Thermal Analysis on Boiler Based Heat Pipe For Domestic Cooking

U. C. Pawar[1], Dr. S. J. Shankargouda[2], Dr. Pravin V. Honguntikar[3]
[1] Assistant Professor, Dept of Mechanical Engineering
[2]Associate Professor, Dept of Mechanical Engineering
[3]Professor, Dept of Mechanical Engineering
[1, 2] DattaMeghe College of Engineering, Navi Mumbai, Maharastra,India
[3] P.D.A. College of Engineering, Gulbarga.India.

Abstract- *An innovative model of a Boiler Based Heat Pipe (BBHP) is fabricated and experimentally analyzed to test its operation with available heat source in the laboratory. The function of BBHP is to supply and regulate the stored heat from heat storage tank to a cooking vessel, with a controlled rate of heat flow as and when required. In the present wok, performance analysis of BBHP is presented. For experimental purpose, an oil bath at maximum temperature of 140oC was used as heat storage medium in the heat storage tank, in which an evaporator section was immersed. A valve was fitted in isothermal section for supplying as well as for regulating heat flow to a cooking vessel, which is kept above the condenser section. An analysis of BBHP has shown that the principle of adapting steam regulating valve at isothermal section of heat pipe work successfully for supply and regulating the heat flow in a required amount. Maximum temperature of water in the cooking vessel was reached up to 72^{o}C and the overall heat transfer rate achieved was 18.3 W.*

Keywords- Heat storage tank; Evaporator; Condenser, Heat pipe, Cooking Vessel, BBHP

I. INTRODUCTION

India consumes about 360 million MW energy per year for cooking which is about 40% of its total yearly energy consumption. Lot of research on efficient and alternate source of energy consumption is being taking place except on cooking sector though it is a major energy consumption sector. Major part of India is gifted with sufficient solar energy that can be utilized for cooking.

Solar cookers are being developed since 1980 when pollution control and energy crisis have become important considerations. The development and performance of solar cookers has been discussed by a number of authors including Domanski et al. [1], Buddhi and Sahoo [2], Sharma et al. [3] and Hussein HMS et al. [5]. Earlier, solar cookers [1-10] were not popular due to long cooking time, outdoor cooking and no control on heating rate. Intermittent availability of solar energy needs storage of solar heat to cook food as and when required. Tremendous research work has been carried out on latent heat storage systems. Most of the large solar cooking systems for community have adopted heat storage which is not feasible and or costly for domestic use. However, regulating the rate of heat supply to cooking vessel like in domestic gas stove is not yet developed. Hence, the significance of the present work is to develop a unit which promotes utility of solar cookers as convenient as domestic gas stove in the kitchen for the domestic applications like warming the food, milk, cooking the food, heating the drinking water etc.

Nomenclature			
T	Temperature (°C or K)	ρ	Density (kg/m^3)
A	Area (m^2)	C_p	Specific heat capacity (kJ/kg K)
Q	Rate of Heat Transfer (W)	m	Mass (kg)
H	Convective heat transfer coefficient (W/m^{2}K)	t	Time (s)

In the Present work the efforts have been taken to develop a model called Boiler Based Heat Pipe (BBHP) which regulates the rate of heat transfer from heat storage tank to the cooking vessel, just in a similar way how a domestic gas stove regulates the gas flow from cooking gas cylinder to the cooking vessel. BBHP is a heat pipe having valve in the isothermal section which regulates the rate of vapor flow, which in turn regulates the rate of heat transfer from heat storage tank to cooking vessel.

There are many heat pipes available in the literature [11-31]. Significant attempts were made to control heat flow in a heat pipe. Various principles have been utilized and many new heat pipe systems were proposed. Some of these inventions are described below. Piyush Sabharwall et al. [12] proposed a thermosyphon to transfer the process heat from the Next Generation Nuclear Plant (NGNP) to the hydrogen plant. Liquid condensate returns to the evaporator assisted by gravity through a separate liquid return line with a liquid return control valve. T.H. Sunet et al [13] presented a thermal actuated switchable heat pipe for use in a passenger compartment heating system of an automotive vehicle. A thermostat 46 is mounted between the condenser and the evaporator for controlling the flow of fluid there between.

