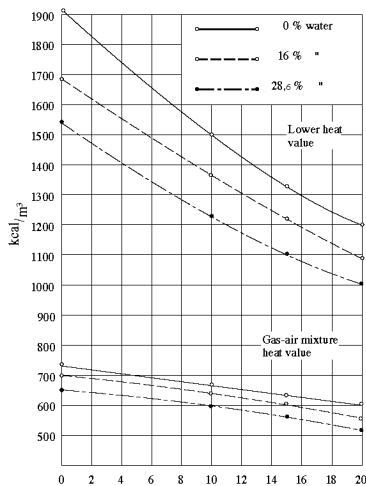


Figure 4: Calculated heat value as function of losses.

Increasing heat value and acceptance of fuel moisture, by decreasing heat losses.

In a wood gasifier we need, apart from the mentioned heat U_m , heat for distillation, super-heating of combustion products, cracking of tar and water, an reduction of CO₂. This heat is produced by oxidation of charcoal and tar char with air oxygen. The latter unfortunately implies a certain quantity of nitrogen, which ‘dilutes’ the producer gas. Obviously, by decreasing heat losses, the air needed for producing this heat and thus the amount of nitrogen per m³ gas also decreases. Better heat economy also increases reaction temperatures and thereby improves CO- and H₂-production, with a consequential decrease of CO₂-levels.

SCHLÄPFER and TOBLER have calculated the heat value for gas as a function of losses by conduction and radiation (fig. 4), vs. heat loss through gas temperature (fig. 5). The authors also calculated the heat values for wood gas, produced without heat losses, see fig. 6. Their calculations emphasizes the importance of heat economy; the difference between “loss free” heat values and measured values is so apparent, that it should be possible to improve the latter by improved design.

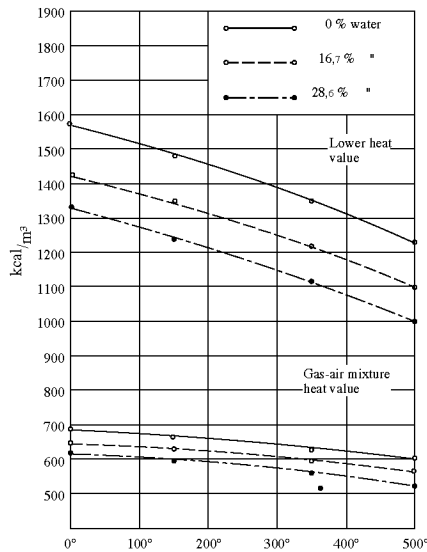


Figure 5: Calculated heat value as a function of gas temperature.

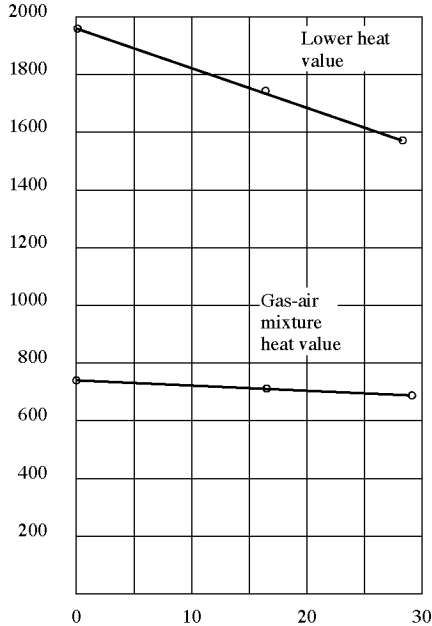


Figure 6: Calculated gas-air mixture heat value as a function of losses.

Gasifier efficiency and gasification heat.

By gasifier efficiency we mean the ratio between heat value of the produced gas, and heat value of the gasified fuel; a good gasifier should reach, say, 80%. The lost 20% is on account of conduction, radiation, and gas temperature. The high efficiency perhaps tempts us to conclude that the gain from decreased heat losses does not stand in proportion to the necessary technical measures. This is admissible regarding fuel economy but certainly not regarding the improvement of gas heat value and improved tolerance for very moist fuel.

The significance of increasing gas heat value by decreasing heat losses, is accentuated by that only $\frac{1}{3}$ of the *total fuel heat value* is transformed to free heat in the gasification process. From gasification of water-free wood of 4 500 kcal/kg, only 1 500 kcal/kg is thus active in the gasification zone, and for wood of 30 % moist, no more than 1 050 kcal/kg.

According to equation (3), for super-heating to 1 200°C of the moist water (30 %) in wood, about 350 kcal/kg fuel is necessary. That is *one third* of the active heat in the gasification zone, which must also suffice to the other gasification subprocesses and on top of that, losses by conduction and radiation.

2 Practical steps for realising the theoretical findings.

It is remarkable that manufacturers have hardly made any attempts to put the theoretical knowledge into practise. The research institute have therefore lined out an extensive test programme, which directions and results is referred below.

Decreasing losses due to conduction and radiation.

Conduction losses via metal parts (gas pipes and mounting details) are insignificant and it should be possible to eliminate any practical importance of it by proper insulation.

Radiation losses goes through the gasifier walls, either from the gasification and fuel spaces straight

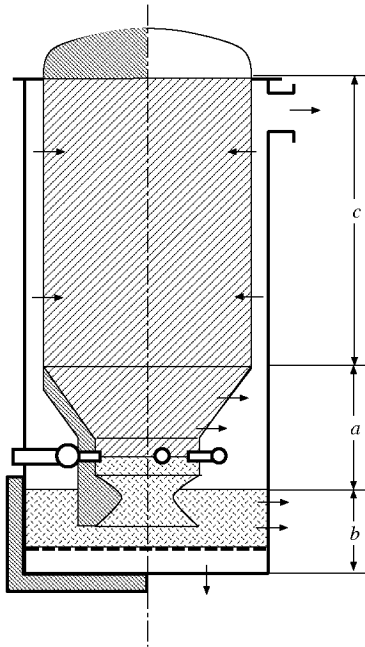


Figure 7: Insulation of double-mantled gasifier.

over to the mantle, if a temperature fall exists in this direction. On fig. 7, right side, the arrows shows heat flow schematically in an Imbert, from the hearth with 1200° to the surrounding gas mantle with 600° temperature in section *a*, and losses through gasifier walls in section *b*. To decrease losses one should insulate the gasifier according to the left half of fig. 7. Regarding the hearth this is easiest done with a ceramic fitting and for the outer walls with a sleeve of rock wool, kieselguhr or similar contained in a protective cover. The lid should also be insulated in this manner. Insulation must not be too thin, but be calculated such that it becomes fully effective, or the result will be unsatisfying.

Some gasifiers are designed as in fig. 8, right side, with proper hearth insulation in ceramic materials. Losses go through the outer walls, which thus should be insulated as in the left part of fig. 8. As recapturing of gas heat appears to demand a heat exchanger (more about that below), it is, due to the better heat transfer in that device, appropriate to keep the gas temperature as high as possible up to

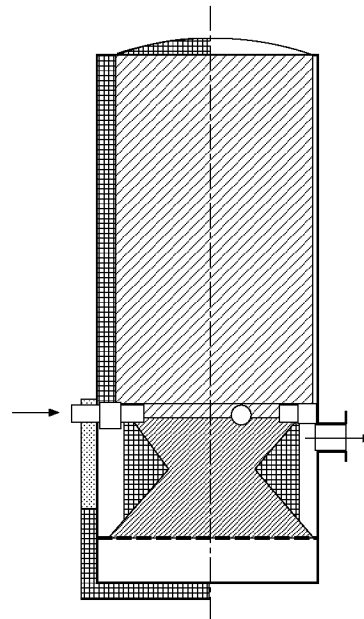


Figure 8: Insulation of gasifier with no outer mantle.

the exchanger and thus insulate the lower part all the way up to the fuel container; this will also decrease heat flow from the hearth to the surrounding mantle.³

A fuel container without double mantle and without condenser should absolutely be insulated, or else a significant heat loss will occur because of the air circulation around it, degrading drying and charification processes in the fuel container. Heat losses through the walls will naturally be greater in cold weather, high vehicle speed, and in rain (due to vaporisation of rain drops falling on the gasifier parts). Bad function of the gasifier may in many cases be caused by some of these conditions.

