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Thermal Simulation and an Analysis on an Exhaust Gas of a Teg Model using Fluent

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ABSTRACT
As the First law of Thermodynamic says "energy is directly proportional to work done" and law of conservation of energy "Energy can neither be created nor can be destroyed, it can only be transformed from one form to another". Unfortunately any energy policy that produces improvements in the short term is often one that destroys the environment in the long run. It is a universal truth that no exponential growth will last forever. In other words, the global net impacts have heavy consequences on the entire planet's inhabitants. Here a study of conservation is being followed. (TEG) Thermo-electric generator is an Electro-mechanical device which converts, heat energy into electrical energy. This waste heat if recovered can be used for various other applications. The TEG used in heat power output and system efficiency works as a heat exchanger. Here the device has been engaged into exhaust system for reuse of heat energy for further use of energy in an automobile or a generator. A model is developed in UNIGRAPHICS NX and updated into ANSYS 16.2 software for this purpose. Air is used as a Fluent, having velocity 1 m/s, 2 m/s and 3 m/s. Fluent workbench is being engaged for the summation of results. The parameters are set and are simulated in double precision. The simulation is based on Temperature and thermal heat transfer is studied.

Keywords: *Fluent, Thermal, Renewable energy, Efficiency, Heat, Temperature*

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INRODUCTION

The lack of access to this basic component of modern civilization is even more acute and commonplace in developing regions, such as countries in Africa and Asia. Furthermore, not having this vital resource has hindered any economic development up to date in remote and developing regions, and is considered to be one of the sources of continued poverty in those areas. Although electrical energy alone is not enough for initiating the conditions for economic growth, it is still certainly essential and plays a most important part. The number of people accessing electricity is one of the most clearly and sound indications of a country's energy poverty status [1].

The ambitious millennium goals that have been set forth to eradicate extreme poverty in the World can never be fully achieved without confronting and resolving this fact. Thus, the existent inequality gap that has persisted over centuries between the West and the East, on one hand, and the urban and rural areas, on the other hand, can certainly be explained by means of the aforementioned electrical energy scarcity issues. At the same time, the inequality between the Western and Eastern civilizations keeps widening even more because of the lack of serious and strong electrical energy policies in the East. Conversely, electronic gadgets, such as smart electronic devices, mobile phones, and computers are becoming more popular in the cities as well as the remote villages [1-22].

As stated in, TEG can be utilized to supply electricity to power either main units or ancillary devices by directly converting any sort of thermal energy or renewable energies, such as solar energy (electromagnetic waves) and geothermal energy to electrical energy. This conversion of energy from solar radiation to electricity is done via the Seebeck effect, named for the discovery made in 1821 by the German physicist, Thomas J. Seebeck [23-45].

In contrast, a micro-grid has not only a higher capital investment cost, but also requires a specialized workforce. The latter supplies only a sufficient amount of electricity for basic household needs, such as charging electronic devices, light emitting diodes (LEDs) for lighting, and fans for household interior comfort. This technology is uncomplicated and inexpensive; it requires no expertise to setup and operate. Besides, it will have a tremendous impact on the lives and the economy of the people in those areas [46-50].

Indeed, a vast array of methods of producing electrical energy does exist today although some of the technologies are still rudimentary. They all operate for the benefit of the rural inhabitants and are completely independent of the grid infrastructure.

Such alternative resources are:

- Solar photovoltaic (PV);
- Wind power;
- Geothermal; and
- Thermoelectric generators (TEG).

New alternatives and inventive renewable energy techniques which encompass both generation and power management solutions are fundamental for meeting remote residential energy supply and demand today, especially if the grid is quasi-nonexistent. thermoelectric generators mounted on a dual-axis sun tracker can be a cost-effective alternative to photo-voltaics for remote residential household power generation. The overall efficiency and system performance sought turned out to be counter-intuitively below research expectations. How heat is lost in the system due to the material defects certainly played a key role as different manufacturers may have different quality standards [51-60].

The following parameters require the maximum power, P_{max}, Thermal Conductivity, k W/m·K, and the optimal efficiency of the module, ɳ. The following values were then computed and succinctly utilized toward the final goal.

- Electrical Resistance
- Seebeck Coefficient
- Thermal Resistance of the Module
- Thermal Resistance of the Insulation Foam
- Thermal Resistance, R_{AL}
- Thermal Capacity, C_{AL}

Comparatively to what Antoine L. Lavoisier stated about chemical reactions in which “matter is neither created nor destroyed,” energy in its various forms cannot be created or destroyed, but rather transformed. In producing electricity, no new energy is being created. In reality one form of energy is changed to another kind. In light of this statement, emitting energy in the form of electromagnetic radiation at a relatively constant rate in the entire universe, remains the sun.

Some of the material properties that turned out to be helpful in this study were mentioned on website of Custom Thermoelectric [66]. Hence, Table 1, 2 depicts the most relevant values. The TE modules were specified by the manufacturer to be bismuth telluride (Bi_2Te_3) and that the ceramic substrates or faces were made of alumina (Al_2O_3).

In which, ρ is density,
c is specific heat, and
κ is conductivity.

Table 1. *TEM properties*

Material	ρ[kg/m^3]	c [J/kg ·K]	κ[W/m · K]
Aluminum	2770	875	177
Alumina	3570	837	35.3
Bi_2Te_3	7530	544	1.5

Table 2. *Nomenclature*

NOMENCULATURE	
A	Area [m^2]
h	Convection heat transfer coefficient [W/m^2.K]
HHRS	Hybrid heat recovery system
q	Heat transfer rate [W]
L	Length of the tank [m]
N	Number of items
P	Power produced [W]
r	Radius [m]
Ta	Temperature [°C]
k	Thermal conductivity [W/m.K]
R	Thermal resistance [K/W]
e	Thickness of the TEG [m]

In order to appropriately study with the topic all the thermal processes taking place inside the thermoelectric module, all the physical parts must be transferable. So, the two equal dimension aluminum plates, (Length 56 mm, Width 56 mm, and Height 12.7 mm), purposely grooved to hold the hot and cold side thermocouples during the laboratory experiment need be accounted for in the computer model. For heat transfer, copper is usually the best choice for designing materials. Advantages of using this material for such systems are mainly because of its high thermal Conductivity, resistant to corrosion by liquids. The disadvantage of using copper for our system is due to high price, high forces when applied on these pipes as these pipes are prone to bending.

It is essential to first have a sound knowledge of the exact mass the TEM, its molar mass, M and its molar heat capacity for us to be able to reproduce the heat capacity of the module in LTspice. Hence, the mass was simply determined by a sensitive electronic balance and compared to the one given on the datasheet. The heat capacity, C_p, of a material can be determined as follows: Where, C_{mol} is the molar heat capacity in J/mol·K, and M represents the molar mass in g/mol. The molar heat capacity of Bi_2Te_3 was found in [67] to be 126.19 J/mol·K at normal temperature, i.e. 298.15 K. In a like manner and for simplicity in the approach, the molar mass, M of the aforementioned material, was accessed at [68] website. It was found there to be 800.760 g/mol. Additionally, the mass of the semiconductor devices can be obtained through a mere subtraction knowing the entire mass ($m_T = 4.8.10^{-2}$ kg) of the TEM [60-76].

Objectives

The main objectives of the thesis are as follows:

1. To perform an extensive literature review to identify the research and development status of this technique and the current guidelines for designing earth to air heat exchanger systems.
2. To develop a transient thermal network model for finding the transient heat flow rate q (w) in thermal profile around an simulated model in order to determine the profiles.

