

# INFLUENCE OF OPERATIONAL PARAMETERS ON TAR FORMATION AND MAIN GAS COMPONENTS DURING ALLOTHERMAL STEAM GASIFICATION

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**ABSTRACT:** Gasification is considered to be a promising way to use biomass with high efficiency in combined heat and power production, for the production of second generation biofuels and in the chemical industry. This paper reports experimental results concerning the influence of operational parameters during allothermal steam gasification on tar formation and on the main gas components.

During the experiments in a bubbling fluidized bed gasifier, the following operational parameters were varied: temperature (700 °C → 840 °C), pressure (1 → 2.5 bar absolute) and steam/biomass (S/B) ratio (0.8 → 1.2). Three biomass fuels, standard wood pellets (Agrol), Willow pellets and pellets from dried distiller's grains with solubles (DDGS), were investigated. It was found that rising temperature reduces the total tar content and affects more heterocyclic and light aromatic than polyaromatic compounds. An increase in the S/B-ratio leads to a decreasing total tar content, for low temperatures the maximum is observed at medium S/B. Increasing pressure leads to increasing total tar due to increasing light PAH's, the effect is most distinct for low (S/B). The effects on the main gas components are as can be expected by equilibrium considerations.

**Keywords:** allothermal gasification, tar, fluidized bed, biomass

## 1 INTRODUCTION

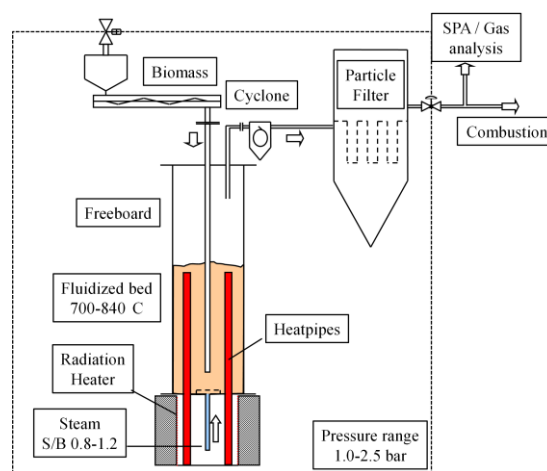
The conversion of solid fuels to a gaseous secondary energy carrier has many advantages since a combustible gas is applicable in a large number of processes. The gas can be used for power production in internal combustion engines, turbines, fuel cells or Stirling engines [1]. The gas can be upgraded further to substitute natural gas that can be stored and transported in the existing gas grid. Liquid energy carriers like Fischer-Tropsch diesel can be produced for the transportation sector. Allothermal, steam blown fluidized bed gasifiers are especially suited since they produce high calorific, H<sub>2</sub>-rich producer gas with no nitrogen dilution. An overview over existing technologies is given in [2]. Before the application in the mentioned downstream processes, the raw producer gas from the gasifier needs to be upgraded. Impurities like tar and sulphur species have to be removed to prevent damage of equipment and the gas composition has to be shifted to the required H<sub>2</sub>/CO ratio for some applications. In general, secondary steps are needed. To facilitate the secondary steps, the possibilities of influencing the gas quality inside the reactor (tar evolution, gas composition) should be exploited. The operating conditions temperature, S/B ratio and pressure have a large influence and are investigated in this work.

## 2 MATERIALS AND METHODS

### 2.1 The gasifier

The experimental work was carried out in a bubbling fluidized bed gasifier at the Technische Universität München. A scheme of the setup can be seen in Figure 1. The reactor vessel is made of high temperature resistant steel, has an internal diameter of 154 mm and a length of 1500 mm. It is designed to work at pressures up to 5 bars at a maximum temperature of 900 °C. As gasification medium superheated steam was used in the experiments. The heat, required for the endothermic process, is provided by electrical heating with a maximum heating power of 12 kW. Alkali metal heat pipes are used to

transport the heat from the radiation heater into the fluidized bed. The axial temperature profile is monitored with thermocouples every 100 mm. A very uniform profile can be observed inside the fluidized bed which has a height of ~700 mm. As bed material olivine was used with a Fe<sub>2</sub>O<sub>3</sub> content of 9.8 wt%.



