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CFD Simulation on Ground Tube Heat Exchanger using Copper and Aluminum as Tube Material

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ABSTRACT
Renewable energy is free in nature and it must be brought into application. Due to use of air conditioning and its refrigerants global warming is a serious issue. Renewable energy is the main concept of an earth tube heat exchanger, which uses the thermal energy of the ground for cooling and heating of the fluid medium. Here, air is used as fluent working medium. The air cools in summer and gets heated in winter due to the temperature difference between the air and underground surface temperature. However, for the study of the surface heat convection study of model is carried out. Researchers have been carried out at beginning as a field investigation. But presently software simulation is used for measurement of heat transfer and temperature difference at the outlet and inlet. The software requires complex model and its dimensioning process, such a system which involves optimization of numerous parameters such as the diameter, air flow rate depth, tube length and condensation in the meantime have to be considered. ANSYS Software is being used for simulation and modeling of result. Computational fluid dynamics (CFD fluent) workbench under ANSYS software is used as simulation analysis the pipe of 45 m length, 0.004 m thickness, 0.08 m diameter and 5 m depth of pipe from the earth ground. Air velocity is considered to be 2 m/s. The inlet temperature is considered for a day of every month in a year according the previous research. Using fluent thermal variations is being analyzed. It is observed at increasing velocity increases the rate of heat transfer, mid temperature, outlet temperature varies in the year.

Keywords: *EATHE (earth air tube heat exchanger), heat convection, numerical simulation, temperature, renewable energy*

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INTRODUCTION

Overview

Utilizing the wasted energy can improve the efficiency of these processes as evidenced by the inception of natural gas combined cycle (NGCC) power plants. NGCC power plants offer thermal efficiencies that are significantly higher than traditional coal fired power plants by using gas turbine exhaust to drive a bottoming steam Rankine cycle. In addition, many cement and metal processing plants have incorporated waste heat recovery devices to improve efficiency and decrease fuel consumption [1–10]. Figure 1 shows earth tube heat exchanger flow diagram.

Ground tube heat exchangers are classified into two types:

- Ground-coupled air heat exchangers
- Ground-coupled water heat exchangers.

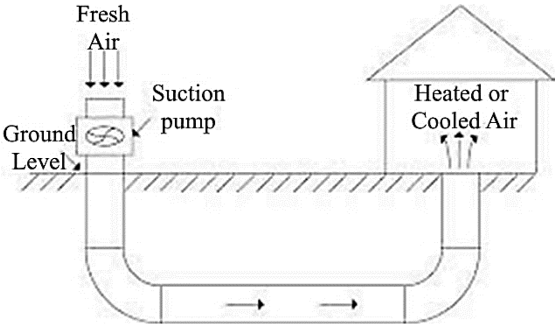

Fig. 1. *Earth tube heat exchanger flow diagram.*

Design and Engineering

Even if some design rules are available, none are provided based on theory. We offer not only to account for heat and mass transfer during the efficiency evaluation of the earth air heat exchangers (EAHEs) but also to discover the underground network architecture. The design of an EAHE is a multi-layered process which has to consider the exchanger itself, its implementation in the ground and its impact on the whole energy consumption. Because the impact of mass transfer on the energy balance was little studied and characterized, we want to discover these new network configurations by accounting both for the heat exchanges and the mass exchanges between the air flow and the ground for the very different climates which are the Brazilian and the French ones.

In addition to poor efficiency, using fossil fuels to produce energy has a significant impact on the environment. Releasing waste heat to the environment can cause imbalances in delicate ecosystems. Further, burning fossil fuels releases greenhouse gases (GHGs) which have contributed to warming of the Earth's climate. Some of the more devastating climate impacts include rising ocean levels, melting Arctic and Antarctic sea ice, increasingly frequent extreme weather events, and extinctions of certain species of animals [6]. Improving the efficiency of power generating processes will reduce overall fuel consumption and help to reduce GHG emissions. There is also an economic benefit to improving the efficiency of power generating systems. In addition to the obvious cost savings from consuming less fuel, several nations have imposed a 'carbon tax'. The carbon tax adds an additional cost to burning fossils and releasing harmful greenhouse gases into the atmosphere [7, 8]. Figure 2 shows fossil fuels and its cycle.

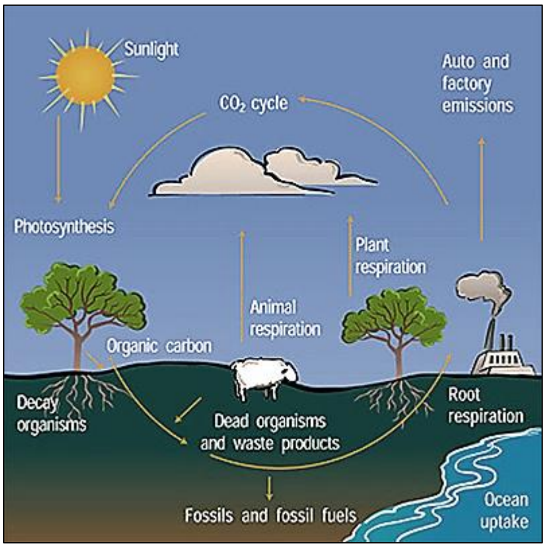

Fig. 2. *Fossil fuels and its cycle.*

An effective way to improve the efficiency of fossil fuel systems is to utilize the two-thirds of the energy input that is typically wasted. This waste heat can be utilized in a waste heat recovery (WHR) system. The following sections will discuss types of waste heat and some common waste heat recovery systems. The primary types of waste heat recovery are internal heat recuperation or regeneration or the conversion of waste heat into useful mechanical work. The present work focuses on the conversion of waste heat into mechanical power [11–25].

On the basis of the design, drawing, efficiency and engineering ground-coupled heat exchangers are classified into following categories, namely.

- On the basis of loop
- On the basis of flow
- On the basis of passes
- Surface area
- Pipe depth
- Heat transfer and tube material
- Boundary condition
- Intake medium
- Energy analysis

Categories Based on Loop

There are three types of configurations,

- A closed loop design,
- An open loop system or
- A combination system.

Waste Heat Availability

The usefulness of waste heat energy depends on the quantity and quality of the waste heat source. The quantity of waste heat is the amount of energy contained in the stream in terms of mass flow rate and enthalpy. The quality of the waste heat is determined by the temperature of the stream. Waste heat sources are divided into three groups based on their temperatures (quality): less than 230°C is considered low grade, 230°C to 650°C is medium grade, while above 650°C is high grade waste heat [9].

The exergy (or availability) of a waste heat source is defined as the maximum amount of work that can be extracted based on the heat input and the reservoir temperatures, as shown in Equation 1.

$$W\,max = Q\,(1 - \frac{Tlow}{Thigh}) \quad (1)$$

The maximum amount of work is based on the heat input to system, $\dot{Q}$, and the temperatures of the hot and cold reservoirs in Kelvin. For example, a 90°C (363.15 K) low grade waste heat source transferring 2 MW of heat to a heat engine with a heat sink temperature of 32°C (305.15 K) will have a maximum work output of 319 kW. At the same conditions, a high-grade waste heat source at 700°C (873.15 K) will have a maximum work output of 1373 kW. For a fixed heat sink temperature, the maximum amount of work that can be extracted will increase with heat source temperature [26–40].

Thus, low grade waste heat is more difficult to effectively convert to work due to its low temperature. As the waste heat stream increases in temperature, a higher fraction of the input energy can be converted to work and in a more economically efficient manner. Low grade waste heat is by far the most abundant of the three different types, but it also has the lowest availability, from Equation 1.

The primary performance metric to compare systems in the following literature review will be the coefficient of performance (COP), which is a ratio of the cooling duty to the input heat. The COP is defined in Equation 2:

$$COP = \frac{Qchill}{Qheat} \quad (2)$$

Where, *Q*chill is the amount of cooling provided by the system and *Q*heat is the amount of heat input to the system. The operating conditions of heat activated cooling systems have a significant impact on the refrigeration COP. In general, COP improvements can be realized by decreasing the heat sink temperature and increasing the evaporator temperature. In some cases, increasing the heat source temperature can improve the COP.

The primary thermal techno-economic metrics used in this work are the payback period and the specific cost. When using waste heat to provide cooling, the payback period can be quantified in terms of energy savings, as shown in Equation 3:

$$\text{Payback Period} = \frac{SystemCost}{EnergySavings} \quad (3)$$

In the case of geothermal cooling, heat activated cooling systems reduce the amount of fuel consumed by producing cooling from waste heat, instead of electricity. Different thermally activated cooling systems can be compared by examining their specific cost. The specific cost is defined in Equation 4:

$$\text{Specific Cost} = \frac{SystemCost}{Qchill} \quad (4)$$

Heat Energy and its Sources

It is estimated that there are 30 quads of waste heat available per year in the United States under 100ºC [11]. The low temperatures of these streams mean the waste heat to power systems must have very large heat exchangers, very high mass flows, or high heat transfer coefficients because the thermal driving potential between streams is lower. These issues produce some problems for waste heat recovery of low-grade streams because the heat exchangers are typically the most expensive piece of any waste heat recovery system. As the heat exchange area gets larger, the overall cost of the system will grow along with it. Advanced heat exchanger technology can increase the heat transfer coefficients but come with a hefty price tag. This can lead to expensive systems with long payback periods, which is not ideal for implementation. The main goals of current studies are to increase the economic viability of low-grade waste heat recovery systems using advanced cycles, advanced heat exchanger technology, and well-optimized working fluids.

There are four primary types of heat activated cooling systems: absorption, adsorption, ejector, and organic Rankine-vapor compression. However, only absorption systems are commercially available. The adsorption system has a number of operational challenges including low coefficient of performance (0.35), batchwise cooling, and very low gravimetric cooling density. The challenges associated with the ejector cycle include low coefficient of performance (0.2–0.4) and inefficient ejector nozzles. The literature review will focus solely on the absorption system and the organic Rankine–Vapor compression cycle.

IMPACT ON ENVIRONMENT

Soil properties may be determined from an on-site thermal conductivity test, and surface temperature data can be approximated from annual weather data. Once the model has the required input data, it uses hourly outdoor air temperature and a series of equations to calculate the air temperature exiting the earth tube. These equations are described here. The first equation calculates the ground temperature in the vicinity of the buried pipe.

The latent heat of the earth is constant almost the year, so on the concept of heat exchanger we the environmental air carrying pipe when comes in contact with the buried soil, by the concept of heat exchanger warm air gets cool and cold air gets warmed up. Earth tubes utilize the fact that the ground temperature is relativity constant during the annual year [41–51].

Research Objectives

- The goal of this work was to simulate a new type of thermally driven cooling system implemented on an ETHE.
- To develop a transient thermal network model for finding the transient temperature profile around an earth tube in order to determine the velocity of intake air in heat exchanger systems and the change of temperature of the soil due to prolonged usage.

- To develop a new methodology for CFD simulation of the earth tube system taking into account heat transfer by different temperature at its velocity 2 m/s.
- To study this technology, we determine the velocity of blower according to change in climate temperature.

