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Generating Heat from Unused and Abandoned Wells with the Advanced/Enhanced Geothermal System Technology

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ABSTRACT

Geothermal resources are one of the leading renewable energy resources in terms of power and heat generation in the 21st century. Geothermal power plants convert underground thermal heat into electrical power. Due to cracks in rock structures, magma rises closer to the surfaces or due to high thermal conductivity of the rock layers temperatures of the rocks closer to the surface rises warmer than the average values. If water penetrates through cracks in rocks or porous rock structures, they will be warm enough to generate electrical power or heat generation. Warm geothermal water is extracted by drilling wells to earth crust. This type of systems where geothermal water resource is naturally existed are called conventional geothermal systems. In zones where hot dry rock is existed without water resources, it is still possible to generate power by sending water from outside to underground and reclaim heated water for heat and use it for power generation. This type of systems is called Advanced/Enhanced Geothermal Systems (AGS/EGS). Advanced/Enhanced Geothermal systems are currently being tested to obtain the temperature in the shallow depths of the wells that cannot be used by many developed countries of the world. Advanced/Enhanced Geothermal systems are an attractive possibility for the development of baseload, carbon-free electricity generation due to wider availability of such resources. However, generating electricity from AGS/ EGS requires a reasonable cost and further technological advances that will reduce installation costs and/or increase the rate of energy recovery. The technology of the first and deepest Advanced/Enhanced Geothermal System in Türkiye has been developed by Geo Energy Holding.

Geo Energy Holding is improving its knowledge base on AGS/EGS and accelerating its efforts to generate electrical energy by further improving its experience in down-hole heat exchanger applications. In geothermal wells with shallow depths (2500 m and shallower), which are not suitable for production and injection, it is aimed to bring them into energy production with the Advanced/Enhanced Geothermal System method. To produce heat and electrical energy from these geothermal wells, optimal method was chosen among the open and closed systems of the deep well heat exchanger (DWHE). The theoretical calculations of the DWHE method and its practical application is introduced in this paper.

1. INTRODUCTION

In the modern world, the problem of energy and fossil fuels crisis is one of the important and controversial issues that the excessive increase of population on one hand and the increase of social welfare on the other hand have exposed the comfort and health of people in human societies to a crisis. The increasing need for energy has made people to use fossil fuels (coal, oil, and gas) more and more. But limiting the use of fossil fuels due to non-renewability and the resulting pollution due to the warming of the earth and the melting of ice and the destruction of the natural ecosystem of the earth has caused the use of these energy sources to be more limited. Enhanced Geothermal Systems (EGS), also sometimes called engineered geothermal systems, offer great potential for dramatically expanding the use of geothermal energy. EGS offers the chance to extend use of geothermal resources to larger areas of Türkiye.

In geothermal systems, which are predominantly flooded, as in Türkiye, the stability of the minerals in the fluid changes depending on the changing pressure and temperature conditions while production and injection (Haizlip et al. 2013). Türkiye is under the influence of important tectonic zones and young volcanism (Figure 1), and these structures allow the formation of the heating rock and reservoir rocks necessary for the formation of geothermal resources and the delivery of the fluids in these reservoirs to the earth via faults (Nicholson 1993). Electricity generation from geothermal energy worldwide has exceeded 13.3 MWe (GEA, A. 2016). In Türkiye, whose geothermal energy potential was estimated at 31,500 MWt by MTA (General Directorate of Mineral Research and Exploration) before 2010, it is anticipated that the current capacity will double with the fluids obtained from newly discovered fields, especially with the private sector starting to invest in geothermal exploration activities in the last five years (Mertoglu et al. 2015).

Unfortunately, the most of the deep geothermal systems installed today (depth of 1 km and more) are unable to obtain heat using multi-well open loop systems (Lopez et al. 2010). In addition, for these systems to work properly, there must be a sufficiently permeable aquifer at a depth. Also, deep aquifers are now an integral part of probes as it is often brine which can cause corrosion problems over time, which can significantly increase the operating and maintenance costs of open-circuit systems. Enhanced geothermal systems artificially increase the permeability of aquifers that are too low at the targeted depth. Additionally, reservoir excitation remains complex and there is a risk of social disapproval associated with the overall risk of induced seismicity (Falcone et al. 2018; Grigoli et al. 2018; Lu 2018; Malo et al. 2019).