**Figure 1:** Gasification reactor

The biomass is fed into the reactor with a pressurized screw driver and a drop tube into the bottom of the fluidized bed. The drop tube is flushed with a small flow of nitrogen to prevent producer gas and steam to enter the screw driver. Due to the size of the system only pelletized fuels can be fed into the reactor. The screw driver can be refilled during operation with a lock hopper cycle. During the refilling process compressed air enters the gasifier and leads to a temporary (~3-5 min) decrease in the main gas concentrations. The producer gas is cleaned of course particles in a cyclone and then passes a ceramic candle filter to remove the fines. After the filter a valve expands the pressure of the producer gas to ambient pressure. A slip stream is channelled to the gas analysis and an access point for taking SPA samples is installed. The dry gas composition (H<sub>2</sub>, CO, CO<sub>2</sub>, CH<sub>4</sub>) is monitored online

using a gas analyser S700 from SICK|MAIHAK. The producer gas is burnt in a combustion chamber. From the exit of the gasifier until the burning chamber all pipes and equipment (cyclone, filter) are trace heated to at least 320 °C to prevent tar from condensation.

## 2.2 The biomass fuels

In the experiments three types of biomass fuels have been investigated. Standard wood pellets (Agrol, a mixture of approx. 80% spruce and 20% pine), Willow pellets and DDGS pellets (dried distiller's grains with solubles). The proximate and ultimate analysis of the fuels is given in Table 1.

**Table 1:** Proximate and ultimate analysis of biomass fuels

	Agrol	Willow	DDGS
Water cont. %	4.8	8.5	6.9
Ash % db	0.1	3.2	4.8
Volatiles % db	85.6	78.4	79.9
Fix C % db	14.3	18.5	15.4
H <sub>u</sub> MJ/kg db	20.6	18.4	19.5
C % waf	49.9	51.3	49.5
H % waf	6.8	6.9	7.7
N % waf	0.1	0.6	5.3
S % waf	0.1	0.1	0.9
O %(100-Σ)	43.2	41.1	36.6

Agrol has the highest heating value, the highest content of volatiles and the lowest ash content. Willow has the lowest heating value and the highest content of fixed C, its ash content is significantly higher compared to Agrol. DDGS has by far the highest ash content. The ultimate analysis shows that DDGS has a very high nitrogen and sulphur content compared to the two kind of wood pellets.

## 2.3 Experimental procedure

The three biomass fuels were gasified at different operating conditions to investigate the influence on tar composition and main gas components. Temperature, pressure and steam to biomass ratio (S/B) were varied during the experiments. The S/B ratio is defined as  $S/B = \text{massflow}_{\text{steam}}/\text{massflow}_{\text{fuel}}$  in this work. The operating conditions that have been investigated are gathered in Table 2.

**Table 2:** Operating conditions during the gasification of the biomass fuels

Agrol			
	750 °C	800/790 °C	840 °C
S/B 0.83	1 / 2.5 bar	1 / 2.5 bar	1 bar
S/B 1.0	1 bar	1 bar	1 bar
S/B 1.2	1 / 2.5 bar	1 / 2.5 bar	1 bar
Willow			
	750 °C	800/790 °C	840 °C
S/B 0.86	1 / 2.5 bar	1 / 2.5 bar	1 bar
S/B 1.0	1 bar	1 bar	1 bar
S/B 1.2	1 / 2.5 bar	1 / 2.5 bar	1 bar
DDGS			
	700 °C	750 °C	800 °C
S/B 0.9	1 bar	1 bar	1 bar
S/B 1.2	1 bar	1 bar	1 bar

For Agrol and Willow the same measurement program has been performed. 9 different operating conditions were investigated for atmospheric gasification and 4 for

the pressurized gasification. For DDGS 6 different operating conditions have been investigated, it has not been gasified under pressure and the temperatures were kept lower due to low ash melting temperatures. In the experiments at atmospheric pressure between 2.0 → 2.6 kg/h of biomass was fed into the gasifier, the steam flow was adjusted in each case to set the requested S/B ratio. To keep the fluidization in the same range during the pressurized experiments the steam mass flow had to be increased to keep the volume flow constant. To gasify with similar S/B ratios also the mass flow of the biomass fuel was increased to 4.5 → 5.3 kg/h. As expected the required heating power increased, nevertheless the temperature in the fluidized bed remained constant and the temperature profile uniform.