LITERATURE REVIEW

Various studies on effect of air on earth tube air heat exchanger were carried out by many researchers in the past. Some of references related to the present study were reviewed in the followings:

Peretti et al. (2013) [19] explained the overall COP of the system for all working fluids is within 5% until the boiler temperature reaches 110°C. When the boiler temperature was greater than 110°C, the R123 system had a significantly higher COP than the other systems and reached a maximum value of 0.65 at 150°C. R600a reached a maximum value of 0.45 at 120°C while R245fa and R600 had a maximum COP of 0.50 at 130°C. In terms of the turbine and the compressor, the R600 and R600a systems had the most favorable characteristics. The specific volume ratio and the size of the turbine was the lowest for these two working fluids. In addition, the compressor pressure ratio (CPR) was the lowest and the ratio of vapor compression COP to CPR was the highest for R600 and R600a, implying that these systems can get the most cooling for the least amount of compressor work. The R600 had a sub atmospheric pressure at the compressor inlet which means air can leak into the system and poses a practical hazard to operation. The work theoretically analyzed an internally recuperated transcritical organic Rankine cycle coupled to a vapor compression chiller. The transcritical thermal system was driven by waste heat available in flue gas. R22, R134a, and R290 were examined for use in the heat exchanger. The transcritical cycle allows the working fluid temperature profile to more closely follow the waste heat temperature profile which decreases the irreversibility in the boiler, improving the system COP. The power and cooling cycles shared the same air coupled condenser, which implies the same working fluid was used on both cycles. The turbine on the organic Rankine cycle was connected to a generator and the compressor.

Tudor and Badescu (2013) [7] explained the saturation temperature in the evaporator were 7°C and in the condenser was 60°C. The condenser rejected heat to 35°C ambient air, while the outlet temperature of the chilled water was 10°C. In full refrigeration mode with R134a, the system could provide approximately 330 kW of cooling that resulted in a COP of 0.34. The total exergy destroyed and exergetic efficiency in the system decreased when increasing the condenser saturation temperature. kW. This study is interesting because the overall system COP was lower than others reviewed above, but the heat exchanger thermal efficiency is slightly higher. The recuperated transcritical heat exchanger has a better efficiency than the subcritical heat exchangers in previous studies. Regardless of the COP, the work provides a good theoretical base for an experimental investigation into the transcritical heat exchanger for combined power and cooling. Thermodynamic performance improvements can be realized by choosing the correct working fluid to the earth tube heat exchanger based on the operating conditions (driving heat source temperature, heat sink temperature). In addition, the choice of working fluid has a significant impact on the size, speed, geometry, and pressure ratio of the turbine and compressor. The relevant research regarding advanced cycles will be presented next as a means to further improve thermodynamic performance.

Capozzaa et al. (2014) [8] studied theoretically and experimentally investigated the performance of a combined organic Rankine cycle and vapor compression cycle that utilized a scroll expander and compressor and microchannel heat exchanger technology. The earth tube heat exchanger was driven by waste heat from stationary and on road heat engines. The vapor compression refrigeration cycle had a nominal cooling capacity of 5 kW. A hot oil loop at 200°C was used to simulate the waste heat source on the internally recuperated power cycle. There was a direct mechanical coupling between the expander and compressor using a torque sensor, which eliminated the mechanical to electrical energy conversion losses. The power cycle used R245fa and the cooling cycle used R134a as working fluids. The experimental investigation rejected heat to 22°C ambient air in the condensers, while the cooling cycle provided refrigeration to ambient air at 22°C. They used plate heat exchangers for the boiler and recuperator, while using microchannel heat exchangers for the condensers and chiller. A maximum cooling capacity of 4.25 kW was achieved at an overall system COP of 0.47. The expander power output at this point was 0.92 kW and the isentropic efficiency of the expander was nominally 80%. This study experimentally showed that the earth tube heat exchanger can operate efficiently with blowing machinery, which offer a smaller alternative with lower mass than traditional turbomachinery. High efficiency targets can be met more easily with scroll machinery in comparison to traditional rotating machinery.

Chaturvedi and Bartaria (2014) [10] proposed to take the previous analysis one step further, simulated various different configurations for the earth tube heat exchanger to maximize the COP of the system. Three different system configurations were examined: a baseline cycle with a recuperator on the power cycle, a cycle that adds a sub-cooler between the condenser and expansion valve on the cooling cycle, and a cycle that includes a suction line heat exchanger on the cooling cycle to transfer heat from the sub-cooler temperature was 18°C and the condenser saturation temperature was 67°C. The temperature lift is high because the system was designed to reject heat from the condensers to ambient air at 48.9°C and cool indoor air at 32°C. In the simulations, R245fa was used in both the power and cooling cycles. The cycle with additional sub-cooler improves the COP of the baseline system from 0.54 to 0.63, which can reduce overall weight and size of every component because the sub-cooling heat exchanger is approximately 1/8th the size of the condenser.

Bisoniya et al. (2015) [18] explained the optimum value for the effectiveness of the power cycle recuperator was 0.85, where the performance is maximized, and the system weight is minimized. Concepts for two advanced earth tube heat exchanger systems were also proposed: a system with a second recuperator where heat is transferred from the compressor outlet to the stream exiting the power cycle pump and a system where two different fluids are used on the power and cooling cycles. The second recuperator allows a closer match between heat capacities entering the first recuperator on the power cycle which will decrease heat transfer irreversibility. Using different fluids on the power and cooling cycles can maximize the COP by tailoring operating conditions to the specific cycles. The high boiling point of R245fa increased the size of the compressor and chilling heat exchanger on the cooling cycle, highlighting an opportunity for potential improvements by using different fluids. This study shows that a number of components can be added to the earth tube heat exchanger to improve thermodynamic performance. The additional components can also decrease the size and weight of the system, improving viability in spaces where footprint is a concern (transportation sector, for example). Another work that sought to characterize the performance of a heat exchanger using positive displacement machines was carried out.

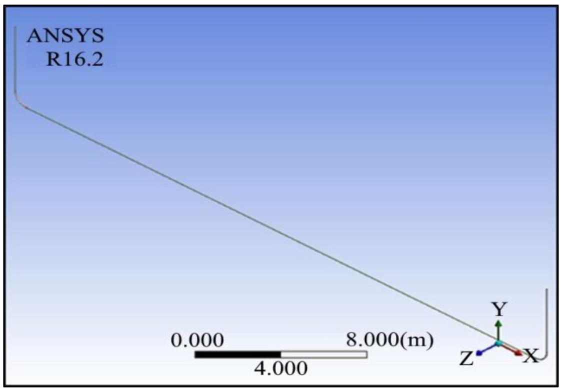

Fig. 3. *Figure after generating on ANSYS CFD workbench (design modular).*

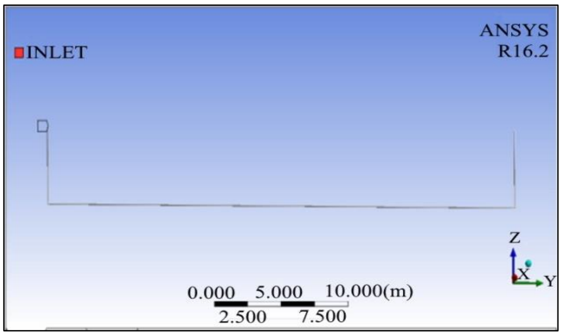

Fig. 4. *Inlet selection of pipe in the simulation.*

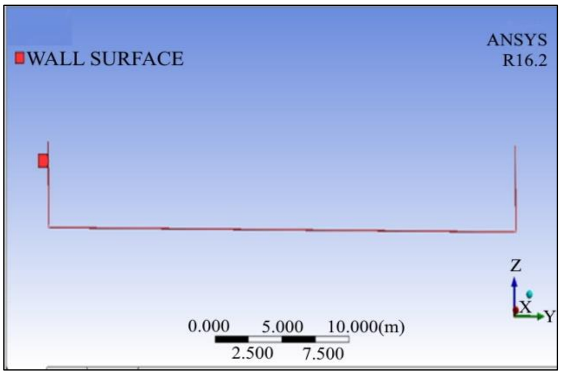

Fig. 5. *Figure shows wall surface selection of pipe in the simulation.*

Jakhar et al. (2015) [1] studied theoretically and investigated a recuperated organic Rankine cycle directly coupled to a vapor compression chiller for low grade waste heat recovery. In this work, the earth tube heat exchanger uses a free-piston expander-compressor unit to link the power and cooling cycles. The free-piston expander-compressor makes it more suitable for small scale refrigeration because of its high efficiency at small sizes. A schematic of this system is shown in Figures 3–5. The unit has two pistons connected via a shaft that transfer power from the heat exchanger to the vapor compression cycle. On the organic Rankine cycle, the high pressure and temperature working fluid leaving the boiler enters the left chamber of the device and pushes the piston to the right. The movement of the piston to the right compresses the working fluid in the right chamber which provides the necessary driving force for the refrigeration cycle. The earth tube heat exchanger and vapor compression cycle shared a condenser and used the same working fluid. The compressor piston had a fixed cross section of 20 cm^2 with a fixed stroke length of 15 cm. Then, a parametric study was completed to understand the performance of the system based on boiler, condenser, and evaporator saturation temperatures. As the chiller and boiler saturation temperatures are increased, the cross-sectional area of the expander decreases while increasing the condenser saturation temperature has the opposite effect. The cross-sectional area of the expander decreases when increasing boiler temperature because the density of the refrigerant increases with temperature and pressure. The cooling duty was independent of boiler temperature because the geometry of the compressor and the properties at the chiller outlet were fixed. Increasing boiler temperature, decreasing condenser temperature, and increasing chiller temperature improve the COP of the system. When the boiler saturation temperature was 80°C, the condenser saturation temperature was 35°C, and the chiller saturation temperature was 5°C, the system had a COP of 0.40 with a cooling duty of 0.75 kW. The system could even utilize waste heat at temperatures as low as 60°C but the COP decreased to 0.28. This work demonstrates that the free piston expander-compressor is a promising technology for small scale, heat driven refrigeration. Further experimental work is needed to confirm the simulation results.

