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High-methane gasification of fuels from waste – Experimental identification

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The paper presents experimental research on innovative technology of RDF fuel produced from combustible waste (other than hazardous) gasification. The gasification process was performed in the compact bed, in the laboratory tubular gas generator with a power of 5 kW. In the first place RDF fuel, not enriched with methane, was gasified with addition of Bio-CONOx. Next, cogasification was performed with 10, 15 and 20% addition of methane-forming formulation. The results indicated that the addition of Bio-CONOx to the fuel resulted in an increase in the content of CH_4 in the syngas (8% - without addition of Bio-CONOx to 18% CH_4 with 20% addition of Bio-CONOx). At the same time there was an increase in shares of other combustible components of syngas (CO and H_2). Enriching fuel with the additive Bio-CONOx increased the calorific value of the syngas LHV from 4 MJ/Nm^3 (RDF) to 9 MJ/Nm^3 (RDF fuel with 20% addition of Bio-CONOx). Studies have shown that the increase in efficiency of the gasification process has been obtained by setting the process conditions in a tubular reactor, i.e. temperature decomposition: 400–450 °C in the layer of fuel and 800–850 °C in the gas zone above the layer of fuel. Such temperature distribution in the layer of fuel favors exothermic process of hydrogenation of CO and CO_2 to CH_4 form and evaporation and decomposition of fat fraction contained in methane forming supplement. At high temperatures over a layer of fuel (in the atmosphere of unreacted oxygen), some organic vapours (greases and tars) were burnt, and some underwent cracking.

1. Introduction

In practical applications, the vast majority of energy technologies to use waste are carried out using combustion processes [1,2]. The fuel used i.e. waste is often in the unsegregated form, as chemically diverse, low-calorie combustion mass with a calorific value HHV = ca. 5–10 MJ/kg [3–5]. High calorific value (HHV = of ~17 MJ/kg to ~25 MJ/kg) and the stability of the composition are achieved by molding process of waste to fuels, e.g. RDF (SRF- in accordance with CEN) [5–7]. RDF (Refuse Derive Fuel) fuels are selected combustible fraction of waste, different than hazardous waste. The waste is subjected to mechanical treatment comprising the following steps: sorting, drying (optional), shredding, separation of metals and mineral non-combustible materials, packaging, briquetting. In case of the fuel briquette, it may be necessary to use various types of binders (which may also be industrial waste), since the fuel of this type needs to have mechanical durability. The unified composition and stable calorific value RDF create the possibility of using these fuels in power and professional utilities. Stabilized fuel properties of waste fuels, such as coal or biomass allow using gas generator technologies, yielding a combustible synthesis gas. Available technologies implemented (due to the still relatively low supply of RDF on the fuel market, which may be the result of low fuel processing efficiency in flammable gas), do not meet a big public interest in the energy sector. Thus, the production of energy with the participation of gasifier still offers ample opportunities for research and development. A particularly interesting and developing cogeneration of energy system is the technology of gas-steam IGGC (integrated gasification combined cycle) [8–10]. The quality of the synthesis gas produced in the gasification process affects greatly the efficiency of combustion and expansion in a gas turbine, which results in high efficiency and low emission process for the production of electricity. Carbon energy (withdrawn from the economies of the EU), thanks to the possibility of producing a reducing gas gasification technology (with a wide participation of CH_4) intended for reburning in the coal

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boilers, has a chance to rebuild its potential in countries rich in cheap coal [11,12].

