Experimental Study of Waste Heat Recovery Using Heat Pipe Heat Exchanger with Hybrid Nano fluid: A Review

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Abstract: **Research has been carried out on the theory, design and construction of waste heat recovery using heat pipes heat exchanger with nano fluid, especially their use in waste heat recovery for energy recovery in automobile exist, reduction of air pollution and environmental conservation. A heat pipe heat exchanger has been designed and constructed for heat recovery in exhaust from IC Engine, where the air must be changed up to 40 times per hour. In this research, the characteristic design and heat transfer limitations of single heat pipes without wick and working with Hybrid Nanofluids have been investigated. There has been increasing interest in nano fluid and its use in heat transfer enhancement. Nanofluids are suspensions of nano particles in fluids that show significant enhancement of their properties at modest nano particle concentrations.**

Keywords: **Waste heat Recovery, Heat Pipe Heat Exchanger, Nanofluid, Thermosyphon.**

I. INTRODUCTION

There are many types of energy recovery systems, but the most commonly used are rotating wheels, plates, heat pipes and run around loops. Heat exchangers made of heat pipes are one of the most effective devices for waste heat recovery. Furthermore, simplicity of design and manufacturing, small end-to-end temperature drops, extremely wide temperature application range and the ability to control and transport high heat rates at various temperature levels are unique features of heat pipes. Numerous investigations have been conducted to study the thermal performance of heat pipes using nanofluids. The limiting factor against increasing the heat transfer performance of heat pipe depends on the properties of the working fluid. The enhancement of liquid thermal conductivity is achieved by adding highly conductive solid nanoparticles within the base fluid. The special characteristics of the nanofluid substantially increase the heat transfer coefficient, thermal conductivity and liquid viscosity. Different types of nanofluid used in heat pipes are Al2O3, CuO and TiO2.

II. LITERATURE REVIEW

In energy recovery ventilation, the technology that recovers the waste energy is studied. Application of air-to-air energy recovery equipment continues to grow in acceptance and use in HVAC systems. Increased outdoor air requirements necessary to meet ASHRAE Standard 62-1989 (1999), Ventilation for Acceptable Indoor Air Quality, and state and local building codes, add substantially to cooling and heating loads. Increasing outdoor air loads escalates both operating cost and system equipment cost. This has intensified interest in energy recovery technologies and their economic applications. Energy recovery can be used for both new and retrofit applications. There are three categories of application: (1) process-to-process, (2) process-to comfort, and (3) comfort-to-comfort. In process-to-process applications, only sensible heat is captured from the process exhaust stream and transferred to the process supply stream. Exhaust temperature may be as high as 1,500°F. In most process-to-comfort applications, energy recovery involves the capture and transfer of sensible heat only. Waste heat is transferred to makeup or outdoor air streams. This is effective during winter months, but requires modulation during spring and autumn to prevent overheating the building. Often, no energy recovery is made during summer. Comfort-to-comfort applications differ from other categories in that both sensible and latent heat are often transferred. The energy recovery device transfers sensible heat from the warmer air stream to the cooler air stream. It also transfers moisture from the air stream with the higher humidity ratio to the air stream with the lower humidity ratio. The directions of humidity and heat transfer are not necessarily the same. This white paper discusses air-to-air, comfort-to comfort applications. Equipment and systems used for energy recovery ventilation are reviewed with particular emphasis given to rotary energy wheels that transfer both heat and moisture. [1]

Research & Energy saving Potential for ventilation system suggests decoupling dehumidification from cooling to reduce energy consumption. The feasible usage and the energy saving potential of heat pipe heat exchanger at the air handler dedicated in accomplishing this objective is investigated. In this paper a dedicated ventilation system combined with a HPHX to reduce energy consumption is tested and investigated under varying conditions by laboratory experiments. The energy saving potential and heat pipe (HP) effectiveness are tested and calculated under various outdoor conditions. The simulation and experimental results demonstrate that for all cases examined, the average HP effectiveness and energy savings have the same trend at various outdoor temperatures and Relative Humidity (RH) values. It has been found that the heat pipe can be applied to save over 60% energy for the air-conditioning operating hours. The reduction in overall energy is from 1.8% to 2.8% for the whole system. Therefore, the results confirm that the proposed set-up is useful for buildings to achieve intended energy saving objectives in subtropical climates where air-conditioning demand is highly variable. Most previous literature research efforts are therefore focused on investigating effective ways to use heat pumps or heat pipe technology for energy savings in this aspect. The feasible use and advantages of HPHX for dedicated ventilation (DV) system to the desired conditions so as to increase COP of the system and avoid additional energy consumption for reheating & dehumidification has not been discussed. Hence, objective of this study was to test and demonstrate a HPHX combined with a direct-expansion (DX) cooling coil for conditioning of outdoor air (OA) to the desired conditions for minimizing additional dehumidification demands in the space air handler so as to virtually separate the dehumidification and cooling process to save energy. [2]