Grossoa and Chiesaa (2015) [2] proposed an organic Rankine cycle and a vapor compression refrigeration cycle were integrated onto a turbocharged 176 kW diesel engine. The waste heat from the exhaust of the turbocharger vaporized the refrigerant on the heat exchanger. The mechanical power from the turbine is used to produce additional electricity in a generator. Some of the electricity generated from the heat exchanger is used to drive the compressor on a vapor compression refrigeration cycle which provides cabin air conditioning. Cost models were applied to the major components in the system including the turbine, heat exchangers, pump, working fluid, piping, and liquid holding tank. The generators or the vapor compression system were not included in cost modeling. The heat exchangers in this study were plate type for the evaporators and condensers. Four different working fluids were examined: n-pentane, R245fa, R134a, and cyclopentane. The ambient temperature was 30°C and the outlet temperature of the turbocharger exhaust was set to 577°C. The cooling duty of the vapor compression cycle was 30 kW. The heat transfer area of the boiler was fixed at 10 m2 and the overall heat transfer coefficient of the boiler was set to 0.13 kW m^{-2} K^{-1}. At these conditions, R134a had the best thermodynamic and economic performance, achieving a thermal efficiency of 9.7% and a power output of 16.5 kW with R134a. The system had an initial investment cost of $7,200 and a payback period of about 4818 operating hours. The system reduced fuel consumption because the automobile no longer diverted power from diesel engine to drive the vapor compression chiller. The R245fa system had the worst performance and yielded a payback period of 5427 hours and a thermal efficiency of 8.4%. The proposed heat exchanger system improved the thermal efficiency of the engine by about 10% in all working fluid cases. As is the case for all thermally activated cooling systems, the performance of the system improves when the boiler temperature increases, the condenser temperature decreases, and the evaporator temperature increases. This study performed a robust TEA for a heat exchanger specifically designed for waste heat recovery which coupled thermodynamic, heat exchanger, and cost models.

Fuxin Niu et al. (2015) [25] performed a thermal analysis and working fluid study on a heat exchanger. The working fluid study examined low Global Warming Potential (GWP) refrigerants on the power and cooling cycles. On the heat exchanger, the performance with R1233zd(E) and R1336mzz(Z) was analyzed, which have a GWP of 1 and 2, respectively, and similar properties to R245fa. On the vapor compression system, the thermodynamic performance with R1234yf and R1234ze(E) was examined, which have zero GWP and similar properties to R134a.

Salsuwanda et al. (2015) [40] stated a feasibility study was performed on the economics of implementing the advanced configuration for the earth tube heat exchanger. The feasibility study used R1336mzz(Z) and R1234ze(E) on the power and cooling cycles, respectively, and assumed a condenser saturation temperature of 27°C, boiler saturation temperature of 127°C, and an evaporator saturation temperature of 2°C. The system provided cooling for 4000 hours of the year and produced electricity for the other 4000 hours of the year. It was assumed that the heat source in the feasibility study was freely available at no cost, i.e. waste heat. The system had an overall COP of about 0.84 and could provide 100 kW of cooling or 16.23 kW of electricity. Assuming an energy cost of $0.15 per kWh, the heat exchanger system could save $17,603 per year and have a payback period of 3.2 years. The cost of the system was estimated to be $55,644.

Manjul and Bartaria (2016) [31] examined the viability of marine diesel waste heat to power was completed. This study performed a thermal optimization of an organic Rankine cycle designed to recover waste heat from a marine diesel engine in the cooling jacket and the exhaust gas. The Net Power Output Index (NPI) was used as a metric to gauge the thermal performance of their system. The NPI is the ratio of net power output to the total system cost, where a higher NPI denotes more power output per dollar spent on implementation. The engine considered in this study was a 6-cylinder Wartsila marine diesel engine with power rated at 34.3 MW. The exhaust gas mass flow rate of this engine is 267,323 kg hr^{-1} and the cooling jacket water volume flow rate was 273 m^3 hr^{-1}. The cooling jacket water heats the working fluid from a sub-cooled liquid to a saturated vapor and then the vapor is superheated by the higher temperature exhaust gas in a second heat exchanger. The evaporator, super-heater, and condenser were designed as shell and tube heat exchangers that were subdivided into 20 regions to accurately simulate heat exchanger performance. Empirical heat transfer correlations were used to determine the overall heat transfer coefficient and the total area of each heat exchanger. Cost models were applied to each heat exchanger, the pump, and the turbine to get the total system cost. The exhaust gas inlet temperature was 170°C and the cooling jacket water inlet temperature was 90°C while the cooling water inlet temperature was 25°C.

Belatrache et al. (2016) [38] studied a simulation model of an earth air heat exchanger (EAHE). He studied HVAC device of building where South Algeria’s Temperature was taken. Tubes of an earth tubes buried in the ground gives an energy savings. A specific program on Matlab was developed. Length, radius and the velocity of the air in the pipe were analyzed. The results were based on performance and energy savings. 1.755 kWh was the maximum daily cooling capacity and 246.815 kWh energy can generate in one-year period.

Yang et al. (2016) [51] proposed the turbine inlet pressure and temperature were varied to characterize the thermodynamic and economic performance of the heat exchanger with five different working fluids: R152a, R245fa, R600a, R1234yf, and R1234ze. The system with R1234yf had the highest net power output and highest total cost at all turbine inlet pressures. As the turbine inlet pressure increased, the net power output, thermal efficiency, and total cost increased while the NPI increased and then decreased after it reached a maximum value. Each working fluid had nearly the same thermal efficiency throughout the range of turbine inlet pressures. The heat exchanger with R1234yf had a highest overall NPI of 0.266 W $-1, which was achieved at a turbine inlet pressure of 2 MPa. R245fa had the lowest NPI of 0.245 W $-1. The heat exchanger system in this work was compared to a traditional heat exchanger that recovered waste heat only from the engine exhaust gas and found that the proposed system improves total thermal efficiency by an additional 6% compared to the traditional heat exchanger. The fuel savings were not quantified to calculate a payback period of the system. The result from this work is interesting because the highest thermal efficiency system yielded the best thermal performance according to their NPI metric. The NPI metric may not be an accurate indicator of practical economic performance because there should be a point where further increases in thermodynamic efficiency are too costly to yield a reasonable NPI.

DESIGN AND METHODOLOGY

Problem Evaluation and Discussions

There are a number of research needs on the heat ventilating air conditioning. Thermodynamic models coupled with high fidelity heat exchangers models are sparse in the literature. In addition, the analysis of the earth tube heat exchanger required for these systems is not prevalent in the literature. Further, there are very few studies that incorporate detailed economic models to understand the interaction between thermal performances of the earth air heat exchanger. A highly flexible modeling platform was developed to analyze the effects of various waste heat scenarios and working fluids on the thermodynamic, heat transfer, and economic characteristics of the earth air heat exchanger cooling/heating system. In this work, air as a working medium using copper as a tube is used for single waste heat scenario was analyzed with velocity of air 2 m/s. Air as a working fluid to understand which working fluid had the most favorable thermodynamic performance. In addition, a cooling/heating optimization was performed for working fluid to determine the cooling/heating system. This chapter a brief overview of the modeling approach will be provided before going into the specific details of the models developed in this work.

Thermal Simulation of Earth Air Heat Exchanger

The thermal Earth air heat exchanger system is a heat recovery system designed to provide useful cooling/heating from renewable source of energy. The thermal Earth air heat exchanger system contains a duct/pipe, a blower, a working fluid pump, and a working fluid. Here, the working fluid is blown through blower whose inlet is from atmosphere and passes through a duct, the duct id buried inside the ground at 5 m. After passing through the pipe the temperature of the air varies either cooling or heating. In this work, air as a working medium uses copper as a tube is used for analysis with velocity of air 2 m/s.

Thermodynamic Modeling

A set of fundamental thermodynamic equations was solved to understand the performance of the earth tube heat exchanger and the thermodynamic cycle. The thermodynamic model was assumed to operate at steady state. Further, it was assumed the copper pipe in the model, so there was heat transfer takes place inside the pipe when working fluid runs inside the pipe. It was also assumed the inlet and outlet velocity of the working fluid are the same. Air is used as a working fluid. The thermal parameters are examined in this study. The temperature is taken by Belatrache et al. (2016) [40] which is temperature of South Algeria. 2 m/s and 3 m/s velocity of air is considered for the results. Table 1 shows parameters of model of earth tube heat exchanger used in present simulation.

Table 1. *Parameters of model of earth tube heat exchanger used in present simulation (Belatrache et al. 2016) [40].*

Parameters	**Reference Value**
Pipe length (L)	45 m
Inside diameter (Di)	80 mm
Pipe thickness (e)	4 mm
Air velocity (V)	2 m/s
Pipe depth	5 m

The pipes are placed in a horizontal position with a minor inclination to remove the condensed vapors of water. To simulate the earth air heat exchanger, it is necessary to know the optimal installation depth of the underground pipes in the region under study, i.e., Adrar, South of Algeria. Belatrache et al. 2016 [40]. The outlet temperature was calculated with the help of using the following governing equation.

The heat transferred along the buried pipe can be expressed as follows:

$$\Phi = \dot{m} \text{ x } Cp_f \text{ x } dT(x) = \frac{dx}{Rconv+Rpipe+Rsoil} \text{ x } (T(z,t)–T(X)) \quad (5)$$

The thermal resistance of the pipe can be expressed as:

$$Rpipe = \frac{1}{\lambda pipe x 2 x\pi} \text{ x } ln(re/ri) \quad (6)$$

The convective thermal resistance between the internal surface of the pipe and air in the pipe is:

$$Rconv = \frac{1}{rixhconvx2x\pi} \quad (7)$$

The thermal resistance of the soil can be expressed as:

$$Rsoil = \frac{1}{\lambda x 2 x\pi} \text{ x } ln(R_{(z,t)}/r_e) \quad (8)$$

The total thermal conductance of the EAHE is then given by:

$$G_{tot} = \frac{1}{(Rconv + Rpipe + Rsoil)} \quad (9)$$

Combining equations (5)–(9), the energy balance can express as follows:

$$\frac{dT(x)}{T(z,t)-T(x)} = \frac{Gtot}{\dot{m}xCpf} \text{x } dx \quad (10)$$

The integral of Equation (10) is then:

$$-ln(T(z,t)–T(X)) = \frac{Gtot}{\dot{m}xCpf} \text{x } dx + Cte \quad (11)$$

The boundary equation at the surface of the ground is [9]:

$$T_{(0)} = T_{(amb)} \quad (12)$$

Replacing the *Cte* in Equation (11) by its expression deduced from the boundary condition of Equation (12), we obtain:

$$ln((T(X)-T(z,t))/(T_{amb}-T(z,t))) = \frac{Gtot}{\dot{m}xCpf} \text{x } X \quad (13)$$

The air mass flow rate is given by the following expression:

$$\dot{m} = \rho_a V_a \pi Di^2/4 \quad (14)$$

The daily average cooling potential is given by the following equation:

$$Qcool = \sum_{i=1}^{24} \dot{m}Cp(T_{amb(i)}-T_{out(i)}) \quad (15)$$

Description of System

Advanced technology provides a number of options to the researchers to carry out study of complicated heat transfer, mass transfer and many other problems on software instead of creating the exact real model. Such ANSYS software tools have become popular to carry out complex flow analysis thoroughly. CFD employs discretizing whole system in smaller grids and applying governing equations like mass, momentum and energy on every grid, it provides solution of differential equations for every grid in flow domain. Present system is designed in Unigraphics NX and meshed in meshing tool of ANSYS Workbench, complex heat transfer and air flow process is examined in Fluent. This study is conducted assuming homogenous soil conditions, incompressible flow and properties of pipe and ground material are independent of temperature. Figure 3 shows the figure after generating on ANSYS CFD workbench (design modular).

