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# HEAT TRANSFER COEFFICIENT AND FRICTION FACTOR CHARACTERISTICS OF A GRAVITY ASSISTED BAFFLED SHELL AND HEAT-PIPE HEAT EXCHANGER

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**Abstract**

The heat transfer coefficients and friction factors of a baffled shell and heat pipe heat exchanger with various inclination angles were determined experimentally; using methanol as working fluid and water as heat transport fluid were reported. Heat pipe heat exchanger reported in this investigation have inclination angles varied between 15$^o$ and 60$^o$ for different mass flow rates and temperature at the shell side of the heat exchanger. All the required parameters like outlet temperature of both hot and cold side of heat exchanger and mass flow rate of fluids were measured using an appropriate instrument. Different tests were performed from which condenser side heat transfer coefficient and friction factor were calculated. In all operating conditions it has been found that the heat transfer coefficient increases by increasing the mass flow rate and angle of inclination. The reduction in friction factor occurs when the Reynolds number is increased. The overall optimum experimental effectiveness of GABSHPHE has found to be 42% in all operating conditioning at $\psi = 45^o$.

Keywords: Effectiveness, Heat pipe, Heat transfer coefficient, Friction factor.

## 1. Introduction

The heat transfer enhancement using different techniques have become wider during the last 50 years. The main aim of heat transfer enhancement is to get compact and cost effective heat exchanger equipment. In order to achieve this, active and passive enhancement techniques were used. Passive technique has been used widely than active technique because it consumes no external power. The most popular surface heat transfer enhancement is obtained by providing "fins" or

## Nomenclatures

| | |
|---|---|
| $b$ | Breadth, m |
| $D$ | Diameter, m |
| $h$ | Height, m |
| $L$ | Length of shell, m |
| $l$ | Length of heat pipe, m |
| $m$ | Mass flow rate, kg/s |
| $N$ | Number of heat pipe |
| $n$ | Number of baffled plates |
| $t$ | Thickness, m |

***Subscript***

| | |
|---|---|
| $c$ | Cold fluid |
| $h$ | Hot fluid |
| $i$ | Inner |
| $o$ | Outer |
| $s$ | Surface |

***Greek Symbols***

| | |
|---|---|
| $\in$ | Effectiveness, % |
| $\psi$ | Inclination angle, deg. |

**Abbreviations**

| | |
|---|---|
| GABSHPHE | Gravity Assisted Baffled Shell and Heat Pipe Heat Exchanger |

"baffles" and passive technique device is "heat-pipe".

The ability of the heat pipe to transfer thermal energy with negligible temperature drop has recently enabled it to become one of the most versatile devices in the field of heat recovery systems [1, 2]. In past few years considerable interest has been generated with regard to the heat pipe heat exchanger as a heat recovery system [3-5]. In a gravity assisted mode, the presence of a capillary structure is not obligatory as in purely a capillary drive heat pipe. Nevertheless, most gravity assisted heat pipes do have a capillary structure in order to protect the liquid against the shear stress exerted by counter flowing vapour [6, 7] and also to induce circumferential distribution of the working fluid within the evaporator section. In gravity assisted heat pipes, relatively high rates of heat transfer can be achieved even with working fluids having low surface tension [8, 9].

Experimental and theoretical investigation of thermal performance of air-to-air thermosyphon with various mass flow rate and inlet temperature of hot water to evaporator section was reported by Noie [10]. The effect of heat capacity ratio on effectiveness was theoretically analysed in the co-axial heat pipe heat exchanger by Azad and Moztarzodeh [11]. The performance of comparison of shell and tube heat exchanger experimentally with segmental baffles and with helical baffles at helix angles $20^o$ $30^o$ $40^o$ and $50^o$ were reported by Zheng et al. [12]. Shimura et al. [13] investigated the heat pipe thermal resistance with different working fluids at various inclination angles in gravity-assisted condition. The use of a heat-pipe using methanol as working fluid to investigate the thermal performance of shell and heat-pipe heat exchanger was reported by Kral et al. [14].

This paper reports the performance of a GABSHPHE with nine numbers of rectangular baffles which were arranged inside the shell of heat exchanger co-axially and the effect of parameters such as mass flow rate and temperature of hot water to the evaporator section were considered. Gravity assistance has been utilized on thermal performance of heat pipe heat exchanger. The effect of heat transfer coefficient and friction factor as a function of inclination angle of heat pipe heat exchanger were reported.

## 1.1. Advantages of gravity assistance

It is better to keep the baffled heat-pipe heat exchanger in an inclined manner i.e. with gravity-assistance because,

- This can help the condensate to return easily from the condenser section to the evaporator section.
- This can also reduce the effect of capillary structure used in capillary drive heat-pipe. GABSHPHE do have an easy capillary structure in order to protect the liquid against the shear stress exerted by the counter flowing vapour and this can enhance the circumferential distribution of methanol in the evaporator section.
- Gravitational effect makes low surface tension in the working fluid which produces high rate of heat transfer.

