International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 6, June - 2014

Effective Utilization of an Axially Grooved Wick Structure in The Heat Pipes and its Performance Analysis for The Heat Pipe Heat Exchanger Used In Waste Heat Recovery

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Abstract: **The demand of energy is a major task for the worldwide generation stations and it is increasing per day for the human living. The researchers are broadly working for reversing the heat energy which is finally added into environment. This energy is waste energy which is exhausted from the thermal power generators at the rate of 15 to 20 % of generated heat energy. So the device which carries more amount of heat by making contact with waste heat is the Heat Pipe. Heat pipe is device working on two phase change of working fluid inside. This phase change of working fluid lead to increasing heat transport efficiency of heat pipe. The basic heat pipe working position is vertical position, when the heat pipe can transport maximal heat flow from evaporator to condenser. This article is mainly focusing on testing and implementation of heat pipe with axially groove wick structure for heat pipe heat exchanger(HPHE). Experimental results of this work will support for the utilization and the analysis of thermal performance improvement in heat pipes. Waste heat is valuable and one addition in the improvement of plant performance. This HPHE can be used to heat the sugar juice or feed water for the production process. This concept may be applied to save almost 10 % of energy which is exhausted per day. This conservation may useful for the reduction in thermal pollution of world.**

[Key Words: Waste Heat, Heat Pipe, Thermal Performance, Experimental results, Thermal pollution]

I INTRODUCTION

A classical heat pipe consists of a sealed container lined with a wicking structure. The container is evacuated and backfilled with just enough liquid to fully saturate the wick. When a heat pipe operates on a closed two-phase cycle with only pure liquid and vapor present, the working fluid remains at saturation conditions as long as the operating temperature is between the freezing point and the critical state. As shown in Fig. 01, heat pipe consist of three distinct regions: the evaporator or heat addition region, the condenser or heat rejection region, and the adiabatic or isothermal region. Heat added to the evaporator region of the container causes the working fluid in the evaporator wicking structure to be vaporized. The high temperature and corresponding high pressure in this region result in flow of the vapor to the other, cooler end of the container, where the vapor condenses, giving up its latent heat of vaporization. The capillary forces in the wicking structure then pump the liquid back to the evaporator. similar devices, referred to as two-phase thermosyphons, have no wick but utilize gravitational forces for the liquid return.

In order to function properly, heat pipes require three major components: the case, which can be constructed from glass, ceramic, or metal; a wicking structure, which can be fabricated from woven fiberglass, sintered metal powders, screens, wire meshes, or grooves; and a working fluid, which can vary from nitrogen or helium for low-temperature (cryogenic) heat pipes to lithium, potassium, or sodium for high-temperature (liquid metal) heat pipes. Each of these three components is equally rtant, with careful consideration given to the material type, thermo physical properties, and compatibility

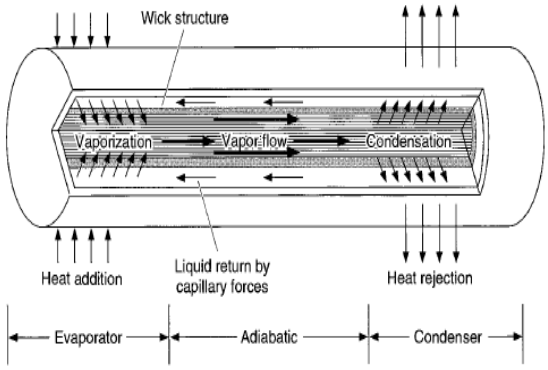


Fig .01 Internal sections of heat pipe

the working fluid and the wicking structure, (2) strong enough to withstand the pressure associated with the saturation temperatures encountered during storage and normal operation, and (3) of a high enough thermal conductivity to permit the effective transfer of heat either into or out of the vapor space. In addition to these characteristics, which are primarily concerned with the internal effects, the container material must be resistant to corrosion resulting from interaction with the environment and must be malleable enough to be formed into the appropriate size and shape. Although The heat pipe container or case provides containment and structural stability. As such, it must be fabricated from a material that is (1) compatible with both heat pipe performance and operation are strongly dependent on shape, working fluid, and wick structure, the fundamental phenomenon that governs the operation of these devices arises from the difference in the capillary pressure across the liquid-vapor interfaces in the evaporator and condenser regions. The vaporization occurring in the evaporator section of the heat pipe causes the meniscus to recede into the wick, and condensation in the condenser section causes flooding. The combined effect of this vaporization and condensation process results in a meniscus radius of curvature that varies along the axial length of the heat pipe . The point at which the meniscus has a minimum radius of curvature is typically referred to as the "dry" point and usually occurs in the evaporator at the point farthest from the condenser region. The "wet" point occurs at that point where the vapor pressure and liquid pressure are approximately equal or where the radius of curvature is at a maximum. It is important to note that this point can be located anywhere in the condenser or adiabatic sections, but typically is found near the end of the condenser farthest from the evaporator [7].\

