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INVESTIGATIONS OF A TWO-STAGE GASIFIER

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ABSTRACT

A 100 kW thermal input Two-Stage Gasifier was built at the University of Denmark (DTU). The gasifier consists of an externally heated pyrolysis unit, a down-draft char gasifier, a gas cleaning system and an internal-combustion engine. Several tests and investigations have been made (Bentzen, 1998). Between the summer of 1996 and the summer of 1998, 11 tests were made with the gasifier. The gasifier had a total operating time of 278 hours (excluding warming up).

The fuel was mainly wood chips, but also briquettes has been used (Henriksen, 1997). Four of the tests lasted 50-70 hours, and stable conditions were reached. All the tests were completed without technical problems.

The particle sizes and amounts were investigated (Hansen, 1998), (Ravn, 1998). The amount of particles depended on the amount of steam led to the gasifier. More than 99% of the particles after the cyclone were soot. The size of the soot particles was mainly between 0.2-0.5 µm. Under normal conditions (biomass:steam = 1:1 (dry mass basis)), the particle load was about 300 mg/Nm^3. With biomass:steam = 3:1 (dry mass basis) the particle load was above 1000 mg/Nm^3.

The pressure drop through the char bed was moderate and seemed to stabilise at about 200 mmH_2O fuelled with wood chips and about 50 mmH_2O fuelled with briquettes.

Char from the gasifier was investigated for its properties as activated carbon. After 72 hours' operation fuelled with wood chips, the gasifier was cooled while nitrogen was led through the bed. Samples were taken from 7 different vertical positions in the bed, and the BET surface area was determined at each position. The surface area was between 775-2158 m^2/g. Two samples were analysed thoroughly for properties as activated carbon. The adsorption tests (Molasses number, Iodine number etc.) showed that these samples had adsorptive properties comparable to a lot of commercial activated carbons (NORIT, 1998).

BACKGROUND

The Department of Energy Engineering of the Technical University of Denmark (DTU) has previously described the Two Stage Downdraft Gasifier and reported its main advantages namely low tar content and high energy efficiency (Henriksen, 1994).

A 100 kW thermal input Two Stage Gasifier was built at the University of Denmark for further investigations.

THE 100 KW TWO-STAGE GASIFIER

The 100 kW two-stage gasifier was built in 1995 and was equipped with gas cleaning system, automatic control and datalogging in 1996.

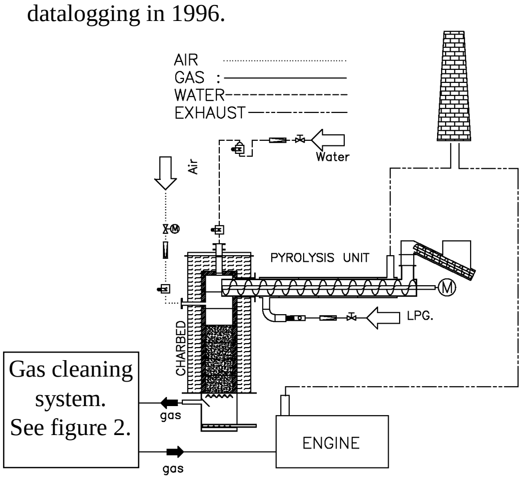

Figure 1. The 100 kW two-stage gasifier at DTU

The gasifier consists of a feeding system, an externally heated pyrolysis unit and a fixed bed gasifier (fig 1). Two kinds of feeding systems were constructed: A screw feeder for wood chips and a lock-hopper for briquettes.

The gas cleaning system consists of a hot cyclone, a gas cooler, a venturi scrubber and demistor, and a simple gas filter (fig 2). A Ford VSG 411 IC engine is connected to the gasifier.

NEW RESULTS FROM THE TWO-STAGE GASIFIER

Previous results from tests with a two-stage gasifier, showing low tar content and high energy efficiency, were published by (Henriksen, 1994). These results were confirmed on the 100 kW gasifier. This paper presents results made during a recent series of tests.

Overview of tests

Between the summer of 1996 and the summer of 1998, 11 tests were made with the gasifier. The gasifier had a total operating time of 278 hours (excluding warming).

