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ORIGINAL

Design of Geothermal Groundwater Heating and Cooling Plant: A Trial Study in Eleme Fertilizer Company in Niger Delta Region

Diseño de una planta de calentamiento y enfriamiento de aguas subterráneas geotérmicas: un estudio de prueba en la empresa Eleme Fertilizer Company en la región del Delta del Níger

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ABSTRACT

A geothermal groundwater heating and cooling plant consisting of a heat pump and heat exchanger has been designed. Geothermal heating and cooling systems play a crucial role in the decarbonization of the environment, helping to prevent global warming and promote energy savings due to the reduced energy required to power the plant, which in turn generates more geothermal energy for the heating and cooling needs of the fertilizer company. This study considered Eleme Fertilizer as a case study for the scaled-up and installation of the prototype designed of the geothermal groundwater heating and cooling plant. Both manual and software simulation designs were conducted based on material and energy balance principles. Error analysis and deviations were used to validate the design results. The results of the plant's unit design showed that the power drive, overall efficiency, and coefficient of performance for heating and cooling were 354,1 kW, 402 %, and 2,82 & 1,05, respectively. For the heat exchanger, design type 10-E-01, the values for heat duty, overall heat transfer coefficient, exchanger area, and tube pressure drop were 309,5 kW, 0,2104 kW/m^2°C, 60,32 m^2, and 390 MPa, respectively. Error analysis conducted on the design work showed negligible values of RMSE (0,02, 0,025, 20 and 0,656) and deviation (0,014, 0,05, 0,05, 0,002) for coefficient of performance of heating and cooling, heat pump efficiency and the drive power of the plant respectively. The values obtained from the design of the units in the geothermal plant were reasonable and are thus recommended for academic and industrial applications.

Keywords: Geothermal Energy; Groundwater; Heating; Cooling; Thermal Energy; Fertilizers.

RESUMEN

Se ha diseñado una planta de calentamiento y enfriamiento de aguas subterráneas geotérmicas que consta de una bomba de calor y un intercambiador de calor. Los sistemas de calentamiento y enfriamiento geotérmicos desempeñan un papel crucial en la descarbonización del medio ambiente, ayudando a prevenir el calentamiento global y promover el ahorro de energía debido a la menor energía requerida para alimentar la planta, que a su vez genera más energía geotérmica para las necesidades de calentamiento y enfriamiento de la empresa de fertilizantes. Este estudio consideró a Eleme Fertilizer como un caso de estudio para la ampliación e instalación del prototipo diseñado de la planta de calentamiento y enfriamiento de aguas subterráneas geotérmicas. Se realizaron diseños de simulación tanto manuales como de software basados en principios de balance de materiales y energía. Se utilizaron análisis de errores y desviaciones para validar los resultados del diseño. Los resultados del diseño de la unidad de la planta mostraron que la potencia de accionamiento, la eficiencia general y el coeficiente de rendimiento para calefacción y refrigeración fueron 354,1 kW, 402 % y 2,82 y 1,05, respectivamente. Para el intercambiador de calor, tipo de diseño 10-E-01, los valores de trabajo térmico, coeficiente de transferencia de calor general, área del intercambiador y caída de presión del tubo fueron 309,5 kW, 0,2104 kW/m²°C, 60,32 m² y 390 MPa, respectivamente. El análisis de errores realizado en el trabajo de diseño mostró valores insignificantes de RMSE (0,02, 0,025, 20 y 0,656) y desviación (0,014, 0,05, 0,05, 0,002) para el coeficiente de rendimiento de calefacción y refrigeración, la eficiencia de la bomba de calor y la potencia de accionamiento de la planta respectivamente. Los valores obtenidos del diseño de las unidades de la planta geotérmica.

Palabras clave: Energía Geotérmica; Aguas Subterráneas; Calefacción; Refrigeración; Energía Térmica; Fertilizantes.