Energy Performance of HVAC Systems is improved in operating theaters are inherently energy-inefficient. In this research, the impact of heat pipe heat exchanger (HPHX) as a heat recovery device on the performance of an existing HVAC system of an operating theater was examined. The existing HVAC system, Plant A, was redesigned by the added HPHX as Plant B and C and the most suitable design in terms of energy consumption and provided air conditions was recommended for the system. TRNSYS simulation program was used for this purpose and a yearly operation of 8760 hours was considered. Based on the results, the application of HPHX, Plant C configuration, could decrease the energy demand of the system and it is recommended to be implemented in the existing HVAC system. Moreover, it was shown that the HPHX integrated system improves the room and supply duct air conditions. In the operating theaters, the exhaust air is not allowed to be mixed with fresh outdoor air; therefore, the possibility of energy recovery is expected to be considerable. In addition, the dehumidification capability of the cooling coils is expected to be improved by the pre-cooling effect of energy recovery devices. Besides the energy aspect, providing an appropriate and clean indoor air for the operating theaters is an important task for the designers. ASHRAE standard recommends 20-24 and 30-60% relative humidity (RH) for the operating theaters. Moreover, ASHRAE recommends RH values higher than 70% for the low-velocity ducts and indoor spaces to prevent fungal growth. In addition, RH higher than 70%, can cause some sorts of diseases, which is mostly happens in high humid spaces. Therefore, maintaining the supply air RH value lower than 70% is strongly recommended. One effective way of reducing HVAC systems energy consumption level is employing heat pipe heat exchangers (HPHXs). HPHXs are passive heat transfer devices that have recently been used for energy recovery purposes. A HPHX consists of individual externally-fined heat pipe tubes that are charged with a proper refrigerant. HPHXs have several advantages over conventional heat recovery devices. One of the main advantages is that HPHXs do not require external power to operate. [3]

In surgery room application, waste heat from kitchen is used. Research has been carried out on the theory, design and construction of heat pipes, especially their use in heat pipe heat exchangers for energy recovery, reduction of air pollution and environmental conservation. A heat pipe heat exchanger has been designed and constructed for heat recovery in hospital and laboratories, where the air must be changed up to 40 times per hour. In this research, the characteristic design and heat transfer limitations of single heat pipes for three types of wick and three working fluids have been investigated, initially through computer simulation. Construction of heat pipes, including washing, inserting the wick, creating the vacuum, injecting the fluid and installation have also been carried out. After obtaining the appropriate heat flux, the air-to-air heat pipe heat exchanger was designed, constructed and tested under low temperature (15±558C) operating conditions, using methanol as the working fluid. Experimental results for absorbed heat by the evaporator section are very close to the heat transfer rate obtained from computer simulation. Considering the fact that this is one of the first practical applications of heat pipe heat exchangers, it has given informative results and paved the way for further research. Heat exchangers made of heat pipes are one of the most effective devices for waste heat recovery. The advantage of using a heat pipe over conventional methods is that large quantities of heat can be transported through a small cross-sectional area over a considerable distance with no additional power input to the system. Furthermore, simplicity of design and manufacturing, small end-to-end temperature drops, extremely wide temperature application range (4±3000 K) and the ability to control and transport high heat rates at various temperature levels are unique features of heat pipes [1±3]. Heat pipes have been applied in many ways since their introduction in 1964. Some of the important applications of heat pipes are as follows: in the area of spacecraft cooling, electrical and electronic equipment cooling, medicine and human body temperature control and as heat exchangers for heat recovery. [4]