Decreasing losses via gas heat content.

The generated gas' heat content can be recaptured either by putting it back to the fuel container, i.e. the fuel, or to the air sucked in to the hearth. The former

³Meaning is somewhat obscure. The Swedish text says 'ringrummet', i.e. 'ring space'. I assume they mean the space surrounding the hearth. — JP 2000

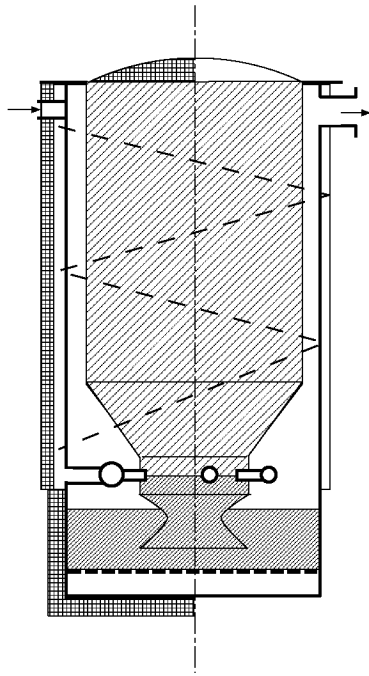


Figure 9: Insulation of triple-mantled gasifier.

can be done by for example using a double mantle as in the Imbert gasifier; the high heat value of the gas for this design is partly due to the heat economy through insulation of the fuel container and heat recapturing, partly also due to pre-heating of primary air at the air pipes mounted inside the mantle. As at least half the heat is lost to the surrounding air through the tin wall for a double mantle design, a triple mantling design has been used, fig 9, in whose outer area air is led against the stream of the gas. For such a modification to be successful, the outer wall should be insulated as shown in the left part of the figure, and air — for example via a tin metal spiral inside — be led such that it effectively flows around the entire gas mantle.

One may also recapture gas heat by transferring heat to primary air in a special heat exchanger. Experience shows that a heat transfer surface of 0.015—0.02 m²/nm³ of full load is sufficient⁴. The heat ex-

⁴Is that m²/[nm³/h]? Anyway, heat conductivity in a heat

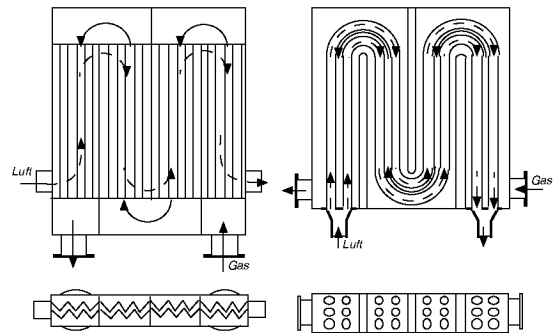


Figure 10: Heat exchanger with wafers (left) and pipes (right).

changer can be built with wafers or pipes, (fig. 10) or in the form of a 100 mm thick box, in which air is brought against the stream of the gas. Fig. 11 displays such a heat exchanger, attached to a rectangular fuel container and combined with a cyclone, placed between the gasifier and the heat exchanger. The cyclone is necessary to prevent the heat exchanger from acting as a gas cleaner and thereby be clogged up or contaminated with dust, degrading its operation. Cyclone as well as heat exchanger should be insulated.

Devices for air pre-heating are by the way incorporated in many gasifier designs, but usually have the flaw of taking heat from combustion instead of from the gas flowing out; some also have too small surfaces for gaining sufficient heat transfer.

The research institute has examined the function of a heat exchanger of above box type, combined with a gasifier of 60 nm³/h maximum capacity with a Ford BB 3.24 litre motor with $n_{max} = 1800$. The tests were carried out with fully open throttle at various rpm's, and the results are shown in fig. 12.

At full load, the gas inlet temperature in the heat exchanger was 540°, and air was heated to 340°, whereby the gas was cooled to 294°, i.e. about as much as in an Imbert double-mantle gasifier. The removed heat from this temperature fall (about 50% of the heat content) was brought back to the gasifier

exchanger also depends upon gas velocities, apart from surface size. JP — 2000

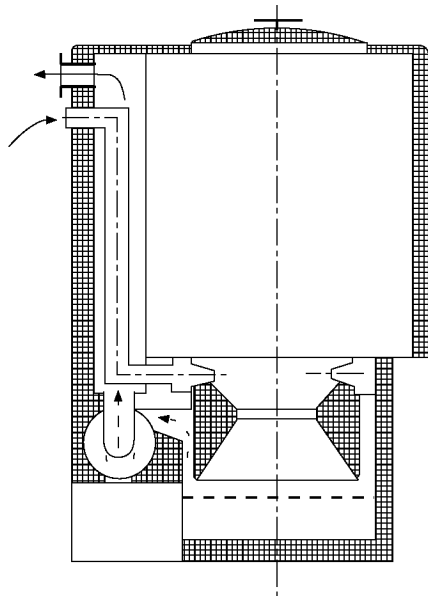


Figure 11: Heat exchanger combined with cyclone and single mantled gasifier.

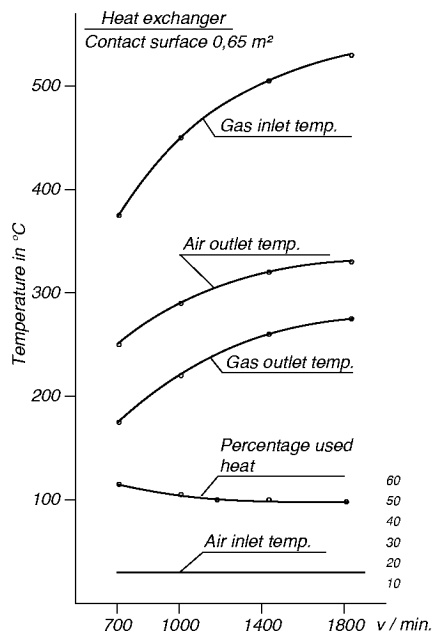


Figure 12: Results from heat exchanger tests.

with the combustion air, apart from the small losses through insulation. For an Imbert double mantle on the other hand, at least half this heat is lost to open air, although certainly at least the fuel container is well insulated outwards by the double mantle, so here we have a gain of heat. The experiments have shown that a gasifier without double mantle but with heat exchanger, recapturing 50 % gas heat, gives gas with about the same heat value as for an Imbert under the same operation circumstances.

It is important that the heat exchanger even at low gas production (half load or less) give good air pre-heating. As fig. 12 shows, the air outlet temperature at 700 rpm's was as high as 254°C. Of course, gas heat recapturing is in particular noticed in transition from full load to idling. Then the heat generation in the hearth drops because of the decrease in air intake flow, but the heat stored in the gasifier is transported away with the gas and the temperature begins soon to fall — degrading the gasification process. If there is a heat exchanger in the system, some of the heat still remaining from the previous full load condition is captured and brought back into the combustion zone with the primary air. The temperature in the hearth thereby do not fall as quickly, and the gasifier can better cope with periods of idling within reasonable limits, particularly with moist fuel.