The following sections will introduce and examine in detail the important pieces of the thermodynamic analysis, beginning with a discussion on the specifics of the full system model. After that, the importance of working fluid selection will be discussed, followed by the details of the thermodynamic calculations for each point in the cycles. Following the thermodynamic calculations, the thermal analysis on the model will be presented.

ANSYS (Computational Fluid Dynamics-Fluent)

- ANSYS Software is also known as Analysis System.
- ANSYS is the global leader in engineering simulation.
- It is a mathematical software Package which gives a practical result for a numerical problem.
- An interactive programme for numerical computation and data visualization which supports practical Design and Drawings.
- The mathematical calculation can be solved through ANSYS
- A natural choice for numerical analysis computations.

Boundary Conditions

Inlet

At pipe inlet speed of air is given 1 m/s simultaneously, The inlet temperature for a day in a year according Belatrache et al. (2016) [40] the climate of Algeria (Figure 4).

Wall Surface

Temperature of the wall is taken similar to earth’s undisturbed temperature (Figure 5).

Outlet Faces

Inlet is taken at the inlet and software boundary conditions are filled, further minimum, maximum value is obtained through the software (Figure 6).

Soil-Pipe Interface

Coupled condition for heat transfer with different velocity is taken.

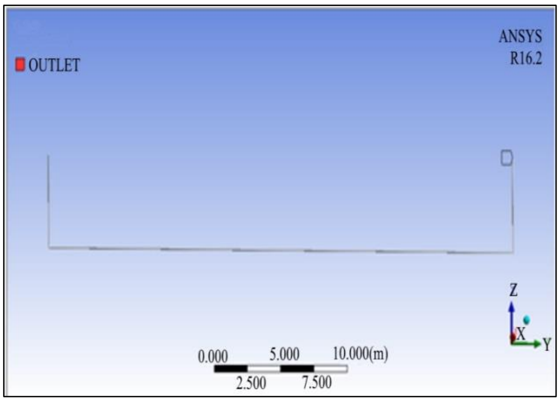

Fig. 6. *Figure shows outlet selection of pipe in the simulation.*

Measurement can be performed under quasi-steady conditions, and manual control were used to override the automatic control. It will be considered as a closed system. The constant basic soil temperature in summer season and winter season is 25.4–37°C throughout the year. CFD Fluent analysis using ANSYS Software on ETHE system a day in every month from June 2016 to May 2017 with velocity of 1 m/s. validated from Djamel Belatrache et al. “Numerical analysis of earth air heat exchangers at operating conditions in arid climates” 2016 [40]. Solution is completed in Fluent’s pressure-based velocity solver, applying realizable k-ϵ model. Second order upwind scheme is used for spatial discretization of governing equations.

Research and Validation Technique

Based on MATLAB Software is and climate conditions of the South of Algeria. Research entitled “Numerical analysis of earth air heat exchangers at operating conditions in arid climates” by the author Djamel Belatrache et al. [2016] [40] by Elsevier Ltd. The same analysis would be carried out at using simulation in ANSYS software to validate research Methodology being adopted. For designing of simulation, model will need software for result output. As further study, result output is found on ANSYS Software, and of its workbench Computational Fluid Dynamics (CFD Fluent).

For validation, needs:

- To investigate the Temperature difference and performance characteristics of an EATHE.
- We will use the Mathematical design and its dimensions of previous study.
- Temperature of South of Algeria will be taken.
- To plot the result for different Temperature variation.
- For Validation, will further compare the results with previous research and our established research standards for validation**.**

With the references it makes an experimental work on Performance of Earth Air Heat Exchanger Cooling of Air, by using Copper of 0.08 m diameter and was buried at a depth of 5 m. They used air velocity of 2 m/s to drive the air through the pipe which was circulated throughout the pipe. Then the simulation is started, considering the blower was switched on and the air passes through the pipe and after some time it achieved the steady state. The velocity at the inlet and outlet can be calculated. The above procedure was repeated with different ambient conditions, it conducted Belatrache et al. [40]. The total cooling and heating have been calculated for flow velocity of 1 m/s by the governing Equation 5–15.

The main objective of the CFD study will be to investigate the transient behavior of simple EAHE system used in continuous heating mode and compare its thermal performance with EAHE operating under steady state condition (assuming that the temperature of soil surrounding the pipe remains constant) in terms of derating factor.

Physical and thermal parameters of different engineering materials used in the simulation are listed below.

Physical and thermal parameters used in the simulation.

1. Material density
2. Specific heat capacity
3. Thermal conductivity
4. Temperature inlet
5. Soil
6. Pipe length
7. Pipe diameter

RESULTS AND DISCUSSIONS

Due to the intermittent nature of energy in general and earth tube heat exchanger system in particular, this study investigated the optimal power solutions by software simulation output stability and enhancement purposes. The study proposes an innovative concept of a copper pipe in earth tube heat exchanger. The proposed model is a real-world environment renewable energy system for thermal power delivery. In order to acquaint ourselves with the theory and the physics behind earth tube heat exchanger thermal technology, the study was carried out on ANSYS Fluent. The idea was to accustom ourselves with the technology before the in-depth real-environment material benefits over and to earth tube heat exchanger system’s implementation. In addition to that, the second and most challenging complete renewable energy system was then design built-up, and simulation, whereby the only input to the system, in the form of heat is Temperature and input parameters.

The CFD Fluent Analysis performed on the ANSYS Software for the forwarded performance investigation of “Numerical analysis of earth air heat exchangers at operating conditions in arid climates” by Belatrache et al. (2016) [40] by Elsevier

Ltd. Inputs are being carried out from of the previous study and software constants, Model is developed and used to carry out for further calculations.

Table 2 shows a tabular result of the research. The data provided is on the basis of Temperature. All the points of temperature are given which is available on the software. The result displayed is on the basis of 2 m/s. The result displays, use of copper pipe is enhancement in the system. The soil temperature is 26.7 degree Centigrade. All the analysis is based on steady conditions. The result is enhanced due to the use of copper material. Earth tube heat exchanger is a very good source of heat utilization, as heat is transformed in electrical energy, further can be used in other mediums. Figures 7–21 show the contour graphical results on various parameters.

Results According to Monthly Temperature

The result of simulation came in close agreement with previous research; thus, this model is considered appropriate for performing in depth analysis. Research: "Numerical analysis of earth air heat exchangers at operating conditions in arid climates" by Author Djamel Belatrache et al. [40] which was based on MATLAB Software is and climate conditions of the South of Algeria. The same analysis is being carried out at using simulation in ANSYS software to validate research Methodology being adopted. For Designing of simulation model will need software for result output. The study of the temperature and its difference also the performance of the model design. The model design and its dimensions are adopted of previous study. Further, the result is simulated for different temperature variation during the summer and the winter. CFD Simulation Results of input and output is shown in Table 3.

Table 2. *Fluent results based on temperature.*

Parameters	Unit	Min. Value	Max. Value
Static Temperature	K	299.7	299.8801
Total temperature	K	299.6985	299.961
Enthalpy	J/kg	1558.457	1822.696
Relative Total Temperature	K	299.6985	299.961
Wall Temperature	K	299.7	299.7003
Total Enthalpy	J/Kg	1559.419	1824.525
Entropy	J/Kg-K	39.51354	40.39483
Static Pressure	Pa	0.0981613	1730.127
Pressure Coefficient	-	0.4185833	2824.695
Dynamic Pressure	Pa	0.256677	4.532304
Absolute Pressure	Pa	101325.1	103055.1
Total Pressure	Pa	1.060409	1732.14
Density	Kg/m^3	1.225	1.225

Table 3. *CFD simulation results of input and output.*

Months	Inlet Temperature		Outlet Temperature Range	
			Minimum	***Maximum***
	°C	K	K	K
January	20.5	293.5	294.4992	296
February	23.2	296.2	296	296.1201
March	27.7	300.7	296	298.8215
April	33.2	306.2	295.9999	302.1232
May	37.2	310.2	295.9999	304.5245
June	43.2	316.2	295.9999	308.1264
July	46.0	319.0	295.9999	309.8073
August	44.3	317.3	295.9999	308.8073
September	40.5	313.5	295.9999	306.5056
October	33.2	306.2	295.9999	302.1232
November	25.5	298.5	296	297.5008
December	15.5	288.5	291.4976	296