3. Study the range of thermal profile of model TEG heat exchange systems.
4. To develop a new methodology for CFD simulation of the model TEG heat exchange systems.
5. To study this technology we introduced a simulation model using copper layer according to change in temperature. Air is used as a Fluent, having velocity 1 m/s, 2 m/s and 3 m/s.

LITERATURE REVIEW

Various studies were carried out by many researchers in the past. Some of references related to the present study were reviewed in the followings:

Rinalde et al. [2009] [49] studied the greenhouse effect has made life possible on Earth by averaging the global temperature to 18 °C. That averaged temperature has increased during the past century by about 0.7 °C. It has been speculated that most of the increase is attributable to the manmade greenhouse effect due to the release in the air of not only the major GHG in general, but particularly to the millions of tons of carbon dioxide emitted when fossil fuels are burned to produce energy on a daily basis. For instance, the US alone emits 2.2 billion tons of CO_2 per annum to produce electricity, which corresponds to approximately 40% of the national total gas emissions.

Champier et al.[2010] [33] studied the literature survey intended to demonstrate the urgent need for finding new long term alternative renewable sources to replace the existing fossil fuel-based sources that may be depleted in the near future. Furthermore, scientists and those in the field of energy came to a valid conclusion in the early 18^{th} century, at the dawn of the industrialization era, that fossil fuel was not a perpetual energy source. Therefore, many new renewable technologies have been investigated to either firmly supplant fossil fuel-based sources or to provide an alternative to them. In the present investigation a comprehensive simulation model was used to analyze by detail the potential benefits in efficiency and power output when combining a Rankine cycle to an existing heavy duty diesel engine used in truck applications.

Meng et al. 2011 [53] suggested a numerical and comparative study of a TEG with multi-irreversibility's. Rankine cycle is a promising technological solution for heavy duty trucks considering present and future fuel prices that are expected to be high. Thermoelectric generators can use energy, in the form of heat, for the generation of electrical power. One of the pioneering works in this field was done before the first oil crisis, in the world. Utilizing the best alloys available at that time, she was able to improve the TEGs efficiency by 3.35 percent. Though the study set the foundation of TEG technology, no real energy application was attempted.

Kraemer et al. [2011] [52] attempted to improve rural communities' living standards by incorporating TEG to a cooking stove for electricity generation in developing regions. The only drawback to their study was that a thermo-coax electric heater was used, rather than a real stove, to provide a continuous power of 150W. The Spice modeling of TEGs based on the thermal-to-electrical analogy using LT spice software is the core piece of this study. analyzed the real performance of Flat-panel TEGs with a high thermal concentration at an AM1.5, equivalent to $1kW/m^2$. The latter value is too ideal for real TEG testing to yield any meaningful result. Nevertheless, their model achieved a peak efficiency of 4.6 percent. Unfortunately, any energy policy that produces improvements in the short term is usually one that destroys the environment in the long term. It is a universal truth that no exponential growth will last forever. In other words, the global net impacts have heavy consequences on the entire inhabitants of the planet. There is, in fact, a global tendency to run out of energy resources that are either non-regenerative or not replenished at a fast enough rate on a human scale.

Gontean and Cernaianu [2013] [12] proposed the drawback of these energy-harvesting systems was that they were limited to laboratory experiments. Therefore, they did not have as significant an impact as if they were conducted in an open environment to harvest the free and abundant energy. There is a generous endowment of wind, geothermal and other renewable resources on Earth. With the current technological development attained, mankind is consistently inventing new ways to improve the existing electrical power generation mix. Learning how to harness these infinitely important renewable resources to replace the traditional fossil fuel energy sources would untangle the current worldwide economic model that is based on fossil fuel.

Date et al. [2014] [38] All the major inner effects, such as Seebeck, Fourier, Joule and Thomson, were considered in the novel model. Unfortunately, accuracy may be lost in the results because the capacitances of the various elements were completely ignored. As per the abundance of literature, consists of n-and p-type semiconductor. Although some of the aforementioned works described remote application of TEGs, none of those. These resulted in an additional 23.7% power improvement. The additional power generation decreased at part loads. in the pre sent work.

Lashof and Yeh [2015] [37] investigated the use of TEG for rural electrification, where they designed an energy-harvesting prototype for isolated households. In this same year evaluated the performance of a micro-energy harvester based on TEG in conjunction with latent heat effects. Their device was sensitive to seasonal variations in radiation and wind patterns, which makes it a good candidate for building wireless applications. metal foams pl ay an important role in enhancing the heat transfer process.

Jaber et al. 2017 [76] the reuse or reduction of wasted heat supplies an excellent opportunity for cost saving in industrial and residential application. This paper deals with a Hybrid heat recovery system that reuses the thermal energy captured by exhaust gases to produce domestic hot water and generate electric power using thermoelectric generators (TEG). The heat recovery process is mainly affected by the temperature of exhaust gases. The effect of gases temperature on the performance of the system water temperature and power generated is studied including different residential applications. It shows that as the exhaust gases temperature increase the heat rate, water temperature, and power generated increases.

DESIGN AND METHODOLOGY

The new energy-harvesting system must be designed to withstand severe conditions. Both the experimental and the simulation of Thermoelectric Module study were put together following a similar methodology, as their inner heat transfer functionalities remain mostly identical. This work proposes to design, build, and test a thermoelectric generator system. Possible methods to enhance its efficiency, understand its functionality, and optimize its performance, i.e. the heat transfer capabilities between the top and the bottom surfaces, will be investigated.

First characterize the device (TEG) parameters from:

- Datasheet,

- Device geometries, and
- Material properties.

Furthermore, the simulation was to not only understand how the TEG operates in real environment, but also to get accustomed to it before the main part of the work.

Several physical phenomena take place in a thermoelectric device. Therefore, only the most significant of them will be mentioned that are of particular relevance in this research.

- Another name for this thermo-electrical phenomenon is resistive heating. It is known to be the process by which the passage of a current through a conductor emits heat. The amount of heat, Q, released due to Joule heating is proportional to the square of the current flow times the resistance
- The Thompson effect-is explicitly neglected at this stage due to its smaller contribution in terms of cooling as reported in.
- The Seebeck effect-occurs when two dissimilar metals are looped together. They develop an electromotive force (emf) when the two junctions are kept at different temperature.