A suitable geothermal heat exchanger design is required to solve this problem. Yavuzturk and Chiasson (2002) and Hellström (1998, 2002) studied both the coaxial and U-tube geometries and their results showed that the coaxial geometry could have certain advantages in reducing the thermal resistance of the borehole, representing the electrical resistance between the circulating fluid and the pipe. The decrease in this resistance has increased the heat transfer between the fluid and the rock and influences the downhole heat exchanger heat transfer area. Kohl et al. (2002) concluded that deep bore heat exchangers installed in abandoned boreholes were operating in Switzerland for many years and show high production temperatures (~40◦C). Beier et al. (2013) were studied the vertical temperature profiles and well thermal resistance. In addition, important factors that affect heat transfer, such as the effects of thermal capacity in coaxial borehole heat exchangers, are investigated for optimum heat transfer (Shirazi and Bernier 2013). In addition, the researchers modeled the properties of many working fluids and examined the optimization for dual geothermal power plants to improve the net power production (Franco and Villani 2009; Hung et al. 2010; Yousefi et al. 2010; Jalilinasrabad. and Itoi 2012; Ghasemi, Paci, et al. 2013; Ghasemi, Tizzanini, et al. 2013).

Limberger et al. (2018) studied on the existing deep wells, research was conducted to obtain optimum heat in geothermal. According to these studies, it was concluded that the flow rate and insulation of the pipeline have a significant influence on the heat exchange process in the borehole. It was concluded that the simulation used the average geothermal gradient of the subterranean formation instead of the actual temperature gradient, and that the well size and shape used were not typical of wells.

Cheng et al. (2013), used the abandoned oil wells for geothermal power generation and concluded that the outlet temperature of the extracted fluid gradually decreases as the system run time increases until it reaches steady state. In another research, thermal energy production from oil and gas wells was examined and numerical studies were performed to find the optimal values of efficiency parameters. Thus, geothermal energy extracted from wells was found to be more dependent on the flow rate of the injected fluid and the geothermal gradient than other parameters (Xianbiao et al., 2012). There are many studies and researches related to EGS geothermal heat sources, renewable energy sources (Paschen et al. 2003; Tester et al. 2006; Hettiarachchi et al. 2007; Guo et al. 2011; Quick et al. 2013; Walraven et al. 2013; Xydis et al. 2013).

In this study, an abandoned geothermal well which is not suitable for geothermal fluid production and injection is modelled to produce geothermal heat by advanced/enhanced geothermal system technology of Geo Energy Holding. Special down hole heat exchanger (DWHE) is developed to make maximum use of the underground heat. The influence of geothermal gradient and flow volume on exit temperature of liquid (water) is evaluated for different depth of well. A 3D model is used by finite element method in an abandoned or inefficient well, and to place casings and concretes to analyze the heat transfer between rock and liquid. These analyzes increase the accuracy of calculations and the accuracy and authenticity of heat and power extraction.

2. MATERIAL AND METHOD

The techniques for extracting heat from geothermal wells in EGS/AGS differ from conventional hydrothermal geothermal systems in that the closed loop circulating liquid is in direct contact with hot rocks. No fluids are naturally introduced to or extracted from the Earth. In the center of the well, the insulated pipe is lowered, and the fluid circulates around the pipe and in contact with the rocks, and heat transfer takes place. Cold water is injected into the well through an outer pipe, heat is transferred from the hot rock to the liquid during injection and then the temperature of the liquid reaches the highest level in the downhole heat exchanger (heat absorber). In order to prevent heat transfer between the outer and inner pipes, it surrounds the inner pipe with insulation material with very low thermal conductivity. An abandoned geothermal well with 3000 m depth is used in this study located in Türkiye. The well features, casings and soil layers and concrete are shown in Figure 1.