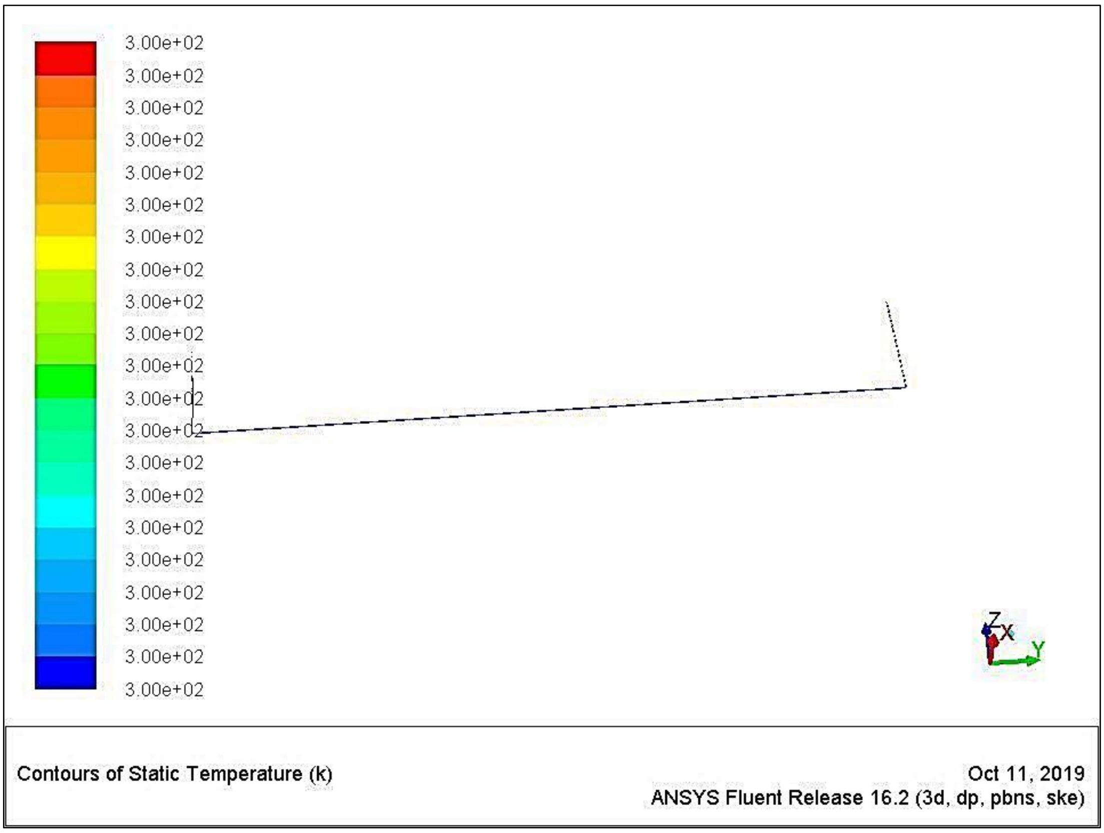

Fig. 7. *Result contour solution of static temperature.*

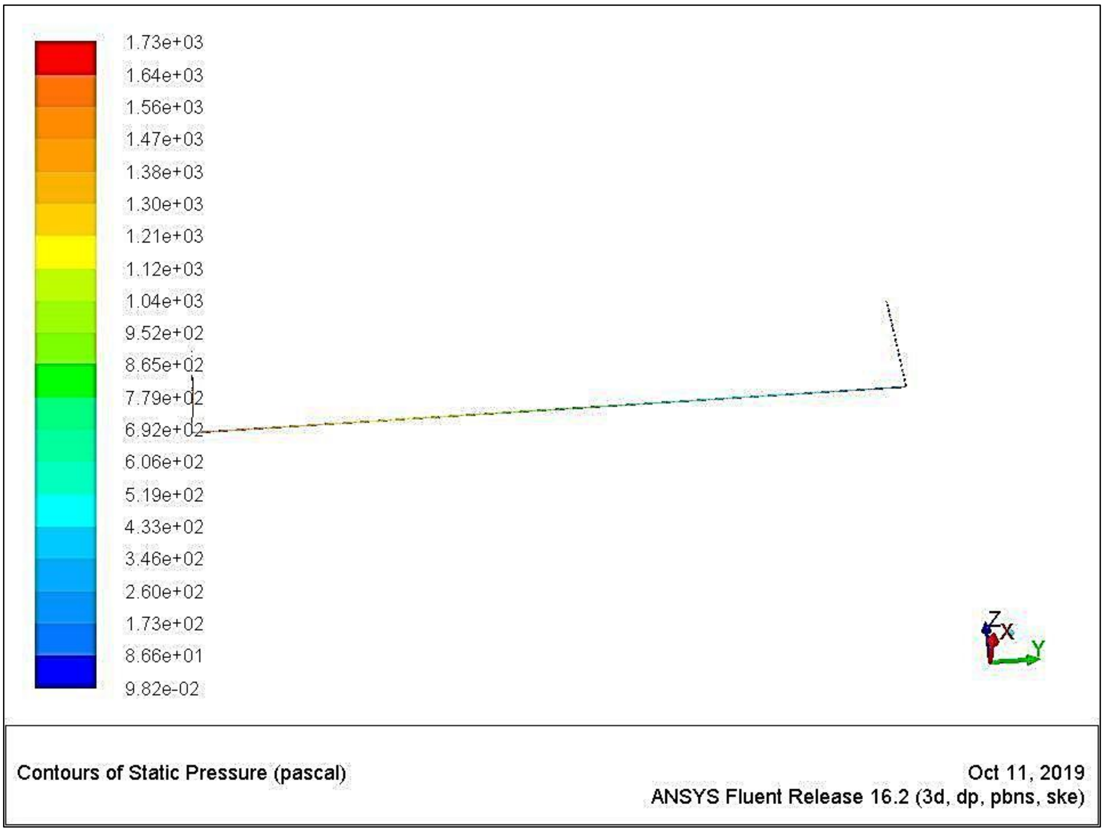

Fig. 8. *Result contour solution of static pressure.*

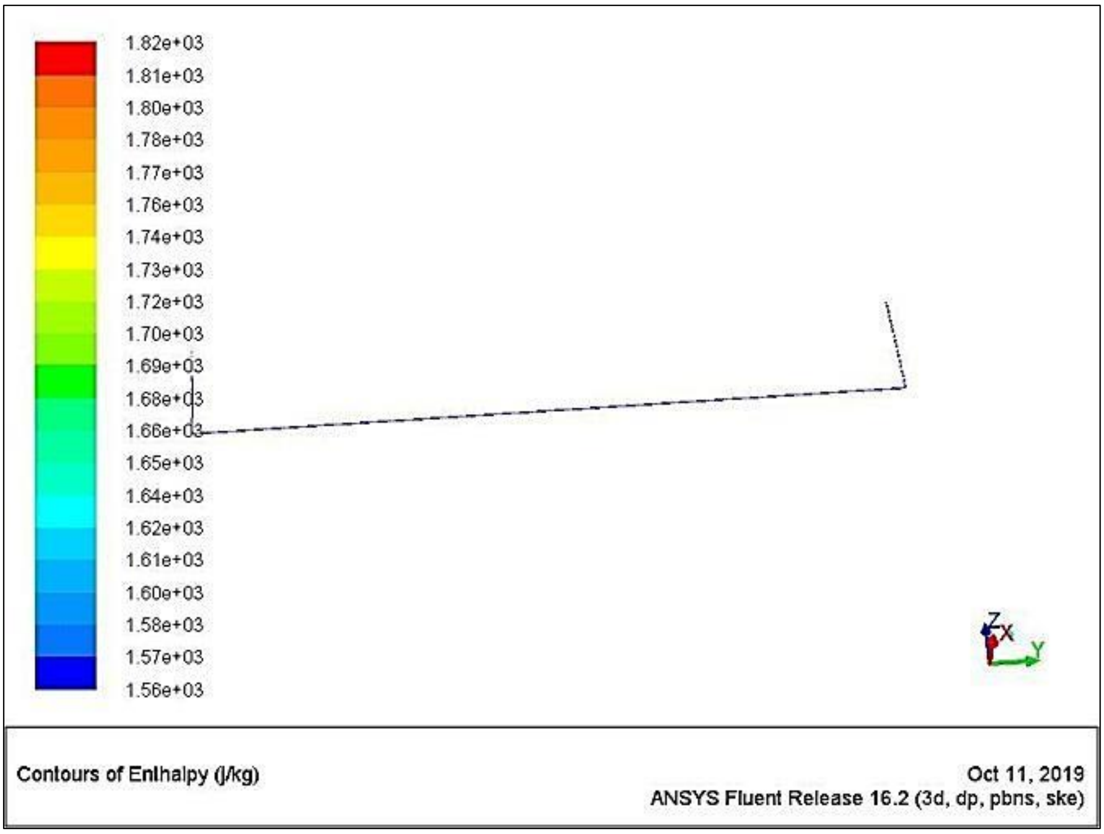

Fig. 9. *Result contour solution of enthalpy.*

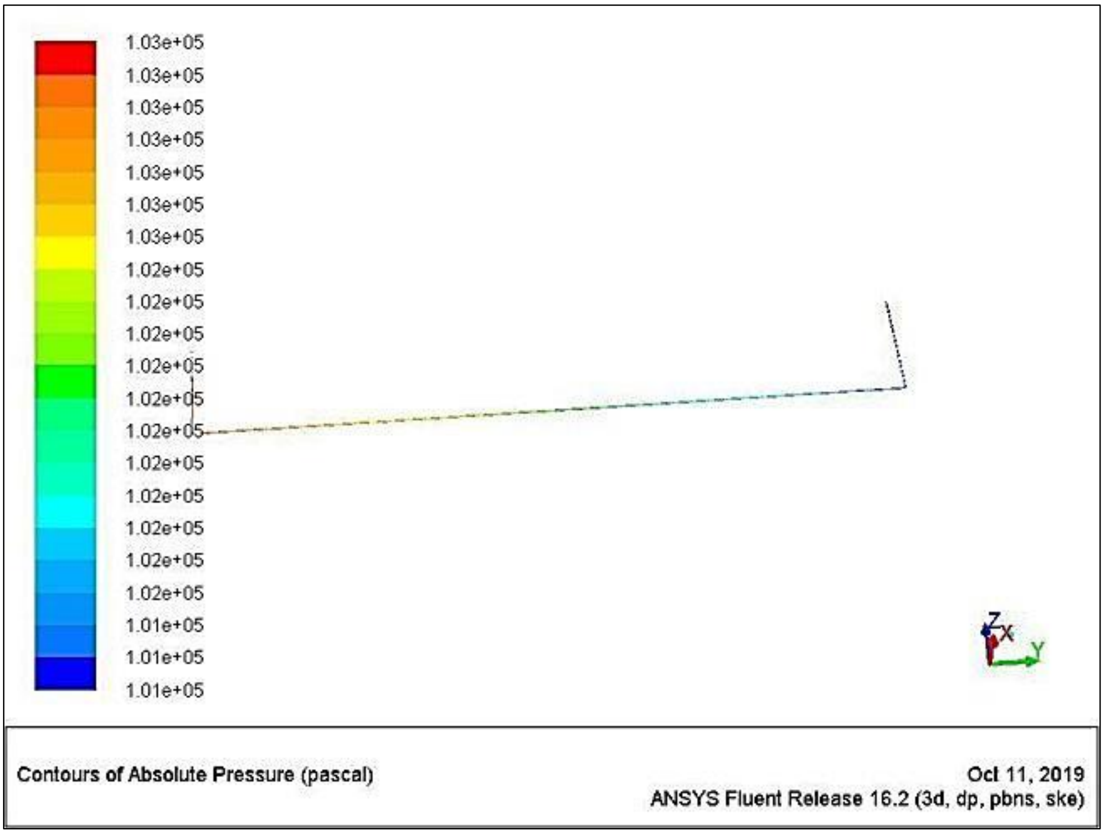

Fig.10. *Result contour solution of absolute pressure.*

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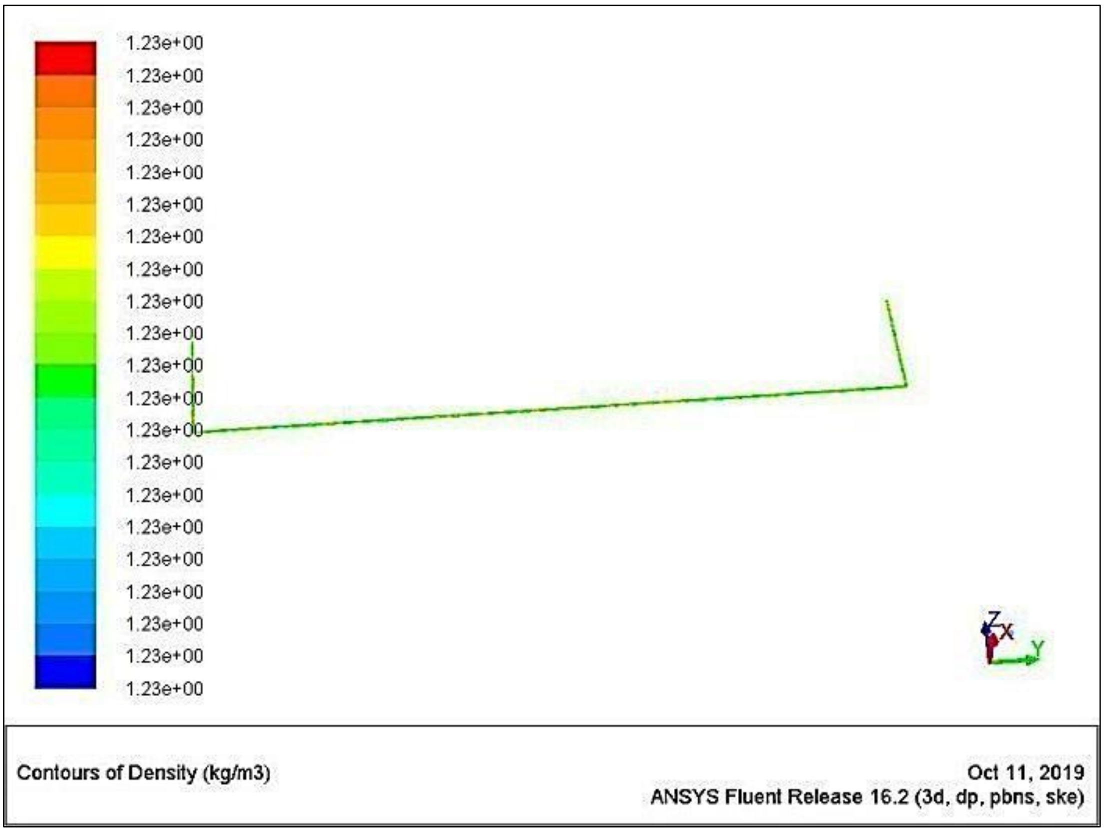