The experiments were performed after the following procedure: The gasifier was heated up and fluidized with steam. When the desired temperature and pressure was reached the biomass was fed into the reactor with the appropriate mass flow to set the S/B ratio. After reaching stable conditions a SPA sample was taken, then the operating conditions were changed for the next operating point. As a criterion for stable conditions the main gas components were chosen. When the gas composition was stable for a time period of ~5-10 min (which took between 20 and 30 min) the SPA sample was taken. The SPA samples were sealed, stored dark and cool before shipped to KTH (Sweden) for analysis. For one SPA sample 100ml of producer gas were drawn up with a syringe over an amino phase column. The results of the analysis are given by KTH as  $\mu\text{g}_{\text{tar}}/\text{sample}$ . With the assumption that the steam in the gas is condensed in the amino phase and does not enter the syringe in vapour form, this value was converted into  $\text{g}_{\text{tar}}/\text{m}^3_{\text{dry}}$  in this work.

## 3 RESULTS AND DISCUSSION

### 3.1 Influence of operating conditions on main gas composition

The operating conditions have a great influence on the main gas components by affecting the chemical reactions. Some of the most important heterogeneous and homogeneous reactions taking place in an allothermal steam gasifier are gathered in Table 3.

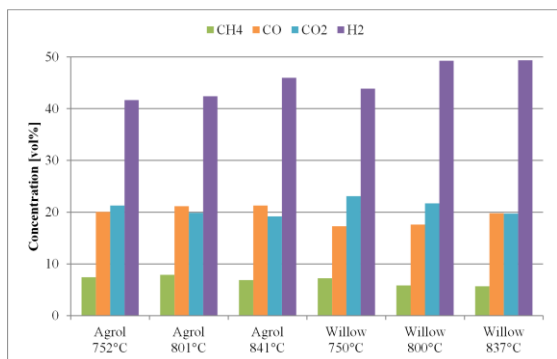
**Table 3:** Important gasification reactions (see [3] and [1])

Chemical equation	$\Delta H$ kJ/mol	Name
$\text{CH}_4 + \text{H}_2\text{O} \leftrightarrow \text{CO} + 3\text{H}_2$	206.3	Steam reforming
$\text{CO} + \text{H}_2\text{O} \leftrightarrow \text{CO}_2 + \text{H}_2$	-40.9	Water gas shift
$\text{C} + \text{H}_2\text{O} \leftrightarrow \text{CO} + \text{H}_2$	118.9	Water gas reaction
$\text{C} + \text{CO}_2 \leftrightarrow 2\text{CO}$	159.9	Boudouard
$\text{C} + 2\text{H}_2 \leftrightarrow \text{CH}_4$	-87.4	Hydrogasification

The well-known principle of le Chatelier implies that a chemical system in equilibrium reacts on a change by shifting the equilibrium to counteract the change. Certainly the equilibrium will not be reached in a biomass gasifier due to low temperatures and short residence time. Nevertheless the qualitative change in the gas composition due to a change in the operating conditions can be estimated by the reactions in Table 3. In the following the results of the measurements are shown.

In Figure 2 the influence of a change in the reactor

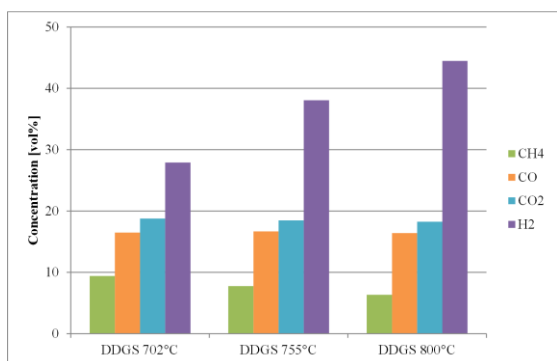
temperature during the gasification of Agrol and Willow at atmospheric pressure and a S/B ratio of 1.0 is shown.



