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Assessment of the Possibility of the CO_2 Use Obtained From Biomass Burning as a Working Medium in Enhanced Geothermal Systems

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ABSTRACT

The article describes the possibility of the use of CO_2 as a working fluid in an enhanced geothermal system. The consideration is focused on the choice of the appropriate closed geological structures in Poland. In typical HDR and EGS geothermal systems, injected water is the carrier of heat. In the proposed system, CO_2 is extracted from exhaust gases coming from a biomass-based power or heating plant. The exhaust gases undergo a process of CO_2 purification and separation. Carbon dioxide after receiving energy from the rock matrix can be used as an energy carrier for its direct or indirect use. According to the nomenclature used in geothermal energy, direct use means obtaining energy for heating purposes, while indirect use means transforming geothermal energy into electricity. In order to determine the effects of the proposed solution, mathematical and numerical model of heat and mass transfer will be used. Due to the preliminary nature of this work, chemical processes in the reservoir were not taken into account. Therefore, the results of mathematical modeling are preliminary.

1. INTRODUCTION

The cooperation of various energy sources and carriers within a single installation is quite common in the energy sector. The energy source connecting multiple energy carriers is called a hybrid source (Cleveland and Morris 2014). The use of many sources is often related to mutual complementation. This cooperation applies to both heat and electricity energy sources. This work describes the assessment of the possibility of cooperation within one installation with two renewable energy sources: biomass and geothermal energy. The cooperation of the energy sources is not like in a case of typical hybrid energy sources. Both sources work separately but one depends on the other. Biomass is being used as an energy carrier (Figure 1). The flue gases generated during the combustion of biomass are subjected to separation and treatment, from which purified carbon dioxide is extracted. The calcium looping technology for CO_2 capture may be used for that purpose (Gładysz et al. 2018). The remaining gases are discharged into the atmosphere. In terms of quantitative composition, these are mainly nitrogen, water vapour, and oxygen. The recovered carbon dioxide is used as a working fluid in the Enhanced Geothermal System (EGS). The technology of heat extraction from EGS or Hot Dry Rocks (HDR) is applied here. In the case of even a small permeability of rocks (the case of EGS) some amount of CO_2 may be permanently sequestrated in the rock formation. Carbon dioxide seems to be an interesting working medium in these systems (Pruess 2006). It is characterized by a low viscosity fluid at reservoir conditions and chemical inertness towards the installation elements. The CO_2 losses will be covered on an ongoing basis with CO_2 recovered from the exhaust gases of the biomass installation. The proposed solution is addressing three important points of the energy sector, as it emphasizes the usage of renewable energy sources (by means of biomass and geothermal energy), the increase of energy utilization efficiency (by means of cogeneration of heat and electricity) and decarbonization (by means of CO_2 capture, utilization and permanent storage). All of them lead to the possibility of obtaining a so-called negative CO_2 emission, and at the same time, to increase the economic profitability of the investment as a result of the synergy among those three pillars. The proposed heat source configuration allows to meet the requirements for the district heating system to be qualified as an efficient district heating and cooling in accordance with the EU Directive 2012/27/EU. Further information about the idea of the described processes can be found in authors' earlier publication (Gładysz et al. 2019b).