Table 1. Major tests with 100 kW gasifier

Date, length of test	Fuel	Investigations to be presented in this paper
April 1997, 50 hours	SGF (briquettes)	Pressure drop through bed.
January 1998, 72 hours	Wood chips	Particle contents and size distribution, activated carbon tests of charcoal, pressure drop through bed.
March 1998, 63 hours	Wood chips	Particle contents and size distribution, baghouse filter for gas cleaning.

PARTICLE INVESTIGATIONS IN THE GAS

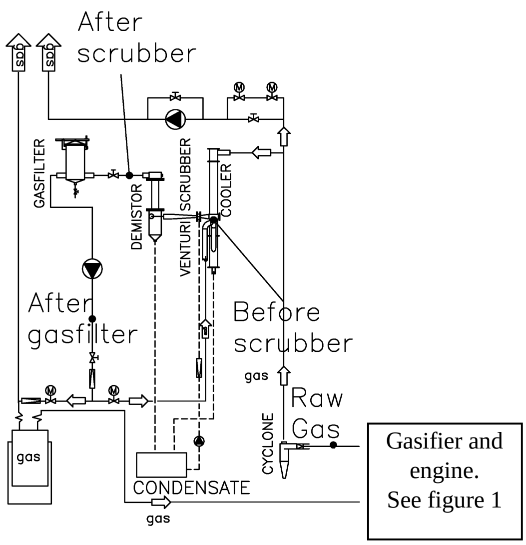

Figure 2. Gas cleaning system with points of measurements.

One of the main purposes of the work with the 100 kW gasifier was to optimise the gas cleaning system. Therefore, measurements were made to determine the amount and to characterise the particles from the gasifier. Additionally, a literature study regarding the formation of soot in gasifiers was made. (Hansen, 1998), (Ravn, 1998.)

To measure the amount of particles in the gas, equipment was built in compliance with the german VDI 2066 standard of dust measurement (VDI, 1975). To determine the size distribution of the particles, a Pilat Mark III cascade impactor and a Berner low-pressure impactor were used.

Particles in the raw gas

When the gasifier was operating in the normal mode with a biomass:steam ratio of 1:1 on mass basis, the particle load in the raw gas was about 200 mg/Nm^3. When the steam generator was turned off, the biomass:steam ratio was 3:1, and the particle load raised to above 1000 mg/Nm3.

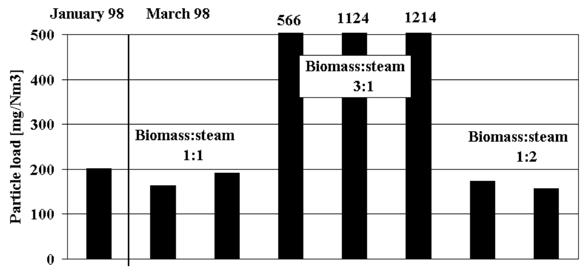

Figure 3. Particle load in the raw gas at different tests and at different biomass:steam ratios.

Size distributions of the particles were measured at different biomass:steam ratios.

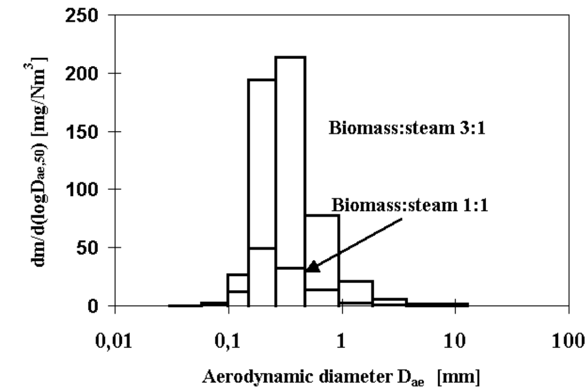

Figure 4. Size distribution of the particles at different biomass:steam ratios (Bentzen, 1998).

The dominant particle size was between 0.2 and 0.5 µm, but sizes between 0.1 –2 µm were observed.

