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# Comparison of downdraft and updraft gasification of biomass in a fixed bed reactor

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**Abstract** The aim of this study was to compare and analyze the gasification process of beech wood. The experimental investigation was conducted inside a gasifier, which can be operated in downdraft and updraft gasification system. The most important operating parameter studied in this paper was the influence of the amount of supply air on the temperature distribution, biomass consumption and syngas calorific value. The results show that the amount of air significantly influences the temperature in the combustion zone for the downdraft gasification process, where temperature differences reached more than 150 °C. The increased amount of air supplied to the gasifier caused an increase in fuel consumption for both experimental setups. Experimental results regarding equivalence ratio show that for value below 0.2, the updraft gasification is characterized by a higher calorific value of producer gas, while for about 0.22 a similar calorific value (6.5 MJ/Nm$^3$) for both gasification configurations was obtained. Above this value, an increase in equivalence ratio causes a decrease in the calorific value of gas for downdraft and updraft gasifiers.

**Keywords:** Gasification; Biomass; Thermochemical conversion

## 1 Introduction

Gasification, or 'indirect combustion', in particular, is the conversion of solid fuel to synthesis-gas through chemical reactions. This process can be

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defined as a partial oxidation of the waste in the presence of an oxidant amount lower than that required for the stoichiometric combustion. Basically, part of the fuel is combusted to provide the heat needed to gasify the rest (autothermal gasification). The result is not a hot flue gas as in the conventional direct combustion of wastes but a hot fuel gas ('producer gas' or 'syngas'), containing large amounts of not completely oxidized products that have a calorific value. The gas can be utilized in a separate process equipment, even at different times or sites. The organic content of the waste is converted mainly to carbon monoxide, hydrogen and lower amounts of methane, however the syngas is generally contaminated by undesired products such as particulate, tar, alkali metals, chloride and sulphide [1]. Gasification also have several potential benefits over traditional combustion of solid wastes, mainly related to the possibility of combining the operating conditions (in particular, temperature and equivalence ratio) and the features of the specific reactor (fixed bed, fluidized bed, entrained bed, vertical shaft, moving grate furnace, rotary kiln, plasma reactor) to obtain a syngas suited for use in different applications. Fuel gas can be combusted in a conventional burner, connected to a boiler and a steam turbine, or in a more efficient energy conversion device, such as gas reciprocating engines or gas turbines. Its main components, carbon monoxide and hydrogen, can also offer the basic building blocks for producing valuable products in chemical industry [2]. Thermal conversion has better environmental performance and more severe emission regulations with respect to other energy sources (it has been publicly recognized as a source of power 'with less environmental impact than almost any other source of electricity' [3]. Typical processing of biomass in a fixed bed gasifier starts from drying, where moisture is released from biomass, then followed by pyrolysis in which gases and char are produced [4]. In the next phase of gasification the gases are mixed with air and combusted to $CO_2$ and $H_2O$, whereas charcoal combines with $CO_2$ and $H_2O$ forming a combustible gas. The most important factors in the gasification process are the temperature and the amount of air supplied to the process [5]. These parameters have a significant impact on the quality of the produced syngas. The aim of this study was to compare and discuss the gasification process of beech wood substrate in both, the downdraft and updraft gasification systems. The most important operating parameter studied in this paper was the influence of the amount of supply air on the temperature distribution, biomass consumption and syngas calorific value.

## 2 Materials

The samples used in experimental investigation were prepared from beech wood (*Fagus* L.), which is common type of wood in Poland. Table 1 presents the technical and elementary analysis of the fuel sample. The calorific value was determined using a KL-11 calorimeter. The moisture content was determined using a MAC (Radwag), and the elementary analysis was performed using a Thermo Scientific CHNS-O Flash 2000 simultaneously elementary analyzer. The low ash content results in a higher yield of solid and gaseous fraction. For the purpose of gasification the fuel was dried to about 8%. The technical and elementary analysis of the beech wood is in good accordance with the literature [1,6,7].