**Figure 2:** Influence of temperature during Agrol&Willow gasification (S/B 1.0, 1 bar)

For both fuels the same qualitative change in the gas composition can be observed: H<sub>2</sub> and CO are increasing, CH<sub>4</sub> and CO<sub>2</sub> are decreasing. The same result obtained from equilibrium calculations is reported by Zhao et al. [4] who found CO to increase while CO<sub>2</sub> and CH<sub>4</sub> decreased when the temperature was increased from 650 °C → 950 °C. This can be explained with the reactions of Table 3. Through higher temperatures the equilibrium of the endothermic reactions is driven to the products side. Hence CO and H<sub>2</sub> are formed due to the steam reforming reaction, the heterogeneous water gas reaction and the Boudouard reaction while CH<sub>4</sub>, C, CO<sub>2</sub> and H<sub>2</sub>O are consumed. The equilibrium of the exothermic water gas shift reaction is driven to the educts side thus reducing CO<sub>2</sub>, H<sub>2</sub>, while CO and H<sub>2</sub>O are formed. The exothermic hydrogasification is driven to the educts side so C and H<sub>2</sub> are formed and CH<sub>4</sub> is consumed. In comparison of the fuels the producer gas of Willow gasification contains more CO<sub>2</sub> and H<sub>2</sub> and less CO and CH<sub>4</sub>. A possible explanation could be the higher water content of the Willow pellets that favour the water gas shift reaction thus reducing CO and forming CO<sub>2</sub> and H<sub>2</sub>. The higher content of CH<sub>4</sub> could be due to the higher volatile content of Agrol, more hydrocarbons are present thus more CH<sub>4</sub> is formed through cracking reactions in the gasifier.

In Figure 3 the influence of temperature during the gasification of DDGS on the main gas components can be seen at a S/B ratio of 0.9 at atmospheric pressure.

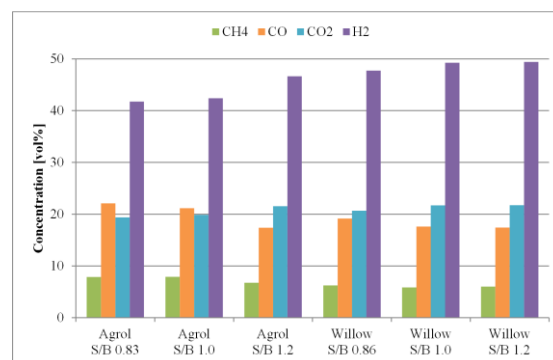


**Figure 3:** Influence of temperature during DDGS gasification (S/B 0.9, 1 bar)

The temperature was varied between 700 → 800 °C. The highest effect in this temperature range is observed for H<sub>2</sub> and CH<sub>4</sub>, whereas the CO and CO<sub>2</sub> content remain

constant. H<sub>2</sub> is increasing and CH<sub>4</sub> is decreasing with increasing temperature as has been observed during the Agrol and Willow experiments. The total sum of the dry gases H<sub>2</sub>, CO, CO<sub>2</sub> and CH<sub>4</sub> is lower compared to the other fuels. The reason could be C<sub>2</sub>H<sub>y</sub> components that are likely to be present at the 700 °C gasification but are not measured.

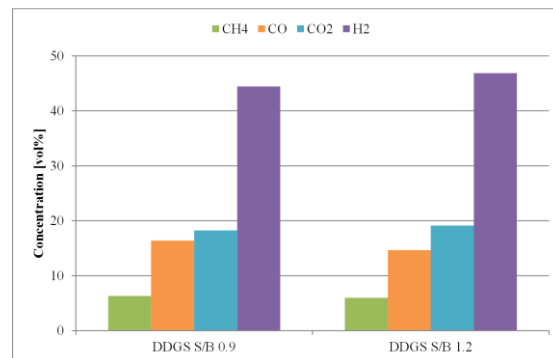
In Figure 4 the influence of the S/B ratio on the gas composition during Agrol and Willow gasification at 800 °C and atmospheric pressure is shown.



