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Waste Heat Recovery by Closed-Loop Oscillating Heat Pipe with Check Valve from Pottery Kilns for Energy Thrift

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Abstract: This study aims to design, construct and test the waste heat recovery by closed-loop oscillating heat pipe with check valve from pottery kilns for energy thrift, were used the working fluids with a filling ratio of 50%. The (CLOHO/CV) was made of copper capillary tube with inside diameter of 2.03 mm. The lengths of evaporator and condenser section were 20 cm. The lengths of adiabatic section 10 cm. The number of turn was 40 meandering turns. The ratio of number of check valves was 0.04. The evaporator section was heated by hot gas, while the condenser section was cooled by fresh air. From the experiment, it indicated that the working fluid changes form water to R123, the heat transfer rate increased to 4,800 and 7,900 Watts and the effectiveness increased from 0.32 to 0.44. The CLOHP/CV heat exchanger can reduce the quantity of using gas in pottery kilns and achieve energy thrift.

Key words: Closed-looped oscillating heat-pipe, pottery kilns, heat exchanger, energy thrift

INTRODUCTION

In the application of closed-loop oscillating heat-pipe with check valves (CLOHP/CV) heat exchanger for the waste heat from pottery kilns, because it can reused the waste heat recovery in pottery kilns systems for energy thrift. The CLOHP/CV was widely accepted as the most efficient heat transfer device. It can the heat transfer by itself with latent heat of working fluid in the tubes. A typical heat pipe consists of an evaporator section, an adiabatic section and condenser section as shown in Fig. 1. The closed-loop oscillating heat pipe with check valve (CLOHP/CV), with capillary tube is bent into many meandering turns and connected the both ends of tube to form closed loop and has one or more check valves in the loop as shown in Fig. 1[1]. 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[3]. The ball can move freely between the ball stopper and the valves seat as shown in Fig. 3. 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. It cans the heat transfer by itself with latent heat of working fluid in the tubes and heat transfer with heat sink such as Water or Air. Pipatpaiboon *et al*.[4] 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) (Fig. 2). 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*.[5] studies the correlation to predict heat transfer of a closed-looped oscillating heat-pipe with check valves (CLOHP/CV). Meena *et al*.[6] studies the application of closed-loop oscillating heat-pipe with check valves (CLOHP/CV) air-preheater for reduced

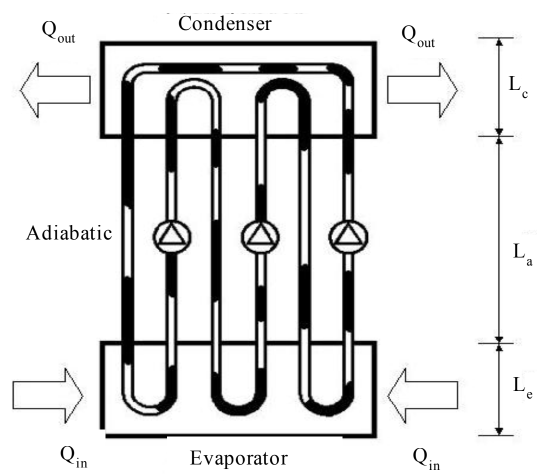

Fig. 1: Closed-loop oscillating heat pipe with check valve

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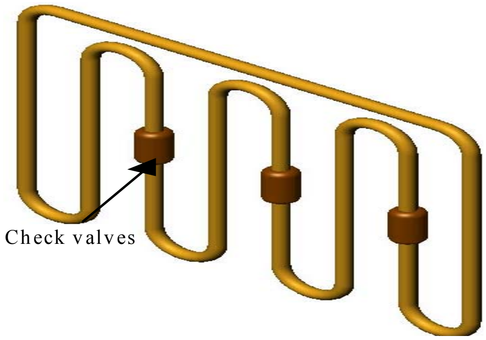

Fig. 2: Closed-looped oscillating heat-pipe with check valves (CLOHP/CV)

