



Energy research Centre of the Netherlands

Tar dew point analyzer as a tool in biomass gasification

B.J. Vreugdenhil

J. Kuipers

Presented at the European Biomass Conference, Valencia, 2 - 6 June 2008

TAR DEW POINT ANALYZER AS A TOOL IN BIOMASS GASIFICATION

B.J. Vreugdenhil, J. Kuipers
Energy research Centre of the Netherlands (ECN)
PO Box 1, 1755 ZG, the Netherlands
vreugdenhil@ecn.nl, kuipers@ecn.nl

ABSTRACT: Application of the Tar Dew point Analyzer (TDA) in different biomass based gasification systems and subsequent gas cleaning setups has been proven feasible. Such systems include BFB gasifiers, CFB gasifier and fixed bed gasifiers, with tar crackers or different scrubbers for tar removal. Tar dew points obtained with the TDA give direct insight in the performance of the gas cleaning section and help prevent any tar related problems due to condensation. The current TDA is capable of measuring tar dew points between -20 to 200°C. This manuscript will present results from 4 different gasification setups. The range of measured tar dew points is -7 to 164°C with comparable results from the calculated dew points based on the SPA measurements. Further detail will be presented on the differences between TDA and SPA results and explanations will be given for deviations that occurred. Improvements for the TDA regarding future work will be presented.

Keywords: tar, tar removal, gasification, circulating fluidized bed (CFB), fixed bed

1 INTRODUCTION

Biomass gasification is a technology which is growing world wide. It is increasingly recognized that biomass gasification can contribute significantly to reducing the greenhouse gas emissions. Fields of interest in biomass gasification are generation of heat and power, using gas engines or gas turbines. Other high grade applications focus on the production of chemicals or fuels. High grade in this case also means that a more sophisticated gas cleaning is involved.

Depending on the gasifier, bed material, operating temperatures, residence times and gasification medium, the resulting gas contains a certain amount of tar. Tar is a description for hydrocarbons which have a larger molecular weight than benzene. Low temperatures (<750°C) result in lower molecular weight tar molecules which contain more heterogeneous atoms. At higher temperatures (>750°C) these tars will react with other gas molecules, like benzene, to form larger tar molecules. Their respective reactivity will go down, but their dew point will increase.

When running a gasifier connected with down stream equipment the temperature at which it is operated is very important for the entire system. An important issue is keeping the temperature above the dew point of the first condensable tar. The temperature at which the first tar molecules will start to condense is based upon their relative concentration. Therefore results from a quantitative measurement for tar, Solid Phase Adsorption (SPA), can be translated into an average dew point. However, this method is time consuming, and regarding to fouling of engines or reactors therefore is not an option.

The alternative is an online measurement technique, which is capable of measuring tar dew points in producer gas, enabling safer operation and preventing any unnecessary down time due to fouling. This online technique is developed at the Energy research Centre of the Netherlands (ECN) in close cooperation with Michell Instruments (MI). The Tar Dew point Analyzer (TDA) has been tested at ECN, as well as at different locations throughout Europe, behind different gas cleaning units.

The following chapters will describe the development of the TDA, the principle on which the technique is

based, the verification and validation that took place to check the accuracy and the measurements performed at different sites throughout Europe. Some remarks for improvements will also be presented

2 DESIGN AND DEVELOPMENT

2.1 Background

Tar in biomass gasification processes is recognized as a major problem. Normally counter measures to prevent fouling can only be taken after the fouling has taken place. Techniques of preventing or reducing tar in the producer gas are numerous, however in most cases tar is not removed up to 100%. However, when going to more sophisticated processes, like producing chemicals, fuels or Substitute Natural Gas (SNG) the need to know the dew point of the tar in the producer gas increases.

This has been one of the drivers to develop an analyses technique that provides online information about the quality of the producer gas. In close cooperation with Michell Instruments, ECN developed the tar dew point analyzer. The TDA can provide information about the dew point of tar components in the gas. It can also be used as a guard device, when monitoring one specific temperature. Upon onset of fouling it can activate counter measures to prevent tar condensation.

2.2 Working principle of the TDA

A picture of the TDA is given in Figure 1. This picture shows the gas stream entering from the top and leaving the bottom of the measuring cell. The measuring cell is cooled with a vortex cooler, for which the pressurized air is entering from the left (top line) and leaving at the bottom (left line). The fiber optics are connected on the right side of the measuring cell.