**Figure 4:** Influence of S/B ratio during Agrol&Willow gasification (800°C, 1 bar)

The tendency of both fuels is again qualitatively the same, with increasing S/B ratio CO is decreasing while H<sub>2</sub> and CO<sub>2</sub> are increasing. This behaviour can be expected regarding the water gas shift reaction Table 3. The increase in H<sub>2</sub>O leads to an enhanced formation of CO<sub>2</sub> and H<sub>2</sub> while CO is consumed. The effect on H<sub>2</sub>, CO and CO<sub>2</sub> was observed to be more distinct at lower temperatures. This can be explained again by the water gas shift reaction that is exothermic and hence at higher temperatures the equilibrium is shifted back to the H<sub>2</sub>O and CO side. A slight decrease in the CH<sub>4</sub> content was observed which can be explained by the steam reforming reaction. The higher availability of H<sub>2</sub>O leads to a consumption of CH<sub>4</sub>. The CO that is built during the steam reforming seems to be consumed by the water gas shift reaction as discussed above.

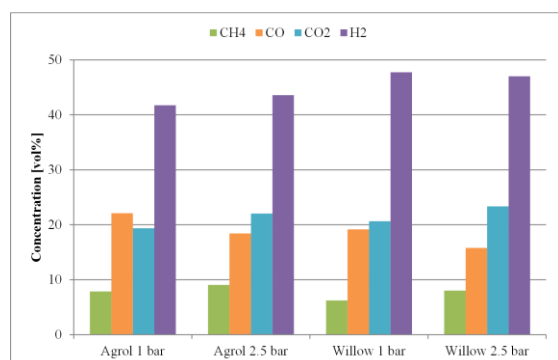
In Figure 5 the influence on the S/B ratio during the gasification of DDGS at 800 °C and atmospheric pressure is given.



**Figure 5:** Influence S/B ratio during DDGS gasification (800°C, 1 bar)

The qualitative influence is the same as has been observed for the gasification of Agrol and Willow. Nevertheless the changes are smaller compared to the other biomass fuels.

The influence of the pressure on the main gas components was investigated for the fuels Agrol and Willow. The results can be seen in Figure 6.



**Figure 6:** Influence of pressure during Agrol&Willow gasification (S/B Agrol 0.83 Willow 0.86, 800°C at 1 bar 790°C at 2.5 bar)

The operating conditions were slightly different: Agrol was gasified at a S/B ratio of 0.83 and Willow at 0.86→0.9, under pressure the gasification temperature was 790 °C compared to 800 °C during the atmospheric gasification. For both experiments one can indicate a significant change in the CO/CO<sub>2</sub> ratio and an increase in the CH<sub>4</sub> content, the H<sub>2</sub> content is not changing essentially. The same observation are reported by Valin et al.[5]. Kitzler et al. [6] observed the same behaviour in their experiments with air blown fluidized bed gasification. In general an increase in pressure is favouring the formation of larger gas molecules. From the reactions in Table 3 the Boudouard reaction is sensitive to changes in pressure shifting the equilibrium to CO<sub>2</sub> and reducing CO. The same tendency is observed in the experiments. During the gasification of Willow the CO<sub>2</sub> is higher and CO is lower compared to the gasification of Agrol. The same has been observed during the change in temperature, as discussed above the reason could lie in the higher moisture content and the slightly higher S/B ratio that favour the water gas shift reaction to the products side. Concerning the increase in CH<sub>4</sub>, both the steam reforming reaction as well as the hydrogasification are influenced by pressure by shifting the equilibrium towards CH<sub>4</sub>.

### 3.2 Influence on tar composition

For every operating condition of the gasification experiments SPA samples were taken to study the influence on the tar content. The resulting tar components were classified after the 5 class system developed at ECN (see [7]) which is gathered in Table 4.

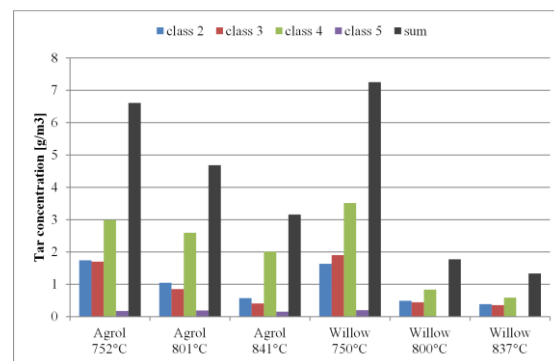
**Table 4:** Tar classification after ECN [7]

