

HOSTED BY



ELSEVIER

Contents lists available at ScienceDirect

Journal of Sustainable Mining

journal homepage: www.elsevier.com/locate/jsm

Short Communication

Thermochemical utilization of low rank coal and flotation concentrate

Rafał Gašior^{a,*}, Adam Smoliński^b^a Polska Grupa Górnicza S.A., Powstańców 30, 40-039, Katowice, Poland^b Central Mining Institute, Plac Gwarków 1, 40-166, Katowice, Poland

ARTICLE INFO

Keywords:

Hydrogen
Gasification
Reactivity
Low rank coal
Flotation concentrate

ABSTRACT

Flotation concentrates are waste material from coal mine operation. The process of steam gasification seems to be an attractive option for their economic utilization and an alternative to their potential combustion in boilers. The gasification process is characterized by both higher efficiency and lower emission of pollution than conventional combustion systems. In this paper the results of the steam gasification of low rank coal and flotation concentrate into hydrogen-rich gas at the temperature of 800 °C are presented. The reactivity for 50% carbon conversion as well as the maximum reactivity in this process were calculated for the samples studied.

1. Introduction

Coal sludge is composed of coal grains with a diameter below 1 mm. It is produced in a coal preparation plant, where the quality of raw coal is improved to obtain higher energy density (Moreno et al., 2019). This takes place in a technological enrichment process involving water. The products from the enrichment process are dewatered. In the coal sludge enrichment process, flotation concentrate is formed, i.e. a waste fuel characterized by high calorific value and grain size of up to 1 mm (Belkin, Zheng, Zhou, & Finkelman, 2008; Dai et al., 2012; Finkelman, 1994; Moreno et al., 2006). The thermochemical utilization of low rank coal and flotation concentrate offers the benefits of reduced loads of waste combined with the partial replacement of limited resources of fossil fuels in energy generation (Howaniec & Smoliński, 2014; 2017; Dychkovskiy, Vladyko, Maltsev, & Cabana, 2018; Sobolev & Usherenko, 2006; Pivnyak, Dychkovskiy, Smirnov, & Cherednichenko, 2013). The conventional methods of the thermochemical conversion of solid fuels, in particularly coal combustion systems, produce significant of air contaminants, including particulates, carbon dioxide, sulfur and nitrogen oxides. An alternative solution may be the gasification or co-gasification of various carbonaceous materials, including waste, such as low rank coal and flotation concentrate in systems of higher efficiency and with lower emissions than conventional combustion plants (Kamińska-Pietrzak & Smoliński, 2013; Krawczyk, Howaniec, & Smoliński, 2016; Lin, Harada, Suzuki, & Hatano, 2002; Smoliński & Howaniec, 2013; Özdemir & Żelkowski, 1998).

In this study the gasification of a low rank coal and a flotation concentrate into hydrogen-rich gas was proposed as a promising method of utilizing mining waste.

2. Materials and methods

2.1. Materials

Low rank coal and flotation concentrate samples were provided by a coal mine located in the Upper Silesia region of Poland. The physical and chemical parameters of the samples were determined in the accredited laboratory of the Department of Solid Fuel Quality Assessment of the Central Mining Institute (Poland) (see Table 1). Analyses were made with the application of the relevant standards, testing procedures and the following equipment: automatic thermogravimetric analyzers LECO: TGA 701 or MAC 500 (contents of moisture, ash, volatiles acc. to PN-G-04560:1998 and PN-G-04516:1998), calorimeters LECO: AC-600 and AC-350 (heat of combustion acc. to PN-G-04513:1981), TruSpecCHN analyzer (contents of carbon, hydrogen, nitrogen acc. to PN-G-04571:1998) and TruSpecS analyzer (sulfur acc. to PN-G-04584:2001). The fixed carbon was calculated according to the formula: $100\% - W - A - V$ (PN-G-04516:1998).