A Mayer & R T Dobson considers the thermal design and the experimental testing of a heat pipe (thermosyphon) heat exchanger for a relatively small commercially available mini-drier. The purpose of the heat exchanger is to recover heat from the moist waste air stream to preheat the fresh incoming air. The working fluid used was R134a and the correlations are given for the evaporator and condenser inside heat transfer coefficients as well as for the maximum heat transfer rate. The theoretical model and computer simulation program used for the thermal design calculations are described. The validity of the as-designed and manufactured heat exchanger coupled to the drier is experimentally verified. The theoretical model accurately predicted the thermal performance and a significant energy savings and a reasonable payback period was achieved. In the light of an ever increasing demand for energy, the need for energy savings has become an important economic consideration. One means of saving energy is to recover a portion of the energy in a warm waste stream and then to use the recovered energy to preheat another colder stream. A heat pipe heat exchanger (HPHE) is a device capable of salvaging energy in this way (Dunn and Reay, 1994). Commercial production of HPHE began in the mid-1970s and has since found many applications, particularly in process and agricultural air drying and the heating ventilation and air conditioning industries (Russwurm, 1980). A characteristic of all these drying operations is the need for large quantities of energy for the evaporation of water from the product and the subsequent release of large quantities of moist hot air back into the atmosphere. A HPHE is a liquid coupled indirect heat transfer type heat exchanger and employs a number of individually-sealed or groups of sealed heat pipes or thermosyphons as the major heat transfer means from the high temperature to the low temperature fluid. Each heat pipe is lined with a wicking structure in which a small amount of working fluid is present and can be divided into an evaporator or heat addition section and a condenser or heat rejection section. When heat is added to the evaporator section, the working fluid present in the wicking structure is heated, vaporizes and flows to the cooler section, condenses and, in so doing, giving up its latent heat of vaporization. The capillary forces in the wicking structure then pump the liquid back to the evaporator. [5]

The heat pipes heat exchangers are used in heat recovery applications to cool the incoming fresh air in air conditioning applications. Two streams of fresh and return air have been connected with heat pipes heat exchanger to investigate the thermal performance and effectiveness of heat recovery system. Ratios of mass flow rate between return and fresh air of 1, 1.5 and 2.3 have been adapted to validate the heat transfer and the temperature change of fresh air. Fresh air inlet temperature of 32 ~ 40°C has been controlled while the inlet return air temperature is kept constant at about 26°C. The results showed that the temperature changes of fresh and return air are increased with increasing the inlet temperature of fresh air. The effectiveness and heat transfer for both evaporator and condenser sections are also increased to about 48 % when the inlet fresh air temperature is increased to 40 °C. The effect of mass flow rate ratio on effectiveness is positive for evaporator side and negative for condenser side. The enthalpy ratio between the heat recovery and conventional air mixing is increased to about 85 % with increasing fresh air inlet temperature. The heat pipes for heat recovery equipment are aimed for recovering sensible heat and they are recommended for systems in which inlet and return air should not be mixed such as surgery rooms in hospitals and chemical and biological laboratories. The advantages of using heat pipes over conventional methods is that large quantities of heat can be transported through a small cross-sectional area over a considerable distance with no additional power input to the system, together with simplicity of design and ease of manufacture. Efforts have successfully developed a series of heat pipes equipment, such as heat pipes gas to gas exchangers, heat pipes steam generators, high-temperature The aim of this study is to investigate the thermal performance and effectiveness of heat pipes heat exchanger for heat recovery in air conditioning applications by measuring the temperature difference of fresh warm and return cold air through the evaporator and condenser side. The heat transfer and enthalpy ratio between heat recovery and conventional air mixing are also targeted. The optimum effectiveness of heat pipe heat exchanger is calculated and compared with the experimental results.[6]