Tar class	Class name	Property
1	GC undetectable	Very heavy tars
2	Heterocyclic	Containing hetero atoms, water soluble
3	Light aromatic	One ring components
4	Light polyaromatic	Two and three ring components
5	Heavy polyaromatic	Larger than three ring components

The SPA samples were analysed by means of Gas Chromatography at KTH, so the very heavy class 1 tars

have not been measured in this work. Benzene is not sampled efficiently with the SPA method and can evaporate from the sample (see [8]). This has to be taken into account since the benzene does not fully contribute to the amount of light aromatic compounds (class 3). In the following figures the influence of the different operating conditions on the tar composition of each biomass fuel is presented.

In most operating points of the gasifier the distribution of the tar classes was similar: the highest amount of the tar compounds are light polyaromatic compounds (class 4), the heterocyclic compounds (class 2) and the light aromatic compounds (class 3) have a similar share of the total tar content, the heavy polyaromatic compounds (class 5) are only present in very small amounts. This distribution with a high content of aromatic compounds is typical for fluidised bed gasifiers (see [9]). In Figure 7 the influence of temperature on the tar composition during Agrol & Willow gasification is shown at a S/B ratio of 1.0 and atmospheric pressure.



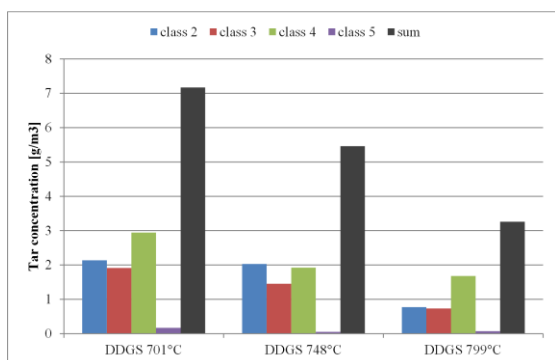
**Figure 7:** Influence of temperature on tar composition during Agrol&Willow gasification (S/B 1.0, 1 bar)

As expected for both fuels the total tar content decreases with increasing temperatures. For Agrol the total tar content decreases by more than 50% when the temperature is increased from 750 °C to 840 °C. All tar classes are affected but not to the same extent: class 2 and class 3 compounds are reduced more than 70% while the class 4 tars are only reduced by ~33%, class 5 tars are not effected but their percentage is very low ~0.15 g/m<sup>3</sup> which is not far from the detection limit of 0.05 g/m<sup>3</sup>. Class 4 tars can be built by polymerisation of smaller aromatic compounds and can increase due to an increasing temperature as has been observed by van Paasen et al. [10]. Their experiments were performed in an air blown bubbling fluidized bed gasifier and the class 4 and class 5 contents had their maximum at the highest investigated temperature of 900 °C. Their results cannot be compared directly to the results of this work due to the effect of steam reforming that can occur in the steam blown bubbling fluidized bed gasifier that was investigated. The steam seems to reduce the class 4 tars at lower temperatures compared to thermal cracking of the tars.

The results for Willow have the same tendency but a much higher decrease in the tar content from 750 °C to 800 °C. During the gasification of Willow problems with the gasifier occurred that led to a temporary shutdown of the facility due to a blocked cyclone. The results of the tar measurements for Willow show that after the first three operating points all other tar contents are

considerably lower to an extent that cannot be explained by a change in the biomass fuel. It is possible that even in the time before the complete blockage of the cyclone tars have been filtered or converted in the cyclone due to hot char and ash. For this reason the results of the tar concentration during Willow gasification are not considered in the following.

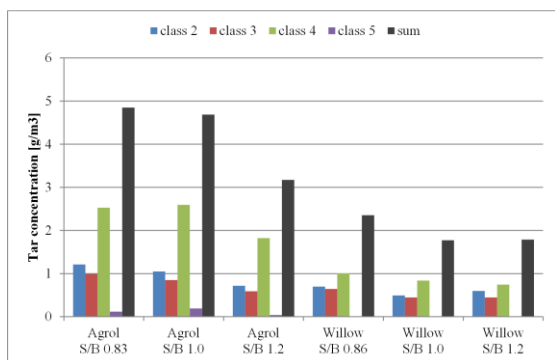
In Figure 8 the influence of the temperature on the tar composition during the DDGS gasification at a S/B ratio of 1.2 and atmospheric pressure is shown.



