

The making of the Källe-gasifier

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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 the Royal Swedish Academy of Engineering'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 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 allways 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 \varnothing , 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 too small and the amounts of nitrogen and CO_2 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.

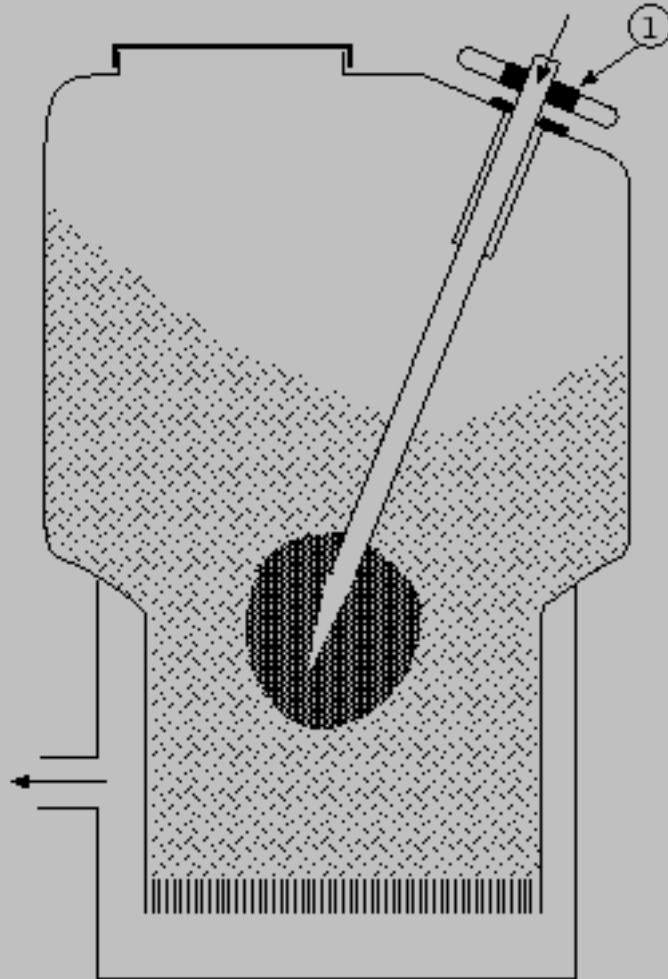


Figure 1: Ordinary charcoal gasifier, with a movable nozzle added to it.

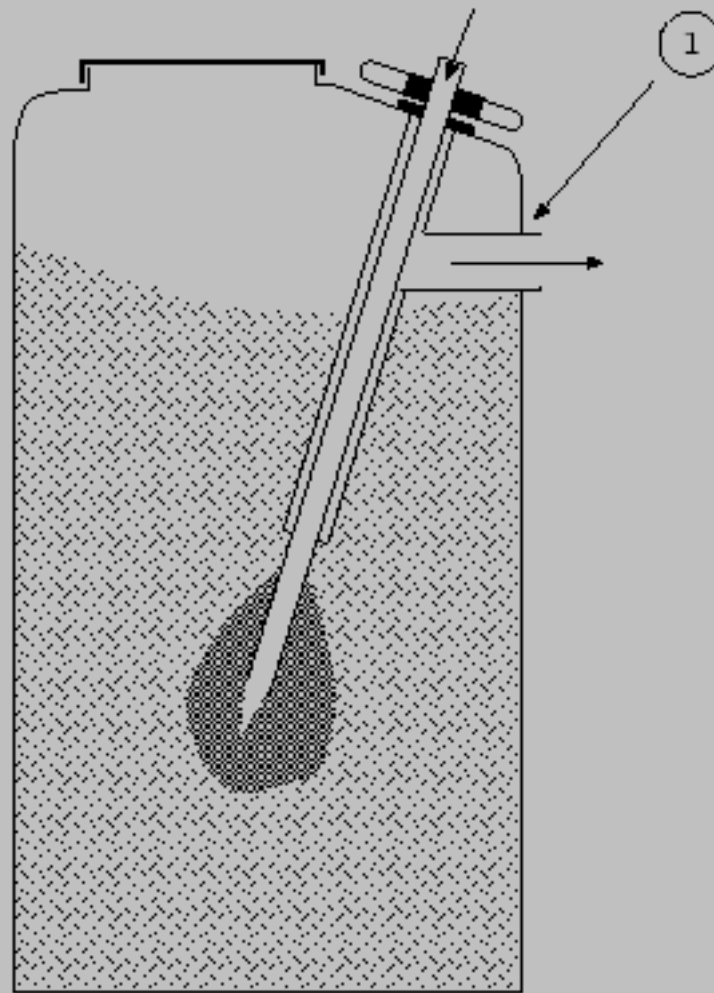


Figure 2: A first outline.

