

Performance Study of Heat Pipe Heat Exchanger Using Nanofluid (BN) Used in Boiler Plant- Experimental Study

Sagar M. Shinde¹, Dr. R. R. Arakerimath², P.J. Bansod³

P.G. Student, Department of Mechanical Engineering, GHRCEM Engineering College, Wagholi, Pune, M.S, India¹

H.O.D., Department of Mechanical Engineering, GHRCEM Engineering College, Wagholi, Pune, M.S, India²

Assistant Professor, Department of Mechanical Engineering, GHRCEM Engineering College, Wagholi, Pune, M.S, India³

ABSTRACT: Hot air plays an important role in modern life. The consumption of hot air represents a significant part of the nation's energy consumption. One way of reducing the energy consumption involved, and hence the cost of that energy, is to reclaim heat from the waste warm air that is discharged to the sewer each day. To recover heat from waste air in residential and commercial buildings is hard to achieve in quality because of its low temperature range. The objective of this research was to develop a multiple Heat pipe 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. The design of the heat exchanger proposed for the present study is significantly different from those used previously. A component experiment is to be carried out to determine the performance characteristics of a wickless heat pipe heat exchanger with working fluid for heat pipe as nano fluid. By replacing the conventional fluid in heat pipe with nano fluid of the heat pipe heat exchanger enhancement in performance of heat pipe heat exchanger can be obtained. With the help of developed test rig energy saving potential for heat source at various temperature would be expected. The performance of heat pipe heat exchanger charged with BN/H₂O nanofluid increases with increase in source temperature. Maximum effectiveness observed for proposed heat pipe heat exchanger is up to 0.39.

KEYWORDS: Heat pipe, Boiler, exhaust heat recovery, Heat pipe heat exchanger

I. INTRODUCTION

Hot air plays an important role in modern life. The consumption of hot air represents a significant part of the nation's energy consumption. One way of reducing the energy consumption involved, and hence the cost of that energy, is to reclaim heat from the waste warm air that is discharged to the sewer each day. The potential for economic waste heat recovery depends on both the quantity available and also the quality fits the requirement of the heating load. To recover heat from waste air in residential and commercial buildings is hard to achieve in quality because of its low temperature range. Nevertheless, efforts to recycle this waste energy could result in significant energy savings.[1] The objective of this research was to develop heat pipe heat exchanger for a waste heat recovery in boiler plant. The advantage of the system proposed in this work is that it provides useful energy transfer during simultaneous flow of cold supply and warm air. While this concept is not new, the design of the heat exchanger proposed for the present study is significantly different from those used previously.[2] Component experiments were carried out to determine the performance characteristics of a wickless heat pipe heat exchanger panel by using nano fluid. By replacing the conventional fluid in heat pipe with nano fluid of the heat pipe heat exchanger good performance can be obtained. A model of multiple type

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heat pipe heat exchanger panel will also develop to predict the energy saving that would be expected. [4]The heat pipe heat exchanger is a self-contained, self-maintaining passive energy recovery device. It has a very high coefficient of thermal transfer utilizing vapor liquid flows. What is more amazing is that heat pipes have no moving parts, require no external energy (other than the heat they transfer), they are reversible in operation and are completely silent A heat pipe heat exchanger consists of three elements: a sealed container, a capillary wick structure and sufficient working fluid to saturate the wick structure. The container is vacuum sealed, the working fluid is in equilibrium with its own vapor. Heating any part of the external surface, causes instantaneous evaporation of the working fluid near that surface (the evaporator region) with the latent heat of vaporization absorbed by the vapor formed. Heat is removed from the surface at the point of condensation by conduction, convection or radiation. A continuous process is established by the capillary pumping forces within the wick structure, thus returning the fluid to the evaporator section. In effect, we have a perpetual motion machine with no moving parts and requiring no energy of its own. Each heat pipe has a transfer efficiency of 99.3%.