2.2. Experimental procedure

The gasification studies were conducted in a laboratory scale installation with a fixed bed reactor presented in Fig. 1. It is composed of a fixed bed reactor with a volume of 0.8 L and a gasification agent supply system. The steam is generated in the steam generator. The temperature and pressure in the reaction zone are controlled with a thermocouple and a manometer, respectively. The allothermal gasification of 3 g of low rank coal or flotation concentrate using steam as the gasification agent were conducted at the temperature of 800 °C. The

* Corresponding author.

E-mail address: ra.gasior@pgg.pl (R. Gašior).

Table 1

Basic physical and chemical parameters of studied low rank coal (LRC) and flotation concentrate (FC).

No	Parameter, unit	LRC	FC
1	Moisture W , %	1.32	1.74
2	Ash A , %	2.66	4.47
3	Volatiles V , %	32.18	27.38
4	Heat of combustion Q_s , kJ/kg	33697	32745
5	Calorific value Q_i , kJ/kg	32506	31663
6	Total sulfur S , %	0.29	0.42
7	Carbon C_t , %	82.19	80.16
8	Hydrogen H_t , %	5.31	4.76
9	Nitrogen N , %	1.52	1.35
10	Fixed carbon, %	63.55	65.99

studied samples were ground and sieved in to fractions with a particle size below 0.2 mm and put at the bottom of the reactor between two layers of a quartz wool for better temperature distribution and protection of the samples against entrainment by the gasification media. The reactor was heated to the temperature 800 °C with the use of a resistance furnace in an inert gas atmosphere. When the set temperature was reached the gasification agent was injected in to the reactor at a flow rate of $5.3 \cdot 10^{-2} \text{ cm}^3/\text{s}$. The amount of the product gas and its composition (CO_2 , CO , H_2 and CH_4) were analyzed with the application of a mass flow meter and a gas chromatograph.

3. Results and discussion

The study of the steam gasification of the low rank coal and flotation concentrate in the fixed bed reactor focused on the optimization of hydrogen-rich gas production.

The average total amount of the product gas in steam gasification at 800 °C was 6934 cm^3 and 7182 cm^3 for the low rank coal and the flotation concentrate, respectively (see Fig. 2). The respective amounts of hydrogen were 4299 cm^3 and 4525 cm^3 .

Reactivity of fuel is the parameter enabling the assessment of the reaction rate in a thermochemical conversion process (Smoliński, 2011; Takarada, Tamai, & Tomita, 1985). The reactivity of the chars of carbonaceous materials is most often determined for 50% carbon conversion. In the study presented this was calculated based on the on-line gas composition analysis and the flow rates of the gaseous products, based

on the following equation:

$$R_x = \frac{1}{m_0} \frac{dm}{dt_x} [\text{mol mol}^{-1} \text{s}^{-1}] \quad (1)$$

where R_x describes the reactivity for $X\%$ of carbon conversion, m_0 denotes the initial carbon content in the fuel sample, m denotes the time dependent carbon content in the mixture of gaseous products, t_x denotes the time required to achieve the carbon conversion of $X\%$ (Alonso, Borrego, Alvarez, Parra, & Menendez, 2001).

The reactivity for 50% carbon conversion, R_{50} for the low rank coal ($1.48 \cdot 10^{-4} \text{ s}^{-1}$ reached after 2292 s) was lower than the one determined for the flotation concentrate ($1.89 \cdot 10^{-4} \text{ s}^{-1}$ reached after 2112 s). The maximum reaction rate determined by the maximum reactivity was similar for both fuels and equaled $3.28 \cdot 10^{-4} \text{ s}^{-1}$ and $3.29 \cdot 10^{-4} \text{ s}^{-1}$ for the low rank coal and the flotation concentrate, respectively. The reactivity of fuel in a thermochemical conversion process depends on operating parameters (pressure, temperature and heating rate) as well as the physical and chemical parameters of the fuels (the content of carbon, volatiles, ash and fixed carbon).

