Review of Thermosyphon heat exchanger charged with hybrid nanofluid for waste heat recovery applications

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Abstract: The objective of this research is to develop a heat pipe heat exchanger charged with hybrid nanofluid for effective waste heat recovery. The advantage of the system proposed in this work is that, it provides more useful energy transfer during simultaneous flow of cold supply and warm drain air. Superior heat transport properties of nanofluid will be effectively utilized in two phase closed thermosyphon (TPCT) heat pipe heat exchanger to obtain efficient heat exchange between two air streams.

Experiments will be carried out to determine the effect of mass flow rate of air and variable source temperature on effectiveness, evaporator and condenser side heat transfer coefficient of a heat pipe heat exchanger charged with hybrid nanofluid. By replacing the conventional fluid in heat pipe with water based hybrid nanofluid as mixture of 75% of copper oxide and 25% carbon nanotubes (75% CuO+ 25% CNT/H_20) nanofluid of the heat pipe heat exchanger good performance can be obtained. The hybrid nanofluid as working fluid in TPCT enhances the effectiveness of heat exchanger.

Key Words—TPCT, Nanofluids, Thermosyphon

I. INTRODUCTION

Hot air plays an import role in modem 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 air heat recovery depends on both the quantity available and whether 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 insignificant energy savings. The objective of this research was to develop TPCT 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 design of the heat exchanger proposed for the present study is significantly different from those used previously. Component experiments were carried out to determine the performance characteristics of a wickless heat pipe heat exchanger panel by using nanofluid. By replacing the conventional fluid in heat pipe with nanofluid of the heat pipe heat exchanger good performance can be obtained. A model of a multi-heat pipe heat exchanger panel will also develop to predict the energy savings that would be expected. 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. Like any other piece of tubing or pipe, they are rugged and can withstand a lot of abuse. 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. Because 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. The rapid generation of vapor at any point on the tube wall area creates a pressure gradient within the heat pipe which forces the excess vapor to a remote area of the pipe having a lower pressure and temperature. Here the vapor condenses on the tube wall and the latent heat of vaporization is transferred (the condenser region). 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%.Heat recovery is an excellent way of reducing energy consumption and ventilation costs. The heat pipe recovery unit contains an efficient air-to-air heat recovery device that controls heat loss in both commercial and industrial applications. This passive heat exchanger has no external power requirements and provides the owner with an excellent opportunity to recover energy normally lost through conventional exhaust systems. Available as a single component or as a packaged system (cooling, fans, filtration, etc.), the Venmar heat pipe is an excellent alternative to flat plate heat exchangers and enthalpy wheels. For source control applications, the heat pipe is the best choice with virtually 0% cross leakage between the exhaust air and supply air. If you have process exhaust air that is greater than 200°F (93.5°C), the heat pipe is also an excellent device to recover the energy normally lost to the outdoors.

II. PROBLEM STATEMENT

Hot air plays an import role in modem 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 air heat recovery depends on both the quantity available and whether 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 insignificant energy savings.

The objective of this research is to develop and experimentally investigate performance of TPCT heat exchanger for a waste air heat recovery system by using nanofluid with variable source temp.

III. LITERATURE REVIEW

Many studies have focused on heat recovery through exhaust heat by using wickless heat pipe heat exchanger in many books and many previous researcher papers. But no literature pertains to enhancement of heat transfer by introducing hybrid nanofluid as heat transfer substance used in TPCT heat exchanger. A variety of experimental, analytical and computational research works has been carried out on enhancement of heat recovery.

In 1970's, I. E. Smith [1] from cranfield Institute of Technology, UK carried out an experimental study on a heat recovery system installed in a house which showed a 10 per cent of energy saving in the total energy consumption. In his system, a small storage tank was located inside the bigger waste collection tank. The ascending cold water running in the small tank was preheated by the descending hot waste water in the big tank. Because suspended material in the waste water can freely pass through the outlet valve, an advantage of this system was low maintenance due to its simplicity in structure.

In late 1980's, G. J. Parker and Dr. A.S. Tucker [2] from University of Canterbury designed and dynamically simulated a domestic hot water system which included a waste water heat exchanger and/or a solar panel collector. The heat exchanger was a concentric cylinder unit. A 70-litre cylinder containing cold water to be pre-heated was surrounded by an annular space of 160 litres of waste warm water. Three tests were carried to study the effects of three thermostat settings for the storage tank on the energy use and water quantity for three water usage patterns (low, average and high usage patterns). The tests included Basic System test; Basic system plus wastewater heat exchanger; Basic system plus heat exchanger plus solar panels. The research shows that the energy saved by only employing the heat exchanger reached a maximum of 32%.

