DETERMINATION OF COOLANT OPTIMUM OPERATING TEMPERATURE IN INJECTION PRINTING PROCESS BASED ON PRODUCT PRECISION LEVEL

Olivia Laras Sati[1], Ambo Intang[1]*, Dendi Dwi Saputra[1]
[1] Department of Mechanical Engineering, Faculty of Engineering, Tamansiswa Palembang University
Tamansiswa Street No.261 Palembang, Indonesia
*Corresponding e-mail: ambo.intang@gmail.com

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ABSTRACT

Currently, plastic is more dominantly used because it is cheap, elastic and easy to process. To maintain the quality of plastic products, especially the type of Polyethylene Terephthalate (PET), the researchers implemented a modern plastic manufacturing system, namely using an injection molding system. In order to be able to meet the demands in solving problems that may arise in the process of making plastic products such as: quality, manufacturing time, and safety systems. The injection molding method replaces the old method, namely the hand press machine. This selection is based on advantages such as the consistency of the product produced because it is programmed, equipped with a control system, shorter product time, adequate security system, and other advantages. In this research, an experiment will be conducted to determine the optimum cooling temperature in the form of Pet Gallon. The problems that often occur are product defects due to shrinkage. In connection with this, the test results are obtained as follows: there is a difference in the shrinkage of product dimensions in the experiment using Cooled Chiller and Tower Chiller cooling, cooling has the greatest influence on the processing time of product manufacture, the optimum cooling temperature occurs at a cooling temperature of 20 ^{0}C.

***Keywords**: Injection Molding, Pet Gallon, Shrinkage*

1 INTRODUCTION

There have been many improvements in the efficiency of the plastic forming process, especially the results of printed products that are close to the results of precession products with minimal defects, uniform results in certain operating periods and maximum production quantities. Yoewono, S.& Kaswadi (2014) stated that the design of the mold cooling system is something that is important and continues to be developed in the plastic injection molding process. The emergence of product defects results in high production costs and inefficient operational levels because many products need to be recycled and the number of final products produced decreases (Zulianto dkk., 2015).

These defects have a major influence on the quality of the final product and cause delays in the production process. The process parameters that have the most influence on defects are injection pressure (Guerrier dkk., 2015)), barrel temperature and cooling time (Cahyadi, 2014; Han, J.H. and Kim, 2017).

There are certain parameters that must be determined and achieved first by relying on the main parts of the printing machine, namely the fixed variables of the product printing process. As for the determining factors that require technological reliability, the ability to determine the operating mechanism and the selection of parameters that cannot go through a trial and error process but must go through a precise testing process, this will have a major impact on achieving the level of precision of printed products.

The printed product referred to here is a printed product obtained through the plastic injection molding process. Injection molding is a method of forming thermoplastic materials, namely plastic seeds are melted by a heater and then pressed by an injector with a specified pressure flowing into a water-cooled mold so that it hardens (Permana, 2013). Just like printed products that are produced through processes other than this process, there is the potential for product defects to occur due to frequent product shrinkage, imperfect shapes, and product dimensions outside of those specified and so on.

This will make production costs inefficient, because many products are defective. The occurrence of this defect can actually be overcome by knowing the reliability of the printing machine, but the occurrence of product shrinkage will still not be resolved if the placement of the injection point and the use of the cooling system in the molding is not appropriate and the shrinkage causes variations in the thickness of the product from certain sides so it is called imprecise. Product defects can occur if it is not appropriate in determining the setting of the injection pressure process parameters, injection temperature and cooling time (Cahyadi, 2014).

The focus of the research is Polyethylene material, a material that is often used for products for food, beverages, household needs and other products. Polyethylene is a type of thermoplastic material, which is a material that can soften when heated and harden when cooled, and will soften again when heated again. Polyethylene is used in various applications, such as automotive components, laboratory equipment, and food also beverage containers. Polyethylene is commonly used in detergent bottles, milk bottles, and water pipes (Budiarto, 2002).

