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Hydrogen-rich gas as a product of two-stage co-gasification of lignite/waste plastics mixtures

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ARTICLE INFO

Article history:
Received 15 February 2014
Received in revised form
8 May 2014
Accepted 11 May 2014
Available online 7 June 2014

Keywords:
Co-gasification
Waste plastics
Lignite
Hydrogen-rich gas

ABSTRACT

Under atmospheric pressure, mixtures of lignite with waste plastics were gasified on a laboratory scale. The resulting tar was cracked in a thermal cracking reactor. For experiments, low-ash and low-sulfur lignite was used; the percentage of waste plastics in the mixtures was 10 and 20 wt.%. The main product of co-gasification was hydrogen-rich gas, as by-products, soot and non-gasified solid residue were obtained. It was found that the higher heating value of obtained gas is fully comparable with that of industrial gas from lignite gasification. Probably, at least 20 wt.% of lignite can be replaced with mixed waste plastics in this process. The effect of waste plastics addition on properties of the obtained gas and of the non-gasified solid residue was evaluated and discussed.

Introduction

Wastes: production and utilization

The current state of the environment is immediately related to the quality of individual areas including mainly air, water management, agriculture and waste management. Due to the large production of wastes, a need arises to replace the existing technologies with low- or no-waste technologies. In the current state of waste production, it is necessary to find a way of the maximum utilization of wastes. Waste materials as alternative fuels are receiving increased attention.

Waste production in the individual categories in the Czech Republic in the years 2002–2012 is evident from Fig. 1 [1–3]. With regard to municipal waste, the production is continually growing since 2007. Whereas in the Czech Republic in 2003–2008, 4.6–3.8 Mt of municipal waste were produced annually, in 2009–2012 this number already amounted to 5.3–5.4 Mt [2,3]. The generated waste contained and still contains a large portion of materials that may be used for power and heat production or to obtain useful liquid, solid or gaseous fuels.

Municipal waste containing a number of further utilizable components is currently predominantly deposited at landfills or biologically modified to form compounds and mixtures which can be landfilled after such a modification. A smaller proportion of the produced municipal waste is used as fuels in incineration plants or other means to generate energy; a portion of municipal wastes is used for recultivation or composting or is deposited as technological material at secured landfills (Table 1). A part of municipal waste can be sold as secondary raw materials [3].

Municipal waste production in EU countries considerably varies, as arises from [4], but the total is quite high; so, wastes

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http://dx.doi.org/10.1016/j.ijhydene.2014.05.054
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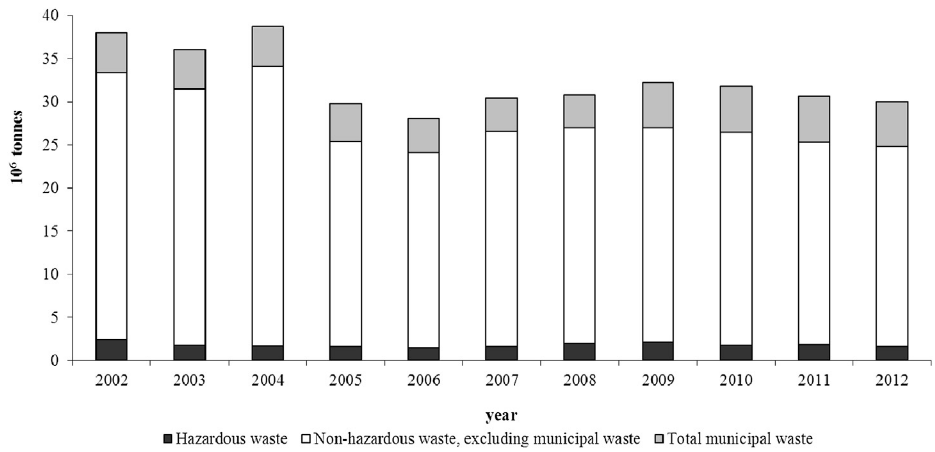

Fig. 1 – The total waste production by category in the Czech Republic, 2002–2012.

must be processed. In this connection, pyrolysis of municipal solid waste (MSW) was studied in order to evaluate the influence of the process conditions: temperature, catalyst, the residence time of the gaseous phase in reactor, and grain size [5–8].