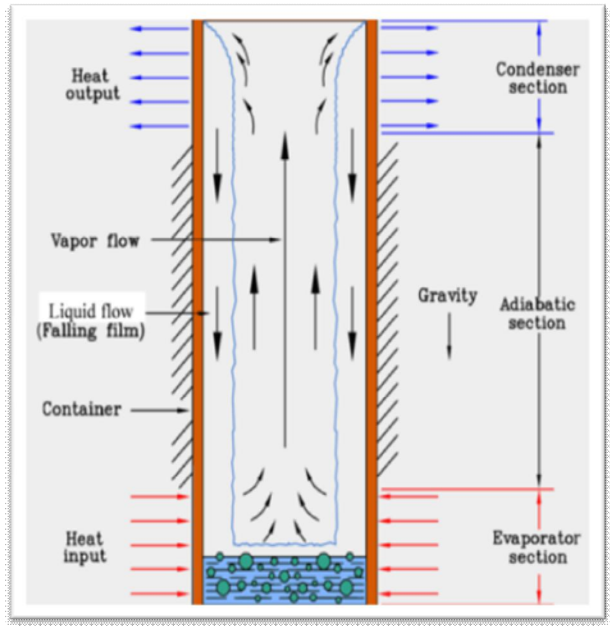
Although the applications of heat pipes are used in different systems in the literature [11-31], but its application have neither been considered in the cooking application for urban buildings nor anything is mentioned about the control or regulating the rate of heating for cooking food for urban buildings until now. Therefore the main objective of this work is to check the operational performance of heat pipe for the cooking application for urban building Fig. 1shows a classical heat pipe and a new model of heat pipe, Boiler Based Heat Pipe (BBHP) with a steam regulating valve at isothermal section.

1.1 Introduction to the new design

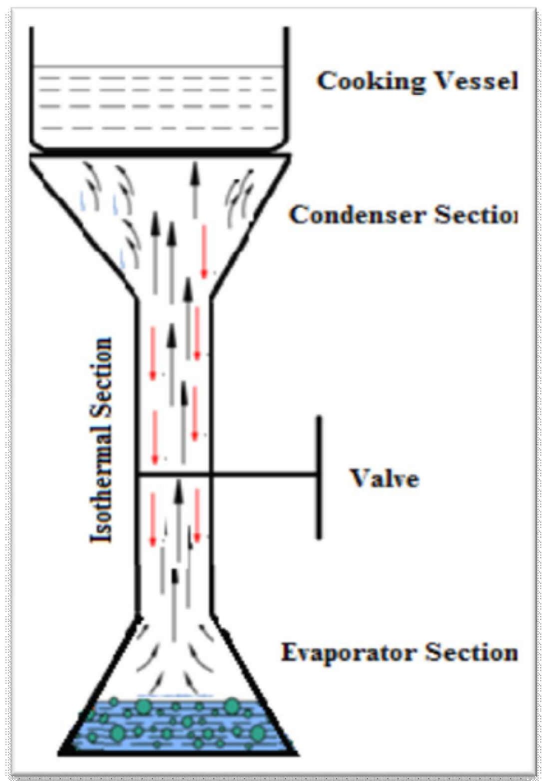
The new design focuses, in contrast to the classical gravity assisted wickless heat pipes or closed thermosyphons designs, a steam regulating valve is provided at isothermal section just in a similar way how a steam control valve is present in boilers. Hence it is named as a Boiler Based Heat Pipe (BBHP) which is shown in Fig. 1b.The goal is to regulate the heat flux as well as to ON/OFF the heat flow like domestic cooking stove.

II. CONSTRUCTION OF THE BOILER BASED HEAT PIPE (BBHP)

To analyze the performance of a Boiler Based Heat Pipe, a preliminary model was fabricated for water heating purpose. BBHP is fabricated using SS304 material, as it is corrosion resistant, strong and can withstand high temperatures for cooking or backing temperatures of up to 250°C. The total length of heat pipe was 800 mm, divided in to three sections an evaporator, an isothermal and a condenser section. An evaporator and condenser are constructed by using two reducers of diameter 100mm respectively. The isothermal section was constructed by using pipe of diameter 12.7mm. At the middle portion of the isothermal section a steam regulating valve of diameter 12.7mm was provided to regulate, to start and to stop heat supply. A pressure gauge is used to measure the pressure. The fabricated photograph of BBHP is shown in Fig. 2. Distilled water was used as a working fluid in the BBHP, as it is easily and abundantly available and it is compatible with SS304 material. Optimum filling ratio of water was determined on the basis of dry-out limit and sonic limit calculations.



(a) Classical design of heat pipe



(b) Boiler Based Heat Pipe (BBHP)
With steam regulating valve at adiabatic section
Fig.1: (a & b) Gravity-assisted wickless heat pipe (two-phase closed thermosyphon).