Fig. 11. *Result contour solution of density streamline.*

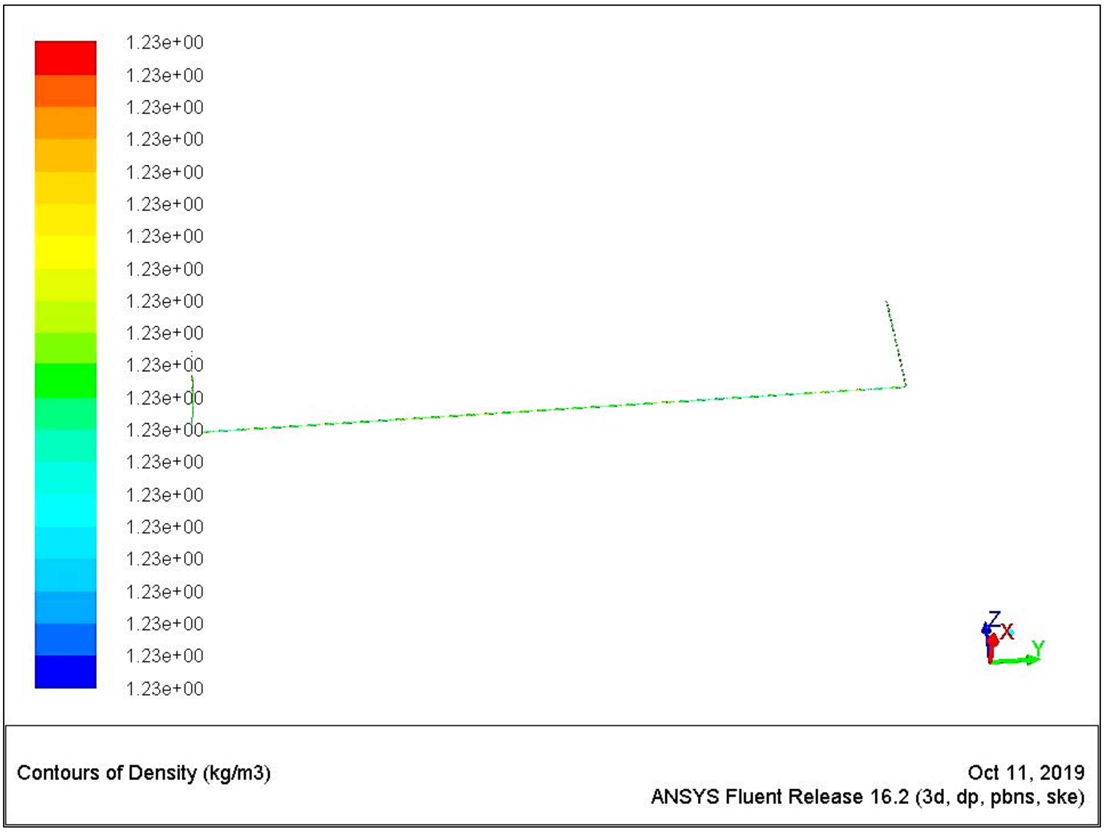

Fig. 12. *Result contour solution of density.*

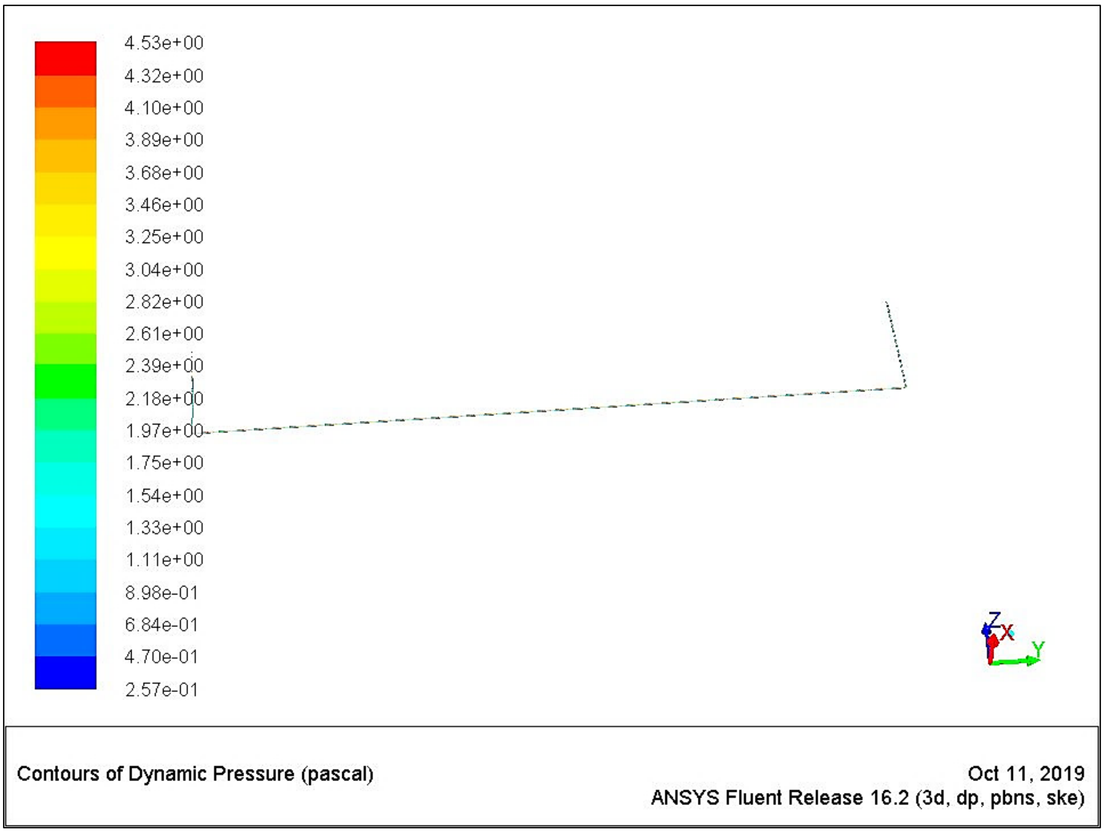

Fig. 13. *Result contour solution of dynamic pressure.*

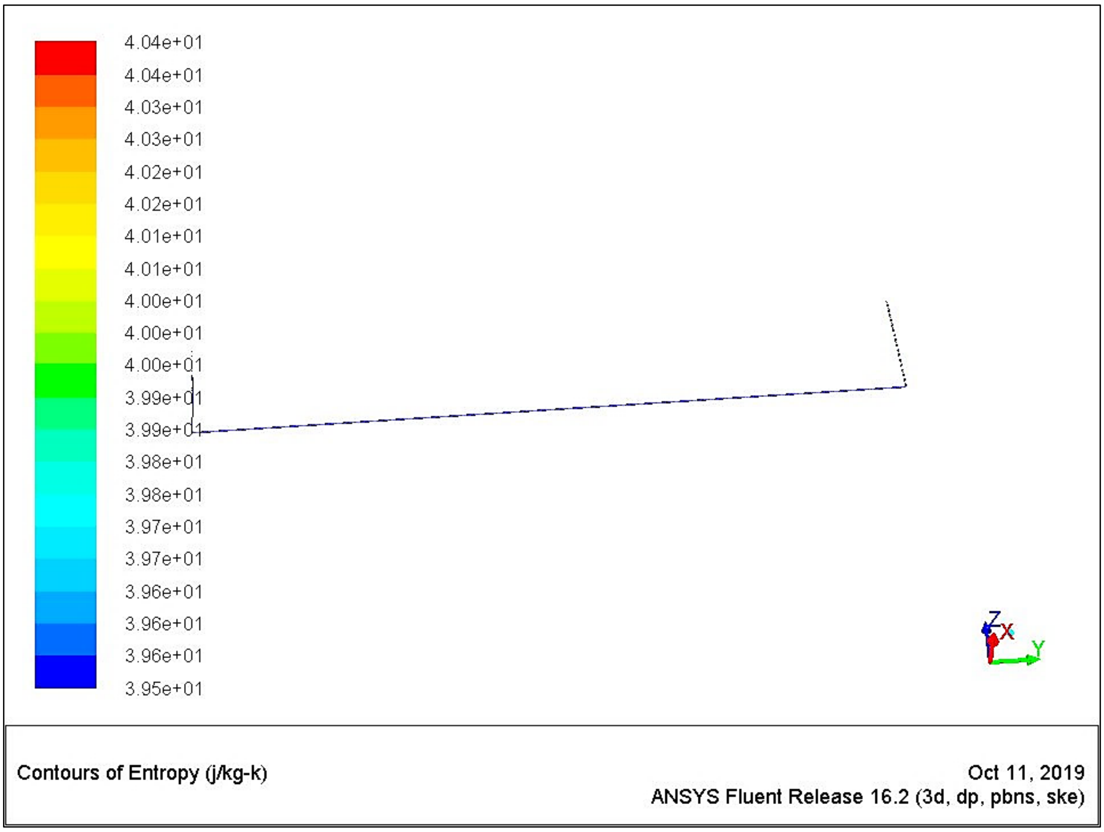

Fig. 14. *Result contour solution of entropy.*

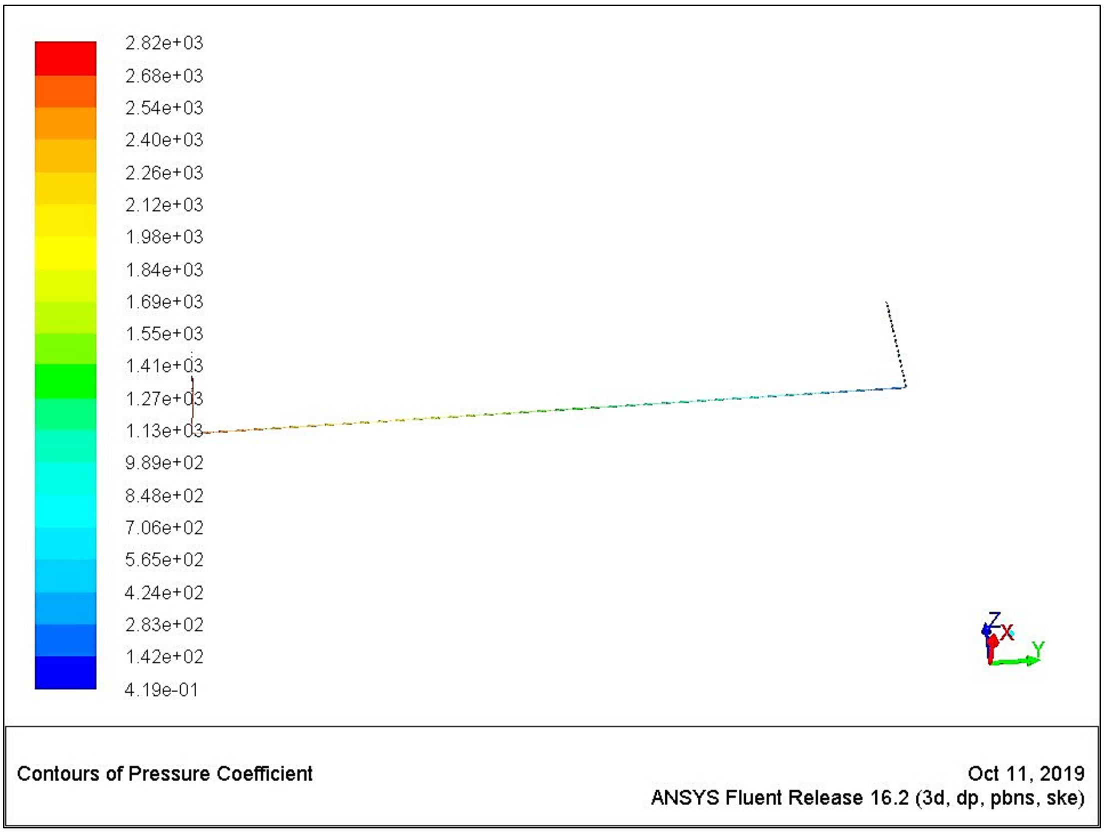

Fig. 15. *Result contour solution of pressure coefficient.*

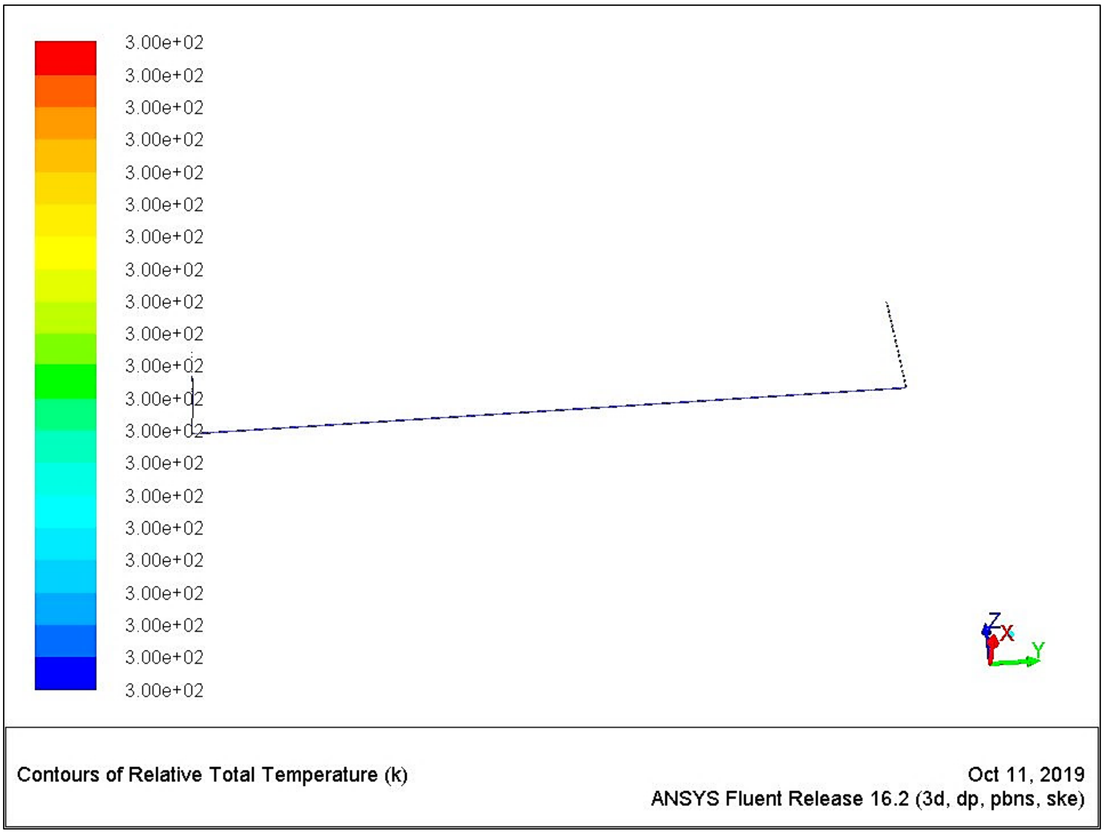

Fig. 16. *Result contour solution of relative total temperature.*

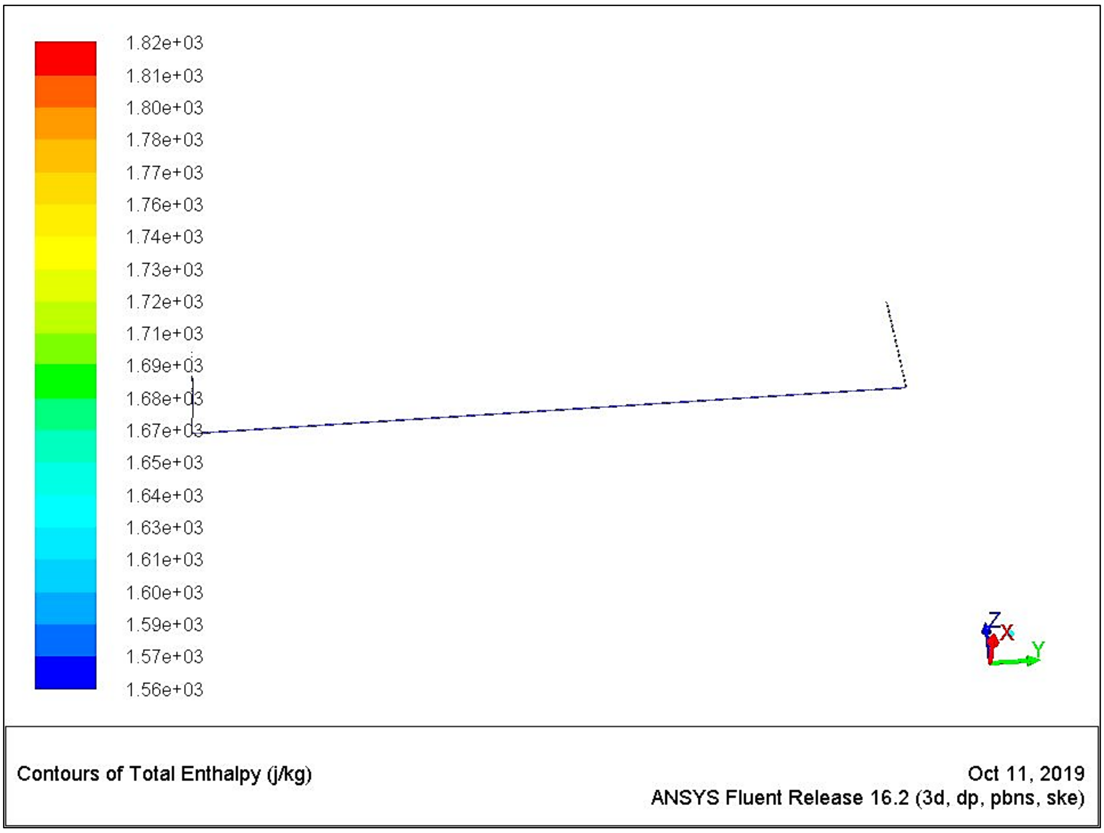

Fig. 17. *Result contour solution of total enthalpy.*

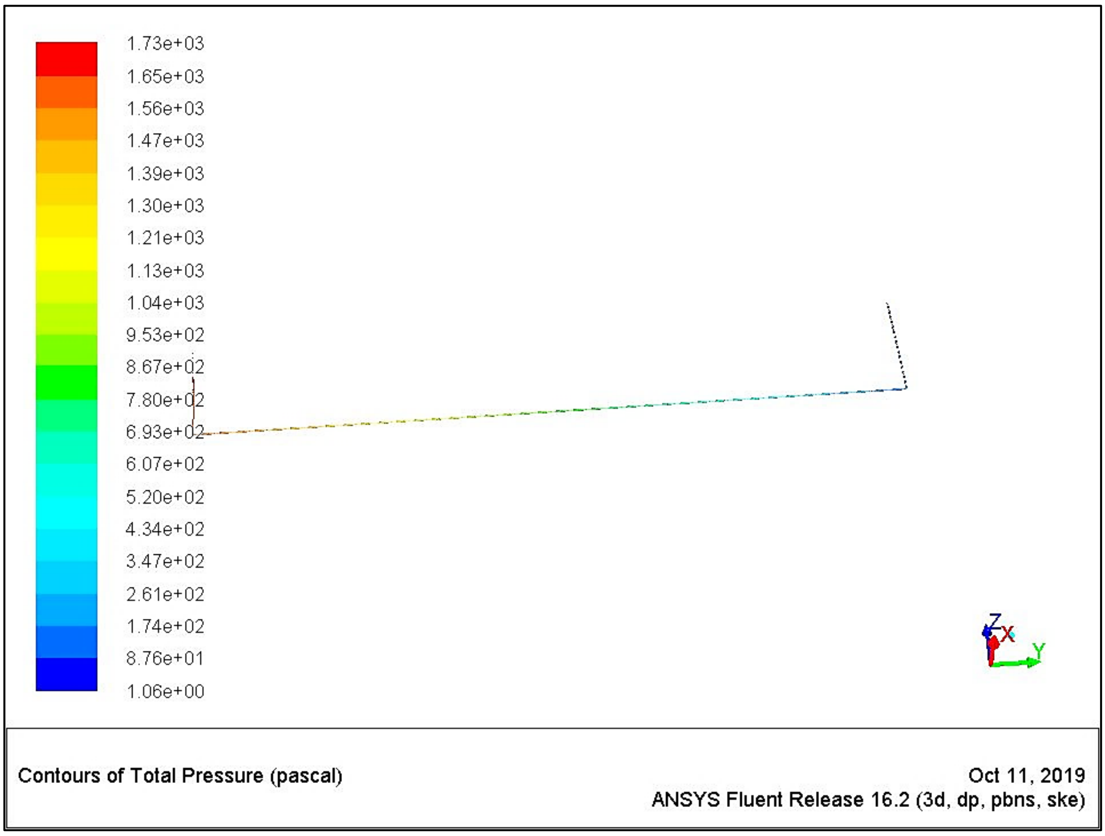

Fig. 18. *Result contour solution of total pressure.*

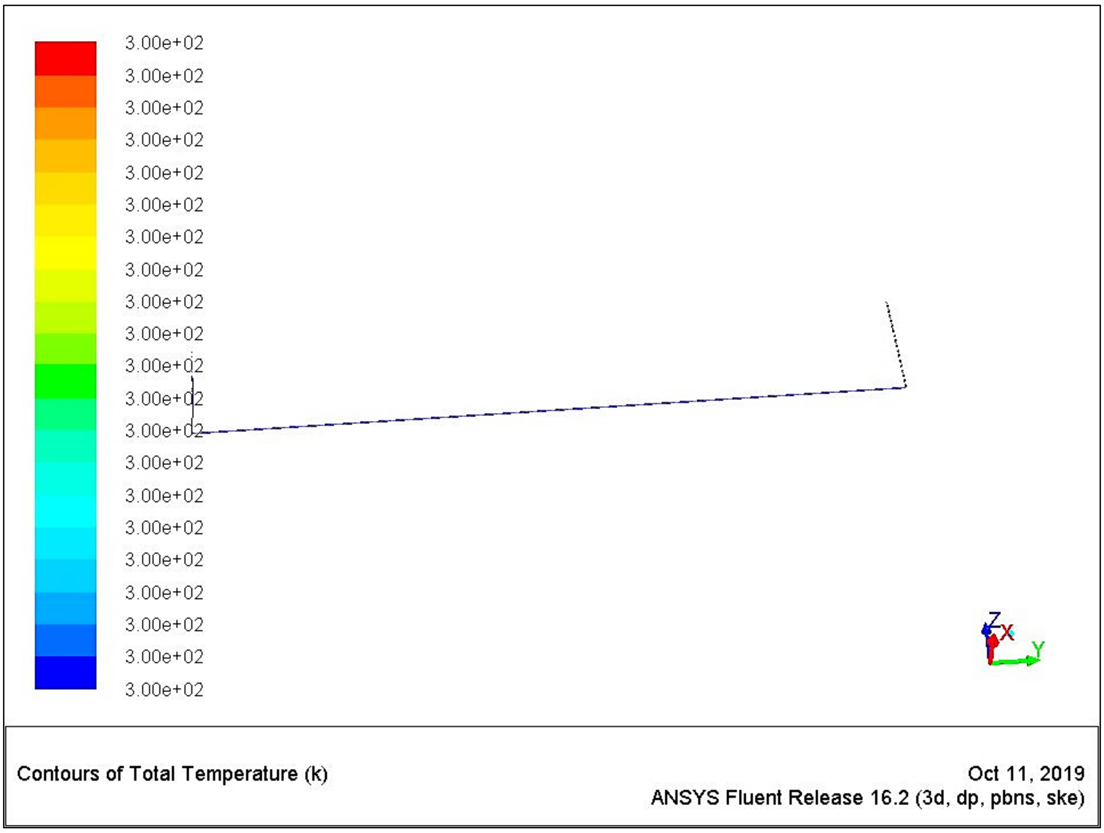

Fig. 19. *Result contour solution of total temperature.*

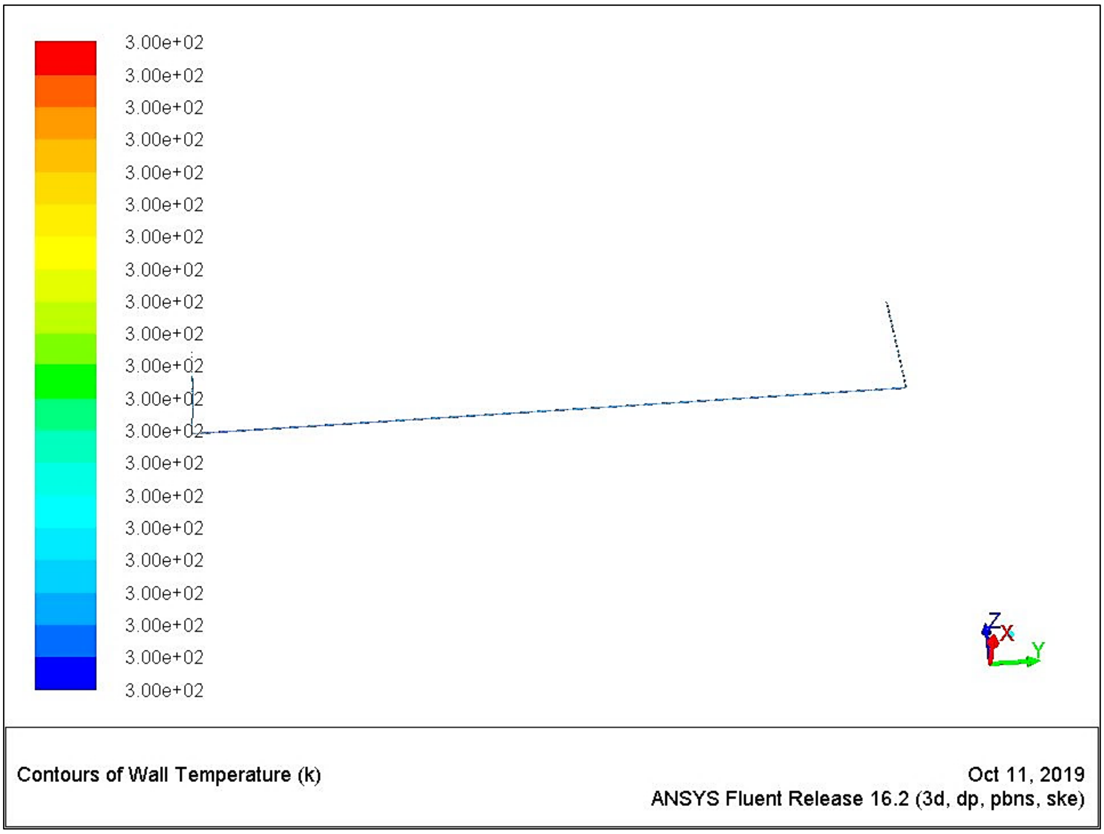

Fig. 20. *Result contour solution of wall temperature.*

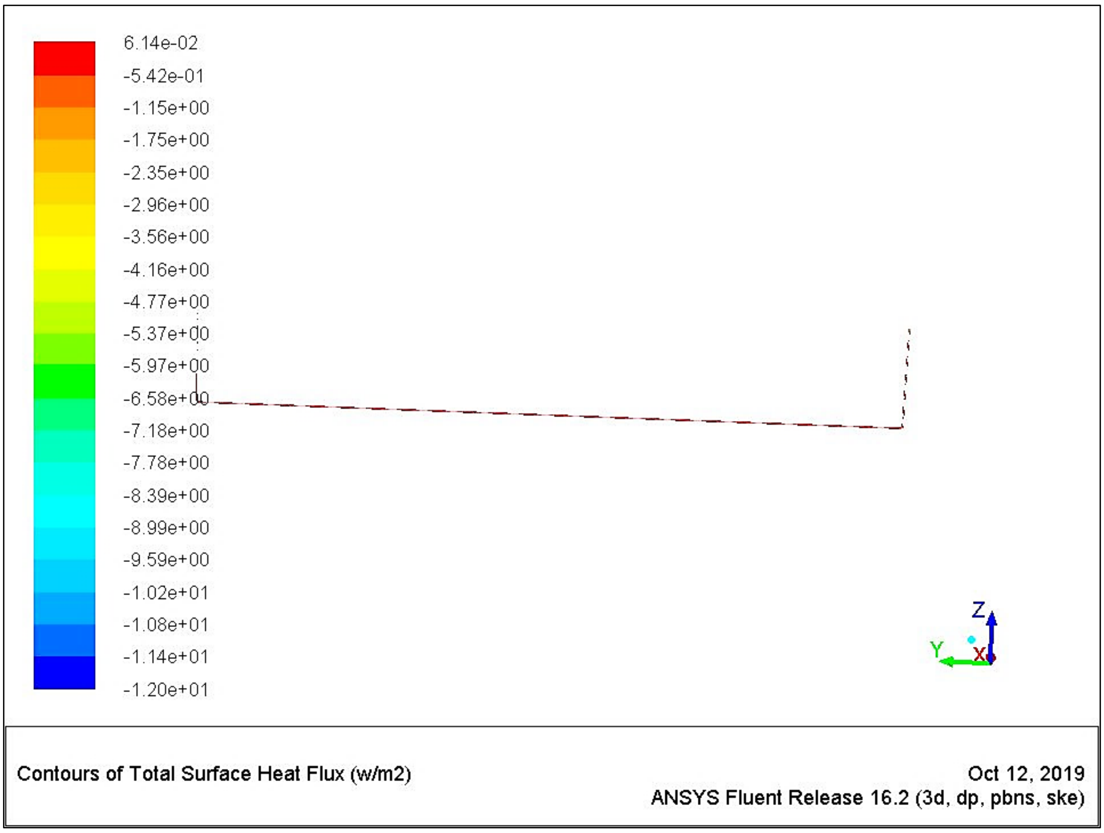

Fig. 21. *Result contour solution of total surface heat flux.*

CONCLUSION

The various authors carried out the experiment related to the earth air tube heat exchanger. According to the above authors, some conclusions are left by the researchers for the following scope:

- The adopted numerical methodology provided realistic results for the model can correctly.
- The simulation is in good agreements
- The current study sought to understand the conditioning performance of a thermal activated cooling system designed to recover waste heat.
- All of components were accounted for in the thermal modeling: heat exchangers, power cycle pump and piping.
- The simple payback period of the system was calculated based on the initial capital expenditures and the fuel savings per year.
- In addition, a discounted cash flow rate of return analysis was performed to find the cost per kWh of conditioning provided by the air.
- Then, the system was optimized by varying the effectiveness values in the heat exchangers until the minimum payback period was found. This procedure was completed.

Future Direction of Research

After studying all research papers, it is found that there are many scopes available for further research with an earth air tube heat exchanger. Some future directions are given bellow:

- Different working fluids should be studied on each side of the cycle.
- In future it can be assumed the power and cooling cycles used the same working fluid for simplicity.
- In future work, different fluids should be used on each cycle to simultaneously maximize the thermal efficiency.

- The size and speed of the model must match on the power and conditioning cycles when using different fluids.
- Investigation of different waste heat scenarios and ambient conditions will be important to confirm the performance of this system.
- Different waste heat scenarios could include water which would quantify the importance of waste heat temperature, phase, and flow rate.
- In addition, examining different ambient conditions is critical to better understand how the conditioning temperature will affect the performance of the conditioning system. This is an essential step towards commercialization of the conditioning system. Predicting the off-design performance of a specific design point thermal conditioning system will provide simple valuable knowledge that will assist in bringing this technology to the updated market.
- Detailed performance maps of the models would have to be generated. In addition, the conditioning geometry would be a fixed input.

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