Based on the total yield of the product gas and its average composition the calorific value was calculated as:

$$Q_g = \sum_i c_i d_i [\text{kJ kg}^{-1}] \quad (2)$$

where c_i denotes the content of the particular component in the product gas (% $_{\text{mass}}$) and d_i denotes the heat of combustion (kJ kg^{-1}). The calorific values of the product gas generated in the steam gasification of the low rank coal and flotation concentrate were 11466 kJ/kg and 11259 kJ/kg, respectively. Based on the results presented in Fig. 2 it may be concluded that steam gasification with the production of hydrogen-rich gas, as an environment friendly energy carrier, may be considered a promising method of the utilization of mining waste.

4. Conclusions

Gasification may be considered as a promising method utilizing low rank coals and flotation concentrate.

Both fuel samples studied presented similar reactivity, indicating their suitability for steam gasification process focused on hydrogen-rich gas production. The calorific value of the product gas for both of the fuels was comparable with the values reported for higher rank coal gasification.

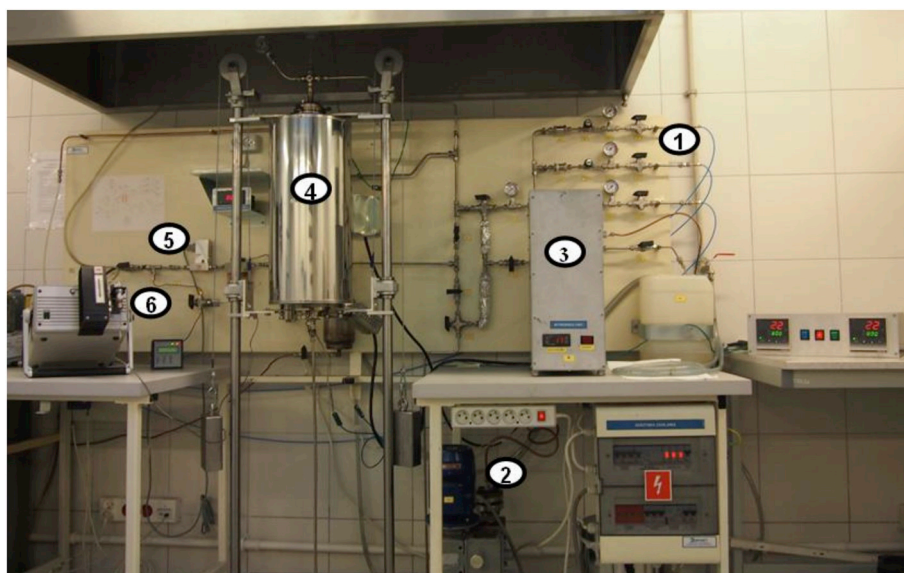


Fig. 1. Lab-scale installation for low rank coal and flotation concentrate steam gasification (1 – gas inlets system with valves and flow regulators; 2 – water pump; 3 – steam generator; fixed bed reactor with resistance furnace; 5 – flow meter; 6 – gas chromatograph).

