iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 9 **Issue:** IX **Month of publication:** September 2021

DOI: https://doi.org/10.22214/ijraset.2021.37944

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue IX Sep 2021- Available at www.ijraset.com

Performance Analysis of Shell and Tube Type Heat Exchanger Using Aluminium Oxide (Al_2O_3) Nano-Particle

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***Abstract:** Research in convective heat transfer using suspensions of nanometer sized solid particles in a base fluid started only over the past decade. Recent investigations on nanofluids, as such suspensions are often called, indicate that the suspended nanoparticles markedly change the transport properties and heat transfer characteristics of the suspension. The very first part of the research work summarizes about the various thermo physical properties of Al2O3 Nanofluid. In evacuated tube solar water heating system nanofluids are used as primary fluid and DM water as secondary fluid in Shell and Tube Heat Exchanger.*

The experimental analysis of Shell and Tube heat exchanger integrated with Evacuated tube solar collector have been carried out with two types of primary fluids. Research study of shell and tube heat exchanger is focused on heat transfer enhancement by usage of nano fluids.

Conventional heat transfer fluids have inherently low thermal conductivity that greatly limits the heat exchange efficiency. The result of analysis shows that average relative variation in LMTD and overall heat transfer coefficient is 24.56% and 52.0% respectively. The payback period of system is reduced by 0.4 years due to saving is in replacement cost of Evacuated Tube Collector.

***Keywords:** ETC; Nanofluid; LMTD; Thermal Conductivity; Overall heat transfer coefficient*

I. INTRODUCTION

Energy is the prime agent in the generation of wealth and a significant factor in economic development. Most of the power is produced by the use of fossil fuels, (like coal, oil gas etc.) which emit tons of carbon dioxide and other pollution every second and more importantly primary energy sources are depleting continuously. The main solution to get rid of this problem is to effectively make use of the Renewable Energy Sources available around us. Solar energy is one such renewable source of energy available and is encouraged to be used in every country for its sustainability. Thus solar energy draws attention of researchers throughout the world. Solar energy is a free source of energy which is not only environment friendly and it also helps in lessening the Green House Effects .Everyday sun radiates enormous amount of energy known as solar energy. The hourly solar flux incident on the earth's surface is greater than all of human consumption of energy in a year [1]. So, the problem lies in efficiently collecting and converting this energy into something useful form.

The basic principle of solar thermal collection is that when solar radiation is incident on a surface (such as that of a black-body), part of this radiation is absorbed, thus increasing the temperature of the surface. As the temperature of the body increases, the surface loses heat at an increasing rate to the surroundings. Steady-state is reached when the rate of the solar heat gain is balanced by the rate of heat loss to the ambient surroundings. In the thermo siphon system, water comes from the overhead tank to bottom of solar collector by natural circulation and water circulates from the collector to storage tank as long as the absorber keeps absorbing heat from the sun and water gets heated in the collector.

The cold water at the bottom of storage tank run into the collector and replaces the hot water, which is then forced inside the insulated hot water storage tank.

The process of the circulation stops when. There is no solar radiation on the collector. Thermo siphon system is simple and requires less maintenance due to absence of controls and instrumentation. Efficiency of a collector depends on the difference between collector temperature and ambient temperature and inversely proportional to the intensity of solar radiation.

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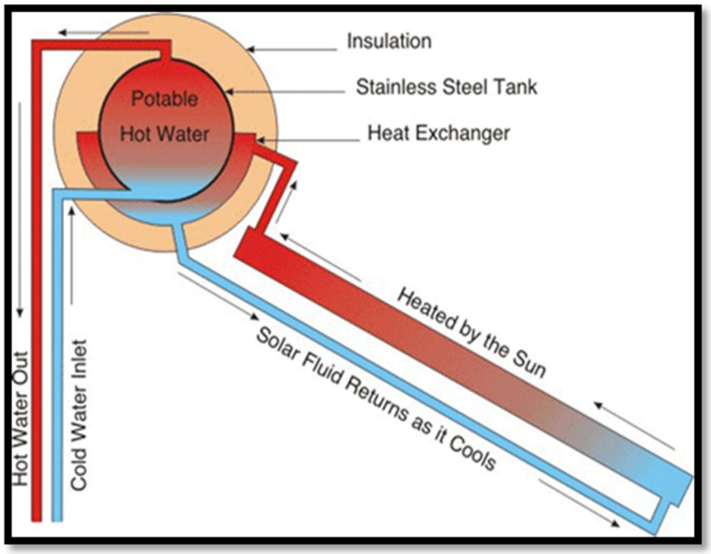

