ISSN: 0974-5823 Vol. 7 No. 2 February, 2022

International Journal of Mechanical Engineering

Counter Flow Heat Exchanger Design Embedded in Solar Powered Air Conditioning System for SHUATS University

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Abstract. This research is designed to feature about the introduction of a heat exchanger design into the solar powered air conditioning system for cooling the rooms in SHUATS University. The eminent aim of this research is to provide a proficient cooling system for the University with a solar powered air conditioning system having a unique featured heat exchanger. The proposed system helps in overcoming the drawbacks of the traditional air-cooling system, which is of high cost, noise during operation and less efficiency in its functioning. Thus, an efficient solar powered air conditioning system with a heat exchanger designed is designed to overcome these issues is proposed. The proposed system can be utilized during any climatic conditions. It can also be used to cool the residential units during summer and provide warmth to the rooms during winter seasons. The proposed system offers a high coefficient of heat transfer, low cost of operation and verily low energy consumption. The proposed system is designed with a counter flow heat exchanger design to achieve ultimate cooling in all climatic conditions. In the system, a heat exchanger is utilized for cooling the hot water with the aid of a 20% cold ethylene glycol solution. This solution is retained at a desired temperature, which could be utilized in cooling and heating process. This heat exchanger is designed and embedded inside the solar air conditioning system, which is utilized to cool the Shuats University campus.

Keywords: Solar air cooling, heat exchanger, coefficient of heat transfer, renewable energy

Introduction

The driving source of technology is the energy. Without the presence of energy, the world will face many difficulties. The demand for energy grows with the growth of population (Shahed M. Farajat& M. Abu Zaid, 2020). About 75% of the energy supply around the world is consumed by the developed and industrial economies. About 25% of the entire energy is consumed by 75% of the total population around the world. Some of the challenges in power production are environmental disasters, radioactive materials, types of pollutions, forest annihilation, ozone layer demolition etc. These problems lead to the need of discovering alternative energy source for minimizing the power generation impacts in the environment for survival in the environment. Thus, the environmental future is based on the future of the energy production. For the past few years, the renewable energy source is preferred for many consumers as they produce lots of benefits such as low cost, clean source of power, green effect etc. Renewable energy production indicates the use of electrical generators, photovoltaic panels, waves, tides, wind etc., to generate electricity. The low emission power generated from renewable sources is regarded as the future hope for energy, as the non-renewable fuels are diminishing (Kamel Hooman, XiaoxueHuand&Fangming Jiang, 2017).

Heat exchangers are embedded in such systems to provide efficient cooling in these systems. A heat exchanger indicates a device, which is used to transfer thermal energy from one medium to another medium. Heat exchangers are utilized to cool and heat rooms inside the residential units. Shell and tube heat exchangers are efficient heat exchangers which could be employed with an operation similar to the plate heat exchanger. Shell and tube heat exchangers encapsulate a facile and robust design and characteristics and low maintenance and purchase costs. They exhibit a high rate of heat transfer, even though they need much space, when compared to a plate heat exchanger, which has the similar capacity of thermal exchange. The shell and tube heat exchanger comprise of a tube set, which is encapsulated within a container referred to as the shell. These tubes are cylindrical in shape and are collectively called as the tube nest r bundle. Each of them of them passes within a set of tube sheets or baffles referred to as tube stacks. One sheet is stable and the other sheet is dynamic for moving and it leads to thermal expansion during heating of the tube exchanger. The flowing solution between the tubes are referred to as tube side medium and outside the tubes, the solution is referred to as shell side medium. Each of this medium possesses one entry point and one exit point. The high-pressure fluid is the tube side medium and it is of small pressure, cost effective and high rated.

