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Simulation of fluid flow in an earth-air heat exchanger with the open loop system

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Abstract. This research focuses on Earth-Air Heat Exchanger (EAHE) that reduces the energy consumption of the air conditioner and analyzes the performance of the EAHE device by calculating the fluid dynamics modelling and validated against experimental observation. The used simulating are transient, incompressible, turbulent and 3-dimensional CFD. The simulation condition was limited to fluid flow only with a variation of 3 m/s, 2 m/s and 27m length of an air exchanger. The results of the simulation are pressure display, temperature, and velocitydeploymenton the passage of EAHE, and the comparison with the experimental results. The decrease in air velocity (V_{air}) can cause the out temperature (T_{out}), the coefficient of performance (COP) and the value of the effectiveness (ε) for EAHE will decrease and inversely proportional to the NTU will increase. The average air temperature out of the 3D simulation result using Ansys 14.5 Software was 26.6°C for air velocity inlet 3 m/s and 26.5°C for 2 m/s, while the experimental result was 27.5°C for 3 m/sand 27.4°C of 2 m/s. The highest deviation between the simulation and the experimental result were 3.452% for 3 m/s, and the lowest was 3.048% for 2 m/s.

1. Introduction

The amount of energy needs in every aspect of human life is not a new thing. It is substantial to find out an alternative source to reduces the use of fossil energy and begin to use renewable to save the earth and the threat of harmful global warming and depletion of ozone layer. In fulfilling the needs in every aspect of human life will spend at least a considerable cost and will also adversely affect the environment if we are not good at development [1, 2]. Today, much of human life support equipment requires the enormous energy to run it, either to cool, heat, or others. Many ways to get comfortable heat conditions inside a building. An EAHE is one of the promising that effectively heat the air in winter or cool down the air in summer. At a depth of 1.5-2 m, the soil temperature is constant throughout the year. An EAHE comprises one or more pipes that are planted on the soil to supply air temperature setting in the building to cool down in the summer and warm in the winter. Environmental air is used for ventilation as well as to reduce or replace some of the energy needs to ensure the air temperatures comfortable in buildings or houses. EAHE has the advantage over its enormous potential regarding energy consumption and low maintenance costs [3,4]. Within the last twenty years, various researches have been done to develop an analytical and numerical analysis of the EAHE system.

The performance analysis of an EAHE is influenced, among other things, the calculation of the conductivity of the soil heat transfer from a pipe with the mass of the soil or the calculation of convection heat transfer in the air circulation into it and the change of

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temperature and humidity. Computational fluid dynamic (CFD) is a beneficial tool for understanding the fluid dynamics in EAHE with the purpose of developing the design. Unlike the analytic methods, experiments, and calculations on lower dimensions, multidimensional CFD modelling can lead to designers to simulate and display the complicated fluid dynamics by completing the core physical laws for mass, momentum, and energy in 3D geometry, with sub-models for critical events such as turbulence and EAHE reaction.

2. Literature Study

Pipes embedded under soil or better known as EAHE is configurations of one or more that could be made of PVC pipes (polyvinyl chloride), HDPE (high-density polyethylene) and galvanized pipes grown at depth specific. The working principle of the air conditioning system is very concise. The land used as a heat storage source. Solar radiation is very abundant energy and has full applicability potential that makes it possible to capture and convert it into other forms of energy [5, 6, 7]. The soil receives radiation from the sun on its surface and functions as a solar energy reservoir. Due to the high thermal inertia, the amplitude of the fluctuation of soil temperatures will decrease with increased depth [8]. The magnitude of the soil's thermal energy capacity has encouraged numerous studies to utilize it as a heat receiver through the cultivated piping system [9, 10]. It is constant heat energy, and stored at a particularistic depth can be used by using a heat exchanger between the soil and air. By draining the air through the planted pipe, there will be a heat exchange between the air flowing with the soil layer. In summer, warm air releases its content to the pipe wall through convection and then dissolves into the soil through conduction [11, 12]. Air out will be cooler than air environment can be used directly to cool the room when the temperature is low enough. Alternatively, the output air can be refrigerated utilizing a refrigeration machine. Both uses of EAHE can reduce the cooling load and energy consumption [13, 14, 15]. The equation of mass value as follows:

$$\frac{\delta\rho}{\delta t} + \nabla \cdot \rho U = 0 = 0 \tag{1}$$

Meanwhile, the equation of value of NTU EAHE as follows:

$$\mathrm{NTU} = \frac{hA}{\dot{m}Cp} \tag{2}$$

The value of the effective exchange of EAHE as follows:

$$\varepsilon = \frac{T_{in} - T_{out}}{T_{in} - T_{soil}} \tag{3}$$

The COP value of EAHE as follows [7]:

$$\mathrm{COP} = \frac{Q_c}{P_f} \tag{4}$$

3. Methodology

3.1. 3D Geometric illustrating

All of the dimension of EAHE that has measured 3D geometric images, the PVC pipe can be made using SolidWorks 2014. The geometry images show in figure 1.