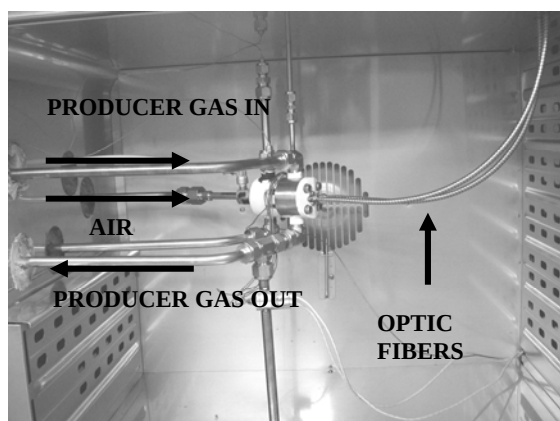


Figure 1: Measuring cell of the TDA

The key element of the TDA is the measuring cell. The fiber optics focuses a beam of light on the measuring cell, which is an optical surface. The reflection is measured and converted to a mVolt signal. This signal is plotted against the optical surface temperature and from the response curve the tar dew point is obtained.

A typical response curve is depicted in Figure 2. The bent in the response curve is the onset of condensation of tar on the optical surface and thus corresponding with the tar dew point. Experience from measurements throughout the years showed that this bent typically appears when the signal is around 300 mV.

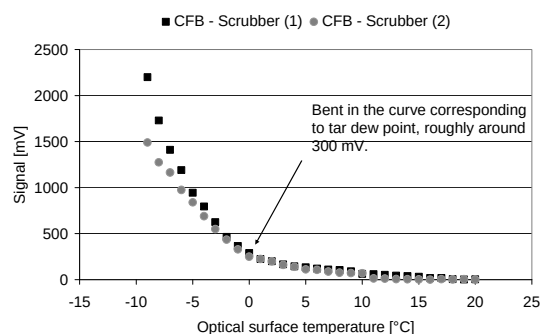


Figure 2: Dew point curves measured in gas from a CFB gasifier and after a scrubber.

The TDA has been validated using a tar condenser to create an artificial tar dew point. The tar dew point will correspond with this temperature and subsequently the TDA was used to measure this temperature. The validation of the TDA with the tar condenser showed a maximum deviation of 3°C from the condenser temperature.

SPA measurements were performed to calculate the tar dew point. In Figure 3 these results are plotted and show a good comparison between the SPA calculated dew points and the TDA measured dew points. A full description about the design and the validation of the TDA is given by van Paasen et al. [1].

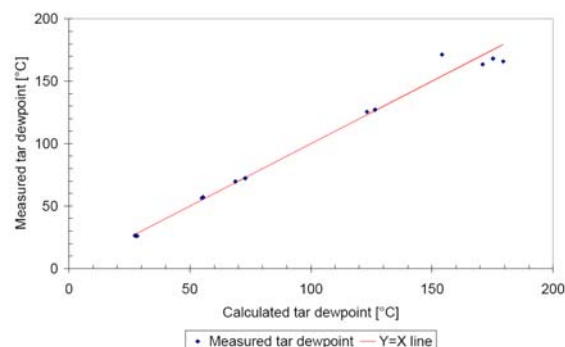


Figure 3: Comparison of the calculated tar dew point (SPA) against the measured tar dew point (TDA)

3 EXPERIMENTAL RESULTS

3.1 Measurements

The TDA has been used at different sites and for different applications. The following paragraphs will describe the results obtained with the TDA used in the different systems between 2006 and 2008.

1. Gas from a Bubbling Fluidised Bed (BFB) gasifier (dry gasification) subsequently cleaned with a catalytic tar cracker, after the tar cracker;
2. Gas from a BFB gasifier (steam gasification) subsequently cleaned with a catalytic tar cracker, after the tar cracker;
3. Gas from a fixed bed gasifier with an RME scrubber and a wet ESP;
4. Gas from a Circulating Fluidised Bed (CFB) gasifier (BIVKIN [2]) after an oil scrubber (OLGA [3]).

