



THERMAL TREATMENT

Investigation of characteristics of solid particles from a mixture of sewage sludge and wood pellets synthetic gas and their clean-up

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ABSTRACT

The most reasonable way to utilise sewage sludge in Europe is in energy production. In the process of thermochemical conversion of sewage sludge, combustible gas is produced. Studies of synthetic gas composition show that this gas contains various impurities, which must be cleaned before gas supply to the final user. Although there are many ways to clean toxic materials existing in the synthetic gas, the application of plasma treatment seems the most promising. Exposure to the high temperature of plasma changes the structure and the chemical composition of solid particulates existing in the gas. In this study on the synthetic gas, ESP cleaning efficiency, size and elemental analysis of solid particles collected from different parts of the experimental setup with a gasifier operating on a mixture of sludge and wood pellets were analysed. The results showed the difference in particle sizes and changes in elemental composition of particles collected from different parts of the experimental setup. It was determined that the synthetic gas obtained by gasification of a mixture of sludge and wood pellets contains a great concentration of solid particles, which leads to the total collection efficiency of an electrostatic precipitator being only about 60%.

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1. Introduction

Great amounts of sewage sludge are accumulated in wastewater treatment plants. Although there are several ways to utilize sewage sludge (Wang et al., 2013), the most reasonable way for utilization of sewage sludge in Europe is in energy production (Kelessidis and Stasinakis, 2012). From this point of view there are a few main thermal utilization technologies applied: combustion, pyrolysis, and gasification (Fytli and Zabaniotou, 2008).

Combustion of sewage sludge greatly reduces its volume. As sewage sludge is mainly composed of organic acids, phosphorus, alkali, potash, sulphur, chlorine, nitrogen, hydrogen, carbon, heavy metals, etc. (Kelessidis and Stasinakis, 2012; Manara and Zabaniotou, 2012), the combustion process, which usually takes place in the temperature range from ~850 to 1000 °C (Murakami et al., 2009) in the presence of oxygen, results in releases of various pollutants: heavy metals, dioxins, furans, particulate matters, NO_x, N₂O, SO₂, HCl, HF, C_xH_y, which adversely affect human health and the environment. Combustion is considered as a potential source of

atmosphere pollution, and therefore it is necessary to use state-of-the-art incinerators and cleaning devices.

The pyrolysis process is less polluting compared to combustion of the sewage sludge (Manara and Zabaniotou, 2012). Pyrolysis is usually performed at lower temperatures to produce more liquid or char. In this case sewage sludge is thermally decomposed in the temperature range of ~300–500 °C in an atmosphere without oxygen, and thus this allows heavy metals to concentrate in a solid residue. The main fractions formed after pyrolysis are the liquid (tar and oil containing acids, methanol and acetone), the gas (containing mainly H₂, CH₄, CO, CO₂) and the solid (mainly pyrolytic char) (Manara and Zabaniotou, 2012). Currently, pyrolysis is being investigated as a way for utilizing domestic waste in compact waste treatment units at home, and it seems to be a rather effective way to deal with such a type of waste (Jouhara et al., 2017).

The traditional gasification process is the most reasonable thermal utilization method for sewage sludge (Striugas et al., 2017). Synthetic combustible gas, which can be used in burners for heat generation, in internal combustion engines, gas turbines and other applications (Spath and Dayton, 2003; Mackaluso, 2007; Mohammad, 2007) is produced during the process of thermochemical conversion applied by gasification. Compared to pyrolysis, gasification is performed at higher temperatures to generate more

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combustible gases. Gasification is usually performed in the temperature range of 650–850 °C and in the presence of oxygen but with an amount, which is not sufficient for complete combustion. Due to this, emissions of NO_x, SO_x, heavy metals and fly ash are reduced. The main products from the gasification process are producer gas and some ash (solid residue). Producer gas mainly contains H₂, CO, CH₄, CO₂, and C_xH_y (Fytili and Zabaniotou, 2008; Jouhara et al., 2017).

A literature review shows that raw synthetic gas generated during the gasification process also contains various impurities, such as dioxins, furans, tars, ammonia, hydrogen sulphides, alkali metals, and particulate matters (Mohammad, 2007; Xu et al., 2010), which must be removed before final use.

In general, various types of such impurities can be cleaned by applying thermal or catalytic cracking, physical and chemical absorption, catalytic decomposition, condensation, agglomeration methods, addition of iron oxides, powered activated carbon injection, cyclones, candle filters, and electrostatic precipitators, as presented in detail in (Prabhansu et al., 2015).

The application of plasma processing for synthetic gas is considered a novel “hot gas clean-up technology” (Sikarwar et al., 2016), which reduces the formation of impurities (mainly of tars, dioxins and furans) (Murakami et al., 2009). The presence of producer gas even for a short period of time in a plasma reactor, due to the very high temperature (1100–1200 °C), ensures rapid and highly efficient destruction of contaminants to simple gaseous products, with reduction efficiencies typically exceeding 96% for complex organic compounds and thiophenes (Materazzi et al., 2015). The plasma treatment of the gases obtained by the gasification process also ensures the conversion of tars to more valuable products, such as H₂ and CO, and almost 100% carbon conversion efficiency.

