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Effect Of Working Fluids And Evaporator Temperatures On Internal Flow Patterns And Heat Transfer Rates Of A Top Heat Mode Closed-Loop Oscillating Heat Pipe With Check Valves (Thmclohp/Cv)

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Abstract: This research was to study the effect of working fluids and evaporator temperatures on internal flow patterns and heat transfer rates of a top heat mode closed loop oscillating heat pipe with check valves (THMCLOHP/CV). The THMCLOHP/CV was made from a Pyrex glass capillary tube with a 2.4 mm inside diameter. There were 10 meandering turns with 2 check valves. Ethanol and R123 were used as working fluid with 50% fill ratio of the total inside volume of tube. The evaporator lengths of 50 mm with evaporator temperatures of 85, 105 and 125 ^{0}C. The inclination angle of minus 90^o from horizontal axis was established. The heater warmed an aluminum plate that was attached to the evaporator section while the condenser section was cooled cold bath. A video and digital camera was used to record the internal flow patterns at specific times. A heat transfer rate was obtained by means of the calorific method from the condenser section. Experimental results found that if working fluid varies from ethanol to R123 and the evaporator temperature increases from 85 to 125 ^{0}C the heat transfer rate will be slightly increases. At the maximum heat transfer rates of THMCLOHP/CV, the main flow patterns were Slug bubble + Disperse bubble+ Churn flow.

Key word: Closed loop oscillating heat pipe, Flow patterns, Top heat mode, Check valves.

INTRODUCTION

The oscillating/pulsating heat pipe (OHP/PHP), first proposed by (Akachi, *et al*., 1996) is one type of heat transfer device. The closed-loop oscillating heat pipe with check valves (CLOHP/CV) is a new type of heat transfer device. It offers high performance heat. Present applications for CLOHP/CV heat pipes include cooling devices, air preheaters etc. In general, the CLOHP/CV has three sections: the evaporator section, adiabatic section and condenser section. The principle is the transfer of the latent heat of the working fluid inside the tubes, which evaporates heat from a heat source at the evaporator section and the heat transfers by condensation to the condenser section. Due to the fact that the latent heat of vaporization of the working fluid is very high, it transfers heat from the evaporator section to the condenser section by a slight temperature difference. It also has the capability to operate in any heat mode such as horizontal heat mode (HHM), bottom heat mode (BHM), of top heat mode (THM). However, the heat pipes operating in horizontal heat mode and bottom heat mode are not always practical for such cooling in electronic devices, humidity control air conditioning system, etc. Therefore, in the present experiment the top heat mode closed-loop oscillating heat pipe with check valves (THMCLOHP/CV) as shown in fig. 1 was evaluated. In the literature review, (Rittidech, *et al.*, 2008) studied the internal flow patterns of a CLOHP/CV. The CLOHP/CV used a Pyrex glass tube with inside diameter of 2.4 mm. The evaporator lengths of 50 and 150 mm. were employed with 10 turns, with R_{cv} of 0.2 and 1. R123 was used as the working fluid with a filling ratio of 50% of the internal volume of tube. It was found that at the high heat source, when the Le decreases, the main flow changes from bubble flow with slug flow to dispersed bubble flow. As the Rcv decreases, the main flow changes from the dispersed bubble flow with bubble flow to dispersed bubble When the velocity of slug increases, the length of vapor bubbles rapidly decrease and the heat flux rapidly increases. (Bhuwakietkumjohn, *et al*., 2010) investigated the internal flow patterns and heat transfer characteristics of a CLOHP/CV. Ethanol and a silver nano-ethanol mixture were used as working fluids with a filling ratio of 50% by total volume of tube. The CLOHP/CV was made of a glass tube with an inside diameter of 2.4 mm. The evaporator section was 50 mm and 100 mm in length and there were 10 meandering turns. An inclination angle of 90^o from horizontal axis was established. Temperature at the evaporator section was controlled at 85, 105, and 125 ^{o}C. The inlet and outlet temperatures were measured. The silver nano-ethanol mixture gave higher heat flux than ethanol. When the temperature at the evaporator section was increased from 85, 105 and 125 ^{o}C., it was found that the flow patterns occurred as annular flow + slug flow, slug flow + bubble flow and dispersed bubble flow + bubble flow respectively. The above literature review does not investigate the effect of parameters on internal flow patterns of the THMCLOHP/CV. Therefore, this research will investigate the internal flow patterns of the THMCLOHP/CV.