Figure 1.Working principal layout of Thermo siphon System [37]

A heat exchanger is a device that is used to transfer thermal energy (enthalpy) between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid, at different temperatures and in thermal contact. In heat exchangers, there are usually no external heat and work interactions. Typical applications involve heating or cooling of a fluid stream of concern and evaporation or condensation of single or multi component fluid streams. In other applications, the objective may be to recover or reject heat, or sterilize, pasteurize, fractionate, distill, concentrate, crystallize, or control a process fluid. In a few heat exchangers, the fluids exchanging heat are in direct contact. In most heat exchangers, heat transfer between fluids takes place through a separating wall or into and out of a wall in a transient manner. In many heat exchangers, the fluids are separated by a heat transfer surface, and ideally they do not mix or leak. Such exchangers are referred to as direct transfer type, or simply recuperate. In contrast, exchangers in which there is intermittent heat exchange between the hot and cold fluids via thermal energy storage and release through the exchanger surface or matrix are referred to as indirect transfer type, or simply regenerators. Such exchangers usually have fluid leakage from one fluid stream to the other, due to pressure differences and matrix rotation/valve switching. Common examples of heat exchangers are shell-and-tube exchangers, automobile radiators, condensers, evaporators, air pre-heaters, and cooling towers. If no phase change occurs in any of the fluids in the exchanger, it is sometimes referred to as a sensible heat exchanger. Classification of heat exchanger is shows in figure 2.

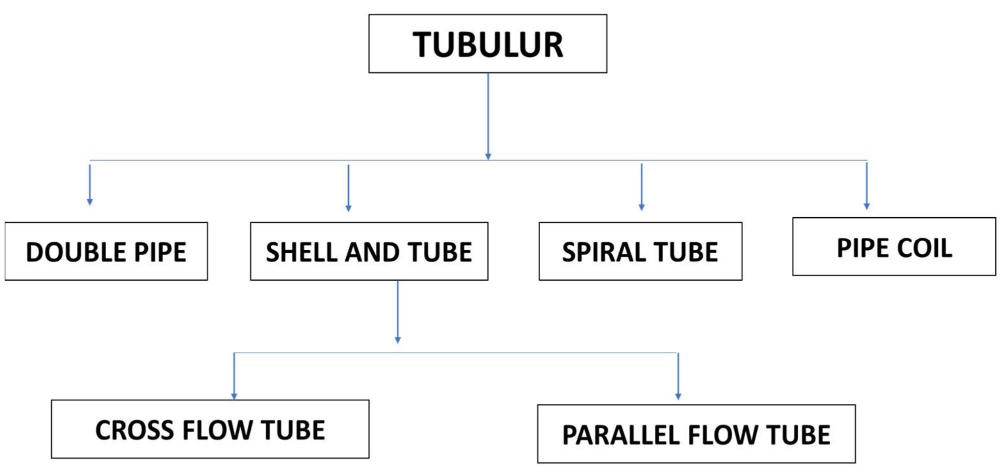

Figure 2. Classification of Heat Exchangers

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A. Shell-And-Tube Heat Exchangers