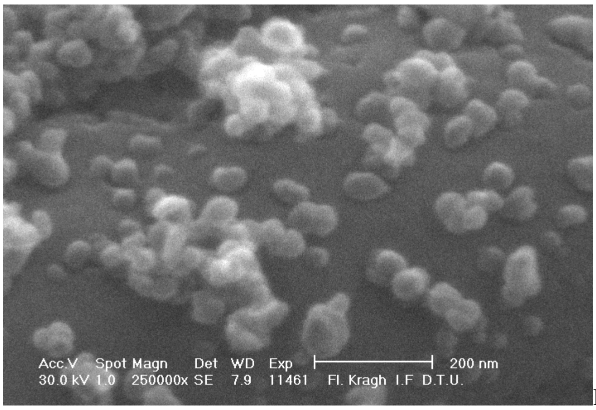

Figure 5. SEM (Scanning Electron Microscope) picture of particles collected in the raw gas.

In figure 5 it can be seen that the particles were agglomerates of small (50-100 nm) spherical particles (which were identified as soot).

Literature study of soot formation in gasifiers

Soot formation is described to follow many different pathways (Ravn, 1998). In reducing atmosphere and high temperatures, soot is formed from the volatiles from the pyrolysis products. The reaction rate increases with temperature, but also the breakdown of soot by oxidation by OH radicals increases with temperature and with the amount of OH radicals. The amount of OH radicals depends most strongly on water addition and moisture. This explains why the soot formation increases when the steam addition is turned off. A temperature dependent maximum of soot production is expected to exist.

Particles after the venturi scrubber

The venturi scrubber is the most efficient scrubber concept with efficiencies exceeding 99%, (Eckman, 1951), but measured particle load after the plants venturi scrubber showed that its efficiency was 60-85% depending on the pressure loss across the scrubber. The particle load after the venturi scrubber was typically 60-90 mg/Nm^3. The reason for this poor efficiency may be that the particles were too small. The submicron particles follow the gas flow and have no direct contact with the water droplets.

Particles after the gas filter.

The gas filter used was a MANN C 23 440/1, which is usually used for air filtration on IC engines. This is known as a 10 µm filter, but the particle load decreased dramatically after the filter.

The particle load was below 5 mg/Nm^3, from the beginning of a test. After 2 days, the particle load was about 0 mg/Nm^3. This high efficiency of particle removal may be explained by Brownian motions. When submicron particles follow the Brownian motions they will flow through a large volume on their way through the gas filter. The risk of particles impacting on the rough material is therefore high. The cleaning efficiency increases over time because the particles collected eventually build up a layer of soot.

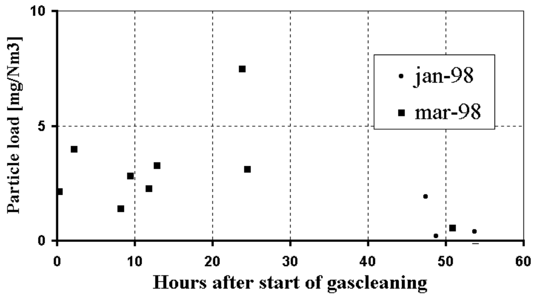

Figure 6. Particle load after the gas filter as a function of the time it has been used.

Experiments with baghouse filter

A baghouse filter would precent an alternative gas cleaning system, thus a small baghouse filter was constructed, and several filter materials were selected for testing during the March 98 test. A Heimbach 302.600 filter replaced the venturi scrubber for 3 hours. When the pressure drop was too high (100-150 mm H_2O) it was backflushed. After 16 backflushes it was still no problem to regenerate the filter. The particle load after the baghouse filter was measured to be 5 mg/Nm^3.

PRESSURE DROP ACROSS CHAR BED

Several tests with the 100 kW gasifier were made continuously during several days, and the pressure drop over the char bed evolved slowly and stabilised after about two days.