3.2 Set-up and procedure

The set-up depicted in Figure 4 shows the lay-out of the TDA. The system is protected against dust using a hot gas filter (1), the pump (5) is protected against tar related fouling by using an oil impinger (4) to co capture any tar components. The gas can be dried when the tar dew point is lower or around the water dew point. This dryer (2) consists of a membrane which selectively removes water. The heart of the TDA is the optical surface (3).

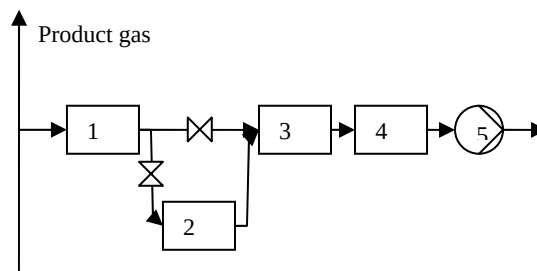


Figure 4: Setup of the TDA, depicting a filter (1), a dryer (2), an optical surface placed inside an oven (3), an impinger with oil (4) and a pump (5).

The pump draws product gas through the system. Based on the required measurement (above or below water dew point) the valves between the filter and the sensor will be open or closed. The system until the sensor and behind the sensor is heated well above the expected tar dew point (~40°C higher). This is required to prevent unnecessary fouling in the lines. The optical surface is

placed in an oven as is shown in Figure 1. On the optical surface a cold spot is generated by a vortex cooler and the reflection of light from the optical surface is measured at this temperature. The temperature is gradually decreased ($\sim 3^\circ\text{C}/\text{min}$) and the signal will increase as can be seen in Figure 2. When the signal reaches 2000 mV the measurement is stopped and the sensor is regenerated. This is done by stopping the air to the vortex cooler and venting with product gas to carry off any tar vapors. It takes about 15 minutes to measure a dew point curve and about 15 minutes to regenerate the optical surface.

In case of severe fouling of the sample line and/or optical surface, the temperature is set at the maximum value and air is sampled. The TDA will be regenerated when the measured dew point is equal to the water dew point of the sampled air. Air is also being sampled during an experiment to check if any tar condensation has occurred in the sample lines.

3.3 Experimental results

The procedure for measuring with the TDA is described in previous paragraphs. Together with SPA measurements this results in a set of data that is given in Table I. This table shows for all four different measurements the results of the TDA and the results of the SPA measurements. The SPA measurements are translated into tar dew points using an in-house model, which is also available online [4]. From Table I it is obvious that for different applications the TDA works pretty well. However, there are a few exceptions where the TDA dew point predicts a quite different dew point than is calculated with the SPA results. These results are also depicted in Figure 5 and from this graph it is quite clear which points deviate from the $X=Y$ line.

Table I: Tar dew point measurements and calculated tar dew points based on the SPA method, using an in-house model.

	TDA [$^\circ\text{C}$]	SPA [$^\circ\text{C}$]
1. BFB gasification (dry)	164	166
	146	150
2. BFB gasification (wet)	93	88
	91	80
	90	86
	83	50
	82	39
3. Fixed bed gasification	62	33
	67	28
4. CFB gasification	-4	-3
	-7	-3

The first system is the BFB gasifier (dry gasification) with a tar cracker. The gas from the tar cracker was measured with the TDA and sampled for SPA. These results show a comparable tar dew point as can be seen from Table I.

The second system is the BFB gasifier (steam gasification) with a tar cracker. This system is comparable with the first system, only steam is used for the gasification. The results are lower tar dew points compared to the dry gasification. The results depicted in Table I do not completely match. The first two values for both TDA and SPA dew points are from a duration test and are averages. They differ 5 and 11°C respectively and this is

due to the detection limit of the SPA method. Some values for heavier tar compounds are below $5\text{ mg}/\text{m}_n^3$. This does not mean they are not in the gas, but cannot be detected. Calculations show that for these compounds just $1\text{ mg}/\text{nm}^3$ can already increase the calculated tar dew point with tens of degrees. The third value is from a second duration test under the same conditions and the variation is less. The last two values are from the same duration test. At the end of this test the temperature was lowered 100°C in two steps. This will give a lower tar dew point, which is proven with the SPA results. However the TDA does not give a tar dew point below the 80°C . When the TDA was used to measure the tar dew point of air it also resulted in a temperature of 80° . Hence it was concluded that the optical surface and the sampling line was fouled. The normal 15 minutes regeneration period was not sufficient, but a longer regeneration of the optical surface and sample lines resulted in a clean system.