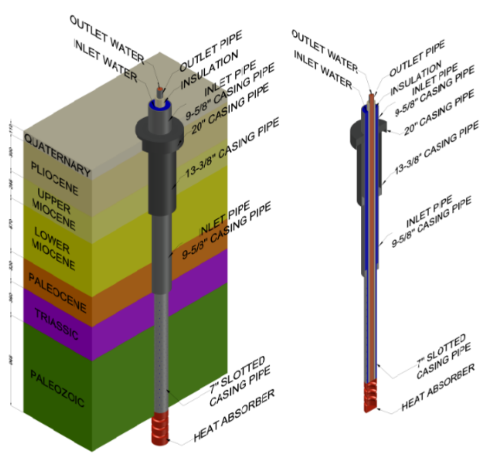

Figure 1: Schematic and cross-sectional view of the deep well heat exchanger at a depth of 3600 meters.

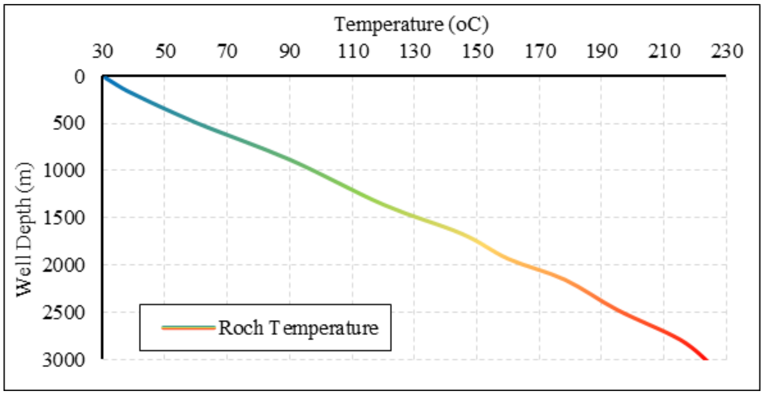

Figure 2: Well features, and schematic of casings, cement layers for the well and rock temperature.

Figure 1 shows a sectional view of geometric primitives while the rock temperatures up to 0-3000 meters are shown in Figure 2. As visible withinside the thermal profile, it follows the conductive warmth switch sample for the well. The bottom maximum temperature in the well we use is 225.3̊C and the temperature gradient is 65.6◦C/km, which corresponds to the world's average large thermal gradient. A 3D model including insulated pipes, casing, cement layers and rock layer of the well of 3000 meters that we will analyze has been created. Cartesian coordinate system is used for all well components in the design modeler. The cross-sectional area of each component was designed in the XZ plane according to their depth, then all the sections were designed in the +Y direction according to their lengths.

2.1 CFD Analyze

The Finite Element Method (FEM) is an analysis method that decomposes real-world structures into finite parts to provide solutions for a large class of engineering analyses. Mathematically (FEM), it is an approximation method for solving many problems. Also called finite element analysis (FEA). FEM can calculate displacements, stresses, strains, temperatures, charges, etc. considering boundary conditions for field variables. It is a numerical or computational technique for solving various field variables such as real structures, which are divided into smaller parts called elements, which are divided into 1, 2 or 3 dimensions. Both numerical simulation and gray relational analysis were used in this study. Numerical simulation is used to predict the performance of deep coaxial borehole heat exchangers in terms of output capacity. Gray relational analysis was used to measure the effects of feature changes on the estimated output capacity.

A flowchart illustrating our procedure is shown in Figure 3. In the numerical simulation, conjugate heat transfer is considered to simulate the output capacity of deep coaxial downhole heat exchangers.

