Case Study of Heat Transfer on Heater Performance of Injection Molding Machines Before and After Maintenace

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Abstract- Injection molding is a thermoplastic material forming method in which the material melted by heating is injected by a plunger into a water-cooled mold so that it hardens. Molding companies have a classic problem with heaters used to heat plastic ores. One of the companies using the Yizumi UN160SK Injection Molding Machine with polystyrene plastic ore faced a heater malfunction that disrupted the production process. A case study of heater performance was carried out to find out signs of damage, what condition the heater was in (electricity consumption, heat generated and the condition of the plastic ore melt).

Keywords—Heat Transfer, Heater Performances, Injection Molding Machine

Keywords: Energy audit, electrical energy

I. INTRODUCTION

The injection molding process is one of the most commonly used plastic forming techniques in various industrial sectors, referring to the absolute ease and convenience provided by this methodology. Statistical testimony to the above-mentioned facts: the global plastic injection molding market size reaches 100 million tons [1]. High automation, short processing time, and the possibility to obtain objects with high dimensional and geometrical accuracy are the main advantages of this process [2]. Currently, growing interest is being directed at improving the sustainability of plastic processes and products due to the problems associated with pollution due to the high amount of plastic waste (microplastics) [3].

In the injection molding process, one of the main operating parameters that affects the properties of the final object is the mold temperature [4]. The surface finish, morphological distribution, and the possibility to produce micro and nanostructures on the mold surface are highly dependent on the temperature adopted in the mold and, in particular, on the cavity surface [5]. The mechanical properties have been found to be dependent on the temperature of the mold; in particular, the tensile strength of molds made of polyether-ether-ketone increases with mold temperature [6]. Similar results have also been obtained in the case of polylactic acid bio-composites [7]. The impact energy and flexural modulus have been found to be dependent on the mold temperature for mixtures made of polyethylene terephthalate and polypropylene [8]. Also, the structure developed, in terms of crystallinity and number of crystalline phase fractions, depends on the mold temperature, in particular, the degree of crystallinity increases with mold temperature for molds made of polypropylene. During the mold filling step to full, heat propagates from the polymer melt to the mold surface after it has made contact with the mold with the melt. Assuming a short contact time and no thermal contact resistance in the front flow region, the melt surface temperature changes to the contact temperature or the interface between the melt and the mold [9]. The characteristics of the melt surface layer that replicate the mold surface depend on the contact temperature. If the contact temperature is lower than the no-flow temperature or the glass transition temperature of the amorphous polymer material or the melting temperature of the semi-crystalline polymer material, the material in the surface layer has a higher stiffness [10]. Due to the higher stiffness of the material on the surface, it is difficult to achieve a higher rate of replication of the mold surface [11]. In the case of high contact temperature conditions near or above the melt temperature, it causes lower surface stiffness or higher fluidity of the material near the surface [12]. Therefore, the surface material easily replicates the microscale structure of the mold surface or fills the small gaps between reinforcing fibers/particles and produces a mold surface. As a result, preformed surface defects in the same molding cycle can be effectively eliminated [13].

The contact temperature depends on the thermal properties of the molten and molded materials, as well as the initial mold and melt temperatures. Compared

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ISSN 0216-8685 (print); 2528-6889 (online)

with the typical and limited melting temperature range, the mold temperature can be adjusted widely and thus has a dominant effect on the contact temperature. Generally, the contact temperature is 10-150 C above the mold temperature [14] because the effusion of the mold material is much higher than that of the polymeric material. Therefore, the influence of mold temperature on surface quality has been considered to be of utmost importance [15].

Research related to heat transfer control systems has been carried out by many researchers and shows that heat transfer control can increase system efficiency [16,17,18]. Thus the heat transfer analysis on the injection molding machine is carried out to determine the performance of the injection molding and the operational optimization of the machine

II. METHODS

The materials used in the injection molding process are thermoplastic and thermoset materials. The material used to make brylcreem products is polysetyrene, which is a class of thermoplastic materials and is amorphous. Polystyrene has the following characteristics: the base color is white, transparent like glass, can be reshaped, has a high level of hardness (cosmo cup products from the lid test reached 250 Kn 43), is very stiff and brittle unless modified, has excellent electrical insulating properties, has low thermal conductivity. because it is classified as amorphous, based on ASTM D-1238 it has melt flow rates of 15g/10min, has high shear sensitivity so that gradual heat is required in the process, very low shrinkage of 0.45- 0.6%.