Shell and tube heat exchangers help assist in the transfer of thermal energy from one fluid to another fluid. These heat exchangers have the feature of low-pressure loss and thus can be applied in air conditioning systems. Air-cooled heat exchangers are only secondary options to the shell and tube heat exchangers in the context of occurrence frequency in petroleum and chemical processing operations. These units are meant for condensing or cooling process streams along with the cooling medium as the ambient air, which is preferred to water. Other design features of the shell and tube heat exchangers are cross-flow, concurrent flow and counter current flow-, single- and two-phase heat transfer and finned tubes. In addition to this, they also possess single, double or multiple configurations (thomasnet, 2020). Shell and tube heat exchangers comprise of a set of tubes encapsulating the fluid, which is either cooled or heated. In the proposed system, shell and tube heat exchangers are embedded in the solar air conditioning system for cooling the rooms of the SHUATS University. The paper encapsulates details about the SHUTAS University, the developed solar air conditioning system with the design of counter flow shell and tube exchanger embedded into the system for cooling the SHUATS University campus. The initial section of the paper includes the related works of the proposed system, the problem statement, input parameters of the design of heat exchanger, proposed solar air conditioning system with heat exchanger design the results of the research and further recommendations related to this study.

Related Works

Solar power supplied air conditioning system is considered as a hot topic in the field of energy building and conservation. Lin Zheng and his colleagues conducted an experiment on the solar power supplied air conditioning system coordinated with MEPCM (Micro Encapsulated Phase Change Material) storage system for evaluating the solar powered air conditioning system's efficiency and its association with the intensity of solar radiation. The indoor and outdoor environmental analysis system was utilized for gathering the functional data of the test room for verifying the cooling efficiency. The results showed that the thermal efficiency decreases with an increase in normal temperature difference. This transient efficiency was found to directly vary with the solar radiation. Also, the MEPCM cold storage system was found to maintain a stable temperature. However further research was found essential to explore about solar power supplied air conditioning system and its impact on the environment (Lin Zheng et. al, 2019). The shell and tube heat exchanger were found to be sustainable, simple and cost effective.

Mohammad Reza Saffarian and his associates conducted a numerical study on the shell and tube heat exchangers having multiple combined and cross-section tubes. In their proposed system, the shell and tube heat exchanger having a 25% baffle cut was utilized and tubes having various cross sections were analyzed. A shell and tube heat exchanger combined with circular and elliptical tubes were proposed. These tubes were analyzed for heat transfer and tube location for heat transfer. The results indicated that the tubes near to the shell had a high impact of heat transfer when compared with the tubes located near the shell's center (Mohammad Reza Saffarian et.al, 2019). The study indicates that the location of the tubes in the heat exchanger has an impact on the heat transfer coefficient and this study proposes further effective use of a good heat exchanger.

S. V. Kota Reddy and his colleagues conducted a research on the air conditioning system embedded with a ground source heat exchanger and analyzed its performance. The study was conducted with the weather conditions in the United Arab Emirates, to reduce the increase in demand for energy and decree of greenhouse gas emissions. In their proposed system, the vertical looping method was applied in the application of ground source heat exchanger that provides a direct exchange. The results were analyzed with the medium as sand, water and air. The best result was obtained with water as the medium. However, the system leads to the research on a best heat exchanger that opts for excellent results on all the mediums.

Ehsan Firouzfar and his colleagues conducted a study on the application of heat exchangers in various air-cooling systems and analyzed their effects in the past years. Based on their research, a thermosyphon heat exchanger or a heat pipe heat exchanger was found to provide savings on energy and enhancement of dehumidification for maintaining acceptable room conditions. Their research showed that the heat pipe heat exchangers are good source for energy savings and they were good heat transfer devices. However, their research requires understanding of the benefits of these systems for savings on energy (Ehsan Firouzfar et. Al, 2011).

Problem Statement

There are many climatic changes observed in the past years because of increase in temperature on earth or global warming due to increased use of fossil fuels, refrigerants etc. People rely on air conditioners for their comfort during hot climatic conditions. Thus, air conditioning became an effective source for cooling in residential and commercial units. Increase in utilization of air conditioners has many problems and challenges like high energy cost, maintenance cost, leakage, blocks, noise etc. Heat exchangers are employed in air conditioning systems for transferring heat between two different mediums and create cooling in the output air of the system. In order to resolve the problems and challenges associated with the air conditioning system. People are now using renewable energy sources like solar energy, wind energy etc for fulfilling their energy needs. Heat exchangers are employed in solar powered air conditioning systems for offering efficient cooling. However, there are problems arising out of the type of heat exchangers employed in solar powered air conditioning systems.