INTRODUCTION

The Earth contains a significant amount of thermal energy, stored underground in the form of a temperature sink.[1] This energy is an abundant, renewable, and clean source of heat. Geothermal energy can be utilized for a variety of applications, including electricity generation, direct use (e.g., spas or hot springs), and commercial or residential heating and cooling operations. The amount of thermal energy available depends on where and how deep one bores into the ground. Geothermal energy is a sustainable, low-carbon renewable resource associated with a wide range of geology-dependent technologies, many of which are actively being researched, developed, and refined (e.g.).[2,3,4]

Goetzl et al.[5] explored the benefits of utilizing power from geothermal heat pumps (GHP) for heating and cooling homes, cities, and companies. This reduces carbon emissions significantly and is more cost-effective compared to boilers powered by natural gas, biomass, and hydropower, which are often located far from urban areas, making cities more vulnerable to supply disruptions. GHPs use a direct electric source, boosted by clean and renewable energy, achieving efficiencies of up to 300–400 %, thus saving a large amount of energy in the process. A transcontinental consortium proposed guidelines aimed at promoting the economic utilization of low-temperature geothermal resources, powered by the U.S. Geological Survey's John Wesley Powell Center for Analysis and Synthesis, as evidenced by the tools, datasets, and scientific recommendations provided.

Nowak[6] presented a key report on heat pump technology, discussing its fundamental principles, the renewable and waste-energy-based sources used, the financial and energy efficiencies achieved, and the business models being deployed. The report also highlighted the non-technical benefits for the environment and society. It further emphasized the integrative role that heat pumps play in decarbonizing the heating and cooling sectors, positioning them as a central component of Europe's future energy system.

Qin[7] developed a tool for calculating the potential benefits of geothermal energy. This tool was implemented in a case study that revealed that replacing 40 % of the natural gas heating system with geothermal-based district heating in Budapest could reduce Hungary's total greenhouse gas emissions by at least 4,6 %. This tool can also be applied elsewhere to evaluate the benefits of geothermal district heating, thereby contributing to the development of geothermal energy.

The use of geothermal heat pumps (GHPs) for heating, ventilation, and air conditioning (HVAC) applications involves explaining the basic elements of geothermal energy and the operating principles of GHPs. Different types of GHPs are examined, and the benefits and challenges of using a GHP system for residential and commercial applications are compared with those of traditional HVAC systems.[1,5,7]

Invanova[8] assessed the energy requirements of GHPs for a typical home in the United States and discovered that heating and cooling account for more than 70 % of the energy consumed. GHPs reduce this energy consumption by half since the ground supplies a large amount of free energy 49 %. GHP systems reduce oil consumption in 100 000 residential homes by 2,15 million barrels per year, with no onsite emissions. Overall, GHPs have the lowest emission levels among all HVAC applications.[9] GHPs reduce the carbon emissions resulting from building energy use by up to 50 %. Recently, commercial buildings in the USA have been credited with 10 % of the total building and construction cost, plus a five-year modified accelerated cost recovery system depreciation, via federal tax credits with no limit on the total credit amount.[10] Homeowners in the USA benefit from tax credits through the Energy Policy Act of 2005, which was renewed with a 22 % tax credit in 2023.[11] Companies also encourage tax rebates for GHP installation by offering customers up to $1000 for every ton of heating and cooling installed.

Geothermal groundwater heat pump (GWHP) offers several advantages over traditional water source heat pump (WSHP). A GWHP is typically designed to handle a wider range of water loop temperatures, from -1,1°C to 32,2°C, compared to the regular GWHP range of 18,3°C to 29,4°C. This allows heat to be extracted from or transferred to the water under a variety of conditions, improving overall efficiency. Another important consideration is the lifespan of the HVAC system. GHP systems typically last longer than traditional air-source heat pumps because most of the system components are located indoors or underground.[12]

According to various reviews, installing geothermal groundwater heating and cooling systems in homes, industries, or companies significantly reduces CO_2 emissions and saves a substantial amount of energy that would otherwise be wasted. These systems are highly efficient and could replace more than 80 % of boilers used for heating and cooling, which rely on natural gas and fossil fuels that emit large amounts of greenhouse gases, contributing to global warming. While much has been done to promote the benefits, awareness, and feasibility of GHPs, as well as their potential to replace boilers, this study focuses on the design and specifications of a geothermal groundwater heating and cooling plant, a laboratory scale to be implemented and installed at Fertilizer company in Eleme Town, Eleme Local Government Area, Rivers State, Niger Delta Region of Nigeria.

A prototype of a geothermal heat pump mounted and connected vertically with pipes acting as heat exchanger, 10 m from the groundwater to the surface of the earth and 16,5 m from the surface to the wall of the company house where it is installed, is considered. The exchanger manual design and simulation connected together with the heat pump is targeted and design results validation with design data collected from the fertilizer plant and the spreadsheet result from Aspen HYSYS, is also focussed.