Tests were carried out with a Hansa-gasifier (in principle same as in fig. 8, right side) at full load (50 nm³/h) with and without heat exchanger, at various fuel moist levels, where the gas was sucked out with a pump; pine wood of low quality was used as fuel. Fig. 13 shows the results with (solid line) an without (dashed line) heat exchanger. At 15 % moist a heat value improvement of 80.5 kcal, from 1 187.5 to 1 268 kcal/m³ was detected with the heat exchanger in use. At greater moist levels the effect is less, apparently because the heat consumption due to the water has a greater impact than heat recapturing through the exchanger. Note however, that a significant displacement of the limit for acceptable moist level occurs, since with heat exchanger and for example 30 % moist, the same mean heat value is achieved as for 22 % without heat exchanger, and at 35 % with heat exchanger the same mean heat value as for 28 % without heat exchanger. The heat ex-

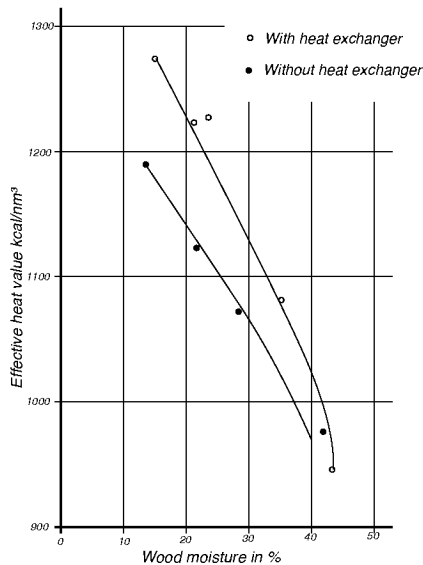


Figure 13: Comparison of Hansa-gasifier with and without heat exchanger.

changer thus makes the gasifier less sensitive for fuel moisture.

The suggested improvement in fig. 9, left side, for Imbert has also been tested in practice. For the test, a 3.24 litre Ford BB motor was used, running at 1800 rpms, and both heat value as well as power measurements were carried out. The results are displayed in figures 14—16.

The first of these show us that the increase in heat value reaches 80—90 kcal/m³, and that the limit for moisture acceptance was moved a fair bit up. *The 1 000 kcal heat value limit is for the standard gasifier 36 % while for the improved design is at 44 % moisture.*

The power increase shown in fig. 15 is welcome; at 15—35 % moisture it reaches about 2 hp, i.e. 8.5—11 % of the corresponding power. The gas diagram, fig. 16, show about the same methane levels (not above 2 %) for both types across the whole moisture interval. The higher heat value of the improved design is mostly due to an increase in CO and H₂ levels; regarding the latter, the reason is probably higher reaction temperature. The low CO₂ levels at

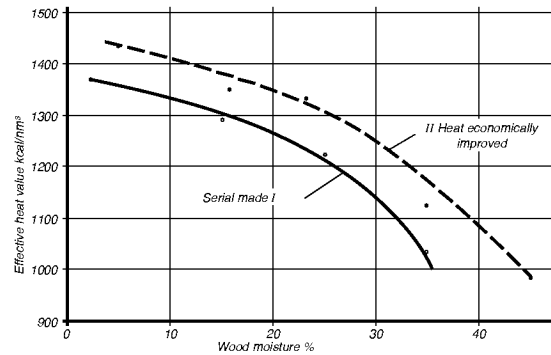


Figure 14: Comparing heat value vs. fuel moisture for Imbert with and without improvements.

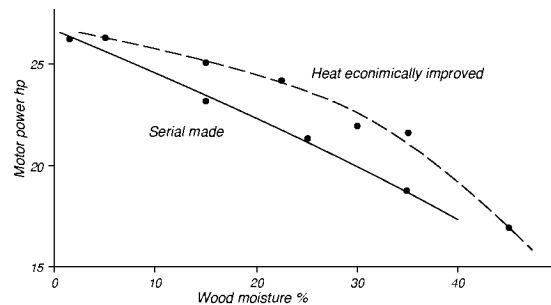


Figure 15: As for fig. 14, motor power and fuel moisture.

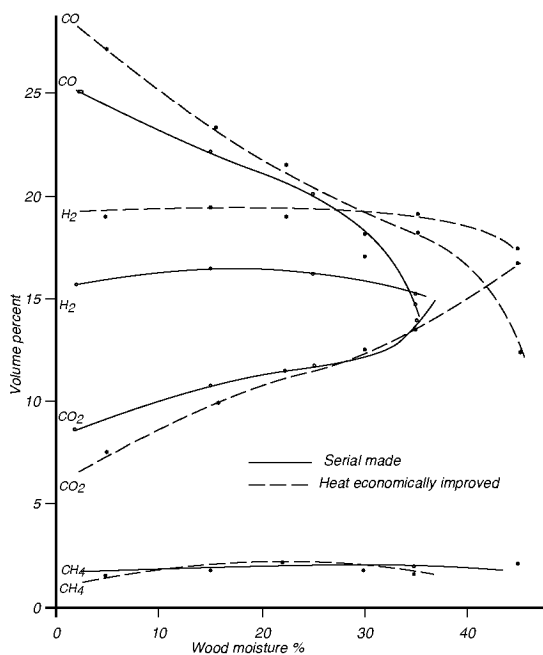


Figure 16: Gas composition for Imbert with and without improvements.

20 % moisture are also remarkable.

In these experiments it was determined that it is possible to significantly improve even a well reputed gasifier by improving heat economy (by recapturing gas heat) and using insulation. The method cannot, however, be applied directly to an existing gasifier, without first ensuring that no over-temperatures occur at sensitive places. The improvement ought to be particularly significant for operation in cold weather — to be specially noted by Swedish technicians.

It should be pointed out in this context, that the laboratory results always are a little better than under practical conditions, which usually involves larger heat losses. A laboratory result of 1119 kcal/nm^3 at 25 % moisture and 20° temperature in the room, corresponded for example to 1074 kcal/nm^3 , with the gasifier standing outdoors in $+8^\circ\text{C}$.

Improving gas heat value by removing steam from the fuel container.

When realising that the fuel container is burdened with an excess of water, fully or partially separating the water vaporised in the fuel container before it reaches the combustion zone has been attempted. The simplest method consists of the familiar condenser mantle, where steam is condensed by cooling the outer walls with the air flow around the gasifier. The effect is however poor; in the winter, in rain, and with extremely wet wood the separated amount of water can reach 10—12 % of the fuel weight, in the summer and with dry wood it can decrease to almost none.

Another tried method is to fit a pipe from the upper part of the fuel container to the car's exhaust pipe, using an ejector nozzle. When the motor runs, a significant amount of gas, consisting mostly of water, vapor is sucked out from the fuel container, but unfortunately also combustionable or crackable substances (e.g. tar) goes out with it, why the fuel consumption increases and the hydrogen content in the gas decreases. The motor's inlet and exhaust can under certain circumstances also interfere with each other.

Instead, dr-ing. Lutz has suggested and tested the device shown in fig. 17, with forced circulation of the

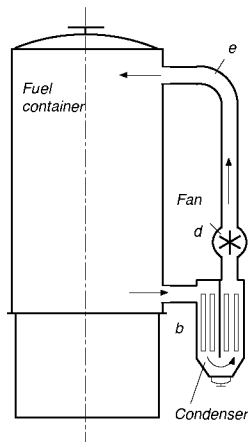


Figure 17: Primary condenser

distillation gases through a condenser. The low pressure fan *d* is motor powered and could during the test supply a circulation of maximum 100 m³/h through the system *b-d-e* from and to the container. The gasifier was the previously used Hansa, with a gas flow of 50 nm³/h at full load.

To mimic practical conditions, cooling wasn't taken below 50–60°C from 65–75°C of the gas sucked out from the container⁵; the gas was thus only cooled about 15°. In fig. 18, results from a test using 35 % moist pine wood is shown. Gas circulation per hour is chosen as abscissa. Ordinates is for the upper diagram effective heat value of gas; for the middle diagram, separated water in % of wood content, and for the lower diagram the separated amounts of water and tar, in kg/h and in percentage of fuel weight. (The fact that water was separated, although the fan was standing still, was due to self-powered flow of steam to the condenser, and condensation in the gasifier's condense mantle.)

The gain with this method consists only of saving the heat that would have been necessary for super-heating the separated water in the form of steam.

