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Review on Waste heat recovery application and scope of Heat pipe heat exchanger charged with Nanofluid

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ABSTRACT

As fuel prices continue to escalate the relevance of efficient energy is apparent to companies everywhere, from the smallest concern to the largest multinational. The methods and techniques adopted to improve energy utilization will vary depending on circumstance, but the basic principle of reducing energy costs relative to productivity will be the same. As such, field of energy conservation calls for a new insight into the new source of energy as well the conventional sources that can be employed in various industries as well as in domestic applications. This paper presents an overview of a variety of waste heat recovery systems that are existing & a study on 'Heat pipe heat exchanger by using nanofluid as a nanofluid' 'as a waste heat recovery system.

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I. INTRODUCTION

Waste heat is heat, which is generate in a process by method of fuel combustion or chemical reaction, and then "dumped" into the environment even though it could still be reuse for some valuable and economic purpose. The fundamental quality of heat is not the amount but rather its "value". The strategy of how to recover this heat depends in part on the temperature of the waste heat gases and the financial side involved.

Large amount of hot flue gases is generated from Boilers, Kilns, Ovens and Furnaces. If some of this waste heat could be recovered, a significant amount of primary fuel could be saved. The energy lost in waste gases cannot be fully recovered. However, much of the heat could be recovered and loss minimized by adopting following measures as outlined in this paper.

Heat Losses –Quality

Depending upon the type of process, waste heat can be rejected at nearly any temperature from that of chilled cooling water to high temperature waste gases from an industrial furnace or oven. Generally higher the temperature, higher the quality and more cost effective is the heat recovery. In any study of waste heat recovery, it is completely necessary that there should be some use for the recovered heat. Typical examples of use would be preheating of combustion air, space heating, or pre-heating boiler feed water or process water. With high temperature heat recovery, a cascade system of waste heat recovery may be experienced to make sure that the maximum amount of heat is recovered at the highest potential. An example of this system of waste heat recovery would be where the high temperature stage was used for air pre-heating and the low temperature stage used for practice feed water heating or steam raising.

Heat Losses – Quantity In any heat recovery condition it is necessary to know the amount of heat recoverable and also how it can be used.

1.1 NEED OF WASTE HEAT RECOVERY

Large quantity of hot flue gases is generate from Boilers, kiln, Ovens and Furnaces. If some of this waste heat could be recovered, a huge amount of primary fuel could be saved. The energy lost in waste gases cannot be fully recovered. However, much of the heat could be recovered and loss minimize.

Depending upon the type of process, waste heat can be rejected at nearly any temperature from that of chilled cooling water to high temperature waste gases from an industrial furnace or kiln. Usually higher the temperature, higher the quality and more cost effective is the heat recovery. In any study of waste heat recovery, it is very essential that there should be some use for the recovered heat. Distinctive examples of use would be preheating of combustion air, space heating, or pre-heating boiler feed water or process water. With high temperature heat recovery, a cascade system of waste heat recovery may be experienced to make sure that the maximum amount of heat is recovered at the highest potential. An example of this technique of waste heat recovery would be where the high temperature stage was used for air pre-heating and the low temperature stage used for development feed water heating or steam raising. In any heat recovery situation it is necessary to know the amount of heat recoverable and also how it can be used.

1.2 CLASSIFICATION AND APPLICATION

In considering the possible for heat recovery, it is useful to note all the possibilities, and rating the waste heat in conditions of potential value as shown in the following Table1.1

Table 1.1 Waste source and quality

Sr. No.	Source	Quality
1	Heat in flue gases.	The higher the temperature, the better the potential value for heat recovery
2	Heat in vapour streams.	As above but when reduced latent heat also recoverable.
3	Convective and radiant heat lost from exterior of equipment	Low grade – if together may be used for space heating or air preheats.
4	Heat losses in cooling water.	Low grade – useful gains if heat is exchanged with incoming fresh water
5	Heat losses in providing chilled water or disposal of chilled water	a) High ranking if it can be utilized to reduce demand for refrigeration. In the b) Low mark if refrigeration unit used as a form of heat pump.
6	Heat stored in products leaving the process	Quality depends upon temperature.
7	Heat in gaseous and liquid effluents leaving process.	Poor if heavily infected and thus requiring alloy heat exchanger.

