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SRF gasification in GazEla pilot fixed bed gas generator for CHP units

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Abstract

The article presents issues associated with the use of SRF (Solid Recovered Fuel) as a fuel for gasification technology. Advantages of the SRF for gasification are summarized. The novel design of the gas generator, developed at the Institute for Chemical Processing of Coal is introduced. Physiochemical properties of the SRF fuel used for gasification are presented. The influence of the main process parameters on gas composition is explained. The results of wet gas cleaning equipment, consisting of an expander, high-temperature filter, oil scrubber and fabric filter are presented. The article presents the results of the reduction of particulate and organic matter at the outlet of the gas cleaning system. Finally, the tests of syngas utilization in a dual fuel piston gas engine are described.

Keywords: SRF, gasification, gas purification, cogeneration

1. Introduction

Environmental concerns have given rise to may initiatives aimed at reducing anthropogenic emissions of greenhouse gases, mainly CO2. The energy industry in Poland and in many other EU countries utilize chemical energy of fossil fuels to produce heat and power.

The main trend in the direction of energy sector development is to reduce the share of fossil fuels in the overall balance of fuels and to increase the amount of heat and power produced from renewable energy sources [1, 8, 12] and from clean, high-efficiency coal technologies [2, 5, 7].

One important issue which is currently under consideration is how to make effective use of process residues and wastes, as they are useful sources of fuel that could contribute to reducing the amount of fossil fuels from current levels. Poland in 2013 produced more than 140 million tonnes of waste, of which more than 11 million tons were of municipal origin.

Most (75%) of the collected municipal waste is landfilled, 15% of the waste is treated biologically and only 10% is thermally processed.

On 1 January 2016, a new regulation of the Polish Minister of Economy on waste landfill entered into force. It mandates that certain waste (including municipal waste) whose heat of combustion exceeds 6 MJ/kg of dry matter, may not be disposed of to landfill for non-hazardous and inert waste. In 2013 over 1.5 million tonnes of SRF were produced in Poland, rising to almost 2 million tonnes in 2014 [10]. One possible way to recycle such a large amount of SRF is to use it to produce heat and power. In addition to large dedicated, centralized units for waste burning, it is worthwhile exploring the use of distributed cogeneration units that will harness heat and power from SRF close distance to the place where the waste is produced, i.e. in local, municipal plants using alternative fuels.

Cogeneration systems are characterized by a wide range of available power outputs: from tens of kW_{el} in small distributed systems to several MW_{el} for power plants. In addition to the high overall efficiency of CHP systems with combustion engines or small scale steam and gas turbines, often exceeding 90%, these systems are characterized by low emission of harmful substances, short construction times, high availability and relatively low capital investment [4, 11].

The above mentioned issues led the Institute for Chemical Processing of Coal (IChPW) to develop a technology that gasifies solid fuels in a fixed bed reactor for the purpose of cogeneration of electricity and heat in distributed systems. This technology is dedicated to systems of small or medium power output.

2. GazEla pilot gas generator

Research conducted at IChPW over the last 10 years resulted in the development of a novel construction of a fixed bed gas generator, commercially named GazEla [3]. The

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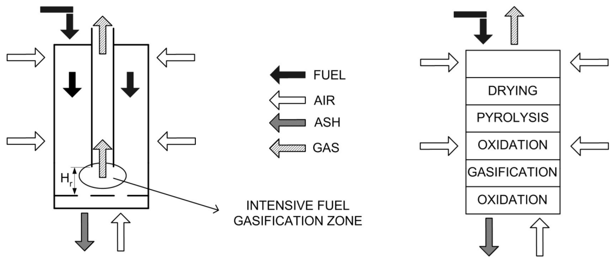

Figure 1: GazEla gas generator - schematic representation of the reactor and its process zones

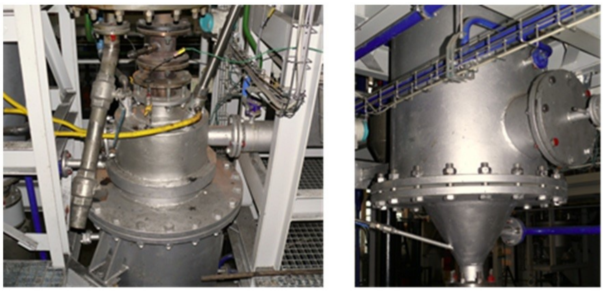

Figure 2: The gas generator – view of the upper part and the left side of the reactor

gasifier is a cylindrical, vertical reactor. An innovative feature of the reactor is a centrally located gas riser pipe (in the vertical axis of the device) designed to retrieve process gas directly from the gasification zone.

