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Effect of Inner Diameter and Inclination Angles on Operation Limit of Closed-Loop Oscillating Heat-Pipes with Check Valves

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Abstract: This research was to study the effect of inner diameter and inclination angles on operation limit of a closed loop oscillating heat pipes with check valves (CLOHP/CV). A set of CLOHP/CV was made of copper tubes in combination of following dimension: 1.77 and 2.03 mm inside diameter: 10 turn, with R123 was used as the working fluid. The working fluid was filled in the tube at the filling ratio of 50%. The inclination angles were 0, 20, 40, 60, 80 and 90° with 5 equal lengths for evaporator, adiabatic and condenser sections. The evaporator section was given heat by heater while the condenser section was cooled by volume water in a cold bath. The adiabatic section was properly insulated. In the test operation, it could be concluded as follows. It indicated that when the inner diameter changed from 1.77-2.03 mm the critical temperature increased. And when increase the inclination angles from 0 until to 90° the critical temperature increased.

Key words: Closed-looped oscillating heat-pipe, check valves, inner diameter, inclination angles, operation limit, critical state, copper tubes

INTRODUCTION

The CLOHP/CV is widely accepted as the most efficient heat transfer device. A typical heat pipe consists of an evaporator section, an adiabatic and condenser shown in Fig. 1. However, it has various limitations of the performance of heat pipes (e.g., capillary limit, entrainment limit, sonic limit, viscous limit, boiling limit). The boiling limit is the most important; because if the evaporator section was given overheat by heat source, the working fluid in the tubes cannot returns to the evaporator section (Dry-out). During the past several years, many researchers have studied this topic. Akachi *et al*.[1]. The CLOHP/CV consists of a long capillary tube bent into many turns and the evaporator section, adiabatic section and condenser section are located at these turns, with the ends joined to form a closed loop and incorporate the check valves in the loop as shown in Fig. 2. Miyazaki *et al*.[2]. The check valve is a floating type valve that consists of a stainless ball and copper tube, in which ball stopper and conical valves seat are provided at the ends, respectively. The ball can move freely between the ball stopper and the valves seat. It incorporates one or more direction-control one-way check valves in the loop so that the working fluid can circulate in specified direction only as shown in Fig. 3. It can the heat transfer by itself with latent heat of working fluid in t he tubes and heat transfer with heat

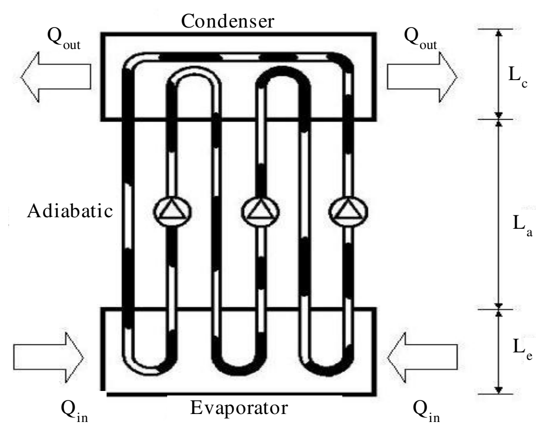

Fig. 1: Consists of a closed-Loop Oscillating Heat Pipe with Check Valve

sink such as water or air. Pipatpaiboon *et al*.[3] studies the effect of inclination angle working fluid and number of check vales on the characteristics of heat transfer in a closed-looped oscillating heat-pipe with check valves (CLOHP/CV). It was found that the CHOHP/CV is equipped with 2 check valves, as highest heat transfer. The CHOHP/CV is equipped with 2 check valves, as highest heat transfer. Rittidech *et al*.[4] studies the correlation to predict heat transfer of a closed-looped oscillating heat-pipe with check valves (CLOHP/CV). Meena *et al*.[5] studies the application of closed-loop

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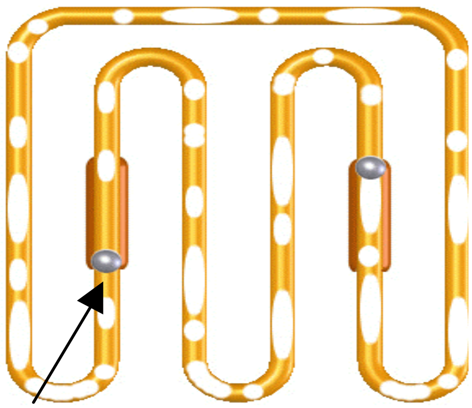

