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## OPTIMISED TWO-STAGE GASIFIER

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**ABSTRACT:** The 100 kW two-stage gasifier at The Department of Energy Engineering of the Technical University of Denmark (DTU) was reconstructed and hereby optimised in order to reduce the tar content in the produced gas and to reduce heat losses.

Comparison of the tar level from the 100 two-stage gasifier before and after the reconstruction show that if very low tar content in the produced gas are to be obtained, absolutely no gas shall be allowed to bypass the char bed.

The tar content in the raw product gas was reduced to below  $25 \text{ mg/Nm}^3$ , and heat losses were reduced about 60% due to the reconstruction.

### 1. 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 [1].

A 100 kW (thermal input) two-stage gasifier was built at the Technical University of Denmark for further investigations. The gasifier was built in 1995 and was equipped with gas cleaning system, automatic control and datalogging in 1996.

The 100 kW two-stage gasifier consists of a feeding system, an externally heated pyrolysis unit and a fixed bed gasifier (Figure 1). Two kinds of feeding systems were constructed: A screw feeder for wood chips and a lock-hopper for briquettes.

Originally, the gas cleaning system consisted of a hot cyclone, a gas cooler, a venturi scrubber and demister, and a simple gas filter, but after an investigation of the particles and after an optimisation of the tar reduction, the gas cleaning system was reconstructed.

### 2. PURPOSE

Biomass gasifiers must have a high energy efficiency, have stable operation over long periods of time and must not pollute the environment in order to meet the requirements of the market. It is, therefore, necessary to optimise the energy efficiency and to reduce the tar content in the produced gas as much as possible in order that gasification can be technically and economically viable.

The purpose of this work was mainly to reduce the tar content in the gas from the 100 kW two-stage gasifier at DTU.

### 3. OPTIMISATION OF THE 100 kW TWO-STAGE GASIFIER

After 11 tests and investigations, the 100 kW gasifier was inspected. The inner ceramic sealing was cracked in several places so that some of the pyrolysis gasses, containing tars, could bypass the char bed and flow through the insulation (see Figure 2). The bypass resulted in high tar levels in the produced gas.

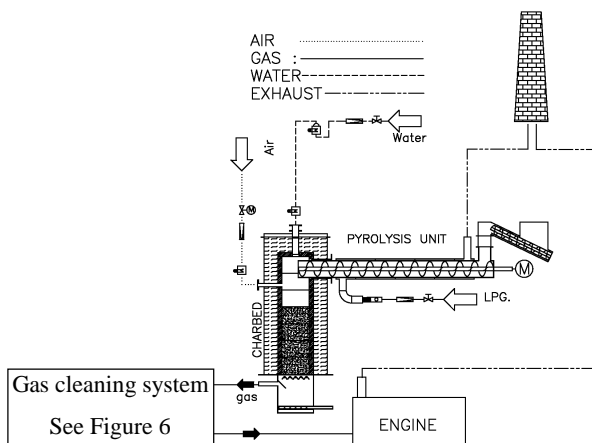


Figure 1. The 100 kW two-stage gasifier at DTU

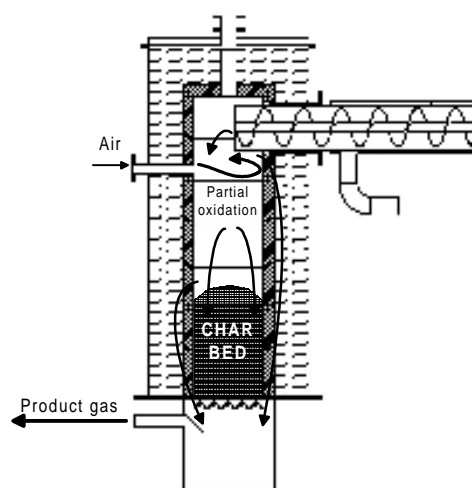


Figure 2. The 100 kW two-stage gasifier before the optimisation. The bypass of the partial oxidation zone and of the char bed is illustrated

In Figure 2 the bypass of the partial oxidation zone and the bypass of the char bed are illustrated. Calculations show that if 50 mg of tar/Nm<sup>3</sup> is the highest acceptable level, and if the gas that flows through the char bed is tar free, less than 0,01% of the product gas can be allowed to bypass the char bed.

