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Simulasi Numerik Performa Termal Closed-Loop Geothermal System pada Sumur HCE-32 PT Geo Dipa Energi
Menggunakan Nanofluida Berbasis Karbon sebagai Fluida Kerja
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INTISARI

Indonesia merupakan salah satu negara dengan potensi energi panas bumi terbesar di dunia karena berada pada jalur *Ring of Fire*. Namun, pemanfaatannya masih belum optimal dan sebagian sumur panas bumi mengalami penurunan produktivitas akibat penurunan tekanan reservoir, *scaling*, serta keterbatasan permeabilitas batuan. Salah satu teknologi yang dapat dimanfaatkan untuk mengoptimalkan kembali sumur tidak produktif (*idle well*) adalah *Closed-Loop Geothermal System* (CLGS) tipe *Downhole Coaxial Heat Exchanger* (DCHE), di mana fluida kerja disirkulasikan dalam sistem tertutup tanpa kontak langsung dengan fluida reservoir. Kinerja perpindahan panas pada sistem ini dipengaruhi oleh jenis fluida kerja dan laju aliran massa yang digunakan. Penelitian ini bertujuan untuk menganalisis pengaruh variasi fluida kerja dan laju aliran massa terhadap karakteristik perpindahan panas pada sistem CLGS sumur HCE-32 milik GeoDipa Energi, serta menentukan fluida kerja dengan performa termal paling optimal. Fluida kerja yang digunakan meliputi air, nanofluida *Graphene Oxide* (GO), dan nanofluida *Multi-Walled Carbon Nanotube* (MWCNT) dengan konsentrasi nanopartikel sebesar 0,5% berbasis air. Metode penelitian dilakukan menggunakan simulasi numerik berbasis *Computational Fluid Dynamics* (CFD) pada perangkat lunak COMSOL Multiphysics dengan pendekatan *Conjugate Heat Transfer* (CHT). Model yang digunakan berupa geometri tiga dimensi *downhole coaxial heat exchanger* dengan asumsi aliran *steady-state*, laminar, dan *incompressible*. Variasi laju aliran massa dilakukan untuk mengevaluasi distribusi temperatur, *heat extraction*, dan daya termal sistem. Hasil simulasi menunjukkan bahwa ketiga fluida mampu menyerap panas dari formasi batuan secara efektif melalui sistem CLGS. Nanofluida GO menghasilkan performa termal terbaik dengan temperatur keluaran tertinggi sebesar 292,67 °C dan daya termal terbesar sebesar 38,65 kW_t, diikuti MWCNT sebesar 38,55 kW_t dan air sebesar 37,90 kW_t pada laju aliran massa 0,03 kg/s. Dibandingkan fluida air, penggunaan nanofluida GO meningkatkan temperatur keluaran sebesar sekitar 1,84% dan daya termal sebesar sekitar 1,98%. Peningkatan performa tersebut dipengaruhi oleh konduktivitas termal nanofluida GO yang lebih tinggi sehingga proses perpindahan panas berlangsung lebih efektif. Meskipun kebutuhan daya pompanya sedikit lebih tinggi dibandingkan air, nilainya relatif kecil karena aliran berada pada rezim laminar. Hasil penelitian ini menunjukkan bahwa nanofluida GO berpotensi digunakan sebagai fluida kerja alternatif untuk meningkatkan performa termal sistem CLGS pada sumur panas bumi tidak produktif.

Kata kunci: *closed loop geothermal system*, sumur panas bumi, nanofluida, *graphene oxide*, *multi-walled carbon nanotube*, COMSOL Multiphysics

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ABSTRACT

Indonesia is one of the countries with the largest geothermal energy potential in the world due to its location along the Ring of Fire. However, its utilization remains suboptimal, and many geothermal wells experience productivity decline caused by reservoir pressure depletion, scaling, and limited rock permeability. As a result, several wells become non-productive and are categorized as idle wells. One technology that can be utilized to optimize these wells is the Closed-Loop Geothermal System (CLGS) using a Downhole Coaxial Heat Exchanger (DCHE), in which the working fluid circulates in a closed-loop system without direct contact with reservoir fluids. The heat transfer performance of this system is influenced by the type of working fluid and the mass flow rate used. This study aims to analyze the effect of working fluid variation and mass flow rate on the heat transfer characteristics of the CLGS system in the HCE-32 geothermal well owned by GeoDipa Energi, as well as to determine the working fluid with the most optimal thermal performance. The working fluids used in this study were water, Graphene Oxide (GO) nanofluid, and Multi-Walled Carbon Nanotube (MWCNT) nanofluid with a nanoparticle concentration of 0.5% based on water. The research method was carried out using numerical simulations based on Computational Fluid Dynamics (CFD) in COMSOL Multiphysics with a Conjugate Heat Transfer (CHT) approach. The model used was a three-dimensional downhole coaxial heat exchanger geometry under steady-state, laminar, and incompressible flow assumptions. Variations in mass flow rate were conducted to evaluate temperature distribution, heat extraction, and thermal power performance of the system. The simulation results show that all working fluids were able to effectively absorb heat from the surrounding rock formation through the CLGS system. GO nanofluid produced the best thermal performance with the highest outlet temperature of 292.67 °C and the largest thermal power of 38.65 kW_t, followed by MWCNT at 38.55 kW_t and water at 37.90 kW_t at a mass flow rate of 0.03 kg/s. Compared to water, the use of GO nanofluid increased the outlet temperature by approximately 1.84% and thermal power by approximately 1.98%. This improvement was influenced by the higher thermal conductivity of GO nanofluid, resulting in more effective heat transfer. Although the required pumping power was slightly higher than that of water, the difference was negligible because the flow remained in the laminar regime. The results indicate that GO nanofluid has the potential to be used as an alternative working fluid to improve the thermal performance of CLGS systems in non-productive geothermal wells.

Keywords: closed loop geothermal system, geothermal well, nanofluid, graphene oxide, multi-walled carbon nanotube, COMSOL Multiphysics