The third system is a fixed bed gasifier with an RME scrubber and a wet ESP. The gas after the ESP is sampled. Based on the SPA results the tar dew point should be around 30°C , however the TDA results show a tar dew point between 62 and 67°C . The difference between the two methods is that with the SPA only a selection of tar compounds is analyzed and used for the dew point calculation. However, the RME scrubber saturates the gas with RME oil. These compounds are not detected with the SPA method, but they do condense on the optical surface of the TDA and cause a higher tar dew point.

The fourth system is the CFB gasifier with an oil scrubber. As can be seen from Table I the oil scrubber used after this gasifier results in very low tar dew points. Also the results from the SPA and the TDA match very well.

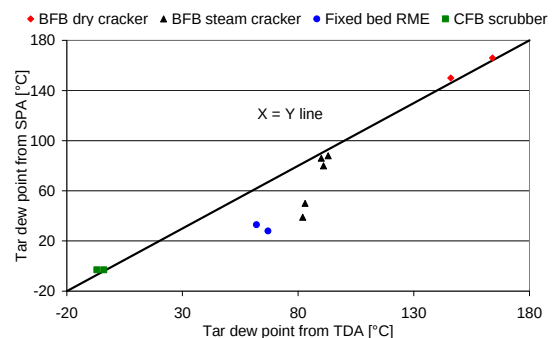


Figure 5: Comparison between tar dew points obtained with the TDA and with the SPA method.

4 FUTURE WORK

4.1 Low temperature measurements

The TDA uses a membrane for drying the producer gas when the dew point is below the water dew point. However, this membrane is not reusable upon fouling. Future work focuses on a membrane which is temperature resistant, stable under reducing conditions, regeneration of the membrane and able to efficiently remove water. Some tests have been performed with a new regenerative membrane showing excellent results.

4.2 High temperature measurements

The optical fibers in the TDA are not capable of withstanding temperatures over $\sim 200^{\circ}\text{C}$. This defines the physical limitation of the tar dew point analyzer. Future work focuses on higher temperature resistant fiber optics and the temperature stability of the optical surface. A partial redesign for measurements at higher temperatures is also considered.

4.3 Continuous operation

The TDA has been used manually so far. However in practice it would be preferred to have an online apparatus that can be controlled from behind an operating terminal. Future work focuses on developing software for automating the different measurement cycles. These are the measurement of a tar dew point, the regeneration of the optical surface and the continuous monitoring of a defined temperature.

5 CONCLUSIONS

The TDA has been proven to operate successfully behind several gasifiers with different gas cleaning systems. The range of the current TDA is between -20 to 200°C .

Measurements behind a BFB gasifier with a catalytic tar cracker showed high tar dew points for gasification processes without steam and substantially lower tar dew points for processes with steam gasification. However, from these measurements it became apparent that within time the optical surface and the sample line of the TDA can be substantially fouled and the 15 minutes regeneration period is not sufficient. Checking the tar dew point with just air will reveal if the optical surface and sample line is fouled and longer regeneration time is needed.

The TDA also revealed that when operating a system with a RME scrubber the possibility of saturating the gas with oil from the scrubber exists. Standard SPA measurements and dew point calculations based on tar concentrations will not point out any increase in dew point, because the SPA method is not suitable for measuring RME oil concentrations. The TDA however is based on physical condensation and therefore will predict more accurate tar dew points. This is also the explanation for the underestimation of the calculated tar dew point with the SPA results as can be seen in Figure 5.

The CFB gasifier with an oil scrubber showed excellent tar removal properties. The measured and calculated tar dew point after the oil scrubber was below 0°C . The deviation between the two methods is very small.

Future work consists of three areas in which the low temperature measurements, below water dew point and high temperature measurements will be the focus of this work.

6 REFERENCES

- [1] S.V.B. van Paasen et al., TAR DEWPOINT ANALYSER, For application in biomass gasification product gases, May 2005.
- [2] <http://www.host.nl/en/gasifiers>
- [3] <http://www.olgatechnology.com>
- [4] <http://www.thersites.nl>