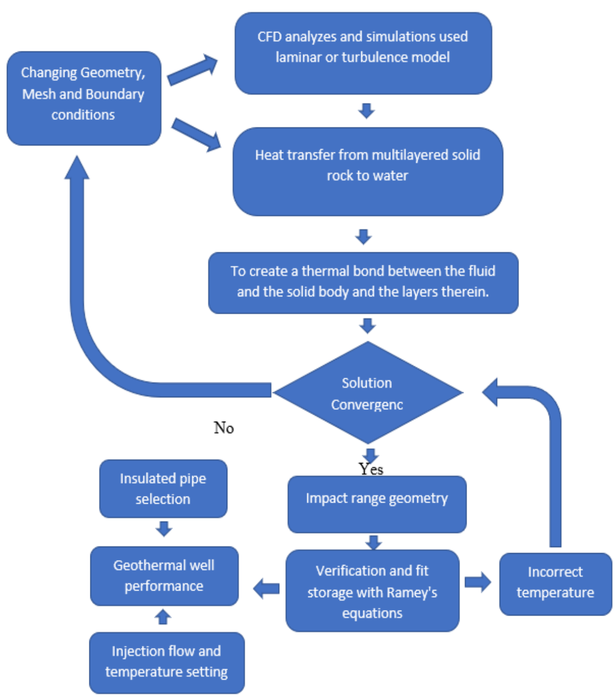

Figure 3: Flow chart for output capacity estimation of deep coaxial downhole heat exchangers affected by temperature-dependent property changes.

In order to understand the effect of insulated pipes of different lengths on heat transfer in the well, CFD thermal analyzes were carried out for 3000 meters of insulated pipe. CFD analyzes were performed at various insulated pipe lengths 2980 meters. During the well drilling, casings and cement of various diameters and lengths 150, 993 and 2000 meters were used. The thermal properties of rocks, cement and casings are calculated as in the literature and given to the Ansys Fluent program. In addition, in these analyses, the thermal conductivity of cement K_{cement}=0.8 W/m-k and casing C_{asting}=50 W/m-k and for Rock k_{rock}=2 W/m-k were accepted. The desired geometry was drawn in detail in the program, and then a 4.5-inch insulated pipe was placed in the well. In addition, according to the previously obtained information from geologists, the temperature profile of the well was taken as 65 C/Km on average and the required UDFs were written in the CFD analysis. The data obtained from our analyzes were taken after 12 hours of operation. The CFD code ANSYS Fluent R21, which is based on the finite volume approximation, is used in this study to solve the governing equations of fluid.

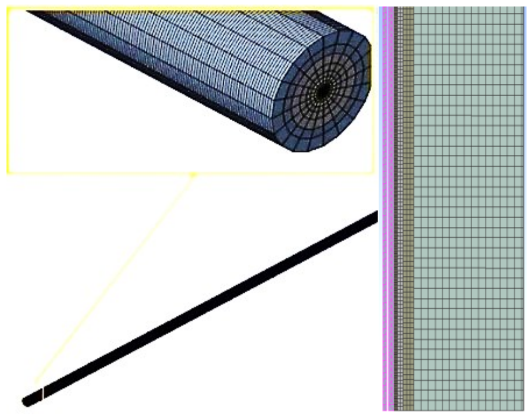

Figure 4: Representation of the mesh formation topology.

In Figure 4, the grid topology used for the three-dimensional Advanced Geothermal System (AGS) is presented. In meshing tools, physical preferences and meshing method were chosen using computational fluid dynamics and multisite method. One of the challenges in fluid dynamics problems is to select a solution method and implement an appropriate meshing method to expedite the simulation. In this article, we'll examine how meshing techniques are used in CFD simulations as well as what to expect from meshing features in commercial simulation packages. The interactions of liquids and gases with solid surfaces and the flow fields around and/or inside these solid bodies are solved with the help of computers. The accuracy of the simulations depends on the mathematical model and numerical methods used. Mostly, CFD simulations are done using parallel computers. Sim Scale offers four primary meshing methods: 1-Tet-dominant 2-Hex-dominant automatic 3-Hex-dominant parametric 4-Hex-dominant automatic "wind-tunnel/external flow" of the four meshing methods, the hex-based mesh is only for use in CFD, while the tet-dominant method can be applied to both CFD and FEA. The tet-dominant method is typically used in 3D meshes where the robustness is more important. Although quadrangular surface elements are an option, sometimes errors may occur if the option is enabled. The mesh, composed of hexahedral cells with local refinement from 0.1 mm to 1 m, is generated with ICEM CFD R21, and exported into the flow solver ANSYS Fluent. A mesh-independent investigation is performed to identify a suitable mesh. Figure 5 shows the numerical outlet temperature and radial temperature distribution of the shaft below the inner pipe obtained with three different meshes.