TABLE 1. CHARACTERISTICS of POLYSTYRENE

Sifat Mekanik	Polystyrene
Modulus Elastisitas	1400 MPa
Kekuatan Tarik	35 MPa
Elongation	10 – 500 %
Raw Material (murni)	82.48
Raw Material (daur ulang)	71.86

Fig. 1. Yizumi UN160SK Injection Molding Machine

The injection molding machine (Yizumi UN160SK) in Figure 1 is used in this production process. The following is a table of 2 engine specifications from the Book Installation and Maintenance Manual UN60SM2-UN320SM2.

TABLE 2. PRODUCT SPECIFICATION YIZUMI UN160SK

Deskripsi	Unit	UN90SK
Screw diameter	Mm	32 36 60
Shot volume	cm^3	132,7 168 207
Injection pressure	Mpa	222,2 175,5 142,2
Max. injection speed	mm/s	107
Screw stroke	Mm	165
Screw speed	Rpm	0-209
Opening stroke	Mm	330
Hydraulic ejection stroke	Mm	100
Hydraulic ejection force	kN	28
Hydraulic system pressure	Mpa	17,5
Heating capacity	kW	6,9/7,8

Temperatures that need to be controlled during the plastic injection molding process include barrel temperature, nozzle temperature and mold temperature. The first two temperatures mainly affect the plasticization and activity of the plastic, and the latter mainly affects the activity and cooling of the plastic. Each type of plastic has a different activity temperature, and the same plastic may have different activity and decomposition temperature due to different sources or levels. This is due to the difference in the average molecular mass and the distribution of the molecular mass. Plastic materials have different plasticization processes in different plastic injection molding machines, so the choice of barrel temperature is not the same.

To change the phase of a material from solid to liquid, it is necessary to first know the heat absorbed by the material. To find the heat absorbed in the material before the melting process is used as follows [19]:

$$Q_1 = m.c.\Delta T \tag{1}$$

where Q1 is the heat absorbed by the material, m is the mass of the material and c is the specific heat of the material. As for the heat equation that occurs during the smelting process as follows [20]:

$$Q_2 = m.L \tag{2}$$

where Q2 is the heat during the melting of the material and there is still a transition material or starting to melt and L is the heat of fusion of the material used in the injection molding process. Furthermore, when the material is actually in a liquid phase until it is ready to be injected into the mold, the plastic material continuously receives heat Q3 with the same equation as the equation used to calculate the heat Q1 received by the plastic material when it is first heated until it starts to melt.

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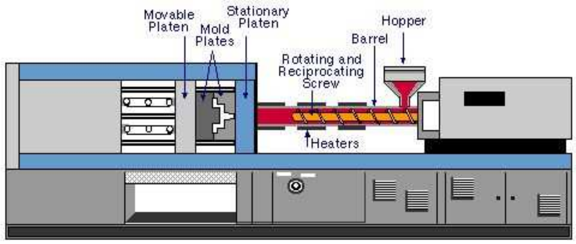


Fig. 2. Illustration of part heating process

III. Results and Discussion

A. Case study 1: heater malfunction

When the injection molding is operating, a low barrel temperature occurs that does not match the specified setting where there is an indication of the thermocontrol light flashing. The problems faced are usually in the form of damage to the heater, namely the temperature cannot reach the set up temperature for the injection process to the molding. Figure 3 shows the display of the heater condition that does not reach the temperature according to the setting point.

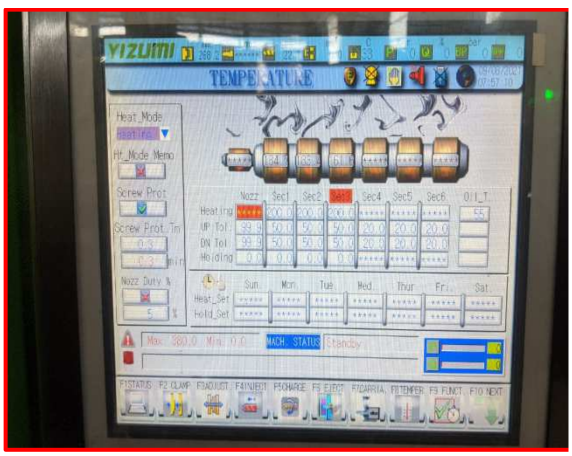


Fig. 3. YIZUMI UN160 SK Machine monitor display

For table 3 below, presents a comparison of the time and temperature when the heater is disturbed or damaged which is displayed in the display in Figure 3.

