Mop fan and electrofilter: An innovative approach for cleaning product gases from biomass gasification

Final project report

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Content of report

Preamble 3

1.0 Project goals 3

1.1 Description of the plant components 4

1.1.1. Plant concept 4

1.1.2 Dimensioning and design 4

1.1.3 Installation work 5

1.2 Examination of tar separation with quench and ESP 8

2.0 References 13

BETH Filtration GmbH

Quench and Tar ESP

Preamble

This report summarizes the work which was carried out between April 2008 and September 2010 within the ERA-NET bioenergy project “Mop fan and electrofilter: an innovative approach for cleaning product gases from biomass gasification”. For this project a consortium was formed with the partners TU Berlin, Institute of energy engineering, Chair EVUR, Beth Filtration GmbH and ERK Eckrohrkessel GmbH - all from Germany and The University of Nottingham, School of the built environment fro the United Kingdom. The project was sponsored by the national research agencies FNR (Germany) and EPSRC (United Kingdom). The project funding was subdivided into three parts by FNR (FKZ: 22018407 (TUB / ERK) and FKZ: 22018507 (Beth Filtration) and by EPSRC EP/F038070/1 (University of Nottingham).

1.0 Project goals

As already shown in chapter 1.2 the combination of coolers or washers with ESP’s are known for quite some time and are still present in heavy industry. In smaller scale application of biomass gasification this technology has been used in pilot plants or in a commercial setup in Denmark but is not very present on the market. If reviewing literature and consulting experienced pioneers of gasification technology the use of ESP’s used to be a standard method for tar removal which has proven functionality over decades. Based on the fact that biomass gasification still faces a major tar problem it is the matter of choice to use and further improve working technologies instead of go on with multiple experiments on the back of unexperienced plant operators in the field.

In the EMF project the tar removal capabilities of a system consisting of quench and ESP were object of more detailed examination. It was goal to find out about plant settings and operation conditions to remove tar from a biomass gasifier efficiently. The initial plan was to work with different quenching media (water and RME) and to run the plant with particle free gas (hot gas filter) and with a remaining particle load (cyclone separator). In addition to that different geometries of the electrodes were planned to be tested.

Major goal is to remove tar as much as possible from the gas stream or to reduce the contents of hazardous or harmful tar substances from the gas to ensure safe and reliable operation of downstream equipment. To reach these goals the partners in the project (Technische Universität Berlin, University of Nottingham and the companies ERK Eckrohrkessel GmbH and BETH Filtration GmbH) have performed different tests on the lab scale bubbling fluidized bed gasifier installed at TU Berlin. Tar measurements were

performed at the inlet of the quench and in the outlet of the ESP to examine the separation efficiency and about the selectivity of tar separation from the gas.

Furthermore the combination of both filter technologies (ESP and mop-fan) and their fields of application were tested for the first time. The experimental data gathered from the collaborative tests is used directly in the dimensioning of new Tar-ESP so that there is a direct connection between research and economy. In doing so the dissemination of the results is ensured.

1.1 Description of the plant components

1.1.1. Plant concept

For the research at TU Berlin a system consisting of quench and ESP were designed.

The total system furthermore included the safety measures like oxygen monitoring and devices for supply and disposal of the operating media. BETH Filtration GmbH has produced and installed the following main components into the TUB gasification plant (positions in correspondence to Figure 6.11):

- Pos. 7 – Quenche,
- Pos. 8 – Wet Electrostatic Precipitator and
- Pos 9 – High voltage unit (delivered by another vendor)
- Pos 10 – Oxygen monitoring.

1.1.2 Dimensioning and design

The quench is installed downstream of the hot gas filter and upstream of the ESP. It is designed with a diameter of 260 mm and an effective height of 2.000 mm. The quench can be operated with 4 nozzles at different height-levels. With them the quench cools the gas from the gasifier from around 400°C to 80°C according to the specifications agreed upon in the consortium. As quench liquid water or RME (Rape Seed Oil Methyl Ester) can be used. The main function besides the quenching (cooling) effect is a precipitation of coarse particles and the condensation/dissolution of tar. The condensates pass through the inlet duct into the ESP. They are lead further towards the bottom of the ESP's filter housing where they can be drained out of the system. Together with the precipitated tar (and dust) from the ESP the tar condensates run through a hose into a waste liquid container (the waste liquid could eventually also be used as a substitute for RME).