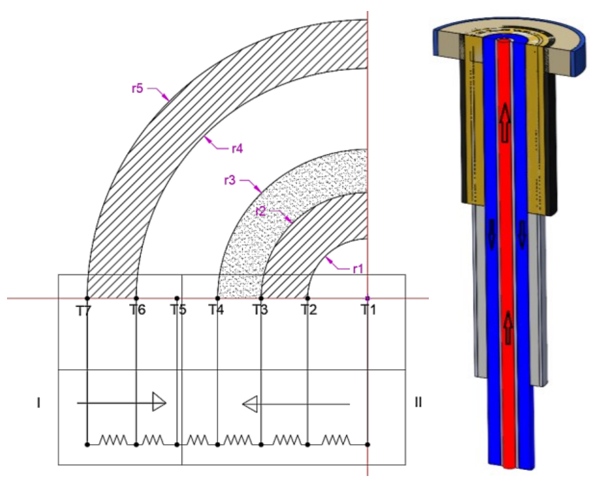

Figure 5: Schematic of a deep coaxial borehole heat exchanger (basic model) showing heat transfer between rock, along the pipe, and in the water.

As shown in Figure 3, only cladding steel was considered in this study, and since the geometry is symmetrical, analyzes were performed in two dimensions on one side. The remaining geometry parameters of the models, and the temperature-dependent properties of water and rock are given in Table 1.

Table 1: EGS/AGS Parameters.

Fluid	#	Water
Flow Rate	t/h	1.80 – 20.00
Step Time	sec	5.00
T7	°C	20.00
T_{inlet}	°C	30.00
L_{pipe}	m	2980.00
Outer Pipe Thermal Conductivity	W/m-C	76.00
Inner Pipe Thermal Conductivity	W/m-C	76.00
Insulation Thermal Conductivity	W/m-C	0.035

r_5	mm	122.24
r_4	mm	112.24
r_3	mm	94.00
r_2	mm	84.00
r_1	mm	74.00
D_h	mm	36.48
Well Depth	m	3000.00
Insulation Thickness	mm	10.00
Thermal Gradient	°C/m	0.064

2.2 Mathematical Model

Since the convective heat transfer coefficient includes all convective heat characteristics of water, it is the key variable for analyzing the temperature dependent properties of water during forced convection heat transfer in the exchanger. The thermal capacity i.e., the capacity of the geothermal well, is a function of the injection rate, the specific heat capacity of the water, and the temperature difference between the injected water and layers of rocks. The thermal capacitance is calculated according to the equation from 1 to 6:

$$P = mC_{water}T \quad (1)$$

$$q = h(T_{\infty} - T_s) \quad (2)$$

$$h = k_{water}\frac{Nu}{d} \quad (3)$$

$$Nu = \frac{\left(\frac{f}{8}\right)(Re-1000)Pr}{1+12{,}7\left(\frac{f}{8}\right)^{0{,}5}\left(Pr^{\frac{2}{3}}-1\right)} \quad (4)$$

$$Pr = \frac{\mu_{water}C_{water}}{K_{water}} \quad (5)$$

$$f = (0{,}79\ln(Re) - 1{,}64)^{-2} \quad (6)$$

$$\alpha_{rock} = \frac{k_{rock}}{C_{rock}\rho_{rock}} \quad (7)$$

$$\rho_{rock}C_{rock}\frac{\partial T}{\partial t} = \nabla(K_{rock}\nabla T) + Q \quad (8)$$

where P is the thermal output capacity of the deep coaxial AGS downhole heat exchanger (W), m is the injection water flow rate (kg/s), C water is the specific heat of water flow (J/kg.K), and ΔT is the temperature difference between the water injection temperature and the production temperature (K).