Dr. D.M. Clucas 1993 [3] from Mechanical Department of University of Canterbury developed a heat recovery system specifically for showers. The concept of the system was that a shower tray installed on the floor of a shower cabinet carried warm water from the shower and an approximately 15m long copper pipe with flowing cold water was attached to the underside of the tray to absorb heat. The system was simple in design and could be easily produced. But it also brings discomfort to the shower-user because of cooling of the shower tray, making it necessary to use a plastic mat as a layer of insulation.

Singh et al., 2010 [4] are proposed for datacenters: 1) Heat pipe heat exchanger (HPHE) pre-cooler for datacenter chiller and 2) Heat pipe based ice storage system for datacenter emergency cooling. Both the systems utilize thermal diode characteristics of passively operating heat pipes, to capture cold ambient energy for cooling purposes. The thermosyphon can extract heat from the high temperature storage media to low temperature ambient by means of continuous evaporation-condensation process. In other words, the thermosyphon can only transfer heat in one direction i.e. when operating in the bottom heat mode (evaporator below condenser).

Wasim saman [5] examined the possible use of a heat pipe heat exchanger for indirect evaporative cooling as well as heat recovery for fresh air preheating. Thermal performance of a heat exchanger consisting of 48 thermosyphons arranged in six rows was evaluated. The tests were carried out in a test rig where the temperature and humidity of both air streams could be controlled and monitored before and after the heat exchanger. Evaporative cooling was achieved by spraying the condenser sections of the thermosyphon. The parameters considered include the wetting arrangement of the condenser section, flow ratio of the two streams, initial temperature of the primary stream and the inclination angle of the thermosyphon. Their results showed that indirect evaporative cooling using this arrangement reduces the fresh air temperature by several degrees below the temperature drop using dry air alone.

Yau and Tucker [6] mentioned that for many years, heat pipe heat exchangers (HPHEs) with two-phase closed thermosyphon, and have been widely applied as dehumidification enhancement and energy savings device in HVAC systems. Components used to improve dehumidification by commercial forced-air HVAC systems. They are installed with one end upstream of the evaporator coil to pre-cool supply air and one downstream to re-heat supply air. This allows the system's cooling coil to operate at a lower temperature, increasing the system latent cooling capability. Heat rejected by the downstream coil reheats the supply air, eliminating the need for a dedicated reheat coil. Heat pipes can increase latent cooling by 25-50% depending upon the application. Conversely, since the reheat function increases the supply air temperature relative to a conventional system, a heat pipe will typically reduce sensible capacity. In some applications, individual heat pipe circuits can be controlled with solenoid valves to provide improved latent cooling control. Primary applications are limited to hot and humid climates and where high levels of outdoor air or low indoor humidity are needed. Hospitals, supermarkets and laboratories are often good heat pipe applications.

Zhang et al. [7] conducted a study on a thermodynamic model built with an air moisture removal system incorporated a membrane-based total heat exchanger to estimate the energy use annually. The outcomes suggested that the independent air moisture removal could save 33% of primary energy.

Yat H. Yau [8] studied an 8-row thermosyphon-based heat pipe heat exchanger for tropical building HVAC systems experimentally. This research was an investigation into how the sensible heat ratio (SHR) of the 8-row HPHE was influenced by each of three key parameters of the inlet air state, namely, dry-bulb temperature, and relative humidity and air velocity. On the basis of his study, it is recommended that tropical HVAC systems should be installed with heat pipe exchangers for dehumidification enhancement. The HPHE evaporator section functions as a pre-cooler for the AC system and the condenser section as a reheating coils. Ventilation air and the annually performance of a membrane-based energy recovery ventilator (MERV) in Hong Kong. The results indicated that approximately 58% of the energy needed for cooling and heating fresh air might be saved yearly with an MERV, while only roughly 10% of the energy might be saved via a sensible-only energy recovery ventilator (SERV).

IV. OBJECTIVES OF THE STUDY

1) To design a simple heat pipe heat exchanger which consists of a hybrid nanofluid and carry out a series of experiments which will lead to a full understanding of thermosyphon heat exchanger performance.

