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LOW TEMPERATURE PARTICLE FILTRATION OF WOOD GAS WITH LOW TAR CONTENT

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ABSTRACT: Baghouse filters and cartridge filters were tested online with wood gas from a two stage down draft gasifier. The gas contained soot and very low levels (10-30 mg/Nm³) of tar. Particle collection efficiencies were above 95%. Continuous operation with cheap self cleaning baghouse filters were tested for a period of three days with good results.
Keywords: Gas cleaning, gasification, tar removal

1 INTRODUCTION

Gas cleanup from biomass gasifiers generally have to deal with high levels of tar in the gas sticking to e.g. pipe walls and movable parts. For low tar gasifiers, this problem is expected to be very small - or even absent. Thus very simple, well known gas cleaning devices may be sufficient to reach a gas quality suitable for IC engines and gas turbines.

On the two stage gasifier at DTU[1] pyrolysis and gasification reactors are separated by a well defined hot tar cracking zone. The resulting gas contain 10-30 mg/Nm³ tar, but approximately 400 mg/Nm³ particles. The vast majority of the particle mass from the two stage gasifier has been identified as soot with sizes about 0.1-0.5 µm[2].

Particles of these sizes can not be efficiently removed by inertial particle separation methods such as cyclones or scrubber systems. This explains why the existing venturi scrubber based gas cleaning system never removed more than 85% of the particle mass despite several optimisation attempts.

Filtration through fibrous materials or electrostatic precipitators have excellent performance with submicron particles. Filtration with baghouse filters and cartridge filters were chosen for evaluation in this work. Attempts to test an electrostatic precipitator failed.

1.1 Fibre filters

In order to identify the important parameters influencing the collection efficiency in fibre filters, a brief filtration theory study was conducted.

In fibrous filters the particles are collected on the fibres by interception and diffusion. *Interception* is when a particle hits a fibre due to inertia effects or because the particle is large enough to touch the fibre as it passes. Interception is the most important effect for larger particles (>1 µm). *Diffusion* is when the Brownian motions of the particle brings it in contact with the filter material. Diffusion is the major collection effect for sub-micron particles (<1 µm).

A theoretical measure for the efficiency of a fibre media is its *single fibre efficiency*, η_s. This is the efficiency of a single, cylindrical fibre. It is assumed, that it is surrounded by a cylindrical gas filled volume. The volume ratio of fibre and air correspond to that of the actual filter material. The following theoretical equation for η_s was proposed by Lee and Liu[4]. They included an empirical constant, $\varepsilon \approx 1.6$:

$$\eta_s = \overbrace{\frac{2.58}{\varepsilon} \cdot \left(\frac{1-\alpha}{K}\right)^{1/3} \cdot \left(\frac{U \cdot D_f}{K}\right)^{1/3}}^{\text{diffusion}} + \overbrace{\frac{1}{\varepsilon}\left(\frac{1-\alpha}{K}\right) \cdot \frac{R^2}{1+R}}^{\text{interception}} \qquad \text{(Eq. 1)}$$

Where $R = D_p/D_f$, α is the fibre packing (ratio of fibre volume to void volume), D_f and D_p are the fibre and particle diameters. The diffusion coefficient, a, can be approximated assuming spherical particles:

$$a \cong 0.420\, v_t \cdot l_{mfp} = 0.420\sqrt{\frac{3R \cdot T}{M_m} \cdot \frac{1}{n \cdot A_p}} = \sqrt{T}\,\frac{0.564}{n \cdot D_p^2}$$

v_t is the mean thermal speed, l_{mfp} is the mean free path, n is the number of particles per volume.

The relation between η_s and the overall filter efficiency is $\eta = 1 - e^{-\eta_s \cdot S}$ where $S = \dfrac{4 m_f}{\pi \cdot D_f \cdot \rho_f}$.