Heat transfers through three thermally possible transport mechanisms. The predominant mechanisms in a TEG are convection and radiation [62]. The former, is the transfer of internal energy, generally in the form of heat, through fluids by obeying the natural laws of diffusion. The latter, i.e., electromagnetic radiation, is the continuous emission of energy from all substances due to their molecular, atomic, and sub-atomic agitations.

$$R_g = \frac{1}{h_g \left(2\pi \left(r_{t,i} - e\right) L\right)} \tag{1}$$

$$R_{TEG} = \frac{ln\left[\frac{r_{t,i}}{r_{t,i} - e}\right]}{2\pi\, k_{TEG}\, L} \tag{2}$$

$$R_p = \frac{ln\left[\frac{r_{t,o}}{r_{t,i}}\right]}{2\pi\, k_t\, L} \tag{3}$$

$$R_{conv,w-p} = \frac{1}{h_w \left(2\pi\, r_{t,o}\, L\right)} \tag{4}$$

$$R_{conv,w-w} = \frac{1}{h_w \left(2\pi\, r_{w,i}\, L\right)} \tag{5}$$

$$R_{wall} = \frac{ln\left[\frac{r_{w,o}}{r_{w,i}}\right]}{2\pi\, k_w\, L} \tag{6}$$

$$R_{air} = \frac{1}{h_a \left(2\pi\, r_{w,o}\, L\right)} \tag{7}$$

$$T_{(n)} = T_{(n-1)} - q.\, R_{(n)} \tag{8}$$

$$P_{1\,TEG} = \left(\frac{P}{\Delta T^2}\right)_{ref} \Delta T^2 \tag{9}$$

$$P_{Total} = N_{TEG} P_{1\,TEG} \tag{10}$$

Where, $T_{g,i}$, TH, TC, $T_{p,o}$, T_w, $T_{wall,i}$, $T_{wall,o}$ and T_a are the temperature of exhaust gases, hot, cold, outer pipe wall, water, inner tank wall, outer tank wall, and ambient air temperature respectively. Also R_g, R_{TEG}, Rp, $R_{conv,w-p}$, $R_{conv,w-w}$, R_{wall}, and R_{air}, are the thermal resistance of internal convection of gases in pipe, conduction in thermoelectric generator, conduction in the pipe wall, convection between water and pipe, convection between water and cylindrical tank wall, conduction in the cylindrical tank wall and convection of tank with air respectively. where h_g, h_w and h_a are the convection heat coefficient of exhaust gases, water and air respectively. k_{TEG}, k_t and k_w are the conduction coefficient of the TEG, tube wall and tank wall respectively. And $r_{t,i}$, $r_{t,o}$, $r_{w,i}$, $r_{w,o}$ and L are the inner, outer radius of the tube and inner, outer radius of the water tank, and length of the tank respectively. *e* is the thickness of the thermoelectric generator.

The ANSYS Fluent is used to solve different types of problems. In each case, features related to problem setup and post-processing. The problem setup and post-processing are with the assumption that have completed. ANSYS Fluent in ANSYS Workbench is used for Fluid Flow and Heat Transfer in a Mixing, Parametric Analysis and that you are familiar with the ANSYS Fluent navigation pane and menu structure. Some steps in the setup and solution procedure will not be shown explicitly.

The manuals form the Fluent product include descriptions of the

- Procedures,
- Commands, and
- Data details are needed to use fluent products.

Fluent contains general information about gcalculating a solution, and analyzing your results. Fluent Meshing contains detailed information about creating 3D meshes using the meshing mode of Fluent. Fluent contains reference information for how the physical models are implemented in Fluent. Fluent UDF Manual contains information about writing and using user-defined functions (UDFs). Fluent contains information about the background and usage of Fluent's adjoin Solver Module that allows you to obtain detailed sensitivity data for the performance of a fluid system.

Research and Validation Technique

As previous research: "Effect of Exhaust Gases Temperature on the Performance of a Hybrid Heat Recovery System" by Author Hassan Jaber et al. 2017 by Elsevier(Science Direct). The given worked experimentally, for the same research present method a FLUENT analysis is carried out. Table 3, 4 shows the data used in the simulation. Figure 1-5 are the screenshots of the model geometery in the simulation.

For validation we need:

- To investigate the Temperature difference and performance characteristics.
- We will use the Mathematical design and its dimensions of previous study.
- For Validation we will further compare the results with previous research and our established research standards for validation**.**

Table 3. *Parameters of TEG heat exchanger used in simulation.*

	Parameter	Unit	Values
Radius	$r_{t,i}$	M	0.049
Radius	$r_{t,o}$	M	0.050
Length of the tank	L	M	1
Radius	$r_{w,i}$	M	0.158
Radius	$r_{w,o}$	M	0.0160
Convection heat transfer coefficient	H_w	W/m^{2}K	300
Convection heat transfer coefficient	H_a	W/m^{2}K	50
Convection heat transfer coefficient	H_g	W/m^{2}K	80
Thermal conductivity	K_t	W/mK	401
Thermal conductivity	K_{wall}	W/mK	80
Thermal conductivity	k_{Teg}	W/mK	1.4
Number of items	N_{teg}	Pieces	99
Temperature	T_a	Deg C	25
Thickness of the TEG	E	M	0.005
Power/Temp Change	P/delT	W/K^2	0.0002
Area	A Teg	m^2	0.0031

Table 4. *Material Properties*

Material:	**Copper**
Density (kg/m^3)	1400 kg/m^3
Cp (Specific Heat)	1046.7 j/kg k
Thermal Conductivity	385 (w/m-k)
Material:	**Air**
Density (kg/m^3)	1.225 kg/m^3
Cp (Specific Heat)	1006.43 j/kg-k
Thermal Conductivity	0.0242 w/m-k
Viscosity	1.7894e-05 kg/m-s
Molecular Weight	28.966 kg/kgmol
Thermal Expansion Coefficient	1/k