METHOD

The study is mainly qualitative and part of quantitative as design models are applied to study the process and simulation analysis using Aspen HYSYS. The result from the simulation provides data used for design computation of the geothermal groundwater plant.

Materials

Geothermal groundwater heat pump (GWHP), shell and tube heat exchanger type (10-E-01) as connecting pipes, thermodynamic tables and data, underground wells, water and air. Figures 1 and 2 describe the GWHP and its process flow diagram for this study.

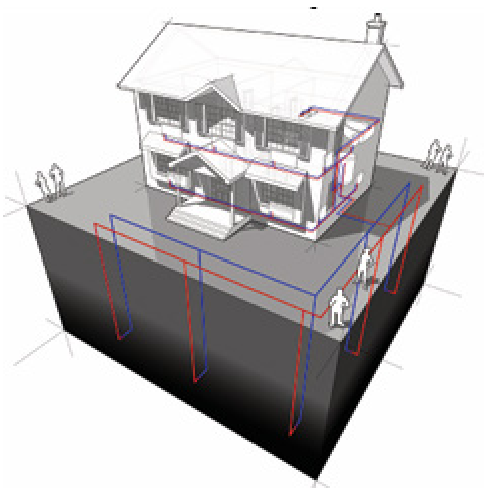

Figure 1. Ground loop system (installation of GWHP) for exchanging of heat

A ground loop system utilizes a brine-to-air heat pump to circulate a brine (anti-freeze) solution through a piping loop beneath the Earth's surface. This system transfers heat between the ground and the building, depending on the need. The heat exchange loop can be installed either in vertical bores or horizontal trenches. The installation costs of closed-loop systems are generally higher than those of conventional HVAC systems due to the size of the pipes and the expense of boring into the ground. The expected service life of geothermal water heat pumps (GWHPs) varies, but components such as the heat exchanger and the overall infrastructure of the system, which operate underground, may function successfully for 25 to 50 years, with a service life of more than 20 years.(1)

At a depth of 2,4 meters, the ground temperature fluctuates between 3,33°C and 16,67°C. The undisturbed soil temperatures at depths of 0,6 meters, 1,5 meters, and 2,4 meters allow the ground to act as a heat sink during the summer, enabling the transfer of heat from the warm building air into the ground. Conversely, the warm ground, at around 7,2°C, can transfer heat to the building during colder periods. Therefore, ground temperatures can be relied upon as sources of clean, renewable energy for heating and cooling throughout the year.

Method

The method consider in this section is qualitative, where design models are applied for the manual computation of key parameters such as the drive work, the coefficient of performance of the heat pump, the efficiency etc. The design of geothermal groundwater heating and cooling plant is carried out in this study with plant's specification and rating. The plant consists of the groundwater geothermal heat pump and heat exchanger acting as vertical pipes connected from the groundwater to the heat pump source. Figure 2 explained clearly the prototype of the geothermal groundwater heating and cooling plant.

Design of Geothermal Water Heat Pump

The geothermal groundwater heat pump sketch with some features is shown in figure 2.

