"HEAT PIPE HEAT EXCHANGER FOR WASTE HEAT RECOVERY IN STEEL INDUSTRY" A REVIEW

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Abstract

Heat pipes (HPs) are widely recognized as being excellent passive thermal transport devices that can have effective thermal conductivities orders of magnitude higher than similarly-dimensioned solid materials. The integration of heat pipes into heat exchangers (HXs) and heat sinks (HPHXs and HPHSs, respectively) have been shown to have strong potential for energy savings, especially in response to the significant reduction in the manufacturing costs of heat pipes in recent years. Present study consists the review on the researches carried out by various researchers on various applications, HPHXs applications, general design procedures, and analysis tools based on the thermal network approach.

Waste heat recovery is indispensable in saving energy, which is an important goal of the world economy and in the future will continue to be one, lowering energy consumption and reducing pollutants. As the world resources decreasing and energy costs increasing, highly efficient heat transfer plays a more important role in energy utilization.

Keywords; Heat exchanger, waste energy, heat pipe, general design procedures etc.

1.1 Introduction

A heat pipe is a simple device with no moving parts that can transfer large quantities of heat over fairly large distances essentially at a constant temperature without requiring any power input. A heat pipe is basically a sealed slender tube containing a wick structure lined on the inner surface and a small amount of fluid such as water at the saturated state, as shown in Figure 1.1. It is composed of three sections: evaporator section at one end, where heat is absorbed and the fluid is vaporized; a condenser section at the other end, where the vapor is condensed and heat is rejected; and the adiabatic section in between, where the vapor and the liquid phases of the fluid flow in opposite directions through the core and the wick, respectively, to complete the cycle with no significant heat transfer between the fluid and the surrounding medium. The operation of a heat pipe is based on the thermodynamic properties of a fluid vaporizing at one end and condensing at the other end. Initially, a wick of the heat pipe is saturated with liquid and the core section is filled with vapor, as shown in Figure 1.1. When the evaporator end of the heat pipe is brought into contact with a hot surface or is placed into a hot environment, heat will flow into the heat pipe. Being at a saturated state, the liquid in the evaporator end of the heat pipe will vaporize as a result of this heat transfer, causing the vapor pressure there to rise. This resulting pressure difference drives the vapor through the core of the heat pipe from the evaporator toward the condenser section. The condenser end of the heat pipe is in a cooler environment, and thus, its surface is slightly cooler. The vapor that comes into contact with this cooler surface condenses, releasing the heat a vaporization, which is rejected to the surrounding medium. The liquid then returns to the evaporator end of the heat pipe through the wick as a result of capillary action in the wick, completing the cycle. As a result, heat is absorbed at one end of the heat pipe and is rejected at the other end, with the fluid inside serving as a transport medium for heat.

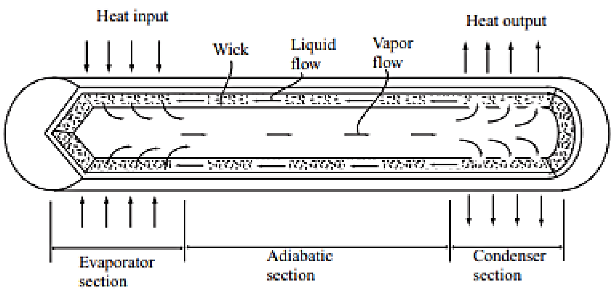

Figure 1.1 Cutaway view of a heat pipe

Heat pipes and thermosyphons both operate on a closed two-phase cycle and utilize the latent heat of vaporization to transfer heat with very small temperature gradients. Thermosyphons, however, rely solely on gravitational force to return the liquid phase of the working fluid from the condenser to the evaporator, while heat pipes utilize some sort of capillary wicking structure to promote the flow of liquid from the condenser to the evaporator. As a result of the capillary pumping occurring in the wick, heat pipes can be used in horizontal orientation, microgravity environments, or even applications where the capillary structure must pump the liquid against gravity from the condenser to the evaporator.

The heat pipe is a device of very high thermal conductance. The idea of the heat pipe was first suggested by Gaugler [1] in 1942. It was not, however, until its independent invention by Grover [2, 3] in the early 1960s that the remarkable properties of the heat pipe became appreciated and serious development work took place.