3. RESULTS AND DISCUSSION

As shown in Figure 3, the wall heat transfer, specific heat and other properties of the rock layer are determined according to the geological formation, and the outer boundary of the soil layer is adjusted for the temperature values. unchanged. Inlet velocity and outlet pressure are selected to determine the boundary conditions of the inlet and outlet regions. The PISO (Pressure-Implicit with Splitting of Operators) algorithm used to combine velocity and pressure. This model is recommended to calculate unstable flow. The quadratic discretization scheme is applied to all convection conditions. As can be seen in the figure, different thicknesses and lengths of cement were used during the well drilling, up to 2000 meters. According to the obtained data, the thermal conductivity of the cement used in the material properties is very low.

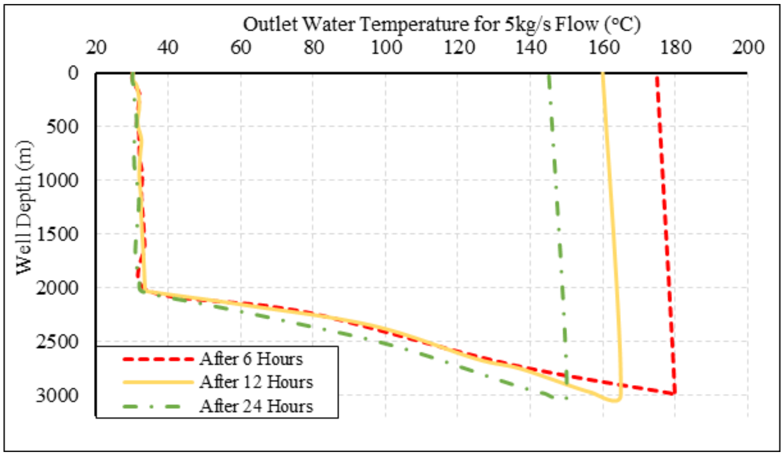

Figure 6: Temperature change of water entering the well at 5kg/s.

At figure 6, only a few studies in computational fluid dynamics CFD have targeted geothermal energy assessment. CFD should however also be applied to predict and study the supercritical conditions present in very hot geothermal systems. In this case, the temperature of the water entering the system reaches approximately 45 (°C). A 4.5-inch diameter insulated pipe was lowered 3000 meters for well. As in all analyzes, a very low heat transfer takes place due to the thermal properties of the cement used in drilling up to 2000 meters. However, from 2000 meters to 3000 meters, heat transfer takes place due to the direct contact of water with the Rock. In this case, the temperature of the leaving water seems to vary between 150-180 (°C).

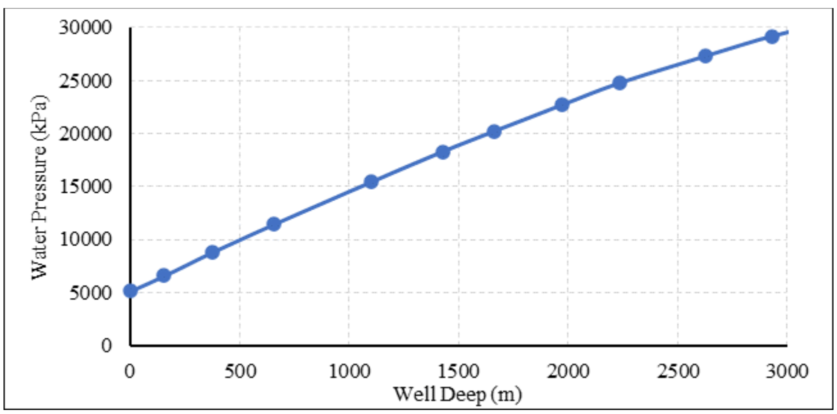

Figure 7: Pressure changes of water entering the well at 5kg/s.

As seen in Figure 7, the pressure variation along the depth of the well shows. The high pressure is necessary to prevent the phase change and transition of the liquid to the vapor phase. On this subject, not only the pump power can withstand, but different processes are kept at the well head.