TABLE 3. CONDITION DAMAGE HEATER

Time (minute)	Temperature Display Machine (°C)		
	Sec 1	Sec 2	Sec 3
1’40’	45	52	50
3’30’	53	60	64
7’20’	65	74	70
12’10’	81	90	93
16’	115	124	120
19’50’	132	146	145
25’	161	183	184

From the data in Table 3 above, it was found that the heater on the injection molding machine was disturbed or damaged which resulted in the temperature heater not being able to meet the required heat needs and had been set according to the product or material to be made. So the graph of time and temperature in Figure 4 is obtained as follows:

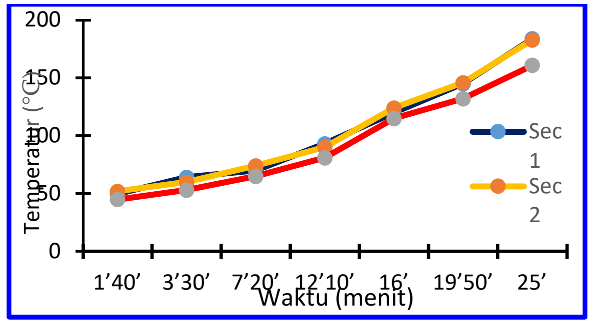
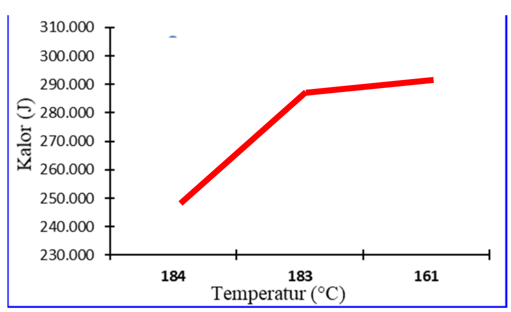


Fig. 4. Graph of Time and Temperature of the heater that was damaged

Figure 4 reveals that in section 1 the maximum preheating only reached 1610C for a duration of 25 minutes and there was no further temperature increase. However, when entering section 2, the material temperature can increase even though it still has not reached the desired temperature where the material does not melt completely there is still solid material. Furthermore, in section 3, the section which ensures the material is in a liquid state before being injected into the molding, has shown a temperature display that is no different from section 2 so that in Figure 4 you can see a graph line that coincides with section 2. Thus, section 3 is clogged and the nozzle is closed. material in the form of a mixture of liquid and solid. Meanwhile, the heat absorbed by the material from the heating process with a mass of 1 kg, room temperature 25°C and the specific heat of the material at 1920 J/kg°C are presented in Figure 5, where the ratio of heat and temperature can be seen in the following graph.



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ISSN 0216-8685 (print); 2528-6889 (online)

Fig. 5. Graph of absorbed heat

From the graph above, it can be seen that in sec 1 with a temperature of 161°C and the heat absorbed is 305,280 J, in sec 2 with a temperature of 183°C and the heat absorbed is 303,360 J, while in sec 3 with a temperature of 184° and the heat absorbed is equal to 261.120 J.

B. Case study 2: heater replacement

With case 1, the production process is disrupted, therefore it is necessary to repair or replace heater components in sec 1, sec 2, and sec 3. The comparison of time and temperature when the heater has been repaired or replaced is presented in Table 4.

TABLE 4. CONDITION HEATER REPLACEMENT

Waktu (menit)	Temperature Display Mesin (°C)		
	Sec 1	Sec 2	Sec 3
1'40'	45	46	50
3'30'	82	85	90
7'20'	114	117	120
12'10'	132	135	140
16'	158	160	175
19'50'	180	183	200
25'	210	219	230

From the data above, the heater temperature in the barrel has returned to normal according to the set up that has been set. This can be presented in a graph of the comparison of time with temperature in Figure 6.