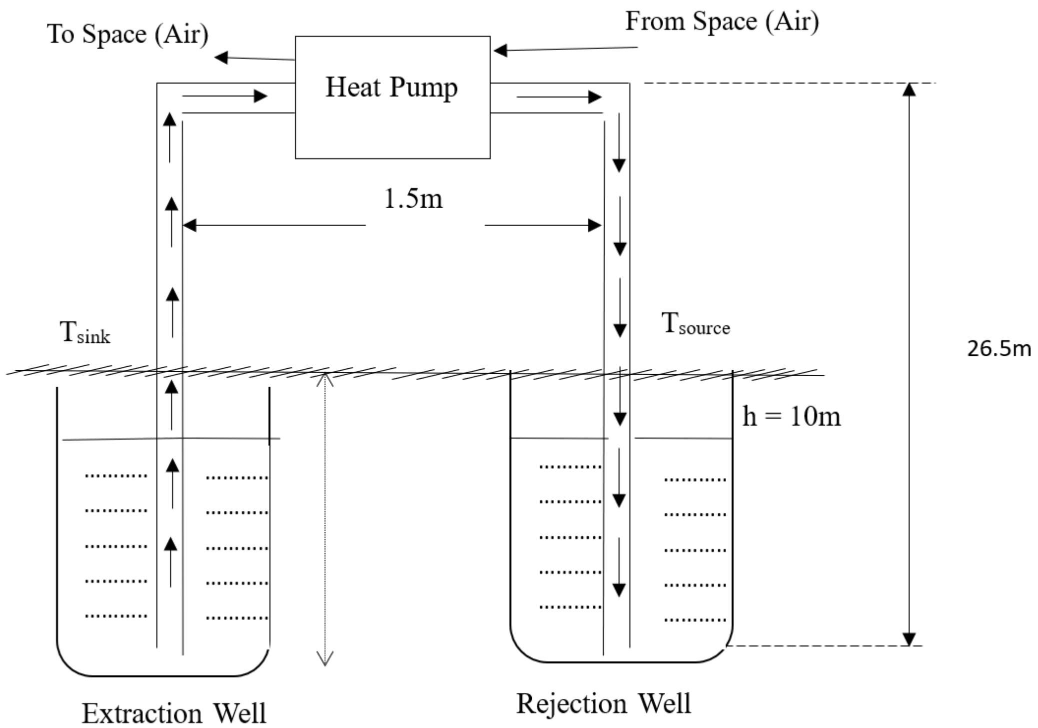

Figure 2. Water-to-air-type vertical heat exchanger from the geothermal groundwater heat pump (GWHP)

The work done by a Geothermal groundwater Heat Pump (GWHP) can be thermodynamically determined using the Clausius-Clapeyron equation, based on the second law of thermodynamics, which is mathematically defined as:

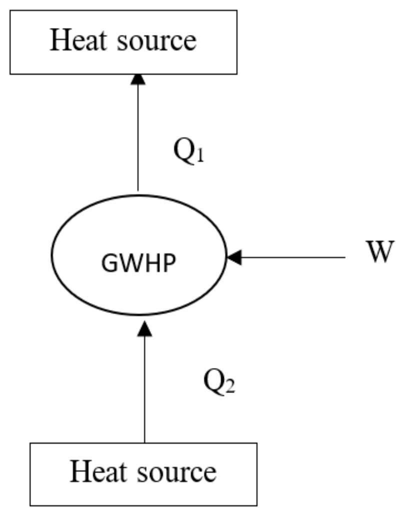

Figure 3. Application of Clausius Clapeyron second law of thermodynamic

The drive power rate is determined from application of second law of thermodynamics via the energy balance on the GWHP applied in figure 3 to give equation (1) as:

$$\dot{W}_{net} = \dot{Q}_1 - \dot{Q}_2 = \dot{m}C_p\,(T_1 - T_2) \qquad (1)$$

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Where, W_{net} is the drive power rate, $Q^{\cdot}$ is the energy rate from the sink temperature T_1 to the source temperature T_2, $m^{\cdot}$ is the mass flow rate, and C_p is the heat capacity of the fluid.
The coefficient of performance of a heat pump based on figure 3 is given as:

$$\beta_{HP} = \frac{\dot{Q}_1}{W_{net}} = \frac{T_1}{T_1 - T_2} \quad (2)$$

Where, T_2 is the source temperature K, T_1 is the sink temperature K, β_{HP} is the geothermal groundwater heat pump coefficient of performance. The geothermal groundwater heat pump energy equally known as the rating of the plant is defined mathematically as:

$$\dot{Q} = \dot{m} C_p \triangle T \quad (3)$$

Where, $Q^{\cdot}$ in the rate of heating or cooling, and $\triangle T$ is the temperature difference of the source and sink.
The pressure head of the geothermal groundwater heat pump for enthalpy of the system determination using thermodynamic tables as part of the overall energy generated from the process is calculated as:

$$P = P_o + \rho g h \quad (4)$$

Where, P is hydrostatic pressure equation, h is the height, 10m, P_0 is atmospheric pressure, ρ density of the water, and g in acceleration due to gravity with value 9,81m/s^2.
The pipe length is calculated as:

$$L = \frac{R\dot{Q}}{(T_g - T_W)} \quad (5)$$

Where, $Q^{\cdot}$ is the rate of heat transfer [kW], L is pipe length, T_g is ground temperature [K], T_w is the working fluid temperature [K] and R is efficient thermal resistance of ground per unit length [mK/kW].
From equation (2), the work done or the drive power can also be determine using coefficient of performance for the heat pump as:

$$\dot{W} = \frac{\dot{Q}_{output}}{\beta_{HP}} = \frac{\dot{Q}_1}{\beta_{HP}} \quad (6)$$

