ENERGY AND HEAT TRANSFER BEHAVIOR OF SOLAR FLAT PLATE COLLECTOR BY NATURAL CONVECTION

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Abstract - Energy is essential for the economic growth and social development of any country. The quality of life is closely related to energy consumption, which has continuously increased over the last few decades in developing countries. A solar thermal collector collects heat by absorbing sunlight. A collector is a device for capturing solar radiation. Solar radiation is energy in the form of electromagnetic radiation from the infrared (long) to the ultraviolet (short) wavelengths. A simple flat plate collector consist plate in an insulated box covered with transparent sheets. The most important part of a solar collector is the absorber, which usually consist of several narrow metal sheets aligned side-by-side. The fluid used for heat transfer generally flows through a metallic pipe, which is connected to the absorber strip. In plate-type absorber, two sheets are sandwiched together allowing the medium to flow between the two sheets. The outer casing which provides mechanical strength to the equipment is insulated to reduce the heat losses from back and side of the collector. Experimental investigation will be done on straight riser tube and zigzag riser tube on heat transfer enhancement, frictional factor.

The heat transfer in the tube with zigzag riser tube is should be more as compared to straight riser tube. The increase in relative heat transfer coefficient of water for zigzag riser tube is higher % than straight riser tube. The relative decrease in frictional factor for zigzag riser tube than straight riser tube. The relative Reynolds number for zigzag riser tube higher than straight riser tube. The relative increase in Nusselt's number for zigzag riser tubes higher than straight riser tube. If we increase the mass flow rate in the form of LPM the result for parameter temperature, pressure, and velocity will must be increase. The zigzag riser tube is better efficient than the straight riser tube.

Key Words: Solar Flat Plate Collector, straight riser tube, Natural convection, relative heat transfer coefficient, zigzag riser tube, CFD etc.

1.INTRODUCTION

Energy is essential for the economic growth and social development of any country. The quality of life is closely related to energy consumption, which has continuously increased over the last few decades in developing countries. For increasing the energy output of solar flat plate, it is very essential to increasing the amount of solar radiation. The energy output of solar-thermal systems using flat plate collectors can be used for heating water. Increasing the amount of solar radiation received by the collector improves heating of cooling water. In the recent year different ways are adopted for improving the power output of solar plate. The power output of solar flat plate depends on the incident beam of radiation i.e. available energy, it is essential to know the actual energy input of solar radiation in each location to establish the energy budget of a solar collector or any other solar-powered process, for these different theories were developed. This study attempted for analysis of heat transfer in riser tube of solar water with the used computational fluid dynamics. In this study the solar flat plate collector is taken under study. The heat transfer analysis of solar flat collector riser with different shape geometries is decide to carried out experimentally and experimental results is compared with CFD for further analysis. In addition to the energy cost saving on water heating, there are several other benefits derived from using the suns energy to heat water. More solar water heaters come with an additional water tank, which feeds the conventional hot water tank. Using benefit from the larger hot water storage capacity and the reduced like hood of running out of hot water. Hot water is essential both in industries and homes. It is required for taking baths, washing clothes and utensils, and other domestic purposes in both the urban and rural areas. Hot water is also required in large quantities in hotels, hospitals, hostels, and industries such as textile, paper, and food processing of dairy and edible oil. Solar water heating system can heat water from ambient temperature to temperature over 90^{0}C depending on the collector type employed in each locality. Using solar collector to heat the water can easily attain required temperature.

Two basic ways to capture the energy

Solar ray can be distinguished according to their wavelength, which determine visible light, infrared and ultraviolet radiation. Visible light constitutes about 40% of the radiated energy infrared 50% and ultraviolet the remaining 10%. Most of the infrared are near infrared 'or ―short-wave infrared rays, with wavelengths shorter than 3000 nanometers, so they are not considered ― thermal radiation‖. The sun 's primary benefit for most people is light, the use of which can be improve in lighting to reduce energy consumption. This area of development, called day lighting, is one of the avenues to reducing energy consumption in building. solar irradiative energy is easily transformed into heat through absorption by gaseous, liquid, or solid materials. Heat can then be used for comfort, in sanitary water heating or pool water heating, for evaporating water and drying things (notable crepe and food), and in space heating, which is major driver of energy consumption. Heat can also be transfer into mechanical work or electricity, and it can run or facility chemical or physical transformation and thus industrial processes or the manufacture of various energy vectors of fuels, notably hydrogen. however, solar radiation can also be viewed as a flux of electromagnetic or photons. Photons from the sun are highly energetic, and can promote photoreaction such as photosynthesis and generate conduction of electrons in semiconductors, enabling the photovoltaic conversion of sunlight into electricity. Other photoreaction is also being used, for example photo catalytic water detoxification. Note that the two fundamental methods to capture energy from the sun heat and photoreaction can also be combined in several ways to deliver combined energy vectors- e.g. heat electricity. thus, from the two basic ways of capturing the sun; s energy, apart from day lighting i.e. heat and photoreaction we, distinguish four main domains of application: photovoltaic electricity, heating (and cooling), solar thermal electricity, and solar fuel manufacture.

