Abstract

The production of heat and power in distributed cogeneration systems, based on the utilization of producer gas obtained through biomass gasification, represents an energy and environmentally efficient alternative to traditional technologies of fossil fuels combustion. This technology seamlessly aligns with the challenges associated with the transition of energy and industrial sectors, encompassing aspects such as decarbonization, increased utilization of renewable resources, overall enhancement of process efficiency, and the utilization of wastes as a source of energy and raw materials.

Gasification of biomass, especially waste biomass such as straw, hydrolytic lignin, or the biodegradable fraction of municipal waste, can serve as the foundation for the currently evolving biorefinery technologies. The rationale lies in the fact that the producer gas when cleaned and upgraded into syngas, constitutes a high-value raw material for the production of renewable polymers, chemicals, pharmaceuticals, lubricants, and synthetic fuels.

On the other hand, the production of syngas through waste gasification not only effectively contributes to their comprehensive chemical recycling but also serves as a valuable tool in reducing the consumption of primary energy resources. It is crucial to note that gasification currently stands as the sole method for recovering chemical energy of contaminated or multi-material waste, where the separation for obtaining high-quality fractions of secondary raw materials is either uneconomical or technically unfeasible. Furthermore, considering the current regulations within the European Union, including waste directive (2018/851) and renewable energy act (2023/2413), starting from the year 2030 onwards, chemical recycling is poised to play a crucial role in what is commonly referred to as the waste revolution.

A fundamental component of most contemporary gasification technologies, alongside the gasification reactor itself, are hot gas filters. They constitute a pivotal component within gas cleaning systems. Nonetheless, the presently market-available technologies reveal notable process constraints, limiting their continuous operation parameters. Additionally, they are characterized by relatively high failure rates, which directly increases investment risks.

One of the main reasons for conducting research on high-temperature gas filtration methods was the ongoing research and development activities at the Institute of Energy and Fuel Processing Technology, focused on developing biomass gasification technology (later on also for waste), where hot gas dedusting was intended to simplify and increase the reliability of gas cleaning installations. The primary causes of technological difficulties associated with the use of hot gas filters in gasification systems are attributed to the insufficiently high pulse regeneration efficiency of the rigid candle filter elements and conducting the filtration process under conditions that adversely affect the characteristics of pollutants in the dedusted gases. Therefore, finding a solution to

these issues was the main objective of the research described in this work. While developing a comprehensive as well as technically and technologically mature method for filtration of hot producer gases, a series of scientific problems were identified. Solving these problems required tackling of the following sub-tasks:

- analysis of the impact of design solutions (including the size and location of pulse nozzles, the use of hydraulic valves) and process parameters (regeneration time, pressure in the buffer tank) of the pulse-jet regeneration system on the efficiency of filter cake removal,
- development of a method for determining the optimal size of the buffer tank used in pulse-jet cleaning systems,
- assessment of the influence of introducing mineral additives into the filtered gas on the reduction of the tensile strength of the produced filter cake, as well as on the removal of other contaminants present in the process gas (tars),
- analysis of the potential use of known analytical techniques, such as thermal and rheological analysis of the filtered dust, as well as quantitative and qualitative analysis of organic substances in the gas, to determine the temperature conditions under which the filtration of producer gas proceeds stably,
- experimental validation of the impact of proposed design and process solutions for the pulse-jet regeneration system, as well as the use of mineral additives, on the stability of the filtration process,
- evaluation of the influence of feedstock (biomass and alternative fuel produced from waste – SRF) and the design of gasification reactor (fixed bed and fluidized bed) on the course of hot producer gas filtration.

The achievement of the aforementioned scientific goals also required the development of several practical aspects. Among them, the most significant included:

- designing and constructing a dedicated research stand enabling the characterization of filter elements and regeneration systems,
- developing the concept, operating parameters, and automatic control system for the pulse-jet regeneration system of candle filters,
- formulating technical (sealing and securing filters, distribution of dust-laden gas, filter cake removal, filter heating, and additive dosing) and process solutions (gas loading, filtration resistance, start-up procedures, regeneration, and device shutdown) to reduce the susceptibility of the filter to failures.

The final outcome of the activities described in this work was the design, construction, and experimental verification of a new hot gas filter system, enabling stable filtration of hot producer gases obtained through the gasification of woody biomass and SRF in fixed-bed and fluidized-bed reactors. Characteristic features of the developed filter include filtration efficiency ensuring reduction of the dust content in the gas to a level not exceeding 5 mg/Nm^3 at a filtration velocity of 2 cm/s and filtration resistance not exceeding 2 kPa. The obtained data and experiences were further collected and systematized in the form of a guide of engineering best practices, which is aimed to serve the engineers and users of hot producer gas filters.