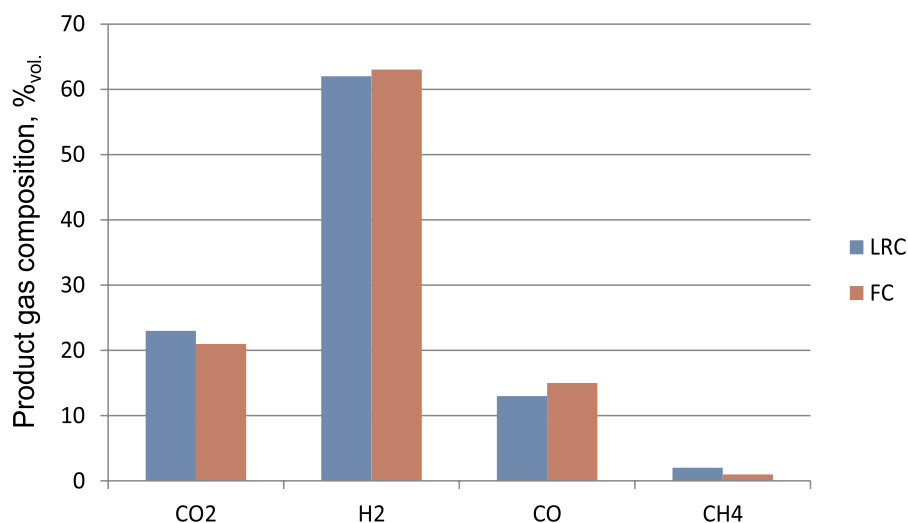


Fig. 2. Average composition of the product gas in the steam gasification of the low rank coal and the flotation concentrate.

The process of steam gasification seems to be an attractive alternative to the conventional combustion of low rank coal and flotation concentrate.

Conflicts of interest

None declared.

Ethical statement

The authors state that the research was conducted according to ethical standards.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jsm.2019.02.009>.

Funding

None.

