Proceedings of the 18th UK Heat Transfer Conference

9-11 September 2024, Birmingham

UKHTC2024-109

PERFORMANCE OF HDPE AND VACUUM-INSULATED CENTRAL PIPES FOR COAXIAL HEAT EXHANGERS IN GEOTHERMAL SYSTEMS

Ján Kubačka[1,2], Tassos G. karayiannis[3]

[1] Energy Institute, Faculty of Mechanical Engineering, Brno University of Technology, Technická 2896/2, 616 69 Brno, Czech Republic
[2] GA Drilling, a. s., Vápenka 4, 841 07 Bratislava, Slovak Republic
[3] Centre for Energy Efficient and Sustainable Technologies, Brunel University London, Kingston Lane, Uxbridge, UB8 3PH, UK

1. ABSTRACT

The thermal performance of a deep borehole coaxial heat exchanger with High-Density Polyethylene (HDPE) and vacuum-insulated central tubing (VIT) is presented in this paper. The analysis was performed for a wellbore equipped with a casing steel pipe of external diameter 198.52 mm and 10.36 mm thick. The central pipe consists of an HDPE tube 139.7 mm in outside diameter and 25.7 mm thick or two coaxial steel tubes, the first having an outside diameter of 139.7 mm and 10.5 mm thick, with the inner tube having an outside diameter of 101.6 mm and a thickness of 6.65 mm giving the same inner diameter of 88.3 mm as the HDPE tube. The gap between the steel pipes was maintained at different partial vacuum pressures. The depth was up to 5 km. Water was used as the working fluid. It was found that the VIT outperforms the HDPE for deep wells with the advantage diminishing for more shallow heat exchangers. A partial vacuum of 10 Pa does not demonstrate any relevant improvements over a gap maintained at normal atmospheric pressure, while the yield can be significantly improved when the pressure is reduced to 1 and 0.1 Pa.

2. INTRODUCTION

Geothermal energy is one of the main renewable energy sources and undoubtedly will play an increasing part in the solution mix in the effort of the engineering and scientific communities to reduce our reliance on fossil fuels and put a stop to the catastrophic consequences of carbon emissions. In comparison to wind and solar, geothermal energy has the advantage of being independent of weather, with a high capacity factor (energy output to the theoretical maximum) of more than 90% hence being able to provide a stable, dependable base load, smaller area footprint than wind or solar [1] and high thermal efficiency, especially when used as a heating source. The main disadvantage comes from possible seismic effects during drilling and subsequent use in open-loop geothermal systems, requiring two geothermal wells and water injection and retrieval. An alternative low-risk geothermal system is the deep borehole heat exchanger (DBHE), where a closed-loop co-axial heat exchanger requires only one well and no fluid interaction with the subsurface structures. In this case, the working fluid, usually water, flows in the annulus and out through a central pipe. Such a closed system will be less prone to corrosion and scaling than the open-loop system [2]. Additional advantages include the fact that it can be installed near populated areas [3] and their thermal response can be more readily predicted. Furthermore, closed-loop, co-axial single-well systems can utilise existing abandoned oil and gas wells, which exist in large numbers, see [4], and thus save the drilling cost, which can be up to 50% of the total cost of the geothermal plant [5] making this technology a possible financially viable option.

In co-axial DBHE heat is transferred from the rock structures to the flow in the annulus of the heat exchanger. However, as the fluid turns and travels upward in the central pipe some of this gained heat will inevitably be transferred to the annular flow, especially at the upper part of the well hence reducing the possible maximum thermal output of the well. Therefore, the size and the conductivity of the central pipe are critical in an effort to maximise the well output for a given borehole diameter, depth and thermal gradient. In this paper, we compare the

Corresponding Author: Tassos G. Karayiannis thermal output of a geothermal well with the inner central pipe made of a high-density polyethylene material (HDPE) or vacuum-insulated tube (VIT).