The gain shows in an increase in gas heat value. At a circulation flow of about 60 m³/h this increase ceases and at increased circulation turns into a loss. This because circulation involves a loss of heat in the

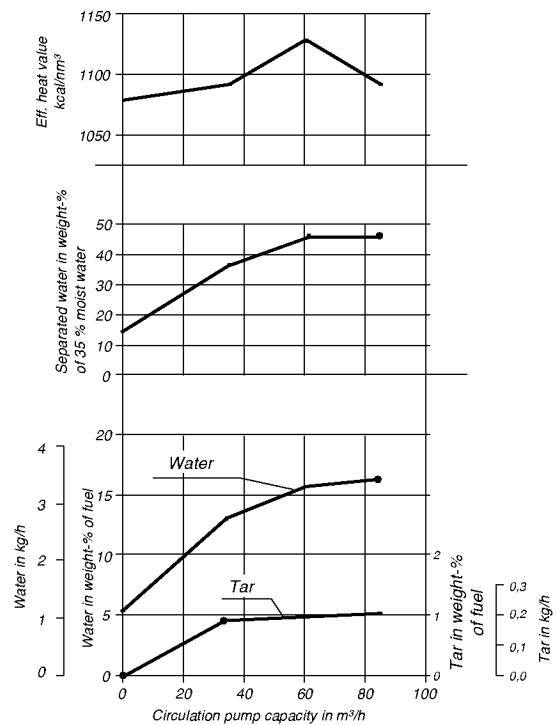


Figure 18: Test of primary condenser attached to a Hansa gasifier.

⁵...and the dewpoint was? — JP

container; this loss increases with temperature, while the gain due to water separation hardly increases for circulation above 60 m³/h. There about we have an optimum for heat value; in the test it reached 1 130 kcal/nm³. This is a very high number for the present moist level, and even supersedes the corresponding value for a standard Imbert with 90 kcal (see fig. 14).

However, this method would not be of great practical importance, because it does not decrease the need for heat for vaporisation per se, which always is quantitatively greater than super-heating heat. There are better ways to improve the gas though, for example:

Supplying heat to the gasification process from an external heat source.

When running a motor on producer gas, one heat source that is always available is exhaust heat, which otherwise would be blown to the skies to no avail at all. Its heat content compared to the gasification heat is tremendous.

Pine wood with a moist content of 27 % has a heat value of about 3 120 kcal/kg (dry wood 4 500). At 80 % efficiency in the gasifier the gas then contains circa 2 500 kcal/kg. If we assume that 20 % of this is lost from the motor in the form of exhaust heat⁶, and that 60 % of this may, with proper measures, be added to the gasification process, the added heat would reach 300 kcal/kg wood of 27 % moisture. This addition is practically the same as the heat need, according to equation (3), for vaporising and super-heating moist water to about 1 200°. By recapturing exhaust heat in this manner, wood of 27 % moisture would, to the gasifier, appear as completely dry wood without external heat source. The increase in heat would be tremendous, and the limit for fuel moist content could be moved a fair bit up.

To put this idea in practice one could supply the device in fig. 17 with an exhaust fed heat exchanger. If this device can extract 50 % exhaust heat, the heat addition would be about 4.5 times as large as the heat

⁶The real number is much higher. However, perhaps Lutz wrote off some heat that inevitably will be lost closer to the exhaust manifold? — JP 2000

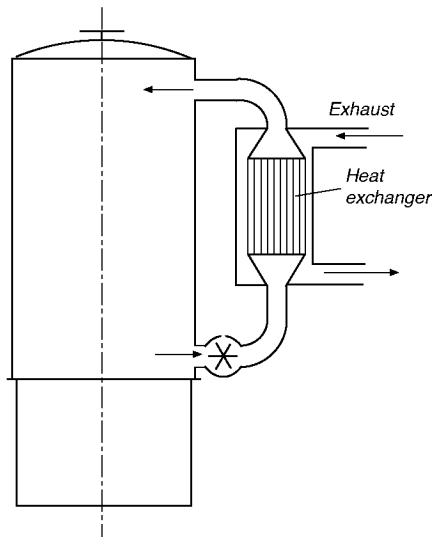


Figure 19: Pre-heating fuel using exhaust heat, via a heat exchanger.

saving from water separation in the condenser. It is tempting then, to skip the latter and build the device as in fig. 19⁷, where the mix of distillation gas and steam is made to circulate only to serve as carrier of exhaust heat. (Thereby one would step off from the goal to *maximise* gas heat value, which indeed was the original incentive to the suggested improvements. On the other hand there is at least a theoretical way to achieve this even without a condenser, namely by prolonging the steam's time in the high temperature zone long enough for a significant steam dissociation to occur. If this is doable in practise, is a different question. — *Ed. note.*)

For the practical tests, the research institute kept

⁷I wonder how gasifier dynamics would be effected by this, when using very moist fuel? Large amounts of steam will be formed, particularly when the gasifier is newly filled. Although there is quite a lot of *heat* available in the exhaust gases, the *temperature* isn't high enough to power the water-gas reaction *without* oxidation heat, i.e. we would still need a net inflow of air to keep the hearth temperature up. But with a large amount of steam flowing from the fuel container, the portion of air may become too small, practically none at idling loads. I would suggest keeping the condenser along with the heater, on a vehicle gasifier or any other gasifier operating under a varying load. — JP 2000

the condenser. For measuring technical reasons, the circulation gases was not heated by exhaust heat, but rather in a heater with a gas flame. At the first test, only as much heat as corresponds about 15 % of the available exhaust heat was supplied. The result was however an increase in heat value for as much as 1 314 to 1 351 kcal/m³. (Pine wood of 15 % moisture.) Then the heat supply was increased to 50 % of the available exhaust heat. The lower limit of the heat value increased, but only from 1 351 to 1 386 kcal/m³, a seemingly small increase compared to the added heat. The reasons are as follows.

When the returning circulation gas is supplied a significant amount of heat, the temperature in the container rises steeply, and an intensive drying and pre-distillation takes place in the upper part of the fuel container as well. Wall temperature increases, and with that, losses to the surrounding air also increases significantly. The same goes for the lower parts of the gasifier, because the gas heat emanating from the hearth is also larger than before, when some of the combustion heat was used up in the fuel container. Heat losses through radiation from this Hansa-gasifier's lower part reaches roughly $0.04 \cdot t^2$ kcal/h, where t is the wall temperature. (Above 400° wall temperature the losses increases faster than the above expression shows.) If one has for example a fuel consumption of 20 kg/h with 15 % moisture, one gets 12 000 kcal/h exhaust heat. With 50 % extraction 6 000 kcal/h is supplied to the gasifier fuel container. This amount of heat corresponds to radiation losses from the lower parts at a wall temperature of 385°C. Proper insulation of the gasifier is thus even more called for, when external heat is provided to it.

Before the next test, the whole gasifier was insulated (container and bottom part) with a 25 mm thick layer of glass wool. This resulted directly in an increase of the lower heat value from 1 386 to 1 420 kcal/m³, further increase ought to be possible by improved insulation.

Summary of test results.

The results can be compiled into the following table:

Design	Gas heat value kcal/m ³	Improvement %
Without heat exchanger	1 187,5	0
With heat exchanger	1 268	6,8
With heat exchanger and water separation.	1 314	10,65
With heat exchanger and water separation + 15 % exhaust heat	1 351	13,8
With heat exchanger and water separation + 50 % exhaust heat	1 386	16,7
With heat exchanger and water separation + 50 % exhaust heat + insulation	1 420	19,6

This table goes for pine wood with 15 % moist content. As a comparison, with the same type of fuel the regular Imbert gasifier gives gas with the heat value 1 275 kcal/m³. The tests has thus shown that there are great possibilities to improve the present gasifiers; single maximum values on up to 1 650 kcal/m³ gives hope for further gains. *Using fuel with 40—50 % moisture is already within reach.* — Tests beyond this is already under way at the research institute. — One can also, from the tests already carried out, draw the conclusion that heat economy in the gasifier has a more significant impact on the function, than various design details like hearth form and air supply has.