It was decided to put a high temperature metal sealing into the reactor to ensure that all the gasses would flow through the char bed. Thus, the tar reduction should be higher, and the convective heat losses should be reduced.

Further, it was decided to reconstruct the top of the gasifier at the air inlet. New air nozzles were designed for better mixing of pyrolysis gas and air, and better insulation of the hottest area of the gasifier was made to reduce heat losses.

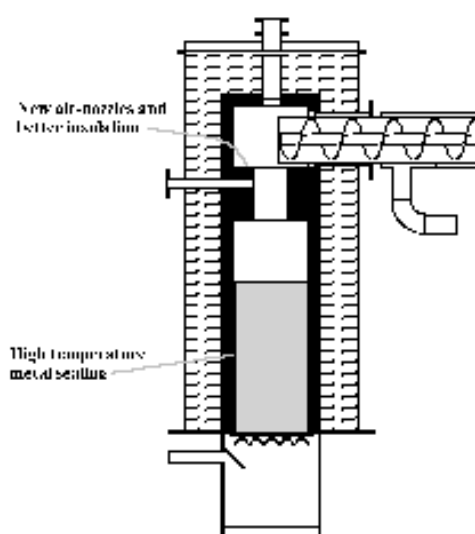


Figure 3. The optimised 100 kW two-stage gasifier at DTU, with high temperature metal sealing to ensure that all the gasses would flow through the char bed; new air nozzles for better mixing of pyrolysis gas and air and better insulation of the hottest area.

2 tests of the 100 kW two-stage gasifier after the reconstruction and several investigations have been made.

The most important results of the investigations are briefly presented in this paper. More detailed information on some of the investigations can be found in [2], [3], and [4].

#### 4. TAR IN PRODUCT GAS

The tar content in the raw producer gas after the two-stage gasifier has been measured by several institutions after the reconstruction. The tar content is now extremely low, see Table 1.

Table 1. The tar content in the produced gas after the gasifier before filtering.

Institution	Method	Date	Tar content mg/Nm <sup>3</sup>
Danish Technological Institute, Denmark	Gravimetric	23 nov 1999	25
		24 nov 1999	25
	GCMS	23 nov 1999	5
		24 nov 1999	25
The Technical University of Denmark (DTU)	GCMS	9 sep 1998	16
		10 sep 1998	3
	GCMS	23 nov 1999	3
		24 nov 1999	6
Royal Institute of Technology, Sweden/DTU	Solid phase adsorption (SPA)	8 measurements 23-24 nov. 1999	5-18 Average 10
Risø National Laboratory, Denmark	GCMS	9 sep 1998	16
		10 sep 1998	2,5

It is seen in Table 1 that the tar content in the product gas now is below 25 mg tar/Nm<sup>3</sup>.

The tar content in the gas after the bag house filter was measured two times by the Danish Technological Institute with the results: 4 and 6 mg tar/Nm<sup>3</sup>.

#### 5. ENERGY EFFICIENCY

Calculations of the heat loss (based on energy balance) before and after the optimisation show that the total heat losses from the gasifier were reduced by about 60%, from around 11,0 kW to 4,3 kW.

Based on the measured gas flow and heating value of the gas and on the fuel input, the cold gas efficiency (energy in cold gas/energy in fuel) is calculated to be 92-97%. This is

an increase from 86-90% before the optimisation. Normally, low-tar gasification processes have a cold gas efficiency of about 80%.

## 6. GAS CLEANING

Target research has greatly improved the knowledge about the origin and the physical and chemical properties of the particles in the produced gas of the 100 kW two stage gasifier [3], [5]. This knowledge has resulted in the introduction of a new strategy for the gas cleaning system.

The physical properties of the particles were essentially unchanged by the reconstruction of the gasifier. Only the particle mass has increased from around 200-300 mg/Nm<sup>3</sup> to 500-800 mg/Nm<sup>3</sup>.