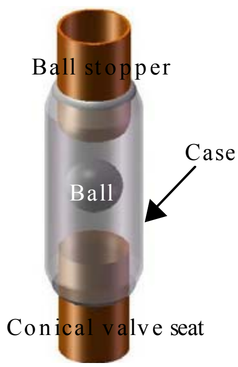

Fig. 3: The check valve

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*.[7] 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*.[8] 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 objective was to study the to design, construct and test the CLOHP/CV heat-exchanger reused the waste heat recovery in pottery kilns systems by a closed-loop oscillating heat-pipe with check valves (CLOHP/CV) for energy thrift as follows:

- To study the to design, construct and test the waste heat recovery by closed-loop oscillating heat pipe with check valve from pottery kilns for energy thrift

The check valves: 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

Design CLOHP/CV heat-exchanger calculator concept: Design the parameters e.g. the maximum heat transfer rate of the heat pipe heat-exchanger for pottery kilns system (Q_{max}, W), as follows:

- $Q_{max} = C_{min}(T_{hi} - T_{ci})$ (1)
  $C_{min} = \rho VAC_p$
- The inner diameter of the CLOHP/CV is calculated by Meazawa *et al*.[2]:

$$D_{max} \le 2\sqrt{\frac{\sigma}{\rho lg}} \quad (2)$$

- Select the type of working fluid that is appropriate to the operation temperature
- Select working temperature for used in drying system
- The heat transfer rate (Q_{max}, W), calculate from Ku_{90} and transfer to heat flux (q, W m^{-2})
- L_e, L_a, L_c, L_t and n are defined the duct size for the dryer
- Bo, Fr_v, Ja, Pr, Rcv, We, $\rho_v, \rho_l, \frac{Le}{Di}$ are described and the heat flux of CLOHP/CV air-preheater is solved by the correlation from[5]. The standard deviation of this equation is ±30%

$$Ku_{90} = 0.0041 \left[Bo^{2.2} Fr^{1.42} Ja^{1.2} Pr^{1.02} \left[\frac{\rho v}{\rho l}\right]^{0.98} Rcv^{1.4} We^{0.8} \left[\frac{L_e}{D_i}\right]^{0.5} \right]^{0.107} \quad (3)$$

The heat transfer rate (Q, W) calculates from Ku_{90} and transfer to heat flux (q, W m^{-2}) are shown in correlation (4):

$$Q90 = (Aq90) \quad (4)$$

KU_{90} indicates the ratio of heat flux through the CLOHP/CV to the critical heat-flux of the working fluid. It shows whether the obtained heat fluxes of a CLOHP/CV exceeds than the critical heat-flux of the working fluid or not, i.e., whether or not there is pool boiling of the working liquid in the evaporator section of the CLOHP/CV. Bo indicates the ratio of buoyancy force to surface tension force of the working fluid. If Bo > 1, nucleate boiling occurs in the heat pipe. Fr, i.e., the inertial force divided by gravitational force, is used in momentum transfer in general and open-channel flow and wave and surface behaviour calculations in particular. Ja is the latent heat divided by the specific heat at constant pressure. Pr indicates the ratio of momentum diffusivity to the thermal diffusivity of the vapour slug. If its value is very low, the vapour slug will be able to transfer the thermal energy to the condenser section relatively efficiently. Therefore, the value of Ku_{90} or heat flux will be high. The vapour-phase density to the liquid-phase density (ρ_v/ρ_l) of the working fluid dictates the working pressure of the working fluid within the CEOHP. R_{cv} indicates the number of check valves to the number of turns of the CLOHP/CV. We is the ratio of the inertial force to the surface-tension force. L_e/D_i defines the size of the CLOHP/CV. For example, if the value of L_e/D_i is very high, then the tube would be large and the evaporator section would be short. Because of the boiling phenomenon, the value of Ku_{90} or heat flux would be high. If the value of L_e/D_i is very low, then the tube would be small and the evaporator section would be long. Because the boiling phenomenon within this type of tube will be akin to the boiling phenomenon in a confined channel, the value of KU_{90} or heat flux will be low.

Values of some of these parameters are shown in Table1.