Fig. 20 shows a skeleton sketch of a tractor gasifier including all the improvement named herein. Next to one side of the fuel container is a heat exchanger for pre-heating air, and on the opposite side the exhaust fed heat exchanger for heating circulation gas and its circulation fan. The whole gasifier is most carefully insulated. Such a gasifier will, as far as we can tell

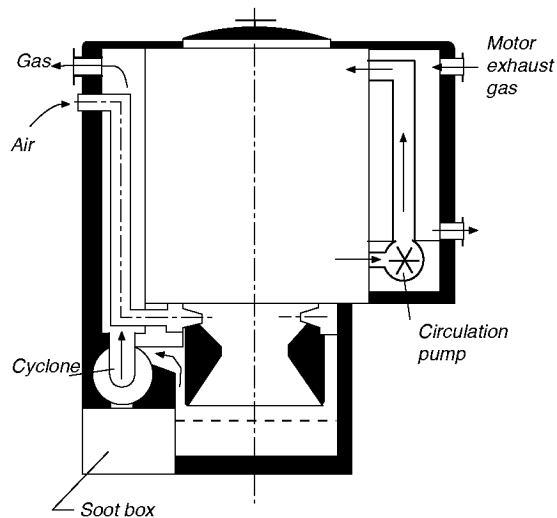


Figure 20: Recapturing both gas heat and exhaust heat.

from the referred investigations, render a gas with a significantly better heat value than the present gasifiers, and make gasification of fuel with a moisture of 40—50 % possible.

So far dr-ing. Lutz, whose thoughts and investigations are of great value for the development of gasification technology. Our gasifier industry has during this 'pioneer period' mostly been occupied with producing enough of safe gasifiers at all, whereby the issue of efficiency has been put aside. Now, however, the industry could be said to have reached a 'stable condition,' and it is now its next task to improve the brands as much as possible. That there in this respect is plenty to be done, no-one would disagree upon, and the thoughts from Lutz may therefore be of value.

For the designer, the improvement of design as usual involves turning the problem of finding best possible balance of profit — increased efficiency — and cost — increased manufacturing costs and gasifier weight. The thing is complicated by, that various aspects must be considered for gasifiers for different purposes. The task is difficult — but enticing.

G. V. Nordenswan.

Gasifier efficiency

By professor E. HUBENDICK

English translation JOACIM PERSSON, 2000

Published in *Teknisk Tidskrift*, December 20th 1941

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 reoccurring 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, rail-

way 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 century¹ 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.

¹i.e. 1900 — JP

²Master 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 neglect, 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 in-consequences, 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. In 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 m³ 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 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 Mole³ 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.

³1 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

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

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

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	1543	1533	1455	1405	1371
m ³ gas per kg coal	3.81	3.704	3.898	4.012	4.065
Total heat in the gas kcal	5879	5678	5672	5637	5573
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 whether 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 m³ 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 m³ 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.

The making of the Källe-gasifier

By TORSTEN KÄLLE

January/February 1942

(Translation to English 2000, JOACIM PERSSON <joacim@ymex.net>)

Preface

Torsten Källe's charcoal gasifier was somewhat ahead of its time. It was very popular due to its easy maintenance and fuel economy. Some features with this gasifier is perhaps recognised in modern gasification technology; among many things it was a sort of predecessor to what today is called 'circulating fluidised bed.' Charcoal gasifiers were generally more popular than wood gasifiers during the producer gas era in Sweden in the days of WW2, even as the wood gasifiers improved in design. Wood gas was cheaper by all means, but charcoal gasifiers were so much easier to handle.

This article perhaps belongs in the historical section, but I feel it is worth reading even today. I for one find Mr Källe's reasoning and experimenting very inspiring.

This article is shamelessly stolen from *Svenska Teknologföreningen's* publication *Teknisk Tidskrift*, namely from the issues as of the 17th January (pp.4—8) and 21st February (pp. 15—16), 1942, in the *Automobil och Motorteknik* section. (Also published earlier in a publication named *Fläkten*, unknown date). Enjoy!

Joacim Persson

The making of the Källe-gasifier

Over a year ago, when I started using a producer gas-powered car I just had bought, I was both impressed and excited; imagine it being even possible to, by such simple means as charcoal and air in a fairly air-tight tin can equipped with a grate at the bottom, a pipe where air were blowing in, plus hatches and lids, be able to produce fuel for such a choosy machine as a modern petrol motor! It all reminded more of a kitchen stove, and seemed in its primitive simpleness really amazing. Obviously, vast fields were open for speculation.

While I was starting and driving with this device, taking off slag and soot, and topping it up with charcoal, I subconsciously made certain observations, and one day I caught myself engulfed in experimentation, trying to get something more out of my gasifier.

Apart from the reoccurring event of taking out the slag, the car was nice for long drives. But it was also my opinion that it ought to be possible to improve its accessibility. In other words: make it start easier and faster from cold condition or after a longer pause in the driving. What more precisely gave me the impulse of this possibility was that when the gasifier was freshly de-slagged and serviced, thus new fresh charcoals were in place in front of the nozzle, the car started significantly faster, maybe in just 5 minutes rather than the normal 10—15 minutes for a car that has cooled down. So I begun studying the reasons for this. The explanation was simple. The fresher, ash-free and cleaner surfaces were more reactive. I also found out that the size of the fuel were of great importance; particularly if the smaller charcoals had clean (new) fractures; a certain amount of moisture also appeared to be beneficial.

As gasifiers in general are made with the nozzle in fixed position somewhere in the combustion zone above the grate, a cavity appears in front of the nozzle when air rushes in and oxidises the charcoals in its way; this cavity is then prevented from being filled out more or less due to bridging in the fuel. This becomes even more obvious when the gasifier is turned off, when vibrations and such are no longer contributing to the filling out of the cavity. So the next time the gasifier is lit, there is a cavity in the charcoals, and a gasifier-match¹ dropped down will lit the charcoal more or less distant from the mouth of the air inlet, resulting in a slower start. This also explains why, as we all know, it is so much easier to start the gasifier if you stir around in it first.

Firing up was even faster if the cavity in front

¹They had special matches for lighting gasifiers in those days. The matches were larger than regular matches, and had a much longer fuse. (translator's note)

of the nozzle was filled with finely crushed charcoal, filled in through the primary air inlet. The explanation for this is that the charcoals in that case has, compared to its volume, a very large surface. One thus had to lit up a smaller mass of charcoal than with coarser chars, to gain enough reacting surface and thereby get enough gas generated for starting the motor on.

By putting fine charcoal in front of the nozzle in the cavity formed when the gasifier cooled down, I now had pressed the starting time down to 30 seconds.

To avoid having to bring two kinds of fuel with me on my journeys; one for firing up, one for driving, I made the nozzle movable. By a simple motion it could be loosened from the outside and with a guider and handle be thrust in and out, so the charcoals in front of the nozzle be crushed. Thereby I always got charcoals with fresh fractures, and immediately after lighting it with a gasifier match, a small reaction-zone, whose reacting surface were enough to generate starting gas for the motor. When the motor was started and its greater sucking power doing its work, the heat quickly spread in the hearth, and the motor speed could soon be increased further.

This implied a great improvement, and the accessibility of the car had increased significantly.

After this minor success, I started working in laboratory scale; above all there was one discovery I wished to take a closer look at: *the uneven generation of gas*, which appeared most wilfully during driving. After a few dozen kilometers the motor could suddenly become weaker and weaker and just as suddenly regain its normal power. Normally, though, the power continued to decrease.

The main suspect was the large grate. What guarantees were there really that the gas would distribute itself evenly across the entire mass of charcoal by a grate as big as 300—500 mm \emptyset , i.e. all gas really be reduced? It could easily be, that the gas according to the law of least resistance sought itself channels through the charcoal, where it was less packed with charcoal dust. In those areas the gas velocity would increase, the reaction more vivid, which in turn decrease the resistance of flow even further.

Yes, why wouldn't the air from the nozzle even burn itself a channel all the way down to the grate, by which the reacting surfaces became far to small and the amounts of nitrogen and CO₂ increasing catastrophically. All these extremes were plausible.