Table 1: Technical and elementary analysis of the beech wood.

| | |
|---|---|
| Higher heating value | 19.6 MJ/kg |
| Moisture | 8.4% |
| **Technical** [**wt.**$\%_{db}$][a] | |
| Volatiles matter | 77.9 |
| Fixed Carbon | 21.4 |
| Ash | 2.3 |
| **Elemental concentration** [**wt.**$\%_{db}$][a] | |
| C | 45.0 |
| H | 6.4 |
| O | 47.3 |
| N | 1.3 |

[a] db=oven-dry basis.

## 3 Gasification system

The experimental setup for the updraft gasification is presented in Fig. 1. The total height of reactor is 135 cm and the internal diameter is 22 cm. The air inlets (three nozzles) were installed 52 cm from the bottom of the reactor, while the syngas outlet 111 cm from the bottom.

The fuel from the hopper was loaded by a screw feeder into the reactor 10 cm below the syngas outlet. Six thermocouples (type K) were installed along the gasifier height in order to measure temperature inside the gasifier: 30, 55, 72, 88, 90, and 119 cm from the bottom of the reactor, respectively.

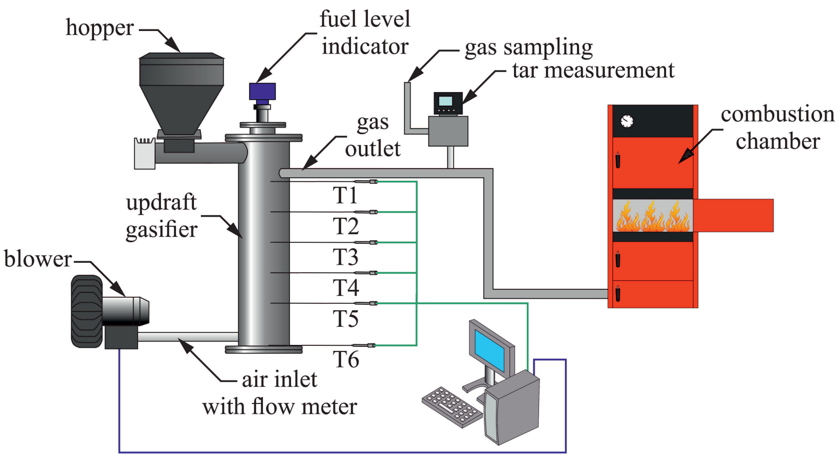


Figure 1: Schematic diagram of the updraft experimental setup.

The air was supplied to gasifier by an electric blower and controlled using the inverter and the thermal mass flow meter. The syngas leaves the reactor and is passing through an outlet tube to the combustion chamber. On the outlet tube, a proportion of the syngas is directed to the sampling system for the purpose of tars and gas analysis. In case of downdraft gasification gas outlet was set as an air inlet, whereas the air inlet was set as the gas outlet. The experimental procedure remained the same.

Before starting of gasification process a batch of 3 kg feedstock was loaded into the gasifier in each experiment. After reached the high temperature of the bed the gasifier has been filled up to the level of the indicator. The start of the measurements was from the point where the gasification process reached the steady-state condition (constant temperature in each zone and constant syngas composition).

## 4 Influence of supply air on the temperature in the oxidation zone

Experimental investigation showed that the amount of supplied air has a significant effect on the temperature in the reactor for the downdraft gasification (Fig. 2). Updraft gasification was characterized by a very high temperature stability, regardless of the amount of supply air and temperature in the combustion zone fluctuated around 1000 °C. This is due to the fact that in the case of updraft gasifier, in the combustion zone there are mainly heterogeneous reactors where the oxygen reacts with the fixed carbon. For downdraft gasification experiments, the low temperature pyrolysis gases could be partially oxidized in the combustion zone, therefore for the same amount of air less oxygen reacts with the char. The increase in the amount of air to 15 Nm$^3$/h and next to17 Nm$^3$/h caused a significant increase in the amount of oxygen and increase in the temperature over 1000 °C.