2. Literature Review

Sanjay Kumar Sharma et.al [1] investigated Fabrication and Experimental of V- Through Flat Plate Collector in Hot Climatic Conditions of Rajasthan. The research work was to improve the thermal performance of V-through flat plate collectors using a novel cost-effective enhanced heat transfer technique. The system was designed for 30 litter water capacity and the 5-litter water inside & outside of the tank for per hour. This was accomplished by employing an aluminum sheet placed at the base within the system to induce a gradient of heat capacitance. Purpose of project was to develop a low-cost solar water heater. Materials were selected based on cost, performance, and accessibility in Jaipur (Rajasthan). Experimental measurements show the water in the tank was heated by the solar energy being absorbed by the solar collector. The water temperature measurements at different heights in the storage tank show the thermo siphon effect. All the thermo-physical properties of the absorber plate and the working fluid are computed in time dependent mode. The passing heat transfer coefficients are also computed in real time. This domestic V- Through flat plat collector system with a capacity of 100 liters per day can achieve significant energy savings in hot climate countries. Results specify that the project of the thermo siphon solar water heating system was a success. More experimental investigations are needed to confirm the efficiency of the proposed model by testing for different cases.
BAA Yousef et.al. [2] studied Performance analysis for flat plate collector with and without porous media. The work involved a theoretical study to investigate the effect of mass flow rate, flow channel depth and collector length on the system thermal performance and pressure drop through the collector with and without porous medium. The solution procedure was performed for flat plate collector in single and double flow mode. The analysis of the results at the same configuration and parameters shows that the system thermal efficiency increases by 10-12% in double flow mode than single flow due to the increased of heat removal and increase by 8% after using porous medium in the lower channel because of the increase of heat transfer area. At the same time the pressure drop will be increased. All collectors show improved efficiency obtained when the collector operates at relatively high flow rates, and at relatively low collector temperature rise since the collector losses will be less in low temperature difference. A mathematical simulation to predict the effect of different parameters on system thermal performance and pressure drop, for flat plate collector in single and double flow mode with and without using a porous media have been conducted. It is found that increasing the mass flow rate through the air heaters results in higher efficiency but also it is increased pressure drop. The double flow is more efficient than the single flow mode due to the increased heat removal for two channels compared to one flow channel, and the using of porous media increase the system efficiency and the outlet temperature hence the use of porous media increases the heat transfer area. This increment will result in the increase of the pressure drop thus increasing the pumping power expanded in the collector.
Aliasghar Owla Iveliet. al. [3] performed Numerical analysis to optimize the geometrical dimensions of the solar energy storage tank considering thermally stratified and increasing tank efficiency. Due to continuous nature of solar energy, solar energy systems require a sub-system to accumulate and reserve energy. In the present study, a thermal energy storage tank has been designed and optimized for supplying hot water for industrial section. At the first step, assuming a Storage tank with full mixture, the area of collector, the volume of the storage tank and solar energy portion have been calculated by TRANSYS software. In the following, the storage tank was simulated through computational fluid dynamics (CFD), using commercial CFD code (ANSYS CFX). Implementing CFD results, the optimization of height to diameter ratio of the storage tank was conducted to improve the quality of thermal stratification inside the tank. It is shown that optimizing the ratio of height to diameter of the tank has significant impact on thermal stratification and not only improves the energy saving efficiency of the storage tank but also increases the solar energy fraction in supplying required thermal load. The main objective of the present study was to find the optimum ratio of height to diameter of the storage tank. The effects of storage tank height on thermal stratification were discussed and proved that by optimizing this dominant parameter, it is feasible to improve the value and quality of thermal stratified inside the tank so which it can be used in hours without accessible solar energy. In addition, optimizing the storage tank design in the present study, the annual solar energy portion is increased from 75% up to 95%, if optimized R value is implemented in the design.
B. N. Mankaret. al.[4] investigated Experimental Investigation of Flat Plate Solar Water Collector by Flow Pulsation and Metal Blocks. This study investigates thermal performance of a flat plate solar collector. The process involves the use of aluminum metal blocks and forced pulsation of incoming fluid to determine the performance characteristics of temperature. Investigations were made to study performance characteristics of solar flat plate collector provided with set of aluminum metal blocks, runner/copper tubes, absorber plate and horizontal–rectangular channel. In the present work, experimental test was carried out for two different conditions. Improved thermal efficiency is achieved than for a steady flow condition. When a flat plate collector was provided with aluminum metal blocks, it shows the improvement in temperature of water. When a flat plate collector is provided with aluminum metal blocks and making the inlet flow of the