My suspicions were confirmed during night-driving. The outer cover of the gasifier showed vaguely red hot spots, whose position varied under way and most irregularly reappeared here and there.

Enough proof! It was quite obvious. The most important part of the reaction process was more or

less left to coincidence. To make it efficient it had to be fixed in precalculated paths. It was also fairly clear in what way this was going to be achieved.

In the same manner as when the primary air left the air pipe at a narrow section, around which the relatively modest oxidation zone were formed, the several times larger reduction zone must also be fixed against a narrowed section, namely by the outlet for the ready gas, i.e. the grate.

This must be shrunk down to a minimum. That was, however, not possible with regular design principles.

There was more to it. The sizes of the fuel must be decrease. I already had gotten a taste of what that implied to the start-up properties.

By simple mathematics it was clear that the size of the charcoals and the reacting volume were in a linear dependence upon one another, e.g. if the size of the charcoals was decreased 6 times, the necessary reacting volume would also decrease 6 times.

On basis on this reasoning and from tangible proof, I came up with the idea for the so called central tube, which eventually grew out to a whole new principle of operation for gasifiers, and it is this principle I now will try to briefly explain.

The figures 1—4 illustrates four different phases in the chain of development. Figure 1 shows a regular type of charcoal gasifier with downdraft combustion and equipped with the already mentioned movable air tube, with which one during start-up can crush the charcoals at the reaction zone. The latter was carried out in the manner that one loosened the handle (1) from its bayonet lock, had two or three thrusts at it, and then locked the handle again. When the gasifier match was dropped down through the air inlet there were a sufficiently amount of fresh surfaces to lit at, and produce a sufficient amount of gas.

In figure 2 the guiding tube has been extended all the way down into the fuel, and also been combined with an exhaust pipe (1) for the gas. A seemingly insignificant change, but yet a radically new way of operation! The grate became obsolete, as also the stove. This laboratory speculation was never tried in a car however, as it immediately apparent that due to the high gas velocities at the mouth of the outlet, a far too great amount of coal dust would be sucked up along with the generated gas.

This nuisance was eliminated as in figure 3, by introducing a grid which let the gas through, but blocked out at least the larger particles. It was really at this stage that the experimenting first could be carried out under more practical circumstances of operation. It was now possible to try out finer and finer selections of charcoal. It was found, however, that it was necessary to sort out the dust from the fuel, at least if there were larger amounts of it.

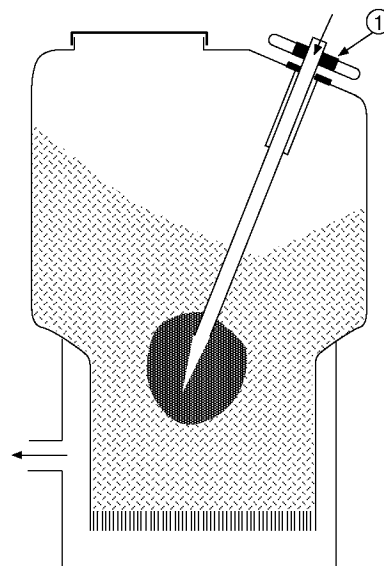


Figure 1: Ordinary charcoal gasifier, with a movable nozzle added to it.

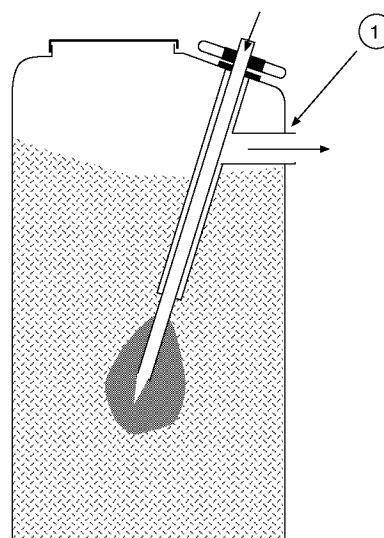


Figure 2: A first outline.

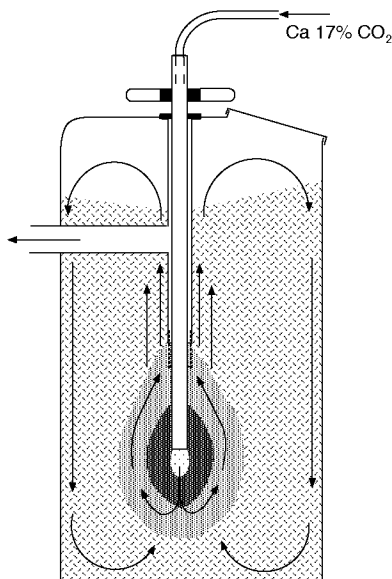


Figure 3: The first experiment with the *grid*.

The operation is thus, that the charcoal particles are sucked onto the grate (which I hereafter will call the 'grid') and with that as centre, build up a more or less extended ball of charcoal, through whose porous walls the gas may pass. If the chars contains a too large amount of finer particles along with dust, the ball of coal can easily become too dense and offer a resistance that is far to great for the gas to penetrate it to the grid.

This was of course a problem, and eventually brought forward the final solution, as shown in figure 4.

The grid (1) is here fixed to the lower part of air tube (2), while the upper part of the air tube is fastened to the membrane (3) in the membrane case (4). The guiding tube (6) is a little wider, so that the grid can slide in and out from the mouth. A spring coil (5) presses the membrane and the air tube upwards, and by that the grid is fully covered by the guiding tube. The device operates in the following manner:

If the motor for example needs more gas, the suck effect at the grid opening increases, the pressure drops in the gasifier and more air flows in by the air tube. The lower pressure in turn affects the rubber membrane, which bends downwards and thus also moves nozzle and grid downwards. The result is that the reaction zone as well as the grid opening is increased. If the motor sucks less gas, the membrane is moved upwards in the corresponding way, as the vacuum in the generator decrease, by the spring (5) and the reaction zone as well as the grid opening decreases. In other words: *the generator has become self-adjusting, not only according to variations in gas consumption from the one and*

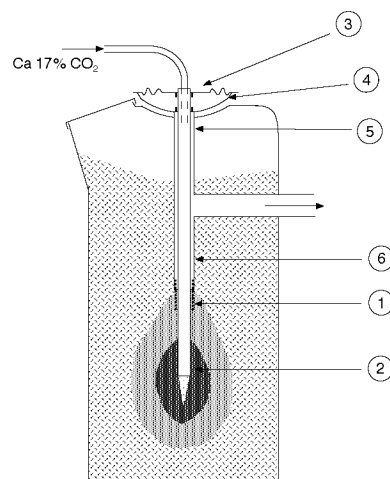


Figure 4: Moveable grid, connected to a membrane and spring.

same motor, but also adjusting itself to motors of varying size!

During normal operation the consumption of gas undergoes reoccurring variations depending upon how the road and traffic varies ahead. The membrane will thus constantly alter its position, and so will the grid. These variations is exploited by the gasifier for scraping the grid clean and thereby prevent it from clobbering up. Every time the driver takes his foot off the throttle, the grid slides into the guider tube and eventual coal particles are scraped off. When the driver again presses down the pedal, the grid automatically slides out as much as decided by the vacuum and the motor speed. The mass of charcoal at the grid is hereby broken up and made porous, so that it lets the gas through without too much resistance. By this even the finest charcoal particles were useful, even if they were severely mixed with char dust. By the moving grid a few other interesting conditions appeared, which I will get back to later.

Due to the central placement of the grid and the nozzle the reaction zones becomes fully separated from the walls of the fuel container, and the fuel itself will thus make an efficient insulation. By the constant grinding of the charcoals the reacting volume is gradually decreased, and so a quite concentrated reaction zone is formed, while at the same time the more compact fuel further prevents heat losses by convection.

At this point, however, a tremendous excess of heat appeared in the gasifier, i.e. the generated net heat was more than what was necessary to convert all of the air to producer gas. The excess heat resulted in such a steep increase in temperature that the nozzles melted down in just a few minutes.