The constructed baffled shell with heat-pipes (without adiabatic section) and their arrangement were shown in Fig. 1. The details of baffle plate are shown in Fig. 2.

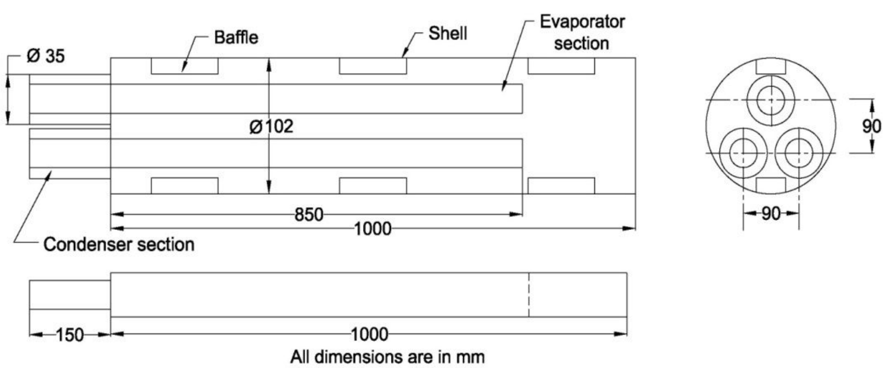


**Fig. 1. Schematic Diagram of Shell and Heat-Pipe and their Arrangement.**

All dimensions are in mm

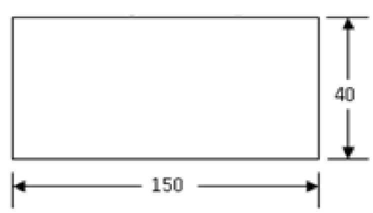


**Fig. 2. Baffle Plate.**

## 2. Experimental Setup

To study the heat transfer characteristics of a GABSHPHE, an experimental setup was fabricated. Figure 3 depicts the schematic diagram of the experimental setup. The physical parameters of the GABSHPHE are given below.

### 2.1. Physical parameters of baffled heat pipe heat exchanger

The physical parameters of baffled heat pipe heat exchanger are:

- Shell diameter ($D$) and length ($L$), mm : 102 and 1000
- Heat pipe inner diameter ($D_i$), mm : 17
- Heat pipe outer diameter ($D_o$), mm : 19
- Heat pipe length ($l$), mm : 1000
- Total number of heat pipe ($N$) : 3
- Total number of baffle plates ($n$) : 9
- Dimension of baffles ($b\times h\times t$), mm : 150×40×10

It consists of three heat-pipes made up of copper with 1 m long, and 19 mm outer diameter and 17 mm inner diameter. The heat-pipe consists of three sections namely evaporator section which is of length 850 mm, condenser section of length 150 mm and no adiabatic section. Methanol is used as working fluid. The evaporator section of heat-pipes is located inside the shell of length 1000 mm and diameter of 102 mm.

The shell is provided with nine number of baffled plates, three number of heat-pipes, electrical heater with water pump seven numbers of thermocouple (four numbers of RTD and three number of copper constantan T-type thermocouples), temperature monitor and temperature indicator. In order to measure and control the flow rate of hot and cold water to the heat exchanger, rota meters were used.

A water tank of 40 liters capacity with two numbers of electrical heaters (each 2 kW capacity) with temperature monitor is used to heat and maintain the required temperature of hot water which is flowing in the shell side of heat exchanger. In order to measure the relative temperature of both hot and cold water, a digital temperature indicator is used. Four number of RTD were provided to measure temperature of hot and cold water. Two thermocouples measures hot water and two of them measures cold water temperatures.

Three numbers of copper constantan (T-type) thermocouples were used to measure the condenser surface temperature ($T_s$) at three different locations as shown in Fig. 3. The heat-pipes were charged with methanol ($CH_3OH$) which is used as working fluid in GABSHPHE.

A vacuum pump has been used to eliminate any non-condensable gases from the heat-pipe. Finally the heat-pipes were charged with the working fluid to make it ready for the experiment. The entire length of shell was insulated properly using foam material and aluminium foil to minimize the heat losses to the surrounding. The effect of mass flow rate of water on the thermal performance of GABSHPHE with constant inlet temperature of hot water was investigated. It was followed by experiments to investigate influence of inlet temperature of hot water with constant mass flow rate of hot water; both experiments were carried out by varying the inclination angle of heat-pipes at $15^o$, $30^o$, $45^o$ and $60^o$. In all operating conditions the Reynolds number and Nusselt number were calculated. It shows that in all operating conditions the flow pattern behaves laminar.