II. LITERATURE REVIEW

Mousa[1] carried out an experimental study on an effect of nanofluid in Circular Heat Pipe. The nanofluid consisted of Al_2O_3 nanoparticles with a diameter of 100 nm. The experimental data of the nanofluids were compared with those of DI water including the wall temperatures and the total heat resistances of the heat pipe. Experimental results showed that if concentration of the nanofluid increasing, then the thermal resistance of heat pipe decreased.

Shang et al. [2] investigated the heat transfer characteristics of a closed loop OHP with Cu–water nanofluids as the working fluid different filling ratios. The results were compared with those of the same heat pipe with distilled water as the working fluid. The experimental results confirmed that the use of Cu–water nanofluids in the heat pipe could enhance the maximum heat removal capacity by 83%..

yang et al. [3] carried out an experimental study of nanofluid is employed as the working medium for a conventional 211 lm wide · 217 lm deep grooved circular heat pipe. The nanofluid used in this study is an aqueous solution of 35 nm diameter silver nanoparticles. The experiment was performed to measure the temperature distribution and to compare the heat pipe thermal resistance using nanofluid and DI-water. The tested nanoparticle concentrations ranged from 1 mg/l to 100 mg/l.

Yulong et al [4] carried out an experimental study on an effect of Al_2O_3 particle on the heat transfer performance of an oscillating heat pipe Water was used as the base fluid for the OHP. Four size particles with average diameters of 50 nm, 80 nm, 2.2 μ m, and 20 μ m were studied, respectively. Experimental results show that the Al_2O_3 added in the OHP significantly affect the heat transfer performance and it depends on the particle size. As the particle size becomes smaller from 20 μ m to 80 nm, the heat transport capability increases or the thermal resistance decreases.

Commercial Waste Heat Recovery Devices Commercial water heat recovery devices includes recuperator, regenerator, heat wheel, heat pipe, economizer, shell and tube heat exchanger, plate heat exchanger, waste heat boilers, heat pump etc. The residual energy recovery from different wastes has become an important goal in energy conservation programs, a significant progress being made for heat exchangers development. The heat pipe heat exchanger is a type of heat exchangers, which are increasingly used in different technological processes due to its advantages like high thermal conductivity, low cost, low volume, easy to manufacture, etc.

1.2 Heat Pipe Heat Exchangers

Heat pipe heat exchangers have the appearance of ordinary finned coils, but each successive tube is independent and not connected to other tubes. Each tube is built with an internal capillary wick material. The tube is evacuated, filled with a compatible fluid depending upon the temperature range and individually sealed. With the tubes installed horizontally, one half of the heat exchanger will act like an evaporator and the other half acts like a condenser. The high temperature air stream passes through the evaporator half of the unit and the low temperature air stream passes through the condenser half. The high-temperature air stream passes over one half of all the tubes. As the working fluid is warmed and vaporized in the evaporator half, the internal vapor pressure gradient drives the gas to the condenser end of the tube. In the condenser end, the fluid releases the latent energy of vaporization as it condenses, thereby warming the low-temperature air stream. Liquid returns to the evaporator end through the internal wick.

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1.3 Performance Enhancement of Heat Pipe

Many researchers have used finned tubes, threaded tubes, sintered tubes, and grooved tubes to increase the contact area between the heat pipe and the internal working fluid, thus improving the heat pipe's thermal performance. Thus, replacing the traditional working fluid by a working fluid with a high heat transport properties is worth considering. Nanofluid is a stable solid-liquid suspension created by mixing nanoparticles with the traditional working fluid. Many studies have shown that nanofluid can effectively improve the heat transfer performance of heat exchange applications. Therefore, using nanofluid in a heat pipe is a topic worthy of further study. The nanoparticles in heat pipe nanofluid include metal particles, diamond and oxide particles. The common types of heat pipes primarily include two-phase closed thermosyphon, pulsating heat pipes, and oscillating heat pipes. The parameters affecting thermal performance of nanofluid includes the nanoparticle material, shape, size, temperature, volume concentration, P^H etc.