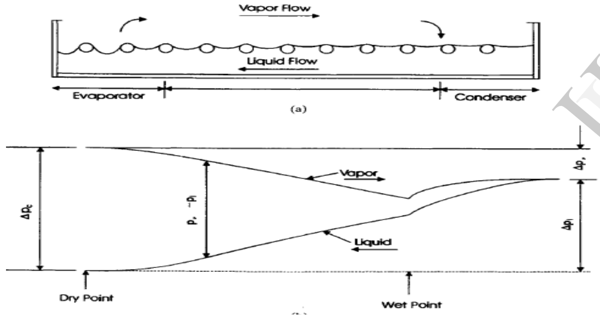


Fig .02 Internal Flow structure of heat pipe

HEAT PIPE HEAT EXCHANGER (HPHE)

Theoretical studies

Wan et al. (2007) theoretically investigated the effect of a loop heat pipe air handling coil on the energy consumption in a central air conditioning system with return air for an office building. Based on the results, the air conditioning system installed with HPHE could save cooling and reheating energy.

The rate of energy saving (RES) is defined by:

$$\alpha = \frac{Q_2 - Q_1}{Q_2} \quad (1)$$

Where Q_2 is the cooling load or total energy consumption in a central air conditioning system with returned air at constant indoor design temperature (kW) and Q1 is the cooling load or total energy consumption with HPHE at constant indoor design temperature (kW).

In the temperature range of 22 to 26°C indoor design and 50% relative humidity, the rate of energy saving in the office building was 23.5 to 25.7% for cooling load and 38.1 to 40.9% for total energy consumption. The rate of energy saving was increased with the increase of the indoor design temperature and decrease of indoor relative humidity. The study demonstrated that by employing a HPHE in an air conditioning system, the energy consumption could be significantly reduced and the indoor thermal comfort and air quality also could be improved.

Numerical study on the application of HPHE in heat recovery systems has been carried out by Lin et al.(2005), using a CFD package called FLOTHERM for simulation of a drying cycle (Figure 02).

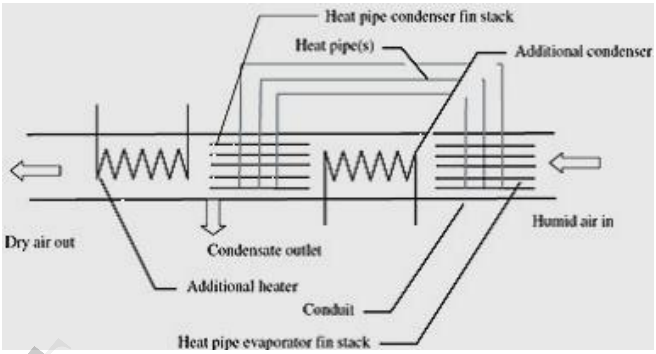


Fig.no. 03. Heat recovery system using HPHE in drying cycle.

The simulation showed that the efficiency of a dehumidification process is completely affected by inlet operational conditions. In general, higher temperature and flow rate of the inlet saturated air result in more heat transfer in the system, but it needs more heating to achieve the mentioned relative humidity.

Alklaibi (2008) has studied the possibility of using a loop heat pipe (LHP) in air conditioning systems along with investigating the coefficient of performance (COP) which is the ratio of the absorbed heat from refrigerated space to the energy supplied into the compressor of refrigeration cycle (Dossat, 1997). Principles of heat transfer in HPHE and LHP are the same, but arrangement of their components is different. In loop heat pipe (LHP), wick is limited to the evaporator section. Whereas in conventional heat pipe the wick structure exists in all parts of evaporator, condenser and the liquid return line. The advantage of LHP compared to common heat pipe is that, since the wick is limited to the evaporator, it is possible to use capillary structure with quite small pores which can create tens kilopascals capillary pressure (Maidanik, 1999). In addition, because the liquid and the vapor lines of LHP do not have wicks, the pressure drops are reduced along these lines, allowing for larger mass flow rates (Figure 03). In hot and humid areas or in places with heavy physical activity, like sports clubs, the room sensible heat factor (RSHF) is defined as:

$$RSHF = \frac{Q_L}{Q_L + Q_S} \quad (2)$$

Where Q_L and Q_S are the latent and sensible heat gains, respectively. To make a room with comfortable conditions in hot and humid climates, an air conditioner should be able to decrease both temperature and humidity. Alklaibi has studied the possibility of using LHP in small air conditioners (such as the window or split type) in two situations PHL (1) : evaporator in front of air conditioner evaporator followed by a LHP condenser, (2) LHP condenser after air conditioner evaporator and LHP evaporator in front of air conditioner condenser. Also, he has studied the use of LHP in larger air conditioning systems. Results of this theoretical study show that the system's COP in each of the three above-mentioned situations increases in comparison with the situation where LHP is not used. In humid climate where RSHF is low, use of LHP results in increasing of COP as much as two times more than the use of heating elements, which results in decreasing the consumed energy by compressor.

EQUIVALENT THERMAL CONDUCTIVITY MODEL OF HEAT PIPES

Thermal conductivity is a physical parameter which describes diathermanous performance. The bigger the thermal conductivity is, the stronger the diathermanous performance is. Thermal conductivity, calculated as in Eq. (1), relies on the material type, structure, density, temperature, and pressure, except the dimensions. For a heat preservation material, density and humidity are pivotal influencing factors and its thermal conductivity can be computed with experimental data

$$\gamma = \frac{q}{\frac{\delta t}{\delta n}} \qquad (2)$$

Where,
λ = is the conductivity coefficient;
q = is the thermal flow quantity;
t = is the temperature; and
n = is the length in the thermal flow quantity direction.

When the heat pipe is operated under the maximum overall thermal transfer limit, its performance can be described by the overall thermal resistance R.

Therefore, the actual overall thermal transfer rate can be defined as where T is the overall temperature difference between the heat source and the heat sink; R is the thermal resistance and can be represented by the idealized thermal resistance network, as shown in Fig. 01.

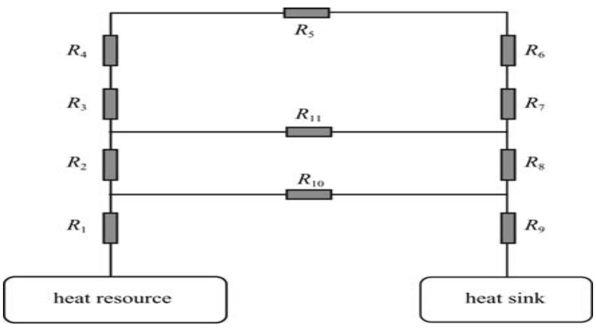


Fig no.04 Thermal resistance ckt.

As shown in Fig. 02, assuming that a heat pipe has an equivalent thermal transfer effect as a stick with the same dimension, the same heat resource, diathermanous conditions, and temperature of the heat resource and heat sink, then according to Eq. (1)

HEAT PIPE CLASSIFICATION BY WICK STRUCTURE

The wick provides a means for the flow of liquid from the condenser to the evaporator section of the heat pipe. It also provides surface pores that are required at the liquid–vapor interface for development of the required capillary pressure. The wick structure also has an impact on the radial temperature drop at the evaporator end between the inner heat pipe surface and the liquid–vapor surface. Thus, an effective wick requires large internal pores in a direction normal to the heat flow path. This will minimize liquid flow resistance. In addition, small surface pores are required for the development of high capillary pressure and a highly conductive heat flow path for minimization of the radial surface to liquid–vapor surface temperature drop. To satisfy these requirements, two types of wick structure have been developed.

These are the homogeneous wicks made of a single material, examples of which are the composite wicks containing two or more materials, with some typical examples displayed in Fig. 06.

One common wick structure is the wrapped screen wick shown in Fig.06. This type of wick structure is designated by its mesh number, which is an indication of the number of pores per unit length or unit surface area. The surface pore size is inversely proportional to the mesh number and the liquid flow resistance can be controlled by the tightness of the rapping. This is attractive, but because of the interruptions in the wick metal by a liquid of low thermal conductivity in the moderate-range heat pipe, the radial temperature drop from the inner pipe surface to the liquid–vapor surface at the evaporator end can be quite high. This problem can be alleviated through use of the sintered metal wick structure shown in Fig. 06. Notice here that the pore size is small but the small pores will make it more difficult for the liquid to flow from the condenser to the evaporator [4].