Since waste plastics are an important part of MSW, it is necessary to deal intensively with their treatment. It was found that household municipal waste contains ca 12% plastics [9] which may be utilized, but currently are mostly landfilled along with other municipal waste. Plastics currently represent 11% of MSW in OECD countries [10]. Various ways of their processing are suggested. Wilk and Hofbauer [11] studied co-gasification of plastics with wood biomass in fluidized bed steam gasifier. Authors found more product gas than expected and more CO and CO_2 were measured in the gas than resulted from mono-gasification of materials. Contrary, the tar content in the product gas was considerably lower than presumed. Sørum et al. studied pyrolysis of waste plastics [12] and Luo et al. [13] monitored the influence of the grain size on pyrolysis performance with plastics, kitchen garbage, and wood as the three most frequent components of MSW. Other authors verified a possible utilization of waste plastics by pressing of them with paper and lignite dust into briquettes, which in the municipal sphere can replace sorted lignite [14]. In summary, pyrolysis has the inherent advantage of high flexibility with respect to plastics with contaminants; gasification has the promising features, such as high conversion efficiency, effective processing of low-grade fuels and wastes, moreover, the producer gas (the gas obtained) can be effectively utilized in a variety of ways ranging from electricity production to chemical industry.

Table 1 – Municipal waste utilization in the Czech Republic in 2007–2012.

Waste management (%)	2007	2008	2009	2010	2011	2012
Landfills (codes D1 + D5 + D12)	86.2	89.9	64.0	59.5	55.4	53.7
Material recovery municipal waste[a]	21.1	24.2	22.7	24.3	30.8	30.3
Energy production (code R1)	9.8	9.6	6.0	8.9	10.8	11.8
Incineration (code D10)	0.07	0.05	0.04	0.04	0.04	0.04

[a] codes R2–R12; N1, N2, N8, N10–N13, N15.

In our case, gasification and co-gasification were considered as advanced methods of the thermal treatment of plastic wastes. Gasification processes may work with or without catalyst [15–19] in a moving or fluid bed or in an entrained flow reactor. A problem is the removal of the formed tar entrained by the gas flow. The currently most promising method for production of purified gas is the catalytic cracking of produced tar in a secondary reactor. For this reason, the first gasification stage was complemented with secondary catalytic reactor with calcined dolomite [20] working at 800–900 °C or with catalysts on nickel basis [21] working at 700–800 °C, which catalytically purify the raw gas. The use of a Ni-catalyst makes it possible to convert ca 90–99% of the tar in the secondary reactor into gases. Although the results are promising, the entire process must be more elaborate, both economically and technically, and have only one-stage, if possible. Other experiments, on the one-stage fluidized bed reactor, showed that $Rh/CeO_2/SiO_2$ catalysts containing 35% of CeO_2 have an excellent influence on the conversion of carbon into gas at low temperature when compared with non-catalytic or dolomite-catalyzed reactions at high temperature [22]. The conversion of carbon into gaseous compounds may be enhanced by introduction of small amount of oxygen from the bottom of the reactor or a sufficient fluidization velocity.

Mastral et al. [23] compared the pyrolysis and gasification of high density polyethylene (HDPE) in a fluidized bed reactor. It was found that the working temperature affects product distribution and gas composition, and that higher temperature increases a gas production and simultaneously reduces a tar production in both pyrolysis and gasification. In the partial oxidation during HDPE gasification, a higher reactivity of HDPE was observed. The gas composition depends on gasification temperature; with increasing temperature, the content of carbon monoxide and methane markedly increase while the content of carbon dioxide decreases. Pinto et al. [24,25] studied the co-gasification of coal with waste polyethylene