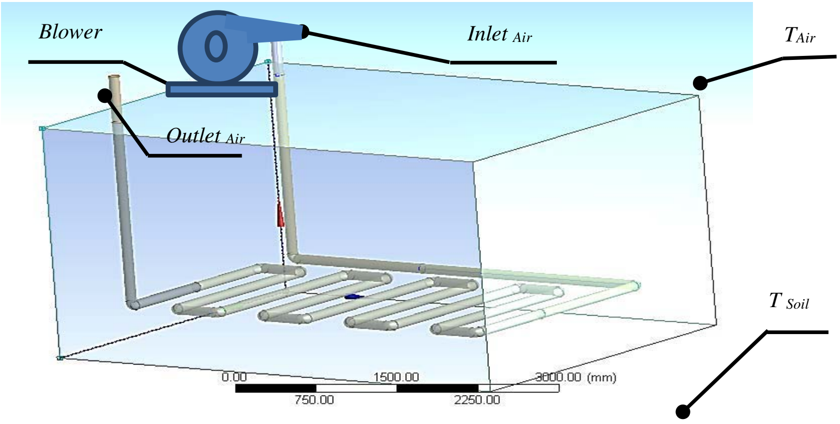

Figure 1. 3D Geometry with display hidden line visible

This geometry should be exported to the Parasolid format (.x_t) for reading by Ansys. A thermocouple was placed at 4 point temperature measurements along the pipe and connected to the computer using the Cole-Palmer 18200-40 data 8 channel. Zone 1, 2, 3 and 4 positioned at a distance of 5 m between the thermocouple. While zone 3 placed at the inlet, and four on the outside. Two thermocouples at a depth of 2 meters and an altitude of 0.5 m above soil level to measure ambient temperature. The acquisition results were presented in the form of data and graphics using the tracer-daq software. The acquired data then stored as a .txt file.The device that used to draw is a laptop, and to execute the simulation was a desktop computer; it can survive and perform the process steadily over 24 hours.

3.2. Simulation scheme

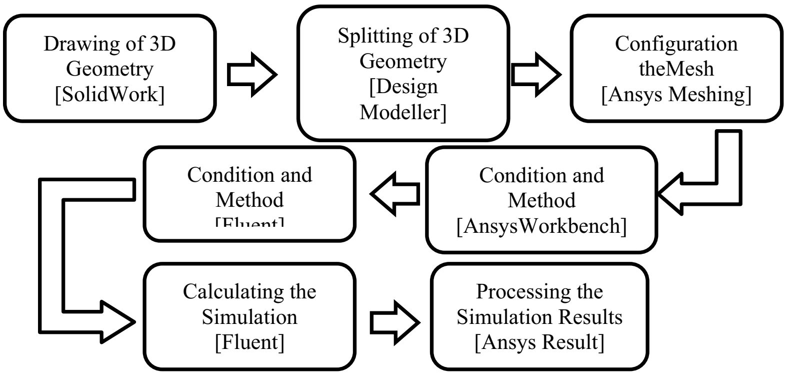

Figure 2. Process path of simulation preparation

3.3. Set-Up of experiment

The air flowed into the pipe using a blower with an inlet air velocity of 3 m/s and 2 m/s. It is connected to the inverter so that it can set the frequency of the blower rotation to provide the desired airflow rate, and to ensure the air velocity produced to anemometer use.