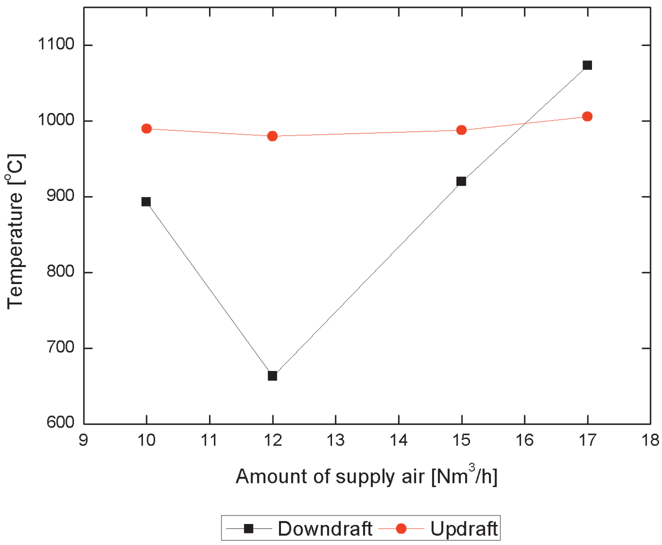


Figure 2: Influence of supplied air on the temperature in the oxidation zone.

Additionally, an updraft reactor, the fuel particles move in opposite direction than gas particles (Fig. 3). The opposite direction of fuel, $q_{particles}$, and gas particles, $q_{gas}$, movement causes the lower heat transfer propagation in a reactor and a large part of the heat remains in the combustion zone. In a downdraft reactor temperature should thus transfer faster due to the addition of heat flux transmitted by convection in gas and fuel. In a downdraft reactor, the biomass and gases are transported in the same direction. In this case the increase the amount of supplied air, from 10 to 12 Nm$^3$/h, caused an increase in the intensity of the combustion process, but the amount of generated heat was not sufficient to raise the temperature in the pyrolysis zone and part of the biomass, which has not complete degassing and low temperature pyrolytic gas mixtures, goes into combustion zone and slow down the process.

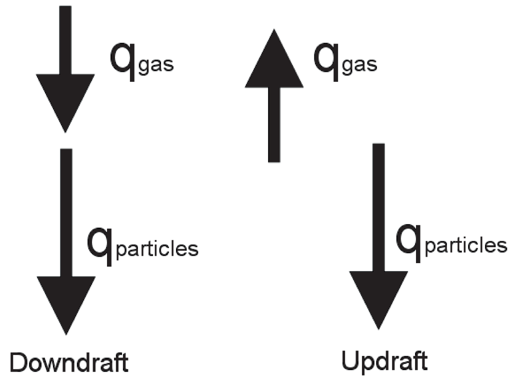


Figure 3: Gas convection and particle movement in the downdraft (left) and updraft (right) gasifying cases.

## 5 Influence of supplied air on the biomass consumption and equivalence ratio

Experimental investigation showed that the amount of supplied air has an impact on fuel consumption for both, the downdraft and updraft gasification (Fig. 4). The fuel consumption generally increases with increasing the amount of supply air, however, the increase in amount of supplied air from 10 to 12 Nm$^3$/h caused a decrease in fuel consumption for both cases. Reason is the same as in the case of temperature – the increase the amount of supplied air resulted in an increase in the intensity of the combustion process, but the amount of generated heat was not sufficient to raise the temperature in the pyrolysis zone and part of the biomass, which has not complete degassing, and goes into the combustion zone and slowdown surface reactions and fuel consumption. The increase in the amount of air to 15 Nm$^3$/h and next to 17 Nm$^3$/h caused a significant increase in the fuel consumption. Figure 4 shows also that for the process of updraft gasification of beech wood more feedstock is consumed. In the downdraft configuration, the pyrolysis gases can be partially oxidized in the combustion zone, therefore for the same amount of air less oxygen reacts with the char.