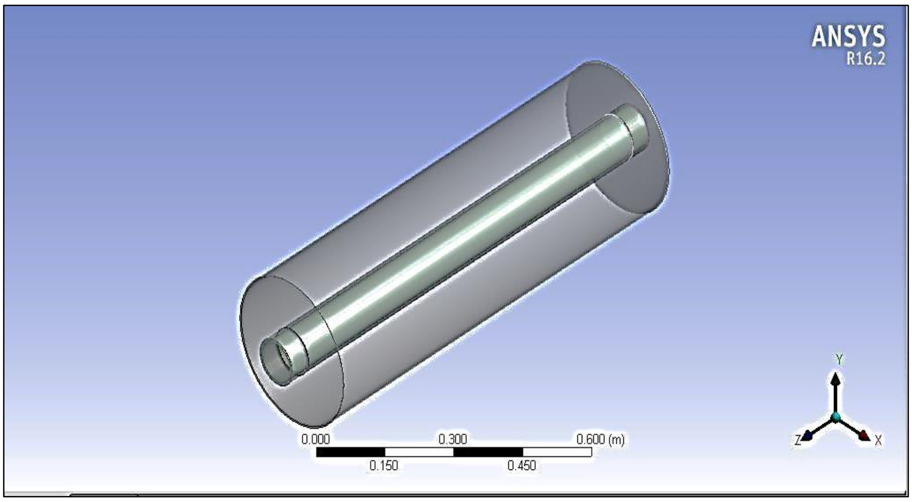


Fig. 1. *geometry for analysis reference by Jader et al. [2017].*

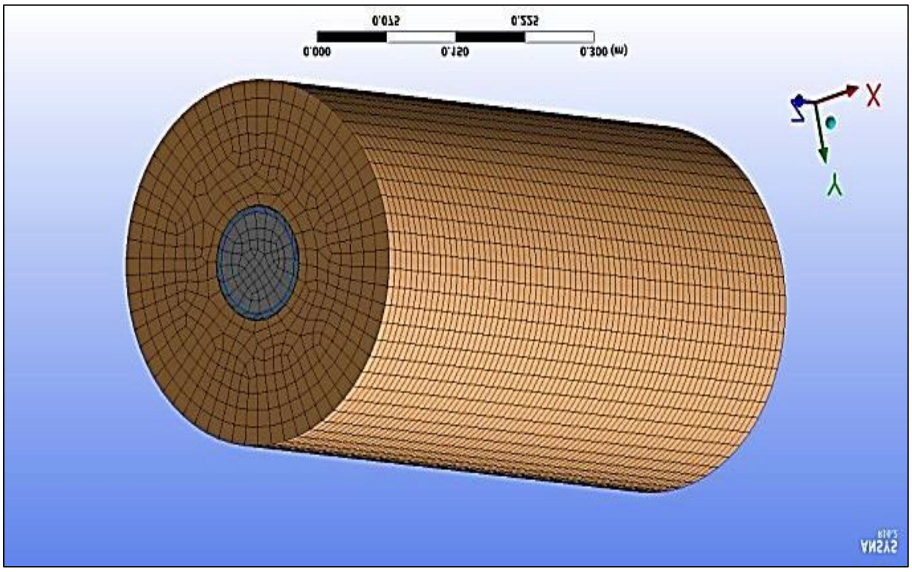


Fig. 2. *Meshed geometry for analysis reference by Jader et al. [2017].*

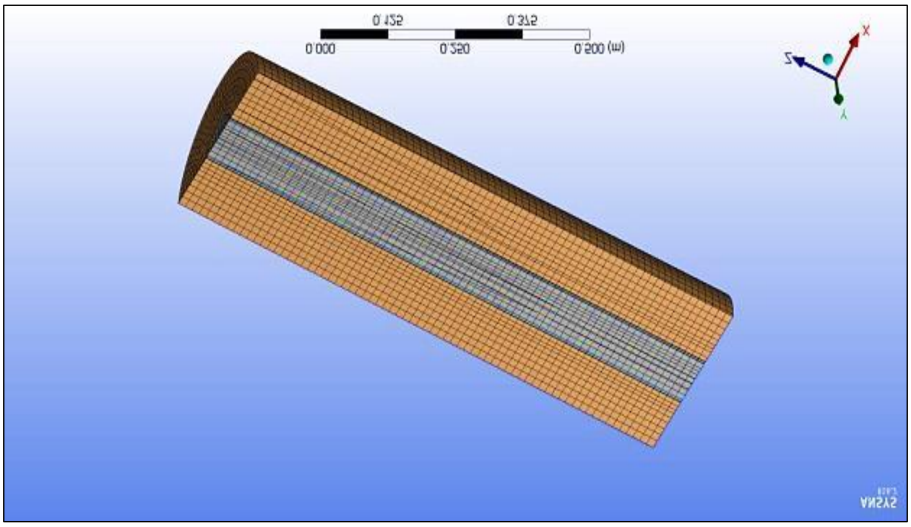


Fig. 3. *Meshed geometry sectional view for analysis reference by Jader et al. [2017].*

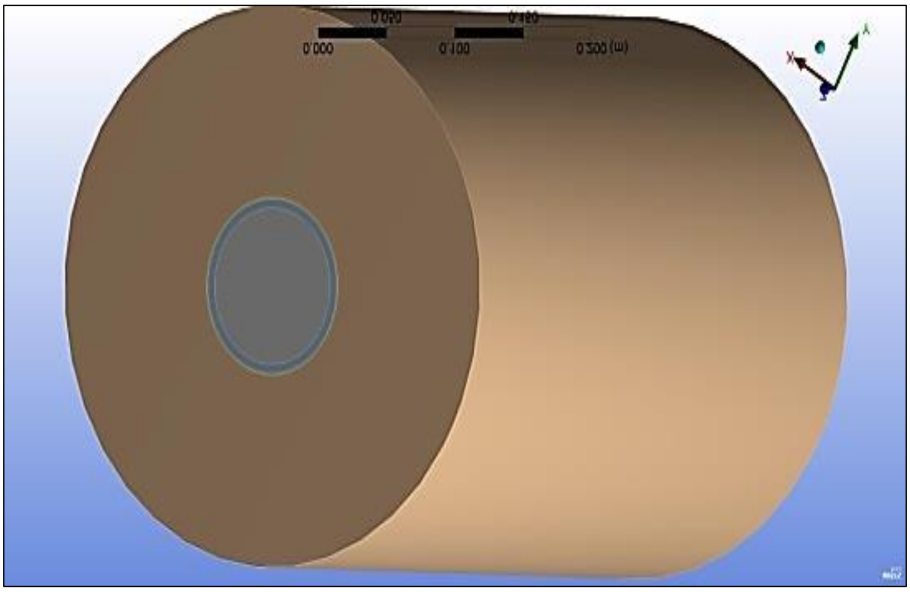


Fig. 4. *geometry for simulation analysis reference by Jader et al. [2017].*

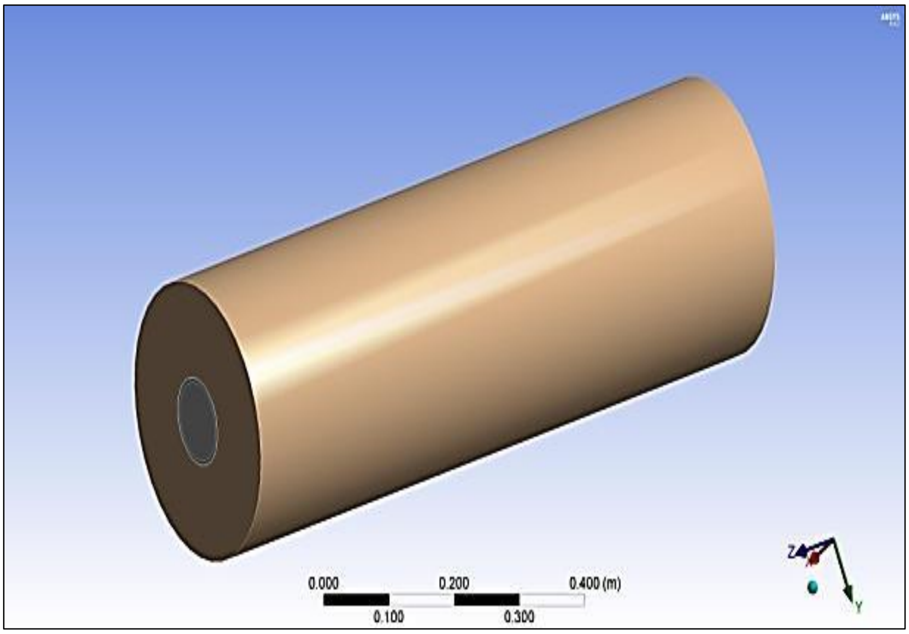


Fig. 5. *geometry for simulation analysis Isometeric viewreference by Jader et al. [2017].*

Steps Followed in Ansys/CFD Fluent

- During pre processing the geometry of the problem is defined.
- Meshing
- The meshing may be uniform or non uniform.
- The physical modeling is defined.
- Boundary condition is defined. This involves specifying the fluid behavior of the problem. For transient problem boundary condition are also defined.
- The simulation is started and the equations are solved iteratively as steady state or transient.
- Finally a post procedure is used for the analysis and visualization of the resulting problem.

Boundary Condition (Operation Condition)

Turbulent intensity = 5%
Hydraulic Diameter = 0.05 m

Body Forces = 1
Momentum = 0.7
Turbulent Kinetic Energy = 0.8
Turbulent Dissipation Rate = 0.8
Turbulent Viscosity = 1
Energy = 1

Solution Method

Pressure- velocity coupling–Scheme-COUPLING
Pressure–Standard
Momentum–Second order
Turbulent Kinetic Energy (k)–First order
Turbulent Dissipation Rate (e) - First order

Solution Initialization

Initialized the solution to get the initial solution for the problem.