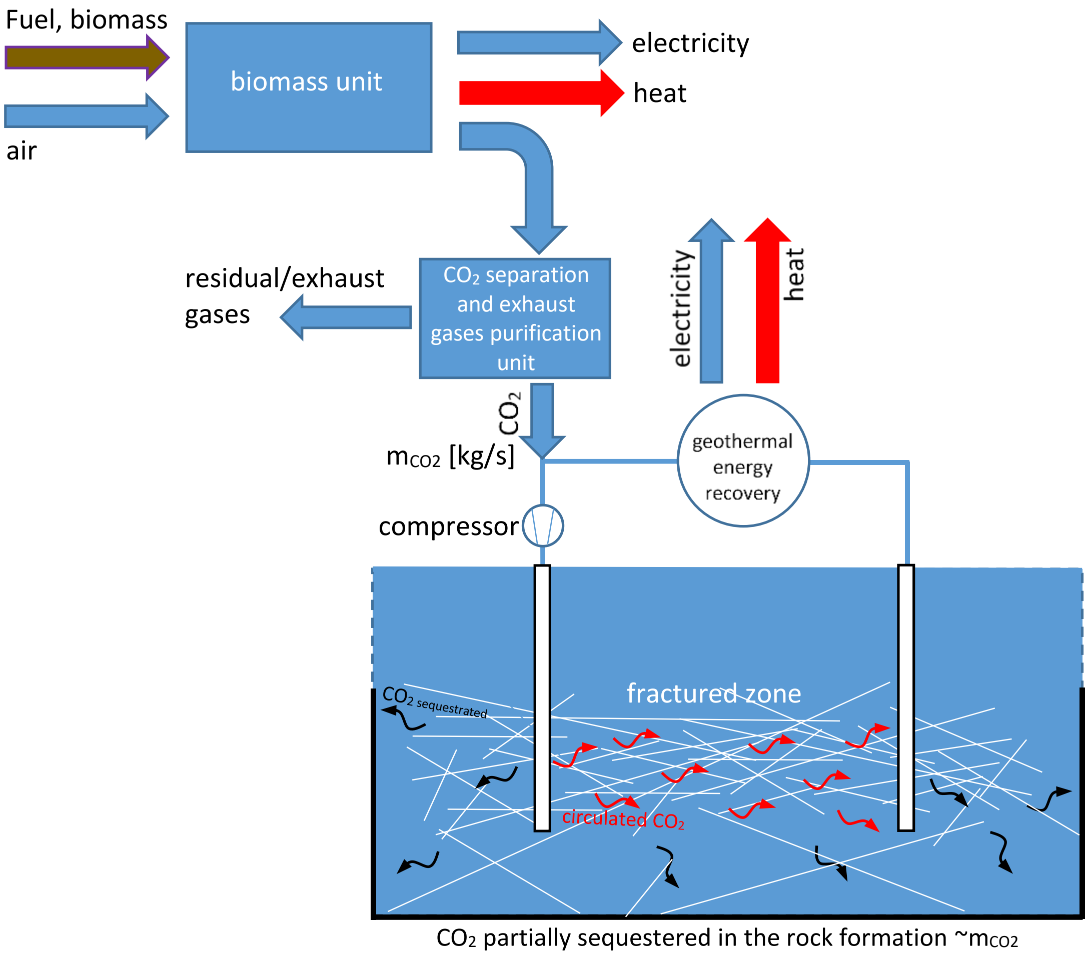

Figure 1. The scheme of the energy source with certain amount of CO_2 permanently sequestrated in the rock formation

2. POSSIBILITIES OF TECHNOLOGY IMPLEMENTATION IN POLISH GEOLOGICAL CONDITION

Preliminary analyses of the described technology implementation were done in the previous work done by the authors and published in the literature (e.g. Sowiżdżał et al. 2019). Geological structures of prospective for a potential application of the EGS technology in Poland were looked for in three different geological settings: in places where magma rocks, particularly crystalline occurs, in volcanic rocks, and also in sedimentary formations. The selection of an optimum structure for the location of EGS systems utilizing CO_2 as a working fluid covered the analysis of geological and hydrogeothermal conditions, suitability for the construction of both EGS systems, and possibilities of underground CO_2 storage. For this reason, since the basic geological condition decisive about a possibility of storing large CO_2 amounts underground is the occurrence of rocks with large thickness, considerable spread with good accumulation properties, and having an insulation rock overburden. A closer look was given to sedimentary formations. The area of Krośniewice-Kutno, located in the central part of the Polish Lowland (Figure 2), has been considered to be the most prospective zone for the location of an EGS system using CO_2 as a working medium. In this area, the most prospective horizon for EGS location are clastic deposits of the Lower Triassic. The top of the reservoir more than 1000 m thick, is behind at depths 5000-5500 m below sea level and the temperature within the reservoir is in the range 165-195°C (Sowiżdżał et al. 2019). The porosity of reservoir rocks is approximately 2.5%, while the permeability is about 0.1 mD (Sowiżdżał et al. 2013, 2016a and 2016b).