1.4 Principle of Operation of heat pipe

The main regions of the standard heat pipe are shown in Figure.1

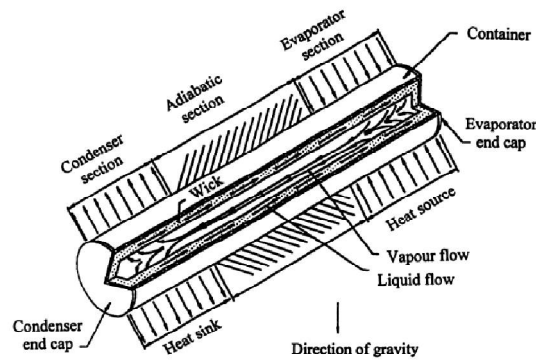


Figure . 1 heat pipe

Heat pipe consists of three components such as, the container, the working fluid .and the wick. Heat applied by a heat source at the evaporator section vaporizes working fluid in that section. This also creates a pressure difference that make the vapor flow from evaporator to condenser section where it condenses latent heat of vaporization. This liquid returns to the evaporator by means of a wick (via capillary forces) so that the heat pipe can continuously transport the heat of vaporization from evaporator to condenser. this process is capable to transport the heat from hot region to a cold region. Therefore, a heat pipe transport large amount of heat with a small temperature difference.

1.5 Heat Pipe Limit Calculation

Heat pipes undergo various heat transfer limitations depending on the working fluid, the dimensions of the heat pipe, and the heat pipe operational temperature

The various heat pipe limits calculated considering the operating temperature and parameters related to heat pipe are shown in Figure 4.6 For heat pipe parameters mentioned above the axial heat flux under variable operating temperatures are calculated for different mentioned above i.e. viscous limit, boiling limit, entrainment limit and sonic limit.

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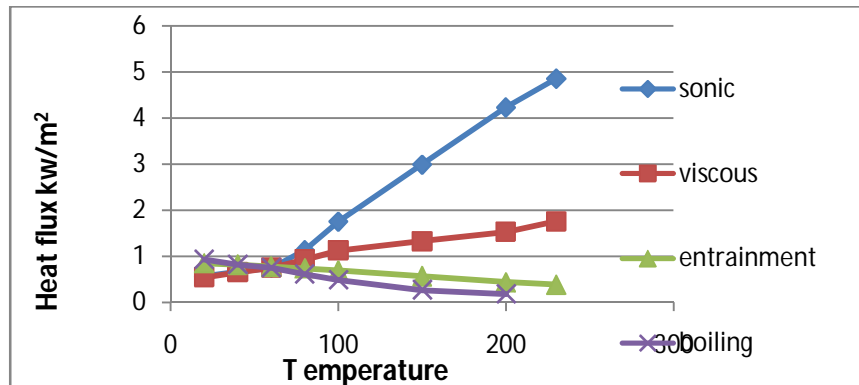


Figure 2 Heat pipes Limits for various operating temperatures

The graphs of operating temperature versus the axial heat flux for various limits are superimposed on each other and the wattage that can be transferred with heat pipe without crossing the limit has been found out. It has been noticed that the amount of wattage to be transferred to which heat pipe is designed is below the maximum axial heat flux for variable temperature and thus design of heat pipe were observed to be successful.

1.6 Preparation of Nanofluid

Many researchers have used the nonmaterial as Al_2O_3 , TiO_2 , CNT and results shows the enhancement in thermal conductivity. At This stage it is necessary to find the nonmaterial's which gives comparatively same enhancement in thermal conductivity at lower cost with previously used nonmaterials. This emphasis on the selection of material as Hexagonal Boron Nitride (Perpendicular). The behaviour of variation in thermal properties of nanofluid with particle size suggest that decrease in particle size leads to higher enhancement in thermal properties up to certain extent of particle size. Thus optimum size of BN selected for proposed work is 70 nm from review of literature. boron nitride is a chemical compound with chemical formula BN, consisting of equal numbers of boron and nitrogen atoms. BN is electronic to a similarly structured carbon lattice and thus exists in various crystalline forms.

1.7 Design and construction of heat pipe

The selected range of heat input was operating the boiler on different pressure within 6 to 9 bar for the single heat pipe. the temperature range between 0 to 250°C ., the heat pipe with the following features was designed.