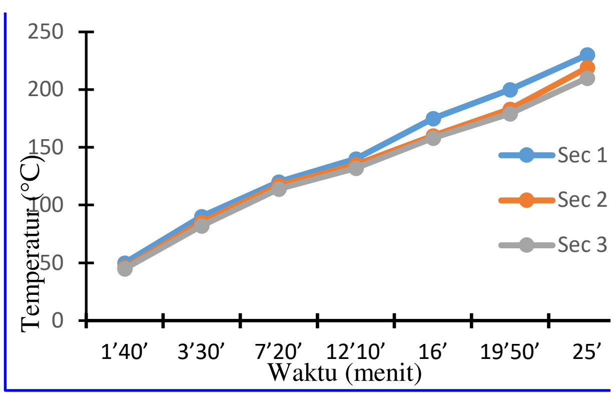

Fig. 6. Graph of Time and Temperature in sections 1, 2 and 3

After repairing and or replacing the heater, injection molding performance is monitored and it can be shown in Figure 6. Section 1 heats the plastic material in the form of solid granules to a temperature of 2100C for 25 minutes. The temperature in this section 1 is in accordance with the normal operating temperature. For section 2 provides further heating to the plastic material to change from the mixed phase until all solids melt with a temperature reaching 2190C within 25 minutes, while section 3 at the same minute reaches 2300C. The three sections have a stable temperature when operating after 25 minutes and the melted plastic can be injected perfectly into the mold. The heat absorbed by the material from the heating process with a material mass of 1 kg with a room temperature of 25°C and a specific heat of material of 1920 J/kg°C is presented in Figure 7 which presents a comparison of heat and temperature.

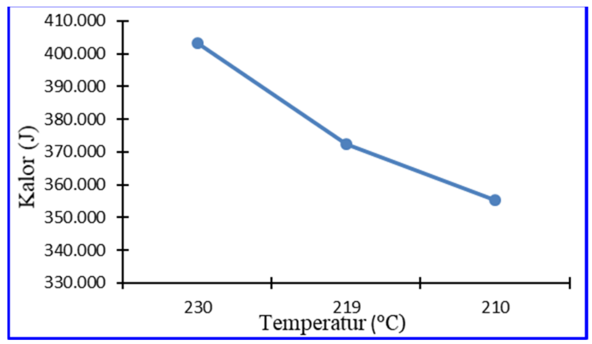

Fig. 7. Absorbed heat graph

From the graph above, it can be seen that in sec 1 with a temperature of 210°C the absorbed heat is 403,200 J, in sec 2 with a temperature of 219°C the absorbed heat is 372,480 J and in sec 3 with a temperature of 230° the absorbed heat is 355,200 J.

Heater power

Mass of barrel (m): 30 kg (assuming), Specific heat of iron matrial (C): 0.113 kg°C, Target heat achieved: 230 °C, Room temperature: 25 °C, Heating time (t): 0.416 hours (25 minutes), Efficiency (n): 0.1 – 0.5

$$Q = \frac{30\ x\ 0{,}113\ x(230-25)}{860\ x\ 0{,}416\ x\ 0{,}3} = 6476{,}7\ Watt$$

To make it easier to buy a heater, rounding is done, so the required heater power is 6500 watts. For the type of electric

heater, the band heater is selected because it can be adjusted to the shape of the heated barrel. To make it easier to purchase, 6 band heaters have been selected with a power of 500 Watts each on dies, 1000 Watts on barrels.

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ISSN 0216-8685 (print); 2528-6889 (online)

The heat received by the material

Specific heat of material (c) : 1920 J/kg°C, Heat of fusion of material (L) : 98000 J/kg°C, Target heat achieved : sec1 (230 °C), sec2 (219°C), sec3 (210 °C), Room temperature : 25 °C, Mass of material (m) : 1 kg (assumption)