Injection molding is a process of forming plastic into the form of a mold (mold) by pressing liquid plastic into a room. The event from heating to injection of plastic material into the mold then cooled again. This is what requires the right temperature and time because with high cooling it causes a rapid cooling process so that shrinkage defects occur. If one of the injection process parameters is ignored, then the results of the mold object are not good, including shrinkage defects in the molded object (Santoso, 2014). However, if the cooling temperature is too low, it can cause the cooling process to take longer so that the cooling time increases and increases the production process time. If the longer the cooling system performance will decrease, it will affect the level of the engine's ability to reach air temperature and humidity (Hidayati dkk., 2021)

Cooling in the injection molding process greatly affects product shrinkage (Ramadhan dkk., 2017). (Budiyono, 2012) stated that in the evaporation process (heating), media is needed to cool the evaporated distillate. The cooling capacity is required for the inlet temperature of the evaporating cooler (in this study the injection engine) of 32 ^{0}C and the outlet temperature of the condenser 42 ^{0}C, to meet these requirements, a closed system cooling unit using a cooling tower is used. Based on the references of previous studies, in this study the researchers discussed the determination of temperature in precision-based molds of printed products which were carried out to evaluate the optimum operating temperature on printing machine test equipment that has a cooling system that has been recognized for its feasibility, namely Cooled Chiller and Tower Chiller cooling.

2. MATERIALS AND METHODS

In order to determine the optimum temperature of the cooling system, a discussion of the cooling system has been put forward, especially the cooling system which allows it to be made into a closed cooling system and has high controllability.

2.1 Tools and Materials

2.1.1 Tools

Supporting equipment used in this research include: water pump, water reservoir, hose, water cooled chiller, cooling tower, spanner, caliper, thermometer, and injection molding machine.

2.1.2 Materials

Plastic is a polymer that has extraordinary properties. Plastic materials used in the manufacture of plastic products include polypropylene, polyethylene, polystyrene, and others (Amri, 2009) on his study, Figure 1 show the plastic material used was Polyethylene Terephthalate (PET) produced by PT. Misubishi Chemical Indonesia, Indramayu, Central Java. Polyethylene has a low density, the molecule does not crystallize well but has many branches. Meanwhile, high-pressure polyethylene is less branched and straight-chained, its density is greater because it crystallizes well so it has high crystallinity. Because well-formed crystals have strong intermolecular forces, this material has high mechanical strength and high melting point.

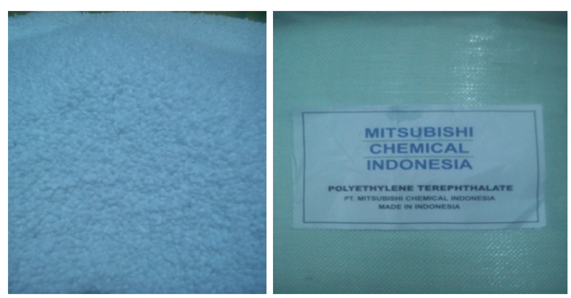


Figure 1. *Polyethylene Terephthalate Material Details*

2.2 Research Procedure

In this research on figure 2, an experiment will be conducted to determine the optimum cooling temperature to the level of precision in the plastic injection process. To make the experiment easier, it begins with several stages where these stages are believed to be the right steps in an effort to achieve the objectives of this study, namely in the form of Pet Gallons, including:

1. Preparation stage, starting from the preparation stage. The preparation stage with a literature study and field survey to determine the factors that cause shrinkage defects. The literature study used literature in the form of books and

journals, while the field survey was carried out by collecting data directly at PT. Palembang Victory Golden Triangle.