Material of pipe, copper

Diameter of pipe, 15 mm

Length of pipe, 0.6 m

Length of evaporator section, 0.275 m

Length of condenser section, 0.275m

Thermal Conductivity of Material (Copper) 385 W/mk

Nano Particle Volume Fraction , 0.02

Density of Nanoparticle (BN) , 0.0021 kg/m^3

After obtaining the above characteristics for the single heat pipe, eight heat pipes were manufactured. This process consisted of washing, creating the vacuum, injecting the working Fluid and testing of each individual heat pipe. The satisfactory experimental results from the constructed heat pipe can be taken as a good indication of the veracity .

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III. EXPERIMENTAL SETUP

Experimental system for Performance investigation of heat recovery heat pipe heat exchanger by using nanofluid with variable source temperature is designed as shown in Figure below The source temperature of waste heat is regulated by operating the boiler on different pressure. The heat pipe heat exchanger consists of the arrangement of holding heat pipe and separating the evaporator and condenser section by an adiabatic partition.

A) Heat pipe heat exchanger

Heat pipe heat exchanger consists of eight hard drawn copper seat pipes 16 mm diameter each. Evaporative section of heat exchanger will be in contact of flow of hot air and condenser section will be in contact with cold air (the air which is to be heated). Heat pipe are designed, manufactured and inserted in the existing evacuated tubes available in the collector .Figure 5.2 shows schematic of heat pipe heat exchanger .Parameters regarding the proposed eight heat pipes are finalized such as material of the heat pipe, heat pipe diameter, and length of heat pipe, length of evaporator, condenser section, and diameter of condenser, filling ratio and volume concentration of BN nanofluid.

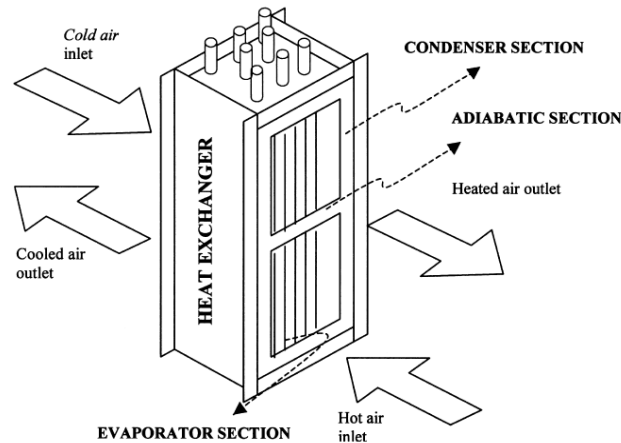


Figure 3 Schematics of the Heat Pipe Heat Exchanger.

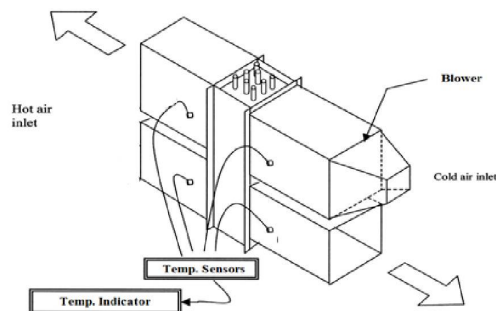


Figure 4. 3D representation of experimental set up

Equal evaporator and condenser lengths, 300 mm each Galvanised sheet steel flanges. The experimental rig consists of blower that provide a flow rate 0.2638 m³/s through condenser. The air velocities of both streams were measured by air

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velocity meters and Pitot tube were 5.24 m/s. To monitor temperatures, K type thermocouples were used and this measurement was processed by digital thermometer

IV. EXPERIMENTAL RESULT AND DISCUSSION

The experimental performance of heat pipe heat exchanger was experimentally evaluated. Experimentation was carried out to investigate the effect of heat input and mass flow rate of hot and cold air streams on the effectiveness of heat exchanger. On the basis of the observations recorded the effectiveness of heat exchanger for particular heat input and mass flow rate of hot and cold air streams were calculated. The variation of effectiveness of heat exchanger with heat input i.e. source temperature and mass flow rate of air streams are represented graphically.