Fig. 2: Closed-looped oscillating heat-pipe with check valves (CLOHP/CV)

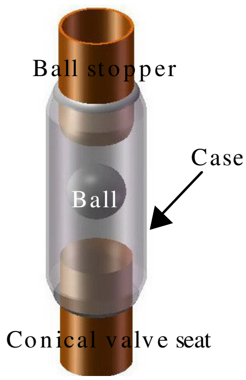

Fig. 3: The check valve

oscillating heat-pipe with check valves (CLOHP/CV) air-preheater for reduced relative-humidity in drying systems. It was found that the (CLOHP/CV) air-preheater can be reduced relative humidity in a drying system. Meena *et al.*[6] studies the effect of evaporator section lengths and working fluids on operational limit of closed loop oscillating heat pipes with check valves (CLOHP/CV). It was found that the evaporator lengths increased the critical heat flux decreased. There was working fluids change from R123 to Ethanol and water the critical heat flux decreased. Rittidech *et al.*[7] studies the effect of evaporator lengths and ratio of check valves to number of turns on internal flow patterns of a closed-loop oscillating heat pipe with check valves. It was found that when the evaporator section length decreased the heat flux rapidly increased.

The objectives of this research was to study the effect of inner diameter and inclination angles on operation limit of a closed loop oscillating heat pipe with check valves (CLOHP/CV):

- To study the effect of inner diameter on operation limit of a closed loop oscillating heat pipes with check valve
- To study the effect of inclination angles on operation limit of a closed loop oscillating heat pipes with check valve

The check valve is a floating type valve that consists of a stainless ball and copper tube, in which ball stopper and conical valves seat are provided at the ends, respectively. The ball can move freely between the ball stopper and the valves seat in shown Fig. 3.

MATERIALS AND METHODS

Test rig: The CLOHP/CV was made of copper tube. with R123 was used as the working fluid. A set of CLOHP/CV were made of copper tubes in combination of following dimensions: 1.77 and 2.03 mm inside diameter: 10 turns: 5 cm equal lengths for evaporator, adiabatic and condenser sections. The working fluid was filled in the tube at the filling ratio of 50% shown in shown Fig. 4.

Figure 4 and 5 show an experimental setup which consists of a CLOHP/CV with a heating bath for the evaporator section and a cooling bath for the condenser section. The adiabatic section was properly insulated.

In the test operation increase the temperature of the evaporator section until critical temperature, while the temperature at the adiabatic section was controlled at 60°C and increase the inclination angles from 0, 20, 40, 60, 80 to 90°. The data logger Yokogawa-MX100 was used with type K thermocouples (Omega with ±1°C accuracy) attached to the inlet and outlet of the cooling jacket, thermocouples were attached to the outside surface wall of the CLOHP/CV and data were recorded. These were 3 points on the evaporator, 2 points on the condenser and 2 points on the adiabatic section. The evaporator section was given heat by heater, while the cold bath was used to pump the cooling substance into the cooling jacket and the floating. Rota meter (Platon PGB411) was used to measure the flow rate of the cooling medium. They were used to calculate the heat transfer of the test CLOHP/CV by using the calorific method, as the following eq:

$$Q = m^{\bullet} c_p \left(T_{out} - T_{in}\right)$$

Where:

$m^{\bullet}$ = Mass per unit time
C_p = Specific heat capacity, constant pressure
T_{out} = Outlet temperature at condenser section

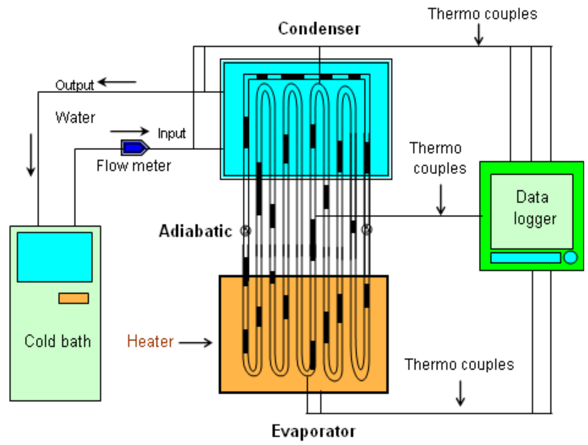

Fig. 4: Test rig

Fig. 5: The prototype experimental setup

T_{in} = Inlet temperature at condenser section
$T_{evap.}$ = Temperature at evaporator section
T_{cond} = Temperature at condenser section

