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SELECTED ENVIRONMENTAL ASPECTS OF GASIFICATION AND CO-GASIFICATION OF VARIOUS TYPES OF WASTE

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Abstract
The process of gasification of carbonaceous fuels is a technology with a long-standing practice. In recent years, the technology has been extensively developing to produce energy or chemicals on the basis of obtained gas. Studies focused on the improvement of the gasification process aims at developing the process by increasing environmental safety, the efficiency and the possibilities to utilize various types of alternative fuels (post-consumer waste, various types of biomass waste, by-products and post-process residues, sewage sludge) independently or by co-gasification with coal. The choice of the gas purification system, the process operating parameters and introducing the necessary modifications to the existing technologies are essential steps while processing these kinds of feedstock, with regard to their individual characteristics. This paper discusses selected environmental aspects of the gasification and co-gasification of municipal solid waste, sewage sludge, various types of biomass waste and post-process residues. Selected alternative fuels are also characterized, focusing on the influence of their presence in the feedstock in terms of production and the emission of polychlorinated organic compounds, tars, heavy metals and toxic elements.

Keywords
gasification, co-gasification, plastics, sewage sludge, biomass waste, heavy petroleum residue, Refuse Derived Fuel, dioxins, heavy metals, tar

1. INTRODUCTION

Gasification is a thermochemical process that converts carbonaceous fuels into a combustible gas consisting of CO, H_2, CH_4, CO_2 and other substances in smaller amounts. Gaseous products may be used in combustion as well as the production of many large volume chemicals such as ammonia, methanol, formaldehyde, OXO alcohols and aldehydes, for the synthesis of hydrocarbons by the Fischer-Tropsch process and in various carbonylation, hydrogenation or hydrotreating processes.

Gasification is a process that facilitates using both solid and liquid fuels, this makes it possible to process post-process and post-consumer waste of various types. Homogeneity of the physical and chemical properties of the fuel directed to a gasification reactor is an advantageous feature, but even in the case of major differences in chemical composition or physical properties (for example, between particular components of municipal waste fraction or in the co-processing), the technology permits obtaining far greater feedstock flexibility than combustion (Nikodem 2007). The gasification of various types of waste (municipal or post-process), or co-gasification with conventional fuel, is an effective method for recovering its energy content, and the resulting gas combustion, as opposed to direct gas combustion, does not cause technological problems regarding the selection of a narrowly specialized stoker.

Waste for which gasification is considered are mainly sewage sludge, biomass waste from wood, pulp and food industry or agriculture, municipal solid waste or their combustible fractions, as well as heavy petroleum residues.

Sewage sludge is a waste derived from the treatment of municipal and industrial wastewater. The content of individual substances in sludge is largely dependents on their origin. They mainly consist of organic (carbohydrates, proteins and fats) and mineral substances. Their common characteristic is a high content of moisture, which reduces the transport efficiency and must be removed. Gasification requires the relatively easy sewage sludge treatment prior to use – the process may be carried out even at 75% moisture content in the fuel, while sludge pyrolysis requires its reduction to about 15% (Manara, Zabaniotou 2012). Sewage sludge is subjected to dehydration (concentration, mechanical dehydration and drying) as well as stabilisation and hygienization (Kordylewski 2005). Currently, a small amount of sludge is utilised by combustion or gasification, however, thermochemical processing technologies are treated as a prospective method for sewage sludge usage. A characteristic feature of sewage sludge as fuel is high content of volatile matters, as well as

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nitrogen and heavy metals. Caloric value of dried sewage sludge is 12–14 MJ/kg (Kowalik 2000).

Waste biomass is a group with widely varied composition and physical properties. Biomass waste can be classified according to origin (plant, animal) or structures which are dominant (cellulose, lignin, fats, wax or albumens). Biomass wood waste (sawdust, shaving), straw and paper industry waste, in which cellulose structures are dominant, are also recognized as fuel. The prevalence of small-scale systems for gasification and co-gasification of lignin and cellulose biomass, and the results of research papers devoted to biomass gasification and co-gasification (Van der Drift, Van Doorn, Vermeulen 2001; Myren et al. 2002; Paasen, Kiel 2004; Pinto et al. 2007, 2009; Abu El-Rub, Bramer, Brem 2008; Mastellone, Zaccariello, Arena 2010) indicate that the technology is effective and safe for the environment. Also pulp industry waste may be disposed of without posing further problems regarding the emissions of unwanted compounds. Some of them, such as "black liquor" – the precipitate formed as a result of the wood pulping process, due to the alkali content can be a catalyst for the reaction, and may allow more complete utilization of the chemical energy contained in the co-gasified fuel (Kuang et al. 2007; Jaffri, Zhang 2007; Zhan, Zhou, Wang 2010).