This exchanger is generally built of a bundle of round tubes mounted in a cylindrical shell with the tube axis parallel to that of the shell. One fluid flows inside the tubes, the other flows across and along the tubes. The major components of this exchanger are tubes (or tube bundle), shell, front end head, rear-end head, baffles, and tube sheets, and are described briefly later in this subsection. A variety of different internal constructions are used in shell- and-tube exchangers, depending on the desired heat transfer and pressure drop performance and the methods employed to reduce thermal stresses, to prevent leakages, to provide for ease of cleaning, to contain operating pressures and temperatures, to control corrosion, to accommodate highly asymmetric flows, and so on. Shell-and-tube exchangers are classified and constructed in accordance with the widely used TEMA (Tubular Exchanger Manufacturers Association) standards (TEMA, 1999), DIN and other standards in Europe and elsewhere, and ASME (American Society of Mechanical Engineers) boiler and pressure vessel codes. TEMA has developed a notation system to designate major types of shell-and- tube exchangers. In this system, each exchanger is designated by a three-letter combination, the first letter indicating the front-end head type, the second the shell type, and the third the rear-end head type [2]. Some common shell-and-tube exchangers are AES, BEM, AEP, CFU, AKT, and AJW. It should be emphasized that there are other special types of shell-and- tube exchangers commercially available that have front- and rear-end heads different those exchangers may not be identifiable by the TEMA letter designation.

Figure 3.Shell and tube heat exchanger

B. Nanofluids

The concept and development of nanofluids is directly related to trends in miniaturization and nanotechnology. Just as downsizing is a fashion in the world of business, downscaling is a clear trend in the world of science and technology. One feature of these rapidly emerging technologies is that they are strongly interdisciplinary. A variety of micro scale products are already available, or soon will be. Miniaturized sensors, actuators, motors, heat exchangers, pumps, heat pumps, valves, heat pipes, fuel cells, instruments, medical devices, robots, and airplanes are just a few of the almost endless variety of micro products in the market or poised to move from the laboratory to the marketplace. The electronics industry has applications in cooling advanced electronic packages; for the automotive industry, the weight difference between conventional and micro channel systems (such as in Air conditioners) could lead to significant gains in fuel economy: in the HVAC industry)'. Refrigeration and air conditioning equipment volumes could be reduced and this would save space in buildings; and in chemical and petroleum plants. In the recent times, due to global warming and projected fossil fuel depletion in reserves the utilization of Renewable energy got more attention. In this context solar energy is projected one of the most reliable alternative energy sources due to its abandon availability and environment friendliness. Performance analysis of Evacuated tube collectors equipped with Shell and tube Heat exchangers using nano fluids have potential use in the field of scientific researches, in industries and can also use for domestic purposes. It is the extensive research where many researchers are still working on it to make the correct use of energy resources. In recent years several researchers have performed analysis of heat exchanger using different nano fluids as primary fluid to investigate the improved overall heat transfer coefficient, convective heat transfer coefficient and other performance parameters [3].

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II. MATERIAL AND METHODS

A. Experimentation

The experimental setup of evacuated solar water heating system has been installed on the flat roof Gwalior, India (latitude 26.0206N and longitude 78.2617E, at an elevation of 190m MSL) to measure the Logarithmic Mean Temperature Difference (LMTD), Overall heat transfer coefficient and effectiveness of heat exchange. An experiment has been carried out form 10:00 hrs. to 16:00 hrs. in the month of January from 10 January to 16 January, 2021. The experimental set up consists two evacuated tube solar collector equipped with a reservoir bank and a shell & tube heat exchanger, a centrifugal pump (for maintain the flow of fluid), rotameter for measuring the mass flow rate, a storage tank and digital thermocouples K type for temperature measurement at entry and exit point of heat exchanger. The actual pic of experimental setup of Heat exchanger is shown in figure 4.