Run Solution

Run the solution by giving 20 number of iteration for solution to converge.

RESULTS AND DISCUSSIONS

Outline of the Result

The study proposes an innovative concept of a copper layer on a pipe over contact with thermoelectric generation system (TEG). The proposed model is a real-world environment energy-harvesting system for thermal power delivery. In order to acquaint ourselves with the theory and the physics behind TEM 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 TEG system's implementation. In addition to that, the second and most challenging complete energy-harvesting 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. Furthermore, the first step was to develop a model for simulation, which was performed by UNIGRAPHICS NX. Then, due to the intermittent nature of energy in general and TEGs in particular, this study investigated the optimal power solutions by software simulation output stability and enhancement purposes. The velocity of air is considered to be 1 m/s for the simulation.

The focus of this chapter is on the results and discussion of CFD Fluent Analysis performed on the ANSYS Software for the performance investigation of "Effect of Exhaust Gases Temperature on the Performance of a Hybrid Heat Recovery System"," by Author Jaber et al. 2017 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. Figure 6–Figure 15 shows the results of the simulation.

Table 5 shows a tabular result of the research. The data provided is on the basis of Temperature. All the points of temperature is given which is available on the software. The result displayed is on the basis of l m/s. The result displays, use of copper layer is enhancement in the system. At the inlet of air the temperature is kept at 373 K. All the analysis is based on steady conditions. The result is enhanced due to the use of copper material. TEG is a very good source of heat utilization, as heat is transformed in electrical energy, further can be used in other mediums.

Table 5. *Fluent Results Based on Temperature.*

Parameters	**Unit**	**Min. Value**	**Max. value**
Static Temperature	K	300.0002	373
Total temperature	K	305.0298	372.9999
Enthalpy	J/kg	6927.032	75331.23
Relative Total Temperature	K	305.0298	372.9999
Wall Temperature	K	0	352.2576
Total Enthalpy	J/Kg	6924.032	75331.73
Total Enthalpy Deviation	J/Kg	6924.032	75331.73
Entropy	J/Kg-K	57.24993	259.7217