The axially grooved wick shown in Fig. 08 possesses highly conductive metal paths for the minimization of radial temperature drop. Axially grooved heat pipes are most commonly found in space applications. The annular and crescent wicks, shown respectively have small resistance to liquid flow but are vulnerable to liquids of low thermal conductivity. The artery wick, shown in Fig. 06 was developed to reduce the thickness of the radial heat flow path through the structure and to provide a low-resistance path for the liquid flow from the condenser to the evaporator. However, these wicks often lead to operating roblems if they are not self-priming, because the arteries must fill automatically at startup or dry out [4].

Cross sections of homogenous wick structures

All the composite wicks shown in Fig. 03 have a separate structure for development of the capillary pressure and liquid flow. Notice that in some of the structures in Fig. 03, a separation of the heat flow path from the liquid flow path can be provided. For example, the screen-covered groove wick shown in Fig. 03 has a fine mesh screen for high capillary pressure, axial grooves to reduce flow resistance, and a metal structure to reduce the radial temperature drop. The slab wick displayed and it is inserted into an internally threaded container. High capillary pressure is derived from a layer of fine mesh screen at the surface, and liquid flow is assured by the coarse screen inside the slab. The threaded groove tend to provide uniform circumferential distribution of liquid and enhance radial heat transfer [4].

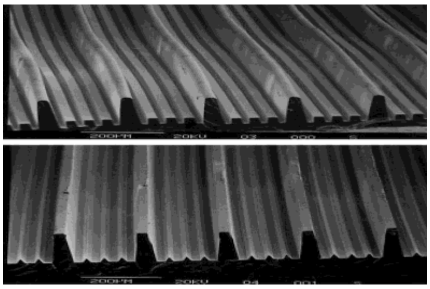


Fig No.05 Cross section of wick structure

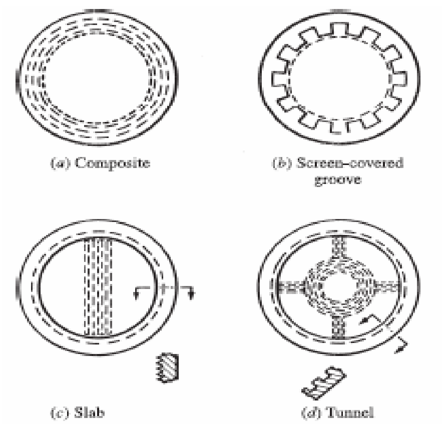


Fig no.06 Cross sections of composite wick structures

Selection of the working fluids

The heat transfer capacity of the heat pipe is mainly depending on the selection of working fluids. The latent heat of evaporation is very important for transferring highest amount of heat from evaporator to the condenser. So depends upon the range of heat sourse the proper fluid is selected.and this may achive more conductivity than best conductors\\\Using a heat pipe, high heat fluxes from a heat source can be injected over a small surface area, which is then rejected over a larger condenser surface area\\\so as I have allowed to utilize water as a working fluid. A variety of physical, chemical, and thermodynamic properties of a particular working fluid must be evaluated to determine whether or not that fluid is suitable for the specific heat pipe application. The general considerations of which apply to candidate fluids are:

1] Operating temperature range
2] Liquid transport factor
3] Vapor phase properties
4] Wicking capability in body-force field
5] Thermal conductivity
6] Fluid operating pressure
7] Fluid compatibility and-stability

Fundamentals of the operation of Heat Pipe

Heat pipe is a closed tube whose inner surface is lined with a grooved channel as shown in figure 01. The wick structure geometry is saturated with the liquid phase of a working fluid and the remaining volume of the tube contains vapor phase. Heat applied at the evaporator by an external source vaporizes the working fluid in that section. The resulting difference in pressure drives vapor from the evaporator to the condenser where it condenses releasing the latent heat of vaporization to a heat sink in that section of the pipe. Circulation of working fluid is an important heat pipe factor. So, the maximum possible circulation is required to obtain the maximum heat transport capability of the grooved channel heat pipe.

Forced convection heat transfer is the most frequently employed mode of the heat transfer in heat pipes. The use of the turbulence promoters or roughness elements, such as welded ribs or grooves on the surface, is a common technique to enhance the rate of heat transfer

Increase in heat transfer rate is depends on recovery of condensed water into evaporator side. This parameter is mainly depends on the pressure drop and heat flux supplied at the inlet. some researchers have developed a mathematical model and its theoretical analysis for the best performance The comparison is shown for the various parameters with Reynolds number and performance.