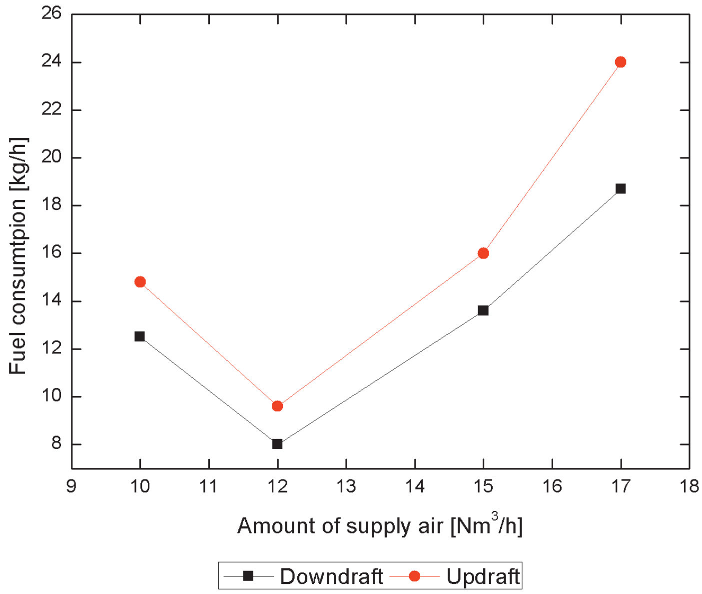


Figure 4: Influence of supplied air on the biomass consumption.

Figure 5 shows the equivalence ratio value, which is defined as the air-to-fuel-to-air weight ratio used divided by the air-to-fuel weight ratio of stoichiometric combustion [8], for experiments with different amounts of supply air, which is reversed to results presented in Fig. 4. The experiment with 12 $Nm^3/h$ of air resulted in the lowest amount of beech wood consumption, and therefore had the highest equivalence ratio, ER. Experimental investigation showed that for the updraft gasification similar heating value of syngas (6.5 $MJ/Nm^3$, Tab. 3) was received for the 10 and 17 $Nm^3/h$ of supplied air, wherein in the first case (10 $Nm^3/h$) the fuel consumption was 15 kg/h and for 17 $Nm^3/h$ received it was 24 kg/h.

## 6 Influence of equivalence ratio on the syngas calorific value

Figure 6 presents the relationship between the gas calorific value and equivalence ratio, ER. Results show that heating value decrease linearly with decreasingequivalence ratio. This relation is similar for updraft and downdraft gasification setup.

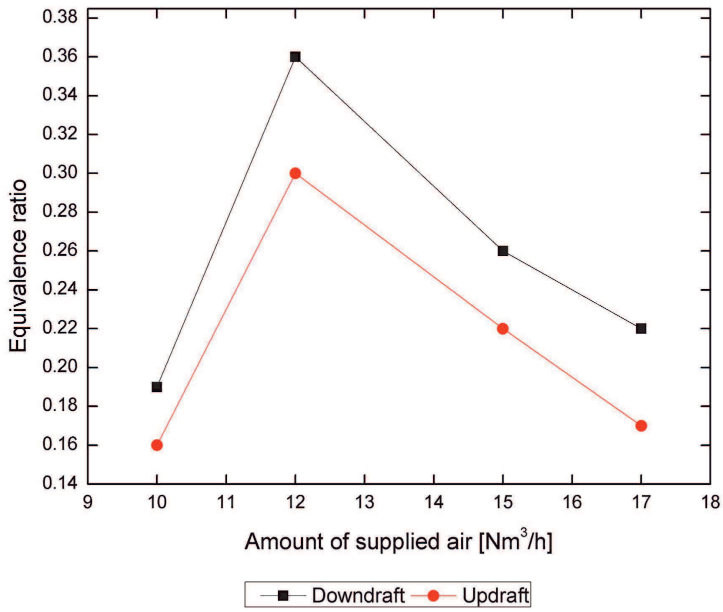


Figure 5: Influence of supplied air on the equivalence ratio value.

Producer gas was analyzed during the process at intervals of 20 min. Average composition and calorific value, lower heating value – LHV, for downdraft gasification are shown in Tab. 2. The most caloric gas was obtained for the 10 $Nm^3/h$ ratio, and 17 $Nm^3/h$ of supplied air, least calorific value of syngas was received for 12 $Nm^3/h$.

Average composition and calorific value, lower heating value, for updraft gasification are shown in Tab. 3. The average gas composition obtained in the updraft was characterized by higher heating value than in downdraft process. This is due to the fact that in the case of updraft gasifier, in the combustion zone there are mainly heterogeneous reactors where the oxygen reacts with the fixed carbon, which resulted in higher amount of carbon monoxide in the syngas.