For the cooling power of the GWHP, the heat transfer rate is the amount of heat the system can remove from the building per unit time defined as:

$$\dot{Q}_{cooling} = \dot{m} C_p \triangle T \quad (7)$$

The cooling coefficient of performance of the pump is defined mathematically as:

$$COP_{cooling} = \frac{\dot{Q}_{cooling}}{\dot{W}} = \frac{t_s}{t_u - t_s} \quad (8)$$

Where, $COP_{cooling}$ is the coefficient of performance of cooling, t_s is the absolute temperature of the cold source, and t_u is the absolute temperature of the hot source.
Work done rate or drive power can also be determined using the cooling system as:

$$\Rightarrow \dot{W} = \frac{\dot{Q}_{cooling}}{COP_{cooling}} \quad (9)$$

Similarly, the coefficient of performance of the heating system is mathematically defined as:

$$COP_{heating} = \frac{\dot{Q}_{heat}}{\dot{W}} = \frac{t_u}{t_u - t_s} \quad (9b)$$

Where, $COP_{heating}$ is the coefficient of performance of heating system, and $Q^{\cdot}_{heat}$ is the rate of heating.

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The Heat Exchanger Design for GWHP

The heat exchanger of type 10-E-01[13] consists of a shell and tube heat exchanger. With the defined geothermal fluid properties (well water and air), the design parameters include the flow rates for both the geothermal fluid and the building fluid, the temperature range (log mean temperature difference), and the heat transfer coefficient U (the efficiency of heat transfer, dependent on the material and design).

The area of the exchange A is defines mathematically as:

$$A = \frac{\dot{Q}}{U \Delta T_{LM}} \quad (10)$$

Where, A is area of the exchange (m^2), $Q^{\cdot}$ is heat transfer rate (W), U is overall heat transfer coefficient ($Wm^{-2}\ K^{-1}$) and ΔT_{LM} is the logarithmic mean temperature difference (LMTD) defined mathematically as:

$$\Delta T_{LM} = \frac{(T_{h1} - T_{c2}) - (T_{h2} - T_{c1})}{\ln(\frac{T_{h1} - T_{c2}}{T_{h2} - T_{c1}})} \quad (11)$$

Where T_{h1} is inlet of source temperature, T_{h2} outlet of source temperature of coolant.

Material selection is based on thermal conductivity corrosion resistance and cost. The design features such as baffle cuts, shell and tube clearance are determined.

A trial design is considered in a situation where the U is assumed and used to obtain the various heat exchangers parameters, such as the heat transfer coefficient of the shell and the tube, the pressure drop for the shell and tube etc. These parameters are then used to determine the actual or refined values of U_0. If the calculated U_0 matches the assumed U (i.e. $U_0 \geq U$), the design is considered acceptable. If not, another U value is assumed, and the process is repeated to actively determine the overall exchanged area.

Solution Techniques

The use of Aspen HYSYS simulator and manual design approach. The simulation of the entire plant provides data which were used for the manual computation to determine the key parameters identified.

Design Data

Table 1 provide the input data for the simulation of the geothermal plant and the manual design calculations to determine essential parameters which are drive power, coefficient of performance of the GWHP (COP_{HP}), overall heat transfer coefficient, heating and cooling rate, exchanger area, heat transfer coefficients of the exchanger, logarithmic mean temperature difference, pressure drops of the shell and tube exchanger, efficiency, and hydrostatic pressure of the GWHP.