Theoretical analysis for heat pipe heat exchanger

Heat pipe is a device which implements rate of heat transfer as compared to other metals like copper. As different fluids takes latent heat of evaporation at a particular pressure it gains more heat for the phase change. As water takes almost 2268 kJ/kg at 100 ^{0}C. So this fluid is used for the heat pipes for the working temperatures from 200 to 300 ^{0}C. now the heat pipe heat exchanger is designed for taking heat from exhaust draft of a sugar industry boiler. The technical specifications are described as shown in table no .A.

Total heat flux may by readily be obtained if we assume:

1. The liquid properties do not vary along the pipe,
2. The wick is uniform along the pipe,
3. The pressure drop due to vapor flow can by neglected.

Sr.No	Heat pipe particulars	Dimensions
01	Dout (mm)	50
02	Number of groove (N)	6
03	Groove depth (H) (mm)	9
04	Vapor core radius (Rv) (mm)	2
05	Pitch between grooves(P) (mm)	9
06	Wall thickness (mm)	1
07	Working fluid	Water
08	Initial amount of liquid charge (g)	310
09	Solid material	hollow
10	Evaporator section mm	100
11	Condenser Section mm	100
12	Adiabatic Section mm	300

Table A shows HPHE designed payameters for test set up

Wick Design concept

The wick provides the necessary flow area for liquid eturn from the condenser to the evaporator and also provides the pores required to develop capillary pumping. The properties of the wick are characterized by the permeability K and an effective pumping radius (rp). These properties and the wick cross-sectional area Aw determine the ability of the heat pipe to overcome hydrodynamic losses.

The choice of a wick design for a specific heat pipe application is determined by trade-offs between a numbers of interrelated parameters. First, the wick should be capable of providing a high capillary pressure which is equivalent to processing a small effective pore radius. Second, it should be capable of supporting high flow rates which means that the wick should have a high permeability and therefore a effective pore radius.

Finally, in many designs, the wick is directly in the heat flow path and therefore its thermal conductivity is an important o thermal performance.

Heat Transport Capability of Heat Pipe

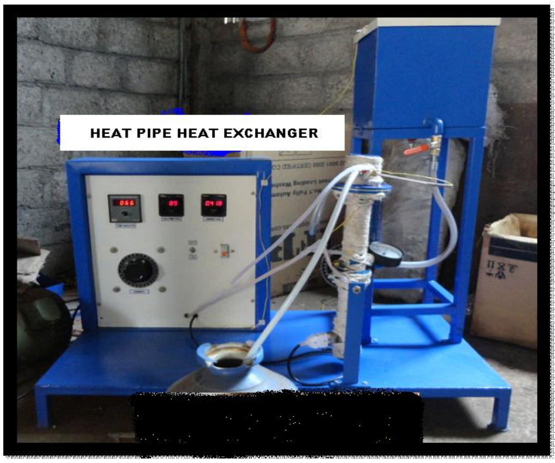
Heat Transport Capability for this conventional heat pipe is given by…

$$Q_L max = \left[\frac{2k\ A_w \quad (1+n)cos\theta_c \quad F_l}{r_p}\right] N_l \qquad (3)$$

As per the given expression the max amount of heat is transferring by increasing the rate of water flow from condenser to evaporator. The more amount of evaporation is possible by collecting continuous flow from no of grooves. Also wetting of grooves area is to be increasing the pressure drop.

So the rate of flow is depends upon the Reynolds number. And which is based on the types of flows.

The maximum heat transport capacity is calculated with ref to above equation Q max at 50 ^{0}C is 18.2 watt..