The ESP consists of a cylindrical collecting electrode and a coiled discharge electrode. At the discharge electrode a high voltage of 60 kV (peak) and 50 mA (arithmetic) is applied.

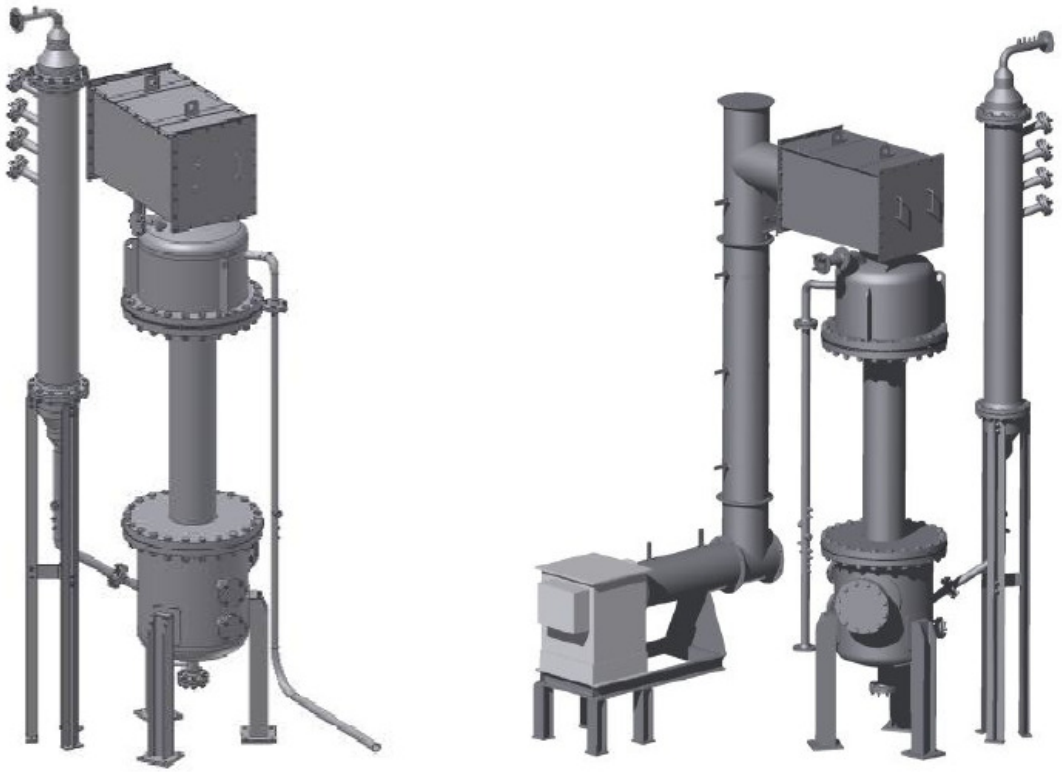

Figure 1.1: Design of quench and ESP (left) as built with HV-supply (right)

1.1.3 Installation work

After the design phase (creation of manufacturing drawing) and the selection of the manufacturer, the system was installed at TU Berlin. The individual steps are mentioned below:

- Installation of the steelwork
- Installation of the filter casing incl. all inner parts
- Alignment of the electrode system
- Installation of the quench
- Installation of the switch cabinet (low voltage)
- Installation of the HV-unit and the protective tube for high voltage connection
- Installation of the oxygen measurement (shut off the high voltage if the oxygen concentration is above 3 Vol.%)
- Installation of the valve table for water injection
- Installation of the RME supply unit
- Wiring of high and low voltage
- Connections of the valve table.

The individual steps of the installation are shown in the following images.

Figure 1.2: The bottomof the Tar-ESP was set into position at TU Berlin.