Adjustability of the height (H_r) determining the distance between the air distributor (grating) and the inlet of gas into the riser optimizes process gas composition and reduces the level of impurities and tar [6, 13].

In addition, control of process air streams fed into 3 separate zones of the reactor optimizes load and process temperature of the particular zone and thus optimizes the reactor's operation on different types of fuel, minimizing the resulting concentration of organic contaminants and producing process gas of optimal composition. This equipment combines the advantages of both co-current and counter current reactors and opens up the opportunity of using fuels having a different grain size and high water content.

3. SRF gasification tests

Prior to SRF gasification tests in the GazEla gas generator, laboratory analyses of physiochemical properties of a number of SRF samples were conducted. The results are presented in Table 1. Because of the low bulk density of raw SRF fuel, it was necessary to prepare the feedstock for the gasification process. For this purpose, SRF pellets were produced. The pellets were stored in the main fuel tank and fed into the reactor by a screw conveyor.

During preliminary gasification tests, several serious issues were observed connected with physiochemical properties of the SRF fuel, which were not present during biomass gasification [9]. To resolve those issues, a series of tests of SRF pellet gasification were devised. The aim was to determine a set of process parameters that would deliver stable operation of the reactor. An important aspect of the work was to determine the flow of gasification agent and its separation into three zones of the reactor (above the fuel bed, in the middle of the reactor and under the reactor grate).

Table 1: Proximate and ultimate analysis of the test SRF

	Parameter	Symbol	Value
1	Total water content, %	W_t^r	24.8
2	Water content, %	W^a	2.5
3	Ash content, %	A^a	18.5
4	Volatile organic compounds content, %	V^{daf}	86.0
5	Total sulfur content, %	S_t^a	0.34
6	Ash sulfur content, %	S_A^a	0.31
7	Combustible sulfur content, %	S_C^a	0.03
8	Carbon content, %	C_t^a	49.0
9	Hydrogen content, %	H_t^a	6.38
10	Nitrogen content, %	N^a	1.11
11	Calculated oxygen content, %	O_d^a	22.3
12	Heat of combustion, J/g	Q_s^a	22100
13	Calorific value, J/g	Q_i^r	15400

The results obtained indicate that the stream of the air/steam mixture and its distribution has a high impact on the stability of the SRF gasification process. Properly determined process parameters eliminate the problem of ash sintering in the lower part of the reactor, where char is burned off. The tests showed that a good temperature profile of the reactor process zones was achieved. Finally, the determined quantitative relations (fuel flow rate / steam flow rate) of the steam flow rate delivered acceptable stability and efficiency of the process.

The temperature profiles in the upper, middle and lower sections of the GazEla reactor, registered during the test, are shown on Fig. 3.The figure is divided into the phases of the test, showing when the reactor was powered with SRF. The changing distribution of the gasification agent between reactor zones meant the temperature could decrease and stabilize in the upper and middle part of the reactor(below 800℃). Optimized process parameters enabled generation of process gas with calorific value suitable for use in gas engines. Chromatographic analysis showed the following composition of process gas (dry basis): CO = 11.57%; CO_2 = 12.17%; H_2 = 6.40; CH_4= 4.97%; C_2H_6 = 0.31%; C_2H_4 = 3.06%; C_3H_6 = 0.55%.

4. Gas cleaning system

The developed wet gas cleaning system, presented on Fig. 5, is comprised of: inertial deduster, high temperature filter, scrubber, heat exchanger and fabric filter. Process gas generated in the reactor (500–700℃ and ca. 10 kPa) is directed to the gas cleaning system. Firstly, it goes to the inertial deduster and the high temperature filter, where it undergoes separation of solids to the level of 15 $mg/m^3{}_n$. The high temperature filter operates on the principle of barrier filtration. There are 'dirty' and 'clean' zones in the filter. During the research tests satisfactory values of gas purity were