3. METHDOLOGY

The analysis was performed with a new purposely developed tailor-made thermal-hydraulic simulation software (WellHT) dedicated to the assessment of complex tasks related to the operation of coaxial and U-type heat exchangers used in geothermal and ground-source heat pump applications. WellHT comprises two basic modelling approaches – a quasi-steady-state assumption of the wellbore boundary based on the infinite line-source model and a full transient approach based on a numerical discretization of the wellbore environment using the Finite Difference Method discretization scheme. The results presented in this paper were obtained using the quasi-steady-state approach. This involves the definition of the radius in influence, r_{inf}, calculated as $r_{inf} = 2\sqrt{\alpha\,\tau}$, where α is the thermal diffusivity of the sub-surface structures and τ is the operational time in seconds; See reference [2] and an indication of its derivation in [6]. The radius of influence specifies the outer far-field location of the undisturbed rock temperature and hence allows for the calculation of the thermal resistance to the heat transfer between the ground and the well outer casing. A system of resistances can then be constructed allowing the calculation of heat transfer to the annulus space and the inner pipe, see [6]. The two geometries studied are depicted in Figure 1.

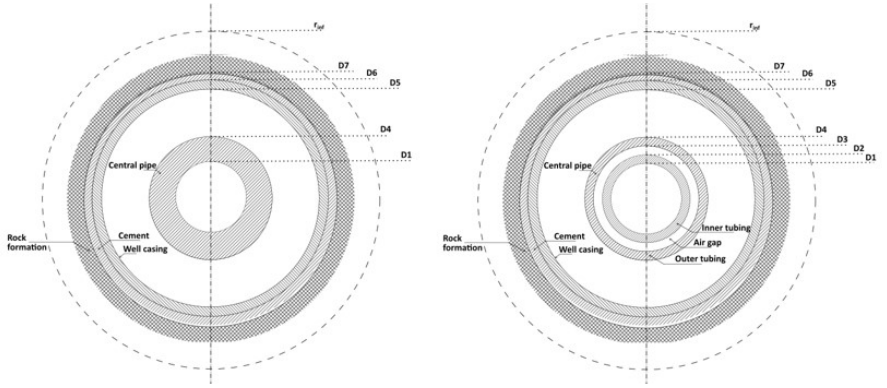

Fig. 1: Outline of the DBHE geometry, HDPE (left), VIT (right).

Table 1: DBHE geometry

	Diameter [mm]	
	HDPE	VIT
D1	88.30	88.30
D2	-	101.60
D3	-	118.62
D4	139.70	139.70
D5	177.80	177.80
D6	198.52	198.52
D7	215.90	215.90

Water has been selected as a heat carrier, with the thermophysical properties taken from [7]. The material properties of solids are as follows: Steel thermal conductivity 45 W/mK, cement thermal conductivity 1.1 W/mK, rock density 2750 kg/m^3, specific heat capacity 800 J/kgK and thermal conductivity 2.5 W/MK. The thermal conductivity of the HDPE was 0.54 W/mK. Different air pressures were examined in the partial vacuum in the central pipe, i.e. 0.01, 0.1, 1.0, 10 Pa and atmospheric conditions. These resulted in different equivalent conductivities for the air gap. The surface emissivity of the steel varies from 0.03 when aluminium foil is used to 0.95 for bare material, see [6] for details. The effect of the axial number of nodes along the depth was examined and it was concluded that two nodes per meter can provide good results. The methodology was validated by comparing our results with the solution provided in Nalla et al. [8], see [6]. In all the modelling runs the inlet fluid temperature was taken as 10 ^{o}C, the soil surface temperature was 15 ^{o}C and the geothermal gradient was 30 K/km. Depths up to 5 km were examined.

4. RESULTS

The thermal output of VIT and HDPE wells of different depths is depicted in Figure 2 as a function of the volume flow rate. As seen in the figure, the thermal output of a shallow well of 1 km, the utilization of VIT has nearly no benefit over the HDPE pipe. The effect of the improved thermal insulation provided by the VIT is more beneficial as the depth increases. The thermal output of the HDPE well reaches only 37% at low volume flow rates, i.e. 5 lpm and 72% at the highest flow rate studied for the 5 km deep heat exchanger. The partial pressure of the VIT gap must be reduced below 10 Pa before any significant improvements are noticed. The equivalent thermal conductivity (not including the radiation part) varies from 0.081 to 0.003 W/mK for the pressure in the VIT gap varying from 1x10^5 to 0.1 Pa [6]. There were no further changes for pressures below 0.1 Pa. The radiative term plays a more important role and the use of reflective layers can be beneficial. The outlet temperature at 300 lpm for the 5 km deep heat exchanger with HDPE and VIT is 44 ^{o}C and 56 ^{o}C, respectively. The maximum value of the temperature outlet occurs at different volume flow rates for the two types of insulation, with the maximum reaching 45 ^{o}C and 86 ^{o}C for the HDPE and VIT tubes respectively [6]. The pumping power required is depicted in Figure 3 as a function of the depth of the heat exchanger and the volume flow rate for a pump efficiency of 0.85. It is demonstrated that in these systems the pumping power requirements are only a small fraction of the thermal output produced by the well, i.e. approximately 2.2%, 1.2 % and 1.0 % of the thermal output for depths of 1, 3 and 5 km.