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fluid pulsating, the improvement in thermal performance is observed as compare to conventional flat plate collector. As creating the pulsation inside the inlet manifold, disturbance in the fluid flow occurs so fluid get a chance to mix in a better way so heat transfer rate increases. The time required to heat fluid is less than conventional collector.

R. Herrero Martín et. al. [5] had done experimental heat transfer research in enhanced flat-plate solar collectors. Enhancement techniques can be applied to flat-plate liquid solar collectors towards more compact and efficient designs. Tube-side enhancement passive techniques can consist of adding additional devices which are incorporated into a smooth round tube, modifying the surface of a smooth tube, or making special tube geometries. For the typical operating flow rates in flat-plate solar collectors, the most suitable technique is inserted devices. Wire coils were selected for enhancing heat transfer. This type of inserted device provides better results in laminar, transitional, and low turbulence fluid flow. To test the enhanced solar collector and compare with a standard one, an experimental side-by-side solar collector test bed was designed and constructed. The testing set up was fully designed following the requirements of EN12975-2 and allow us to accomplish performance tests under the same operating conditions. In this work the preliminary results obtained are presented and the standardized efficiency curve is shown for both tested solar collectors. A relevant improvement of the efficiency has been reported and quantified through the useful power ratio between enhanced and standard solar collectors. Wire-coil devices can be successfully inserted within the flow tubes in solar water heaters for enhancing heat transfer rate**.**

3. Methodology

Solar heaters, or thermal system, provide environmentally friendly heat for household water heating and the heating of swimming pool. Such system collects the sun energy to heat a fluid. The fluids then transfer solar heat directly or indirectly to your water or pool.

3.1 Solar collector

A solar thermal collector collects heat by absorbing sunlight. A collector is a device for capturing solar radiation. Solar radiation is energy in the form of electromagnetic radiation from the infrared (long) to the ultraviolet (short) wavelengths. If radiation is converting electricity directly, the collector is known as a PV collector but since the emphasis is on collectors for solar water heating, the word solar collector is meant to be solar thermal collector.

3.2 Flat Plate Collector

Flat-plate collectors, developed by Hottel and Whillier in the 1950s, are the most common type. They consist of a dark flat-plate absorber, a transparent cover that reduces heat losses, a heat-transport fluid (air, antifreeze, or water) to remove heat from the absorber, and a heat insulating backing. The absorber consists of a thin absorber sheet (of thermally stable polymers, aluminum, steel, or copper, to which a matte black or selective coating is applied) often backed by a grid or coil of fluid tubing placed in an insulated casing with a glass or polycarbonate cover. In water heat panels, fluid is usually circulated through tubing to transfer heat from the absorber to an insulated water tank. This may be achieved directly or through a heat exchanger. Most air heat fabricators and some water heat manufacturers have a completely flooded absorber consisting of two sheets of metal which the fluid passes between. Because the heat exchange area is greater, they may be marginally more efficient than traditional absorbers. Sunlight passes through the glazing and strikes the absorber plate, which heats up, changing solar energy into heat energy. The heat is transferred to liquid passing through pipes attached to the absorber plate. Absorber plates are commonly painted with "selective coatings", which absorb and retain heat better than ordinary black paint. Absorber plates are usually made of metal—typically copper or aluminum—because the metal is a good heat conductor. Copper is more expensive, but is a better conductor and less prone to corrosion than aluminum.

