IOP Conf. Series: Materials Science and Engineering **191** (2017) 012034 doi:10.1088/1757-899X/191/1/012034

Closed loop oscillating heat pipe as heating device for copper plate

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Abstract. In manufacturing parts by molding method, temperature uniformity of the mold holds a very crucial aspect for the quality of the parts. Studies have been carried out in searching for effective method in controlling the mold temperature. Using of heat pipe is one of the many effective ways to control the temperature of the molding area to the right uniform level. Recently, there has been the development of oscillating heat pipe and its application is very promising. The semi-empirical correlation for closed-loop oscillating heat pipe (CLOHP) with the STD of ±30% was used in design of CLOHP in this study. By placing CLOHP in the copper plate at some distance from the plate surface and allow CLOHP to heat the plate up to the set surface temperature, the temperature of the plate was recorded. It is found that CLOHP can be effectively used as a heat source to transfer heat to copper plate with excellent temperature distribution. The STDs of heat rate of all experiments are well in the range of ±30% of the correlation used.

1. Introduction

In manufacturing parts by molding method, temperature uniformity of the mold holds a very crucial aspect for the quality of the parts. Poor designed molds may lead to non-uniform temperature of the mold cavity and core plates which lead to low quality parts and part rejection. Studies have been carried out in searching for effective method in controlling mold temperature. Using of heat pipe is one of the many effective ways to control the temperature of the molding area to the right uniform level. Standard parts of heat pipe are cataloged in many cutting edge mold making companies. Recently, there has been the development of oscillating heat pipe (OHP) and its application is very promising. However, most applications of OHP, nowadays are concentrated in energy management of air conditioner, refrigerator, heat exchanger, and in computer application. There are not many studies of OHP in industry application such as molding. Since molding industry has been growing rapidly, i.e. in plastics injection molding alone, the growth was anticipated to be increased by 40% within 5 years [1]. In injection molding, rapid cooling and heating technique of cavity and core plates is of important. There are two main categories of heating system used, surface heating and volume heating. Surface heating, as its name implied, is heating of the cavity surface using different heating method such as induction heat and infrared. Whereas in volume heating, channels are drilled and cartridge heaters are placed evenly in the core side as shown in Fig. 1(a), where the center plate is the heating plate and the right-hand plate is the cooling plate. Fig. 1(b) shows another design where water and heater could be placed in the same channel.

The objective of this paper is then to adapt the volume heating concept by replacing the cartridge heater and water with CLOHP. By this adjustment, the heating and cooling process can be combined using just CLOHP and the system is much more simplified as there is no leakage problem since CLOHP is a closed system with no moving parts. The basic characteristics of OHP is a capillary tube meandered into equally space-wise turns as shown in Fig 2. Inside of the tube is evacuated and partly filled with working fluid. It can then be placed in between the mold plate to transfer heat into the cavity with a more uniform temperature distribution. Moreover, the tube can be bent in any required shape (Fig.3). For preliminary study, this research is concentrated on only heating of the copper plate to the set surface temperature. The temperature distribution was then studies and reported as the standard deviation value of the set surface temperature. For comparison, the same experiment but using cartridge heater was also carried out. The results were as well compared with the result studied with P-20 of the previous study.

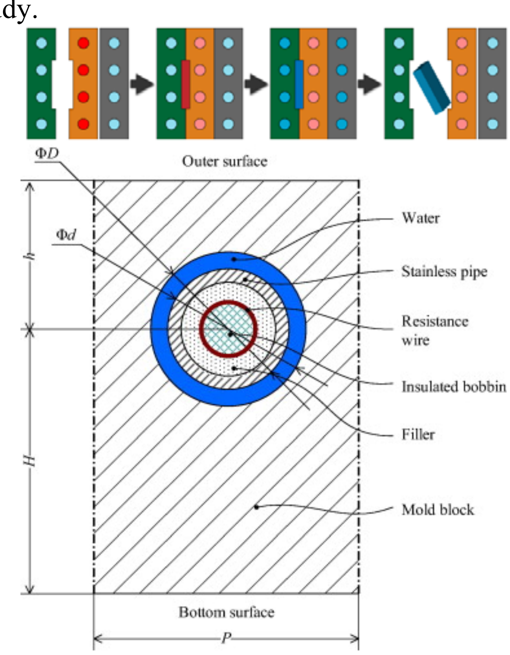
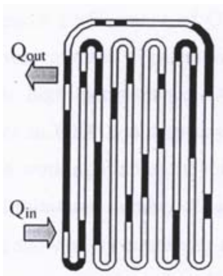


Figure 1. Rapid Mold Heating/Cooling Process [2, 3]