2) To investigate effect of variable source temperature on effectiveness of proposed heat exchanger.

3) To choose a different mass flow rate of cold and hot air by keeping source temperature constant.

4) To evaluate effect of variable mass flow rate on performance of proposed heat exchanger charged with hybrid nanofluid.

5) To compare the performance of heat pipe heat exchanger charged with hybrid nanofluid to that of heat pipe heat exchanger charged with conventional fluid under same mass flow rate and source temperature.

6) Results from experimental investigation can be validated with CFD based analysis.

V. SETUP LAYOUT

Heat pipe heat exchangers are devices that made the exchange of energy (waste heat) from a waste heat source to a colder source. The system is composed of three major parts: air heater (for waste air preparation), heat pipe heat exchanger and devices for measurement and control of parameters. In the installation there are two circulating fluids: the hot agent (waste air) in the lower chamber of the heat exchanger and the cold agent (cold air) in the upper chamber of the heat exchanger. The heat pipe heat exchanger was equipped with 08 heat pipes arranged vertically at an angle of 90°. The working fluid used in heat pipe is nanofluid. The source temperature waste heat is regulated by heating load on heater. Determination of efficiency of heat recovery will be achieved under the various temperature conditions.

- **Experimentation:**

Actual experimentation will be conducted to Performance investigation of heat recovery heat pipe heat exchanger by using nanofluid with variable source temperature. The heat will be generated within the variable temperature source. An arrangement will be made to measure and vary the heat input with the help of transformer, voltmeter and ammeter. The hot and cold air temperatures will be measured with the help of RTD's mounted at different locations of ducts. Four RTD's are to be fixed inside of ducts at inlet and outlet of hot and cold air in order to measure temperature. Heat input to heater will be varied from 250 W to 1000 W in the step of 50W to vary the source temperature. By varying the source temperature the hot air at different temperature will pass on heat pipe heat exchanger.

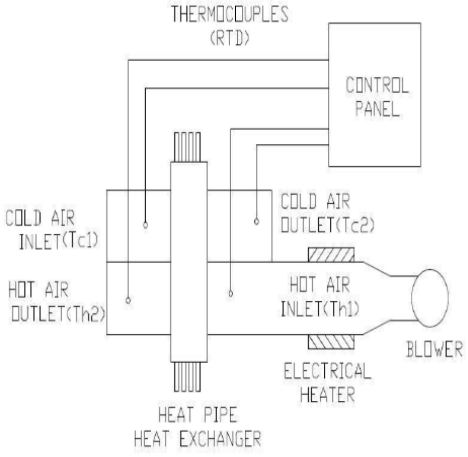

Fig 5.1: Schematic diagram of the experimental setup

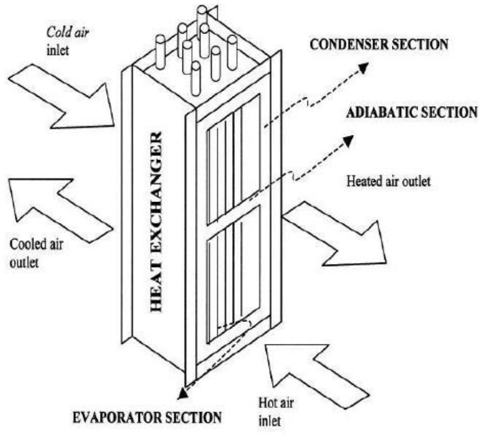

Fig 5.2: Schematics of Wickless Heat Pipe Heat Exchanger.

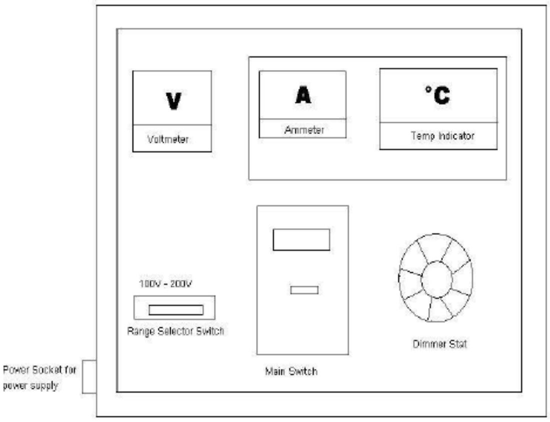

Fig 5.3: Control panel for forced convection apparatus

VI. DESIGN OF SET UP

Proposed experimental system to Performance investigation of heat recovery heat pipe heat exchanger by using nanofluid with variable source temperature consists of the following components.