Studies of the particles in the product gas have documented that the major part of the particles is soot. Soot is formed from the volatiles from the pyrolysis process in reducing atmosphere at high temperatures.

The dominant particle size is between 0.2 and 0.5 μm, but sizes between 0.1–2 μm are observed. When the amount of steam is decreased, the amount of particles is increased.

Typical particle size distributions measured by the gasifier outlet are shown in Figure 4, and a SEM picture of collected particles is shown in Figure 5.

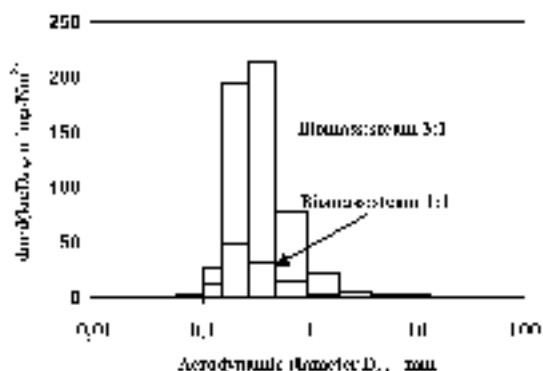


Figure 4. Size distribution of the particles at different biomass steam ratios.

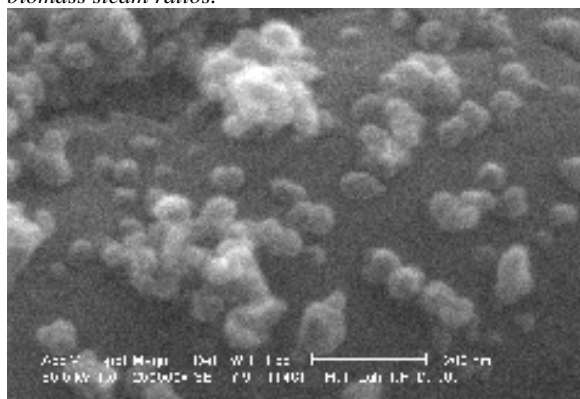


Figure 5. SEM (Scanning Electron Microscope) picture of particles collected in the raw gas.

The gas cleaning system was originally based on a venturi scrubber. Since better technologies exist for removing submicron particles, the gas cleaning system was rebuilt and is now based on a fabric bag filter (see Figure 6).

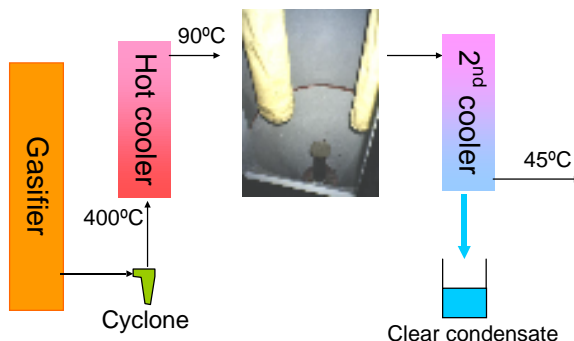


Figure 6. The new gas cleaning system with a bag filter that operates above the dew point.

The results with the bag house filter were very good. The filter operates with a gas temperature of about 90°C - well above the dew point of the gas. Two different types of filter materials were tested with good results. The collection efficiencies were above 95%. The regeneration of the filters was very effective throughout the tests.

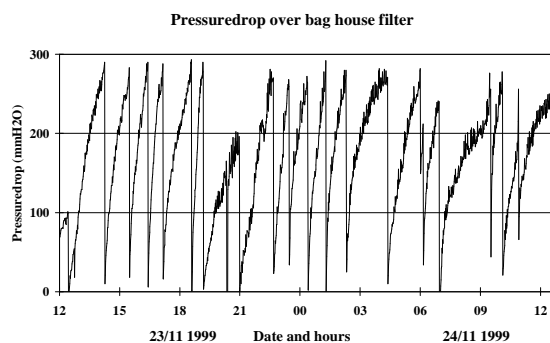


Figure 7 Pressure drop over bag house filter during one of the tests.