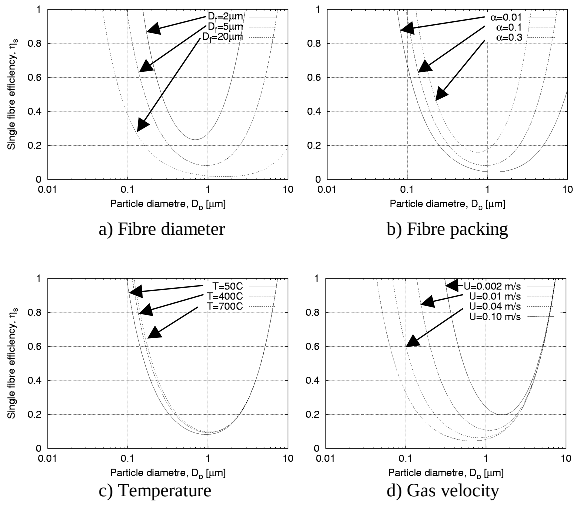

Figure 1: Theoretical single fibre efficiency plots varying different parameters.

The plots in Figure 1 show the single fibre efficiency as functions of different parameters using eq. 1. The following base values were used: fibre packing

α = 0,1; gas velocity U=0.02 m/s; gas temperature T=50°C=323 K; particle concentration n=0.03 µm^{-3}; and fibre diameter D_f=5 µm.

Figure 1c shows that the temperature has only negligible impact on η_s (if the gas velocity is kept constant). This indicate that the advantage of faster Brownian motions in the filter is negligible under these conditions. In contrast, fig. 1a indicate that the choice of materials with small fibres (small D_f) markedly increases η_s.

For submicron particles Figure 1d shows that the gas velocity are important to η_s. Thus larger area of the filter not only means a lower pressure drop. It also results in better removal of submicron particles.

2 METHODS

The filters were tested during a one week test programme with the two stage gasifier at DTU fueled with wood chips. The existing gas cleaning system based on a venturi scrubber was replaced by a setup in which either a baghouse filter or a cartridge filter would clean the full amount of produced gas (approx. 60 Nm³/h).

A system with two gas coolers was built (see figure 2). First the gas was cooled from 700°C to 90°C which is intentionally just above the dew point of water in the gas in order to avoid liquid water to enter the filters. Cooling reduce gas the volume to be cleaned was reduced and makes wider range of filter materials possible. After filtration of the gas further heat was recovered in a cooling condenser.

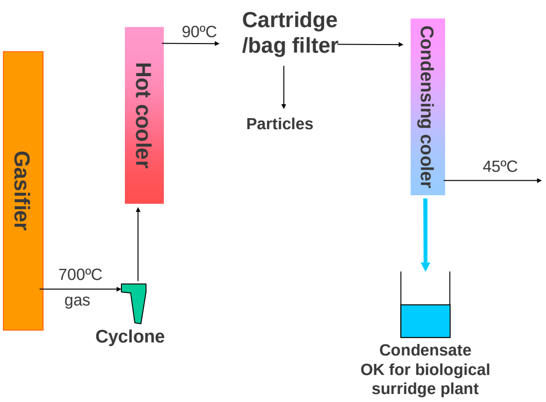

Figure 2: Schematic of the test setup.

2.1 Baghouse filters

	DT/DT 501	PE/PE 501
Material	Dralon-T	Polyethylene
Mass	500 g/m²	500 g/m²
Area	0.92 m²	0.92 m²
Gas velocity	18 mm/s	18 mm/s
Thickness	2.3 mm	1.8 mm
Max. temperature	120 °C	150 °C
Hydrolysis resist.	Good	Bad
Packing density, α	19 %	20 %

Table 1: Data for bag filters from data sheets. "Gas velocity" is the gas velocity occurring in this work.

Baghouse filters made of polyethylene (PE) and Dralon-T were tested. Polyethylene was the cheaper of the two and was the more temperature resistant, but could be subject to destruction by hydrolysis in the gas, which could quickly break the filter. Two different bag types were tested (Table 3).

For each of the two bag materials, a setup with two bags (1 meter, 0.46 m² each) were tested. The total filter area was 0.92 m² corresponding to an average gas velocity of 0.02 m/s. The baghouse filters were tested with cleaning pulses of 50 ms with N_2 from a pressurised tank with 3.5 bar gauge.

2.2 Cartridge filters

Four different cartridges were tested. One of these were of the membrane type, the others fibrous (Table 2).