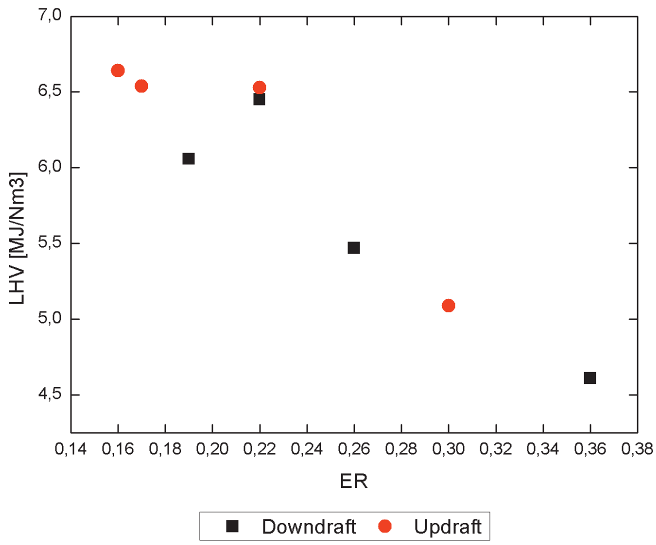


Figure 6: Influence of equivalence ratio on the syngas lower heating value (lower heating value – LHV).

Table 2: Influence of amount of supplied air on the syngas composition and lower heating value for the downdraft gasification.

| Amount of supplied air [$Nm^3/h$] | Syngas composition [%] | | | | | LHV [$MJ/Nm^3$] |
|---|---|---|---|---|---|---|
| | CO | $CO_2$ | $H_2$ | $CH_4$ | $N_2$ | |
| 10 | 26.6 | 13.1 | 14.2 | 3.3 | 42.8 | 6.1 |
| 12 | 22.6 | 15.7 | 9.4 | 2.1 | 50.2 | 4.6 |
| 15 | 23.8 | 11.2 | 13.4 | 2.9 | 48.8 | 5.5 |
| 17 | 25.3 | 13.3 | 18.8 | 3.5 | 39.2 | 6.4 |

The results shows higher calorific value of gas in the updraft gasification. It is associated with more concentration of carbon monoxide. Also the amount of $CO/CO_2$ is higher for updraft process, which is advantageous in view of the improved conversion of char. Despite the much lower caloric gas produced in a downdraft gasification, experiments were characterized by a higher content of hydrogen at a slightly higher methane content in the syngas.

Table 3: Influence of amount of supplied air on the syngas composition and caloric value for the updraft gasification.

| Amount of supplied air [$Nm^3/h$] | Syngas composition [%] | | | | | LHV [$MJ/Nm^3$] |
|---|---|---|---|---|---|---|
| | CO | $CO_2$ | $H_2$ | $CH_4$ | $N_2$ | |
| 10 | 36.6 | 7.4 | 10.3 | 2.7 | 43.4 | 6.6 |
| 12 | 27.2 | 10.6 | 8.6 | 2.1 | 51.5 | 5.1 |
| 15 | 32.7 | 9.3 | 10.6 | 3.6 | 41.1 | 6.5 |
| 17 | 37.4 | 5.8 | 10.1 | 2.1 | 44.7 | 6.5 |

# 7 Summary

The aim of this study was to analyze the downdraft and updraft gasification of beech. The most important aspect studied in this work was the influence of the amount of supply air on the temperature distribution, biomass consumption and syngas calorific value. The results indicate a higher calorific value of the syngas obtained in the updraft gasification experiments, which is associated with a significantly higher content of carbon monoxide. Furthermore, the ratio of the $CO/CO_2$ is also higher for the updraft gasification, which means more effective conversion of the fixed carbon contained in the fuel. Gas produced in a downdraft gasification, despite the lower calorific value, is characterized by a higher content of hydrogen and a slightly higher methane content compared to the updraft gasification case. Operating parameters of the gasifier indicate a lower fuel consumption in a downdraft gasification for the same amount of supplied air. In the downdraft gasifier the pyrolysis gases can be partially oxidized in the combustion zone, therefore for the same amount of air less oxygen reacts with the char. In the case of updraft gasification, increase of supplied air from 10 to 17 $Nm^3/h$ caused the increased fuel consumption from 15 kg/h or 24 kg/h (similar equivalence ratio value) and obtaining gas with the same calorific value.

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