The A COMPARATIVE INVESTIGATION OF HEAT TRANSFER CAPACITY LIMITS OF HEAT PIPES thesis shows that, Heat pipe is a passive two phase device capable of transferring large rates of heat with a minimal temperature drop. It is a sealed tube with a wick structure lined in it and with a working fluid inside the tube. It consists of three parts: an evaporator, a condenser and an adiabatic section. The heat pipes are widely used in electronics cooling and spacecraft applications. Although they can transfer large rate of heat in a short range, they have operating limits, namely: the capillary limit, the viscous limit, the entrainment limit, the sonic limit and the boiling limit. These limits determine the heat transfer capacity of the heat pipe. The properties of the working fluid, the structure of the wick, the orientation of the pipe, the length and the diameter of the tube etc. are the parameters that affect the limits. In this study, an analytical 1-D heat pipe model is formed and a computer code is prepared in order to analyze the effects of the parameters on the heat transfer capacity of a heat pipe. Water, Ammonia and Mercury are investigated as working fluids for different operating temperature ranges. The software is tested for a typical application for each working fluid. The most important equipment in a computer is the central processing unit (CPU). It is also the most heat dissipating equipment in a computer. Today, an Intel Pentium M CPU dissipates 60 W of heat. If new dual core CPUs are considered, this value becomes 70 W. The heat dissipation problem may be solved more easily in desktop computers. A big size heat sink may be used in a desktop computer coupled with a bigger fan. But this is not the case in notebook computers. The space is limited and the weight impact should be considered. Today, the demand in the notebook computer field is to have notebook computers that are thinner, lighter in weight than and as fast as desktop counterparts. Also to be able to increase the battery life, notebooks should consume as less energy as possible. [7]

The purpose of study in Waste Heat Recovery by Heat Pipe Air-Preheater to Energy Thrift from the Furnace in a Hot Forging Process is to design, construct and test the waste heat recovery by heat pipe air-preheater from the furnace in a hot brass forging process. The mathematical model was developed to predict heat transfer rate and applied to compute the heat pipe air-preheater in a hot brass forging process. The heat pipe air preheater was designed, constructed and tested under medium temperature operating conditions with inlet hot gas ranging between 370-420°C using water as the working fluid with 50% filling by volume of evaporator length.The experiment findings indicated that when the hot gas temperature increased, the heat transfer rate also increased. If the internal diameter increased, the heat transfer rate increased and when the tube arrangement changed from inline to staggered arrangement, the heat transfer rate increased. The heat pipe air-preheater can reduced the quantity of using gas in the furnace and achieve energy thrift effectively. A simple heat pipe consists of a closed container that contains only a working fluid, liquid part and vapor part. Heat is transferred along the tube by a process of boiling, vapor flow, condensation and returned condensate. The vapor travels at high speed to a condenser section of the container, where the heat is rejected during condensation from the returned condensate by gravity. The heat pipe has very good thermal respond because of very high thermal conductance, heat pipes operate almost isothermally with a small temperature difference between the upper and lower end. [8]

In APPLICATIONS OF HEAT PIPES IN ENERGY CONSERVATION AND RENEWABLE ENERGY BASED SYSTEMS, design and characteristics of different energy conservation and renewable energy based system using heat pipes as thermal control element have been discussed. Heat pipes provide two-phase reliable heat transfer system with passive operation and high effectiveness for these applications.Renewable energy based electricity generation system developed in this study utilizes thermosyphons to extract stored heat (solar pond, geothermal), to dissipate waste heat to ambient and to store waste heat into phase change materials. Heat pipe provide economical and zero greenhouse gas emission solution for these applications. Basically, the heat pipe and vapor chamber are two-phase heat transfer devices (Dunn and Reay, 1994). They involve an evacuated and sealed container with a small quantity of working fluid. One end of the container is provided with waste heat from the source, causing the contained liquid to vaporize. The vapor flows to the cold end of the container where it condenses. Since the latent heat of evaporation is much larger than the sensible heat capacity of a fluid considerable quantities of heat can be transported using these devices with a very small end to end temperature difference. For the condenser above evaporator configuration (bottom heat mode), the return of the condensate can be aided by gravity e.g. gravity assisted heat pipes or thermosyphons. While for the evaporator above condenser configuration (top heat mode) or horizontal (evaporator and condenser at same level) configuration, porous structure is lined on the inner circumference of the heat pipe to promote capillary pumping of the working fluid. In this paper, research and development in the areas of energy conservation and renewable energy using heat pipes has been discussed. [9]