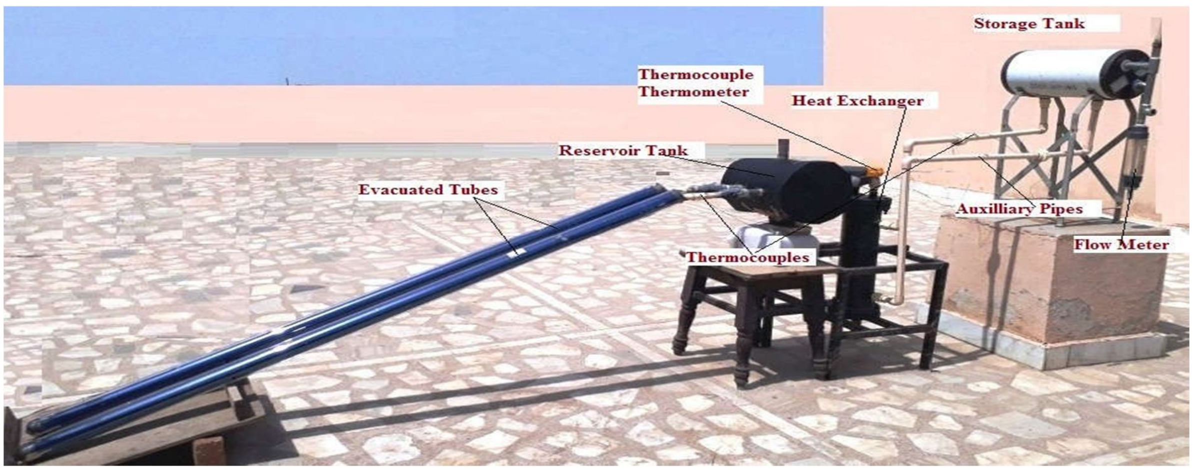

Figure 4.Actual pic of experiment setup

An evacuated tube solar collector consists of two tubes is used to absorb the solar radiation and transfer it to the primary fluid (nano-fluid) filled into tubes. Thus primary fluid get heated and through natural convection moves to the reservoir bank (diameter of 20cm) connected to the tubes. This hot primary fluid further flow inside the tube of the shell and tube type heat exchanger and transfers its heat to the secondary fluid (water) which is flowing into the shell of the heat exchanger. This secondary fluid after getting heat from the primary fluid moves to the insulated tank. A centrifugal pump of 20 watts is used between the insulated tank and the shell of the heat exchanger to provide the constant mass flow rate. The schematic view of experimental setup is presented in figure .5

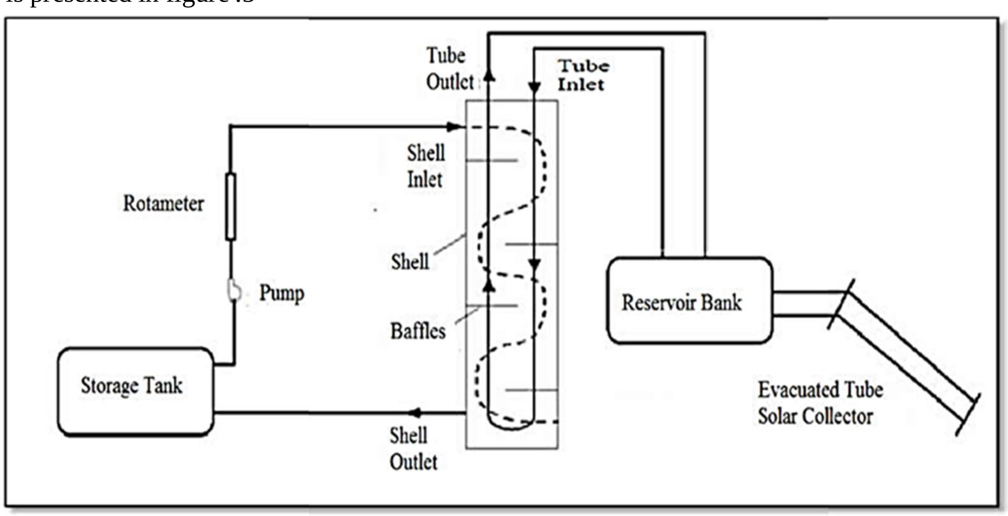

Figure 5. Schematic view of experimental setup

B. Performance Analysis

The performance analysis of heat exchanger by using nano fluids and comparative analysis of the parameters with that of conventional fluid. The parameters which are to be evaluated are LMTD, Overall Heat Transfer Coefficient, Convective Heat Transfer Coefficient and Effectiveness of the heat exchanger. The mathematical models for evaluation of mentioned parameters are described below.