Fig 3.1 flat plate collector

3.3 Evacuated Tube Collector

Most vacuum tube collectors in use in middle Europe use heat pipes for their core instead of passing liquid directly through them. Direct flow is more popular in China. Evacuated heat pipe tubes (EHPTs) are composed of multiple evacuated glass tubes each containing an absorber plate fused to a heat pipe. The heat is transferred to the transfer fluid of a domestic hot water or hydronic space heating system in a heat exchanger called a "manifold". The manifold is wrapped in insulation and covered by a protective sheet metal or plastic case. The vacuum inside of the evacuated tube collectors have been proven to last more than 25 years, the reflective coating for the design is encapsulated in the vacuum inside of the tube, which will not degrade until the vacuum is lost. The vacuum that surrounds the outside of the tube greatly reduces convection and conduction heat loss, therefore achieving greater efficiency than flat-plate collectors, especially in colder conditions. This advantage is largely lost in warmer climates, except in those cases where very hot water is desirable, e.g., for commercial processes. The high temperatures that can occur may require special design to prevent overheating.

Fig. 3.2 Evacuated Tube Collector

3.4 Bowl

A solar bowl is a type of solar thermal collector that operates similarly to a parabolic dish, but instead of using a tracking parabolic mirror with a fixed receiver, it has a fixed spherical mirror with a tracking receiver. This reduces efficiency, but makes it cheaper to build and operate. Designers call it a fixed mirror distributed focus solar power system. The main reason for its development was to eliminate the cost of moving a large mirror to track the sun as with parabolic dish systems

3.5 Parabolic Dish

With a parabolic dish collector, one or more parabolic dishes concentrate solar energy at a single focal point, similar to the way a reflecting telescope focuses starlight, or a dish antenna focuses radio waves. This geometry may be used in solar furnaces and solar power plants. The shape of a parabola means that incoming light rays which are parallel to the dish's axis will be reflected toward the focus, no matter where on the dish they arrive. Light from the sun arrives at the Earth's surface almost completely parallel. So, the dish is aligned with its axis pointing at the sun, allowing almost all incoming radiation to be reflected towards the focal point of the dish. Most losses in such collectors are due to imperfections in the parabolic shape and imperfect reflection. Losses due to atmospheric scattering are generally minimal. However, on a hazy or foggy day, light is diffused in all directions through the atmosphere, which reduces the efficiency of a parabolic dish significantly.

4. Experimentation

4.1 Experimental Setup

A simple flat plate collector consist plate in an insulated box covered with transparent sheets. The most important part of a solar collector is the absorber, which usually consist of several narrow metal sheets aligned side-by-side. The fluid used for heat transfer generally flows through a metallic pipe, which is connected to the absorber strip. In plate-type absorber, two sheets are sandwiched together allowing the medium to flow between the two sheets. The outer casing which provides mechanical strength to the equipment is insulated to reduce the heat losses from back and side of the collector.

Fig. 4.1 : Solar Flat plate collector with straight riser tube

4.2 Design of New Type of Solar Collector

The collector can reach temperature up to 2000c when no liquated flow through it and therefore all the material used must be able to resist this high temperature. the absorber is usually made of metallic material such as cooper, steel, or aluminum. The collector housing can be plastic, metal or wood and the glass front cover must be sealed so that heat dose not escape, and the collector itself is protected from dirt, insect, or humidity. The collector housing is highly insulated at the back side to reduced heat losses. Still the heat losses due to the temperature difference between the absorber and ambient air result in convection and radiation losses. The convection losses are caused by the spacing between the glass cover and the plate, while the radiation losses are caused by the exchange of heat between the absorber and the environment.

Any absorber plate must perform three functions: absorb the minimum possible amount of solar irradiance, transfer this heat into the working fluid at a minimum temperature loss and lose a minimum amount of heat back to the surroundings.

Solar irradiance passing through the glazing is absorbed directly onto the absorber plate. Surface coating that has a high Absorptivity value for short wavelength light are used on the absorber. Paint or plating is used and the resulting black surface will absorb almost over 95% of the incident radiation. the second function of the absorber plate is to transfer the absorber energy into a heat transfer fluid at a minimum temperature difference. This is achieved by conduction the absorbed heat to tube that contain the heat transfer fluid. The heat transfer fluid is generally water. Transferring the heat absorbed on the absorber surface into the fluid gives rise to heat losses. Liquid collector absorber plates consist of a flat sheet of metal with tubes spaced 120 mm apart and attached to it. The sheet of metal absorbs most of the solar irradiance and acts as a carrier to bring the absorbed heat into the fluid .in an efficient system the absorber sheets is made of a material with high thermal conductivity. the tubes are not spaced far too apart otherwise a much lower temperature will occur halfway between them. The difference between the earlier straight riser tube collector and new zigzag riser tube collector is the riser tube configuration. Although it serves the same function the physics is difference from the conventional once. In this collector the heat transfer heat conducted from the fins to the zigzag riser tube first and then convection to the fluid from zigzag riser tube. Whereas in the conventional collector the heat is conducted to the fluid from the takes place.