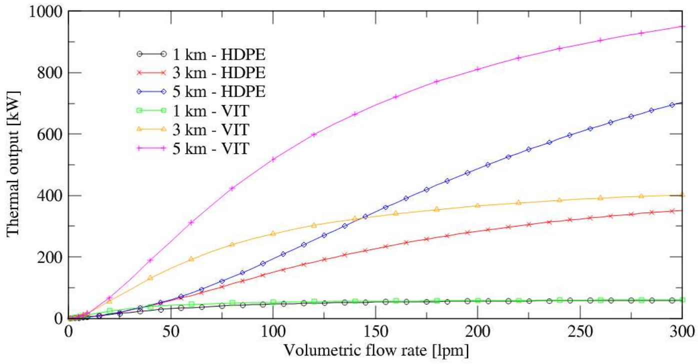

Fig. 2: Thermal output as a function of flow rate for various depths – one year of operation.

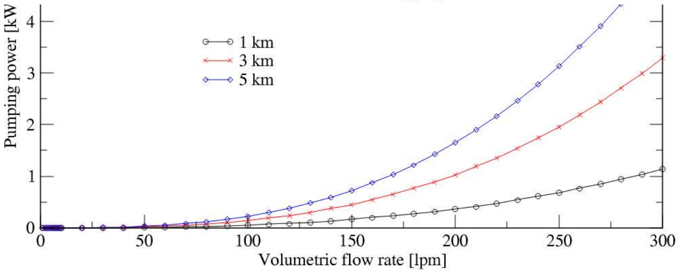

Fig. 3: Pumping power as a function of flow rate for various depths (VIT) and one year of operation.

5. CONCLUSIONS

It is concluded that the superior thermal insulation provided by a VIT central pipe compared to a HDPE one can be significant, especially for deep geothermal wells and lower mass flow rates. The effect of reduced pressure gap in the VIT system becomes effective for pressures below 10 Pa. An optimisation study is recommended to consider different heat exchanger dimensions, thermal gradients, inlet temperature, volume flow rates and different periods of operation. The pumping power required was found to be only a small fraction of the thermal output and probably constitutes a lesser criterion in designing closed-loop co-axial heat exchangers for geothermal wells. However, this remains to be verified for higher mass flow rates and different geometries.

REFERENCES

[1] Li, K., Bian, H., Liu, C., Zhang, D. and Yang, Y., Comparisons of geothermal with solar and wind generation systems, Renewable and Sustainable Energy Reviews, 42, 1464-1474, 2015.

[2] Alimonti, C. and Soldo, E., Study of Geothermal Power Generation from a Very Deep Oil Well with a Wellbore Heat Exchanger, *Renewable Energy* 86: pp.292-301, 2015.

[3] Kolo, I., Brown, C.S. and Falcone, G., Thermal power from a notional 6 km deep borehole heat exchanger in Glasgow, Proceedings, 48 Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, Feb. 6-8, 2023. SGP-TR-224, 2023.

[4] Nian, Y-L. and Cheng, W-L., Insights into Geothermal Utilization of Abandoned Oil and Gas Wells. Renewable and Sustainable Energy Reviews, Volume 87, pp. 44-60, 2018.

[5] Barbier, E., Geothermal energy technology and current status: an overview, *Renewable Sustainable Energy Reviews* 6: pp.3-65, 2002.

[6] Kubačka, J. and Karayiannis, T. G., Performance of vacuum-insulated central pipes for deep borehole heat exchangers in geothermal systems, Submitted, Int. Journal of Low-Carbon Technologies, 2024.

[7] Anon. (2024) NIST Chemistry WebBook [online]. Available at: https://webbook.nist.gov/chemistry/ [Accessed 25 March 2024].

[8] Nalla, G., Shook, G. M., Mines, G. L. and Bloomfield, K. K., Parametric Sensitivity Study of Operating and Design Variables in Wellbore Heat Exchangers. *Geothermics* 34: pp.330–346, 2005.