Simultaneously, inorganic particulate and ash-type components are converted into stable vitrified products. The obtained hydrogen-rich synthetic gas contains low levels of tars. Besides, the plasma treatment results in insignificant soot formation (Materazzi et al., 2014) and increases the gas yield and the total amount of the produced energy (Striugas et al., 2017).

Taking into account all the benefits of the synthetic gas treated by plasma, it can be concluded that such gas has a great potential to be used for high efficiency power generation (Materazzi et al., 2014).

During the gasification process, not only synthetic gas but also solid slag is formed. This could also be a valuable product if appropriately treated. The differences in structure and elemental analysis and other properties of thermally untreated and thermally treated slag (at a temperature in the gasifier ~1000 °C and oxygen 0.1%) obtained from a mixture of sewage sludge and wood pellets (70 + 30% by weight) were analyzed in (Kavaliauskas et al., 2015). It was shown that before the thermal treatment, the slag surface was formed of microgranules with microtubes. After the thermal treatment, the diameter of microgranules decreased, the surface became smoother and big solid particles split into smaller ones. It was concluded that composition of treated slag with its large surface area of particles could be used for the production of supercondensers, while untreated slag is more suitable for coatings.

There is still a need for filtration devices for removing solid particles from synthetic gas. There are a few types of cleaning devices used to remove particulate matters from flue gas, which are also applied to the removal of solid particles from synthetic gas. The most popular cleaning device is an inertial separator-cyclone. Other types of devices, so called barrier filters when the gas stream flows through fabrics, fibers, granules or porous solids (Woolcock and Brown, 2013), are also used.

Particulate matters from synthetic gas can also be cleaned using wet scrubbers and electrostatic precipitators (ESPs). The precipitators are of a rather simple design and apply electrostatic forces

(Parker, 1997) on particulate matters. In general, ESPs are very effective devices for removing small particulates ($\leq 30 \mu\text{m}$). A review of cleaning technologies presented in (Prabhansu et al., 2015) addresses the cleaning of synthetic gases by electrostatic precipitators; however, in the case of the ESP, the information provided is rather limited and mainly attributed to the cleaning of flue gases.

The literature review shows that publications related to investigations of collection efficiency, characteristics and elemental analyses of solid particulates obtained during the gasification of sewage sludge in different parts of experimental setups are rather limited.

The aim of the present study, as the extension of the results presented in (Striugas et al., 2017), is to evaluate the collection efficiency of the ESP operating on producer gas from the gasified mixture of sewage sludge and wood pellets and to study and compare the sizes and chemical composition of solid particles in different parts of the experimental setup. The mixture of sewage sludge and wood pellets was chosen in order to avoid operational problems with the gasifier, i.e. clogging, complicated removal of coke particles from the gasification reactor, which were revealed during the preparatory experiments with the gasification of pure sewage sludge.

2. Materials and methods

2.1. Experimental setup

The experimental setup with the gasifier includes the following main components (Fig. 1): a downdraft gasifier (details presented in (Striugas et al., 2014)), two cyclones, an air plasma unit, a gas cooler, an ESP, a fan, a gas boiler, a flue gas exhauster and a chimney.

The fuel (feedstock) is loaded into the tank, which has a capacity sufficient to run the gasifier for up to 5 h of operation. During the experiments, the fuel was dried sewage sludge mixed with wood pellets (30% of dried sewage and 70% of wood pellets, by weight). The fuel is supplied to the gasifier (100 kW) from the tank by the screw conveyor. The gasification process is fully automatic and the main parameters are controlled from and stored in the computer.

From the gasifier, synthetic gas with a temperature of about 600 °C enters the cyclone where a certain amount of the solid particles is collected. The cyclone is made from stainless steel. The outer diameter of the cyclone is about 0.130 m, the height ~0.640 m (straight part 0.297 m). The cyclone inlet pipe is rectangular in shape with the area of 75 × 25 mm².

The synthetic gas then flows into the air plasma unit. The plasma unit is an atmospheric pressure DC arc plasma generator (power ~80 kW), and it is necessary for neutralizing hazardous substances, such as dioxins, furans (Sikarwar et al., 2016; Kavaliauskas et al., 2015), which exist in the gas.

The flow rate of synthetic gas after the plasma unit is about 80 m³/h. From the plasma unit, hot synthetic gas (~1100 °C) is supplied to the counter-current water-cooled heat exchanger, where the temperature of the gas is reduced to about 300 °C. After the gas cooler, the cooled gas is routed to the second cyclone (which is identical to the first one) and then to the electrostatic precipitator.

The gas temperature at the entrance to the ESP is about 140–160 °C. In the ESP, the particulates present in the synthetic gas are charged by the electric field and settle on the collection electrodes. From the ESP, synthetic gas is supplied to the gas boiler by the fan, where the gas-air mixture is incinerated. Flue gases from the boiler with the help of the exhauster are directed to the

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