Low Temperature Particle Filtration of Wood Gas with Low Tar Content

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The following theoretical equation for $\eta_s$ was proposed by Lee and Liu[4]. They included an empirical constant, $\varepsilon \approx 1.6$:

$$
\eta_s = \frac{2.58}{\varepsilon} \left( 1 - \alpha \right)^{3/2} \left( \frac{U \cdot D_p}{K \cdot R} \right)^{1/2}
$$

where $R = D_1/D_2$, $\alpha$ is the fibre packing (ratio of fibre volume to void volume), $D_1$ and $D_2$ are the fibre and particle diameters. The diffusion coefficient, $a$, can be approximated assuming spherical particles:

$$a \equiv 0.420 v_t \cdot l_{mfp}$$

$$= 0.420 \frac{3RT}{M_w} \cdot \frac{1}{\pi \cdot A_p}$$

$$= \sqrt{\frac{0.564}{n \cdot D_p}}$$

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

The relation between $\eta_s$ and the overall filter efficiency is

$$\eta = 1 - e^{-\eta_s \cdot S} \quad \text{where} \quad S = \frac{4m}{\pi \cdot D_1 \cdot \rho_f}.$$
$\alpha = 0.1$; gas velocity $U = 0.02 \text{ m/s}$; gas temperature $T = 50^\circ \text{C} = 323 \text{ K}$; particle concentration $n = 0.03 \text{ mm}^{-3}$; and fibre diameter $D = 5 \mu m$.

Figure 1c shows that the temperature has only negligible impact on $\eta_\alpha$ (if the gas velocity is kept constant). This indicates 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 $D_j$) markedly increases $\eta_\alpha$.

For submicron particles Figure 1d shows that the gas velocity are important to $\eta_\alpha$. 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. $60 \text{ Nm}^3/\text{h}$).

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.](image)

2.1 Baghouse filters

<table>
<thead>
<tr>
<th>Material</th>
<th>DT/DT 501</th>
<th>PE/PE 501</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>500 g/m²</td>
<td>500 g/m²</td>
</tr>
<tr>
<td>Area</td>
<td>0.92 m²</td>
<td>0.92 m²</td>
</tr>
<tr>
<td>Gas velocity</td>
<td>18 mm/s</td>
<td>18 mm/s</td>
</tr>
<tr>
<td>Thickness</td>
<td>2.3 mm</td>
<td>1.8 mm</td>
</tr>
<tr>
<td>Max. temperature</td>
<td>120 °C</td>
<td>150 °C</td>
</tr>
<tr>
<td>Hydrolysis resist.</td>
<td>Good</td>
<td>Bad</td>
</tr>
<tr>
<td>Packing density, $\alpha$</td>
<td>19 %</td>
<td>20 %</td>
</tr>
</tbody>
</table>

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).

![Figure 3: Particle load determinations. The approximate particle collection efficiencies during the tests are shown in parenthesis.](image)

<table>
<thead>
<tr>
<th>Material</th>
<th>Envi-EN-13</th>
<th>Envi-EN-247</th>
<th>Envi-EN-712</th>
<th>MANN-C23 440/1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber / $D_i$</td>
<td>Membr.</td>
<td>Coated</td>
<td>Cellulose</td>
<td>4MPN</td>
</tr>
<tr>
<td>Mass</td>
<td>200 g/m²</td>
<td>190 g/m²</td>
<td>130 g/m²</td>
<td>-</td>
</tr>
<tr>
<td>Area</td>
<td>2.0 m²</td>
<td>4.5 m²</td>
<td>4.5 m²</td>
<td>1.7 m²</td>
</tr>
<tr>
<td>Velocity</td>
<td>8 mm/s</td>
<td>4 mm/s</td>
<td>4 mm/s</td>
<td>10 mm/s</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>&gt;18 %</td>
</tr>
</tbody>
</table>

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:

- 25.11.99-26.11.99: Vortex mode¹, medium loads.

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 N₂-pulses were successfully demonstrated for 50 hours cleaning woodgas. The pressure of the backflush N₂ was 2.5 bar gauge. Figure 5 shows the pressure development with backflushes approximately every 60 minutes.

![Figure 5](image-url)

**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 N₂ 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](image-url)

**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](image-url)

**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 indicates 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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REFERENCES