In Figure 7, the pressure drop over the house filter during a test is shown. It is seen that the bags are easily regenerated.

The acetone solubles ("tar") content in the particles was as low as 3-5% by mass and did not seem to cause problems in the filter bags. [3]. The particles were easy to remove from the filter and had no tendencies to agglomerate or stick to surfaces.

Since the particles are removed above the dew point, all condensate in the following pipes has very low particle contents. Compared to the scrubber system, the bag filter has lower energy consumption, since its pressure drop is much lower. In addition, no water has to be added to this cleaning system.

## 7. CONDENSATE

Investigations of the condensate from the gasifiers show that the condensate is so clean that it can be led to the public sewer without further treatment.

As regards inhibition of nitrifiers, the condensate of the two-stage gasifier can be led to the public sewer. Almost all the inhibition in the condensate of the two-stage gasifier can be related to the ammonia content [6].

The content of PAH and other organic compounds is very low in the condensate of the two-stage gasifier after the optimisation of the gasifier [2], [6].

## 8. ACTIVATED CARBON

Samples from different layers in the char bed bed have been analysed for the BET surface area. More detailed analyses of the charcoal were made, and SEM (Scanning Electron Microscope) pictures of samples of the partial gasified char were taken, see Figure 9.

The surface area was measured on samples from the seven layers from the char bed after a test in January 1998. The BET surface area of the samples was between 800-1200 m<sup>2</sup>/g. The molasses numbers (Europe) were 150-185, and the Iodine numbers were 790-865. The conclusion of the test from the laboratory 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)....."

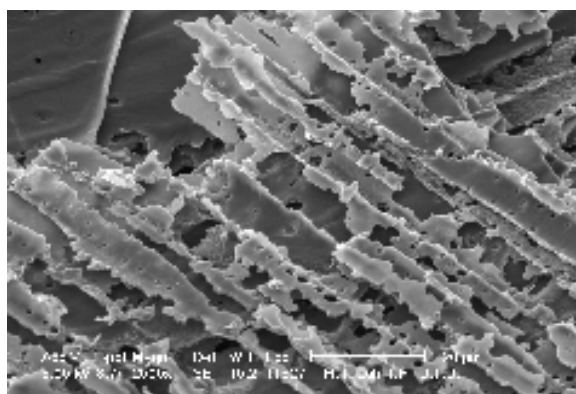


Figure 9 Charcoal of the char bed from a test in January 1998. It is seen how the pores of the char open evenly while the main structure is maintained.

## 9. CONCLUSIONS

**Tar in product gas:** The tar content in the product gas was dramatically reduced due to the reconstruction. From tar measurements made by DTU, TI (Danish Technological Institute) and RISØ National Laboratory and KTH in Stockholm, it can be concluded that the tar level in the raw gas is between 5-25 mg/Nm<sup>3</sup> after the reconstruction for optimisation.

The tar content in the gas after particle filtration in a bag house filter is about 5 mg tar/Nm<sup>3</sup>.

**Energy efficiency:** Calculations of the heat loss (based on energy balance) before and after the reconstruction show that the total heat losses from the gasifier were reduced by about 60%, from around 11,0 kW to 4,3 kW.

The coldgas efficiency (energy in cold producer gas/energy in fuel) increased because of the lower heat losses from between 86-90% before the reconstruction to between 92-97% after.

**Gas cleaning:** The particle content in the raw gas increased due to the reconstruction from around 200-300 mg/Nm<sup>3</sup> to around 500-800 mg/Nm<sup>3</sup>. The size distribution was unchanged: Particles consist of soot agglomerates of sizes between 0,1-2 µm.

The higher load of particles causes no problems for the gas cleaning system. Due to the very low tar content and the very small particles [3], [5] it was decided to install a bag house filter for particle filtration. The bag house filter functioned well with no increase in pulse frequency.

**Condensate:** Investigations of the condensate from the gasifiers show that the condensate is so clean that it can be led to the public sewer without further treatment [2], [6].

**Activated carbon:** Analyses and tests of charcoal from the two stage gasifier show that the charcoal has good absorptive properties.

## ACKNOWLEDGEMENTS

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