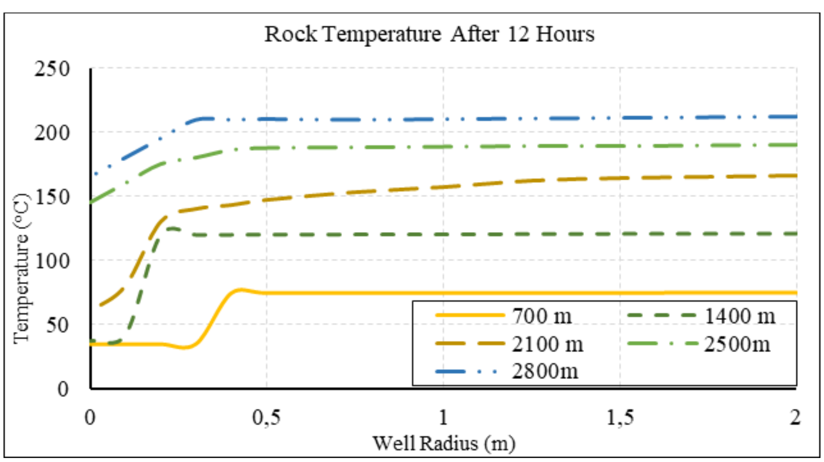

Figure 8: Temperature change of rock at well.

As seen in figures 8 and 9, CFD analyzes were made on the symmetric well radius and well temperatures 700, 1400, 2100, 2500 and 2800 meters were measured in different regions. In this case, at Well, at 700, 1400 and 2000 meters, heat resistance is shown due to casing and cement layers. The heat transfer coefficient of the rocks was kept constant throughout the well K_{rock}=2 W/m.K. In the temperature profile, the well beats along the depth. As a result of this increase after 12, 24 and 36 hours, the temperature value in the well radius was 160°C for 2800 meters.

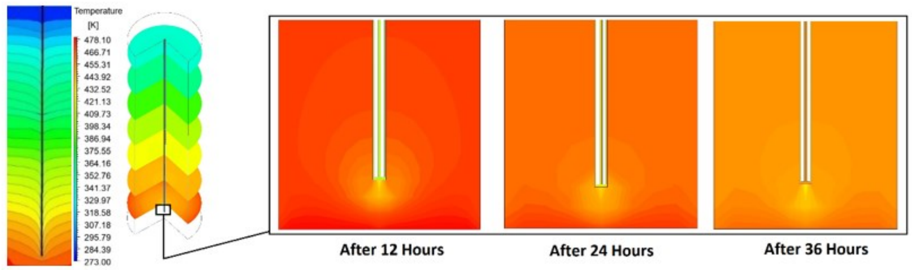

Figure 9: Temperature contours of rock at 3000m.

4. CONCLUSIONS

As a result of this research, a 3D geometric model of the abandoned well was drawn and CFD simulations were studied, and governing heat transfer equation was then applied to the simulation. A deep well heat exchanger (DWHE) is developed to absorb the underground heat. The results from the simulation were deemed suitable for electricity generation, which is part of our future research in geothermal energy. Geometry of the actual well, analyzes were made for 12, 24 and 36 hours and soil layer properties and temperature gradients were entered as UDF simulation input. Moreover, the present study highlighted that the performance of EGS/AGSs are significantly affected by optimized design and process parameters at different flow rates. Although many studies have evaluated design parameters, the most research have not considered the materials used in commercial well drilling such as casing, cement, heat transfer coefficient of formation at lithology etc. Therefore, it was emphasized that these parameters were very effective in our study, so the current study is presented to be a guide for future research.

Nomenclature

c_p	Specific Heat at Constant Pressure J/(Kg.K)	Δt	Finite Difference Time Step Seconds
d_{out}	Diameter at Water Rock Interface (m)	t	Time Seconds
d_{in}	Diameter Of Inner Return Pipe (m)	x	X Direction
f	Friction Factor	y	Y Direction
g	The Gravitational Constant	z	Depth Of Well
h	Heat Transfer Coefficient (W/m^2.K)		
k	Thermal Conductivity (W/m.K)		
Pr	Prandtl Number	α	Thermal Diffusivity
P	Pressure (kPa)	ρ	Density (kg/m^3)
n	Finite Difference Step Number in r Direction	μ	Dynamic Viscosity
Nu	Nusselt Number		
Δr	Finite Difference Step Distance Inner Direction		
r	Distance In Rock Formation from The Well		
Re	Reynolds Number		
T	Temperature (K)		

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