[Fig no 07. Heat pipe Heat exchanger experimental test set up]

DESCRIPTION OF EXPERIMENTAL SET UP

The application of heat pipe is for the HPHE in the path of flue gas having the max temp up to 250 ^{0}C. As the Heat pipe is simple but ingenious device to heat transfer. Heat transfer by heat pipe occur based on evaporation and consequential condensation of working fluid. After this meaner is possible to transfer great thermal performance by little dimensions devices, too. The basic heat transfer is higher in the gravity oriented heat pipes (7) as shown in fig.07 .The velocity of return water increases from the outside wicks and the Renolds number increases due to the curved space . Condenser end is covered by passing cold water through outer jacket. Jacket water absorbs latent heat from steam and flows out by increment in initial temp . This difference is used to calculate the heat collection at condenser end , So the various tests have been carried out for different positions. As the scope of this work is the application of tested heat pipe and its results for HPHE in recovery of waste heat from flue gas path in sugar industry. The various methods have described by researchers to determine performance of heat pipe is calorimetric method, which was used in experimental measurement by Calorimetric method emanating from calorimetric equation where known mass flow, specific heat capacity, input and output temperature of coolant. The length and diameter of heat pipe is so designed to expose more area of evaporator section towards heat region. The length of evaporator and condenser section is same. Internal structure is a wick structure having internal and external grooves for the separation of backflow water and generated steam. The max heat flow is to be checked at various positions of heat pipe with the variation in positions and angle measurement. Condenser section is made in the contact with cool water and to transfer this carried heat to cool Water. The flow and time is measured with the help of rot meter.

Procedure and Methodology

Part I

We have tested two heat pipes of two different wick structures. Heat pipe A with maximum grooves for different volumetric ratios

- Heat pipe B with minimum grooves for different volumetric ratio.

Part II

Present design is analyzed by using CFD analysis and results are compared for the same boundary conditions.

Heat performance solution of heat pipe is based on calorimetrical equation and values from experimental measuring. The same calculations were used at work,

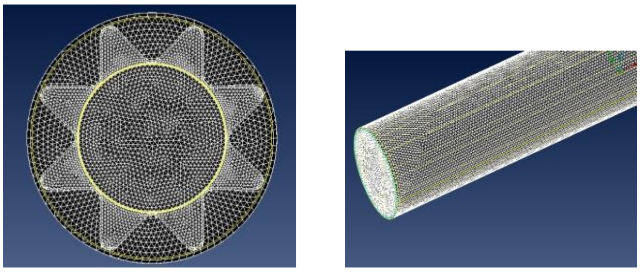


Fig no. 08 Meshing of HPHE and simulation with CFD

Q = m.c.Δt

Where is Δt [°C] – temperature difference, t1 [°C] – input temperature, t2 [°C] – output temperature, m& [J.kg-1.K-1] – mass flow of liquid, c [J.kg.s-1] – special thermal capacities of liquid.

The total Q max is calculated at the steady states based on positions and various parameters discussed as above Measurement of thermal performance of heat pipe was at three positions: horizontal, vertical and angel 45° and temperature of heat source were 50 to 70 °C.

$$Q_{max} = 2\left(\frac{n\rho_1 h_{v1}\, a}{\mu_1}\right)\left(\frac{b\delta}{X_T}\right)\left(\frac{g\rho_1}{\sigma}\right)_{WR}\frac{1m}{k_1} \quad (4)$$

Q max = 18.2 watt. (At 50 ^{0}C water temperature & 500mm of hg)

In the current analysis the HPHE is tested for the 3 different orientations and heat supply..

The heater is supplying heat at evaporator side ane it heats the internal water at evaporator section

Observations of HPHE at various Heat inputs and horizontal position (L500)				
Heat in Watt	T1	T2	T3	Heat out watt
18	41	34	32	3.6
24	60	45	40	8.0
30.78	72	65	60	6.96
53.5	78	66	54	13.93
56	77	65	56	14
64	81	48	45	15
80	86	65	55	11.6

Table no.1 shows the amount of heat transfer and rate of thermal performance (HPHE) at horizontal position on test rig)

Observations of HPHE at various Heat inputs at 45 degree inclined position (L500)				
Heat in Watt	T1	T2	T3	Heat out watt
18	40	32	31	3.6
24	60	50	46	8.0
30.78	72	66	62	16.5
53.5	73	64	69	18.3
56	74	72	68	23.8
64	81	76	73	31.7
80	86	64	56	26.7

Table no.2 shows the amount of heat transfer and rate of thermal performance (HPHE) at inclined on test rig)

. The observations are recorded for the evaporator, adiabatic and condenser sections (T1, T2, and T3) with thermocouples. Condenser end is covered by cooling water jacket. Steam is condensed due to removal of heat by supplied water. . Temperature T4 and T5 is recorded at the input and output of water jacket.