	Envi EN-13	Envi EN-247	Envi EN-712	MANN C23 440/1
Material	Tetratex on PE	Coated paper	Cellulose PE	4MFN paper
Fiber ⌡D_f	*Membr.*	-	-	37-50 µm
Mass	200g/m²	190g/m²	130g/m²	-
Area	2.0 m²	4.5 m²	4.5 m²	1.7 m²
Velocity	8 mm/s	4 mm/s	4 mm/s	10 mm/s
α	-	-	-	>18 %

Table 2: Data for cartridge filters from data sheets. The filter areas were measured on the actual filters. "Velocity" is the gas velocity occurring in this work.

3 RESULTS

Figure 3 shows the particle determinations during the test. The determinations of collected particles are averages over the full operation time of each filter. These are shown as vertical lines filling the time span of filter operation. For reasons unrelated to this filter evaluation the gasifier was operated in three different operating conditions explaining the different particle loads in Figure 3:

- 21.11.99-23.11.99: No steam, high particle loads.
- 23.11.99-25.11.99: With steam, low particle loads.
- 25.11.99-26.11.99: Vortex mode[1], medium loads.

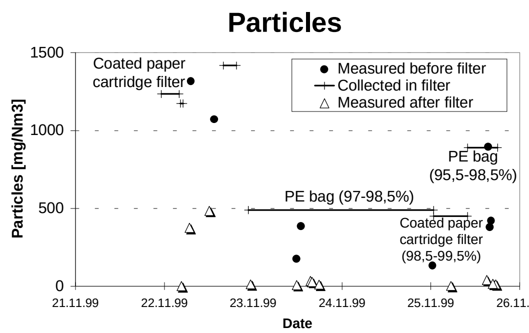

Figure 3: Particle load determinations. The approximate particle collection efficiencies during the tests are shown in parenthesis.

The filters apparently collect more particles than were measured in the gas before the filter. This is because the particle loads increase dramatically when the

[1] See poster V2.82.

grate supporting the fixed bed in the gasifier is moved. This is done as a routine operation to relieve the fixed bed from excess pressure drops. This operation is done by the plant personnel but was intentionally avoided during particle and tar measurements in the gas *before* the filters in order to have consistent measurements. Thus the filters collected these particle "bursts" while they were not included in the gas measurements.

Particle measurements *after* the filters were not as sensitive to grate movements. Partly because they spanned over longer time.

Particle collection efficiencies were calculated from the mass of particles collected by the filters and the particle measurements after the filters. Inspections of a police cartridge filter placed after the condensing cooler confirmed that virtually no visible amounts of particles reached this filter.

3.1 Baghouse filters

Unfortunately dirty gas leaked past the Dralon-T bags due to insufficient fastening of the bags. This caused a collection efficiency of around 50%. The police filter in effect caught considerable amounts of particles and the condensate was contaminated. Thus the efficiency evaluation of these filters failed, but the fact that the collected particles were dry and easy to handle was encouraging.

The PE bags were correctly fastened and showed no signs of destruction due to hydrolysis. Backflush cleaning of the baghouse-filters with N_2-pulses were successfully demonstrated for 50 hours cleaning woodgas. The pressure of the backflush N_2 was 2.5 bar gauge. Figure 5 shows the pressure development with backflushes approximately every 60 minutes.

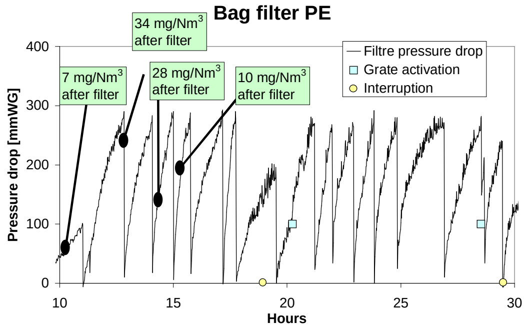

Figure 5: Pressure development for the PE baghouse filter. The times of two grate movements as well as two short stops due to external causes are indicated.

The particle load before the filters were 400-500 mg/Nm³ while 10-30 mg/Nm³ was left after filtration. Peaks in the particle load after the filter occurred during backflushes. According to the filter producer, this should be avoided if lower the pressure of the backflush N_2 could be reduced.