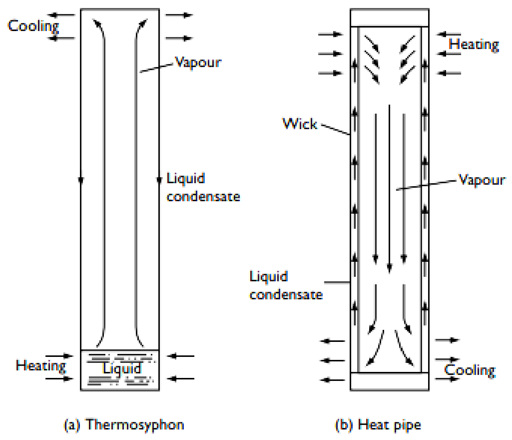

Figure 1.2 Heat pipe and thermosyphon

1.2 The Heat Pipe–Construction, Performance and Properties

The main regions of the standard heat pipe are shown in Figure 1.3. In the longitudinal direction, the heat pipe is made up of an evaporator section and a condenser section. Should external geometrical requirements make this necessary, a further, adiabatic, section can be included to separate the evaporator and condenser. The cross-section of the heat pipe, Figure 1.3, consists of the container wall, the wick structure and the vapour space.

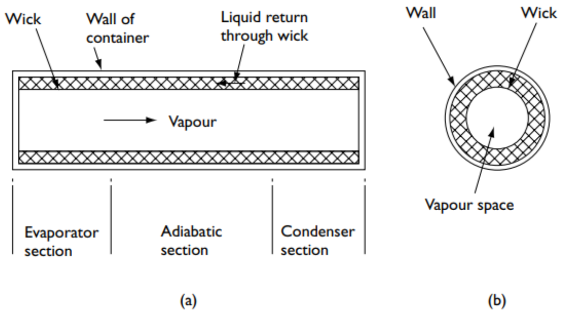

Figure 1.3 Main regions of the heat pipe

The performance of a heat pipe is often expressed in terms of 'equivalent thermal conductivity'. A tubular heat pipe of the type illustrated in Fig. 1.3, using water as the working fluid and operated at 150 C would have a thermal conductivity several hundred times that of copper. The power handling capability of a heat pipe can be very high – pipes using lithium as the working fluid at a temperature of 1500 C will carry an axial flux of 10–20 kW/cm^2. By suitable choice of working fluid and container materials, it is possible to construct heat pipes for use at temperatures ranging from 4 K to in excess of 2300 K.

For many applications, the cylindrical geometry heat pipe is suitable but other geometries can be adopted to meet special requirements. The high thermal conductance of the heat pipe has already been mentioned; this is not the sole characteristic of the heat pipe. The heat pipe is characterised by the following:

(i) Very high effective thermal conductance.

(ii) The ability to act as a thermal flux transformer.

(iii) An isothermal surface of low thermal impedance. The condenser surface of a heat pipe will tend to operate at uniform temperature. If a local heat load is applied, more vapour will condense at this point, tending to maintain the temperature at the original level.

2 Previous Researches

Many researchers have done a lot of research to improve the drying performance and efficiency of clothes dryers. When a dryer's energy and exergy efficiency are improved, it means that the drying performance has also been improved.

The domestic venting tumble clothes dryer consumes a lot of energy during the drying process, which has drawn more and more attention. Q. Jian et al; 2018 reports a method to reduce its energy consumption by using heat recovery. A self-made heat pipe heat exchanger was used for a domestic venting tumble clothes dryer as a heat recovery unit. The performance of the clothes dryer in the case of heat recovery and no heat recovery was tested under the same conditions, including weighing before drying, drying and weighing after drying. Compared with the case of without heat recovery, it can be found that the exergy efficiency of the venting tumble clothes dryer with heat recovery is increased from 10.122% to 12.292%, and the energy efficiency is increased from 47.211% to 57.335%.

Hongting Ma et al; 2016 presents the waste water mass flow rate varied from 0.83 m^3/h to 1.87 m^3/h, the effectiveness and exergy efficiency varied from 0.19 to 0.09 and from 34% to 41%, respectively. In the present work, the optimal flow rates of waste water and fresh water were 1.20 m3/h and 3.00 m^3/h, respectively. The on-line cleaning device had an obvious effect on the heat transfer, by performing the device, heat transfer rate, heat transfer coefficient, effectiveness and exergy efficiency were improved by 6.11%, 9.49%, 7.19% and 7.93%, respectively.

