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New concept for steam condensation

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This paper explores the feasibility of using the heat pipe for steam condensation. In this paper an attemptis made to replace thousands of condenser tubes by hundreds of heat pipes.The design details of heat pipe like material, length, diameter etc., are described in this paper. The feasibility study was carried out for smooth operation of the heat pipe that is without ceasing during operation. Experimental setup and results of steam condensation are presented.

Keywords: *Wickless heat pipe, thermal syphon, steam condenser, heat transfer coefficient.*

1.0 INTRODUCTION

Condensation is an important function in the power plant. The main purpose of steam condensation is to reduce the turbine exhaust pressure so as to increase the specific output of the turbine and to recover high quality feed water in the form of condensate for pumping it back to boiler. This important activity of condensation takes place in the condenser. These condensers are two types viz. direct contact condenser and surface condensers. Surface condensers which are mostly used in the power plants essentially shell and tube heat exchangers.

In these type condensers of the power plant the, turbine outlet steam enters the condenser and incidents on the tube surfaces. The cold water flows inside the tubes and maintains the tube surface below the saturation temperature of steam. Hence the steam condenses on the tubes surface. Temperature of cooling water in the tubes will rise due to latent heat of steam condensation on the tube surface. There will be phase change of steam into condensate and cooling water will undergo only sensible temperature rise. Due to this reason, large area of heat transfer required, in turn more of tubes, i. e., thousands of tubes required as the capacity of power plant increases. As the number of tubes increase the problem regarding the operation and maintenance increases as well as the size of condenser also increases [1-5]. Hence, it is necessary to reduce the number of tubes in the condenser.

The heat transfer mechanism in the conventional condensers is that, the cooling medium absorbs the heat load only by sensible temperature rise. If the phase change of the cooling water is considered, then because of higher latent heat of vaporization of the cooling water, the heat carrying capacity will be increased and hence, there will be reduction of heat transfer area that is number of tubes in the condenser. To achieve this phase changer of cooling water, the heat pipes can be considered. The cooling water in the heat pipe will be maintained under vacuum, hence the lower boiling temperature of the cooling water.

Historical Development of heat pipes dates back 1942 when the first Patent for a heat pipe employing a capillary wick for

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pumping liquid against gravity was applied by Gaugler in 1942 [2]. In the words of Grover, who alongwithhis co-workers reinvented the heat pipe in 1963, a heat pipe is asynergistic engineering structure which is equivalent to a material having thermal conductivity greatly exceeding that of any known metal [3]. In other words , a heat pipe is a passive two – phase heat transfer device capable of transferring large quantities of heat with minimum temperature drop. Due to its commendable ability to transport heat energy the use of heat pipe becoming popular, starting from space shuttles to electronic industry [6-11].

2.0 THE DESIGN OF HEAT PIPE FOR STEAM CONDENSATION

The heat pipe was designed for the purpose of steam condensation. The line diagram of designed heat pipe was shown in Figure 1 and design details were given below. A patent for this design was applied.

Material of tube is copper and it is commercial designation is ‘K’ type.

Outside diameter of the heat pipe,

$d_0 = 0.053975$ m,

Inside diameter of the heat pipe, $d_i=0.0497586$ m,

Thickness of the heat pipe wall,

$t = 2.1082 \times 10^{-3}$ m

This designed heat pipe is wickless, gravity assisted type. Hence strictly it is a two phase closed thermo-syphon. Vacuum inside heat pipe = 7 kPa. Hence saturation temperature for water inside heat pipe is 39.02°C.

The input steam incidents on the heat pipe evaporator surface at 100ºC. The evaporator portion of the heat pipe will be having the water at a pressure of 7 kPa. At this pressure the boiling temperature of the water is 39.02º C. Hence the working fluid inside heat pipe (water) starts boiling. The vapors from the evaporator regions enter the condenser portion of heat pipe. This portion is maintained at a surface temperature of 27º C with help of inlet cooling water. So the vapors which reached the top portion of the heat pipe will condense on side surface of the heat pipe by releasing heat gained at evaporator section to the cooling water. The condensate will flow down due to gravity. The cycle repeats as the process go on.