Used in power industry on a small scale, gasification technologies are characterized by relatively low efficiency of the process, i.e. conversion of fuel into a combustible gas, estimated at approx. ca. 50% (cold gas chemical efficiency) [13–15]. The process (chemical) efficiency of gasification, defined by the ratio of the calorific value of the fuel to the calorific value of syngas obtained in the gasifier, clearly identifies the advancement in technology of producing combustible gases from solid fuels. Quality gas products, and therefore technological advancement, alongside the quality of fuel used, depends on three basic parameters: (i) the nature of the gasifying agent, (ii) the effectiveness of the processes of heat and mass, where the key role is attributed to the construction of the reaction chamber gasifier, including the possible recovery of heat supplied to the gasification process, (iii) the application of catalysts to intensify the conversion process. In literature, much attention was paid to research the process of gasification of various solid fuels, setting the goal on high efficiency of gas production. Gasifying agent is the next essential reactant in the fuel gasification process, taking place in the gasifier. A commonly used gasifying agent is air. Then a low calorie gas with a calorific value of 3–5 MJ/m^3 is obtained [16–19]. Better properties of calories, i.e. higher calorific value of gas generators 4–6 MJ/m^3 are obtained in the fluidised bed technology with the use of the gasification agent of oxygen or steam and air [20–24]. In practical applications of solid fuel gasification plants, based mainly on the idea of the classic gasification on the grate, where the process takes place in several process areas (drying, pyrolysis, gasification, combustion). According to these technologies a lean gas with a calorific value of about 3–6 MJ/Nm^3 and CH_4 methane content of about 0.9–3% is achieved [25–27]. Slightly better properties of caloric gas, which is affected by increased proportion of methane – 3–6%, is obtained in gasification technologies in a fluidized bed with a solid (BFB) and circulating (CFB) layer [28–30]. In applied and developed technologies, the increase in calorific value of the gas is obtained by improving the technological indices of the process affecting the kinetics of chemical reactions. A commonly used parameter in the technology of low pressure (governing the efficiency of the process) is the temperature increase in the layer of fuel. This is a spontaneously produced synthesis gas, rich in hydrogen and poor in 1–2% methane content [31–33]. There are also known methods for improving the quality of syngas, where the increase in the share of hydrogen occurs through the use of catalysts, alkali mineral sorbents, provided directly to the reaction chamber [34–36]. In such conditions, the fraction of hydrogen in the synthesis gas can reach approx. 54% [37]. In contrast, due to the high temperature in the fuel bed, higher calorie methane yield is low, and is approx. 2%. The high proportion of methane in the gas (approx. 9.5%) and a higher heating value (HHV = 15.5 MJ/m^3) is obtained by gasification in the two chambers, in FICFB technology. Implementation of the process in the two chambers requires a complex structure of the gasifier. Part of the char formed in the first chamber, is burned (incinerated) in the second chamber. Emergent energy while combusting, is a factor supporting the methane creating processes, during gasification in the first chamber. Similar technology – Silva Gas - uses a two phase process, i.e. gasification (syngas obtained with a high proportion of methane 15.6% and a calorific value HHV = 17.3 MJ/Nm^3) and combustion (as in the above-quoted technology). The high share of hydrogen and methane are obtained in the process of hydrogasification and hydro-plasma gasification [38]. It should be added, that the high methane content and high calorific value of the syngas were obtained during gasification of woody biomass. It can be assumed that similar results will be achieved during the gasification of RDF, where the carbon share is approx. 40%, so similar as in the woody biomass.

This paper presents a different (taking into account the current state of research in the development of gasification technology) concept of forming medium calorific synthesis gas from RDF fuel. The aim of the research was to produce a synthesis gas with a high proportion of CH_4, i.e. above 15%. The high share of methane and higher calorific value of gas were obtained by using a new gasification technology in the laboratory scale. The high proportion of CH_4 is achieved by: (i) the tubular structure of the gasifier, where a significant role in the gasification is played by flow dynamics of the gasifying agent through the fuel bed, (ii) the use of a fuel additive formulation Bio-CONOx – i.e. the combustible substance with specific properties [39,40]. The Bio-CONOx preparation is a flammable synthetic material, composed of biological waste of agro origin, of a special composition and properties as defined in Ref. [41] and determining the specific behavior under high temperature conditions. The starting model (natural) material for composing synthetic Bio-CONOx is rapeseed meal containing fatty acids and protein. Shortcut Bio-CONOx means: Bio-biological origin, CO- the ability to create a reducing atmosphere around the fuel seed in thermal transformation, NOx - the ability to reduce NOx in combustion processes (the formation of methane and ammonia). Technological possibilities of producing gas with a high content of CH_4 (and thus a higher calorific value) is justified by discussing the results of the experiment gasification of RDF fuel pellets with the addition of Bio-CONOx preparation below. The experiment was carried out on a laboratory scale. The proposed technological solution and design can be applied to: (i) - a low-carbon coal combustion technologies in power units-mainly concerns the reduction of NOx emissions through the use of high gas, produced in the technology of Bio-CONOx as so called reburning gas; (ii) - highly efficient heat and production in below cogeneration gas and steam IGCC (iii) - highly efficient gasification of fuels from municipal and industrial waste in the technology of low and medium power (iv) - supply engines and gas microturbines of low power (e.g. 30–200 kW) medium calorific gas in prosumer power industry, (v) - power fuel cells (vi) - power Stirling engines, (vii) production of gaseous fuels for transport means e.g. in public transport.

2. Materials and methods

2.1. Properties of fuels used

In laboratory studies, RDF fuel was gasified. Due to the use of fuel additive with a reserved name Bio-CONOx in the gasification process (which significantly affects the increase in the amount of methane in the gas generator), the technology was called “gasification Bio-CONOx”. Preparation Bio-CONOx is under patent protection [42].

RDF fuel used in the tests is a standard pellet molded fuel from selected combustible fraction of waste, different than hazardous waste. Bio-CONOx preparation is a combustible waste material of natural origin. Samples of the research material were collected according to the procedures used for sampling solids. After homogenization (in order to obtain representative samples) fuel analysis was carried out. For this purpose, the following was determined: moisture, flammable and non-combustible parts, heat of combustion - in accordance with PN-ISO standards (PN-Z–15008–02:1993, PN-ISO 1171:2002, PN – ISO 1928:2002); elemental composition of the flammable substance - carbon, hydrogen, nitrogen, and sulfur by means of CHNS elemental analyzer model 2400 series II from Perkin Elmer, and chlorine according to Polish Standard PN-ISO 587/2000.