Table 1. Design data for the simulation

Parameter	Symbol	Value/Unit	Reference
Atmospheric Pressure	P_O	101,3kPa	
Coolant fluid	t_{c1} and t_{c2}	11ºC and 27,3ºC	[15]
Hot fluid	T_{h1} and T_{h2}	32ºC and 26ºC	
Flow rate	m_f	2,77kg/s	
Specific heat of water	C_P	4,18kJ/kgºC	Aspen HYSYS 2014
Density of water and air	ρ	997kg/m^3 and 1,15 kg/m^3	[14]

Validation of the Models

The simulations results are validated with design data using root mean square error (RMSE) and deviation as shown in equations (12) and (13) respectively according to Ojong et al.[16]

$$\text{RMSE} = \sqrt{\left(\frac{\text{Design Result} - \text{Design Data}}{\text{N}}\right)^2} \quad (12)$$

Where, N is the number of design data involve:

$$\text{Deviation} = \left|\frac{\text{Design result} - \text{Design.data}}{\text{Design data}}\right| \quad (13)$$

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RESULTS

The Aspen HYSYS simulation results for the GWHP and the heat exchanger are displayed in table 2 and discussed. The results of the manual design of the geothermal water heating plant, including the essential parameters mentioned earlier, are displayed and discussed in table 3.

Aspen HYSYS Results for the Plant

The simulation of the entire Geothermal groundwater heating and cooling plant is shown in figure 3 with some of the data from table 3. The results especially the outlet temperature value obtained from the simulation indicates that the system save up to 0,40 of CO_2 emission compared to regular boiler as agreed by Ojong et al.[19].

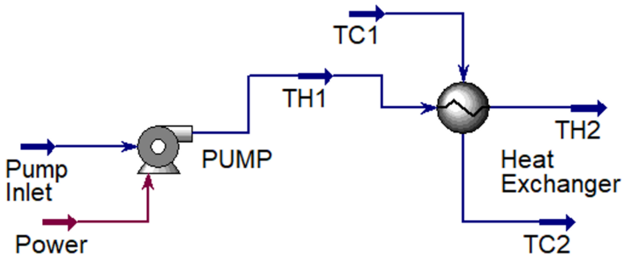

Figure 4. Process flow diagram for the geothermal groundwater heating plant

The connection of the GWHP and the vertical pipes serving as heat exchanger with proper simulation using Aspen HYSYS 2014 gave a process flow diagram shown in figure 4. This generated spreadsheet results which were used for the manual design and determination of the design results in line with works carried out in this area.[17,18,19,21]

Manual Calculations and Validation Results for the Plant

The values of the parameters determined are based on the application of material and energy balance principles on the units.[16,17,18,21] Tables 3 and 4 shows the results of these parameters and the validation of the design results with design data selected for the process based on error analysis.[16]

Design Model Results

The design model results for the GWHP after the simulation of the whole plant using Aspen HYSYS version 2014 with design data from Almadi et al.[14] is presented in table 3.

Table 3 presents the design of the geothermal water heat pump, including the heat pump parameters. These parameters encompass the drive power rate (W), the coefficient of performance (COP) for heating and cooling, the efficiency of the pump, the source and the sink heat rate (Q_1 and Q_2), and enthalpy of the pump, with values as detailed in table 3. The design data from Almadi et al.[14] used for the process when the plant was simulated gave an efficiency of 420 %, indicating green process and 0,00 CO_2 emission (kg CO_2/kWh heat) as stated by Mustafa[22]. Based on the COP values computed in table 3, it is suggested that heat pump is considered for the heating and the cooling process which can save more than 9 % and 16,5 % energy when compared to the use of gas and coal fired heating processes respectively.[23] The result of the energy rate showed that 1,024 kilotons is needed to install GWHP capacity as agreed by Bayer et al.[24].

Table 3. Design results for the GWHP

Parameter	Symbol	Value	Unit
Drive Power	W	354,1	kW
Pump Pressure	P	2,00	Bar
Coefficient of Performance for heating & Cooling	COP	2,82 & 1,05	-
Efficiency	H	420	%
Adiabatic Efficiency	η_A	30	%
Sink & Source Heat Rate	Q_1 & Q_2	3367 & 3604	kW
Enthalpy Rate	H	11532	kW

The design of the heat exchanger (10-E-01) used for the geothermal groundwater heating and cooling plant has been completed, with the design parameter values shown in table 4. The material used is stainless steel. The values of the parameters were simulated following manual calculations, as outlined in the methods section. The value of the overall heat transfer coefficient (U) calculated was greater than the assumed value,

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which then was used to update the exchanger's area to 60,32 m^2. The design result shown in table 5 indicates that the typical heat exchanger can be used, sized, and specified alongside the rated geothermal heating pump to actually heat and cool the households within the Indorama company.