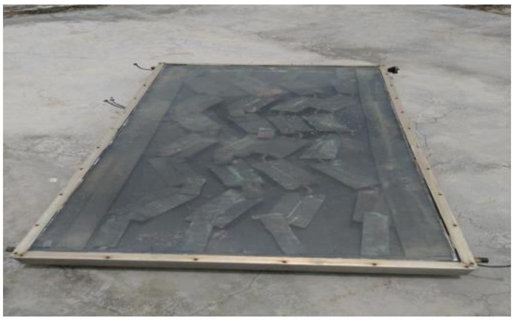
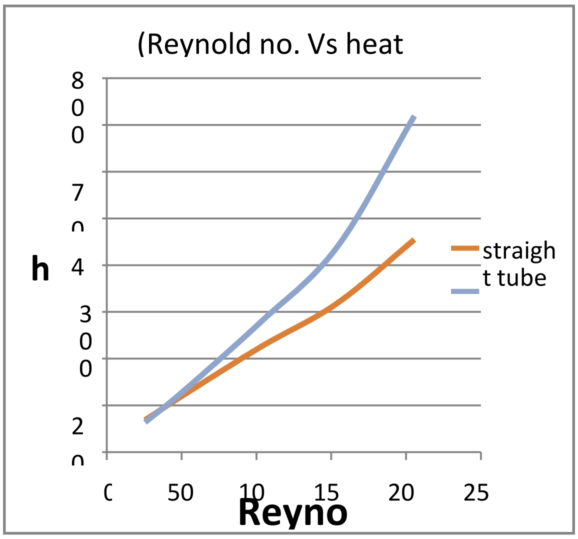


Fig. No. 4.3: Flat plate collector with zigzag riser tube

This work is primarily concerned with the possibility of replacing the conventional straight riser tube with zigzag riser tube. So, only the important practical parameter like the steady state outer temperature and the pressure drop can be compared.

5. Results and Discussion

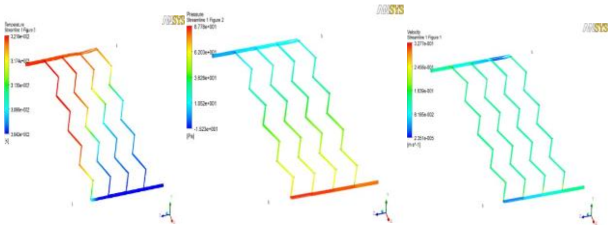
The experiment was carried out with the straight tube and zigzag riser in passive heat transfer enhancement methods. Heat transfer coefficient and friction factor are calculated for all cases. Parameter were plotted for Reynolds no. and mass flow rate. Following graphs are plotted to compare the performance of different used in tube.

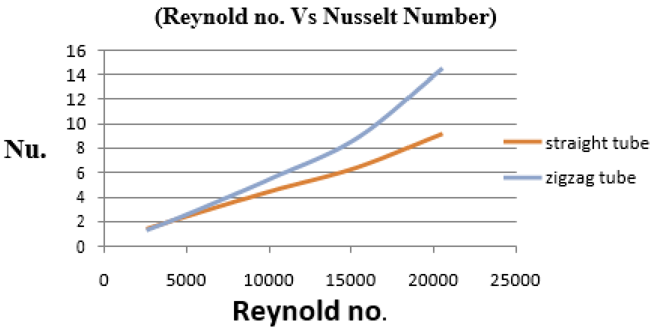


Graph. 1 Reynolds Number Vs Heat Transfer Coefficient

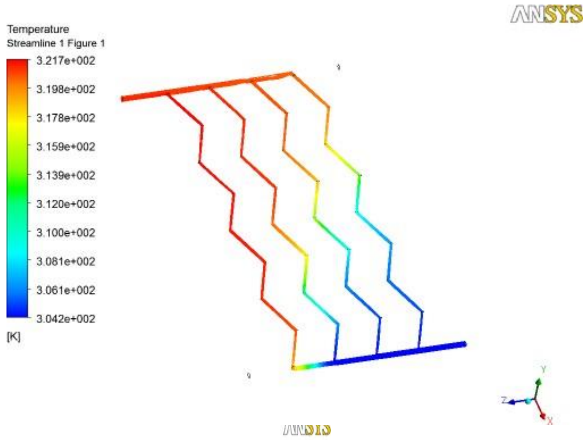
From the above graph, it is observed that the heat transfer coefficient increases with increase in Reynolds Numbers. As Reynolds number increase, the water flow will cause more turbulence, so due to which the heat transfer rate will increase. From the graph 1 it is observed that the tube with straight riser gives less heat transfer coefficient than the zigzag tubes. Zigzag riser tubes create more turbulence in tube which increases the heat transfer coefficient as compared to straight riser tube.