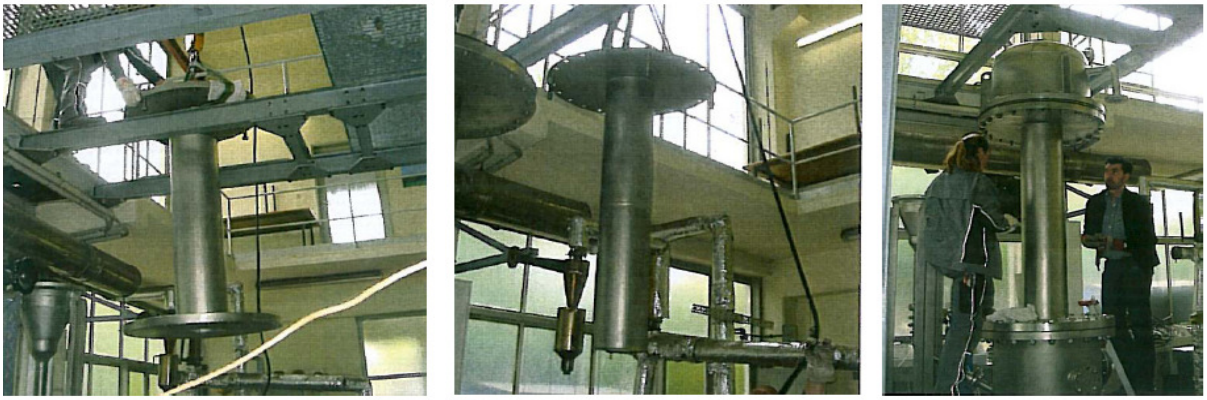

Figure 1.3: Middle part of the ESP, Collecting electrode and installation of the filter head.

Figure 1.4: General view of the plant (ESP and Quench), incl. HV-unit and switch cabinet.

1.1.4 Test runs

After installation all functions of the system had to be tested. According to the proposal

the following parameters and their influence on separation efficiency and selectivity of the precipitation of individual tar components were planned to be examined:

- Quench liquids
  - Water
  - RME
  - (vegetable oil)
- Temperature
  - Gas temperature inside the ESP
  - Influence of the quench
  - Variations of the secondary voltage (high voltage)
  - Variations of the secondary current
  - Tar precipitation depending on the retention time
  - Particles loading of the gas
- Examination of special problems

  Deposits of individual tar components (like heteocyclic compounds from coal processing), cristallisation and condensation result in downtime and induce to an uneconomic operation of a commercial ESP. If also occurring in biomass gasification, solutions and improvements for such problem should also be identified.

First test showed that the relative small volume flow of 6 Nm^3/h was not significantly heating up quench and filter system. These parts of the plant are not heated. So the resulting temperature of the ESP was near ambient temperature or just slightly 3 - 5 °C above it. It took a couple of hours until the quench reached temperatures in the range of 50 °C.

A minimum of 35 °C was set for the filter inlet temperature. To reach this temperature some hours during preheating of the system are needed. To shorten this time an additional heater was applied to one of the nozzle levels. Due to the fact that the temperature dropped in the filter nearly by itself from about 400 °C at the inlet pipe to 50 °C at the quench outlet it was decided not to use water as quenching liquid. This would have cooled the system even further down. So RME only was used for the tests.