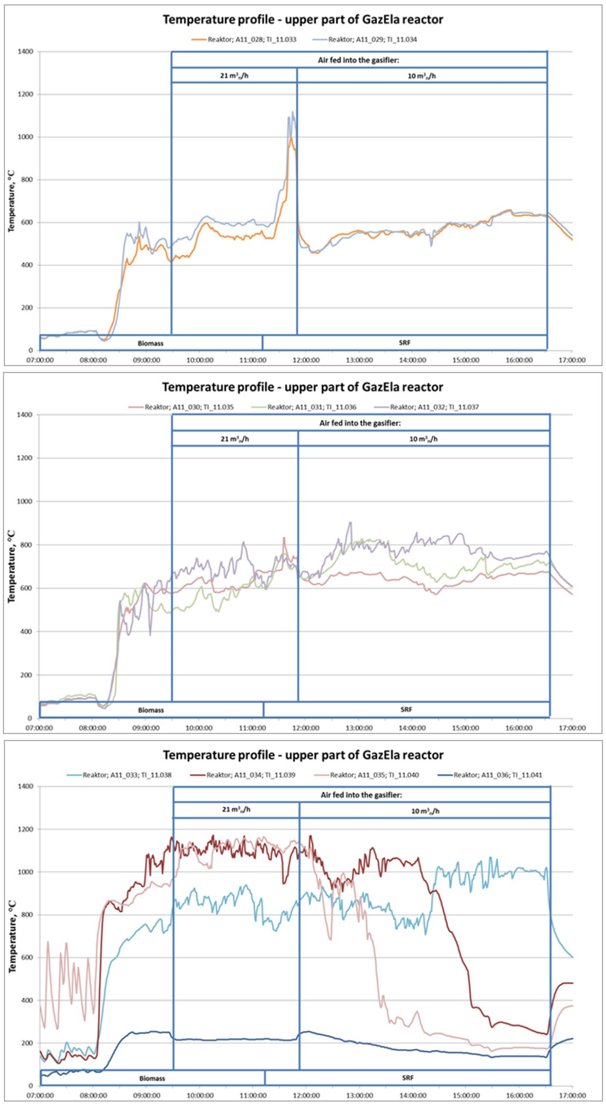

Figure 3: GazEla gas generator – temperature profile of the reactor

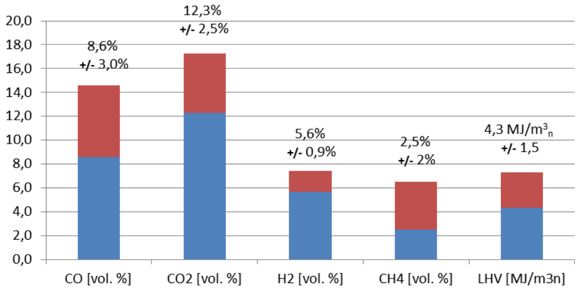

Figure 4: Average concentrations of the main components of the gas generated by the GazEla reactor (on-line measurements done with IR-analyzers)

obtained, which indicated stable conditions of the dedusting system operation, both with ceramic and metallic filter elements. Due to their low price, good filtration efficiency and high resistance to process conditions, ceramic materials based on sinters of aluminum and silica oxides were selected for further studies. In the wet system hot and dedusted gas enters the scrubber at a temperature of ca. 400 °C. The scrubber runs on diesel oil or biodiesel. It consists of an oil tank, two separated non-structural beds (Raschig rings) and a demister. The temperature of the gas at the scrubber outlet lies within the range of 30–150 °C. In order to collect (condensate) the fraction of low molecular weight organic compound and water vapor that passes through the scrubber, a shell and tube heat exchanger with internal water cycle was developed. This solution, i.e., washing the heat exchange surface with process water (thin layer of water film) from the internal water cycle of the installation delivers high efficiency of the cooler and minimizes the risk of tar deposition on the tubes. The dedusted, cleaned and cooled process gas is then directed to the fabric filter system, which protects the cogeneration unit.

The tests showed satisfactory results for removal of solid contaminants from the process gas (<15 mg/m$^3{}_n$) and reduction of tar content to ca. 230 mg/m$^3{}_n$.

As a result of the research the process gas from SRF gasification achieved a quality that corresponded to the requirements of piston engines manufacturers in terms of water, tar and solid content.

5. Gas combustion in the piston gas engine

The results of research on the gasification process, the levels of reduction of dust and tar, and the operational experience acquired provided invaluable insight when testing the cogeneration system fueled by process gas from gasification of SRF. A John Deere 4045DF158 generator set was used during the tests (Fig. 6). The engine is a self-igniting dual-fuel unit. During the start-up phase the engine is supplied only with diesel fuel. The electricity produced is utilized in a resistance power taking system, air cooled with a radial fan.

Running the engine depends on the load of the power taking system. Changes in the load of the generator will cause an automatic change in the fuel flow rate, initiated via an internal motor controller. The increase in process gas flow is automatically tracked, resulting in a decrease in the diesel fuel (primary fuel) flow rate.

During the test, the generator produced 26.0 kW$_{el}$.

The following process parameters are measured during gas combustion in the gas engine: electric power generated in the generator N$_{el}$ and diesel fuel flow rate $m_{ol.nap.}$. The process gas flow rate was taken from a mass balance of the gasification plant and was 14.96 m$^3{}_n$/h (wet gas) during the test. Average calorific value of the gas was 5.8 MJ/m$^3{}_n$ (dry gas).