Table 4. Design results for the heat exchanger

Parameter	Symbol	Value	Unit
Heat Duty	Q	309,480	kW
Overall Heat Transfer Coefficient	U	0,2104	$kW/m^2.^oC$
Exchanger Area	A	60,32	m^2
Tube Side Pressure Drop	ΔP	3,9e04	kPa
Shell Diameter	D_s	739	mm
Tube Length	L	6	m
Outside and Inside diameters & tube thickness	OD, ID & t	20, 16 & 2	mm
Tube pitch and tube per shell	P_t and TPS	50 and 160	mm and -

DISCUSSION

Validation of the Design Results with Design Data

Design data was used to validate the design models and simulation results based on the root mean square error and deviation as shown in table 5.

Except the drive power value of RMSE shown in table 5, the error analysis and deviations values determined showed that the design results obtained from the design models and the simulation performed are good and reliable and could be used for different design data outside the case study, which agrees with works from.(17,18,21) The value of the efficiency determined as shown in table 3 when compared with literatures(14,16,25) indicated that apart from preventing CO_2, H_2S, SO_2, and NH_3 emissions decreases also using the GWHP. The higher RMSE value for drive power value depends on the different design data used and vary from plant to plant.

Table 5. Validation of design result with design data

Parameter	Symbol/Unit	Design Data	Design Result	RMSE	Deviation
Heating and Cooling Performance	COP/-	2,78 [40]	2,82	0,02	0,014
		1,00 [40]	1,05	0,025	0,05
Efficiency	η /%	300-400	420	20	0,05
Drive Power	W /Kw	353,444	354,1	0,656	0,002

CONCLUSIONS

The geothermal groundwater heating and cooling plant has been designed to include a heat pump and a heat exchanger for providing heating and cooling to the fertilizer company in Eleme, Eleme LGA, Rivers State, in the Niger Delta Region. The drive power, efficiency, and coefficients of performance (heating and cooling) for the GWHP are 354,1 kW, 420 %, and 2,78 and 1,05, respectively. The results of the heat exchanger design show the duty, overall heat transfer coefficient, exchange area, and tube pressure drop as 309,5 kW, 0,2104 $kW/m^2\cdot{}^\circ C$, 60,32 m^2, and 390 MPa, respectively. These figures provided a bench scale for scaled up, implementation, and installation of the prototype plant in the company. Negligible values from error analysis and deviations obtained except the value of drive power showed the reliability of the design models and the simulation developed.

Key Points of the Article

Design of a prototype geothermal groundwater heating and cooling plant comprises of heat exchanger and the heat pump. A case study of the fertilizer plant (Indorama company) with suitable design data is test run and the plant simulated with Aspen HYSYS. Secondary data obtained from the spreadsheet of the simulations results for manual computations. Validation of the design results with data using RMSE and deviations.

BIBLIOGRAPHIC REFERENCES

1. U.S. Department of Energy. GeoVision: Harnessing the heat beneath our feet. DOE/EE-1306. Washington, DC: DOE; 2019. Available from: https://www.energy.gov/sites/prod/files/2019/06/f63/GeoVision-full-report_opt.pdf

2. Fleuchaus P, Godschalk B, Stober I, Blum P. Worldwide application of aquifer thermal energy storage – a review. Renewable Sustainable Energy Rev. 2018; 86:861–76.

3. Burns ER, Bershaw J, Williams CF, Wells R, Uddenberg M, Scanlon D, Cladouhos TT, van Houten B. Using saline or brackish aquifers as reservoirs for thermal energy storage, with example calculations for direct-use heating in the Portland Basin, OR, USA. Geothermics. 2020; 88:101877. https://doi.org/10.1016/j.geothermics.2020.101877

4. Pepin JD, Burns ER, Dickinson JE, Duncan LL, Kuniansky EL, Reeves HW. National-scale reservoir thermal energy storage pre-assessment for the United States. In: Proceedings of the 46th Workshop on Geothermal Reservoir Engineering; 2021 Feb 16–18; Stanford, CA. Stanford, CA: Stanford University; SGP-TR-218:10. https://pangea.stanford.edu/ERE/db/GeoConf/papers/SGW/2021/Pepin.pdf

5. Goetzl G, Burns ER, Stumpf AJ, Lin YF, Kolker A, Kłonowski MR, Steiner C, Cahalan RC, Pepin JD. City-scale geothermal energy everywhere to support renewable resilience – a transcontinental cooperation. In: Proceedings of the 48th Workshop on Geothermal Reservoir Engineering; 2023 Feb 6–8; Stanford, CA. Stanford, CA: Stanford University.