**Figure 8:** Influence of temperature on tar composition during DDGS gasification (S/B 1.2, 1 bar)

One can observe the same tendency as before: the total tar content is decreasing, class 2 and class 3 components are affected more by the reduction than class 4 compounds, class 5 compounds are almost not present. For the lower temperatures of 700 °C and 750 °C the difference between class 2&3 and class 4 tars is not distinct, the large reduction of class 2&3 tars is observed from 750 °C to 800 °C.

The influence of the S/B ratio on the tar composition during Agrol & Willow gasification at 800 °C and atmospheric pressure can be seen in Figure 9.

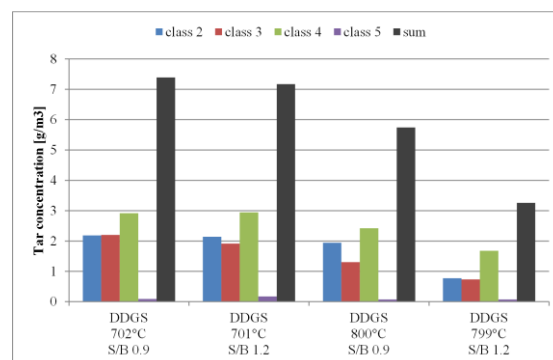


**Figure 9:** Influence of S/B ratio on tar composition during Agrol&Willow gasification (800 °C, 1 bar)

The total tar content is decreasing with increasing S/B ratio. In the gasification experiments with Willow significantly less tar has been detected compared to the experiments with Agrol at the same operating condition. As discussed above the results from willow might not be reliable due to problems with the gasifiers' cyclone in the Willow gasification experiments. A decrease in the total tar content due to increasing S/B ratio has been reported by Herguido, Corella et al. [11]. They investigated among other things the influence of a change in the S/B ratio (0.5→2.5) on the total tar content at 750 °C. For Agrol the total tar is only reduced slightly when the S/B ratio

increases from 0.83→1.0. Class 4 tars are even increasing and have a maximum at a S/B ratio of 1.0. This behaviour was observed also at changes of the S/B ratio at gasification temperatures of 750 °C and 840 °C. When the S/B ratio is increased further from 1.0→1.2 also the class 4 tars are reduced and the total tar content is reduced more significantly. A possible explanation could be the reactivity of the different tar classes towards steam reforming that was e.g. investigated by Coll et al. [12]. They determined the steam reforming reaction rate of benzene, toluene, naphthalene, anthracene and pyrene over commercial Ni-based catalysts and found the following order of reactivity benzene >toluene>>anthracene>>pyrene>naphthalene. With the assumption that this order is valid also for steam reforming without catalyst this explains why class 2&3 tars are affected more than the class 4 tars. The increase in class 4 compounds could be due to the parallel build up of polyaromatic tars due to the higher availability of partially reformed class 2&3 compounds.

In Figure 10 the influence of the S/B ratio on the tar composition during DDGS gasification at 700 °C and 800 °C and atmospheric pressure is shown.