Earlier solar powered air conditioning system utilized Earth to air heat exchangers for cooling. In this system, ground acts as the heat sink in the winter and summer seasons. The soil temperature is lower when compared to the ambient temperature in summer and this soil temperature is much higher during the winter season. Excess heat of the building is transferred to ground with the help of horizontal ground pipes, thus minimizing the room temperature during summer. During winter, these pipes are meant for heating the ventilated air, thus minimizing the heating in buildings (M. Santamouris, 2006). The block diagram of the air conditioning system with earth to air heat exchanger is shown below

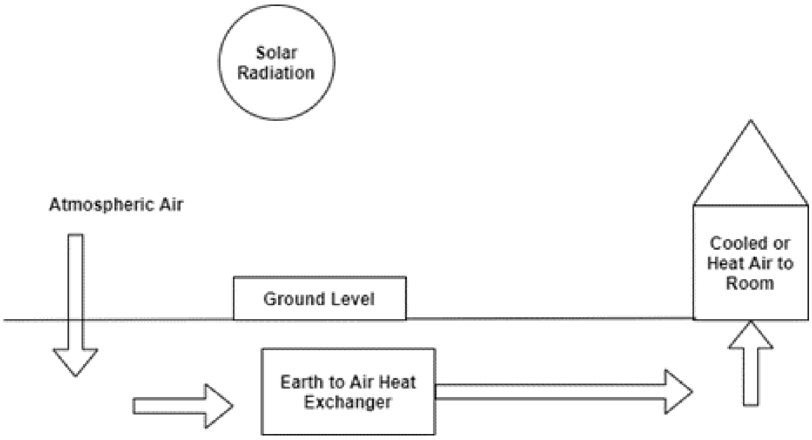

Fig. 1 Air Conditioning System with Earth to Air Heat Exchanger

However, the problem with the use of earth to air heat exchangers is that they must suit to certain conditions before installation into earth such as the applied control system, the air speed of the pipes, the diameter and length of the pipes and the heat exchanger's depth. Also, the installation and maintenance cost for the earth to air heat exchanger is high. Hence to minimize these problems, the shell and tube heat exchanger is utilized in the proposed solar powered air conditioning system applied to SHUATS University.

Proposed System

In the proposed system, a counter flow type heat exchanger is constructed and embedded inside the solar power supplied air conditioning system. The shell and tube heat exchanger that induces an opposite flow of fluids in the proposed system is employed. In this type of heat exchanger, the fluids flow along the tubes in the heat exchanger in opposite direction. In this heat exchanger, a higher difference in temperature is observed. Efficiency is enhanced with corrugations or fins, which induces fluid flow turbulence or resistance. The surface area is increased with a decrease in resistance (energyxchangeml, 2017). The following figure represents the proposed system, which is used to cool the rooms of the SHUATS University.

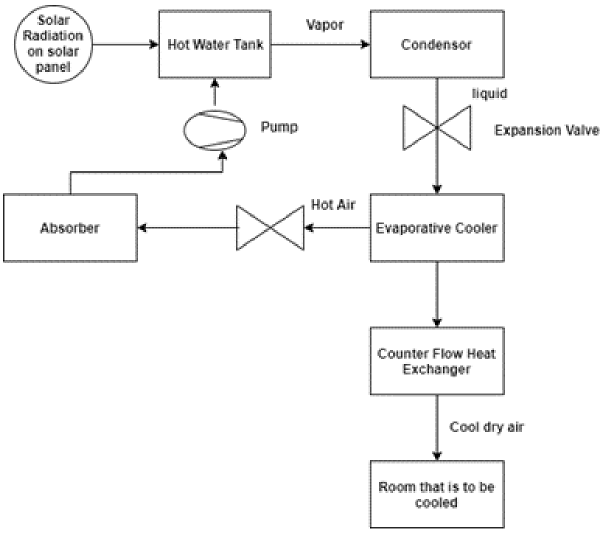

Fig. 2 Block Diagram of the Proposed System

The solar radiation falls on the solar panel and this heat is used to heat the water in the water in the hot water tank. The vapors from the hot water tank fall in the condenser. The condenser converts the heat vapors into liquid. The liquid flows inside the evaporative cooler, where the liquid is cooled and then passes to the counter flow heat exchanger that transfers the cool dry air to cool the rooms of the University. The hot air from the evaporative cooler passes through a valve into the absorber and from the absorber the heat vapors are pumped back into the hot water tank. The counter flow heat exchanger embedded here is the shell and tube heat exchanger. The construction of this heat exchanger is essential in the solar power supplied air conditioning system for cooling the rooms of the Shuats University.