3.2 Cartridge filters

The cartridge filters appeared to work effectively until they were saturated with particles. The measured efficiencies of the filters exceeded 98 %. The pressure developments of the tested cartridges are shown in Figure 4. The cartridge filters are very compact and would be a good choice for filtering gas streams with small particle contents or short operation times. E.g. it would be good as a "police filter" after other gas cleaning components in order to ensure clean gas even if the main gas cleaning systems should fail.

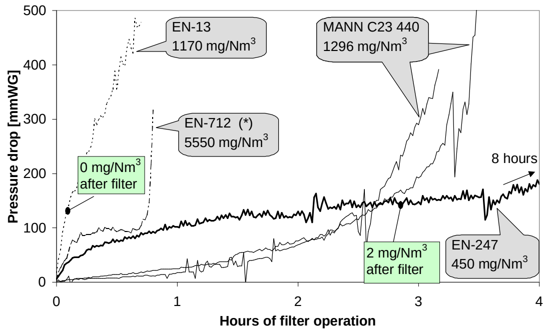

Figure 4: Pressure development for the tested cartridges. The legends show the type and average collected particle masses. The results of two isokinetic particle measurements after the filters are shown.
(*) The EN-712 filter test was interrupted by very high particle loads due to sudden massive movement of the gasifier grate.

A similar Danish low tar gasifier have later tested a similar baghouse filter setup with good results[6].

3.3 Tar removal

The tar content found in the particle samples were determined by two different methods:

1. pyrolysing samples at 600°C.
2. extracting samples with acetone.

The mass loss due to pyrolysis tend to overestimate the tar levels compared to extraction[5].

Figure 6 shows a summary of the tar determinations during the tests. The x axis is the time of determination. The "pyrolysable" and "acetone solubles" are calculated from the determined particle tar mass. These determinations are averages over the full operation time of each filter shown as vertical lines filling the time span of filter operation. The sum of tar determinations done by the Danish Technological Institute (TI) are included in the figure.

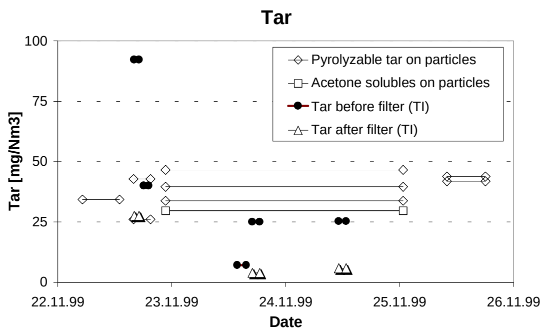

Figure 6: Tar determinations in the gas measured by particle and gas samples. Some of the pyrolysis determinations were repeated on particle samples from the same filter.

It is seen from Figure 6 that the tar content generally decreased from 25-40 mg/Nm³ to levels not exceeding 5 mg/Nm³. Extractions of the particles collected by the PE baghouse filter in acetone showed that the removed amount of tar was found on the collected particles, indicating that most of the tars had condensed on the particles during cooling. So cold particle filtration seemed to remove a significant fraction of the tar even though the initial tar levels were very low. It also indicate that even though particles in the gas are generally depreciated, certain levels of particles may improve tar removal; in the absence of particles, tar would instead condense on the inner surfaces of coolers and piping.

4 CONCLUSIONS

Two dry, cold particle filter types were successfully tested with cooled producer gas from the two-stage gasifier at DTU: Baghouse filters and four different cartridge filters.

It was demonstrated that the bag and cartridge filters had very good cleaning efficiencies (95-99 % mass). It is shown theoretically that larger filter areas could further improve the collection efficiencies of such filters for submicron particles such as those found in the producer gas. This was confirmed by the fact that the measured collection efficiencies of the cartridge filters (with larger filter areas) were the highest. The choice of filter material will also potentially improve collection efficiencies.

Summarised, baghouse and cartridge filters are effective for particle removal from producer gas with low tar content. Cartridge filters are more compact but have lower particle capacity and should be preferred as a police filter in the clean gas after the primary filter.

ACKNOWLEDGMENTS

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