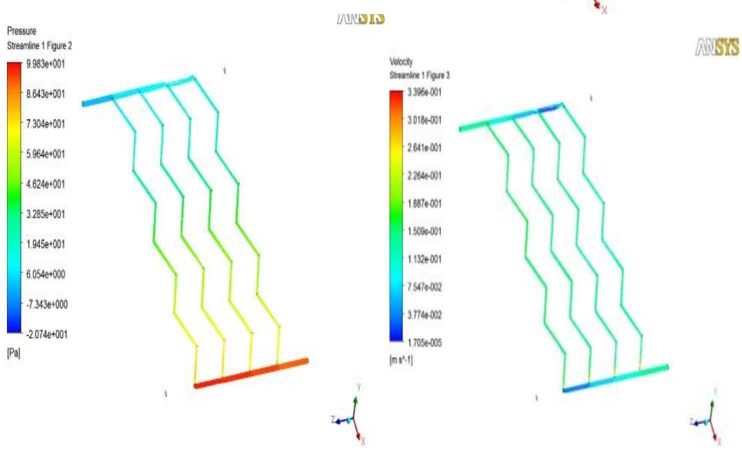
From the below graph, it is observed that there is increase in Nusselt number with Reynolds number. As Reynolds number increase the water flow will cause more turbulence due to which transfer rate will increase. As heat transfer coefficient is directly proportional to Nusselt number, Nu= hD/k i.e. increase in heat transfer coefficient increase the Nusselt number. From graph it is observed that maximum Nusselt number is obtained for zigzag riser tube as compared to straight riser tube. Minimum Nusselt number is obtained for straight riser tubes without any modification.



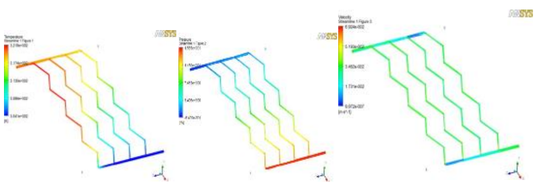


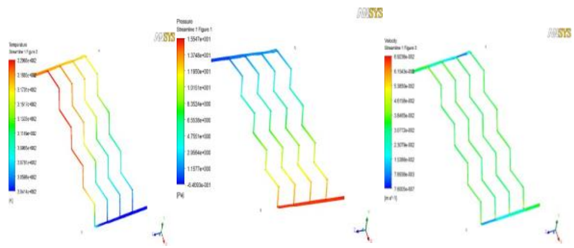
Graph 2 Reynolds Number Vs Nusselt number