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.

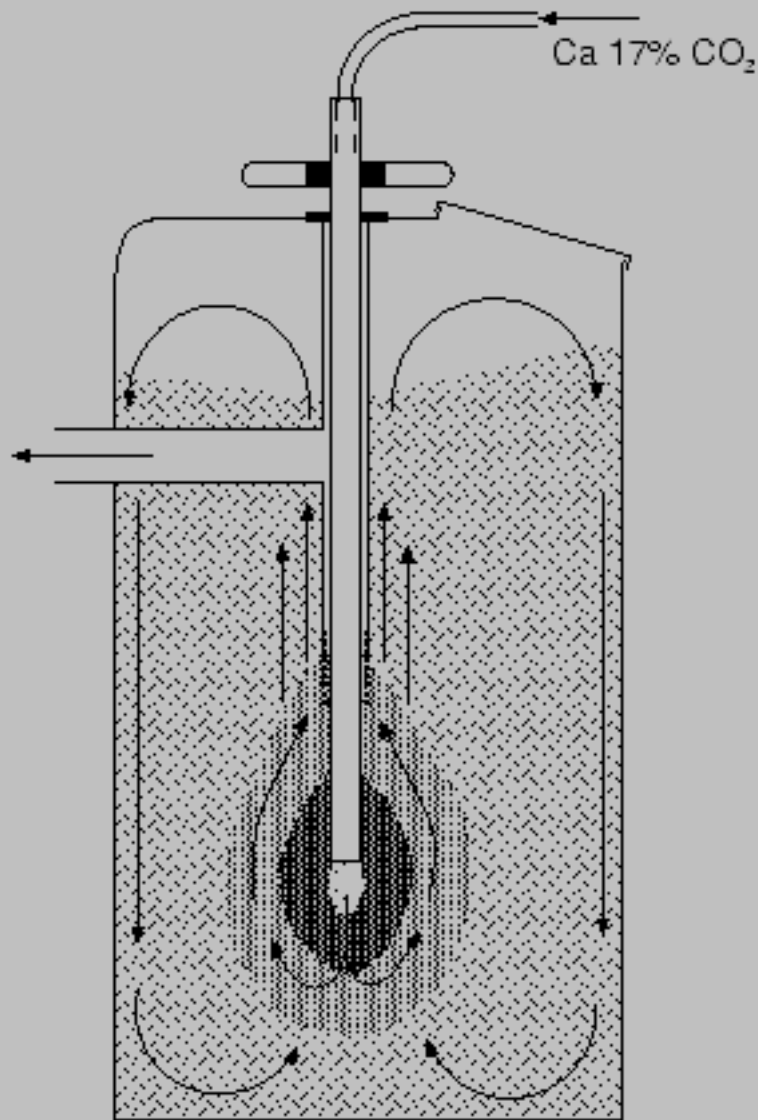


Figure 3: The first experiment with the *grid*.

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.

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.