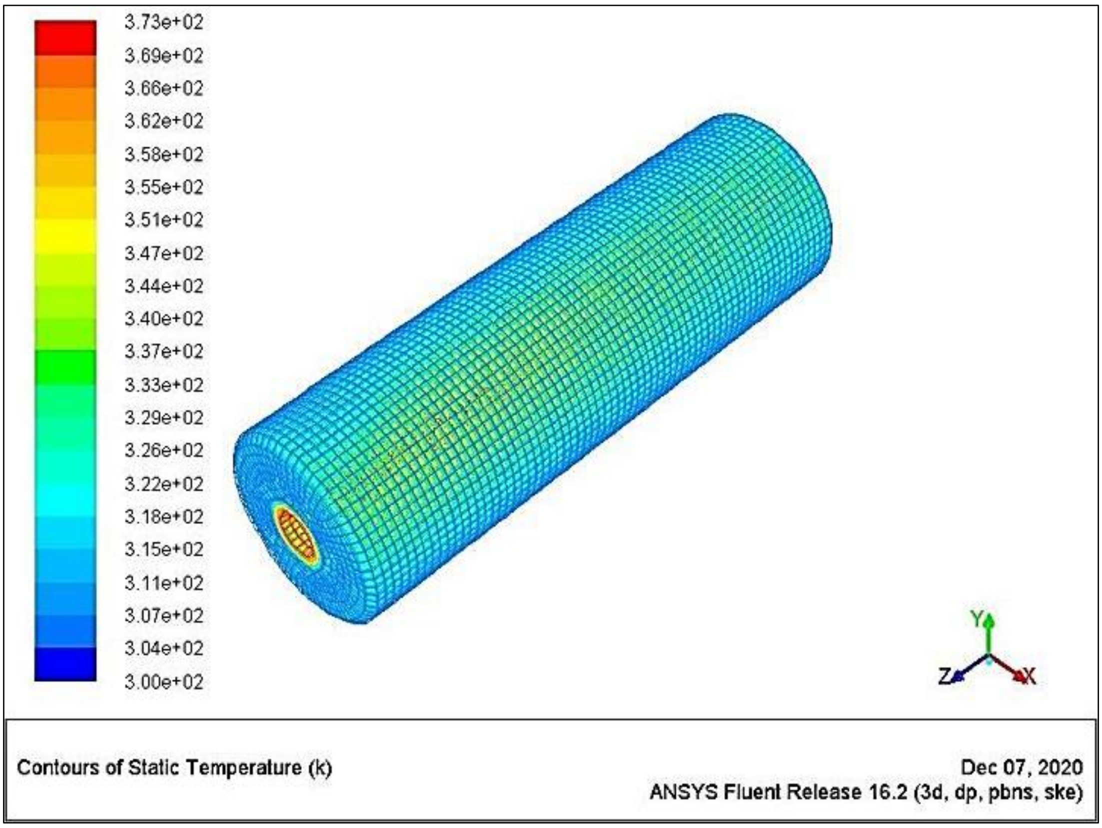


Fig. 6. *Result Contour solution of Static Temperature in streamline.*

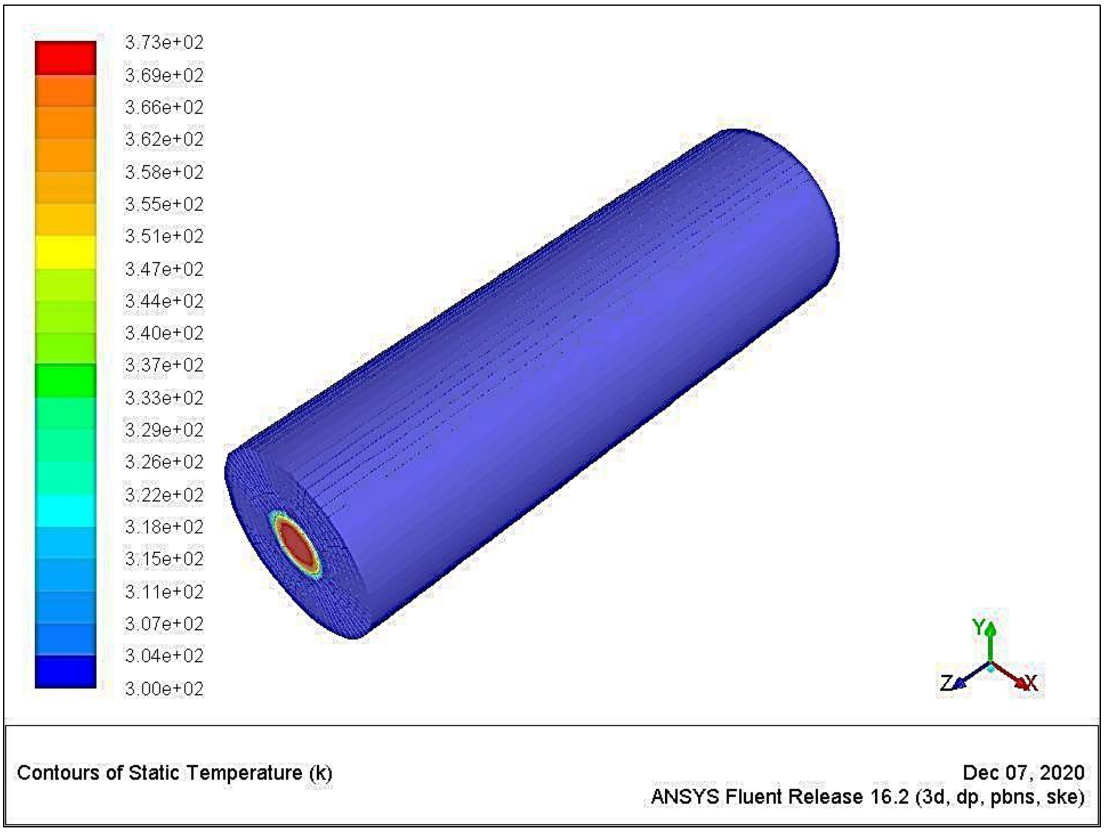


Fig. 7. *Result Contour solution of Static Temperature.*

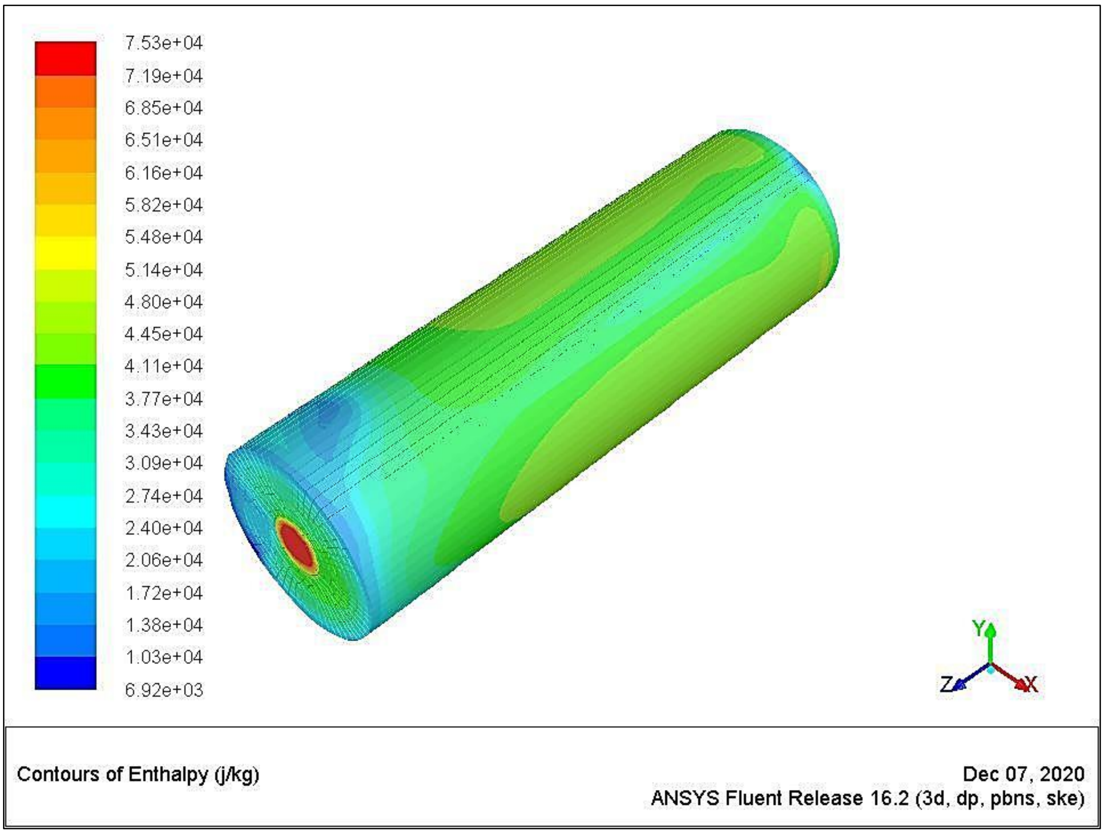


Fig. 8. *Result Contour solution of Enthalpy.*

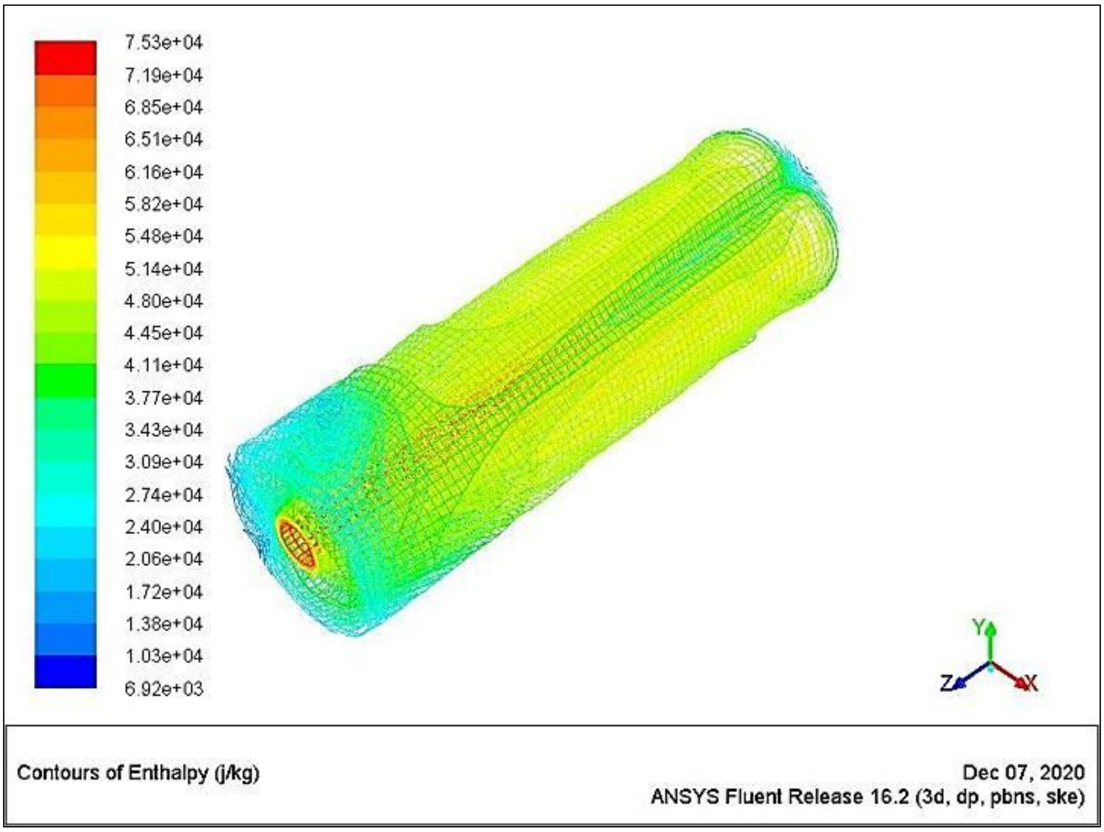


Fig 9. *Result Contour solution of Enthalpy in streamline.*

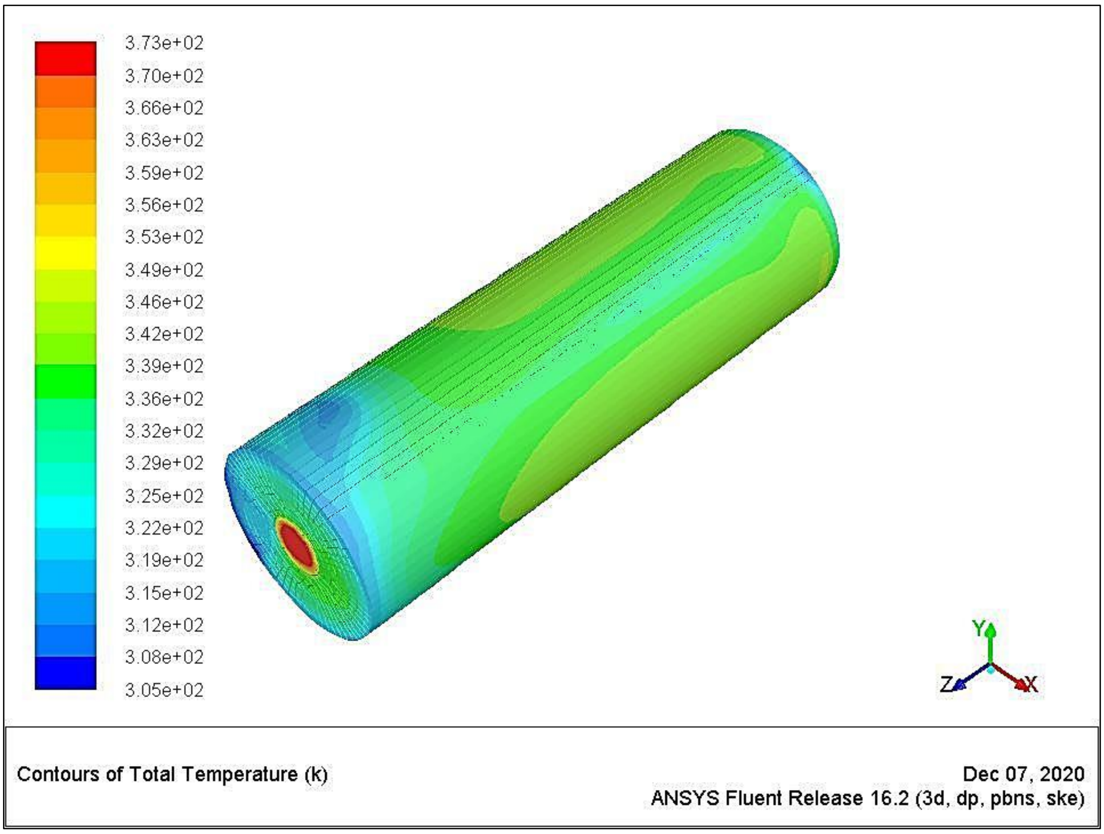


Fig. 10. *Result Contour solution of Total Temperature.*

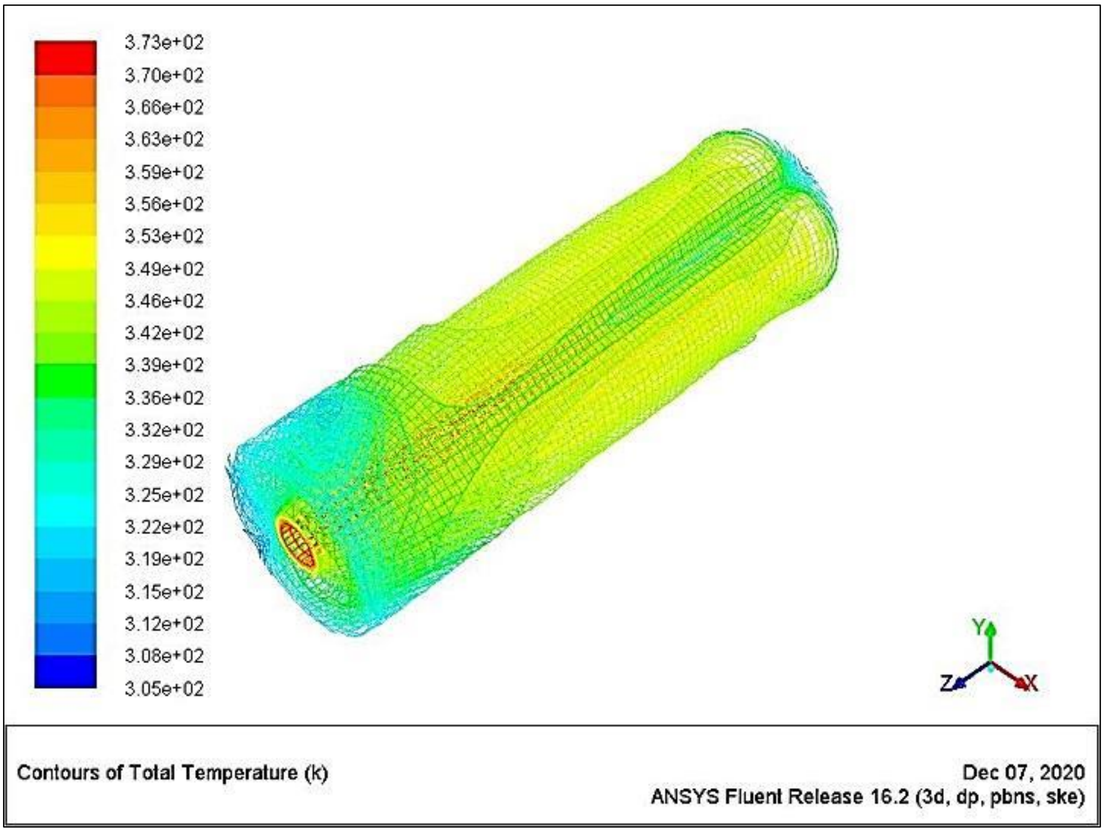


Fig. 11. *Result Contour solution of Total Temperature in streamline.*

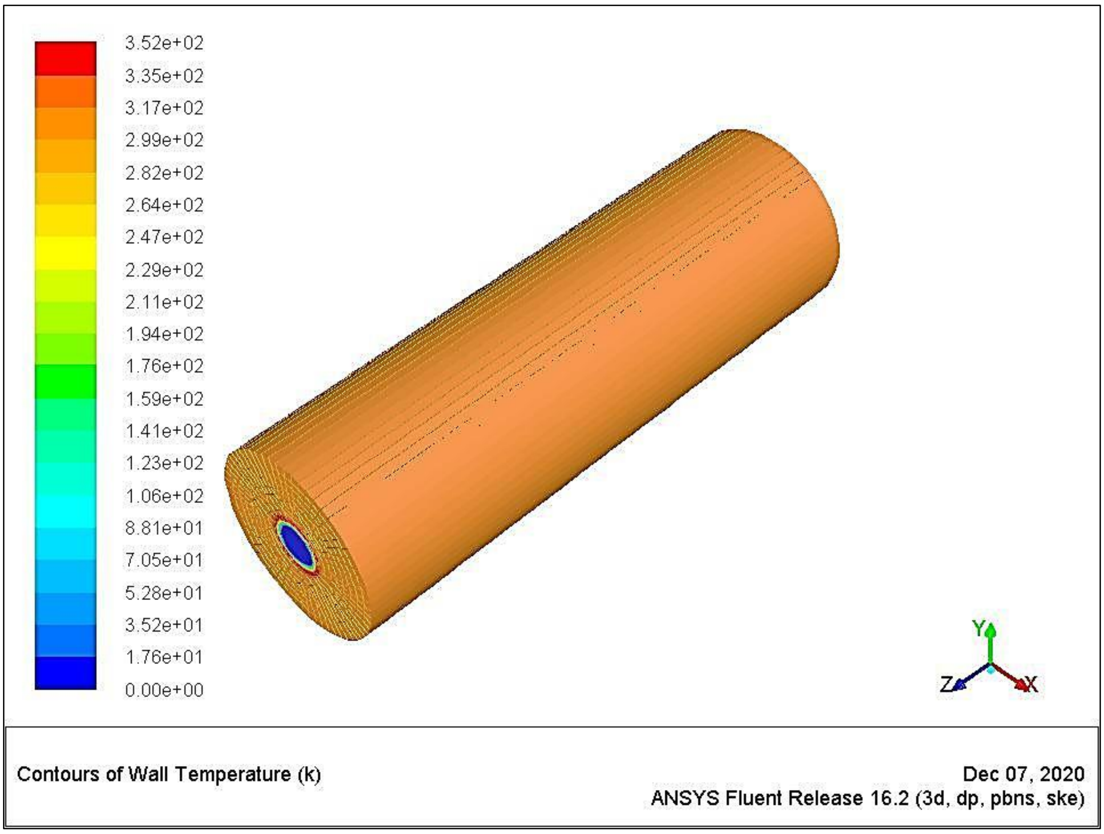


Fig.12. *Result Contour solution of Wall Temperature.*

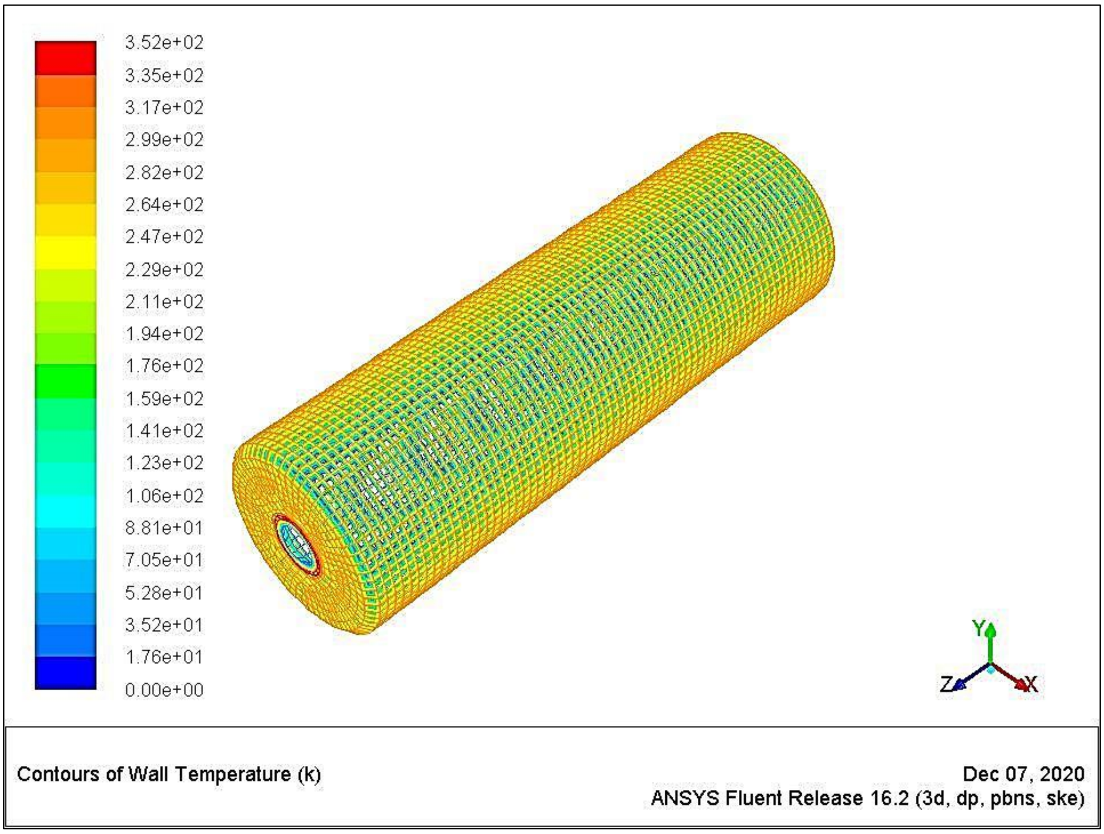


Fig. 13. *Result Contour solution of Wall Temperature in stream line.*

RESULTS CONCLUSION AND VALIDATION

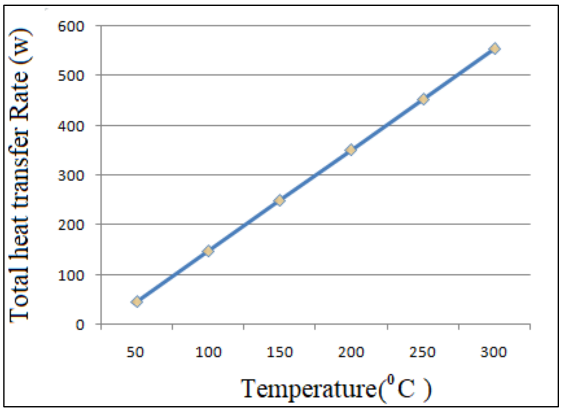
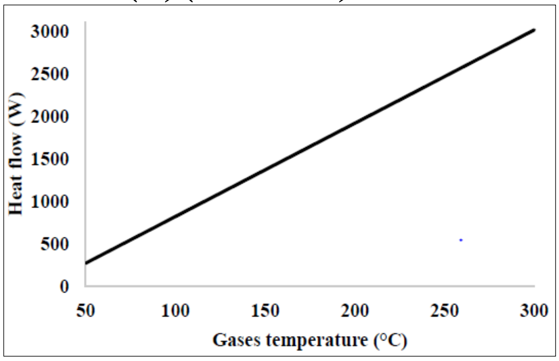


Fig. 14. *Graph result solution of inlet-outlet based on Total Transfer Rate (w).*