We now had to eliminate this excess heat, but preferably in some way that the heat was made use-

ful. As so many times before, an opportunity was given to make a virtue of necessity!

One could say, that the carbon-dioxide (CO_2) is the 'fuel' from which producer gas, that is carbon monoxide (CO) is made. It could thus be considered a pure waste to generate carbon dioxide from charcoal, when the former—as the final product of combustion in the motor—is available in sufficient quantities from the exhaust gases! It also goes without saying, that the larger portion of the CO_2 in the exhaust that can be reused for producing carbon-monoxide, the more economically the gasifier operates, and the longer one can drive on the same amount of charcoal, and the cheaper the driving is.

I therefore decided to mix a certain portion of the exhaust gases from the motor into the primary air. The combustion gases, passing from the combustion zone to the reduction zone will thereby contain more carbon dioxide than what corresponds to the consumed charcoal. The excess of heat will be consumed for reducing the excess CO_2 . If the portion of exhaust gases is small, the reaction will become complete and the producer gas becomes entirely free from CO_2 . In practice it is however better to let the producer gas contain one or two percent CO_2 . The heat value of the gas will not be significantly lowered by it, but it guarantees that all the heat is made useful.

Further experiments showed, that *the best effect was gained by an adding of about 17% CO_2 to the gasifier*, which, under the condition that all of that was turned into CO , *results in a significant saving of charcoal.*

The temperature in the oxidation zone is in this way automatically regulated down to $1000^\circ\text{--}900^\circ\text{C}$, and I can mention that it keeps itself remarkably constant around that even for different loads. Naturally, this is so because the CO_2 is added proportionally to the need for primary air.

I now get to the third phase in the development. By the constant moving of the grid and the nozzle, an interesting phenomenon could be observed. As mentioned earlier, the charcoal particles is scraped off from the grid, and thereby fed into the oxidation zone below it. Here they are caught by the jet from the nozzle, whereby their surface temperature is quickly raised, while at the same time they are caught on by the circulating flow of gas. Some of it is stuck on the grid again while others returns to the circulation, until they have more or less completely been gasified. In fact, most of the mass of charcoal that is active in the reaction is in constant motion inside a cavity, which automatically alters its shape and size according to the velocity of the gas. When the need for gas for instance increases and the grid along with the nozzle penetrates deeper into the charcoal, the nozzle fumes up more char, which also is set in motion. A large portion of this is sucked

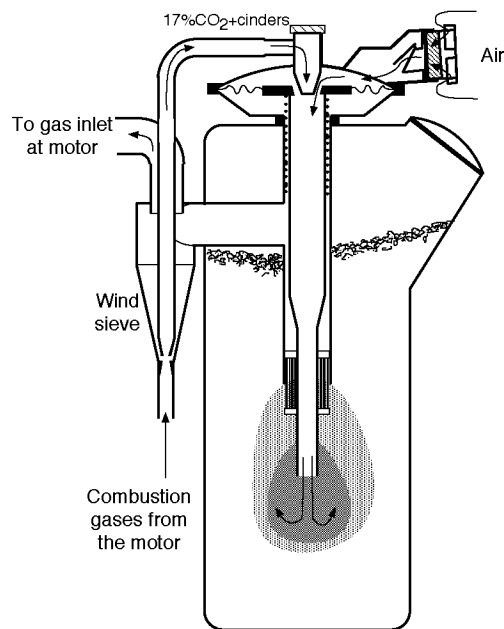


Figure 5: The final Källe-gasifier, complete with wind sieve.

onto the exposed surface of the grid, where thus a tremendously efficient reduction zone is formed as the reactivity of these chars reaches an optimum. The slag dust which is generated during the combustion of these clean-blown charcoals, together with the finer charcoal particles goes along with the gas, and was for a start caught up by a plain cyclone cleaner.

Because of the motion of the grid it was quite a lot of charcoal which in this manner was sucked along with the gas, and it added up to relatively large quantities of useable fuel that thereby was separated in the cyclone purifier. Most of this could by all means be put back in the gasifier and prevent loss of fuel, but the trouble and risks with the highly flammable and sooty cyclone dust remained.

So it was logical to try to return the charcoal particles and dust to the gasifier continuously, and preferably to its oxidation zone, to thereby get them back in the process again.

The recirculation of CO_2 from the motor was already in operation, and since the exhaust gases leaves with a certain pressure it was obvious that they could be used for transporting the charcoal particles back!

So we came to the design we can see in figure 5.

This device, or the so called *wind sieve*, is in principle designed as an ordinary cyclone. The flow of gas enters tangentially into a mostly cylindrical container, where it flows in circulation from the perimeter and inwards. The exhaust opening is placed centrally by the upper gable plate. During the circu-

lation, heavy particles are thrown outwards against the cylindrical mantle and sinks down to the bottom. The bottom is cone-shaped to collect the separated material. By proper dimensioning of the wind sieve one can limit the centrifugal effect so that only the largest particles, consisting of uncombusted charcoal, is separated. The smaller particles consists mostly of ashes and follows the gas to the filter.

The separated material is returned to the gasifier in the following way: The return gas from the exhaust pipe was lead in a tube straight through the wind sieve. In the lower part of it, an injector is mounted, in which the return gas catches the charcoal powder separated in the wind sieve. This is then blown back into the gasifier through the primary air inlet, and the combustion zone is thus somewhat fuelled by charcoal powder. The wind sieve with its accompanied recycling device is fully automatic and craves no maintenance whatsoever. *Parts of the dirty and risky work with regular gasifiers have thereby been eliminated.*

To gain enough pressure for this transport the CO₂ is taken from the exhaust pipe with a so called *catcher*, a sort of pitot-resembling device, which turns the velocity energy of the exhaust gases into a for the purpose fully sufficient static pressure.

That the mini charcoals circulates during the reaction process is of course highly interesting, and must be of great importance for the dynamics of the gasifier, or its capability to quickly adapt according to the operating conditions on the road. There is also ongoing research to closer seek out the above condition and what really is going on in the reaction zones.

I imagine that each time the char particles are caught by the primary air flow, a hasty oxidation of the particles surface takes place. Since the heat conducting parameter for the particle is very small, the reacting surface can be approximated to have a heat capacity of zero, why the increase in temperature also becomes exceedingly steep. During the next fraction of a second, the particle is bathing in its own atmosphere of CO₂, and the reduction to CO is in full operation, whereupon the temperature hastily decreases. While the particle is levitating in this manner, the surface is however kept free from ash, so the purified carbons' catalytic effect becomes highly efficient and the reduction benefits greatly from that, so that it can be kept up even at low temperature.

The circulation of the particles also contributes to *automatically keep the gasifier free from slag*. Naturally under the condition that this is not brought to it in the form of pebbles, earth and even nails, which has happened. The very fine slag powder, which originally is inside the charcoal in the form of salts, is blown out through the grid, passes the wind

sieve, and finally is caught by the filter. If one could receive completely pure charcoal without *strangers* (mechanically mixed-in pollution), the gasifier would never need to have slag to carry out manually. Even at the present, with our primitive production of charcoal, one can, if one handles the gasifier properly, *drive 2000—3000km without noticing any decrease in gas production* or increased resistance in from grid!

I have here discussed the levels of slag in the charcoal. There is however another matter connected to the charification work that calls for attention, that being *the charcoal content of so called vaporous parts, to which also tar is counted!*

I would really like to meet the gasifier driver who never have been crossed over what he has felt was 'the bad job of the gasifier designer.' Because it is always the designer that is blamed if tar occurs, and I won't defend him in this matter. On the contrary!

The problem with tar, should in my opinion almost be one of the basis of gasifier design, because producing charcoal completely free from tar is practically impossible, in any case irrational, and where tar occurs in the gasifier it is the dominating problem. The whole issue of wood or charcoal gas with all the existing mixed designs is, if one takes a closer look at it, very complicated and filled with considerations and compromises, which by no means makes the task of the designer easier.