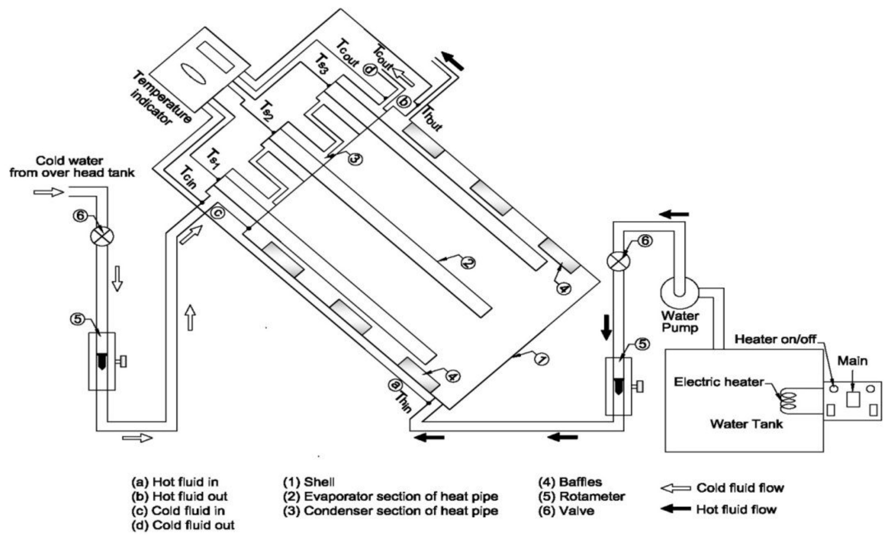


**Fig. 3. Schematic Diagram of Experimental Setup of GABSHPHE ($\psi = 60^o$).**

## 3. Results and Discussion

In order to determine the heat transfer coefficient and friction factor of a GABSHPHE, the following were considered as fixed parameters.

- Type of Working fluid (Methanol), Diameter, length of heat pipe and shell, Size of the baffle plates, Materials of heat pipes and shell

The following parameters were considered as variable parameters

- Mass flow rate of hot water to the shell side (40 – 120 kg/s), $\frac{C_h}{C_c} = 1-3$,

($C_h$=heat capacity rate of hot fluid, Cc= heat capacity rate of cold fluid)

Inlet temperature hot water to the shell side ($50^o$C – $70^o$C)

In each set of experiments, the mass flow rate of hot water at the inlet of evaporator section was fixed and varying the mass flow rate of cold water was fixed in the ratio of 1:0.5, i.e., $\frac{C_h}{C_c} = 2$.

Figure 4 shows the variation of Nusselt number on different Reynold number values for different value of inclination angle of heat pipe heat exchanger. For all inclination angles and operating conditions, with $m_{hi}$ = 120 kg/s, the maximum value of Nusselt number was obtained. From this figure it has been found that, the Nusselt number is increased by increasing the inclination angle and maximum value was obtained at an inclination angle of 60°. Further increase in the inclination, the Reynolds number starts decreasing due to thermal resistance in the heat pipe.

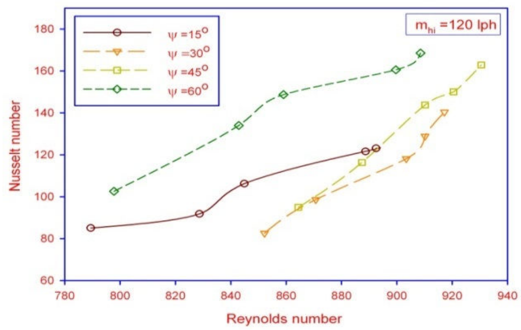


**Fig. 4. Reynolds Number versus Nusselt Number for $m_{hi}$ = 120 kg/s.**

Figure 5 shows that the heat transfer coefficient has been increased by increasing mass of flow rate of hot water to the evaporator section of heat exchanger, for all inlet temperature of hot water with $\psi$= 60°. It is found that the heat transfer coefficient is the function of mass flow rate and maximum value was obtained at 120 kg/s and $T_{hi}$ = 70°C.

