THE CONCEPT OF AUTONOMOUS INSTALLATION FOR METHANE GENERATION COUPLED WITH RENEWABLE ENERGY SOURCES

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ABSTRACT

Presented article is based on the concept of autonomous generator of methane which may be potential used in small and medium scale industries for the energy generation. The installation is powered by renewable energy sources, using both the solar and wind energies. An essential element of the system is reactor of methane filled by hydrogen and carbon dioxide. Operation of the presented reactor is also supported by a catalytic activity of nanoparticles, which can be synthesized via a bioreduction process. Methane may be used directly or injected into local distribution network, also may support local cogeneration installations. In the article, it is described in details all stages of the whole process leading to the methane generation. The possibility of cooperation between developed solution and the national energy system is also discussed.

INTRODUCTION

Currently, the main objectives of the Polish energy policy in relation to the report presented in [1], are increasing the energy safety, improving competitiveness and efficiency of the energy generation and reducing negative environmental impact. Implementation of these provisions entails continuous improvement of existing energy technologies and developing new ones. This assumption also open the way for the broad development of distributed energy, or using energy sources with low power. In this type of installations, there can be classified energy generation from waste fuels as well as fuel processed chemically. The article describes an original concept of installation equipped with a reactor for the synthesis of methane (CH₄), hydrogen (H₂) and carbon dioxide (CO₂), assisted addition of a catalyst in the form of metal-nanostructures produced by the method based on a chemical bioreduction process.

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FUNCTIONALLITY

Operating of presented system involves the synthesis of CH₄ based on two essential substrates - hydrogen generated through the electrolysis of water and CO₂ supplied from a cylinder. The second one, due to the oversupply expected in the future by progressive research and implementations of CCS (Carbon Capture and Storage), become cheap raw material for chemical synthesis. It is also possible to use local gasifier, air separation unit circuits (cryogenic, membrane, adsorption), or bioreactors (the processes of methane fermentation and composting). Scheme of the designed solution is presented on figure 1.

![Scheme of the described installation.](image)

Synthesis of the main component of natural gas, methane, will take place in chemical reactor with assistance of nanoparticles of cobalt, iron or nickel. Manufacture of nanostructures will take place during reaction which is based on the bioreduction process with assistance biomass aqueous solution as reducing factor for introduced into system precursor of nanoparticles. Due to the high surface to volume ratio for the nanoparticles, the highest catalytic activity is expected. This may also reduce the minimum requirements of the process, i.e. temperature and pressure in the reactor chamber. Moreover, generation of nanoparticles takes place under conditions favourable for the secretion of CH₄ as a component of biomass, which should substantially reduce the investment and operating costs per unit of methane produced in the system. Energy requirements for the system may be provided by a hybrid power system consisting of photovoltaic cells and a wind turbine (with vertical or horizontal axis of rotation). Average output power of individual components will depend on the local conditions of sunlight and wind velocity. In order to maximize the utilization of wind turbines it is important to select machines with the lowest possible startup speed (at 1-2 m/s) due to installation in close of household and in areas with unfavourable wind conditions. The demand for energy has been increased by losses resulting from voltage drop in cables (3%) and those related to operation of batteries (3%). For photovoltaic
module, there is also loss factor associated with fluctuations in voltage equal to 0.9 (10% losses of generated electricity) and negative effect of high temperature of the module for electricity generation. It is possible to enable additional energy sources which are environmentally friendly, such as water turbines, ORC systems (ang. Organic Rankine cycle) powered by waste heat or geothermal energy. It is also possible to equipped installation with batteries that could be recharged at night by a much less expensive power from the grid.

**CALCULATIONS**

The essence of the project is to develop autonomous installation for methane generation in the small and medium-scale. It is therefore important to determine energy requirements of installation which should be covered.

Preparation of methane occurs as a result of high exothermic Sabatier reaction (1). According to [2] this reaction at 400°C occurs enough fast to be able to rely on it for production of methane. The enthalpy of formation based on 1 mole of substrate for this reaction is \( dH = -165 \text{ kJ/mol} \) and an efficiency of approx. 50% [2].

\[
CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \quad (1)
\]

Due to fact, that there is a need to remove heat from the reactor, cooling is necessary. It can be done by installing a fan. As a result, the additional heat flux will be obtained, which can be used for heating purposes.

The Sabatier reaction has to be realized with presence of a catalyst. As it was previously mentioned, due to high reactivity with respect to size, there are many types of catalysts in form of nanoparticles. There are catalysts based on nanostructures of iron, gold, platinum, palladium and nickel [3]. Because of the higher efficiency, system based catalyst with nanometric size is proposed. To obtain this size, it is necessary to reduce metal ions entered the system with aqueous solutions of plant extracts or a solution of solid biomass [4].