In order to evaluate the effects of cogeneration unit operation, the efficiency of electricity generation was calculated.

Operational tests of the engine's syngas combustion were performed for two variants:

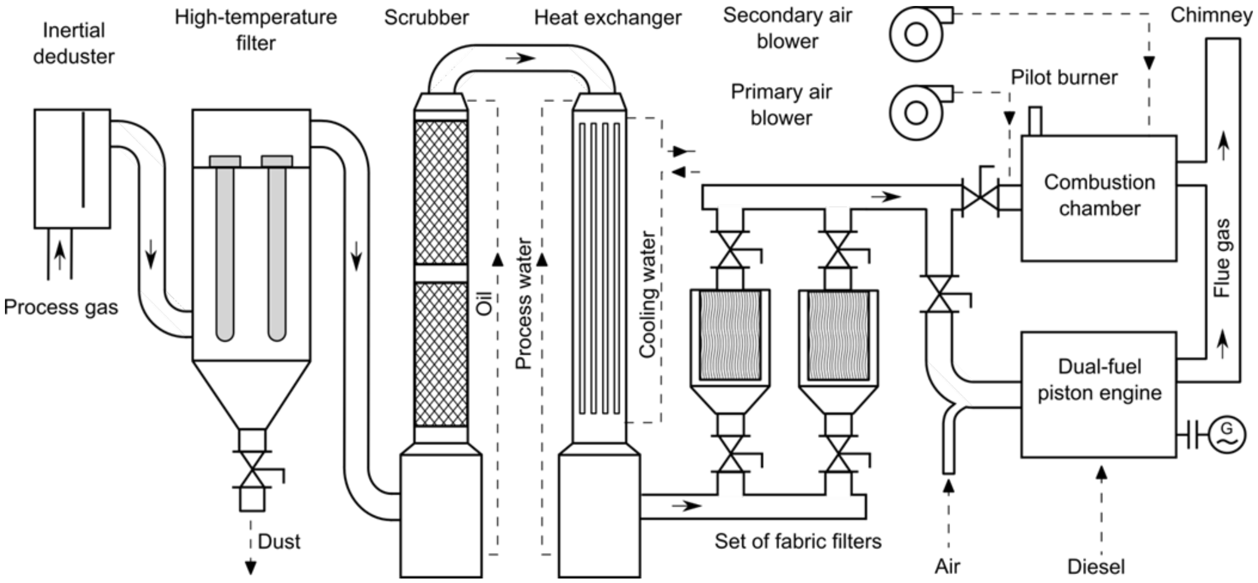

Figure 5: Schematic presentation of the wet gas cleaning system

- A – Gas engine working on primary fuel only (diesel oil) and power 26.0 kW$_{el}$,
- B – Gas engine working on a diesel-process gas mixture and power 26.0 kW$_{el}$.

Operational tests of dual fueled gas engine syngas combustion were performed in two variants: during the work on primary fuel (variant A), the share of diesel oil in feeding fuel was 100%, the fuel flow to the engine was 8.60 l/h during the generation of 26 kW$_{el}$. Efficiency reached approx. 30.2%, without setting an optimum angle for diesel-process gas mixture injection.

In the second case (variant B) usage of diesel oil was reduced to 6.1 l/h, and efficiency was approx. 32.7%.

6. Summary and conclusions

Growing European demand for alternative fuels is driving the development of novel methods of fuel management, to correspond to consumers' needs. One of the most interesting methods of alternative fuel usage is gasification, which enables cogeneration of heat and power in economical fashion in small and medium scale energy systems.

In this research experimental tests and retrofit of a pilot scale SRF gasification plant resulted in stable and reliable work of the plant.

During the research nominal parameters of reactor and other devices were specified. The key issues were determining the best flow rates of process air and steam, and their distribution between the three reaction zones. Optimization of the process parameters resulted in producing 5.0–6.0 MJ/m^3_n LHV syngas.

The final configuration of the gas cleaning system discussed in this article reduces solid contaminants to levels below 15 mg/m^3_n and tar content to ca. 230 mg/m^3_n.

Figure 6: Dual–fuel engine John Deere 4045DF158

The quality of the cleaned and cooled gas corresponded to the standards set for piston engines.

The cleaned gas was used as a fuel in a dual fuel gas engine, producing heat and electrical power. The power produced depended on the installed load. Tests confirmed the ability to produce heat and power in a gas engine fueled by process gas from the gasification of SRF.

Stable and continuous operation of all subsystems of the fixed bed SRF gasification plant combined with a CHP production system proved the ability of the applied technical and process solutions and the reliability of the technology for SRF gasification in distributed CHP generation.

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