Research on the potential of electrolysis and gasification of solid fuels for the production of synthetic natural gas in a polygeneration system

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Badanie potencjału procesów elektrolizy i zgazowania paliw stałych do produkcji syntetycznego gazu ziemnego w układzie poligeneracyjnym

Abstract

The doctoral disseration presents the results of research on the power to synthetic natural gas (PtSNG) systems based on water electrolysis and oxy-gasification of biomass. The main benefit of such a method is the production of a fuel that, in contrast to pure hydrogen, has a greater potential for use in current energy systems, can be easily transported through current transmission networks, and is significantly simpler to store. The various configurations of proposed power to SNG systems studied within the scope of this dissertation are in line with the direction of research into new energy storage systems.

The dissertation involved research on methanation process based on two main parts - experimental and techno-economic analysis. Experiments were conducted to broaden understanding of the methanation process under various operating conditions and to collect data relevant to research on PtSNG applications. The goal was to develop a methanation reactor with main aim of being effective, simple, and inexpensive (in terms of capital and operation costs) at the same time, as well as to evaluate the influence of the main process conditions on the effectiveness of methane production. The experimental work additionally allowed to determine the influence of selected parameters on the course and indicators of thermodynamic evaluation of the methanation process, as well as to optimize the operational parameters of the process.

In case of experimental analysis on methanation installation, the reactor filled up with ruthenium on alumina catalyst was tested with carbon dioxide and hydrogen volumetric flows (in stoichiometric ratio, H_2:CO_2 = 4:1) ranging from 4.5 Ndm^3/min to 10 Ndm^3/min, resulting in chemical energy of SNG produced ranging from 0.81 kW to 1.44 kW. The values of the carbon dioxide conversion coefficient for the methanation reactor operation in atmospheric conditions are from 84.37% to 88.47%. Carbon dioxide conversion to methane is kinetically boosted by raising the pressure. For the case of gauge pressure in the methanation reactor of 6 bar, CO_2 conversion parameter is equal to 94.36 – 95.83%.

A techno-economic analysis of various configurations of SNG production system was performed depending on type of gasifier used for simulations and also on

the availability of renewable hydrogen. In order to obtain SNG composition with CH_4 content equal to or higher than 90% and H_2 content equal to 5% or less (to fulfil the requirements of the conventional natural gas grid), it was necessary to perform a methanation simulation in the nonstoichiometric ratio of H_2:CO_2:CO. The calculated cold gas efficiency of the proposed SNG production systems ranges from 63.27% to 77.10%.

The sensitivity analysis on the break-even price of SNG was performed for different prices of biomass and electricity from RES. Depending on the considered case and assumed feestocks prices, calculated SNG break-even prices ranged from 57.9 €/MWh_{SNG} to 137.7 €/MWh_{SNG}. Achieved ranges of SNG production costs are in line with the data found in the literature.

It can be concluded that the analyzed power to SNG systems are characterized by high efficiency and have the potential to produce SNG, which may become competitive with conventional natural gas in the future. Basing the proposed systems on the electrolysis process also contributes to the possibility of balancing energy systems by storing surplus energy accumulated by the renewable energy sources (RES).