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Experimental and procedure:

Fig. 2 shows an experimental setup which consists of a THMCLOHP/CV. The THMCLOHP/CV was made from a Pyrex glass capillary tube with 2.4 mm inside diameter and there were 10 meandering turns. The length of the evaporator section of 50 mm. The working fluid used were ethanol and R123 with the filling ratio of 50% of the total inside volume of tube. The temperatures of evaporator section were 85, 105 and 125 ^{o}C. The inclination angle of minus 90^{o} from horizontal axis was established. The heater warmed an aluminum plate, which was attached to the evaporator section while the condenser section was cooled by water from cold bath (EYELA CA-1111, volume of 6.0 l with an operating temperature range of -20 to 30 ^{o}C with ±2 ^{o}C accuracy) and then pumped into the cooling jacket. The mass flow rate inside the cooling jacket was measured with a floating rota meter (Platon PTF2ASS-C with a measure flow rate of 0.2–1.5 L/min). The thermocouples (OMEGA type K) with on uncertainty of ±1 ^{o}C connect to the data logger (Yokogawa DX 200 with ±1 ^{o}C accuracy, 20 channel input and -200 ^{o}C to 1100 ^{o}C measurement temperature range) that were measure the inlet and outlet of the condenser section to determine the heat transfer rate. A video camera (Sony CCD-TR618E) was employed to continuously record the flow patterns at the evaporator section, adiabatic and condenser sections, and the total part of THMCLOHP/CV. A digital camera (Nikon D90) was used to take a photograph of the flow patterns of a THMCLOHP/CV at specified times. The experiment was conducted as follows. Firstly, a THMCLOHP / CV was installed with the test rig. The temperature of the heater and cold baths was set at the required value and cold fluids were supplied to the jackets of the condenser section. After reaching the steady state, continuous movies were recorded by video cameras, while photographs were taken at specified times by the digital camera. The temperature and flow rate of the cooling water were recorded.

RESULTS AND DISCUSSION

In this experimental study the heat transfer rate can be calculated by equation (1)

$$q = \frac{Q}{A_c} \qquad (1)$$

Where $Q = \dot{m} C_p \Delta T$, A_c is the outside diameter of the tubes in condenser section, q is the heat flux (W/m^2), Q is heat transfer rate (W), $\dot{m}$ is mass flow rate (kg/s), C_p is specific heat (J/ kg. °C), ΔT is the different temperatures of inlet and outlet of the water in condenser section (^{o}C)

The internal flow patterns of THMCLOHP/CV were recorded by video camera and digital camera at specific times. The internal flow patterns show the relationship between effect of working fluids, evaporator lengths and the evaporator temperatures. The results show the internal flow patterns, the length of the vapor slug, the velocity of vapor slug and heat flux.

At working fluid of R123, Fig. 3, 4 and 5 shows the internal flow patterns of THMCLOHP/CV with the heat source temperature at evaporator section of 85, 105 and 125 ^{o}C. It was found that, the flow patterns are the same; all were Slug flow + Disperse bubble flow + Churn flow. These flow patterns caused the vapor plug to move to the evaporator section. It pushed the liquid slug to the evaporator section and the liquid slug was nucleated boiling to dispersed bubble at the lower part of evaporator section and dispersed bubble coalescence was vapor plug, and the vapor moving across the U-bend tubes with churn flow.

Table 1 and Fig. 9 shows that at the heat source temperature at evaporator section of 85 ^{o}C with a heat flux of 1.33 kW/m^2. The length of the vapor slug is approximately 0.14 m. The velocity of vapor slug is 0.3 m/s. At the heat source temperature at the evaporator section of 105 ^{o}C with a heat flux of 2.32 kW/m^2. The length of the vapor slug is approximately 0.09 m. The velocity of vapor slug is 0.36 m/s. And the heat source temperature at evaporator section of 125 ^{o}C with a heat flux of 3.32 kW/m^2. The length of the vapor slug is approximately 0.082 m. The velocity of vapor slug is 0.54 m/s, due to at the high heat source temperature at the evaporator section. As a result, the pressure at the evaporator increased because the volumetric expansion of the vapor reduced, resulting average velocity of the vapor increased and the heat transport from the evaporator section to the condenser section increased.