Input Parameters

Conventional solar heat absorption system comprises of heat exchangers such as absorber, evaporator, condenser and generator. The coefficient of performance (COP) is impacted by mass and heat transfer efficiency of the above four components. The commercial and industrial application of heat exchangers allows for new designs of heat exchangers in solar absorption systems. Thus, a shell and tube heat exchanger are constructed and embedded into the proposed system. The operating condition such as temperature and pressure are essential to be considered during selection of a heat exchanger. The boundary conditions indicate that the coolant here is the ethylene glycol solution in the heat exchanger. The overall heat transfer equation is given by,

$$Q = Ua\Delta T_m$$

Where,

Q-> Transferred heat per unit time (W)

A-> Area of heat transfer (m^2)

U-> Overall heat transfer coefficient (W/m^2) °F

ΔT_m-> Mean temperature difference (°F)

Design Procedure for Heat Exchanger

Initially define the temperatures, fluid flow rates and heat transfer rate. Collect the information on physical properties such as thermal conductivity, viscosity and temperature of fluids. Choose the type of heat exchanger to be used in the proposed system. Here a shell and tube heat exchanger are used. Choose the value for overall heat transfer coefficient, U. Calculate the mean temperature difference with the help of the below equation.

$$\Delta T_m = [(T_1\text{-}t_2) – (T_2\text{-}t_1)]/ \ln (T_1\text{-}t_2/T_2\text{-}t_1)$$

Where

T_1-> Inlet temperature of the hot fluid (°F)

T_2-> Outlet temperature of the hot fluid (°F)

t_1-> Inlet temperature of the cold fluid (°F)

t_2-> Outlet temperature of the cold fluid (°F)

Then the total heat transfer area is calculated and decision on the heat exchanger layout is made. The individual values are then calculated. The total heat transfer coefficient is calculated and its difference is observed. If the found value and the estimated value are not equal, then put equal the calculated and estimated value and then again find the entire heat transfer area. Then note down the pressure drop allowance values in the heat exchanger and design the heat exchanger accordingly. Here we must construct a shell and tube heat exchanger for cooling hot water using ethylene glycol as the coolant. The flow rate of ethylene glycol is 300 gpm with a temperature rise from -10°F to 15°F.

Boundary conditions for designing the heat exchanger

Temperature of hot water = 80^0F

Volumetric flow rate of hot water = 400gpm

Inlet temperature of the fluid into the heat exchanger = -10°F

Outlet temperature of ethylene glycol from the heat exchanger = 15°F

Volumetric flow rate of ethylene glycol = 300gpm

Pressure drop allowance for each stream = 10 psi

The construction of a shell and tube heat exchanger comprises of five eminent concepts such as; finding of the heat transfer area, tubes' number, tube diameter, layout, length and the available number of shell and tube passes. There are seven rooms in the University in zone 1 and accordingly the design and analysis of the heat exchanger is made. The input parameters of the University's building are latent heat value, humidity, air flow, heat and temperature. The input parameters of the heat exchanger design are temperature of water, flow rate of water, inlet temperature of the coolant (ethylene glycol), ethylene glycol's outlet temperature and flow rate and pressure in the system.

CFD Analysis and Synthesis

CFD indicates Computational Fluid Dynamic analysis. It initiates with the desired mesh and geometry for designing the system. A non-simplified model is utilized for CFD analysis. Meshing assists in the division of the domain into smaller units. This model initiates with the boundary defining, boundary conditions and modeling of the entire system. The analysis and results are made finally. CFD analysis is done for assembly model of the fluid. The symmetric view of the model is fetched off the geometry and it minimizes the Ansys's load. Meshing of the symmetry model is done with the Ansys simulation and the entire model is cleaved into smaller elements. Ansys fluent simulation is used in modeling of the heat exchanger. Boundary conditions of the design are defined by utilizing Kern's method. Based on CAD tools, the design of the counter flow exchanger is done and analysis is made on its working. The shell and tube heat exchanger designed for the proposed system is given below.