2. Determining the Melting Temperature, The melting temperature of the plastic injected into the mold is set at 280 ^{0}C (Devalia & Arief, 2019). This can be achieved by channeling cooling water from the cooling tower to the injection engine at 30 ^{0}C.
3. Determine the cooling water inlet temperature from the mold by 30; 25; 20; 15^{0}C by channeling from the Air Cooled Chiller. The determination of the cooling temperature was taken based on initial tests that had been carried out by looking at the cooling time and the level of precision visually which showed that at a temperature of 30^{0}C it takes a long cooling time but after being passed to a temperature of 15^{0}C the cooling time is too fast and the printed object is very irregular in shape. To obtain the figures for the shrinkage of the dimensions of the pet gallon product, a molding operation is carried out with variations of cooling in the mold as mentioned above with the following steps:
   a) Injection molding cooling 30^{0}C where after the molten plastic with a temperature of 28^{0}C is injected into the mold, it is cooled with water flowing through the cooling channel in the mold within a cooling period of 160 seconds.
   b) Injection molding cooling 25^{0}C where after the molten plastic with a temperature of 28^{0}C is injected into the mold, it is immediately cooled by flowing water into the cooling channel in the mold. With a cooling time of 130 seconds.
   c) Injection molding cooling 20^{0}C where after the molten plastic with a temperature of 28^{0}C is injected into the mold it is cooled with water flowing through the cooling channel in the mold. With a cooling time of 95 seconds.
   d) Injection molding cooling 15^{0}C where after the molten plastic with a temperature of 280^{0}C is injected into the mold, it is immediately cooled to flow water into the cooling channel in the mold. With a cooling time of 60 seconds.
4. Performing Shrinkage Analysis Product dimension shrinkage analysis is carried out by measuring the height and diameter of the three-dimensional Pet Gallon product. First, process the data obtained through calculations using the shrinkage formula, then compare it with the size of the mold, so that it can be concluded that the cooling temperature produces precision products with molds.

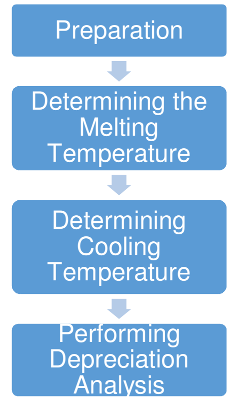


Figure 2. *Research Flow Chart PET Gallon*

2.3 Data and Data Processing

2.3.1 Shrinkage Depreciation Amount

Analysis of product shrinkage is taken from three axes, namely the X axis (product height) Y (outer diameter of the product), and Z (outer diameter of the product), the Y and Z axes are taken randomly. The X axis is taken from the line parallel to the injection direction, the Y axis is taken from the line perpendicular to the injection direction, and the Z axis is taken from the line perpendicular to the Y axis and perpendicular to the injection direction.

Measurements on the X and Y axes are taken from three outside diameter reference points, namely the top point (A), the middle point (B), and the bottom point (C). For the X-axis, what is measured is the height of the product. From all measurements of each point, only the average number is taken.

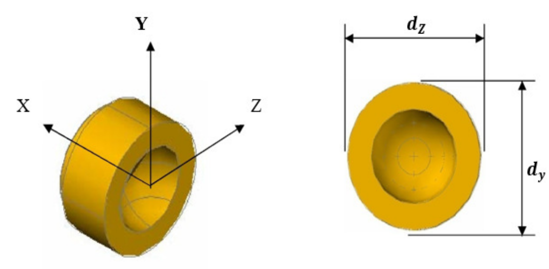
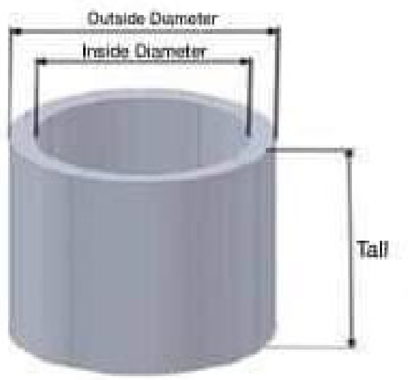


Figure 3. *Draw the Direction and Measurement Points of Shrinkage*



Cylinder Product Specification		
Product Dimension	Outside diameter	63 mm
	Inner Diameter	45 mm
	Height/length	435 mm
Material	*Polyethylene Terephthalate* (PET)	

Figure 4. *Cylinder Product Specifications*

Shrinkage size is directly determined based on equation 4:

$$S = \frac{(do-d)}{do} \quad (1)$$

so that the calculation of the shrinkage on the product height in the x (h_x) direction can be determined by the following equation:

$$S = \frac{\Delta h_x}{h_o} \text{ x } 100\ \% \quad (2)$$

Calculation of shrinkage on the outer diameter of the product in the y (d_y) direction:

$$S = \frac{\Delta d_y}{h_o} \text{ x } 100\ \% \quad (3)$$

Calculation of shrinkage on the outer diameter of the product in the z-axis (d_Z) direction:

$$S = \frac{\Delta d_z}{h_o} \text{ x } 100\ \% \quad (4)$$

The calculation of the shrinkage volume (v) and the average radius (r) on the hemispherical shape of the product is shown in the following equation:

$V_0 = \frac{22}{7} . r^2 .t$: Mold volume

$V = \frac{22}{7} r^2 .t$: Product volume (5)

Description:

S : Shrinkage (mm)
h_o : Mold height dimension
h_x : Product height dimension
r_o : Mold radius (mm)
r : Product radius (mm)
t_o : Mold height (mm)
t : Product height (mm)
Δr= ro-r : difference in radius (mm)
$\Delta V = V_o - V$: Volume difference (mm^3)

(Kwon K., 2006)

2.3.2 Test Result Data

2.3.2.1 Data of product manufacturing process time at each Temperature Cooler

Cooling temperature, is carried out by conducting direct tests with the following characteristics:

Material : Polyethylene *Terephthalate* (PET)
Mold Type : Cylinder
Print Volume : 1356547,5 (mm^3)
Heating Temperature : 270 – 280 (C^0)

The test results to determine the time required for the process of making Pet Gallon can be seen in the table below:

Table 1. Data on the Time of the Product Manufacturing Process at a Cooling Temperature of 30⁰C

Shrinkage Direction	T (C^0) Heating	Pressure (kg/ cm^2)	Time t(s) mold closure	Time t(s) injection	Time t(s) cooling	Time t(s) mold opening	T (^{0}C) average Product	T (^{0}C)average Outlet
x	280	20	15	20	110	15	43	36
y	280	20	15	20	110	15	43	36
z	280	20	15	20	110	15	43	36
r	280	20	15	20	110	15	43	36
v	280	20	15	20	110	15	43	36

Data source From EMPC-9600 Injection Molding menu

Table 2. Data on the Time of the Product Manufacturing Process at a Cooling Temperature of 25⁰C

Shrinkage Direction	T (C^0) Heating	Pressure (kg/ cm^2)	Time t(s) mold closure	Time t(s) injection	Time t(s) cooling	Time t(s) mold opening	T (^{0}C) average Product	T (^{0}C) average Outlet
x	280	20	15	20	92	15	39	32
y	280	20	15	20	92	15	39	32
z	280	20	15	20	92	15	39	32
r	280	20	15	20	92	15	39	32
v	280	20	15	20	92	15	39	32

Data source From EMPC-9600 Injection Molding menu

Table 3. Data on the Time of the Product Manufacturing Process at a Cooling Temperature of 20⁰C

Shrinkage Direction	T (C^o) Heating	Pressure (kg/ cm²)	Time t(s) mold closure	Time t(s) injection	Time t(s) cooling	Time t(s) mold opening	T (⁰C) average Product	T (⁰C) average Outlet
x	280	20	15	20	45	15	34	30
y	280	20	15	20	45	15	34	30
z	280	20	15	20	45	15	34	30
r	280	20	15	20	45	15	34	30
v	280	20	15	20	45	15	34	30

Data source From EMPC-9600 Injection Molding menu

Table 4. Data on the Time of the Product Manufacturing Process at a Cooling Temperature of 15⁰C

Shrinkage Direction	T (C^o) Heating	Pressure (kg/ cm²)	Time t(s) mold closure	Time t(s) injection	Time t(s) cooling	Time t(s) mold opening	T (⁰C) average Product	T (⁰C) average Outlet
x	280	20	15	20	18	15	31	27
y	280	20	15	20	18	15	31	27
z	280	20	15	20	18	15	31	27
r	280	20	15	20	18	15	31	27
v	280	20	15	20	18	15	31	27

Data source From EMPC-9600 Injection Molding menu

Based on table 1 to 4 of the EMPC-9600 Injection Moulding menu with the shrink age direction (x, y, z, r, and v) using a heating temperature of 280⁰C, pressure 20 kg/ cm², mold closing time 15s, ejection time 20s, and time opening moul 15s as follows:

a) Cooling temperature 30⁰C with cooling time of 110s, average product temperature 43⁰C, and average outlet temperature 36⁰C.
b) Cooling temperature 25⁰C with cooling time of 92s, average product temperature 39⁰C, and average outlet temperature 32⁰C.
c) Cooling temperature is 20⁰C with a cooling time of 45s, the average product temperature is 34⁰C, and the average outlet temperature is 30⁰C.
d) Cooling temperature is 15⁰C with a cooling time of 18s, the average product temperature is 31⁰C, and the average outlet temperature is 27⁰C.