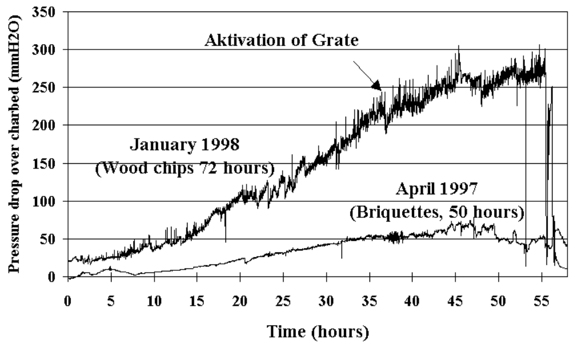

Figure 7. Pressure drop over char bed during test with briquettes and with wood chip.

During the tests, the grate was only activated once (marked on figure 7). When the ashes on the grate were removed the pressure drop across the char bed was reduced.

It is evident that the pressure drop over the bed was small when fuelled with briquettes, and moderate when fuelled with wood chips. The pressure drop in the December and the March tests evolved similar to the pressure drop in the January test.

CHARCOAL FROM THE TWO-STAGE GASFIER AS ACTIVATED CARBON

A number of tests on the char bed have been made after the test in January 1998. The bed was allowed to cool as nitrogen was led through it. Samples from different layers in the bed were analysed at DTU for the BET surface area. The Dutch company NORIT has made more detailed analyses of the charcoal, and SEM (Scanning Electron Microscope) pictures of the pyrolysed and the partial gasified char were taken.

The most important parameters to determine how active the charcoal is, are the pore structure and the total surface area. (NORIT). Commercial activated carbons have a surface area between 500-1500 m^2/g.

The surface area was measured on samples from the seven layers from the charbed after the test in January 1998.

Table 2. BET surface area of charcoal from the charbed in different heights above the grate

Place of sample Height above the grate [cm]	BET surface area [m^2/g]
121	775
101	1269
79	995
59	1249
39	983
17	2158
5	796

In table 2 it is seen that the surface area is high in all parts of the charbed.

Samples from the layer of 39 cm above the grate were sent to NORIT for further investigations. The molasses numbers (Europe) were 150-185, and the Iodine numbers were 790-865. The conclusion was "…It is obvious that the results of the adsorption tests (molasses number etc.) show that these samples have absorptive properties, which certainly are comparable with a lot of activated carbons in the market (powdered activated carbon)….."

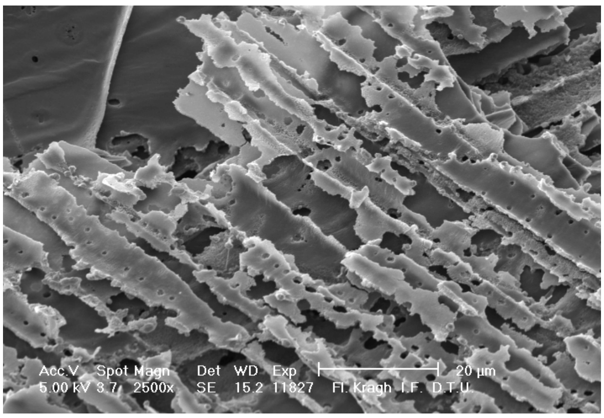

Figure 8. Charcoal from 39 cm above the grate from test in January 1998.

In figure 8 is seen how the pores of the char open evenly while the main structure is maintained.

Conclusions

Investigations of particles

Except for a very small fraction of gasborne biomass particles, the particles from the gasifier consist of 50-100 nm soot particles which have agglomerated to particles ranging from 0.1 - 2 µm. Most of the particles were between 0.2-0.5 µm.

Since the particles were so small, the venturi scrubber did not have the expected high efficiency. A simple gas filter after the scrubber, was very effective. The particle load after the gas filter was <0-5 mg/Nm3.

A bag house filter was successfully tested for 3 hours. Its efficiency was 97%.

Pressure drop over charbed

When wood chips or briquettes are gasified the pressure drop develops slowly. After a few days it stabilises. Activation of the grate reduces the pressure drop, since the ashes on the grate are removed.

Charcoal from the two stage gasifier as activated carbon

From these investigations was concluded that charcoal from the two stage gasifier can be utilised as activated carbon.

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