An irremissible requirement is, that the gasifier more than well must be able to take care of, and crack the quantities of tars that occurs as maximum in prime quality charcoal. This limit is set by the Governments Fuel Commission's norms for solid fuel vehicle fuels to circa 15 % glow loss.

But note well, that this must be fulfilled not only under fully forced long drives, but also during shorter trips as for instance cab driving.

What possibilities does this gasifier have then, compared to other charcoal gasifiers, to handle such impurities in the fuel?

The only way to neutralise these distillation products is to put them in contact with the glowing or reactive mass of charcoal. Hereby they are cracked down depending upon their kind more or less easily into products that improves the gas in the form of CO and hydrogen.

The figures 6—9 show a schematic comparison, how these conditions appears in a common gasifier with horizontal combustion, and in the gasifier described herein.

If we first look at figure 6 and 7; these illustrates horizontal combustion in varying load. Figure 6 show us how one believe the reaction zone looks like at start and slow driving. The reaction zones cannot extend themselves to cover the whole large surface of the grate, but this is covered with charcoal that doesn't reach reaction temperature.

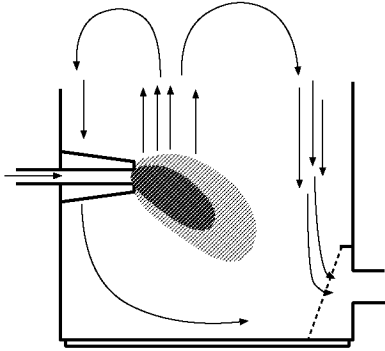


Figure 6: Regular charcoal gasifier operating at low power.

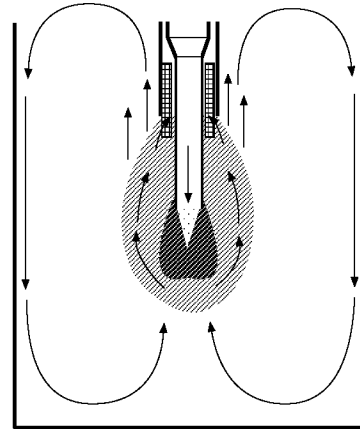


Figure 8: Källe-gasifier at low load.

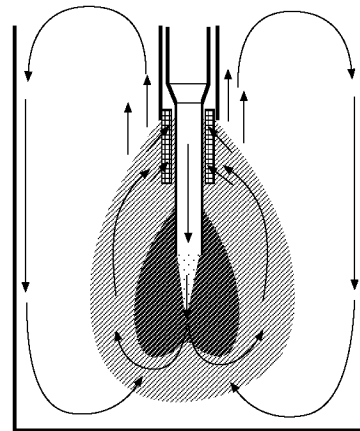


Figure 9: ...and at high load.

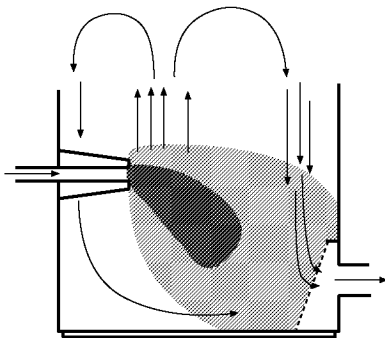


Figure 7: Same as in fig. 6, now on full power.

Because of the large differences in temperature that rules inside a gasifier, a spontaneous circulation of gas and distillation products occurs, emanating from the region where the temperature is the highest, there the gas rises straight up; whereafter it is cooled down and sinks back along the colder surfaces or its outer walls.

From figure 6 we can clearly see that distillation products along with water vapour without hindrance can pass through the grate during start and low load, without having been in contact with reactive charcoals. In figure 7, where the load is full, the conditions are better. Figures 8 and 9 displays a cross section of the new gasifier design under the same conditions. The difference in path of circulation is apparent. Since the grid and the nozzle at low loads are retracted to the guider tube, the now insignificant grid surface is covered with reactive charcoal, and there are no paths for the gas to go past the grid on its way out. In addition the circulation is more pronounced and has a different pattern in this gasifier. The maximum temperature is in this gasifier

concentrated to the central tube and the fact that it in its full extent becomes hot, participates in leading the circulation into the right ways. The rising stream of gas in the centre sinks eventually down along the perimeter of the gasifier and is forced to pass through the oxidation zone, where thus even the heavier tars can be cracked completely. The pattern is the same at full force. Then the nozzle and grid slides out from the guider tube. The grate surface becomes larger but has good opportunities to be constantly covered by reactive charcoal, and the circulation remains the same.

That the circulation really goes on in this manner and is a part of the gasifier's normal way of operation has been proved by applying screens upon the central tube to prevent the circulation, and also on the inner walls of the gasifier to lead off the gas flow and force it directly towards the grid. If one attempts to disturb the normal circulation in this manner, the gasifier becomes significantly more vulnerable to tar formation.

Finally one can ask oneself: what does the design look like today, after being subject of industrial manufacturing, how has it been made out in practice, what does it look like, has it lived up to the expectations etc. I shall briefly touch that side of the matter as well.

What demands should one have on an automobile gasifier?

Primary I feel, that it should be designed for *front mounting*, because the advantages with this are so apparent:

1. It requires no permanent changes to chassis or bodywork.
2. It leaves the boot free.
3. It provides best possible balance to the car. If the fuel is brought along in the boot, the weight distribution at the front and to the rear are about the same.
4. It is logical to place the gasifier as close to the motor as possible, since it practically speaking is a part of it—and by that the piping, and thereby the mounting, becomes as simple as possible.

I considered these four pros of front mounting so strong that I choose that without hesitation.

I now set up the following four conditions as a requirement for making front mounting realisable.

1. The gasifier must admit free view from the driver's seat. Therefore the height must be small.
2. Weight must not exceed 40kg.
3. Radius of operation should be 100km for regularly sized cars (3—4 litres cars)

4. Considering the appearance, the gasifier should be possible to paint using the same paint as for the rest of the car. Thus surface temperature must be low.

If I, finally, present an oversight of the results, that indeed has been reached, one shall find that the outlined requirements have been fairly achieved.

1. The view is perfectly clear—and yet the driver can, because of the moving indicator, constantly monitor the gasifier with his eyes.
2. The gasifier weighs 50 kg now, by all means, including cooler and filter—but if raw material becomes available so that certain details, as planned, can be made of light metal, the outlined requirement of 40 kg may easily be met.
3. A radius of operation of 150km per filling is not uncommon for smaller cars.
4. The exterior has been possible to make elegant, thanks to lean proportions and a consequently streamlined design.
5. The issue of keeping the surface temperature so low that regular car paint won't take damage is yet to be solved. The original plan was that it should be possible to let the fuel burn down completely between the fillings, until the motor stalled by itself on the road. This can actually be done with this gasifier without running any risk of damaging inner parts. But when this happens the surface temperature becomes so high the paintwork may take damage!
6. The accessibility is high—due to the quick start. Correctly maintained, the gasifier can be started from cold condition in 30 seconds. It can stand 6—7 hours without having to be lightened again.
7. Fuel economy is just as good as for petrol². Due to the recycling of char dust and exhaust gases and the fact that idling is not allowed, the fuel consumption has been taken down to a minimum. I calculate that even a cab driver by this can save in more than 50% of the fuel.
8. The dynamics of the gasifier is excellent, thanks to the varying grate (the grid), which automatically adapts the position and extent of the reaction zone to the driving conditions. This also implies that the same gasifier can be used for any car with a motor power of between 40 and 95 hp.

²Those were the days. Today, with European petrol prices anyway, even charcoal gasifier powered cars would be much cheaper to drive than on petrol powered such. (JP 2000)



Figure 10: Automobile with a front mounted Kalle-gasifier.

9. The gasifier is self-cleansing within reasonable limits. If charcoal with normal levels of char is used, one can drive 2000—3000km without having to take out slag manually.

By this I hope I have given an at least fairly clear description of my gasifier, how it was invented and designed, and what it can do in practice.