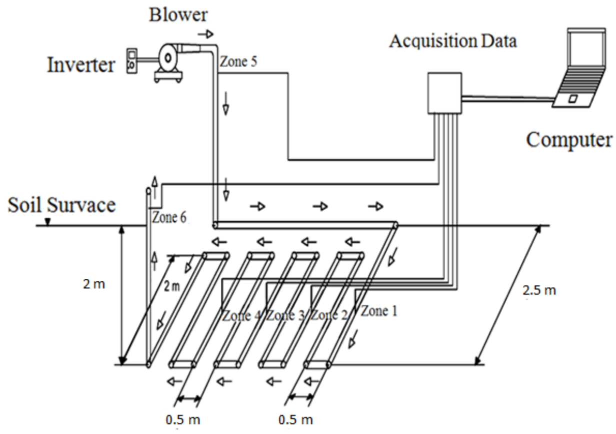

Figure 3. Set-up experimental of EAHE

4. Results and Discussion

4.1. The Result of analysis of fluent software Ansys 14.5

After the data inputted on the fluent, the pipe analyzer of EAHE is littered up to the temperature in the PVC pipe in the soil for 6 hours of testing from 10:00 WIB to 16:00 WIB. The temperature input during the simulation is shown in table 1.

Table 1. Temperature input during the experiments

V_{air}(m/s)	Statistic	T_{in} (^oC)
3	Maximum	39.0
	Minimum	29.3
	Mean	34.9
2	Maximum	36.6
	Minimum	29.7
	Mean	32.7

The reason for sampling analysis on the clock is due to warming of the surrounding air due to solar radiation. The temperature on the pipe wall is assumed to be equal to the average temperature of the soil at a depth of 2 m as shown in table 2.

Table 2. Temperature soil during the experiments

V_{air} (m/s)	Condition	T_{soil} (^oC)
3	Maximum	27.6
	Minimum	25.2
	Mean	26.6
2	Maximum	27.7
	Minimum	25.9
	Mean	26.6

4.2. Analysis of temperature contour

From the result of temperature contour simulation, it could be seen that the first incoming liquid temperature drops along EAHE distribution of fluid temperature contour that flows along the pipe at the velocity of 3 m/s and 2 m/s as shown in figure 4 and 6.

A. The dispersion of temperature at the velocity of 3 m/s.

If viewed from the law of Pascal, the pressure that fills one room should distribute and equal, but in some circumstances, the pressure may be uneven. For example, in case of flow in the PVC pipe, the effect of the length and shape of the fluid flow present in the heat exchangerchamber can be reduced by the pressure and heat imposed on it may cause a pressure drop and temperature at the different point, even in the same room. The fluid temperature distribution flowing along the pipe at a velocity of 3 m/s can be seen in figure 4.

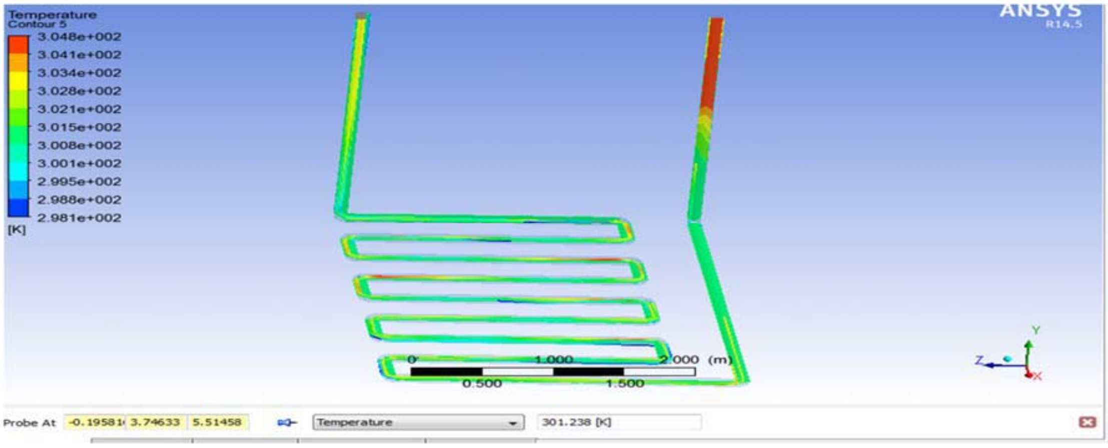

Figure 4. The result of fluid contour analysis in the transmitter of at velocity of 3 m/s

Figure 4 shows the velocity of the fluid in EAHE was reduced so that the longer air circulate with the pipe wall and the liquid that comes out colder than the inlet fluid. Figure 5 shows the comparison of T_{out} simulations and trials for V_{air} = 3 m/s.