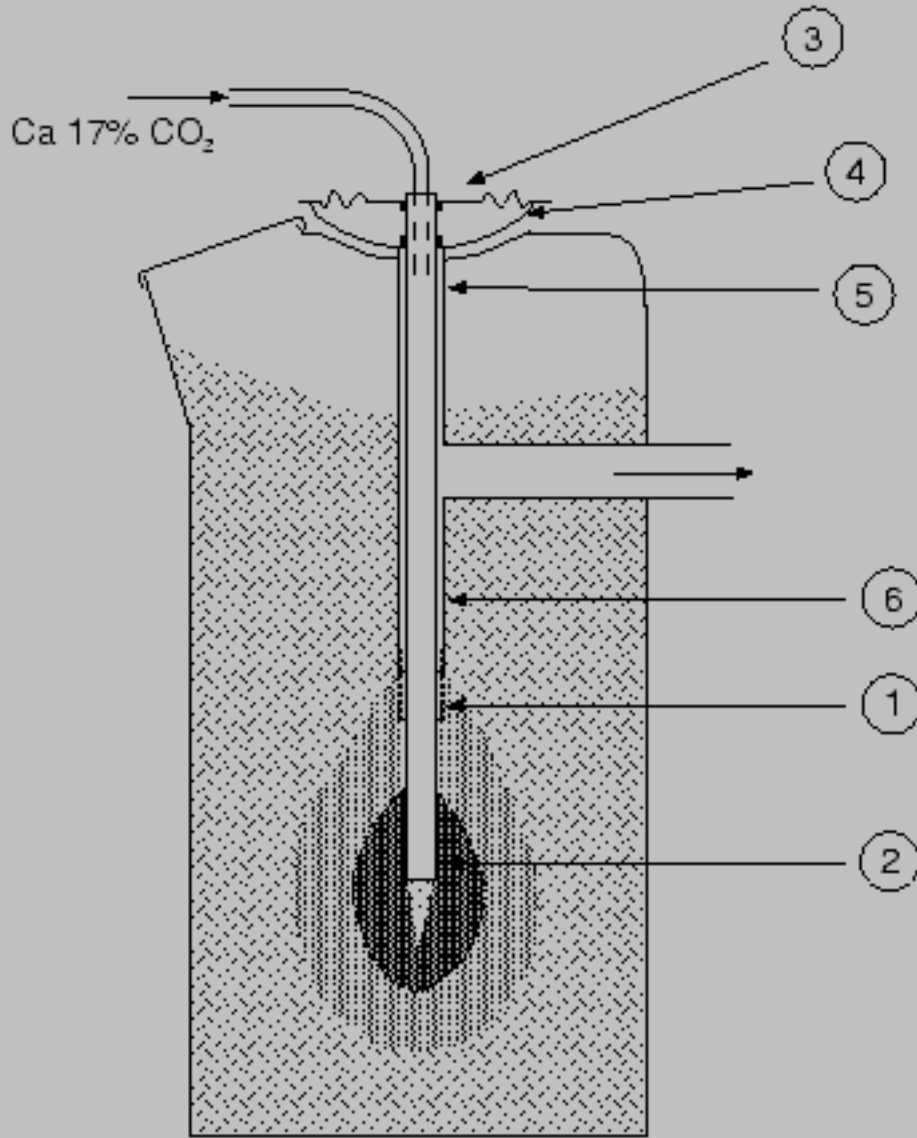


Figure 4: Moveable grid, connected to a membrane and spring.

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 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 useful. 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 carbondioxide 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 carbonmonoxide, 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 carbondioxide 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 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 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](#).