Observations of HPHE at various Heat inputs and at vertical position (L500)				
Heat in Watt	T1	T2	T3	Heat out watt
18	40	33	32	3.8
24	60	51	48	8.5
30.78	71	66	64	17.5
53.5	78	63	71	19.6
56	77	72	71	23.8
64	80	76	74	32.1
80	87	64	56	28.2

Table no.3 shows the amount of heat transfer and rate of thermal performance (HPHE) at vertical position on test rig.

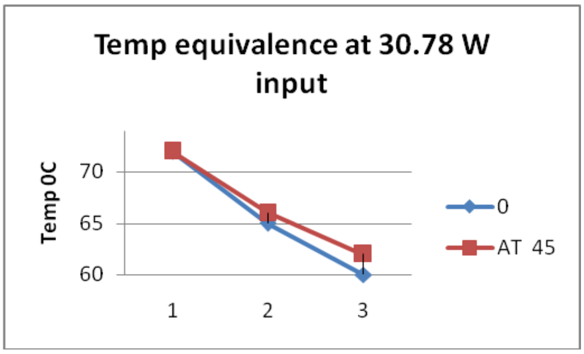
In the next analysis the designed model is validated by simulating with CFD software. The graph no. shows that the thermal conductivity of HPHE is increasing as per the input heat supply but as the rate of stem pressure increases nearealy equal to both the sides the conductivity decreases. Also the error in both the results is almost 5 to 6 %. As compared with actual results. Again it is observed that at the supply of 60 to 64 watt the rate of heat transfer is more and losses are very less.

As HPHE is tested and analyzed for the heat recovery from the path of flue gas. So the construction is considered for the longer length and its orientation.

So as per the listed observations in table no. 01,02 and 03 it is observed that the Δt is more for the horizontal orientation. As the gravity is influencing on the mass flow rate of condensate water and it reflects in the increment in the Reynolds number of back water . so at the 45 degree and vertical orientation the rate of heat transfer increases and this capacity reaches up to 30 to 32 watt as a maximum rate of heat removal by heat pipe heat exchanger.

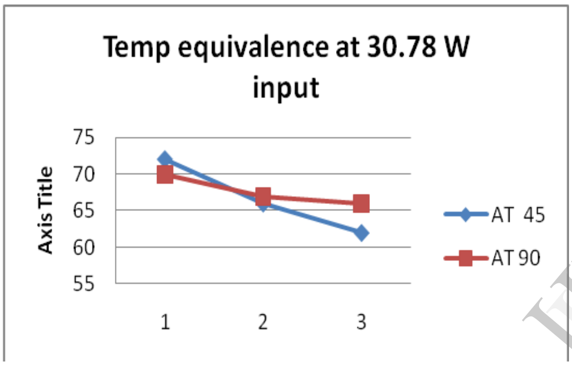
The relation in the improvement in the heat transfer and the orientation of HPHE is shown in the graph no 1.2.&3 . this means as the input heat supply increases the condensate recovery should be increased. but as per the gravity orientation the flow becomes the laminar flow and this rate is very slow at horizontal orientation. So the output of HPHE is low and heat losses are more due to time unbalance. This results are improved (graph no.2 and 3) and the thermal performance is more as the condensate flow rate is more..

increment in internal steam pressure puts effect on the conversion of phase change from steam to saturated liquid.

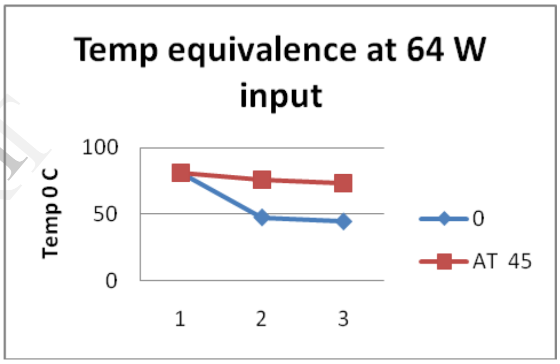


Graph no. 01 Temperature shows its effect on HPHE at various inclinations.

So the rate of heat removal decreases and the total heat becomes the super heat at atm. pressure. So the rate of thermal performance is failing from 64 watt input supply for the present cross sectional area.