1) *Evaluation of LMTD:* LMTD is the logarithmic mean of temperature difference of the fluids at both the sides of the heat exchangers. The LMTD is the driven force for the heat exchange between the two fluids. As the LMTD value increases, the amounts of heat transfer between the two fluids also increase. LMTD can calculate by the help of following Equation 1 [5].

$$\theta = \frac{(tpi-tso)-(tpo-tsi)}{ln\{\frac{(tpi-tso)}{(tpo-tsi)}\}} \quad (1)$$

2) *Evaluation of Overall Heat Transfer Coefficient:* The overall heat transfer coefficient is influenced by the thickness and thermal conductivity of the mediums through which heat is transferred. The larger the coefficient, the easier heat is transferred from its source to the product being heated. In a heat exchanger, the relationship between the overall heat transfer coefficient (U) and the heat transfer rate (Q) can be demonstrated by the following Equation 2 [6].

$$Q=UA\,\theta m \quad (2)$$

Where,

Q = Heat transfer rate, W=J/s [btu/hr].

A = Heat transfer surface area, m^2 [ft^2].

U = Overall heat transfer coefficient, W/ (m^2°C).

θ = Logarithmic Mean Temperature Difference, °K.

3) *Evaluation of Effectiveness of Heat Exchanger:* The effectiveness of heat exchanger is determined using NTU. In addition to the effectiveness, the ratio of C_{min}/C_{max} is needed (C_{min} is the smaller of the two heat capacity rates C_c and C_h and C_{max} is the higher one). From the effectiveness graphs, the intersection point of the ratio C_{min}/C_{max} and effectiveness value gives the NTU value. Equation 3 & 4 find the effectiveness of heat exchanger [7].

$$\varepsilon = \frac{Actual\ Heat\ transfer}{Maximum\ Possible\ Heat\ Transfer}$$

$$\varepsilon = \frac{Ch(Thi-Tho)}{Cmin\,(Thi-Tci)} \quad (3)$$

$$\varepsilon = \frac{Cc(Tco-Tci)}{Cmin(Thi-Tci)} \quad (4)$$

The results obtained by using above mentioned analysis are compared for evaluating the optimum results. Later pay calculation of installed setup is also done to determine the reduction in payback time as compared to conventional ETC systems without heat exchangers.

4) *Payback Period:* The payback period is calculated by considering the annual discounted cash flow and the period at which the net present value becomes equal to zero is taken as the break-even period or the payback period. The payback period of system without heat exchanger is compared with that of present modified system to evaluate reduction id payback time. The results show that 1.40 year is the payback period of system without heat exchanger whereas 1.14 years is the payback period of present system [8].

$$\boldsymbol{Payback\ period} = \frac{Cost\ of\ installation + Cost\ of\ Heat\ Exchanger}{Saving\ per\ year + Cost\ of\ ETC} \quad (5)$$

III. RESULT AND DISCUSSION

The process of heat exchange (HE) between two fluids that are at different temperatures and separated by a solid wall occurs in many engineering applications. The device used to implement this exchange is called a heat exchanger, and specific applications may be found in space heating and power production, waste heat recovery and chemical processing. The flow of heat from a fluid through a solid wall to a coated fluid is often encountered in chemical engineering practice. The heat transferred may be latent heat accompanying phase changes such as condensation or vaporization, or it may be sensible heat coming from increasing or decreasing the temperature of a fluid without phase change. In present paper the variation of Overall Heat Transfer coefficient (U), Logarithmic Mean Temperature Difference (LMTD), density viscosity, specific heat, Thermal conductivity, effectiveness of heat exchanger and payback period was discussed.

