



# Proceedings Experimental Research on the Air Gasification of Oily Sawdust <sup>+</sup>

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**Abstract:** In this article were present experimental results of the air gasification of oily sawdust. In a laboratory-scale countercurrent gas generator, gas composition measurements were made. We evaluated the fuel properties of the selected material with variable technological parameters (i.e., fuel to air ratio). Additionally, we evaluated the methanization coefficients and the dependence of their value on fuel and gasification agent content delivered to the chamber of the reaction.

Keywords: gasification; biomass; countercurrent reactor; methanization coefficient

#### 1. Introduction

Energy production is one of the most relevant aspects of economic and human activity. With the exception of fossil fuels, biomass wastes are transformed in thermal processes such as gasification. Biomass waste could be an alternative energy carrier to fossil fuels. The chemical energy contained in feedstock can be recovered using thermal processes. Besides combustion and pyrolysis, gasification is one of the basic methods of the thermal transformation of feedstocks [1]. The recovery of chemical energy from a combustible substance contained in waste feedstock further neutralizes it to inert ash [2]. The transformation of waste to recover usable energy is a trend in waste minimization [3]. The processing gas called syngas, containing CO, H<sub>2</sub>, CH<sub>4</sub>, and higher hydrocarbons ( $C_nH_m$ ), is the product of gasification [4]. The composition of the combustible gas depends on the processing conditions and the content of the delivered substrates. Gaseous products are widely used in the power supply of combustion engines [5]. Furthermore, syngas can be directly combusted in boilers, when used as fuel in an associated energy system (boiler + turbine), or when used as a substrate in chemical synthesis [6]. In this paper we show experimental results on the gasification of biomass in a small-scale countercurrent reactor. We have selected oily sawdust as our experimental material.

#### 1.1. Research Purpose

The purpose of this research was to search for optimal conditions for the laboratory-sale gasification of oily sawdust. We attempted to obtain the reactivity of methane substrates using methanization coefficients.

#### 1.2. Gasification Process

We have evaluated the activity of the selected combustible gases. These gases participate in methane formation in dependence of the fuel-to-air ratio. Gasification is a chemical transformation cycle between fuel and conversion agent. Combustible syngas is the main product of gasification. Syngas' lower heating value depends on the combustible gases concentrations [4]. Substrates and

gaseous products participate in different exothermic and endothermic chemical reactions. The chemical reaction intensity and frequency depend on the syngas chemical composition [4,7].

#### 2. Materials and Methods

Sawdusts from coniferous wood as a post-production waste were selected for our experimental research. Sawdusts were soaked in 1:1 mass ratios with vegetable oil. Material fuel properties were analyzed in accordance with actual norms. Fuel analysis measurements are shown in Table 1.

Parameter	Value
C(dry basis), %	56.31
H(dry basis), %	6.75
N(dry basis), %	0.85
S(dry basis), %	0.13
Cl(dry basis), %	0.33
O(dry basis), %	20.61
Combustible substance, %	84.98
Moisture (as given), %	6.00
$LHV_{(dry \ basis)}$ , $MJ/kg$	23.626

Table 1. Fuel analysis measurements.

#### 2.1. Research Placement

This research was done in a small-scale countercurrent gas generator. The experimental setup is shown in Figure 1.



**Figure 1.** Research installation scheme. 1: process chamber, 2: fuel delivery, 3: gas outlet, 4: syngas analyzer, 5: air chamber, 6: grid, 7: air delivery, 8: thermal isolation, 9: cooler with heat,  $T_1$  – thermocouple over the grid,  $T_2$  – thermocouple over the fuel layer.

The gasification agent (i.e., air) was delivered to the reactor chamber at a temperature of 25 °C. The temperature over the grid and over fuel layer was measured using type-K nickel thermocouples. Syngas composition analysis, including the contents of CO, CO<sub>2</sub>, CH<sub>4</sub>, H<sub>2</sub>, and C<sub>n</sub>H<sub>m</sub>, was measured using a GAS 3100 Syngas Analyser. Additionally, before analysis, gas was cooled using a thermoelectric cooler with an "EZ Clean" heat exchanger. In the next step, syngas was purified using a countercurrent scrubber set and filter-filled with activated carbon.

The fuel-to-air ratio  $\Phi$  was used for the evaluation of process conditions, in accordance with Equation (1):

$$\Phi = \frac{G_{\text{fuel}}}{G_{\text{air}}},\tag{1}$$

where G<sub>fuel</sub> is the fuel stream delivered in kg/h, and G<sub>air</sub> is the air stream delivered in kg/h.

#### 2.2. Methanization Coefficients Evaluation

As part of this paper, we attempted to evaluate the activity of components involved in the formation of methane. The methanization process occurred in the reaction chamber. Reactions were based on the reactivity of the components participating in the methane formation [8]. Substrates originated from the products of primary reactions between fuel and gasification agent. Methane can be obtained in the gasification process is in two different ways. The energy balance is differential because of the different values of enthalpy formation for CO and CO<sub>2</sub>. As a result of Sabatier-Sendersens reaction, methane and steam are the final products of carbon dioxide hydrogenation:

$$CO_2 + 4H_2 \Leftrightarrow CH_4 + 2H_2O. \tag{2}$$

Fischer–Tropsch synthesis with carbon monoxide hydrogenation is the second method of methane production:

$$CO + 3H_2 \Leftrightarrow CH_4 + H_2O.$$
 (3)

The following equation was prepared for calculation of the methanization coefficient:

$$W_{mx} = \frac{CH_4}{zX},\tag{4}$$

where  $W_{mx}$  is the methanization coefficient (unitless), zX is the methanization substrate present in the syngas, and  $CH_4$  is the gas generator methane concentration, as a percentage.