A CASE STUDY ON ENERGY SAVINGS IN AIR CONDITIONING SYSTEM BY HEAT RECOVERY USING HEAT PIPE HEAT EXCHANGER shows that, In air conditioning facilities with high outside air requirements such as clean room air conditioning systems, considerable energy savings is possible by heat recovery using heat pipe heat exchanger (HPHX).The literature review indicated that the annual energy saving analysis of air conditioning system with HPHX for Indian climatic conditions has not been performed. The paper investigates the possible energy savings using HPHX for heat recovery in air conditioning system for a process air conditioning facility in Pune city, India. The impact of number of rows of HPHX and variations in the operating air conditions on the savings in cooling coil capacity is presented in this paper. The paper also reveals the comparative analysis of annual energy savings with number of rows of HPHX for Pune weather conditions. The application of heat pipe heat exchanger for energy savings in air conditioning system is strongly recommended. Heat pipe heat exchanger (HPHX) is an excellent device used for heat recovery in air conditioning systems. Among the many outstanding advantages of using the heat pipe as a heat transmission device are constructional simplicity, exceptional flexibility, accessibility to control and ability to transport heat at high rate over considerable distance with extremely small temperature drop. The authors investigated the energy saving and dehumidification enhancement aspects of HPHXs and made a summary of experimental and theoretical studies on HPHXs. [10]

In Heat Pipes for Steam Condensation, paper explores the feasibility of using the heat pipe for steam condensation. In this paper an attempt is made to replace thousands of condenser tubes by hundreds of “Heat Pipes”. The design details of heat pipe, that is, material of heat pipe, heat pipe length, diameter of heat pipe for condensation purpose is described. The feasibility study was carried out for smooth operation of the heat pipe that is without ceasing during operation. Experimental setup and results of steam condensation studies are presented. [11]

A nanofluid is a mixture of nano sized particles of size up to 100 nm and a base fluid. Typical nanoparticles are made of metals, oxides or carbides, while base fluids may be water, ethylene glycol or oil. The effect of nanofluid to enhance the heat transfer rate in various heat exchangers is experimentally evaluated recently. The heat transfer enhancement using nanofluid mainly depends on type of nanoparticles, size of nanoparticles and concentration of nanoparticles in base fluid. In the present paper, an experimental investigation is carried out to determine the effect of various concentration of Al2O3 nano-dispersion mixed in water as base fluid on heat transfer characteristics of double pipe heat exchanger for parallel flow and counter flow arrangement. The volume concentrations of Al2O3 nanofluid prepared are 0.001 % to 0.01 %. The conclusion derived for the study is that overall heat transfer coefficient increases with increase in volume concentration of Al2O3 nano-dispersion compared to water up to volume concentration of 0.008 % and then decreases. Different types of heat exchangers are extensively used in various industries to transfer the heat between cold and hold stream. To optimize the operational parameters play a key role in enhancement of heat transfer rate after the design of heat exchanger. The method of enhancement of heat transfer rate operationally is broadly divided as active methods and passive methods. Active method includes electro hydrodynamics, jets, sprays, ultrasound waves, synthetic jet heat transfer and high amplitude vibratory motion, while passive method include surface coating, nanoscale coating, nanofluid, hydrodynamic cavitations, turbulence promoters and mixing promoters. Among them, three methods are considered as effective methods to enhance the heat transfer which are utilizing nanofluids, inserting fluid tabulators and roughing the heat exchanger surface. A nanofluid is a mixture of nano sized particles and a base fluid. [12]

A Nano particles application is studied in ENHANCING THERMAL CONDUCTIVITY OF FLUIDS WITH NANOPARTICLES. Low thermal conductivity is a primary limitation in the development of energy-efficient heat transfer fluids that are required in many industrial applications. This paper proposes that an innovative new class of heat transfer fluids can be engineered by suspending metallic nanoparticles in conventional heat transfer fluids. The resulting "nanofluids" are expected to exhibit high thermal conductivities compared to those of currently used heat transfer fluids, and they represent the best hope for enhancement of heat transfer. The results of a theoretical study of the thermal conductivity of nanofluids with copper nanophase materials are presented, the potential benefits of the fluids are estimated, and it is shown that one of the benefits of nanofluids will be dramatic reductions in heat exchanger pumping power. Fluids are often used as heat carriers in heat transfer equipment. Examples of important uses of heat transfer fluids include vehicular and avionics cooling systems in the transportation industry, hydronic heating and cooling systems in buildings, and industrial process heating and cooling systems in petrochemical, textile, pulp and paper, chemical, food, and other processing plants. In all of these applications, the thermal conductivity of heat transfer fluids plays a vital role in the development of energy-efficient heat transfer equipment. With an increasing global competition, industries have a strong need to develop advanced heat transfer fluids with significantly higher thermal conductivities than are presently available. [13]