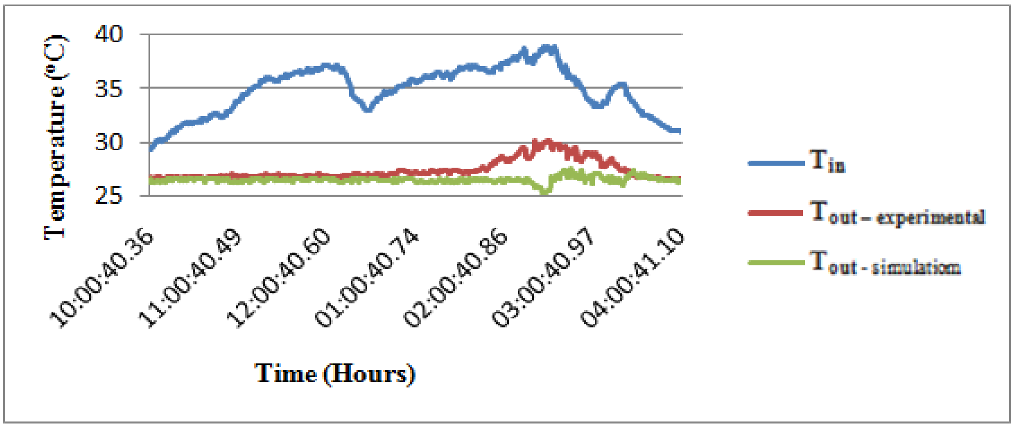

Figure 5. The comparison of T_{out}experiment and simulation (V_{air} = 3 /s)

B. Temperature spread at velocity 2 m/s

Figure 6 shows the temperature distribution at velocity2 m/s.

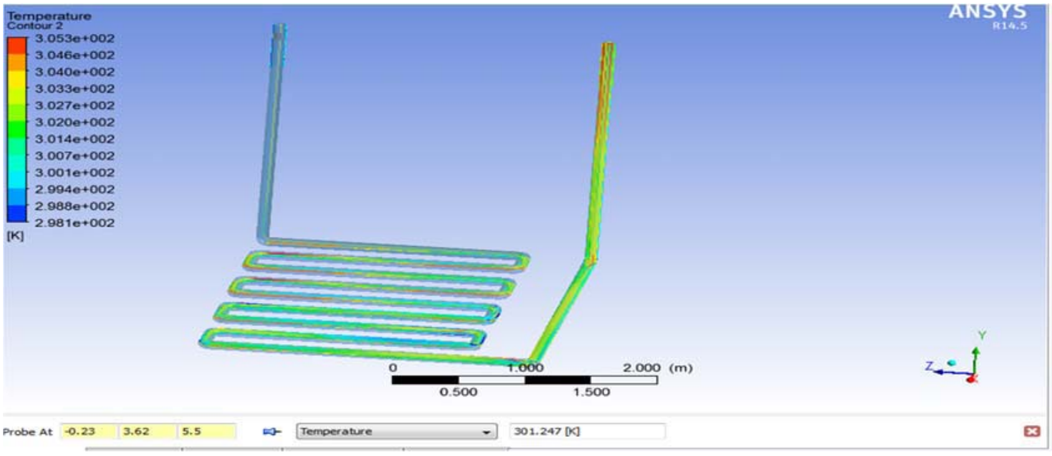

Figure 6. The analysis result of fluid contour temperature in the pipe EAHE at the velocity of 2 m/s

Figure 7 shows a simulation and experimental T_{out} comparison for V_{air} = 2 m/s.

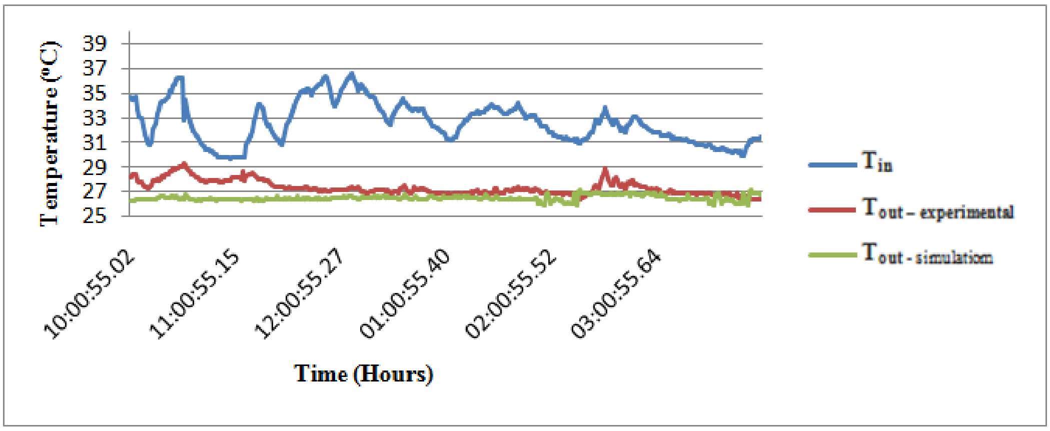

Figure 7. The comparison of T_{out} experimental and simulation (V_{air} = 2 /s)