Methanization coefficients were appointed in accordance with substrates participating in the process. Gases like CO, H<sub>2</sub>, and CO<sub>2</sub> participated in the methane formation.

### 3. Results

Biomass gasification results are shown in dependence of the fuel-to-air ratio. Methanization coefficient calculation results are shown in Figures 2 and 3.

## 30 25 5 20 15 10 5 0 0,32 1,19 2,06 Fuel-to-air ratio value, -

#### Concentrations of gaseous components - oily sawdust's

Figure 2. Concentrations of gaseous components-oily sawdusts.

The measured average temperatures were in the ranges 475–500 °C over the grid, and 790–820 °C over the fuel layer. With increasing fuel-to-air ratio, concentrations of substrates such as CO and H<sub>2</sub> were decreased. With increasing values of the fuel-to-air ratio, CH<sub>4</sub> concentrations also increased. Changes in component activity were shown as a function of fuel-to-air ratio. Hydrogen was the most active component in the methane formation. Carbon monoxide was the next most active component. Substrate activity indicates the presence of conditions conductive to the Fischer–Tropsch reaction. Increased technological parameter ( $\Phi$ ) value caused a 12-fold increase in carbon monoxide. Additionally, the presence of incombustible gas such as CO<sub>2</sub> was observed. The presence of this gas

indicates conditions for Sabatier-Sendersens reaction. However, the Fischer-Tropsch reaction had the greatest influence on methane formation.



**Figure 3.** Changes of methanization coefficients values in function of fuel-to-air ratio  $\Phi$ .

#### 4. Conclusions

In this research, syngas chemical composition was characterized on the presence of combustible gases like CO, H<sub>2</sub>, CH<sub>4</sub>, and incombustible CO<sub>2</sub>. A higher concentration of CH<sub>4</sub> was reached (8%) with increasing fuel-to-air ratio. We also observed that concentrations of CO and H<sub>2</sub> decreased with increasing fuel-to-air ratio. Experimental results were related with changes in the methanization coefficients. Methanization coefficients increased with decreasing gas concentrations. The measured temperature and gas concentration changes indicated that the Fischer–Tropsch reaction had the greatest influence on methane formation. Proof of this was fact that the greatest coefficient values were achieved for CO and H<sub>2</sub>. Methane formation efficiency depended on process conditions such as the temperature over the grid and fuel layer and the fuel-to-air ratio. This research indicates that gasification is an interesting alternative to other thermal processes such as pyrolysis and combustion. The wide use of methane makes the gasification of oily sawdust a promising solution for this product's recovery from syngas.

**Author Contributions:** D. Król conceived and designed the experiments; G. Galko performed the experiments; D. Król and G. Galko analyzed the data and contributed reagents/materials/analysis tools; G. Galko and D. Król wrote the paper.

Conflicts of Interest: The authors declare no conflicts of interest.

#### References

- Waste Act of 14th December 2012 (in Polish) Ustawa z dnia 14 Grudnia 2012 o odpadach (Dz.U.2013poz.21). Available online: http://prawo.sejm.gov.pl/isap.nsf/download.xsp/WDU20130000021/T/D20130021L.pdf (accessed on 28 June 2019).
- 2. Hawrot-Paw, M.; Koniuszy, A.; Mikicuk, M.; Izwikow, M.; Stawicki, T.; Sędłak, P. Analysis of ecotoxic influence of waste from the biomass gasification process. *Environ. Sci. Pollut. Res.* **2017**, *24*, 15022–15030.
- 3. Directive of the European Parliament and of the European Council 2008/98/EC of November 19, 2008 on Waste Repealing Certain Directives (Dz.U.L.312 dated November 22, 2008). Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32008L0098 (accessed on 28 June 2019).
- 4. Bach-Oller, A.; Furusjo, E.; Umeki, K. Fuel conversion characteristics of black liquor and pyrolysis oil mixtures: Efficient gasification with inherent catalyst. *Biomass Bioenergy* **2017**, *79*, 155–165.

- Sharma, T.; Yepes Maya, D.M.; Nascimento, F.R.M.; Yunye, S.; Ratner, R.; Silva Lora, E.E.; Mendes Neto, L.J.; Escobar Palacios, J.C.; Andrade, R.V. An Experimental and Theoretical Study of Miscanthus Briquettes in a Double-Stage Downdraft Gasifier: Syngas, Tar and Biochar Characterization. *Energies* 2018, 11, 3225–3324.
- 6. Grzywa, E.; Molenda, J. *Technology of Basic Organic Synthesis*; Wydawnictwo Naukowo-Techniczne: Warszawa, Poland, 1987. (In Polish)
- 7. Emami-Taba, L.; Faisal Irfan, M. Fuel blending effects on the co-gasification of coal and biomass A review. *Biomass Bioenergy* **2013**, *57*, 249–263.
- 8. Frusteri, F.; Frusteri, L.; Costa, F.; Mezzapica, A.; Cannilla, C.; Bounara, G. Methane production by sequential supercritical gasification of aqueous organic compounds and selective CO<sub>2</sub> methanation. *Appl. Catal. A Gen.* **2017**, *545*, 24–32.



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