Types of biomass waste other than wood are characterized by a generally higher content of chlorine, sulphur and ash (Paasen, Cieplik, Phokawat 2006). Some of them, especially the shells of different types of nuts and fruit seeds, due to the content of metal oxides having a catalytic activity, permit achieving higher grades of carbon conversion and gas production yield during the co-gasification process with coal (Di Donato et al. 2011). Waste with a low content of cellulose and lignin, such as used fats or oil seed pomace, is fuel with different properties. The long chains of hydrocarbon fragments contained in fats, especially with a large number of unsaturated bonds between carbon atoms, favour the formation of large quantities of liquids and gas rich in hydrocarbons (Pinto et al. 2005; André et al. 2005). Due to the relatively low reactivity and the lower gas yield, research focuses on processing feedstock rich in fats with the addition of catalysts or their co-gasification with fuel containing metal oxides catalysing the reaction of hydrocarbons with a gasifying medium (Pinto et al. 2005, 2009).

Only a moderate part of research on gasification and co-gasification of the biomass waste concerns animal waste. The high fat and heteroatoms content present in the tissues of animal organisms is the cause of large amounts of impurities. Depending on their type, this entails the need to expand node gas purification (Cascarosa et al. 2011). An essential aspect of the waste treatment of animal waste, as in the case of sewage sludge, is the microbiological risk. Therefore, thermochemical processes of energy recovery contained in this type of waste are a prospective and desired direction of their disposal.

Plastic waste is another group of alternative fuels with different properties. The share of plastics in municipal waste from developed countries stands at around 8%. World production increased from 1950 to 2008 from 1.5 million tonnes to 245 million tonnes (Biois… 2010). This involves the need to develop methods of disposal combined with the recovery of a portion of materials or energy used to produce them. Gasification technology of plastic waste, as a method of energy recycling is not sensitive to polymer changes occurring under the influence of light, in contrast to the methods of material recycling. Gasification also does not require such thorough cleaning of waste, as in the case of chemical or material recycling. Taking into account the consumption of water and energy for material recovery or monomers recycling and greenhouse gas emissions, gasification can be considered a relatively environmentally beneficial form of recycling (The Environment… 2004). Plastics are present in municipal solid waste in extremely varied sizes and forms, and therefore, the larger elements of the waste should be fragmented (to less than 5 cm diameter), while the films – should be subject to concentrating by concentration and clumping. Predominant part of plastic fractions from waste dumps is waste polyethylene that can successfully undergo gasification process (Chiemchaisri, Charnnok, Visvanathan 2010). Polyolefin waste provides a good feedstock for thermochemical processes because it consists almost exclusively of carbon and hydrogen, and typically contain small amounts of impurities and has a high calorific value (e.g. 43.5 MJ/kg of high density polyethylene and 44 MJ/kg of polypropylene) (The Environment… 2004; Kordylewski 2005). The share of plastics in the fuel increases the amount of hydrocarbons and tar in the gas (Chiemchaisri, Charnnok, Visvanathan 2010; Pinto et al. 2012). The high content of halogens is also a major difficulty in the thermochemical processing of certain types of plastics.

Heavy petroleum residue is a fuel with a relatively low reactivity, so research on its gasification and co-gasification focuses on finding efficient catalysts that can enhance the conversion of the contained carbon (Zhan, Zhou, Wang 2010; Ohtsuka 2009; Revankar, Gokarn, Doraiswamy 1987). Heavy residue has a low volatile content compared with coal or biomass. It contains, however, large amounts of sulphur and heavy metals. The calorific value of heavy petroleum residue is 36.2 MJ/kg (Zhan, Zhou, Wang 2010).

Fuel produced from mixed waste (municipal and industrial) is referred to collectively as Refuse Derived Fuel, RDF. Table 1 shows the characteristics of selected materials found in municipal waste.

Table 1. Selected characteristics of municipal waste (Tillman 1991)

Components	C	H	O	N	Cl	S	Moisture [% mas.]	Ash [% mas.]	Combustion heat [MJ/kg]
Paper	33.0	4.6	33.0	0.1	0.13	0.21	16	13	12.7
Plastics	56.4	7.8	8.1	0.85	3.0*	0.3	15	9	18–45
Rubber and leather	43.1	5.4	11.6	1.34	5.0	1.2	10	22	19.6
Wood	41.2	5.0	35.0	0.24	0.1	0.07	16	3	16.2
Fabric	37.2	5.0	27.1	3.1	0.3	0.3	25	2	15.3
Garden waste	23.3	3.0	17.5	0.9	0.13	0.15	45	10	9.3
Food waste	18.0	2.5	12.9	1.1	0.4	0.06	60	5	7.6

* Depending on the type of plastic involved, 0–0.45 chlorine.

The waste undergoes partial processing, so that the RDF fuel mixture has sufficient heating value and does not contain inert ballast, bulky waste, toxic substances, and other undesirable elements during thermochemical processing. A typical procedure prior to the energetic use of waste is based on the following steps (Spliehoff 2010; Kordylewski 2005)

- magnetic separation of ferrous and non-ferrous metals

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