The average value of output temperature for both simulation and experimental result as shown in table 3.The equation of the temperature error as follows: $G = \frac{\Delta T_{Experiment} - \Delta T_{Simulation}}{\Delta T_{Simulation}} \times 100\%$

Table 3. The comparison of the output temperature of experimental and simulation

V_{air}(m/s)	Condition	T_{in}(°C)	T_{Out}(°C)		Error
			Experimental	Simulation	
3	Maximum	39.0	30.2	27.6	19.048%
	Minimum	29.3	26.6	25.2	-1.460%
	Mean	34.9	27.5	26.6	3.452%

	Maximum	36.6	29.3	27.2	10.985%
2	Minimum	29.7	26.4	26.0	-2.574%
	Mean	32.7	27.4	26.5	3.048%

C. Analysis of pressure contour

Similar to the temperature, pressure analyzer is also required to determine the pressure concentration on each side of EAHE pipe. Below shows the fluid pressure contour produced in the soil exchange tube with the inlet temperature equal to that performed in the temperature analysis.

D. Spreading pressure at the velocity of 3 m/s

After analyzing the maximum and minimum temperature at a velocity 3 m/s on the first day, 2 m/s continued on the second day, so it could be seen how high the velocity of pressure changes. Figure 8 shows the pressure distribution on each side of EAHE.

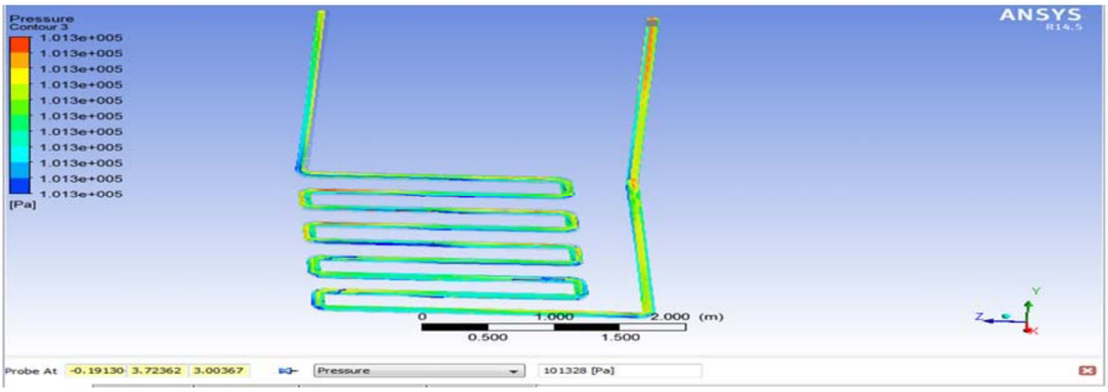

Figure 8. The analysis result of fluid contour temperature in the pipe EAHE at the velocity of 3 m/s

E. Spreading pressure at the velocity of 2 m/s

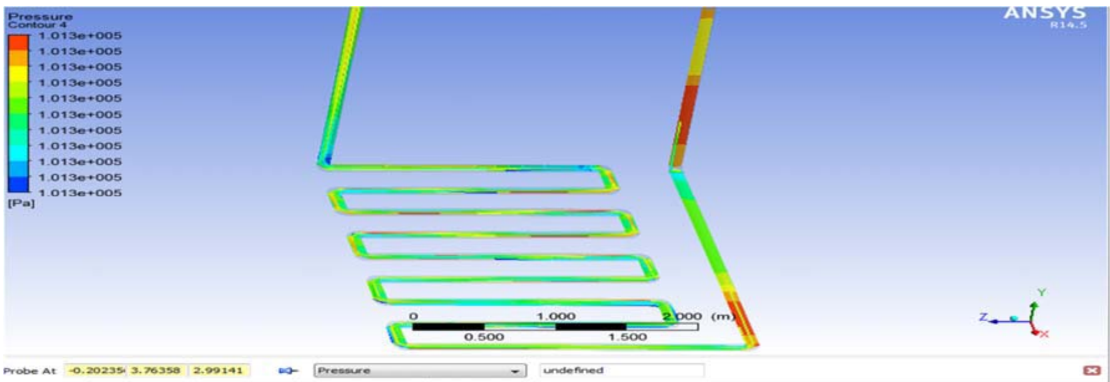

Figure 9. The analysis result of fluid contour temperature in the pipe EAHE at the velocity of 2 m/s