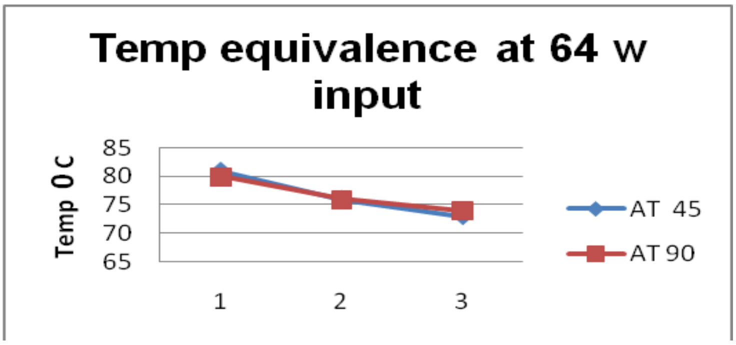


Graph no. 02 Temperature difference and its relation for the gravity orientation at equal heat inputs.



Graph no.03 Temperature difference and its relation for the gravity orientation at equal heat inputs.

Theoretical value of thermal performance is high due to minor losses of heat at lower temperature. But as per the comparison between these three results the higher conductivity and performance can be achieved at 70 to 80 ^{0}C of evaporator temperature and at vertical orientation.The



Graph no.04 shows the temperature differences at maximum heat input supply at 64 watts.

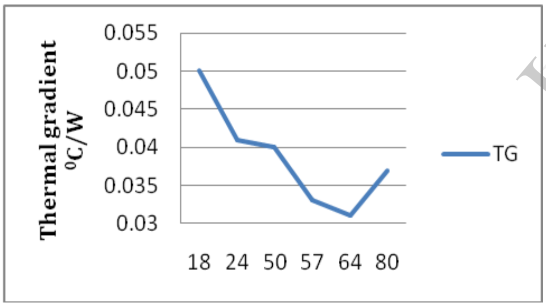
External wick area is used to flow the condensate water from condenser side to evaporator side. The back flow water is partially separated from the passage of steam flow. As the contact of steam and condensate is reduced, this reflects in decrement in the heat addition for returned water. The continuity in the steam flow is due to prevention in heat loss to ater. The rate of flow is depends on the condensate temp and its density. The orientation of HPHE plays an important role for the gravity application. So the graph no. 05 shows the overall analysis of performance of HPHE. The rate of thermal conductivity is lower at lower heat inputs but it improves as the rate of heat input increases and the at the orientation position which is from 45 degree to 90 degree as compared to horizontal positionThe thermal gradients and its relation is refered different heat inputs. (Graph no. 06) So the thermal gradients are (^{0}C/W) decreasing up to the 64 watts and increases above the higher due improvement in the heat loss.

Table no.04 Case study of waste heat from flue gases of sugar industry

The validation of these results is done by using the CFD software. It is observed that the all the performance parameters are showing the 5 to 7% error in experimental results. So as in the experimental set up the heat loss is due to convection & radiation and which is the actual loss reflects in results.

Present HPHE is the utilization for the heat recovery from the path of flue gas exhausted from sugar factory boilers (3500 TCD) as shown in table no.04 . so the analysis of revenue generation from the waste heat is almost 25 lac. per year and help to reduce thermal pollution.

Table no.04 Case study of waste heat from flue gases of sugar industry



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Sr. No .	Parameters of HPHE	Quantity
01	Possible Heat saving from the flue gases passing through the chimney for recovery(3500 TCD)	100 kJ/sec
02	Highest capacity of heat transfer from HPHE	32 Watt
03	No. of exchangers required for the recovery	3000 nos.
04	Total electricity generated from 100 kg bagasse	22 KW
05	Amount of bagasse saved by HPHE	450 kg
06	Annual saving from HPHE @ Rs.7(150 days)	25.20 Lac.

Graph no.06 shows the variation of temperature gradients (^{0}C/W) w.r.t. the input power (watt)

CONCLUSION:

Heat pipe plays an important role in the application of heat transfer at various systems. This work is mainly proposed for absorbing heat from the path of flue gases .the experimental analysis of HPHE is manufactured with axially grooved wick structure and the results are compared from test set up and simulation .it is observed that

- HPHE can work for the longer length up to 500 mm and the highest amount heat can be transferred at steady state.
- The rate of condensate flow is influenced by the gravity orientation
- The design and construction is simple and improved with the utilization of steel material.
- The thermal gradients are quite reliable for Mainly at the 45 degree or at vertical position the higher heat source and material.
- HPHE is helpful for reducing the 8 to 10 % addition of exhaust heat from flue gases of the industrial boilers and preventing the increment in thermal pollution to safe the environment.

ACKNOWLEDGEMENT

The supportive data required for this research work is taken from the Survodaya sahakari sugar industry, Karandawadi, Sangli, Maharastra.

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