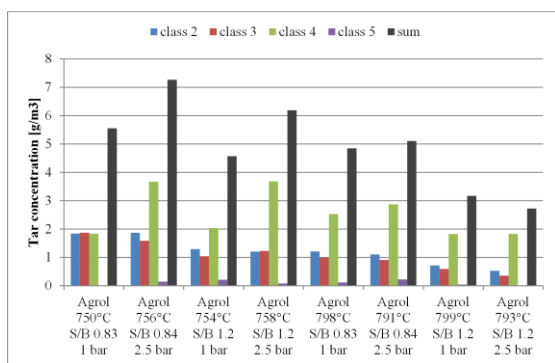


**Figure 10:** Influence of S/B ratio on tar composition during DDGS gasification (700/800 °C, 1 bar)

Two S/B ratios have been investigated during the DDGS gasification for each temperature. For the low temperature of 700 °C the increase in S/B ratio has almost no effect on the tar content or composition. The total tar content at 800 °C is decreasing significantly with increasing S/B ratio and class 4 tars are affected less than class 2&3 tars. Rapagnà et al. [13] report similar findings. They performed experiments with crushed almond shells in a steam blown bubbling fluidized bed gasifier and changed the S/B ratio from 0.5→0.7→1.0 at 700 °C and 820 °C. At 700 °C they observed no decrease in the total tar content, at 820 °C the tar reduction due to the higher S/B ratio was in the range of 50%. This behaviour can be qualitatively explained by the steam reforming of hydrocarbons. The conversion of every hydrocarbon (including tar compounds) by means of steam reforming is a highly endothermic process, hence when the available heat is not sufficient the addition of steam does not have a measurable effect on the hydrocarbon conversion.

The influence of pressure on the tar composition was investigated for the fuels Agrol and Willow. Since the results for Willow are not reliable only Agrol is discussed here. In Figure 11 the influence on the tar composition due to a change in the reactor pressure 1→2.5 bar at ~750 °C and ~800 °C at a S/B ratio of 0.83 and 1.2 is shown.





**Figure 11:** Influence of pressure on tar composition during Agrol gasification (750/800 °C S/B 0.83/1.2)

For the lower temperature case the total tar content increases noticeably with increasing pressure for both S/B ratios. The different tar classes show the following behaviour: class 2&3 tars are more or less stable, the class 4 tars increase by ~100%, the class 5 tars have a very small share. For the cases at 800 °C no clear tendency was observed at the S/B ratio of 0.83 the tar content increases slightly, for the S/B ratio of 1.2 it decreases slightly. The results are different compared to results obtained by Wolfesberger et al.[14] and Knight [15] who performed experiments in air blown and air/oxygen steam blown fluidized bed gasifier respectively. Wolfesberger found the total tar content to decrease by ~30% when the pressure is increased from 1→3 bar at a gasifier temperature of 825 °C. Knight reports results from measurements performed at 8.0 / 21.4 bar at 824 °C reactor temperature. The total tar content decreased with increasing pressure by ~20%, which is mainly due to a decrease of the water soluble tar compounds and phenols, while polyaromatic compounds increase. Both results are obtained in autothermal gasifiers contrary to the experiments in this work. Valin et al. [5] performed experiments in an allothermal steam blown bubbling fluidized bed gasifier and report no noticeable influence of pressure on condensable tars during steam gasification of wood sawdust.

It has to be mentioned that it is difficult to change only the pressure in a fluidized system: the volume flow has to be kept constant to ensure good fluidization, hence the mass flow of steam has to be increased or an inert gas has to be introduced. In the first case also the biomass mass flow has to be increased to keep the S/B ratio constant and in the second case the gas phase components are diluted. A third possibility is a change in the bed material particle size, but all possibilities change the behaviour of the gasifier in a way that is hard to estimate.

#### 4 CONCLUSION

In this work the influence of temperature, S/B ratio and pressure on the gas and tar composition during allothermal steam gasification has been investigated. Three biomass fuels (standard wood pellets Agrol, Willow pellets and DDGS pellets) have been gasified throughout the experiments.

An increase in temperature leads to a higher H<sub>2</sub> and CO content while CO<sub>2</sub> and CH<sub>4</sub> decrease which can be explained qualitatively by increased endothermic reaction. The total tar content is reduced significantly and class 2&3 tars are more affected than the light

polyaromatic class 4 compounds.

An increase in the S/B ratio leads to decreasing CO content and increasing CO<sub>2</sub> and H<sub>2</sub> content due to the enhanced water gas shift reaction. CH<sub>4</sub> decreases slightly which is due to enhanced methane reforming. Total tar content is decreasing due to the steam reforming of tar compounds. Class 2&3 tars are again more affected than class 4 tars. The effect is not significant for low temperatures at 700 °C where not enough heat is available for the endothermic reaction.

An increase in pressure leads to a significant decrease in the CO content while CO<sub>2</sub> and CH<sub>4</sub> increases. This could be due to the sensitivity of the Boudouard and the methane reforming reaction on pressure. The tar content increases under pressure.

The results show the large influence of the operational parameters on gas composition and the tar yields and can be valuable in the design of fluidized bed gasifiers.

#### 5 ACKNOWLEDGEMENTS

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