2.3.2.2 Data *Shrinkage*

The dimensions of the Pet Gallon were obtained from the test, processed to produce real data from each direction of the review which were carried out five times each test and then compared with the standard size of the mold to get the amount of shrinkage in percentage of the actual size. In the tables shown below are the average shrinkage percentages for each direction of review at each cooling temperature show that on table 5 to 8.

Table 5. Shrinkage Data on Injection Molding Testing with Cooling Temperature 30⁰C

Shrinkage Direction	Cooling time t (s)	Dimensions Average (mm)		Average Dimension Difference (mm)	*Average Shrinkage (s) (%)*
		Mold	Product		
X	160	435	433,27	1,73	0.3977
Y	160	63	61,24	1,76	2,7936
Z	160	63	61,20	1,80	2,8571
R	160	31,5	30,60	0,90	2,8571
V	160	1356547,5	1277177,5	79370	5,4528

Table 6. Shrinkage Data on Injection Molding Testing with Cooling Temperature 25⁰C

Shrinkage Direction	Cooling time t (s)	Dimensions Average (mm)		Average Dimension Difference (mm)	*Average Shrinkage (s) (%)*
		Mold	Product		
X	142	435	433,70	1,30	0.2988
Y	142	63	61,72	1,28	2,0317
Z	142	63	61,73	1,27	2,0158
R	142	31,5	30,87	0,63	2,0000
V	142	1356547,5	1299257,5	57290	4,2232

Table 7. Shrinkage Data on Injection Molding Testing with Cooling Temperature 20^{0}C

Shrinkage Direction	Cooling time t (s)	Dimensions Average (mm)		Average Dimension Difference (mm)	*Average Shrinkage (s) (%)*
		Mold	Product		
x	95	435	434,12	0,88	0,2023
y	95	63	62,20	0,80	1,2698
z	95	63	62,26	0,74	1,1746
r	95	31,5	31,12	0,38	1,2063
v	95	1356547,5	1321338	35209,5	2,5955

Table 8. Shrinkage Data on Injection Molding Testing with Cooling Temperature 15^{0}C

Shrinkage Direction	Cooling time t (s)	Dimensions Average (mm)		Average Dimension Difference (mm)	*Average Shrinkage (s) (%)*
		Mold	Product		
x	68	435	432,85	2,15	0,4942
y	68	63	60,76	2,24	3,5555
z	68	63	60.67	2,33	3,6984
r	68	31,5	30,34	1,16	3,6825
v	68	1356547,5	1255097.25	101450,25	7,4785

3. RESULTS AND DISCUSSION

3.1 Research Results

From the results of experimental data and calculations carried out, an accurate data is obtained regarding the relationship between variations in cooling temperature to: Cooling Time, Product Temperature and Outlet Temperature (cooling water output temperature). This relationship can be seen in Figure 5 below.

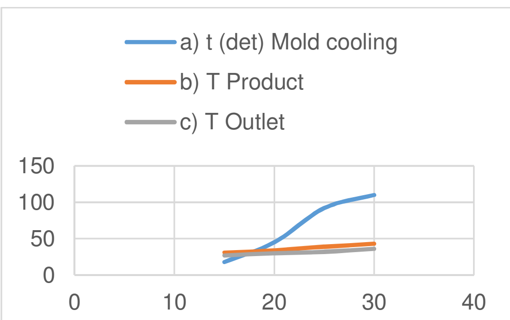


Figure 5. *Relationship between Cooling Temperature a). Mold Cooling Time b). Product Temperature and c).Outlet Temperature*

3.1.1 Relationship between Cooling Temperature and Cooling Time

In Figure 5a it can be seen that by lowering the cooling temperature, the cooling time required to complete a production process will be shorter. In this case, the injection molding process requires a cooling process to speed up the production process.