F. Analysis of velocity contour

The simulation begins by entering the initial velocity value of 3 m/s. Figure 10 shows the system has decreased velocity up to 1.2 m/s during the heat transfer process.

a. Velocity spread of 3 m/s

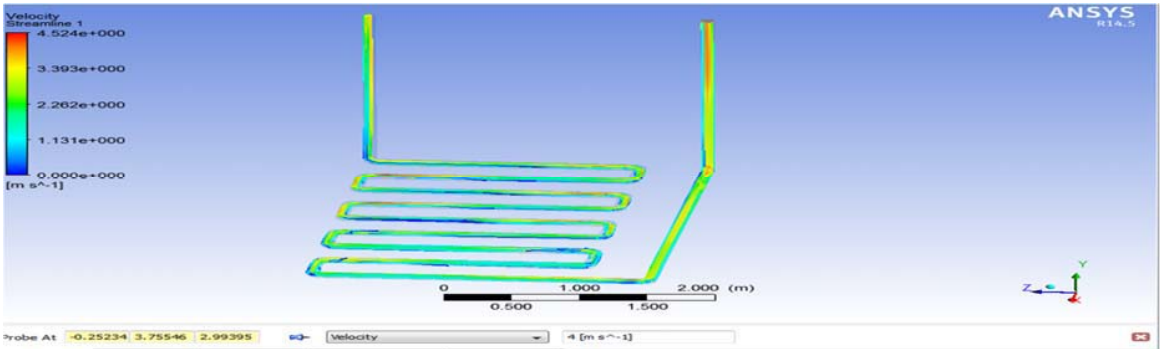

Figure 10. The analysis result of fluid contour temperature in the pipe EAHE at the velocity of 3 m/s

b. Velocity spread of 2 m/s

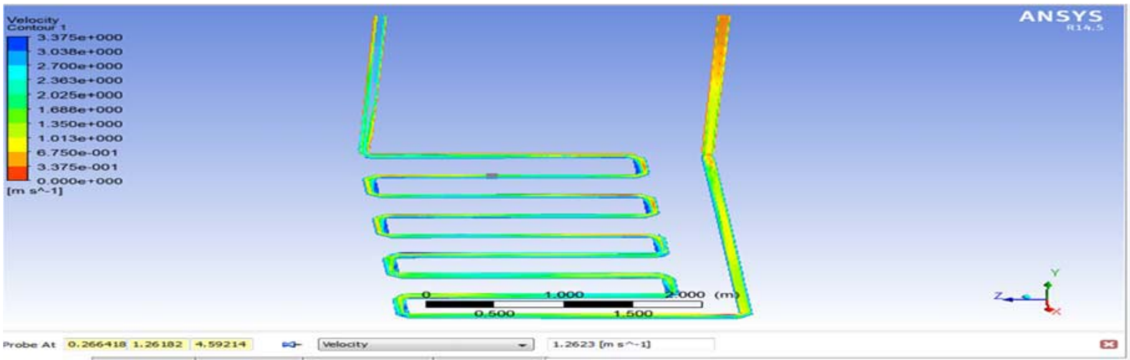

Figure 11. The analysis result of fluid contour temperature in the pipe of EAHE at velocity2 m/s

E. The effectiveness of the simulated heat exchanger

From the equation (3) is obtained the comparison of experimental effectiveness with simulation effectiveness as shown table 4.

Table 4. The comparison of experimental effectiveness with simulation effectiveness

V_{air} (m/s)	Condition	T_{in}(°C)	Effectiveness(ε)		The Difference (%)
			Experimental	Simulation	
3	Maximum	39.0	1.00000	1.16667	16.66700
	Minimum	29.3	0.63380	0.87324	23.94400
	Mean	34.9	0.90128	1.00074	9.94500
2	Maximum	36.6	1.02571	1.18421	16.66700
	Minimum	29.7	0.36364	0.34286	23.99400
	Mean	32.7	0.87340	0.86100	9.99290

5. Conclusions

In simulation and experiment, we have found out that the decrease in air velocity (V_{air}) the outgoing temperature (T_{out}), the coefficient of performance, and the efficiency value (ε) for the Earth-Air Heat Exchange device will decrease and inversely with the NTU will increase.

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