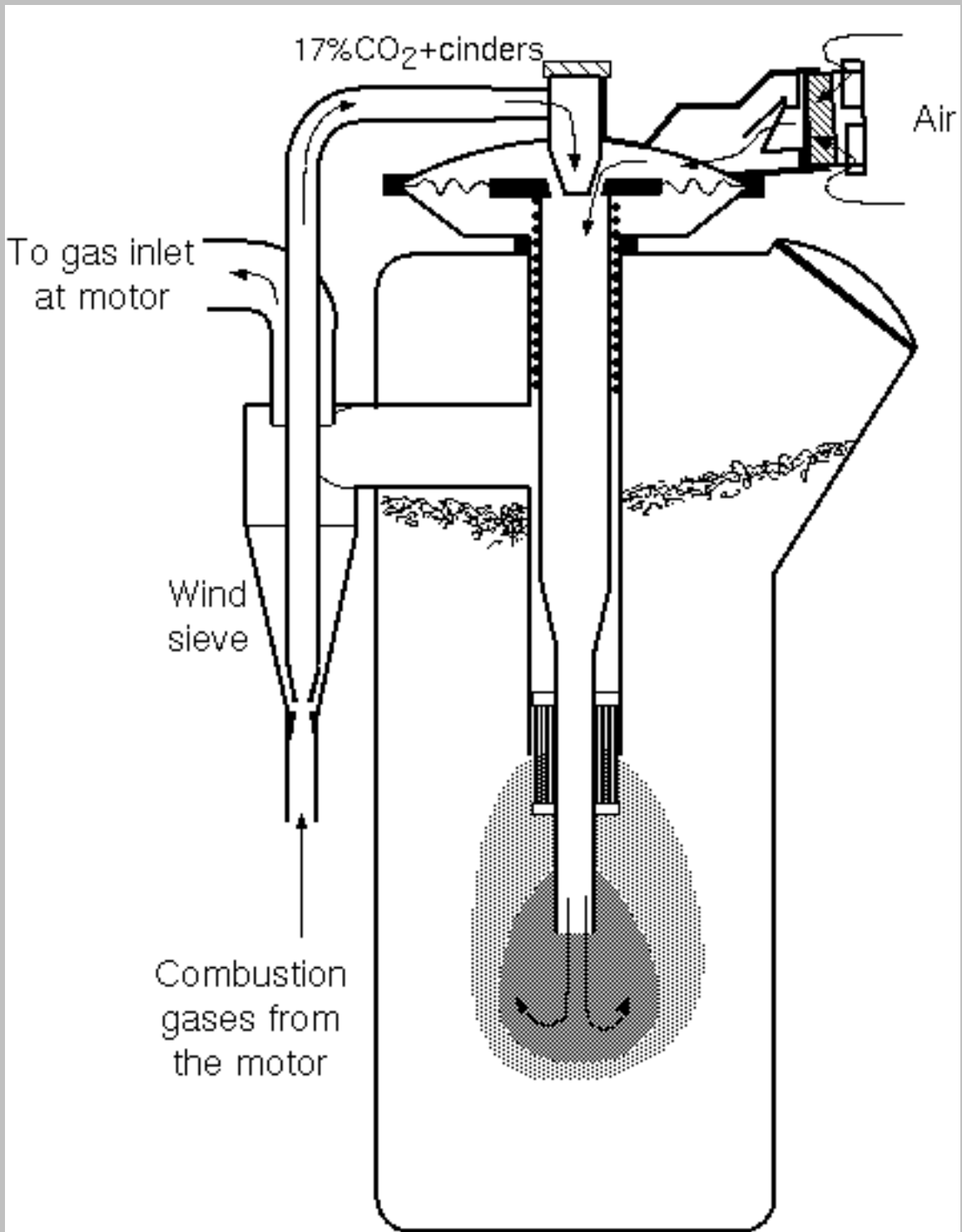


Figure 5: The final Källe-gasifier, complete with wind sieve.

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 circulation, 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 allways 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 Comission'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.

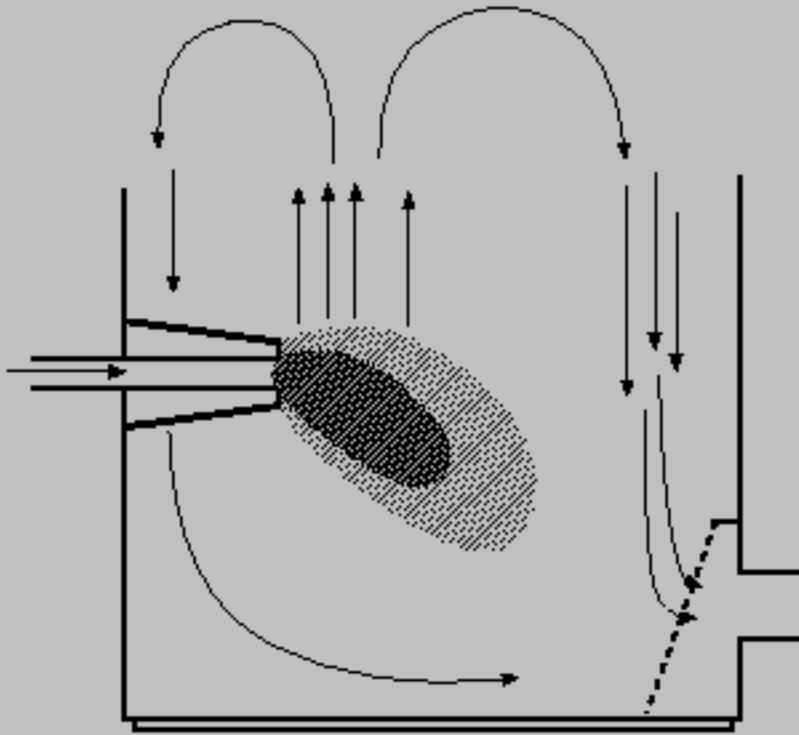


Figure 6: Regular charcoal gasifier operating at low power.