At working fluid of ethanol Fig. 6 shows the internal flow patterns of THMCLOHP/CV with the heat source temperature at evaporator section of 85 ^{o}C. It was found that, the flow patterns are Slug flow + Annular flow. These flow patterns caused the vapor plug to move to the evaporator section. It pushed the liquid slug to the evaporator section and the liquid slug was nucleated boiling at the left side to Annular flow at the lower part at the right side and the vapor moving across the U-bend tubes with Annular flow. Fig. 7 and 8 shows the internal flow patterns of THMCLOHP/CV with the heat source temperature at evaporator section of 105 and 125. It was found that, the flow patterns are the same; all were Slug flow + Bubble flow . These flow patterns caused the vapor plug to move to the evaporator section. It pushed the liquid slug to the evaporator section and the liquid slug was nucleated boiling to Bubble flow at the lower part of evaporator section.

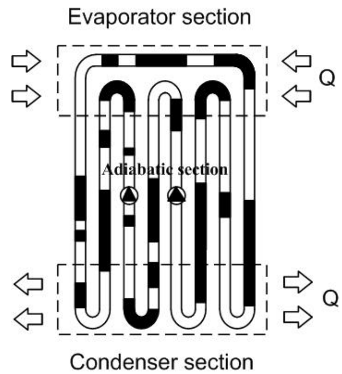
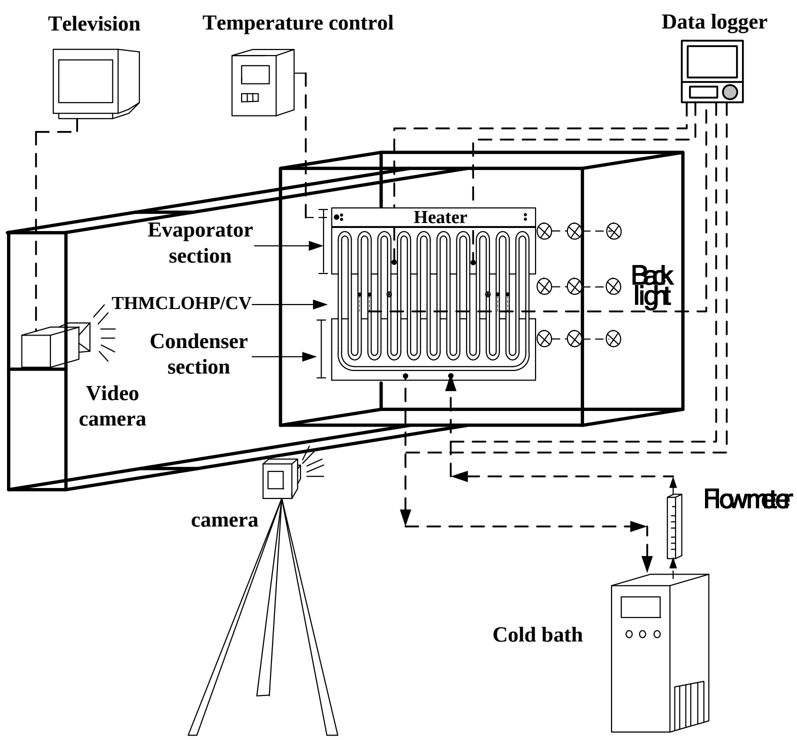
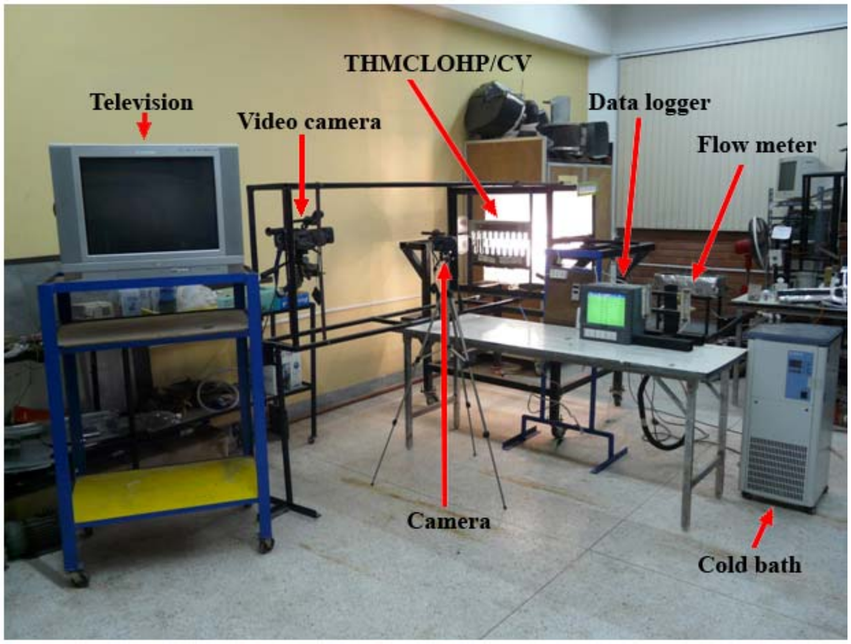