The effectiveness of CLOHP/CV heat exchanger, ε, is defined as the ratio of the actual heat-transfer rate for the heat-exchanger to the maximum possible heat transfer rate, i.e.

Test rig: The CLOHP/CV was made of copper tube. with R123 was used as the working fluid. A set of CLOHP/CV was made of copper tubes, 0.002 m inner diameter 2.03 mm: 40 turns: 20, cm equal lengths for evaporator and condenser, 10 cm for adiabatic sections. The working fluid was filled in the tube at the filling ratio of 50% shown in Fig. 5.

Figure 4 and 5 shows an experimental setup which consists of a CLOHP/CV with the evaporator section was given heat by heater while the condenser section was cooled by fresh air. The adiabatic section was properly insulated.

In the test operation, the temperature of the evaporator section was 200°C, with the working fluids changed from R123 to water. The data logger Yokogawa-MX100 was used with type K thermocouples (Omega with ±1°C accuracy) attached to the inlet and outlet of the condenser section on heat exchanger, the thermocouples were attached to the outside surface wall of the CLOHP/CV, inner the pottery kilns and data were recorded. These were 3 points on the evaporator, 2 points on the condenser and 2 points on the adiabatic section, 3 points on the top, center and bottom of pottery kilns. The evaporator section was given heat by heater, while the condenser section was cooled by air. They were used to calculate the heat transfer of the test CLOHP/CV by using the calorific method, as the following eq:

Table 1: The physical parameters of the CLOHP/CV heat exchanger

The physical parameters	Description
Material of tube	copper
Inner diameter	0.002 m
Physical dimension of the heat exchanger	0.2×0.2×0.2 m (Height× Length×Width)
Evaporator section length	0.20 m
Adiabatic section length	0.10 m
Condenser section length	0.20 m
CLOHP/CV arrangement	Staggered, S_L = 20 mm, S_T = 20 mm
Row number of the CLOHP/CV	n_L = 11 n_T = 10
Number of turns/Set	20
Working fluid	R123, Water
T_{hi}, T_{Ci}	200, 30°C

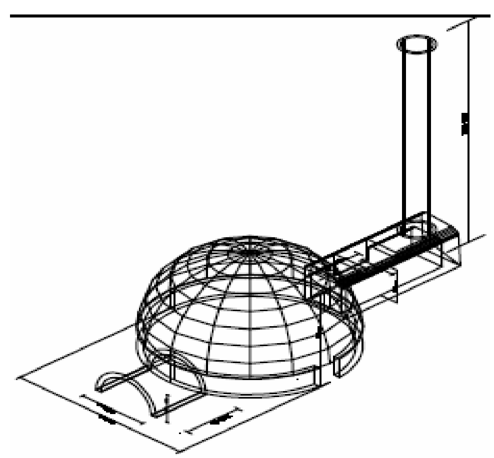

Fig. 4: Pottery kilns

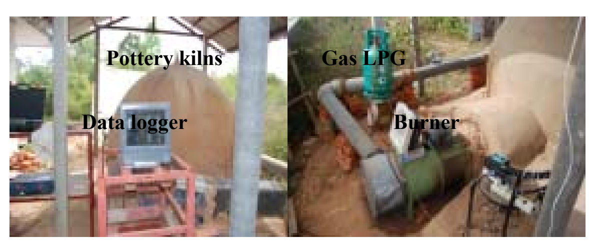

Fig. 5: The experimental setup

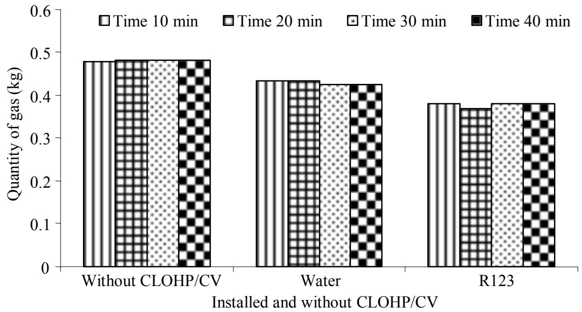

Fig. 6: Installed and without CLOHP/CV

$$Q = m^{\bullet} c_p \left(T_{out} - T_{in}\right) \qquad (5)$$

$$\text{Effectiveness } (\varepsilon) = \frac{Q_{exp}}{Q_{max}} \qquad (6)$$

and

Variable parameters were:

- Temperatures were 200°C
- Working fluids were R123 and Water

An inner diameter of the tubes was 2.03 mm

RESULT AND DISCUSSION

The comparison between installed CLOHP/CV and without CLOHP/CV on quantity of gas.