Fig. 15. *Graph Result solution of effect of exhaust gases temperature on heat rate (W) (Jaber et al.) [76].*



CONCLUSIONS

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:

- This work delivers an idea to use renewable energy.
- A novel transient heat transfer analysis method was introduced.
- Thermoelectric modules that work based on the principles of Seebeck theory were selected for both technical and economic reasons to accomplish the work at hand.
- TEGs can be a good competitively attached to the plants exhausts to potentially recover waste heat.
- Although the current price of thermoelectric modules is seemingly high, they are extraordinarily small. Hence, Software simulation is required before installations.
- Requires expertise persons for installations.
- All the internal parasitic components variations with temperatures were incorporated in the model for accuracy purposes.
- Copper layer in contact with TEG or material shows a improved results, as the conductivity of copper is high.
- Fluent set up model can provide a precise result, also reduces time and cost.
- This study gives an idea of restoration of the energy through heat transformation and the waste heat energy.
- TEG is compact design compared to Heat Exchanger, can be used in less space areas.

FUTURE DIRECTION OF RESEARCH:

- Similar investigations could be done with different types of TEGs for calibration purposes.
- The performance of the new set of TEGs with and without a DC-DC converter, and their consequent respective results, should be studied meticulously.
- This future study should then put a particular emphasis on a comparison of the two TEG energy harvesting system.
- To further investigate how this TEG energy harvesting system will actually perform under different electrical load conditions, i.e. light, normal, and heavy loads.
- A thorough and systematic cost-effective investigation of the TEG system and then perform a reliability and economic comparison with PV system setup for the same purpose of

energy delivery to remote residential regions in developing countries.

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