High temperature heat recovery of waste gases from industrial process tools in the high temperature range (650-1650°C). All of these results from direct fuel fired up processes. Medium temperature heat recovery of waste gases from process equipment in the medium temperature range (230-650°C). The largest part of the waste heat in this temperature range comes from the exhaust of directly fired process units.

The following Table 1.2 lists some heat sources in the low temperature range. In This range it is frequently not practical to extract work from the source, though steam manufacture may not be completely excluded if there is a need for low-pressure steam. Low temperature waste heat may be useful in a complementary way for preheating purposes.

Table 1.2 Typical waste heat low temperature range from different sources

Source	Temperature (°C)
Process steam condensate	55–88
Furnace doors	32–55
Bearings	32–88
Welding machines	32–88
Injection molding machines	32–88
Annealing furnaces	66–230
Forming dies	27–88
Air compressors	27–50
Pumps	27–88
Internal combustion engines	66–120
Air conditioning and refrigeration condensers	32–43
Liquid still condensers	32–88
Drying, baking and curing ovens	93–230
Hot processed liquids	32–232
Hot processed solids	93–232
Exhaust gases from Kitchen	35-80

The Figure 1.1 shows that though the low temperature range waste heat carries less thermal energy, it provide a much better potential for energy recovery based on the volume exhausted.

The Figure 1.1 indicate the potential energy content amount of the three different temperature category of waste heat based on cooling the exhaust air stream to a temperature of 77°F.

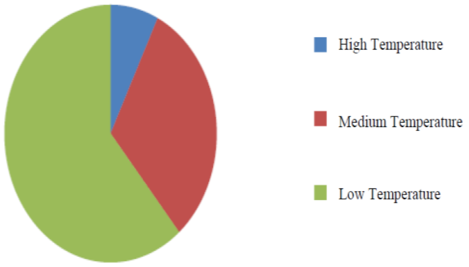

Figure 1.1 Unrecovered waste heats in different temperature groups

1.3 COMMERCIAL WASTE HEAT RECOVERY DEVICES

1.3.1 Heat Pipe Heat Exchangers

Heat pipe heat exchangers have the look of ordinary finned coils, but each consecutive 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 well-suited fluid depending upon the temperature range and separately 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 throughout the evaporator half of the unit and the low temperature air stream pass through the condenser half. The high-temperature air stream passes over one half of all the tubes. As the working fluid is heated and vaporized in the evaporator half, the internal vapour 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, in this manner warming the low-temperature air stream. Liquid returns to the evaporator end through the internal wick. Figure 1.2 shows the heat pipe heat exchanger.

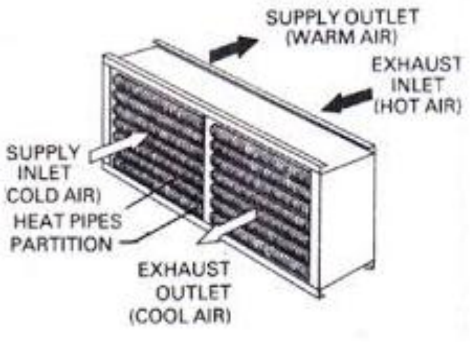

Figure 1.2 Heat pipe heat exchanger

1.3.2 Recuperators

Figure 1.3 Waste Heat Recovery using Recuperator

In a recuperator, heat substitute takes place between the flue gases and the air through metallic or ceramic walls. Duct or tubes carry the air for combustion to be preheated; the other side contains the waste heat stream. A recuperator for recovering waste heat from flue gases is shown in Figure 8.1.

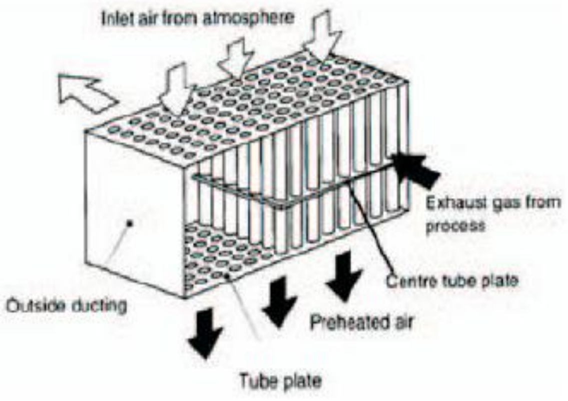

Figure 1.3 Waste Heat Recovery using Recuperator

1.3.3 Regenerator

The Regeneration which is preferable for large capacities has been very broadly used in glass and steel melting furnaces. Important relations exist between the sizes of the regenerator, time between reversals, thickness of brick, conductivity of brick and heat storage ratio of the brick. In a regenerator, the time between the reversals is an key aspect. Long periods would mean higher thermal storage and hence higher cost. Also long periods of reverse result in lower average temperature of preheat and accordingly reduce fuel economy. (Refer Figure 8.5).