Variable parameters were:

- Inclination angles were 0, 20, 40, 60, 80 and 90°
- Inner diameters of the tubes were 1.77 and 2.03 mm
- Working fluid was R123

RESULT AND DISCUSSION

The effect of inclination angles on critical heat flux: Figure 6 shows the relationship between inclination angles and critical heat flux of a closed-looped oscillating heat pipe with check valves CLOHP/CV. It indicated that when the inclination angles increased from 0 until 90° the value of the critical heat flux is increased, because the frictional pressure drop of the fluid flow is reduced. Also the trend of the inclination

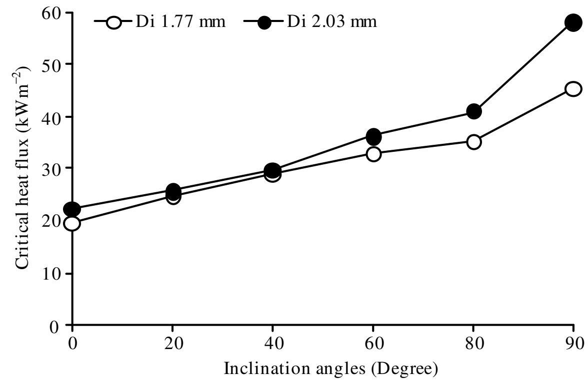

Fig. 6: Inclination angles and critical heat flux

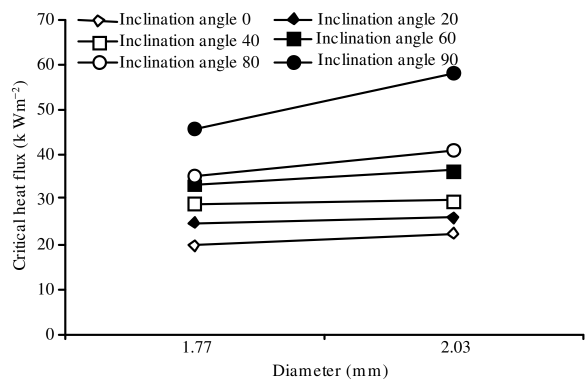

Fig. 7: Inner diameter and critical heat flux

angles on the heat flux is in good agreement with Rittidech *et al.*[4].

The effect of inner diameter on critical heat flux: Figure 7 shows the relationship between inner diameter and critical heat flux of a closed-looped oscillating heat pipe with check valves CLOHP/CV. It indicated that the value of the critical heat flux inner diameter 2.03 mm is higher than 1.77 mm, because as the inner diameter decreased, surface tension becomes dominant. The vapor bubbles cannot easily move to the condenser section. Also the trend of the inner diameter on the heat flux is in good agreement with Rittidech *et al.*[4].

The effect of inclination angles and inner diameter on critical temperature: Figure 8 shows the relationship between inclination angles and inner diameter of a closed-looped oscillating heat pipe with check valves on the critical temperature. It indicated that when the inclination angles increased and the inner diameter changed from 1.77 to 2.03 mm the value of critical temperature increased. Because the frictional

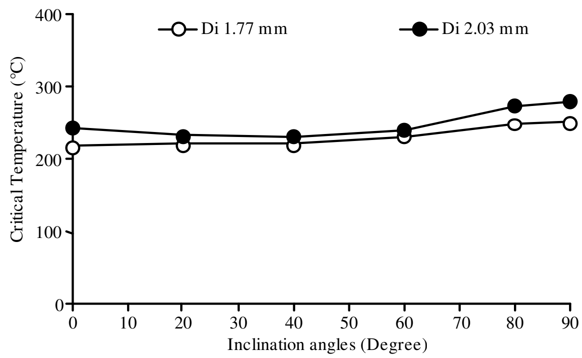

Fig. 8: Inclination angles and inner diameter on critical temperature

pressures drop of the fluid flow is reduced, the inner diameter decreased and the vapor bubbles can easily move to the condenser section.

CONCLUSIONS

The inclination angles increased from 0 until 90° and the inner diameter changed from 1.77 to 2.03 mm the value of the operation limit (critical heat flux and critical temperature increased). Also the result of this research can design the heat pipe heat exchange for the most efficient heat transfer of exchange device.

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