References

- Alonso, M. J. G., Borrego, A. G., Alvarez, D., Parra, J. B., & Menendez, R. (2001). Influence of pyrolysis temperature on char optical texture and reactivity. *Journal of Analytical and Applied Pyrolysis*, 58(59), 887–909. [https://doi.org/10.1016/S0165-2370\(00\)00186-8](https://doi.org/10.1016/S0165-2370(00)00186-8).
- Belkin, H., Zheng, B., Zhou, D., & Finkelman, R. (2008). Chronic arsenic poisoning from domestic combustion of coal in rural China. A case study of the relationship between earth materials and human health. *Environmental Geochemistry*, 401–420. <https://doi.org/10.1016/B978-0-444-53159-9.00017-6>.
- Dai, S., Ren, D., Chou, C.-L., Finkelman, R. B., Seredin, V. V., & Zhou, Y. (2012). Geochemistry of trace elements in Chinese coals: A review of abundances, genetic types, impacts on human health, and industrial utilization. *International Journal of Coal Geology*, 94, 3–21. <https://doi.org/10.1016/j.coal.2011.02.003>.
- Dychkovskiy, R., Vladyko, O., Maltsev, D., & Cabana, C. E. (2018). Some aspects of the compatibility of mineral mining technologies. *Rudarsko-Geolosko-Naftni Zbornik*, 42(4), 73–82. <https://doi.org/10.17794/rgn.2018.4.7>.
- Finkelman, R. B. (1994). Modes of occurrences of potential hazardous elements in coal, level of confidence. *Fuel Processing Technology*, 39(1–3), 21–34. [https://doi.org/10.1016/0378-3820\(94\)90169-4](https://doi.org/10.1016/0378-3820(94)90169-4).
- Howaniec, N., & Smoliński, A. (2014). Effect of fuel blend composition on the efficiency of hydrogen-rich gas production in co-gasification of coal and biomass. *Fuel*, 128, 442–450. <https://doi.org/10.1016/j.fuel.2014.03.036>.
- Howaniec, N., & Smoliński, A. (2017). Biowaste utilization in the process of co-gasification with hard coal and lignite. *Energy*, 118(1), 18–23. <https://doi.org/10.1016/j.energy.2016.12.021>.
- Kamińska-Pietrzak, N., & Smoliński, A. (2013). Selected environmental aspects of gasification and co-gasification of various types of waste. *Journal of Sustainable Mining*, 12(4), 6–13. <https://doi.org/10.7424/jsm130402>.
- Krawczyk, P., Howaniec, N., & Smoliński, A. (2016). Economic efficiency analysis of substitute natural gas (SNG) production in steam gasification of coal with the utilization of HTR excess heat. *Energy*, 114, 1207–1213. <https://doi.org/10.1016/j.energy.2016.08.088>.
- Lin, S., Harada, M., Suzuki, Y., & Hatano, H. (2002). Hydrogen production from coal by separating carbon dioxide during gasification. *Fuel*, 81(16), 2079–2085. [https://doi.org/10.1016/S0016-2361\(02\)00187-4](https://doi.org/10.1016/S0016-2361(02)00187-4).
- Moreno, T., Querol, X., Alastuey, A., Viana, M., Salvador, P., Sánchez De La Campa, A., et al. (2006). Variations in atmospheric PM trace metal content in Spanish towns: Illustrating the chemical complexity of the inorganic urban aerosol cocktail. *Atmospheric Environment*, 40(35), 6791–6803. <https://doi.org/10.1016/j.atmosenv.2006.05.074>.
- Moreno, T., Trechera, P., Querol, X., Lah, R., Johnson, D., Wrana, A., et al. (2019). Trace element fractionation between PM10 and PM2.5 in coal mine dust: Implications for occupational respiratory health. *International Journal of Coal Geology*, 203, 52–59. <https://doi.org/10.1016/j.coal.2019.01.006>.
- Özdemir, M., & Zelkowsky, J. (1998). New applications of the fixed bed reactor to the measurement of coal reactivity under dynamic combustion conditions. *Energy Conversion and Management*, 39(16–18), 1891–1898. [https://doi.org/10.1016/S0196-8904\(98\)00082-X](https://doi.org/10.1016/S0196-8904(98)00082-X).
- Pivnyak, G., Dychkovskiy, R., Smirnov, A., & Cherednichenko, Y. (2013). Some aspects on the software simulation implementation in thin coal seams mining. In G. Pivnyak, O. Beshta, & M. Alekseyev (Eds.), *Energy efficiency improvement of geotechnical systems*. Taylor & Francis Group.
- PKN (1981). *PN-G-04513:1981 Paliwa stałe – Oznaczenie ciepła spalania i obliczanie wartości opałowej (Solid fuels – determination of the heat of combustion and calculation of the calorific value)*.
- PKN (1998a). *PN-G-04516:1998 Paliwa stałe – Oznaczenie zawartości części lotnych metodą wagową (Solid fuels – determination of volatile matter content by gravimetric method)*.
- PKN (1998b). *PN-G-04560:1998 Paliwa stałe – Oznaczenie zawartości wilgoci, części lotnych oraz popiołu analizatorem automatycznym (Solid fuels – determination of moisture content, volatile parts and ash with an automatic analyzer)*.
- PKN (1998c). *PN-G-04571:1998 Paliwa stałe – Oznaczenie zawartości węgla, wodoru i azotu automatycznymi analizatorami – Metoda makro (Solid fuels – determination of carbon, hydrogen and nitrogen content by automated analyzers – Macro method)*.
- PKN (2001). *PN-G-04584:2001 Paliwa stałe – Oznaczenie zawartości siarki całkowitej i popiołowej automatycznymi analizatorami (Solid fuels – determination of total sulfur and ash content by automatic analyzers)*.
- Smoliński, A. (2011). Coal char reactivity as a fuel selection criterion for coal-based hydrogen-rich gas production in the process of steam gasification. *Energy Conversion and Management*, 52(1), 37–45. <https://doi.org/10.1016/j.enconman.2010.06.027>.
- Smoliński, A., & Howaniec, N. (2013). Application of gas chromatography in the study of steam gasification and co-gasification of hard coal and biomass chars. *Acta Chromatographica*, 25(2), 1–14. <https://doi.org/10.1556/AChrom.25.2013.2.8>.
- Sobolev, V., & Usherenko, S. (2006). Shock-wave initiation of nuclear transmutation of chemical elements. *Journal de Physique IV (Proceedings)*, 134, 977–982. <https://doi.org/10.1051/jp4:2006134149>.
- Takarada, T., Tamai, Y., & Tomita, A. (1985). Reactivities of 34 coals under steam gasification. *Fuel*, 81(10), 1438–1442. [https://doi.org/10.1016/0016-2361\(85\)90347-3](https://doi.org/10.1016/0016-2361(85)90347-3).