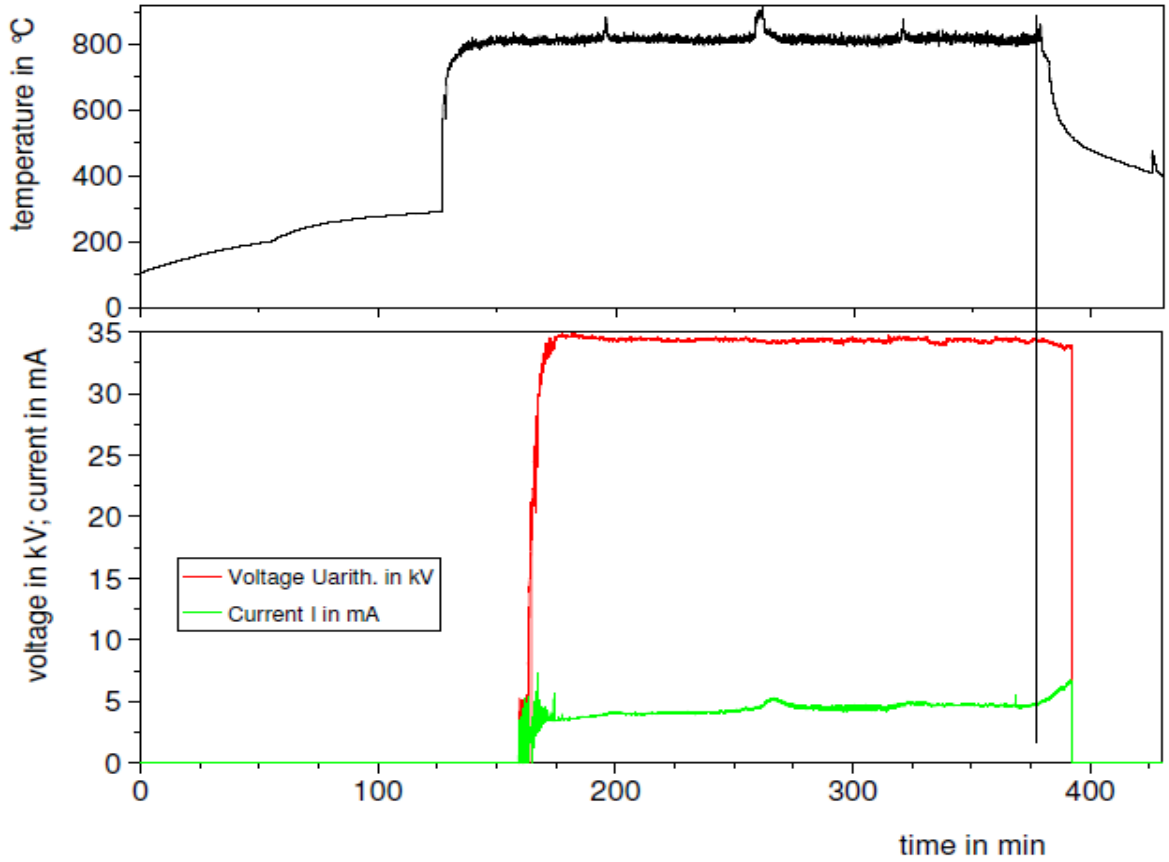

Figure 1.5: Filter current and voltage distribution during a consecutive run.

In Figure 1.5 filter current and filter voltage are shown. They are quite uniform during the run. In the beginning the startup temperature of the filter was not reached so that the filter started up a bit after the gasifier produced gas. Tar and water in the gas and filter lead to spark over which could be heared. After a while the system ran calm and steadily through the duration of the run. At the end the reactor was set under nitrogen while the filter remained in operaion. The dottet line in the figure shows this. Under nitrogen the electric field behaves different from the normal operation conditions under gasification atmosphere.

1.2 Examination of tar separation with quench and ESP

The GC/MS was connected online with the system. Sample points were realized after the hot gas filter before entering the quenche and at the outlet of the ESP. In Figure 1.6 the concentration of selected tar species are shown. The value for naphthalene changed during the run whereas the other compounds showed less change. The first four measurements were done with the raw gas and then the sampling was switched to the point after the ESP. The last two values are downstream the ESP. It is obvious that the heavier tar compounds phenanthrene, pyrene but also fluorene are removed completely whereas naphthalene is reduced compared to the last raw gas measurements.