Fig. 1: The (THMCLOHP/CV).

Table 2 and Fig. 9 shows that at the heat source temperature at evaporator section of 85 ^{o}C with a heat flux of 0.89 kW/m^2. The length of the vapor slug is approximately 0.15 m. The velocity of vapor slug is 0.27 m/s. At the heat source temperature at the evaporator section of 105 ^{o}C with a heat flux of 1.78 kW/m^2. The length of the vapor slug is approximately 0.10 m. The velocity of vapor slug is 0.31 m/s. And the heat source temperature at evaporator section of 125 ^{o}C with a heat flux of 2.44 kW/m^2. The length of the vapor slug is approximately 0.099 m. The velocity of vapor slug is 0.43 m/s, due to at the high heat source temperature at the evaporator section. As a result, the pressure at the evaporator increased because the volumetric expansion of the vapor reduced, resulting average velocity of the vapor increased and the heat transport from the evaporator section to the condenser section increased.



(a)



(b)

Fig. 2: (a) Diagram of the experimental test rig (b) experimental test rig.

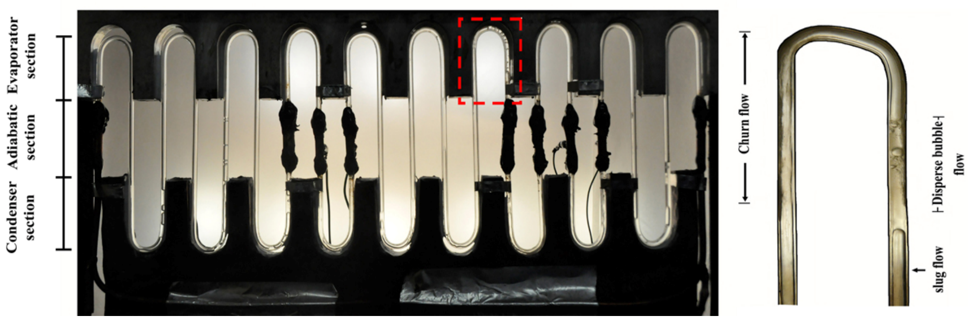


Fig. 3: Internal flow patterns of THMCLOHP/CV using a R123 at Le of 50 mm. -90^{o} and evaporator temperature of 85 ^{o}C.

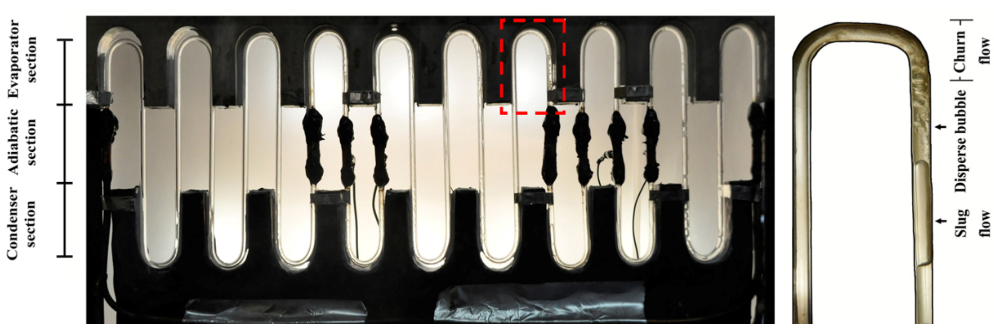


Fig. 4: Internal flow patterns of THMCLOHP/CV using a R123 at Le of 50 mm. -90^{o} and evaporator temperature of 105 ^{o}C.