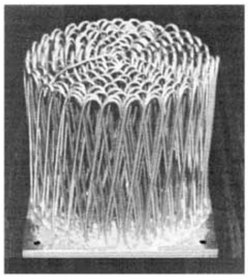


Figure 2. Oscillating Heat Pipe **Figure 3.** OHP in Commercial Used [4]

Khandekar et al. [5] proposed the semi-empirical correlation which determine the maximum heat transfer achievable for CLOHP (filling ratio of 50%) with the STD of ±30%. The correlation together with other dimensionless terms required in the design are as shown in Eq. 1 to Eq. 5 and Fig. *4*.

$$\dot{q} = \left(\frac{\dot{Q}}{\pi D_i \cdot N \cdot 2L_e} \right) = 0.54\,(\exp(\beta))^{0.48}\ Ka^{0.47}\ Pr_{liq}^{\ 0.27}\ Ja^{1.43}\ N^{-0.27} \tag{1}$$

$$B_o = \frac{g(\rho_l - \rho_v)D_i^{\,2}}{\sigma} \tag{2}$$

$$Ja = \frac{h_{fg}}{C_{pl}\Delta T_{sat}^{e-c}} \tag{3}$$

$$Pr_{liq} = \left(\frac{C_{pl}\mu_l}{k_l} \right) \tag{4}$$

$$Ka = f\mathrm{Re}^2 = \frac{\rho_l(\Delta P)_l D_i^3}{\mu_l^2 L_{eff}} \tag{5}$$

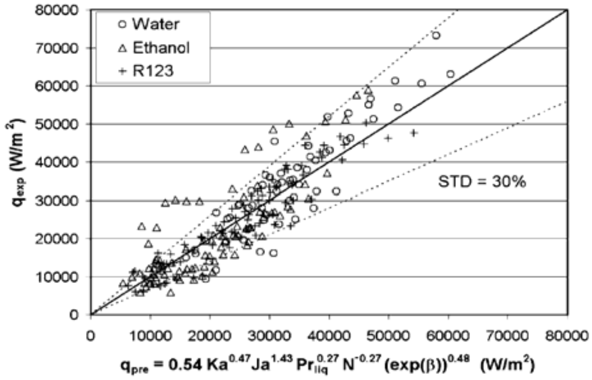


Figure 4. Semi-empirical correlation of CLOHP [5]

2. Experimental setup and analysis

CLOHP was designed for 300 Watts of heat transfer using Eq. 1 to Eq 5. Choosing water as working fluid, the number of turns needed is 12 with the inner diameter of 2 mm. Fig. 5 shows dimensions of CLOHP used in this study. Fig. 6 shows the experimental setup. Fig.7 shows locations of 16 thermocouples. Fig. 8 shows the recorded temperature from the experiment with standard deviation (SD) at each point. The CLOHP was placed at 5 mm and 10 mm from the surface of the copper plate. The surface temperature of interest in this study was 80°C -130°C, with the increment of 10°C.