III. EXPERIMENTAL SET UP

For the experimental purpose, oil bath is used as a heating medium in the heat storage tank. The BBHP was tested by submerging an evaporator section in an oil bath whose temperature was maintained at 140°C. Oil bath temperature was measured by using mercury filled in glass tube thermometer (0 to 360°C). Above the condenser section, a stainless steel vessel was placed with 100 ml water in it to check how much amount of heat being transferred by the condenser section to the water in the cooking vessel of BBHP. Stainless steel was selected for cooking vessel, as it is available instantly and also they are generally used for cooking purpose. Experiment setup and Schematic of cooking Vessel Placed on Condenser Section is Shown in Fig. 3 respectively.

Fig. 2: Boiler Based Heat Pipe

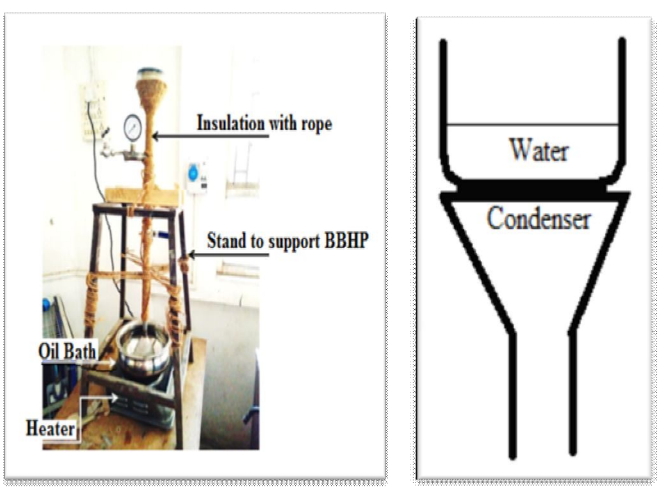


Fig. 3: Experiment setup and Schematic of Vessel Placed on Condenser Section

IV. TESTING AND RESULTS

In In the present test, mainly temperatures of oil bath and water in the vessel were measured with time intervals of about 10 to 60 s. Oil bath temperature represents the heat storage temperature in the heat storage tank and water temperature in the cooking vessel represents the temperature of cooking. Secondly, the rate of heat absorbed by the water was calculated from weight of water and rise in temperature of water with respect to time. Oil bath temperature was maintained constant at 140°C. Temperature variation of water in the vessel with respect to time was measured and presented in the form of graph in Fig. 4. Temperature of water in the cooking vessel was constant at 33°C up to first 1140 s as the steam regulating valve was closed and oil bath temperature was at 140°C. After 1140 s, steam regulating valve was fully opened. Gradually temperature of water in the cooking vessel was increased up to 69°C during 1140 s to 1840 s. The rate of heat transfer increased suddenly as soon as valve was opened and the rate of rise in temperature of water in the cooking vessel was also high and is approximately 15 to 20°C/min. At this stage valve was closed completely and therefore heat transfer rate to the water was decreased suddenly as it can be seen in the graph of Figure 4. The temperature of water gradually decreased to 36°C during 1840 to 2820 s. This is due to heat transfer from the vessel including water to the surrounding. Again the valve was opened fully at 2840 s, and the temperature of water was increased gradually up to 72°C during the period 2840 s to 3420 s. Stored vapors in the evaporator section rushed to condenser section and hence rate of heat transfer was increased suddenly as seen in Fig. 4.Finally in this experiment three points were observed.

- Rate of heating can be regulated with the help of valve in isothermal section of BBHP
- Overall rate of heat transfer obtained was 18.3W and
- Maximum water temperature in cooking vessel was reached up to 72°C.