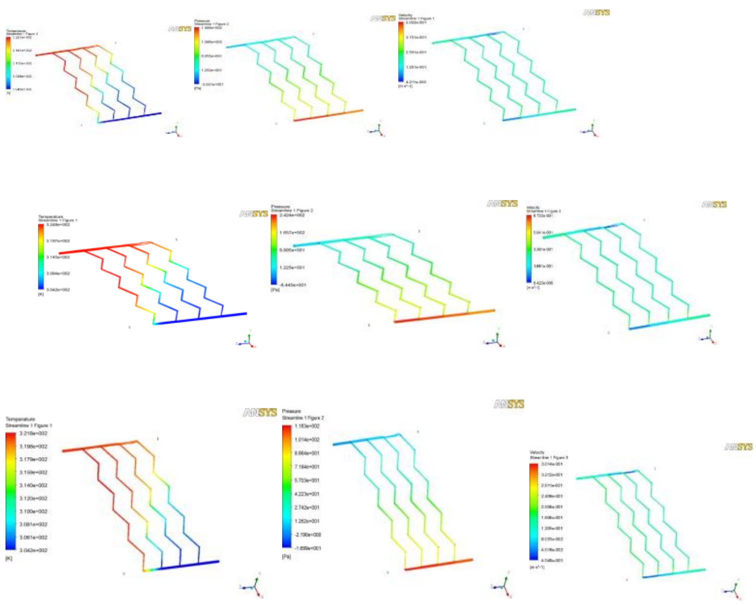


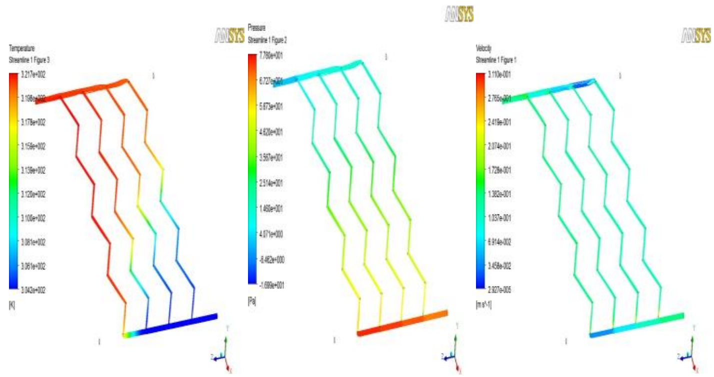
COMPUTATIONAL FLUID DYNAMIC RESULT FOR ZIGZAG RISER TUBE

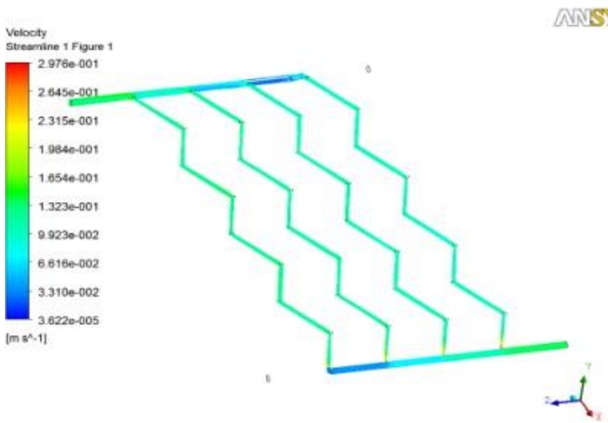




Variable diameter Results







CONCLUSION

Experimental investigation has been carried out on straight riser tube and zigzag riser tube on heat transfer enhancement, frictional factor. from the graph plotted following conclusions are made.

1) The heat transfer in the tube with zigzag riser tube is found to be more as compared to straight riser tube. The increase in relative heat transfer coefficient of water for zigzag riser tube is 27.04 % higher than straight riser tube.
2) The relative decrease in frictional factor for zigzag riser tube is 3.38 % than straight riser tube.
3) The relative Reynolds number for zigzag riser tube is 8.50% higher than straight riser tube.
4) The relative increase in Nusselts number for zigzag riser tubes is 26.16% higher than straight riser tube.

As the conventional energy sources are getting exhausted non-conventional energy sources like solar energy will play a major role in the field of energy. As the consumption of hot water increase solar flat plate collector will play a major role in this field. Solar hater water was utilized for several application. Until 1930, hot water for domestic purpose and for space heating was mainly engaged by the coal fired boilers. Solar water heater becomes commercial product in the early 1960s. installing a solar flat plate water heating system for your home can reduce your energy consumption by as much as 40% to 50%. It only takes 1 or 2 solar flat plates to heat over 80 gallon of hot water per day –all for free. One of the simplest and more direct application of this energy is the conservation of solar radiation into heat, which can be used in water heating systems

REFERENCES

1. Sanjay Kumar Sharma, Dheeraj Joshi, Fabrication and Experimental Investigation of V-Through Flat Plate Collector in Hot Climatic Conditions of Rajasthan: A Case Study of Jaipur, International Journal of Emerging Technology and Advanced Engineering. ―ISSN 2250-2459, ISO 9001:2008‖
2. BAA Yousef, Performance analysis for flat plate collector with and without porous media, Journal of Energy in Southern Africa, Vol 19 No 4, November 2008.
3. Aliasghar Owla Iveli, Numerical Analysis in Order to Optimize the Geometrical Dimensions of The Solar Energy Storage Tank Considering Thermally Stratified an Increasing Tank Efficiency, Indian J.Sci.Res.1(2),599-610, 2014, ISSN:0976- 2876(Print), ISSN: 2250-0138 (Online).
4. B. N. Mankar, Experimental Investigation of Flat Plate Solar Water Collector by Flow Pulsation and Metal Blocks, International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181 Vol. 4 Issue 05, May-2015.
5. R. Herrero Martín, A. García Pinar, J. Pérez García, Experimental heat transfer research in enhanced flat-plate solar collectors, world renewable energy congress 2011-sweden, 8-13 may 2011, Linkoping Sweden
6. Sunil. Amrutkar, Solar Flat Plate Collector Analysis, IOSR Journal of Engineering (IOSRJEN), ISSN: 2250-3021, Vol. 2 Issue 2, Feb.2012, pp.207-213
7. Fabio Struckmann, Analyzed the solar flat collector, Project Report 2008, Sweden.
8. Ismail.N.R. R, collectors' innovation to increase performance solar water heater, International Journal of Research in Engineering and Technology eISSN: 2319- 1163 | pISSN: 2321-7308.
9. Rakesh Kumar, Thermal performance of integrated collector storage solar water heater with corrugated absorber surface, Applied Thermal Engineering 30(2010)1764e1768.
10. Dr. A.R. Jaurkar, experimental study of solar water heater by using different riser tubes in a flat plate collector, International Journal of Innovation In Engineering Research & Management Issn :2348-4918
11. H. Vettrivel, Thermal Performance Optimization of A Flat Plate Solar Water Heater Collector Using MATLAB, International Journal of Mechanical and Production Engineering, ISSN: 2320-2092, Volume- 1, Issue- 5, Nov-2013.