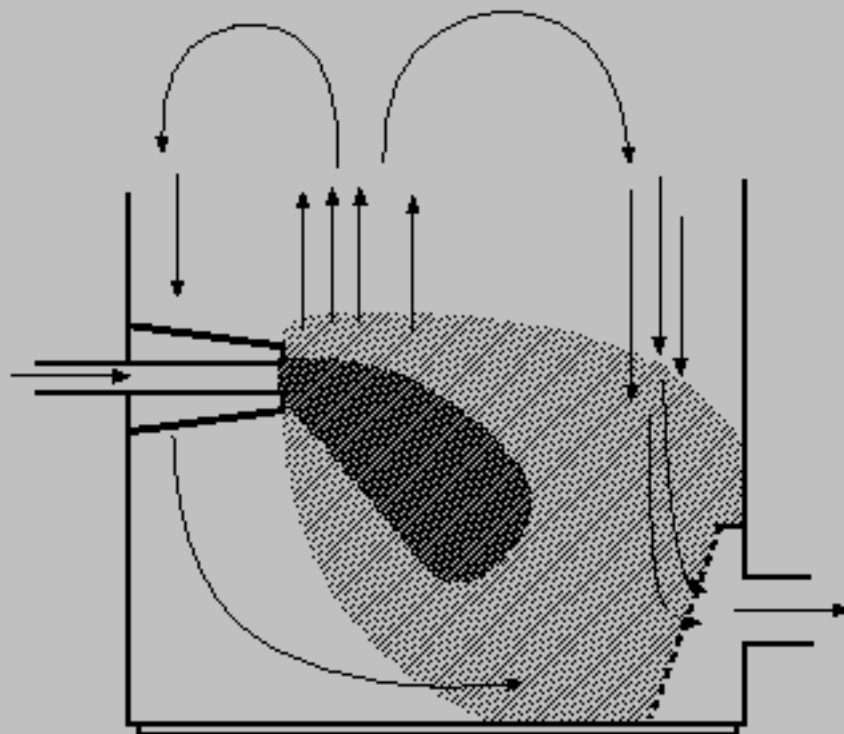


Figure 7: Same as in fig. [6](#), now on full power.

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.

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.

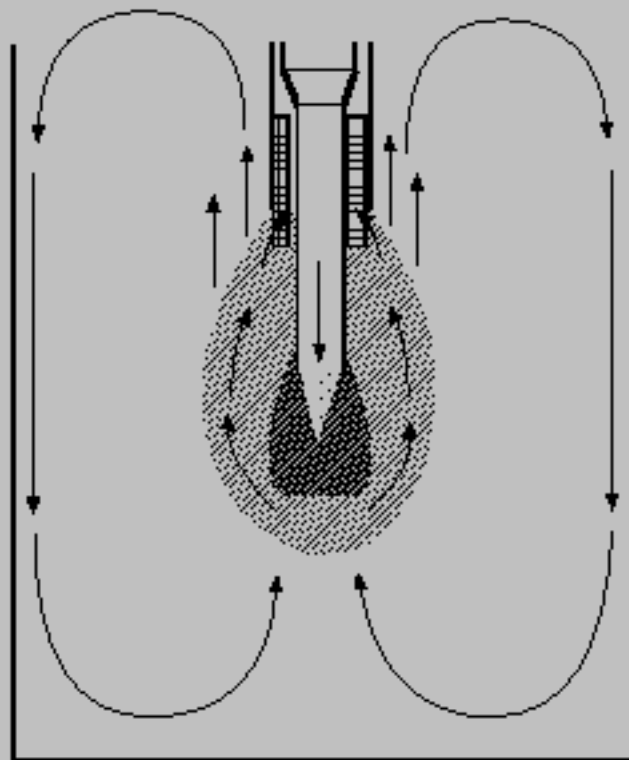


Figure 8: Källe-gasifier at low load.

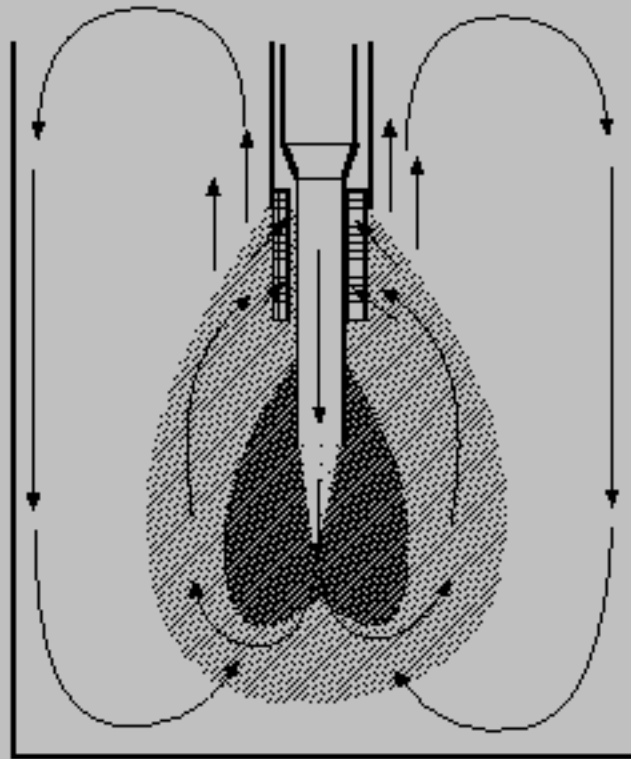


Figure 9: ...and at high load.

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 to constantly be 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.
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.



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

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.

1

They 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)

2

Those 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)

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