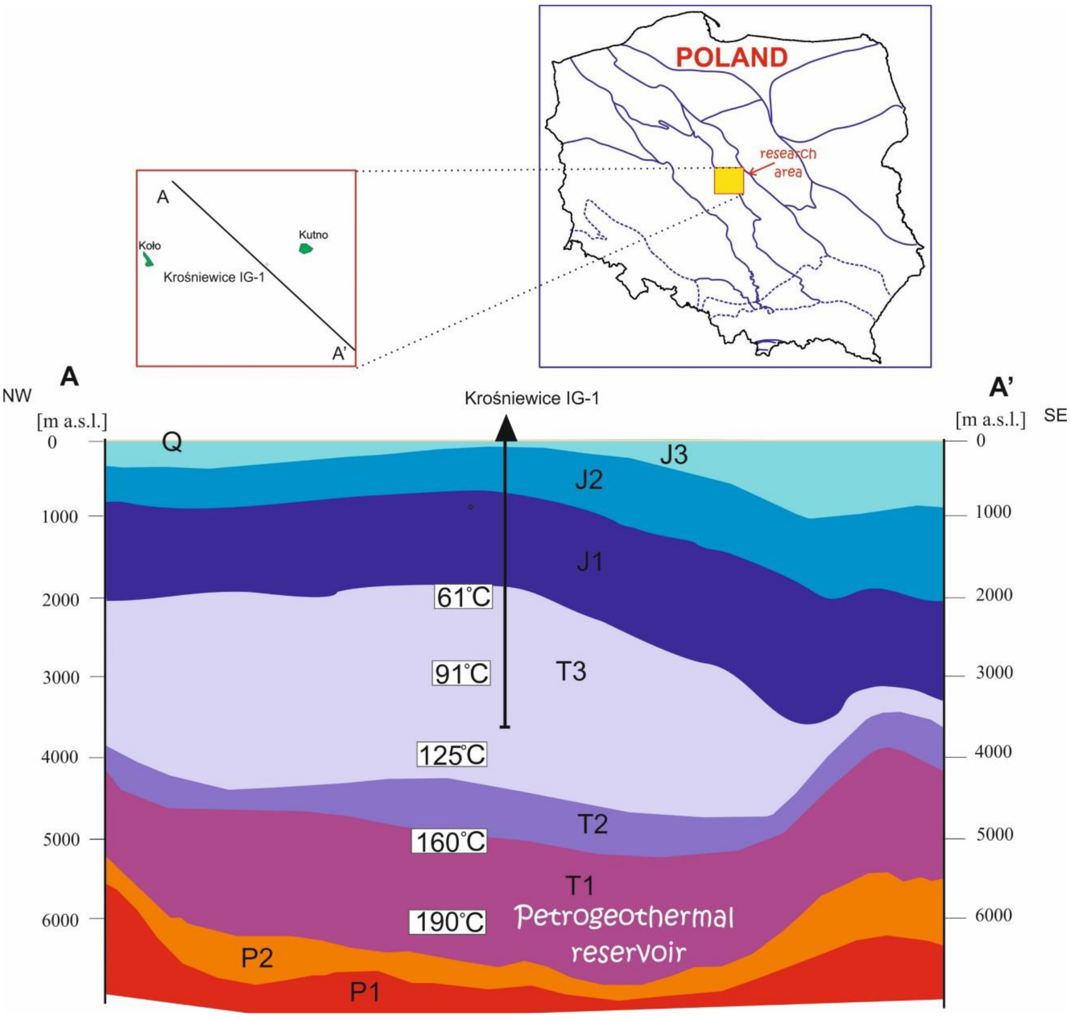

Figure 2. The geological cross-section through the Krośniewice-Kutno study area, suggested as the perspective zone for the system utilizing CO_2 as a working fluid in EGS system in Poland (Sowiżdżał et al. 2019)

3. RESULTS AND DISCUSSION

Based on the selected geological structure, the energy and environmental analyses were done (detailed description in Gładysz et al. 2019c). The combined heat and power (CHP) installation with thermal power 22.2 MW_{th} is analysed. The simplified scheme of the energy source is presented on the Figure 3. It was assumed that biomass used as the energy carrier has the lower heating value (LHV) 9.5 MJ/kg (biomass is quite wet, dry one has LHV ~12-16 MJ/kg). The steam generated by boilers has 53 bar pressure and 480°C temperature, and is directed to the turbine. The outlet steam (out of the turbine) has pressure 0.04 bar. The efficiency of CO_2 capture is assumed at 90% (purity 99.5%). The energy consumption of the CO_2 capture process is assumed with reasonable value 3.36 MJ/kg_{CO2}. Captured CO_2 has temperature 35°C and following compression to 130 bar is injected to the injection well with flow rate 190 kg_{CO2}/s. About 5% of the injected mass of CO_2 is assumed to be sequestrated (9.5 kg_{CO2}/s). Due to the high energy demand of the CO_2 capture unit, the average efficiency of the system is expected to be 24.8% net (Gładysz et al. 2019c), while net electrical efficiency of the sCO_2 unit is expected to be around 14% (Gładysz et al. 2019c). The electrical efficiency of the sCO_2 unit was estimated as a function of the flow rate and the wellhead pressure (Figure 4).