Figure 6 shows the comparison between installed CLOHP/CV and without CLOHP/CV on quantity of using gas for the waste heat recovery by closed-loop oscillating heat pipe with check valve from pottery kilns. It indicated that when installed the CLOHP/CV the value of quantity of using gas was lower than the without CLOHP/CV. And it was found that the value of quantity of using gas was decreased when working fluids changed from water to R123 all period of time.

The effect of working fluids on the heat transfer rate: Figure 7 shows the effect of working fluids on heat transfer rate for the waste heat recovery by closed-loop oscillating heat pipe with check valve from pottery kilns. It can be seen that the heat transfer rate was decreased when working fluids changed from R123 to water all period of time.

The effect of working fluids on the effectiveness: Figure 8 shows comparisons the effect of working fluids on the effectiveness for the waste heat recovery

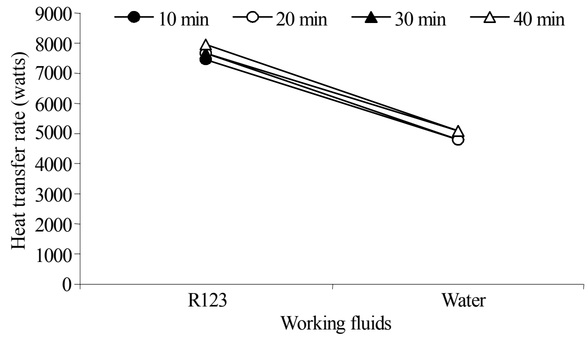

Fig. 7: Working fluids and heat transfer rate

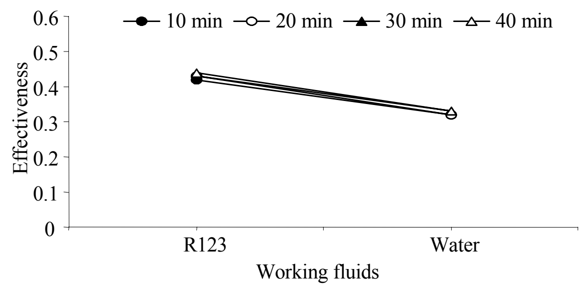

Fig. 8: Working Fluids and Effectiveness

by closed-loop oscillating heat pipe with check valve from pottery kilns. It indicated that the value of effectiveness decreased when the working fluids changed from R123 to water all period of time.

CONCLUSION

- The quantity of using gas for the waste heat recovery by closed-loop oscillating heat pipe with check valve from pottery kilns. Also when installed the CLOHP/CV was lower than the without CLOHP/CV
- The heat transfer rate for the waste heat recovery by closed-loop oscillating heat pipe with check valve from pottery kilns. Also working fluids changed from R123 to water, the value of heat transfer rate decreased
- The effectiveness for the waste heat recovery by closed-loop oscillating heat pipe with check valve from pottery kilns. Also when the working fluids changed from R123 to water, the value of effectiveness decreased
- The CLOHP/CV heat exchanger can reduce the quantity of using gas in pottery kilns and achieve energy thrift

ACKNOWLEDGEMENTS

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NOMENCLATURE

$m^{\bullet}$ = Mass per unit time
C_p = Specific heat capacity, constant pressure
T_{out} = Outlet temperature at condenser section
T_{in} = Inlet temperature at condenser section
T_{evap} = Temperature at evaporator section
$T_{cond.}$ = Temperature at condenser section
ε = Effectiveness
Q_{act} = Actual heat transfer rate
Q_{max} = The maximum heat transfer rate
L_e = Evaporator section length
L_a = Adiabatic sections length
L_c = Condenser sections length

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