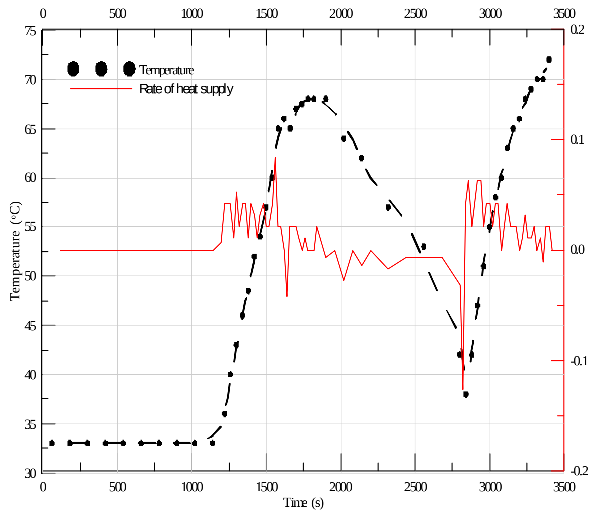


Fig. 4: Graph of Time versus Temperature and Rate of Heat Supply

V. ANALYSIS

An evaporator section of BBHP was immersed in hot oil bath, whose maximum temperature was maintained at 140°C. As a result, working fluid in the BBHP evaporates and heat was transferred to condenser section when valve in the isothermal section was opened, and also it regulates the flow rate of vapors to control amount of heat transfer to the cooking vessel as per the requirement of cooking from the heat storage tank (oil bath). Condensed vapors during cooking, in the condenser section flows back to the evaporator section by gravity. However, above the valve, condensate collects and vapors bubble up in this liquid while liquid flow down just like a water filled bottle opened and held upside down. When, valve was fully opened vapors rise easily and condensate flows down easily for maximum heat transfer. This heat transfer can be stopped by closing the valve when there is no cooking. Heat transfer rate increases as soon as vapour control valve opens as seen in the graph of Fig. 4. Thereafter it decreases as the rate of boiling of working fluid in evaporator is less than condensation. It is therefore necessary to design evaporator to increase the evaporation. Maximum temperature of water in the cooking vessel was reached to 72°C when oil bath temperature was 140°C. This temperature difference is due to following thermal resistances involved in heat transfer from oil bath in the storage tank to the water in the cooking vessel as shown in Fig. 5. These resistances are estimated and presented in Table 1

Table 1: Thermal Resistances Involved and Heat Transfer in BBHP

	Thermal Resistances	K/W
R1	convective resistance at outer surface of evaporator	2.17400
R2	conductive resistance due to SS304 Evaporator coil	0.01524
R3	convective resistance of water and evaporator inner surface	1.23450
R4	convective resistance of steam and condenser inner surface	0.12300
R5	conductive resistance due to SS304 and condenser plate	0.01524
R6	convective resistance due to SS304 and vessel	0.00593
R7	convective resistance of water in container	0.11310
	Total resistance involved	3.68101
	Rate of heat transfer	5.4W

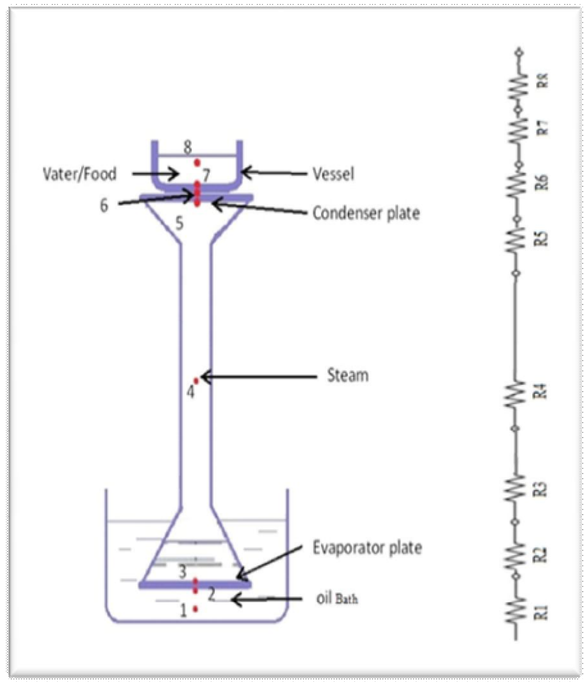


Fig. 5: Thermal Resistance involved in the model.

R_1, R_2, R_3 can be decreased by increasing the effective heat transfer area of the evaporator.R_4, R_5, R_6 can be decreased by increasing the effective heat transfer area of the condenser, so that the temperature of the cooking vessel can be increased up to 100°C ,while the heat storage temperature can be at 140°C.

In the present work heat transfer rate achieved is 18.3W as shown below.

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Rate of heat transfer $\dot{Q} = \frac{\dot{m} C_p dT}{dt}$

$$\dot{Q} = \frac{0.1 \times 4.186 \times (72-33)}{15 \times 60} = 18.3\ W$$

VI. CONCLUSION

Boiler based heat pipe was fabricated and analyzed to test its operation for supply and regulating the heat transfer from hest storage tank to cooking vessel. Test results have shown that the principle of adapting steam regulating valve at isothermal section of heat pipe work successfully for supply and regulating the heat flux from the heat storage tank to cooking vessel as per requirement. In present test maximum temperature of water in the cooking vessel was reached up to 72^{o}C and Rate of heat transfer obtained was 18.3W, when heat source (oil bath) temperature was 140^{o}C. However, test has been conducted without any effective insulation. After care full analysis of BBHP it is concluded that, Heat transfer areas are mainly to be increased in the future work so that the difference in temperatures of heat source and sink, decrease. This unit can be used wherever controlled quantity of heat is to be supplied from a heat storage tank where maximum safe temperature is defined.

VII. ACKNOWLEDGEMENTS

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