6. Nowak T. Heat pumps: integrating technologies to decarbonize heating and cooling. Brussels: European Copper Institute; 2018. p. 1–86.

7. Qin M. The environmental and socio-economic benefits of geothermal district heating. Master's thesis, School of Engineering and Natural Sciences, Reykjavik University, Iceland; 2022. p. 1–94.

8. Ivanova I. Cities are banning natural gas in new homes, citing climate change. Moneywatch, CBS News. Last modified 2019 Dec 6. https://www.cbsnews.com/news/cities-are-banning-natural-gas-in-new-homes-because-of-climate-change/

9. GeoExchange. Geothermal 101. Accessed 2020 May 21. https://www.geoexchange.org/geothermal-101/

10. Internal Revenue Service. About Form 3468, investment credit. 2020 Apr 16. https://www.irs.gov/forms-pubs/about-form-3468

11. ENERGY STAR. ENERGY STAR certification for your building. Accessed 2020 May 21. https://www.energystar.gov/buildings/facility-owners-and-managers/existing-buildings/earn-recognition/energy-star-certification

12. Bais AS, Ankit G. U.S. geothermal heat pump market size by product, by application, industry analysis report, regional outlook application potential, competitive market share & forecast, 2018–2024. Report No. GMI3002. Selbyville, DE: Global Market Insights, Inc.; 2018.

13. Uzono RI, Ojong OE. Mathematical modelling of operating temperature variations of shell-and-tube heat exchanger. World J Eng Technol. 2022;10(2):422–33.

14. Ahmadi MH, Mehrpooya M, Pourfayaz F. Thermodynamic and exergy analysis and optimization of a transcritical CO2 power cycle driven by geothermal energy with liquefied natural gas as its heat sink. Appl Therm Eng. 2016; 109:640–52.

15. Indorama Eleme Fertilizer and Chemical Limited. Production of granular urea (organic fertilizer). Eleme, Rivers State, Nigeria; 2016. Available from: https://www.indorama.com

16. Ojong OE, Akpa JG, Dagde KK, Amadi D. Rate expression model from thermodynamics application and optimal kinetic parameters determination for urea synthesis and production process. Results Eng. 2024; 24:102885. Available from: https://doi.org/10.1016/j.rineng.2024.102885

17. Ojong OE, Wosu O, Emenike A, Ubi P. Design and simulation of 30,000 tons per year of cumene plant from natural gas field. Pure Appl Chem. 2024. Available from: https://doi.org/10.1515/pac-2023-1135

18. Ojong EO, Etim VI, Aquah GE-E, Uzono RI. Design and simulation of the major units of acetone plant from isopropyl alcohol (IPA) route. Adv Sci Technol. 2024; 142:171–80.

19. Ojong EO, Zina J, Wosu CO, Ekpenyong AA, Dadet W, Anaba CU, Emenike A, Sedi P, Forwah JN. The use of models to evaluate corrosion effects on mild steel heat exchanger in water and monoethanolamine. Adv Chem Eng Sci. 2024;13(4):336–50.

20. Jenkins DP, Tucker R, Rawlings R. Modelling the carbon-saving performance of domestic ground source heat pumps. Energy Build. 2009; 41:587–95.

21. Dadet W, Ojong OE, Dagde KK. The design and energy simulation of CO2 capture process (CCP) for a liquefied natural gas (LNG) plant. Adv Sci Technol. 2024; 142:181–92.

22. Mustafa Omer A. Ground-source heat pumps systems and applications. Renew Sustain Energy Rev. 2008; 12:344–71.

23. Chai L, Ma C, Ni J-Q. Performance evaluation of ground source heat pump system for greenhouse heating in northern China. Biosyst Eng. 2012; 111:107–17.

24. Bayer P, Saner D, Bolay S, Rybach L, Blum P. Greenhouse gas emission savings of ground source heat pump systems in Europe: a review. Renew Sustain Energy Rev. 2012; 16:1256–67.

25. Islam MM, Mun HS, Bostami ABMR, Ahmed ST, Park KJ, Yang CJ. Evaluation of a ground source geothermal heat pump to save energy and reduce CO2 and noxious gas emissions in a pig house. Energy Build. 2016;111: 446–54.

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