Numerical investigation of heat transfer over a backward facing step (BFS), using nanofluids is presented in Application of nanofluids for heat transfer enhancement of separated flows encountered in a backward facing step. Different volume fractions of nanoparticles are presented in the base fluid besides different type of nanoparticles have been used. The finite volume technique is used to solve the momentum and energy equations. The distribution of Nusselt number at the top and the bottom walls of the BFS are obtained. For the case of Cu nanoparticles, there was an enhancement in Nusselt number at the top and bottom walls except in the primary and secondary recirculation zones where insignificant enhancement is registered. It was found that outside the recirculation zones, nanoparticles having high thermal conductivity (such as Ag or Cu) have more enhancements on the Nusselt number. However, within recirculation zones, nanoparticles having low thermal conductivity (such as TiO_2) have better enhancement on heat transfer. An increase in average Nusselt number with the volume fraction of nanoparticles for the whole range of Reynolds number is registered. The extensive interest and research conducted on BFS, in the last two decades, with the complex physics encountered in separated flow over the BFS and the continuous interest in nanofluids has motivated the present investigation. Therefore, the goal of this research is to study heat transfer characteristics of flow over a backward facing step using nano fluids. The problem is investigated numerically by solving the Navier-Stokes and energy equations (NSE). Heat transfer characteristics are analyzed for a wide range of volume fractions of the nanoparticles, Reynolds numbers and various types of nanofluids. [14]

The detail study of conductivity of nanofluid is done in Thermal Conductivity of Nanofluids. Nanofluids are suspensions of nanoparticles in base fluids, a new challenge for thermal sciences provided by nanotechnology. Nanofluids have unique features different from conventional solid-liquid mixtures in which mm or µm sized particles of metals and non-metals are dispersed. Due to their excellent characteristics, nanofluids find wide applications in enhancing heat transfer. Research work on the concept, heat transfer enhancement mechanism, and application of the nanofluids is still in its primary stage. This study provides a review of research in this field with focus on thermal conductivity studies of nanofluids. The mixture of suspended nanoparticles in a base liquid is usually referred to as a nanofluid. Nature is full of nanofluids, like blood, a complex biological nanofluid where different nanoparticles (at molecular level) accomplish different functions, and functional components actively respond to their local environment. According to the types of liquids (organic and inorganic) and kinds of nanoparticles, one can get different types of nanofluids like process extraction nanofluids, environmental (pollution-controlling nanofluids), bio-, and pharmaceutical nanofluids. A new class of polymer nanofluids, drag-reducing nanofluids, aim at enhanced heat transfer, as well as, flow friction reduction. A wide range of active self-assembly mechanisms for nanoscale structures start from a suspension of nanoparticles in fluid. Addition of nanoparticles in liquid remarkably enhances energy transport process of the base liquid. [15]

Woo-Sung HAN and Seok-Ho RHI studied the specially designed grooved heat pipe charged with nanofluids was investigated in terms of various parameters such as heat transfer rate (50-300 W with 50 W interval), volume concentration (0.005%, 0.05%, 0.1%, and hybrid combinations), inclination (5°, 45°, 90°), cooling water temperature

(1 °C, 10 °C, 20 °C), surface state, transient state and so on. Hybrid nanofluids with different volume concentration ratios with Ag-H_2O and Al_2O_3-H_2O were used as working fluids on a grooved heat pipe. Comparing with the pure water system, nanofluidic and hybrid nanofluidic systems shows greater overall thermal resistance with increasing nanoparticle concentration. Also hybrid nanofluids make the system deteriorate in terms of thermal resistance. The post nanofluid experimental data regarding grooved heat pipe show that the heat transfer performance is similar to the results of nanofluid system. The thermal performance of a grooved heat pipe with nanofluids and hybrid nanofluids were varied with driving parameters but they led to worse system performance. [16]