A. Variation in Overall Heat Transfer Coefficient (U)

Figure 6 shows the variation in overall heat transfer coefficient (U) with respect to time for DM water is 81.4% and for Al_2O_3 nanofluid is 68.2%. The relative variation of overall heat transfer coefficient (U) for both the fluid is 52.0%.

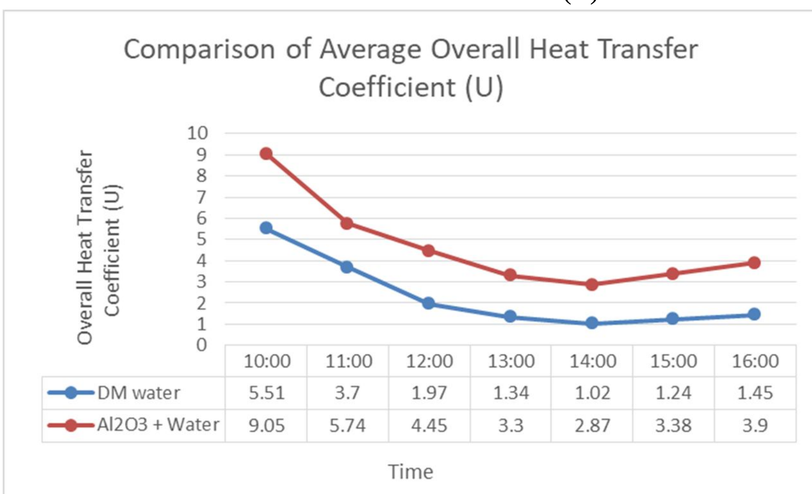

Figure 6. Variation in Overall Heat Transfer Coefficient for DM Water and Al_2O_3

It is clearly that the overall heat transfer coefficient is higher in the morning time at 14:00 pm. Overall heat Transfer Coefficient is minimum in all cases because the value of temperature is increases much faster than the heat gained by the Heat exchanger.

B. Variation in Logarithmic Mean Temperature Difference (LMTD)

Figure 7 shows the variation in Logarithmic Mean Temperature Difference (LMTD) with respect to time for DM water is 80.7% and for Al_2O_3 nanofluid is 78.8%. The relative variation of Logarithmic Mean Temperature Difference (LMTD) for both the fluid is 24.56%.

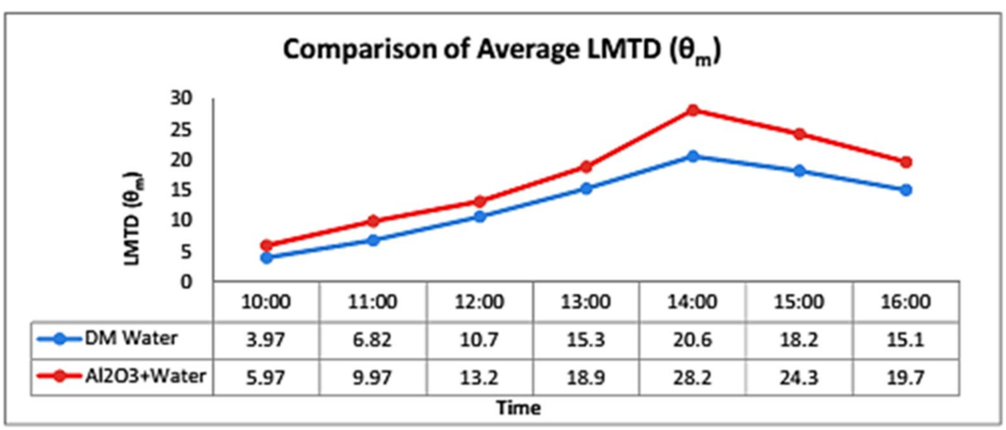

Figure 7. Variation in Logarithmic Mean Temperature Difference (LMTD)

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C. Variation of Effectiveness of Heat Exchanger

The variation in Effectiveness of Heat Exchanger with respect to time for DM water is shown in figure 8.