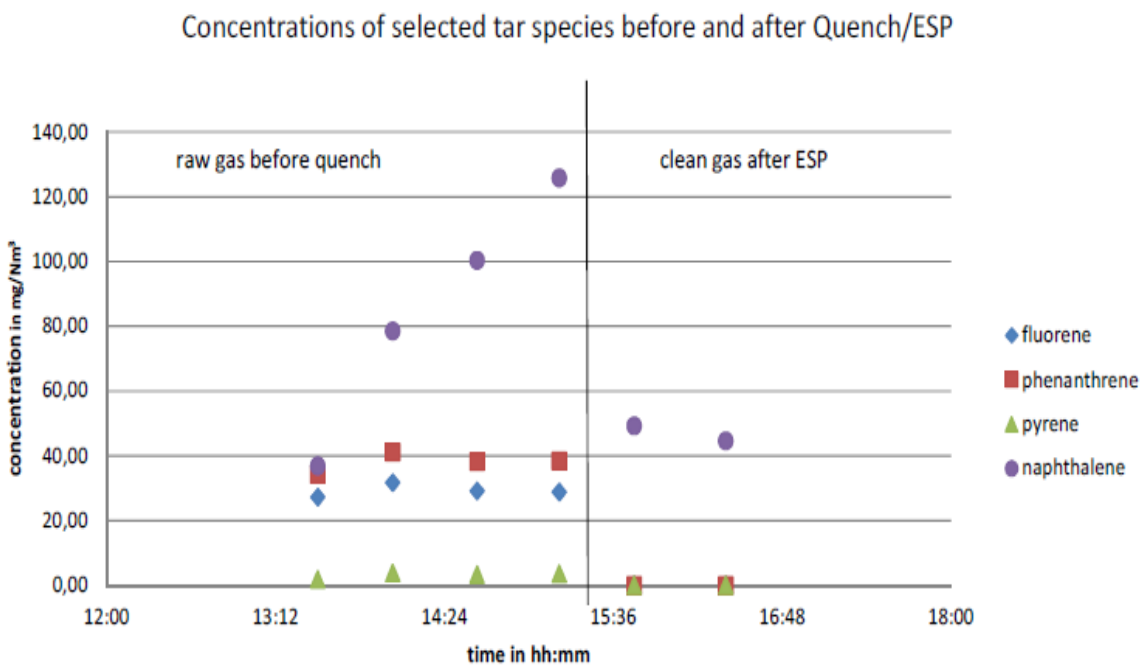

Figure 1.6: Online GC/MS measurement results for selected tar species in the product gas; Last two measurements were taken behind quench section and ESP.

When comparing with Figure 1.7 where benzene and naphthalene are shown the reduction is nearly not visible.

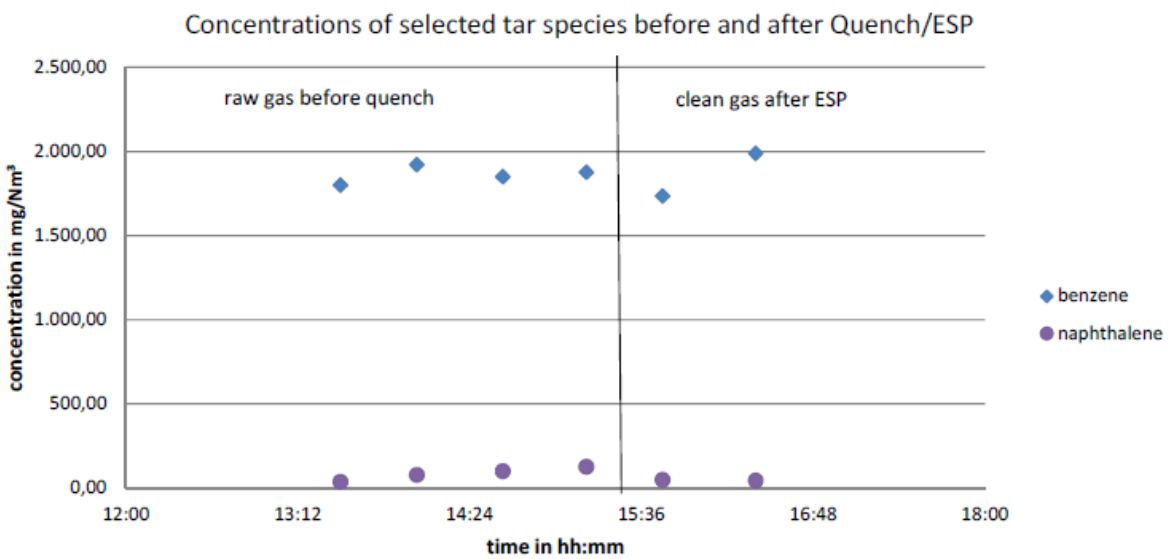

Figure 1.7: Benzene (and naphthaline for comparison with figure 1.6).

The Ion Chromatograms in Figure 1.8 show more clearly what is meant. On the left hand side the peaks formed from the single ring aromatic compounds such as benzene, toluene, xylene, phenol or styrene can be found.