12. L.M. Ayompe, Analysis of the thermal performance of a solar water heating system with flat plate collectors in a temperate climate, Applied Thermal Engineering 58 (2013) 447e454.
13. Anuj Mathur recent development in the field of solar water heater using flat plate collector-A review, International Journal of Advanced Engineering Technology, E-ISSN 0976-3945
14. Marwaan AL-Khaffajy, Optimization of the heat exchanger in a flat plate indirect heating integrated collector storage solar water heating system, Renewable Energy 57 (2013) 413e421
15. I. Budihardjo, Performance of water-in-glass evacuated tube solar water heaters, science direct, Solar Energy 83 (2009) 49–56
16. P.M.E. Koffi, Theoretical and experimental study of solar water heater with internal exchanger using thermosiphon system, Energy Conversion and Management 49 (2008) 2279–2290, science direct.
17. Filiz Ozgen, Experimental investigation of thermal performance of a double-flow solar air heater having aluminum cans, Renewable Energy 34 (2009) 2391–2398,
18. Punnaiah Veeraboinaa, G. Yesu Ratnamb, Analysis of the opportunities and challenges of solar water heating system (SWHS) in India: Estimates from the energy audit surveys & review, Renewable and Sustainable Energy Reviews 16 (2012) 668– 676,
19. S. Farahat, F. Sarhaddi, H. Ajam, Exergetic optimization of flat plate solar collectors, Renewable Energy 34 (2009) 1169–1174,
20. T. Roulleau, C.R. Lloyd, International policy issues regarding solar water heating, with a focus on New Zealand, Energy Policy 36 (2008) 1843–1857,
21. Soteris A. Kalogirou, Solar thermal collectors and applications, Progress in Energy and Combustion Science 30 (2004) 231–295,
22. Govind N. Kulkarni, Shireesh B. Kedare, Santanu Bandyopadhyay, Optimization of solar water heating systems through water replenishment, Energy Conversion and Management 50 (2009) 837–846.
23. Yong Kim a, Gui Young Han b, Taebeom Seo, An evaluation on thermal performance of CPC solar collector, International Communications in Heat and Mass Transfer 35 (2008) 446–457.
24. Georgeta Vasies, numerical simulation of wind action on flat roofs with and without parapet.
25. Mayank Patel, Krunal Patel, A critical review of evacuated tube collector, International Journal of Advanced Engineering Research and Studies, E- ISSN2249–8974.
26. Prashant M Khanorkar, R. E. Thombre, CFD analysis of natural convection flow through vertical pipe, ISSN 2278 – 0149, www.ijmerr.com,Vol. 2, No. 3, July 2013, IJMERR.
27. K. Vasudeva Karanth, Madhwesh N., Shiva Kumar., Manjunath M.S., numerical and experimental study of a solar water heater for enhancement in thermal performance, International Journal of Research in Engineering and Technology, eISSN: 2319-1163 | pISSN: 2321-7308.
28. Mr. Mainak Bhaumik, CFD simulation of SDHW storage tank with and without heater, International Journal of Advancements in Research & Technology, Volume 1, Issue2, July-2012 1 ISSN 2278-7763
29. M. YAHYA, CFD analysis of solar hot water heater with integrated storage system, Proceedings of the 7th WSEAS International Conference on SYSTEM SCIENCE and simulation in engineering (ICOSSSE '08).
30. S. Eswaran, M. Chandru, M. Vairavel, R. Girimurugan, Numerical Study on Solar Water Heater using CFD Analysis, IJESRT, ISSN: 2277-9655