4.1 Effect of Discharge on Effectiveness of Heat Pipe Heat Exchanger

The effect of heat input on the performance of Heat Pipe heat exchanger is studied by varying the heat input from operating the boiler on different pressure and maintaining the flow rate of air stream from 0.0513 m³/s to 0.2567 m³/s as mentioned earlier. The effectiveness of heat exchanger was calculated under conditions mentioned above and results are as follows.

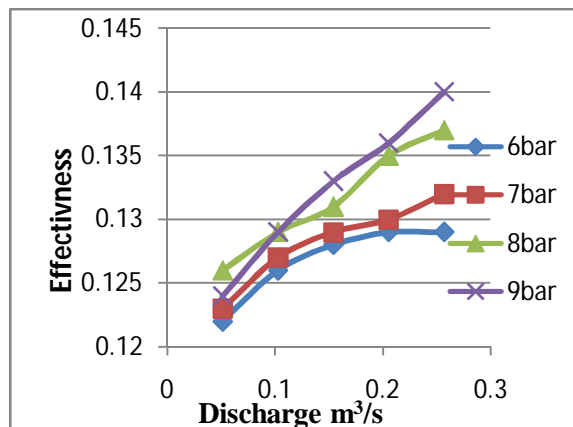


Figure 5 Variation in effectiveness of heat pipe heat exchanger with discharge

Fig. 5 shows the variation in the effectiveness of heat exchanger with variation in heat input. It is observed that the effectiveness of two phase closed thermosyphon charged with nanofluid increases with increase in heat input for a particular air stream flow.

4.2 Effect on Temperature Difference at Evaporator Section of Heat Pipe Heat Exchanger

Variation in temperature difference observed at evaporator section because of heat absorption at evaporator section of the heat exchanger this occurs because of variation in air stream flow rate and heat input. The findings of variation in temperature difference depict that with increase in heat input temperature difference increases for given mass flow rate of air. For given heat input with increase in mass flow rate of air the temperature difference increases. The numerical and graphical variation of the temperature difference is shown in figure 6

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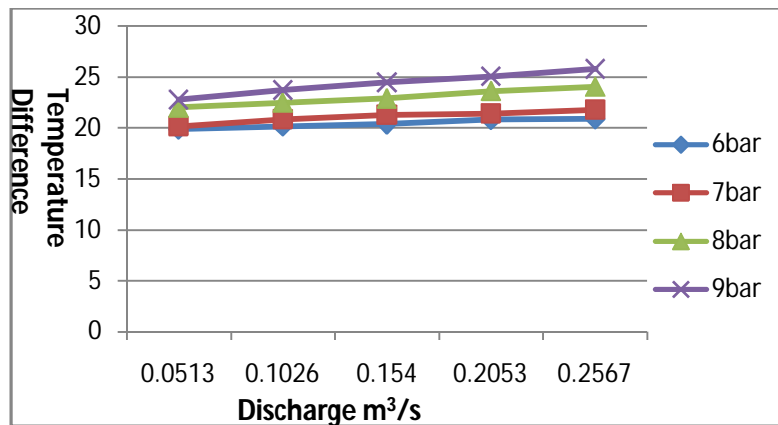


Figure 6 Variation in ΔT at evaporator section

4.3 Variation in Inlet Temperature at Evaporator Section of Heat Pipe Heat Exchanger

Variation in inlet temperature at evaporator section is observed due to the heat input supplied heater with increase in heat input, temperature at inlet of evaporator section increases and Figure 7 shows the variation.