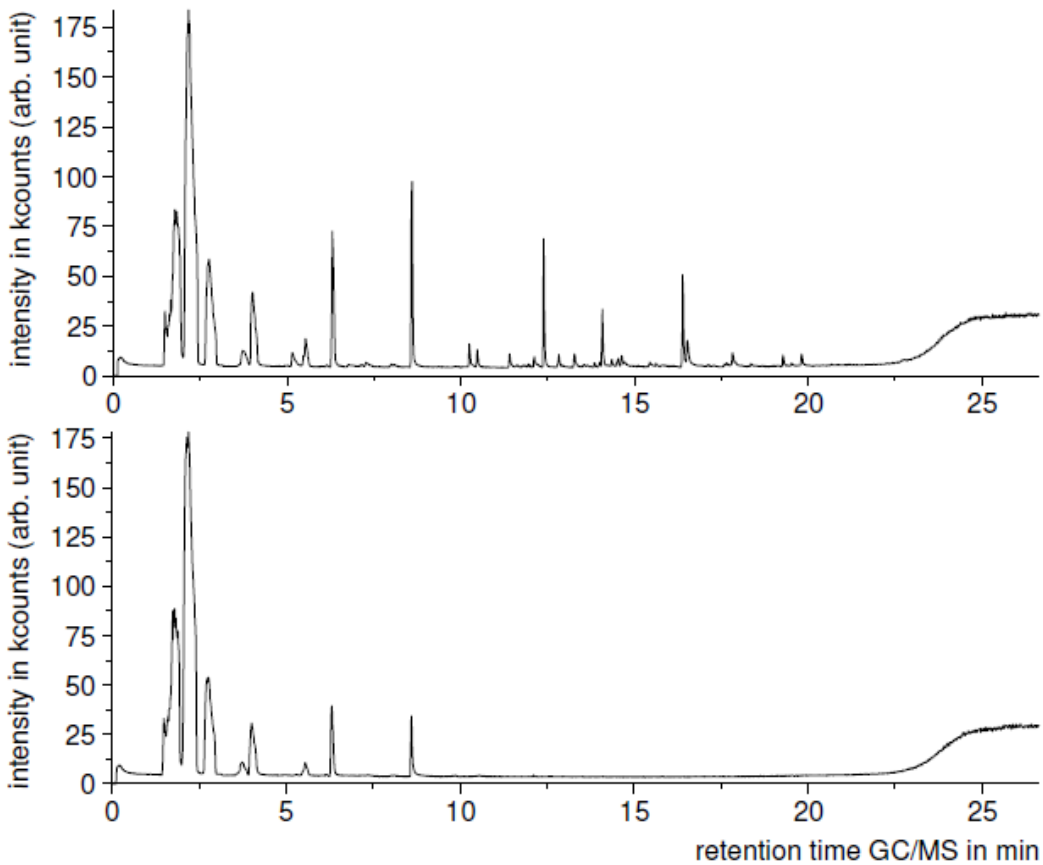

Figure 1.8: GC/MS ion chromaograms of measurements before (top) and after (bottom) quench / ESP.

It is obvious that all heavy tar is removed from the gas. The last peak visible in the bottom spectrum is naphthalene. The level of the more complex PAH go to zero whereas naphthalene is just reduced. Benzene (the largest peak on the left hand side in the spectrum) is not effected at all by the system. The same is true for Toluene. At 5 minutes residence time the phenol peak is missing in the second spectrum as well. This could be due to dissolution of Phenol in condensing water.

Figure 1.9 shows the residue which is collected in barrels. It consists mainly of water. The tar is very little miscible with water and floats on top of the solution. Some water soluble compounds from the tar or the RME colour the water light brownish.

Figure 1.9: Tar - RME - Water misture from ESP outlet.

The oily phase was dissolved in acetone and then analysed with the GC/MS. Qualitatively most common tar species which can be detected by SPA, tar protocol or online GC measurements are present in the washing liquid. Figure 1.10 shows the reconstructed ion chromatogram of this analysis. The largest biodiesel peak at around 24 minutes is not measured. The higher tar compounds with more than three rings eluate together with the biodiesel components in the sample. Light tar compounds such as benzene and toluene as well as other abundant tar species were found.