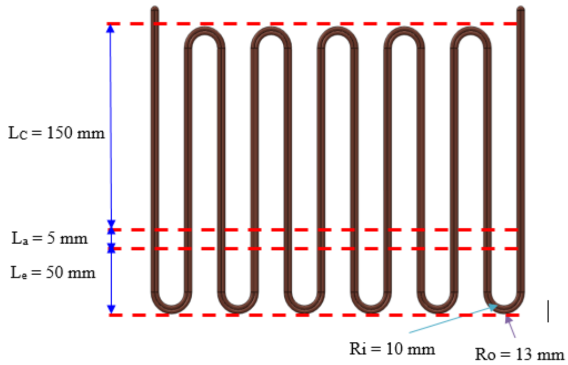


Figure 5. Dimensions of CLOHP

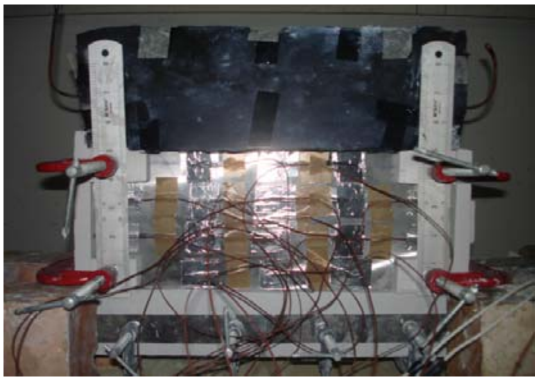


Figure 6. Experimental setup

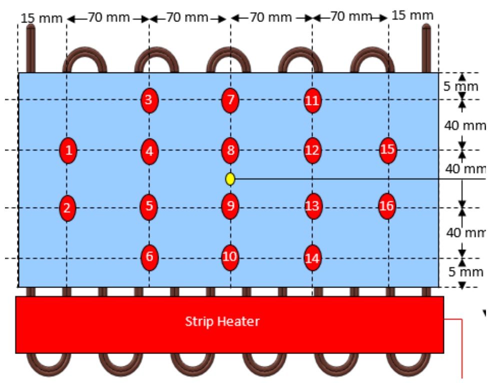
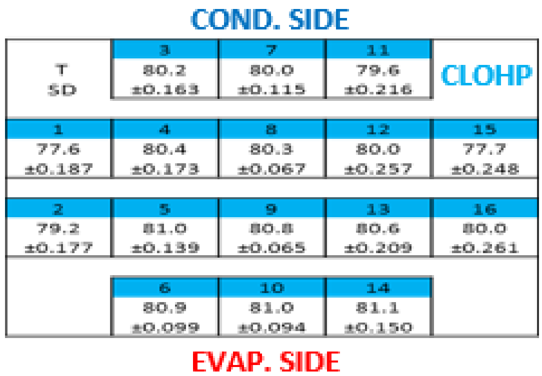


Figure 7. 16-location of thermocouples



COND. SIDE

T SD	3: 80.2 ±0.163	7: 80.0 ±0.115	11: 79.6 ±0.216	CLOHP
1: 77.6 ±0.187	4: 80.4 ±0.173	8: 80.3 ±0.067	12: 80.0 ±0.257	15: 77.7 ±0.248
2: 79.2 ±0.177	5: 81.0 ±0.139	9: 80.8 ±0.065	13: 80.6 ±0.209	16: 80.0 ±0.261
	6: 80.9 ±0.099	10: 81.0 ±0.094	14: 81.1 ±0.150	

EVAP. SIDE

Figure 8. Recorded temperature with SD value

When the system was at steady state, the temperatures of 16 locations were recorded for 60 minutes. With the data from 3 replications, the temperature at each location was reported as mean temperature with SD value which was calculated by Eq. 6.

$$SD = \sqrt{\frac{\sum_{i=1}^{N}\left(X_i - \bar{X}\right)^2}{N}}. \tag{6}$$

Where SD is the standard deviation at each location
X is the measured temperature
$\bar{X}$ is the average measured surface temperature
N is sampling size

However, when refer to surface temperature of the whole plate, the standard deviation (STD) is used, where $\bar{X}$ is set surface temperature and N is sampling size. However, for comparison, when 2 set of temperature distribution results are considered, the relative standard deviation (%RSD), as in Eq. 7, was used.

$$\%RSD = \frac{STD}{\bar{X}} x100 \tag{7}$$

3. Result and discussion

The designed CLOHP can heat the copper plate to the desired set temperatures with acceptable deviation. The results of set surface temperature of 100 °C will be used as a representative for the data at other set temperature as well since they all show the same trends. Fig. 9 shows 16-location of surface temperature of copper plate at set surface temperature of 100 °C. The deviation (STD) of the whole plate from the set surface temperature was ±0.28 °C. The deviations (SD) at each 16-location are also shown on the right side of the figure. It can be clearly seen that the temperature distribution of the copper plate with CLOHP as the heat source is rather uniform. Fig. 9 also shows the result in the case of using cartridge heater (HR) at the same surface temperature for 16-location as well. The deviation in this case was ±0.62 °C. From Table 1, it can clearly be seen from the temperature deviation that the copper plate with CLOHP as the heat source shows good temperature distribution than those with cartridge heater (HR).

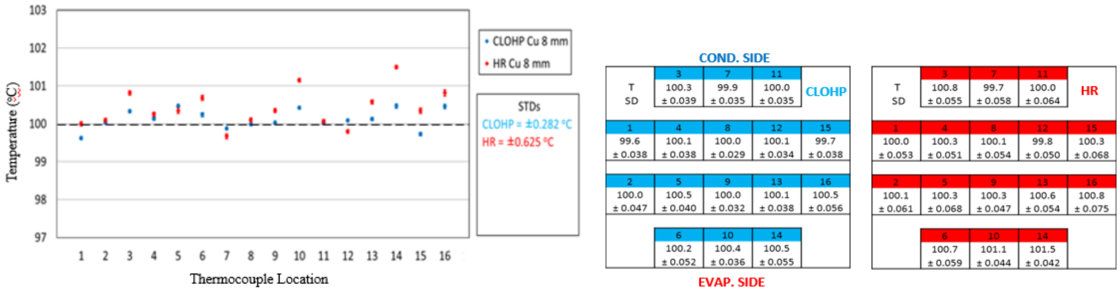


Figure 9. 16-location surface temperature of the copper plate at set temperature of 100 °C with the deviation (SD) at each location and deviation temperature of the whole plate (STD), comparison between using CLOHP and HR as the heat source

Table 1. STD of surface temperature at 5mm and 10mm depth.