In EFFECT OF FILLING RATIO ON THERMAL CHARACTERISTICS OF WIRE-MESH HEAT PIPE USING COPPER OXIDE NANOFLUID, An experimental study was carried out to investigate the thermal characteristics of heat pipe using nanofluid and Deionized water (DI water) is presented in this work. The CuO/water nanofluid is used as one of the working fluid in experimental heat pipe with concentration of 1.0% wt .The test section of the heat pipe is made of copper tube with outer diameter 22 mm, inner diameter 20.8 mm and length 600 mm. The heat pipe is tested with (DI water) and nanofluid respectively. This study focused on the effects of heat input, fill ratio and angle of inclination on the thermal efficiency and thermal resistance of heat pipe. The experimental results indicate that the thermal efficiency increases when nanoparticles are added with the DI water (nanofluid) and also the heat pipe which uses nanofluid as working fluid shows lower thermal resistance value when compared to the heat pipe which uses DI water alone. [17]

Kamble D.P., Gadhave P.S, M.A.Anwar presents the behaviour of nanofluid to improve the thermal performance of a circular heat pipe. The heat pipe is made of straight copper tube using hybrid nanofluid (Al_2O_3 + CuO) with water base as working fluids. An experimental setup is designed and constructed to study thermal performance of the heat pipe under different operating conditions. Total thermal performance of heat pipe for pure water and water based nanofluid is predicted. This study presents a discussion on the effects of the charged volume ratio of the working fluids. The effect of filling volume ratio, volume fraction of nano particles in the base fluid on the thermal resistance is investigated. Thermal performance of heat pipe increases with increasing (Al2O3 + CuO)-water based nanofluid compared to that of pure water. [18]

Vikramsinh H Magar & K. V. Mali develop a thermosyphon heat exchanger for a waste air heat recovery system. The advantage of the system proposed in this work is that it provides useful energy transfer during simultaneous flow of cold supply and warm drain air. While this concept is not new, the conventional fluid is replaced by nanofluid in proposed heat exchanger, makes the present study is significantly different from those used previously. Component experiments were carried out to determine the performance characteristics of a heat pipe heat exchanger by using nanofluid. By replacing the conventional fluid in heat pipe with nanofluid, the performance of heat pipe heat exchanger is increased. A model of a multi-heat pipe heat exchanger predicts the energy savings. [19]

Thermal performance of wickless heat pipe solar collector with surfactant added nanofluid and solar tracking- A Review, introduced a several techniques for heat transfer enhancement to improve the overall thermal performance of heat exchangers resulting in the reduction of the heat exchanger size and the cost of operation. In general, the heat transfer enhancement techniques can be classified into two methods including active method (requires external power source) and passive method (not requires external power source). The mechanism for improvement of heat transfer performance in the passive method is promoting the turbulence near the tube wall surface to reduce the thermal boundary layer thickness. This turbulence introduces a chaotic fluid mixing which acted by several enhancing modified tubes such as a finned tube, tube with rib, tube with spirally roughened wall, corrugated tube, fluted tube, helical tube, elliptical axis tube and micro-fin tube, etc. Active techniques, which require an extra external power source, include mechanical aids, surface vibration, fluid vibration, fluid pulsation, electrostatic fields, injection or suction of fluid and jet impingement. Consideration about tube heat transformation in the inner gradient of temperature was mainly concentrated on the boundary layer, if boundary layer could be broken effectively and the thermo-resistance which lay in laminar boundary layer or turbulence sub layer could be diminished, we could enhance local heat exchange coefficient and intensify heat exchange process by convection. [20]

III. CONCLUSION

The manufacture of lightweight heat pipes is a very important objective for current heat pipe industries and researchers, and further investigations are needed .The understanding of the fundamentals of heat transfer and wall friction is very important for developing nanofluids for a wide range of heat transfer applications. Heat transfer performance in a straight circular tube is amplified by suspension of hybrid nanoparticles in comparison with that of pure water. The average increase in Nusselt number for hybrid nanofluid is 10.94% when compared to pure water.

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