The rate of temperature drop will take place faster and may slow down. This happens because over time the cooling time the temperature difference to be achieved has begun to decrease (Asiah, 2020)

3.1.2 Relationship between Cooling Temperature and Product Temperature and Outlet Temperature

Figure 5b shows that by lowering the cooling temperature, the product temperature will also decrease and the same event can be seen in Figure 5c where the outlet temperature also decreases, but the product temperature is higher than the outlet temperature, this is because the cooling water occurs more heat transfer. Faster than it happens with the product.

Furthermore, from the five variables of the direction of shrinkage, it can be seen in Figure 6 that the shrinkage in the x direction or height is the smallest, the shrinkage in the y, z and r directions or the shrinkage in the radial direction of axial symmetry coincides and the price is almost the same but the shrinkage rate is greater than the shrinkage in the x direction. The largest depreciation rate occurs in volume shrinkage, this is because volume shrinkage is the accumulation of depreciation from all directions of the review.

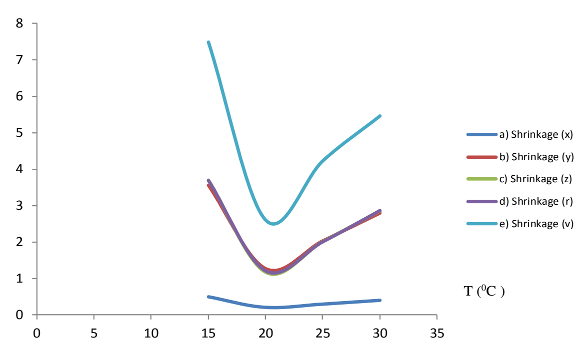


Figure 6. *The relationship between the average Shrinkage values (%) of products on several sides of the review with Changes in Cooling Temperature*

3.2 Discussion

Cooling has the greatest influence on the processing time of the product (Figure 5a) in plastic injection molding. Cooling also affects the shrinkage of the product and the shrinkage makes the product easy to remove from the mold cavity, so the faster the product cools, the faster it will remove the product from the mold cavity, meaning that the mold cavity can be opened quickly.

The combination of the two cooling effects finally shows that the most optimum cooling temperature is at a temperature of 20⁰C. At this temperature the cooling system (Cooled Chiller and Tower Chiller) will produce a more even distribution of the temperature gradient in the cavity so that the temperature in the mold changes according to the right temperature gradient and therefore the right cooling speed is obtained. The even distribution of this temperature gradient will make the mold more precise in cooling so that the shrinkage will be smaller at the cooling temperature of 20⁰C as shown in Figure 5. Another consideration that can be put forward here to strengthen this is to look at the product temperature and the outlet temperature of the cooling water (Outlet) both of which show a temperature level that is very close to the ambient temperature (figure 5b&5c), namely the average product temperature of 34⁰C and the average outlet temperature of 30⁰C.

The graph in Figure 5a shows that cooling time has the greatest influence on cycle time. The average cooling time in the cooling system using the Cooled Chiller and Tower Chiller and taking into account the smallest shrinkage or producing the most precise product at a temperature of 20⁰C is 45 seconds and the average cooling time in a cooling system with a temperature of 30⁰C is 110 seconds with the larger shrinkage rate is shown in Figure 5. The most contradictory thing is the data shown by cooling with temperatures below 20⁰C, namely 15⁰C, although the production time of the product is much faster (18 seconds) but the shrinkage rate actually exceeds the shrinkage at a Cooling temperature of 30⁰C.

The difference in product dimension shrinkage in the experiment using Cooled Chiller and Tower Chiller cooling at several temperature variations significantly occurs in the outer diameter of the product, while for the axial direction of the product shrinkage does not show a significant difference with the variation of the cooling system and this is evidenced in Figure 6.

4. CONCLUSION

Based on the previous explanation, that there are differences in product dimensions in experiments using Cooled Chiller and Tower Chiller cooling at several significant temperature variations in product diameter. Furthermore, it gives the greatest influence on the product manufacturing process in plastic injection molding, and the optimum cooling temperature that occurs at 20⁰C by considering the cooling speed and different levels, namely by looking at the operating time, product temperature, outlet temperature, and the level of product precision shown by its low level.

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