For the case study, following assumptions were made (Gładysz et al. 2019c):
- gross electricity production: in the steam turbine generator 153.5 GWh/a, in the sCO_2 turbine generator 24.9 GWh/a,
- electricity own consumption: in the CHP plant 7.3 GWh/a, CO_2 capture and compression unit 32.3 GWh/a, sCO_2 cycle 3.6 GWh/a,
- net electricity production: 135.2 GWh/a,
- heat production: steam turbine extraction 269.0 TJ/a, interstage cooling of CO_2 compressors 102.3 TJ/a,
- energy input: chemical energy of biomass 2478.4 TJ/a, heat extracted from the geological reservoir 979.8 TJ/a,
- CO_2 balance: sequestrated 241 798.4 Mg_{CO2}/a, emission to the atmosphere 26 866.6 Mg_{CO2}/a.

The positive effect of the negative CO_2 emission based on date above is estimated at 21 4932 Mg_{CO2}/a.

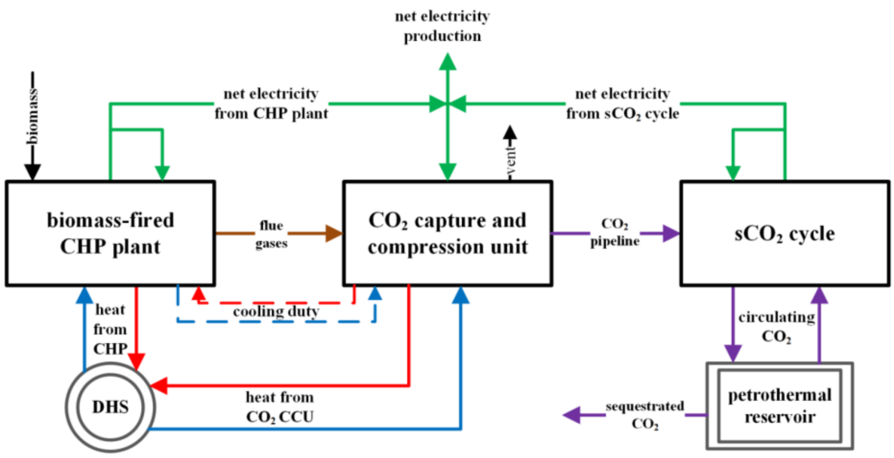

Figure 3. The simplified scheme of the biomass-geothermal energy source (Gładysz et al. 2019c)

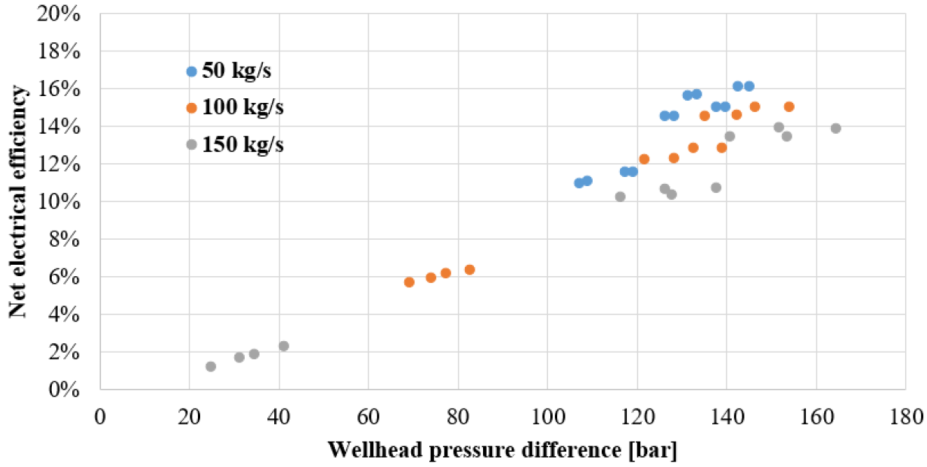

Figure 4. The relation between net electrical efficiency, wellhead pressure difference between production and injection well and sCO_2 mass flow for different EGS scenarios (variable wells' casing roughness, EGS zone permeability and reinjection temperatures; constant reservoir temperature: 170°C) (Gładysz et al. 2019a)

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