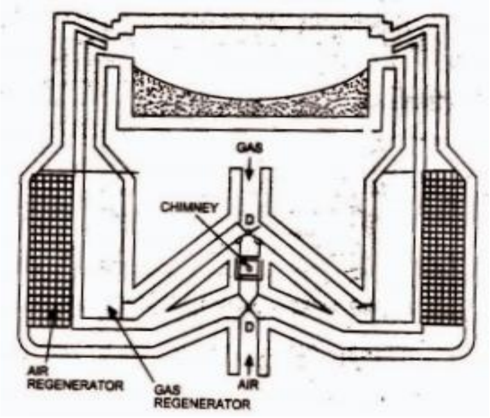

Figure 1.4 Regenerator

1.3.4 Heat Wheels

It is a sizable porous disk, fabricate with material having a quite high heat capacity, which rotates between two side-by-side ducts: one a cold gas duct, the other a hot gas duct. The axis of the disk is located parallel to, and on the separation between, the two ducts. As the disk slowly rotates, sensible heat (moisture that contains latent heat) is transferred to the disk by the hot air and, as the disk rotates, from the disk to the cold air. The overall efficiency of sensible heat transfer for this kind of regenerator can be as high as 85 percent. Heat wheels have been built as large as 21 metres in diameter with air capacity up to 1130 m^3/ min. A variation of the Heat Wheel is the rotary regenerator where the matrix is in a cylinder revolving across the waste gas and air streams. The heat or energy recovery wheel is a rotary gas heat regenerator, which can transfer heat from exhaust to inward gases. Its main area of application is where heat exchange between large masses of air having small temperature difference is required. Heating and ventilation systems and recovery of heat from dryer exhaust air are distinctive applications.

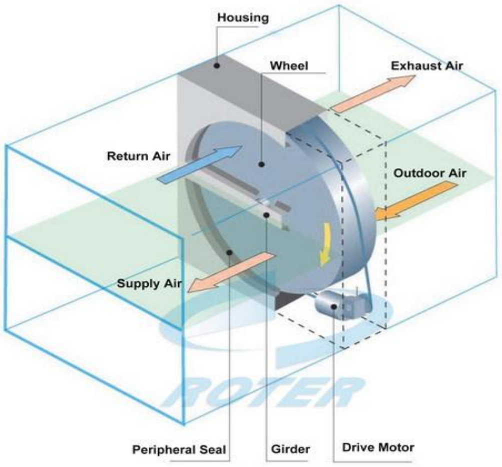

Figure 1.5 Heat Wheel

1.3.5 Thermoelectric energy conversion technology

Being one of the hopeful new devices for an automotive waste heat recovery, thermoelectric generators (TEG) will become TE devices may potentially produce twice the efficiency as compared to other technologies in the current market. TEG is used to convert thermal energy from different temperature gradient existing between hot and cold ends of a semiconductor into electric energy as shown in Fig.

4. This phenomenon was discovered by Thomas Johann Seebeck in 1821 and called the ‘‘Seebeck effect’’. The device offers the conversion of thermal energy into electric current in a simple and dependable way.

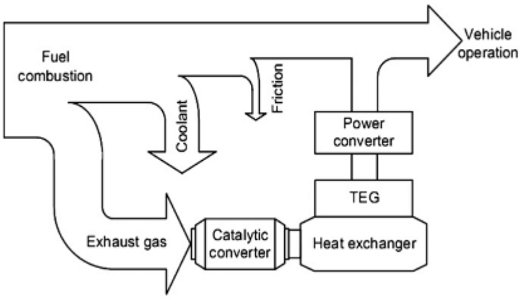

Figure 1.6 A representative waste heat energy recovery system by using TEG

2. LITERATURE REVIEW

Many studies have focused on heat recovery through exhaust heat by using heat pipe heat exchanger in many books and many previous researcher papers. But no literature pertains to enhancement of heat transfer by introducing nanofluid as heat transfer substance used in heat pipe heat exchanger. A range 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 utilization. In his system, a small storage tank was situated 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 during 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 incorporated 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 treatment 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 distinctively for showers. The concept of the system was that a shower tray installed on the floor of a shower cabinet carried hot water from the shower and an approximately 15m long copper pipe with flowing cold water was attached to the bottom of the tray to absorb heat. The system was easy 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 essential to use a plastic mat as a layer of insulation.