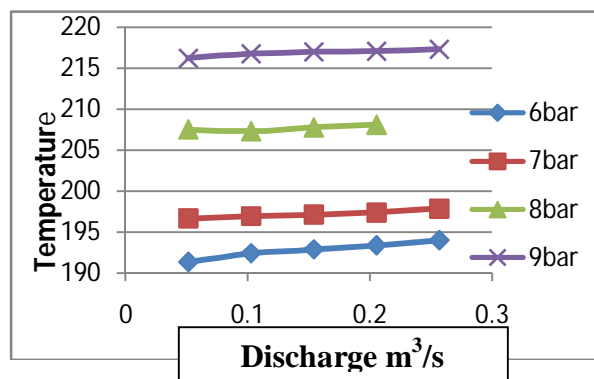


Figure 7 Variation in inlet temperature at evaporator section

4.4 Variation in Outlet Temperature at Evaporator Section of Heat Pipe Heat Exchanger

Variation in outlet temperature of evaporator section is observed due to the absorption of the heat by heat pipe working fluid during the phase change. At evaporator section working fluid absorbs the heat and it gets evaporated. So at the outlet of evaporator section temperature increases and Figure8 shows the variation.

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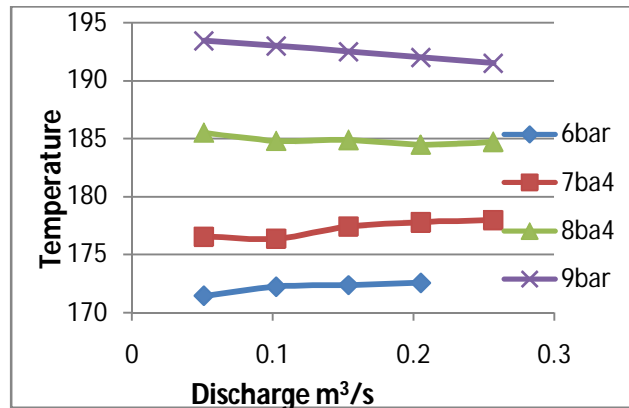


Figure 8 Variation in outlet temperature at evaporator section

4.5 Variation in Outlet Temperature at Condenser Section of Heat Pipe Heat Exchanger

Variation in outlet temperature of condenser section is observed due to the rejection of the heat by heat pipe working fluid during the phase change.

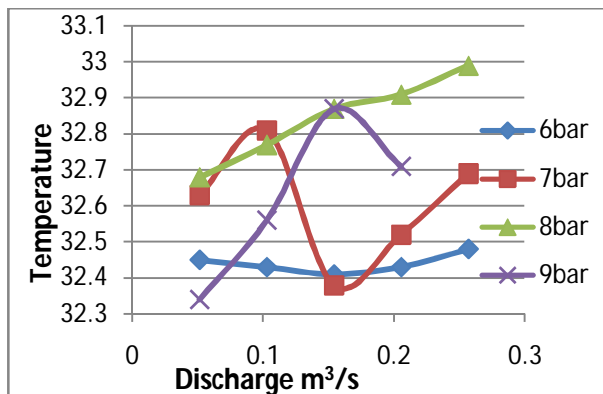


Figure 9 Variation in outlet temperature at condenser section

With increase in heat input the temperature at the outlet of condenser section increases. Figure 9 shows variation in outlet temperature at condenser section.

V. CONCLUSION

The experimental investigation was carried out on two phase closed thermosyphon heat pipe heat exchanger charged with BN/H₂O nanofluid. The effect of source temperature and mass flow rate of hot and cold air streams on effectiveness of nanofluid charged heat pipe heat exchanger was experimentally investigated. The heat input from boiler was varied on operating the boiler on different pressure and hot and cold air stream flow rate varied from 0.0513 m³/s to 0.2567 m³/s. The effect of variation in source temperature and mass flow rate of hot and cold air streams on effectiveness of heat exchanger was experimentally studied. The heat pipes used in heat exchanger was specially designed for heat recovery application. Conclusions from studied experiment are as follows,

- The performance of heat pipe heat exchanger charged with BN/H₂O nanofluid increases with increase in source temperature.
- Maximum effectiveness observed for proposed heat pipe heat exchanger is up to 0.39.

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- The results obtained for Heat Pipe heat exchanger charged BN/H₂O nanofluid are superior with that of Heat Pipe charged with conventional fluid .

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