Set Surface Temperature (°C)	STD (± °C) at 5mm Depth		STD (± °C) at 10mm Depth	
	CLOHP	HR	CLOHP	HR
80	0.51	0.64	0.50	0.64
90	0.45	0.59	0.52	0.59
100	0.28	0.62	0.47	0.62
110	0.25	0.58	0.43	0.58
120	0.22	0.48	0.48	0.48
130	0.24	0.53	0.55	0.53

From the result above, it is found that the CLOHP can transfer heat to the copper plate with better temperature distribution than HR, consequently, the discussion hereafter will be concentrated on using only CLOHP as the heat source and comparing the temperature distribution of the copper plate to those of P-20 plate from previous study [6]. Table 2 compares the result of the STD values of the surface temperature of both plate using CLOHP at 5mm and 10mm deep from the surface of the plate. The STD values of the copper plate, in all cases, are less than those on the P-20 plate. This suggests that the temperature distribution of the plate using CLOHP as the heat source with copper plate is more uniform than those with P-20. Fig. 10 and Fig. 11 compare the effect of specific heat and thermal conductivity on the RSD, respectively. Copper which has lower specific heat shows less RSD than P-20 which has higher specific heat. Lower specific heat material requires less thermal energy to raise the temperature of material of the same mass up to one degree, as a result the temperature distribution is undoubtedly more uniform. When considering the heat conductivity, copper shows less RSD than P-20. Material with higher thermal conductivity allows thermal energy per unit area to transfer and increase its temperature much faster. These results are in agreement with the study of Wang, G. et. al. [7]

Table 2. STD of surface temperature at 5mm and 10mm depth.

Set Surface Temperature (°C)	STD (± °C) at 5mm Depth		STD (± °C) at 10mm Depth	
	Copper	P-20	Copper	P-20
80	0.51	1.03	0.50	0.63
90	0.45	0.98	0.52	0.89
100	0.28	0.99	0.47	0.86
110	0.25	0.97	0.43	1.07
120	0.22	0.96	0.48	0.91
130	0.24	1.08	0.55	0.78

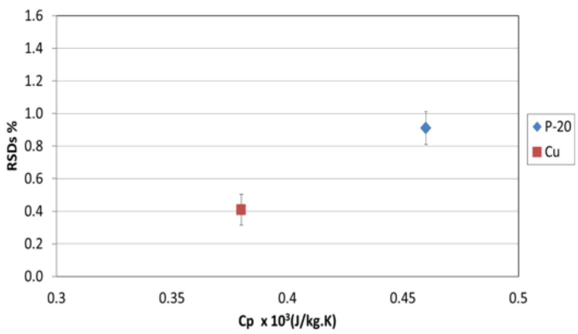


Figure 10. Effect of Specific Heat on RSD

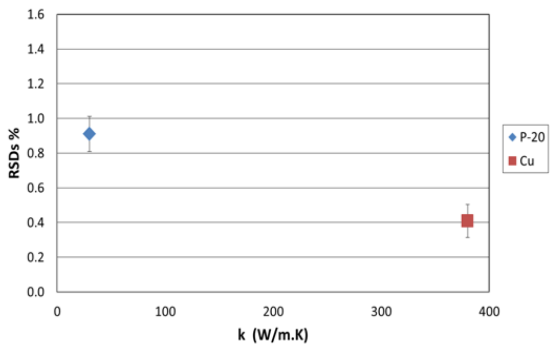


Figure 11. Effect of Thermal Conductivity on RSD

Table 3 shows the STD of the all the experiments. It is found that the STD of all the experiments are well in the range of the STD of the correlation which is ±30.0%. Consequently, the correlation can be well used for this design.

Table 3. STD of the heat transfer rate from experiment

Depth	STD of the Heat Transfer Rate	
	Copper (%)	P-20 (%)
5 mm	29.48	25.87
10 mm	9.41	6.76

4. Summary

CLOHP can be effectively used as a heat source to transfer heat to copper plate with much better temperature distribution. The STD of surface temperature from CLOHP is ±0.22°C to ±0.55°C while

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those used HR is ±0.48°C to ±0.64°C. Copper plate yields better temperature distribution than P-20. The STD of surface temperature of copper plate is ±0.22°C to ±0.55°C while those of P-20 plate is ±0.63°C to ±0.1.08°C. The STDs of heat rate of all experiments are well in the range of ±30% of the correlation used.

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