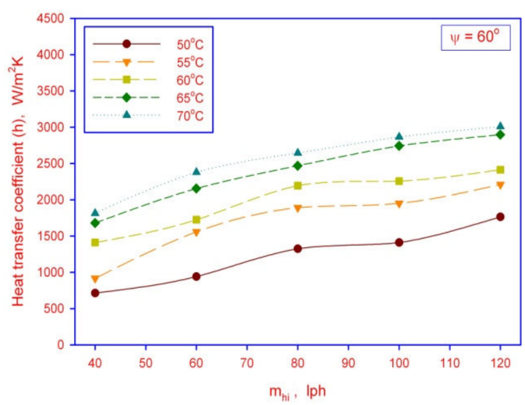


**Fig. 5. Effect of Mass Flow Rate of Hot Water on Heat Transfer Coefficient.**

Figure 6 shows the effect of Reynolds number over friction factor of GABSHPHE for different inclination angle of heat pipe along with shell. It is clear from the plot that the friction factor of heat exchanger decreased considerably by increasing the Reynolds number. It is found that lowest value of friction factor of heat exchanger obtained at $\psi = 30^o$ at which Reynolds number is the maximum and the friction factor found to be minimum if the mass flow rate of hot water has been increased.

Figure 7 shows the effect of inclination angle over effectiveness of heat-pipe heat exchanger for different inlet temperature of hot water. It is clear from the plot that the maximum effectiveness of heat exchanger occurs at $45^o$ inclination angle of heat pipe in all operating conditions. It has been inferred from the above analysis that the optimum effectiveness of GABSHPHE has been obtained at $45^o$ inclination angle and 100 kg/s of mass flow rate of hot water and at $60^oC$ inlet temperature of hot water.

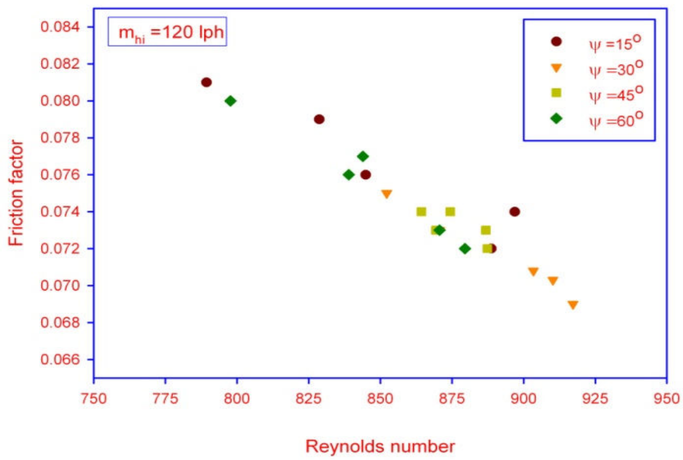


**Fig. 6. Effect of Reynolds Number on Friction Factor for $m_{hi}$ = 120 kg/s.**

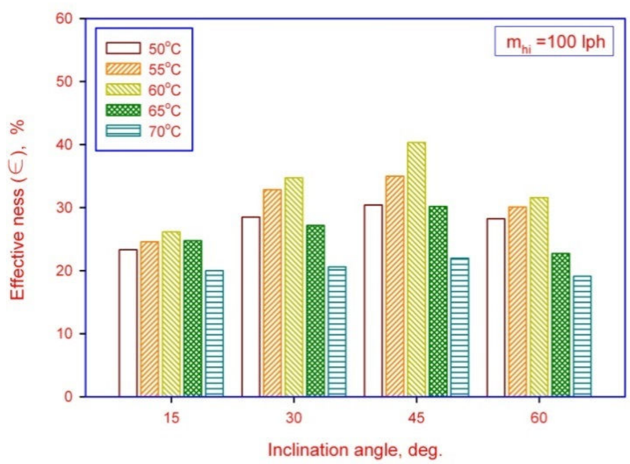


**Fig. 7. Effectiveness versus Inclination Angle for $m_{hi}$ = 100 kg/s.**

## 4. Conclusions

Based on the experimental study, this paper presents the effect of mass flow rate of water, and its inlet temperature for various inclination angles of heat-pipes on heat transfer coefficient and friction factor GABSHPHE. From this analysis it has been found that Reynolds number has considerable significance in the variation of effectiveness and heat transfer coefficient of heat exchanger.

In all operating conditions the experimental results shows that minimum effectiveness of GABSHPHE took place at lowest mass flow rate and inlet temperature of hot water to the evaporator section. It has been found that optimum effectiveness of GABSHPHE has been obtained when $m_{hi}$=100 kg/s, $T_{hi}$=60°C and $\psi$=45°.

For all operating conditions the heat transfer coefficient of GABSHPHE hit the maximum at a mass flow rate of hot water (120 kg/s) and inclination angle is 60°. It is noticed that the heat transfer coefficient is the function of mass flow rate, inlet temperature of hot water and less significance with inclination angle.

From this study it was clear that reduction of friction factor occur when Reynolds number is increased for all inclination angle of GABSHPHE. The friction factor of heat exchanger has been lowest at maximum mass flow rate of hot water and $\psi$ = 30°.

The overall optimum experimental effectiveness of the gravity-assisted baffled heat-pipe heat exchanger was 42% for all operating conditions and at 45° inclination.

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