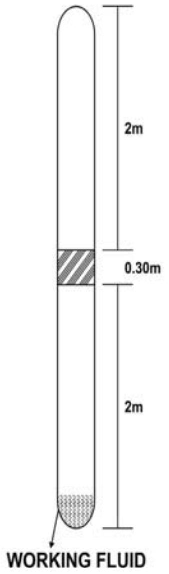

FIG. 1. LINE DIAGRAM OF HEAT PIPE

3.0 DESIGN AND FABRICATION OF EXPERIMENTAL SET UP

The line diagram for the heat pipe based condenser is shown in experimental set up is shown in Figure 2. Steam enters the condenser along the two sides as shown in figure. The cooling water will enter inside the condenser just above the separator plate and exited from top portion. The condensate will be collected at the bottom of condenser.

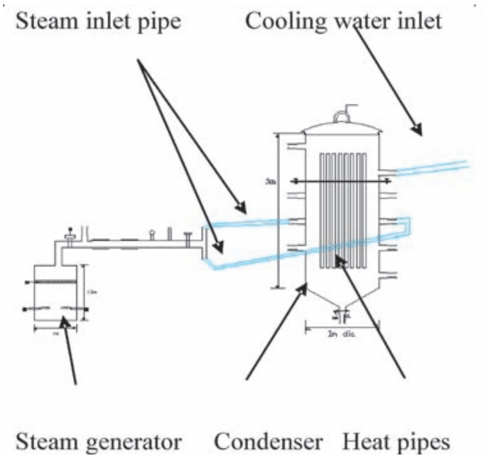

FIG. 2. LINE DIAGRAM OF EXPERIMENTAL SET UP

The fabrication work carried out for this experimental set up and shown in Figure 3.

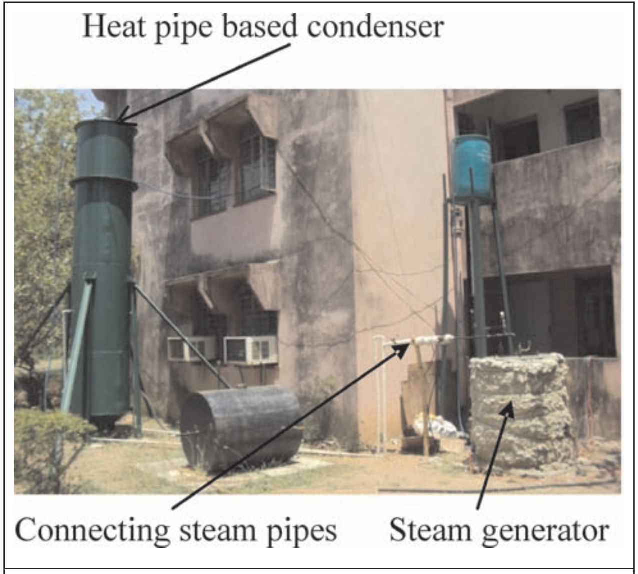

FIG. 3 ACTUAL EXPERIMENTAL SET UP

The experimental set up shown in the above Figure 3 consists of a steam Generator, heat pipe based condenser, connecting pipes and required instrumentation.

FIG. 4 CLOSE UP VIEW OF HEAT PIPES PLACED INSIDE CONDENSER

The steam generator is equipped with four heater of 300 kW capacity .The generated steam will be fed into the condenser as shown in the Figure 3. As the steam incidents on the heat pipe, the heat pipe liquid inside the heat pipe starts evaporating taking latent heat of vaporization from the incident steam outside the heat pipe. Due to this action the there will be phase change of incident steam and covert into condensate liquid. This liquid accumulated at the bottom of condenser. The evaporated heat pipe liquid will reach the top of the heat pipe as shown in Figure 4 i.e., is condenser portion of the heat pipe. The condenser portion of the heat pipe is cooled by the external cooling water. This cooling water absorbs the heat from the heat pipe fluid, hence vapors fluid converts back to fluid and drops to bottom of heat pipe. Thus the cycle repeats.

4.0 EXPERIMENTAL RESULTS

The steam from the boiler at a temperature of 100 º C is fed into the heat pipe based condenser. The steam condensed into the water and water is collected from the bottom of condenser as shown in Figure 5 & 6. The temperature of the condensate is around 40 ºC.