a. Fin tube heater.

b. Blower.

c. Heat pipes heat exchanger.

d. Digital Voltmeter.

e. Digital Ammeter.

f. Dimmerstat.

g. Temperature sensors.

h. Temperature indicator.

i. Insulating materials.

a. Fin Tube Heater:

As mentioned in the objectives of the project it is decided to carry out the performance of wickless heat pipe heat exchanger with variable source temperature for variable mass flow rate of air.

From reference [9] proposed flow rate of air, Q=0.103 m^3/s. Therefore, mass flow rate of air will be, m = flow rate × density of air at mean bulk temperature (27.5°C)

= 0.103×1.17

= 0.12 Kg/s.

The proposed maximum mass flow rate of hot and cold air is 0.12 kg/s across duct cross section of 150 mm x 300 mm. The amount of heat required to raise the temperature of air from 25^0C to 30^oC for maximum mass flow rate of kg/s can be calculated by

= mass flow rate x specific heat x rise in temperature

= $\dot{m}$ x Cp x ΔT

= $0.12 \times 1.0 \times 10^3 \times 5$

= 600 W

Considering the heat loss from the duct as 10% of total heat generated is equal to 60 W

Thus total heat load = Q_T = 600 +60 = 660 W, Thus two fin tube air heaters can be selected with 500 W capacity of each heater.

b. Blower:

The proposed mass flow rate of air through the duct of cross section 150 mm x 300 mm is 0.12 kg/s.

Discharge needed is

Q= mass flow rate/ density of air at mean bulk temp.

= 0.12/1.17 =0.103 m^3/sec

= 218 cfm.

Thus from manufacturers catalogue, available lowest capacity centrifugal blower selected with capacity of 500 cfm.

c. Heat Pipe Heat Exchanger:

While designing the heat pipe heat exchanger the arrangement will be made in a fashion that the heat exchanger containing six heat pipes. Evaporative section 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 heat). Nanofluid can be designed, manufactured and inserted in the existing evacuated tubes available in the collector.

Parameters regarding the proposed six heat pipes will be finalized such as material of the heat pipe, heat pipe diameter, length of heat pipe, length of evaporator, condenser section, diameter of condenser, filling ratio, vacuum in heat pipe, 2 % volume concentration of (75 % CuO & 25% CNT) nanofluid. The additional properties required to calculate the heat pipe working limits can be taken from the standard literature whereas the properties related to nanofluid can be calculated from the following correlations available in the literature [9]. Total heat capacity = 660 W

Selecting 8 no's of heat pipe

Heat capacity of single heat pipe $= \frac{Total\ \ heat\ capacity}{Total\ no.of\ heat\ pipes}$

$$= \frac{660}{8}$$

$$= 82.5 \text{ W}$$

d. Voltmeter:

Digital Voltmeter of Range 0-230V (AC) single phase can be selected.

e. Ammeter:

Digital Ammeter of Range 0-10A (AC) single phase can be selected

f. Dimmerstat:

Manual operated enclosed Dimmerstat (variable auto transformer) 230V, 10A of capacity can be selected.

g. Temperature sensors:

The temperature sensors are required to measure the temperatures of cold and hot air at inlet and outlet of heat pipe heat exchanger. The four RTD's (PT-100 type) range up to 250 ^{0}C can be selected to achieve stated purpose.

h. Temperature Indicator:

Digital Temperature Indicator compatible with above mentioned temperature sensors of three and half digit which can indicate maximum temperature of 400^{0}C can be selected.

i. Insulating material:

The insulating material is used to minimize the heat losses from the duct to the surrounding. The said purpose can be solved by selecting the insulating material with lower thermal conductivity and sustain the mentioned temperature.

Rockwool can be selected as insulating material for proposed situation.

SUMMARY

From the literature survey, it is seen that with the application of heat pipes and nanofluid in waste heat recovery, the rate of heat transfer can be increased. The rate of heat transfer is depending on various factors such that source temperature, nanofluid concentration, types of nanofluids, mass flow rate of air etc. Heat transfer rate in solar water heater can be increased by replacing conventional fluid by hybrid nanofluid of higher thermal conductivity.

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