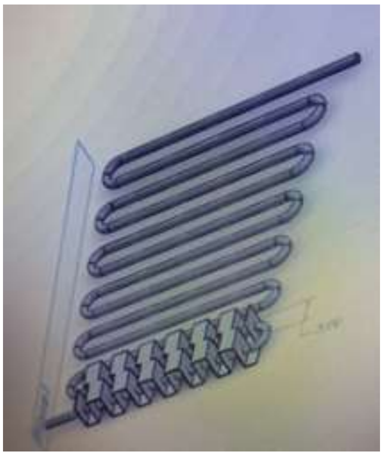

Fig 3. Number of tubes represented in the heat exchanger design

The quantity of tubes designed in the shell and tube exchanger of the proposed system is represented here. The effective condition for an efficient heat transfer is to have a highest number of tubes within the shell for increasing the turbulence in a shell and tube heat exchanger. The thickness of the tube must be strong enough for withstanding the internal pressure in addition to the corrosion allowance. Materials used for tube design can be of copper, nickel or bronze alloys, stainless steel, brass etc.

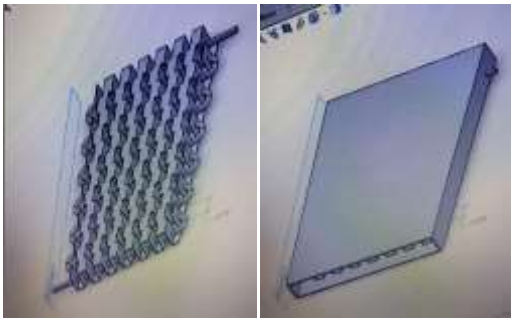

Fig 4, 5. Number of shells represented in the figure 4 and overall design of the shell and tube heat exchanger is indicated in figure 5

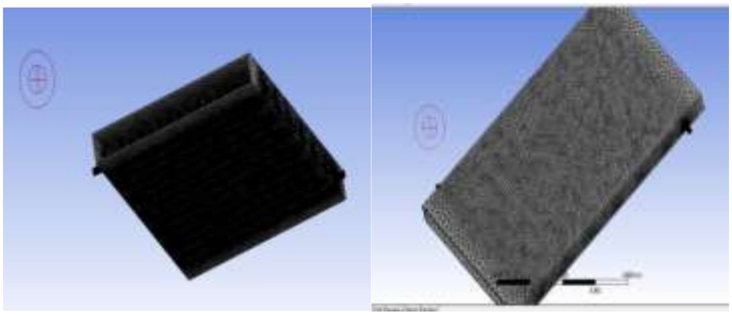

Fig 6, 7. Design generated by mesh analysis

The shell fluid flows within the shell and the tubular bundle, which is encapsulated within the shell. The diameter of the shell is chosen in accordance with the tubular bundle. Shells are fabricated using steel pipes with corrosion resistance. The shell thickness designed in the heat exchanger is 3/8 inches, which is able to withstand an operating pressure of up to 10psi. Shell diameter is minimized by using longer tubes. The shortest distance between the centers of the adjacent tubes is indicated as the tube pitch. The arrangement of the tubes can be either square, triangular or rotated square. Based on the given boundary conditions, the tubes in the proposed heat exchanger are arranged in a rotating square pattern. Tube count indicates the maximum number of tubes, which could be encapsulated in a shell ID. Here the outer diameter of the tube is ¾ or 1. The tube count relies on parameters such as; design pressure, heat exchanger type, tube passes, layout of the tube, tube pitch, tube outer diameter and shell ID.

To minimize scale formation and to gain a higher heat transfer coefficient, the number of tube passes is selected for obtaining the needed tube side velocity of the fluid. The values of the tube passes vary from 1 to 16 and commonly employed values are 1, 2 and 4. Here the value employed is 4. The tube sheets act as a separating unit between the shell and tube fluids. Furthermore, the baffles in the heat exchangers are used to obtain high heat transfer coefficient and fluid velocity.

Results and Discussion

All the boundary conditions were applied and the needed shell and tube heat exchanger is designed as follows.