Products from the reaction are methane and water. Water can be pumped into the tank where it will be re-directed to an electrolyses. Methane is a gas with a high calorific value - 50 MJ/kg [6], which as an energy carrier, can be variously used. In the article, the effect of combustion in gas boiler for hot water production was calculated. The calculations were carried out according to values set out in Table 1.

<table>
<thead>
<tr>
<th>Parameters for coclulation</th>
<th>Wartość</th>
<th>Jednostka</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sabatier reaction efficiency</td>
<td>50 - 80</td>
<td>%</td>
</tr>
<tr>
<td>Heat exchanger efficiency</td>
<td>90</td>
<td>%</td>
</tr>
<tr>
<td>Electric generator efficiency</td>
<td>98</td>
<td>%</td>
</tr>
<tr>
<td>Combustion efficiency</td>
<td>90</td>
<td>%</td>
</tr>
<tr>
<td>Turbine efficiency</td>
<td>80</td>
<td>%</td>
</tr>
<tr>
<td>Pressure ratio</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>Air/fuel ratio for gas turbine [7]</td>
<td>4</td>
<td>-</td>
</tr>
</tbody>
</table>
There are two substrates for the reaction. Carbon di-oxide taken from the gas cylinder and hydrogen produced in electrolyzes. Efficiency of this unit became a starting point for energy balance of the system. For this study there was chosen electrolysis from catalogue [5] with a hydrogen production capacity up to 10Nm3/h requiring supply of 49 kWe.

RESULTS

The calculations allowed to determine energy requirements of the developed system, which result from flow of reagents, substrates, and refrigerants, which are listed in Table 2.

<table>
<thead>
<tr>
<th>Device</th>
<th>Value</th>
<th>Unit</th>
</tr>
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<tbody>
<tr>
<td>Deionizer [8]</td>
<td>0.01</td>
<td>kW</td>
</tr>
<tr>
<td>Electrolyser</td>
<td>49.0</td>
<td>kW</td>
</tr>
<tr>
<td>Pumps [9]</td>
<td>2x0.053</td>
<td>kW</td>
</tr>
<tr>
<td>Fan</td>
<td>0.34</td>
<td>kW</td>
</tr>
<tr>
<td>SUM</td>
<td>49.5</td>
<td>kW</td>
</tr>
</tbody>
</table>

Meeting needs of energy system is assumed by installing 4 wind turbines, with a capacity of 10 kW [10] per unit and 8 solar panels with a capacity of 255 W per unit. [11]. This concept will provide an overproduction of energy in case of favorable weather conditions making it possible to charge the batteries.

Fig. 2 shows characteristics depending on the growth of electric power installations and possibility of hot water production with a temperature of 60 °C with theoretical increase of Sabatier reaction efficiency obtained by using nanoparticles. Comparing data and information contained in [11], there can be seen that for 80% efficiency, the system can provide access to hot water for 41 people a day. Demand for electricity [12] may be covered for 76 persons/day.

![Fig. 2](image_url)

Hot water flux and electricity generation in function of Sabatier reaction efficiency for designer conception.
SUMMARY

Presented solution exhibits a high potential for implementation. Despite the relatively low electricity generation in relation to the necessary effort, there should be aware that the main tasks of the presented solution is utilization of CO₂ which may bring additional economic and environmental benefits.

Generated methane may enable supplying local cogeneration installations. This system can also increase capacity of power plants. In case of separation and production of biomethane, previously waste CO₂ stream may be used to generate an additional stream of methane, increasing the efficiency of both biogas and designed concept. Developed technology may constitute an important element of the expanded domestic energy sector, enabling the realization of diversification of energy sources.

Implementation of the project may brings many benefits. It allows to increase potential of the national economy in terms of natural gas production at relatively low cost investment. The installation will be able to allow the use of heat and electricity by customers away from gas networks. Functioning of the system may provide emergency sources of natural gas in the event of a network failure or sudden, temporary increase in demand. Potential users can get yellow and purple energy certificates of origin, which will translate into concrete financial gains. In addition, thanks to the relatively small footprint, compact design and independence, the installation will be able to be easily transported and invested according to demand. An important advantage of the installation is also no need for hydrogen storage because it is produced in the cell and supplied to the process of "just-in-time". This allows considerable cost savings because, according to [13], these costs can reach up to 18 USD/kWh.

REFERENCES

[2] Bartczak P, Nanometaliczne katalizatory Au, Ag, Pd, Pt, synteza i zastosowania w reakcjach utleniania, Praca Doktorska, Katowice 2013