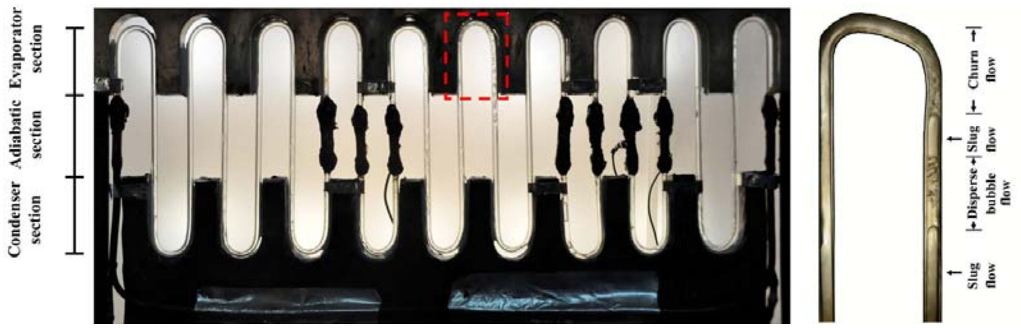


Fig. 5: Internal flow patterns of THMCLOHP/CV using a R123 at Le of 50 mm. -90^o and evaporator temperature of 125 ^{o}C.

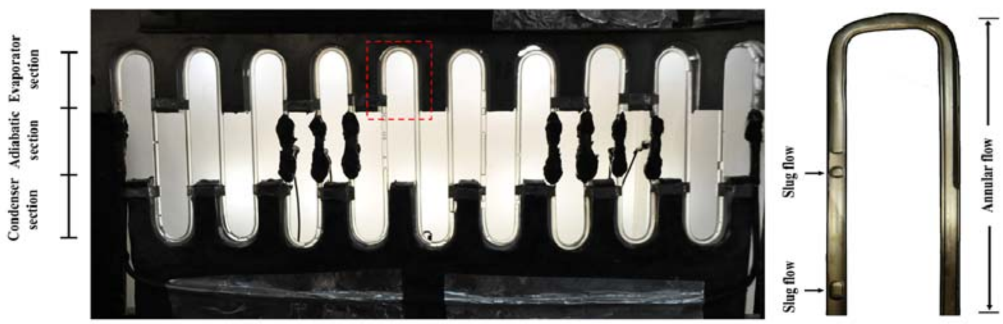


Fig. 6: Internal flow patterns of THMCLOHP/CV using a Ethanol at Le of 50 mm. -90^o and evaporator temperature of 85 ^{o}C.

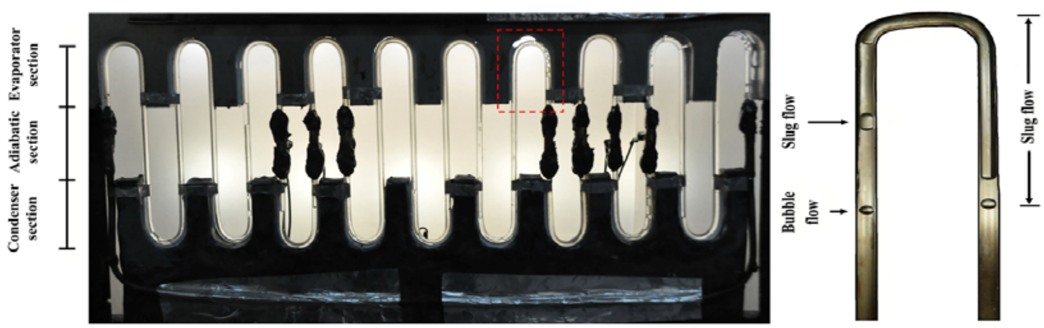


Fig. 7: Internal flow patterns of THMCLOHP/CV using a Ethanol at Le of 50 mm. -90^o and evaporator temperature of 105 ^{o}C.