In order to investigate the characteristics of a heat pipe heat exchanger (HPHE) used for recovering the waste heat in a slag cooling process in steel industry, a waste heat recovery experimental system has been designed and established. Main parameters representing the HPHE are investigated experimentally and theoretically, the optimum operation conditions are determined by integrating the first and the second law of thermodynamics. The results indicate that the heat transfer ratio and heat transfer coefficient increase with waste water mass flow rates increasing at constant cold-water mass flow rate. As the waste water mass flow rate varies between 0.8 and 1.9 m^3/h, exergy destruction rate, exergy efficiency and effectiveness of the HPHE have the values from 0.277 to 0.510 kW; from 66.1% to 42.9% and from 0.085 to 0.192, respectively. The optimum waste water and cold-water mass flow rate are deduced as 1.40 and 2.90 m^3/h, respectively. In addition, the effect of on-line cleaning device on the heat transfer and fouling cleaning has been verified by experiments in this study. It is concluded that the heat transfer performance has been significantly improved after using the on-line cleaning device. ***(Hongting Ma et al; 2017)***

Heat exchangers are commonly employed as heat recovery devices to reuse the wasted heat energy from exhaust outlets so it may be furtherly reused or stored for a later use. According to the research of ***Haddad et al.*** 90% of the wasted heat energy is found at low to medium-grade heat applications (temperatures from 100 to 400°C), as can be seen in Fig. 1. It is in this environment that heat pipe-equipped heat exchangers are finding wide use due to an array of advantages ranging from a complete flow separation, great redundancy and ease of maintenance. All of the advantages are a direct result of the mechanism of phase change happening within the heat pipe.

Joao Ramos et al; 2016 applied CFD modelling and numerical calculations to predict the thermal performance of a cross flow heat pipe-based heat exchanger. The heat exchanger under study transfers heat from air to water and it is equipped with six water-charged wickless heat pipes, with a single-pass flow pattern on the air side (evaporator) and two flow passes on the water side (condenser). For the purpose of CFD modelling, the heat pipes were considered as solid devices of a known thermal conductivity which was estimated by experiments conducted on the exact same heat pipe configuration under an entire testing range. The CFD results were compared with the experimental and the numerical results and it was found that the modelling predictions are within 10% of the experimental results

Heat pipes (HPs) and thermosyphons (TSs) are passive devices which operate by utilizing the latent heat of an internal working fluid to transfer large amounts of heat, nearly isothermally, with a minimal driving temperature difference through a small cross-sectional area presented ***by A. Faghri***. A HP/TS is divided into three segments: evaporator, adiabatic and condenser sections denoted based on their external thermal boundary conditions. A HP/TS functions when heat is applied to the evaporator section, which causes vaporization of the working fluid. The vapor flows through the adiabatic section to the lower temperature condenser section, within which condensation of the HP/TS working fluid occurs. TSs differ from HPs only by the exclusion of an internal wick.

The industrial waste heat carrier, such as exhaust gas, mostly contains oil, particles, fibers and other impurities. If the conventional heat transfer enhancement techniques are applied in the gas side to recovery waste heat, the gas side flow channels are easily to be blocked, which not only greatly reduces the waste heat recovery efficiency but some time also makes the heat exchanger out of work. In the work carried out by ***En Tian et al; 2017,*** a new type waste heat recovery heat pipe exchanger has been designed and applied to recover thermal energy in high temperature exhaust gas emitted from setting machine in the dyeing and printing industry. Its major feature is that clean air passes though fin-enhanced vertical tubes whose inner side is a condenser while dirty gas passes though inner smooth surface of horizontal tubes whose outside is an evaporator.

A heat pipe air conditioning (AC) system which used heat pipe heat exchanger (HPHE) to realize secondary heat recovery was proposed. With the meteorological parameter of Hefei city (31◦53°N and 117◦15°E) as the reference, we analysed the consuming energy between secondary heat recovery HPHE AC system and the common heat recovery HPHE AC system theoretically. The analysis of experimental data revealed that the average heat recovery efficiency of the HPHE AC system in winter is 21.08%, while 39.2% in summer. The results show that the secondary heat recovery HPHE AC system has a certain energy-saving advantage. ***(Haitao Wang et al; 2016)***

III- Conclusion

Based on the literature review it can be stated that numerous studies have been presented to show the effects of the heat exchanger configuration on energy performance by the NTU method, and apply the laws of thermodynamics to determine the optimal operating conditions. There are various applications of Heat pipe heat exchanger in industrial segments and all of them are need to optimize separately.

Steel Industry is one of them which required heat recovery to enhance the efficiency. There is a need to carry out the research focusing on the waste heat recovery of slag cooling process in steel industry application by using a Heat Pipe Heat Exchanger.

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