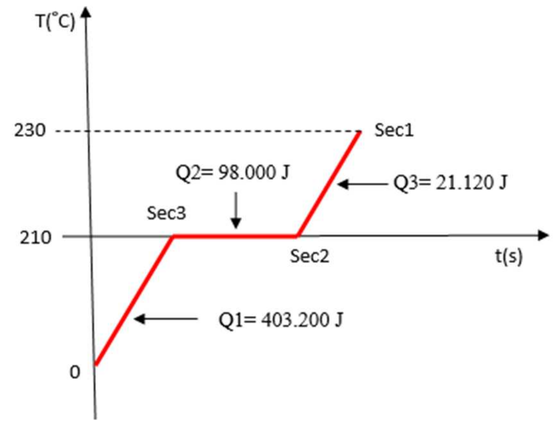

Fig. 8. Heat Transfer Chart

for $Q_1 = m.c.\Delta T$

$$= 1\ x\ 1920\ x\ (210 - 0) \qquad = 403.200\ J$$

for $Q_2 = m.L$

$$= 1\ x\ 98000\ = 98.000\ J$$

for $Q_3 = m.c.\Delta T$

$$= 1\ x\ 1920\ x\ (230 - 219) \qquad = 21.120\ J$$

From the graph above, it can be seen that the process of heating the material by increasing the temperature occurs in Q1, the heat received in Q1 is 403,200 J. Furthermore, the smelting process from solid to liquid in the Q2 process, the heat received in Q2 is 98,000 J. Then the temperature is increased again to ensuring the material is completely melted and keeping the material liquid so that it can be injected through the nozzle occurs in Q3, the heat received in Q3 is 21,120 J.

The time required to increase the temperature of the barrel

From the known data, the heat in the barrel is 2,767,500 J, so the length of time to raise the temperature of the barrel is: P=Q/t, where : P : Electric power (W), Q : Barrel Heat (J), t : temperature rise time(s) so:

$6500 = \left(\frac{2.767.500}{t}\right) = 425{,}7\ s$, for time analysis (±7.09 minutes)

Eficiency Production

- Before the heater is repaired

$$Eff\ Production = \frac{actual\ production}{production\ hour\ x\ 3600\ x\ cavity} xCT\ std\ x\ 100\%$$

$$Eff\ Production = \frac{800}{8\ hour\ x\ 3600\ x\ 1} x\ 30\ x\ 100\% = 83{,}3\ \%$$

- After the heater is repaired

$$Eff\ Production = \frac{actual\ production}{production\ time\ x\ 3600\ x\ cavity} xCT\ std\ x\ 100\%$$

$$Eff\ Production = \frac{1100}{8\ hour\ x\ 3600\ x\ 1} x\ 25\ x\ 100\% = 95{,}4\%$$

From the observations, data obtained before there was a heater repair with an actual production value of 800, cycle time 30, production hours of 8 hours and the number of cavity 1, production efficiency was 83.3% with a total NG of 45. After repairing the heater, the actual production value was 1100, cycle time 25, production hours 8 hours and the number of cavity 1, production efficiency is 95.4% and NG 7. This comparison can be seen in the following graph:

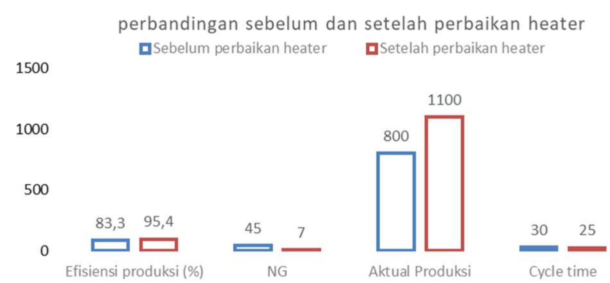

Fig. 9. Comparison chart before and after heater repair

The production process before repairing the heater did not run optimally because the heat for smelting the material was not optimal so that the material injected into the mold experienced defects or NG. for such NG products cannot be sold or used. After replacing the heater the production process becomes normal because the temperature for melting the material is reached. The material injected into the mold is maximized so that the NG product is reduced.

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ISSN 0216-8685 (print); 2528-6889 (online)

IV. CONCLUSION

A case study of heater damage in injection molding was detected in the damage indicator which showed that the operating temperature did not reach the desired heat, namely barrel section 1 of 1610C, section 2 of 1830C, and section 3 of 1840C. The consumption of heat energy absorbed by each heater in each barrel section is 305,280 J, 303,360 J, and 261,120 J. After repairing, the temperature achieved after being turned on for 25 minutes, section 1 is 2100C, section 2 is 2190C, and section 3 of 2300C with an electric power consumption of 403,200 J, sec 2 of 372,480 J and in sec 3 of 355,200 J.

Damage to the heater also affects production with a total of 800, cycle time of 30, duration of 8 hours and the number of cavity 1, with a production efficiency of 83.3% and the number of rejects as many as 45 units. After repairing the heater, the number of production is 1100, cycle time is 25, with a duration of 8 hours and the number of cavity is 1, with a production efficiency of 95.4% and rejects 7 units.

ACKNOWLEDGMENT

Authors can acknowledge people or organizations providing supports for the research.

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ISSN 0216-8685 (print); 2528-6889 (online)