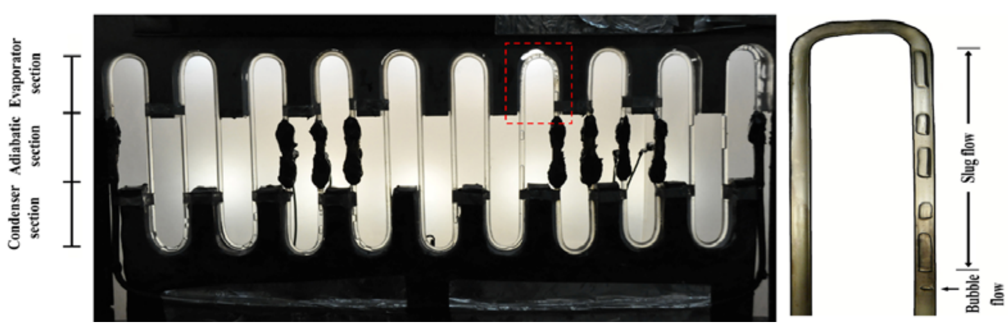


Fig. 8: Internal flow patterns of THMCLOHP/CV using a Ethanol at Le of 50 mm. -90^o and evaporator temperature of 125 ^{o}C.

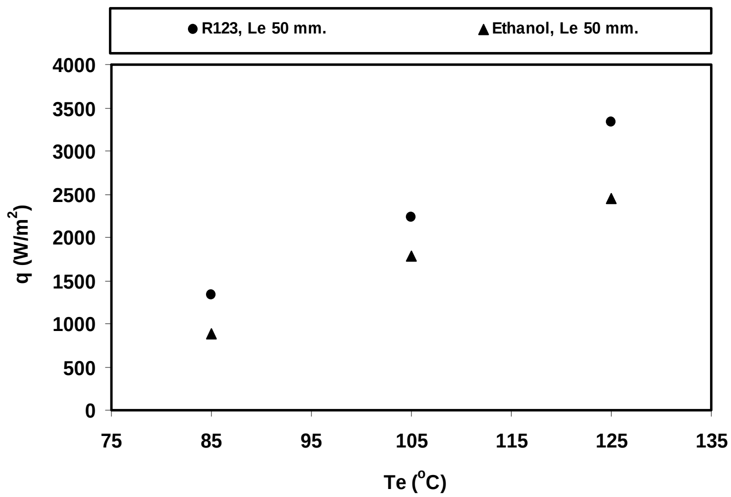


Fig. 9: Working fluids and evaporator temperatures on heat transfer rates.

Table 1: Experimental data with R123 at Le of 50 mm. -90° of angle, 2.4 mm ID.

Fig.	T_H (°C)	Main flow patterns	L_V (m)	V_S (m/s)	q (kW/m²)
3	85	Slug + Disperse bubble + Churn	0.14	0.3	1.33
4	105	Slug + Disperse bubble + Churn	0.09	0.36	2.22
5	125	Slug + Disperse bubble + Churn	0.0825	0.54	3.33

Table 2: Experimental data with Ethanol at Le of 50 mm. -90° of angle, 2.4 mm ID.

Fig.	T_H (°C)	Main flow patterns	L_V (m)	V_S (m/s)	q (kW/m²)
6	85	Slug + Annular	0.157	0.27	0.89
7	105	Slug + Bubble	0.105	0.31	1.78
8	125	Slug + Bubble	0.099	0.43	2.44

Conclusions:

This section describes the conclusions of the studied result of the effect of internal flow patterns on heat transfer characteristics of a top heat mode closed loop oscillating heat pipe with check valves (THMCLOHP/CV) as follow. For the internal flow patterns of THMCLOHP/CV at the inclination angle of 90° minus with the heat source temperature increased at the evaporator section from 85, 105 and 125 °C. It was found that R123 will provided maximum heat transfer rates with main flow patterns were slug flow + dispersed bubble flow + churn flow for the high heat source the velocity of vapor slug increased and the length of vapor slug decreased.

ACKNOWLEDGEMENTS

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Nomenclature:

ID internal diameter of the tube (m)
Le length of evaporator section (m)
Q heat transfer rate (W)
A_c the outside diameter of the tubes in condenser section (m²)
q heat flux (W/m²)
$\dot{m}$ mass flow rate (kg/s)
C_p specific heat (J/ kg. °C)
ΔT the different temperatures of inlet and outlet of the water in condenser section (°C)

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