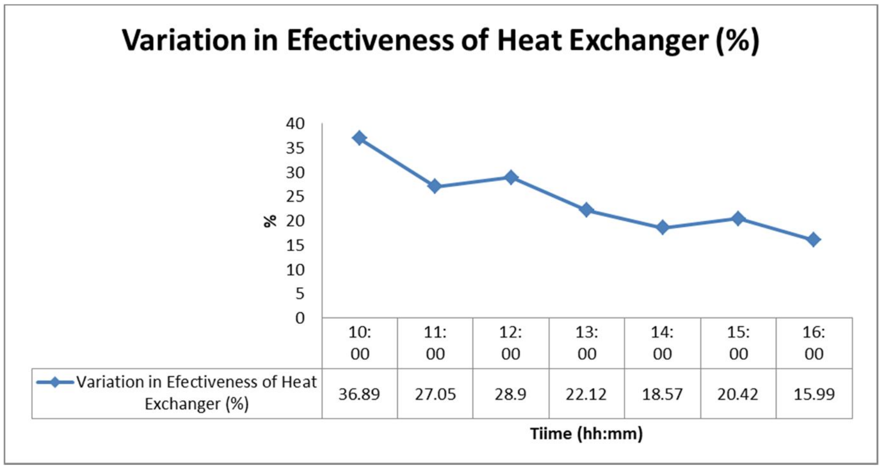

Figure 8 .Effectiveness of Heat Exchanger

Figure 8 illustrate that Effectiveness of heat exchanger decreases with respect to time. At 10:00hrs effectiveness of heat exchanger is highest and at 16:00hr the effectiveness of heat exchanger is at its lowest.

D. Variation of Payback Period

The variation in payback period of Heat Exchanger with or without heat exchanger is shown in figure 9.The result shows that payback period is decreased by 0.27 years (75 days approx.) due to reduction in replacement cost of scaled out evacuated tubes.

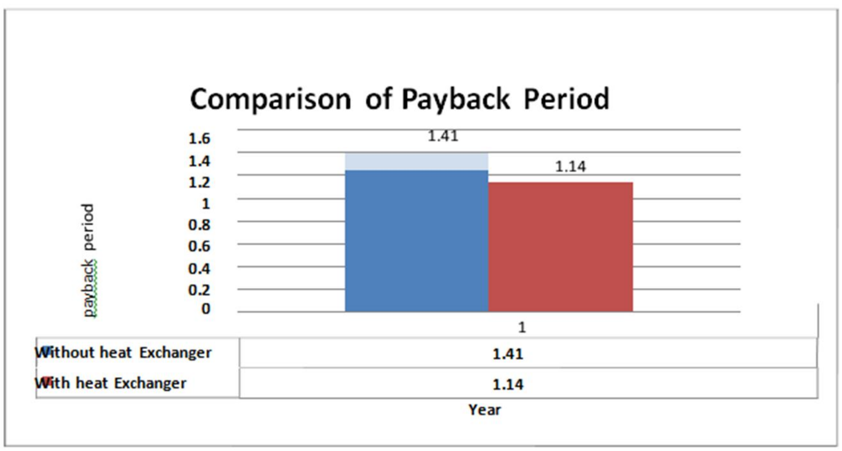

Figure 9. Variation in Payback Period

IV. CONCLUSION

In present research work nano fluid is used as a primary fluid for evacuated tube heating and DM water as a secondary fluid to avoid scaling and damage of ETC. Through experimental analysis determination of thermal and flow parameter is done. The results of analysis are summarized as follows:-

A. The variation in overall heat transfer coefficient with respect time. The relative variation of overall heat transfer coefficient both the fluid is 52.0%.
B. LMTD variation in with respect to time. The relative variation of LMTD both fluid is 24.5%.
C. The mean effectiveness of heat exchanger is 24.22%, where variation in effectiveness of heat exchanger 56.65%.