FIG. 5. CONDENSER OUTLET

FIG. 6. CLOSEUP VIEW OF CONDENSER OUTLET

5.0 ANALYSIS OF EXPERIMENTS

The experiment conducted for one hour after steady state conditions. The numerical values are as follows.

Power consumed = 11.73 kWh

Steam pressure maintained = 140 kPa

Boiler efficiency = 80 %

As per calculations steam produced will be 15 kg/h. The steam produced is superheated and throttled before entering into the condenser. The condenser shown in Figure 3 is built with 16 heat pipes whose design details are described above.

The condensate collected in one hour is 13.0 Liters. This is close to the quantity of steam produced that is 15 kg.

Similarly another three experiments are carried out and results are presented in the table 1.

TABLE 1

Experiment No	Steam Inlet Temperature in º C	Steam inlet Pressure in Bars	Condensate collected in Liters
1	106	0.22	11
2	126.6	0.26	12
3	164.5	0.41	13

6.0. THE HEAT TRANSFER COEFFICIENTS

In the above described heat pipe, there are four heat transfer regions. The heat transfer coefficients are calculated at these regions as below.

6.1 Calculation of Heat Transfer Coefficient (h_1) for the portion of heat pipe which is exposed to inlet steam

According Chato/Dobson (Dobson *et. al.,* 1993) the heat transfer coefficient correlation of two-phase region of the condenser,

$$h_l=h_{tp}=f(\chi_u)\{k_f^3\rho_f(\rho_f-\rho_g)gh_{fg1}/\mu_f.d_i.(t_{sat}-t_s)\}^{1/4} \quad ....(1)$$

Where $f(\chi_u) = 0.375/\chi_u^{0.23}$

And χ_u= Lockhart-Martinelli Parameter

$$=\left[\frac{\rho g}{\rho f}\right]^{0.5}\left[\frac{\mu f}{\mu g}\right]^{0.1}\left[\frac{1-x}{x}\right]^{0.9} \quad ....(2)$$

6.2 Calculation of Heat Transfer Coefficient (h4) for the portion of heat pipe which is exposed to water Pool

The heat transfer coefficient for portion of heat pipe immersed in the cooling water pool can be calculated based on correlations suggested by Whitakar (7) and Zhukaushas A, (8).

The Nusselt number for this, situation is,

$$Nu = C.\ Re_{2,max}^{m}\ .\ Pr^{0.36.}\ (Pr/Pr_s)^{1/4} \quad ....(3)$$

For $N \geq 20$, $0.7 < Pr < 500$, $1000 < Re_{max} < 2 \times 10^5$

6.3 Calculation of Heat Transfer Coefficient (h_2) for the evaporator section , inside of heat pipe

The heat transfer coefficient for evaporator section inside heat pipe can be calculated based on correlations suggested by Imura (1979) et. al.,

$$h_2= 0.32\ [\ (\rho_l^{0.65}k_l^{0.3}c_{pl}^{0.7}g^{0.2}q_e^{0.4})/(\rho_v^{0.25}h_{fg}^{0.4}\mu_l^{0.1})]x\ [p_{sat}/p_a]^{0.3} \quad ....(4)$$

ρ_l = liquid density inside heat pipe

q_e= heat flux at evaporator section from outside

ρ_v = vapor density inside heat pipe , μ_l = density of liquid ,k = thermal conductivity of the liquid

6.4 Calculation of Heat Transfer Coefficient (h_3) for the condenser section , inside of heat pipe

For the laminar flow the heat transfer coefficient for condenser section inside heat pipe can be calculated based on correlations suggested by Mc Adams correlation,

$$h_3 = 1.13\ \{\rho_l g k_l^3(\rho_l- \rho_v)[h_{fg} + 0.68\ x\ c_{p.l}(T_{sat}-T_w)]/\ (\mu_l d_i(t_{sat}-t_w)\}^{1/4} \quad ....(5)$$

t_w = surface wall temperature at condenser section that is part of heat pipe immersed in the water pool.

7.0 CONCLUSION AND USEFULNESS TO POWER PLANTS

This experiment proved that heat pipes can be used for steam condensation purpose. Due to the usage of heat pipes, there will be considerable reduction in the heat transfer area. Hence number of tubes carrying the cooling water will be reduces. This results easy operation and low maintenance problems in power plant condensers.

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