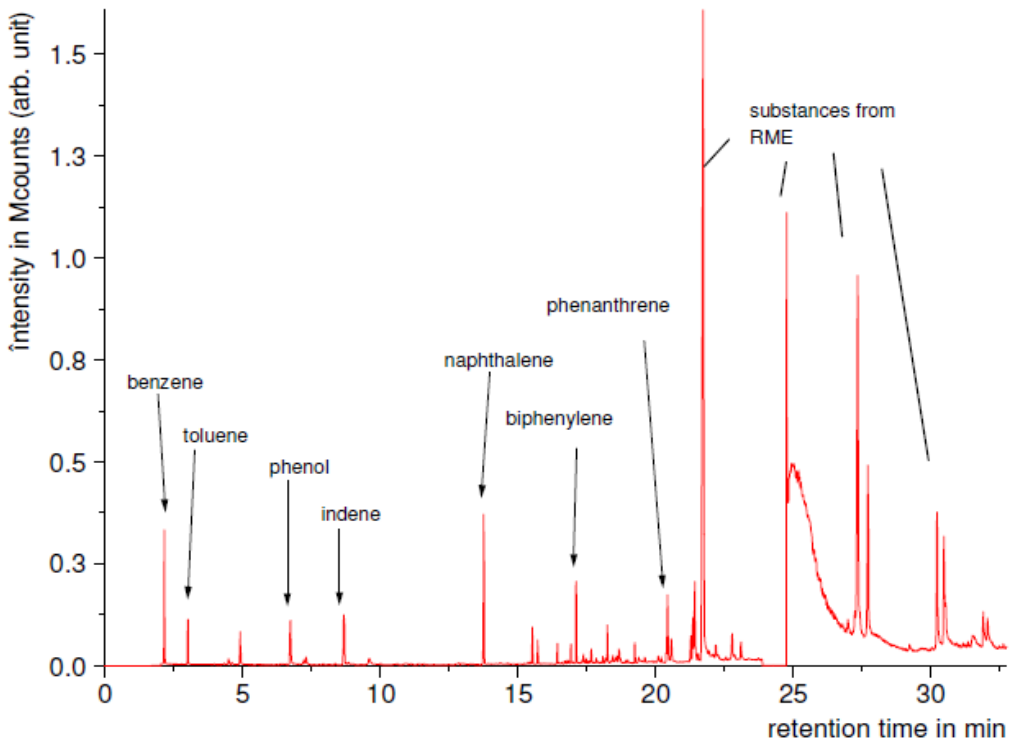

Figure 1.10: GC/MS analysis of biodiesel (RME) from ESP containing tar.

In order to determine tar removal efficiencies, the term tar has to be specified. Reported efficiencies of 99,4% removal [Sei/1928] were measured according to a method of Franz Fischer without specifying a source. Van Paasen et al. [vPa/2004] used the solid phase absorption method (SPA) and correlated the results to the 5 class tar model of ECN. Here no removal rate is given but numeric values for the individual classes. In this project we analysed tar species before quench and after ESP by online GC/MS: The values are fluctuating. Light aromatics are only little influenced by the system. As seen in Figure 5.7 also the light onering aromatic compounds are found in the RME sample from the ESP. A light reduction for benzene was observed ranging from 5 – 10 %. Naphthalene is not removed completely either but a reduction 80 – 95 % was observed. Water soluble compounds were removed very efficient as well as tar compounds more complex than the two-ring-PAH naphthalene. Heavy tar compounds are nearly completely removed (or not detected by GC/MS).

2.0 References

[Sei/1928] Seidenschnur, F. and Groh, E.: Untersuchungen über mechanische und elektrische Teerabscheidung. Brennstoff-Chemie, 11, 9 (1928), 188-193

[vPa/2004] van Passen, S. V. B., Rabou, L. P. L. M. and Bär, R.: Tar removal with a wet electrostatic precipitator (ESP); A parametic study. Proceedings of the 2nd World Conference and Technology Exhibition on Biomass for Energy, Industrie and Climate Protection. Rome 2004