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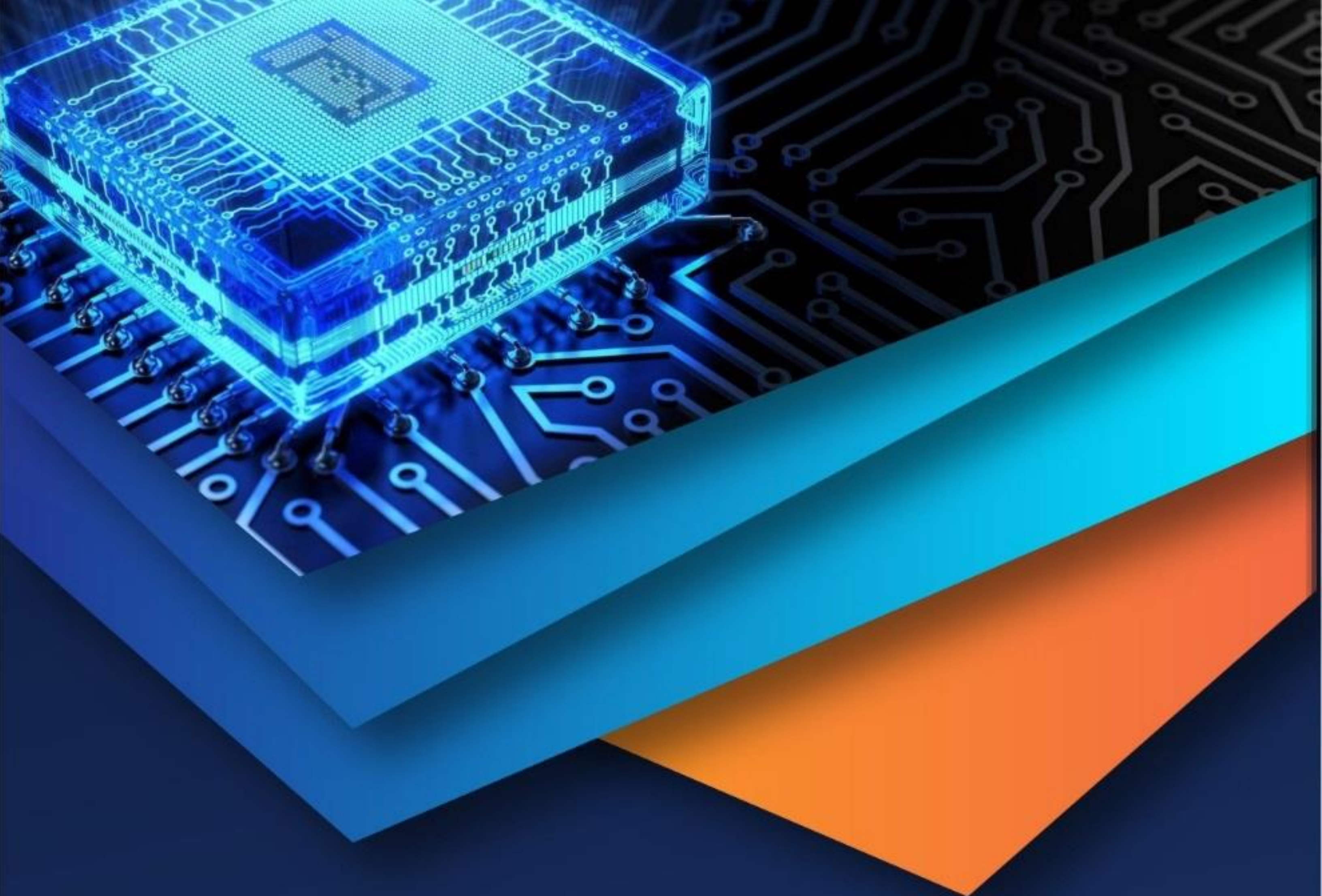

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