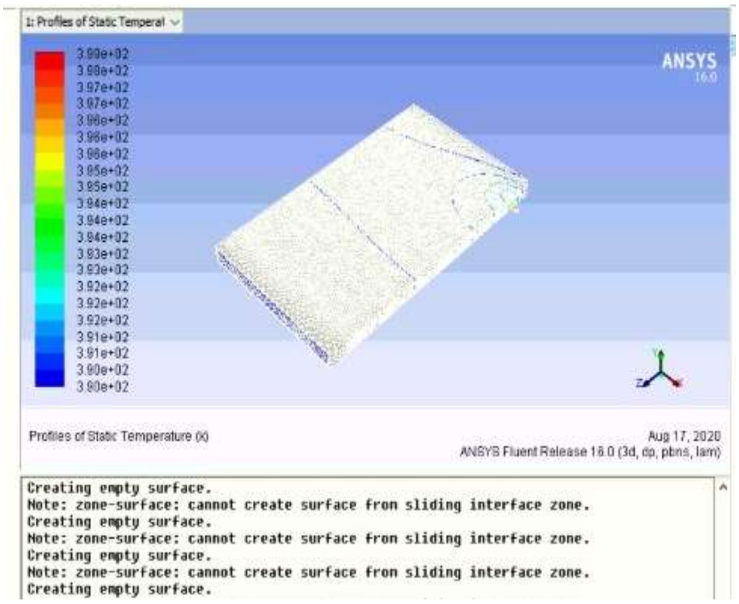

Fig. 8 Design of Shell and Tube Heat exchanger

All the calculations were made with the iterations defined in the shell and tube heat exchanger design for the proposed system. The temperature profile of the heat exchanger is shown below, which is generated by using CAD tools. There is no uniformity in the heat transfer within the outlet and inlet of the shell. The heat transfer is uniform in the middle of the heat exchanger. This is because of the application of counter flow model of heat exchanger in the system.

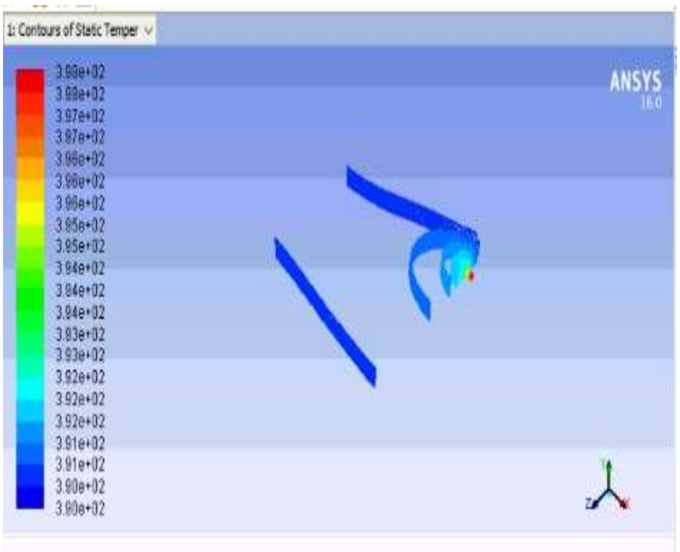

Fig. 9 Temperature profile

By applying the pressure and velocity plots, the shell and tube heat exchanger for the proposed system is defined as follows.

Fig. 10 Pressure plots

The pressure profile of the heat exchanger is shown above. This pressure plot indicates the representation of the fluid function within the tubes and shells. The pressure o the shell's inlet is higher and reduces throughout the profile of the shell, thus indicating a reduction in the fluid velocity.

Fig. 11 Velocity plots

Conclusion

Thus, the results indicate that the output temperature is based on the material, the inlet and outlet pressure or temperature of the shell and tube heat exchanger and thickness of the tubes in the heat exchanger. There are multiple benefits gained out of the shell and tube heat exchangers in solar, commercial and industrial sectors, because of its compact structure and improved heat transfer characteristics. The tube is designed in a spiral shape and inclined at a helical angle 30 degree. Calculations are performed based on the effectiveness of heat transfer. Hit and trial method is used for geometry optimization. CFD tools are utilized for maintaining the coolant's outlet temperature. Baffle spacing, tube length and pitch spacing are eminent to design the heat exchanger for the proposed system. Furthermore, heat transfer relies on the coolant properties. CFD model is used to maintain the simulation cost. The CFD tool offered a better prototype for the study. The results of this study are in accordance with the given boundary conditions for designing the heat exchanger. The only challenge in the study is to match the effectiveness and the result of the study.

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