Singh et al., 2010 [4] are planned for data centres: 1) Heat pipe heat exchanger (HPHE) pre-cooler for data centre chiller and 2) Heat pipe based ice storage system for data centre emergency cooling. Both the systems utilize thermal diode characteristics of inactively 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 constant 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] examine 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 thermosyphon set 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 restricted and monitored before and after the heat exchanger. Evaporative cooling was achieved by spraying the condenser sections of the thermosyphon. The parameters measured 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 a number of 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 useful as dehumidification improvement 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 work 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. In opposition, 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 restricted 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 regularly good heat pipe applications.

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

Yat H. Yau [8] considered 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 subjective 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 suggested 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 indicate that approximately 58% of the energy required 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).

Mousa [9] 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 show that if concentration of the nanofluid increasing, then the thermal resistance of heat pipe decreased.

Shang et al. [10] investigated the heat transfer characteristics of a closed loop OHP with CuO–water nanofluids as the working fluid different filling ratios. The results were comparing with those of the same heat pipe with distilled water as the working fluid. The experimental results confirmed that the use of CuO–water nanofluids in the heat pipe could enhance the maximum heat removal capacity by 83%. It was conformed that directly adding nanoparticles into distilled water without any stabilizing agents had greater heat transfer enhancement compared to the case where a stabilizing agent was added to the distilled water.

Ang et al. [11] 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 evaluate 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. The condenser section of the heat pipe was attached to a heat sink that was cooled by water supplied from a constant-temperature bath maintained at 40^0C. At a same charge volume, the measured nanofluid filled heat pipe temperature distribution demonstrated that the thermal resistance decreased 10–80% compared to DI-water at an input power of 30–60W. The measured results also show that thermal resistances of the heat pipe reduce as the silver nanoparticle size and concentration increase.

Yulong et al. [12] carried out an experimental study on an effect of Al_2O_3 particle on the heat transfer performance of an oscillate 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 lm, and 20 lm were studied, respectively. Experimental results show that the Al_2O_3 added in the OHP significantly influence the heat transfer performance and it depends on the particle size. As the particle size becomes smaller from 20 lm to 80 nm, the heat transport capability increases or the thermal resistance decreases, but if the particle size further decreases less than 50 nm, the thermal resistance cannot be more reduced. This means there exist an optimal particle size for the maximum heat transport capability. Among four particles of 20 lm, 2.2 lm, 80 nm, and 50 nm tested herein, it looks that 80 nm particles can result in the best heat transport capability for the OHP investigated here.

Senthilkumar et al. [13] an experiment was carried out to study the effect of Inclination Angle in Heat Pipe Performance Using Copper nanofluid the thermal efficiency enhancement as the working fluid. The average particle size of the copper is 40 nm and the concentration of copper nanoparticle in the nanofluid is 100 mg/lit. The study discuss about the effect of heat pipe inclination, type of working fluid and heat input on the thermal efficiency and thermal resistance. The experimental results are evaluate in terms of its performance metrics and are compared with that of DI water. The result show that if inclination angle increase then thermal efficiency increase and thermal resistance reduce.

3. CONCLUSIONS

Thus we see that due to the use of heat pipe heat exchanger charged with nanofluid as a result of which, following benefits are obtained:

a) Direct Benefits:

Recovery of waste heat has a direct effect on the efficiency of the process. This is reflecting by reduction in the utility consumption & costs, and process cost.

b) Indirect Benefits:

  a) Reduction in pollution:

  A number of toxic combustible wastes such as carbon monoxide gas, sour gas, carbon black off gases, oil sludge, etc, release to atmosphere if/when burnt in the incinerators serves dual purpose i.e. recovers heat and reduces the environmental pollution level.

  b) Reduction in equipment sizes:

  Waste heat recovery reduces the fuel consumption, which leads to reduction in the flue gas produced. This results in reduction in equipment sizes of all flue gas handling equipments such as fans, stacks, ducts, burners, etc.

  b) Reduction in auxiliary energy consumption:

  Reduction in equipment sizes gives supplementary benefits in the form of reduction in auxiliary energy consumption like electricity for fans, pumps etc.

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