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Investigation of the Effect of Various Coolants on Cooling Time in Injection Moulding Process

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ABSTRACT

This paper presents the design of injection mould and study of cooling time with different coolants and compare the results with practical experiments. Clamping, injection, dwelling, cooling, mould opening, and ejection are the six major phases in injection moulding. The process parameters and cycle time are affected by each stage. Cooling is an essential stage in injection molding process that accounts for over 60% of the total cycle time. The objective of this study is to evaluate the effects of different coolants on cooling time, mould temperature, and part temperature. Additionally, the study aims to identify a suitable alternative to water that can be used as an effective coolant. The study was carried out on plastic component made of Polycarbonate Seven alternative coolants were selected in addition to water for this study. The simulation results showed that, among the selected coolants, Multitherm PG-1 delivered the best performance, achieving the shortest cooling time of 14.02 seconds. In contrast, Coolanol 45 recorded the longest cooling time of 15.95 seconds. To validate the simulation results, practical experiments were conducted using an injection moulding machine. Each coolant was tested by replacing the existing coolant, and the cooling time required for the component to be ejected was recorded. In addition, the temperatures of both the mould and the moulded part were measured. The experimental results closely matched the simulation findings. Multitherm PG-1 again demonstrated the best performance, with a cooling time of 14.09 seconds, while Coolanol 45 exhibited the longest cooling time of 15.60 seconds. These results indicate that Multitherm PG-1 is a promising alternative coolant to water for improving cooling efficiency in injection moulding applications.

Keywords- Injection molding, Mould Design, Mold Flow Analysis, Coolant, Cooling Time.

I. INTRODUCTION

Injection molding is the most versatile process for the manufacture of plastic products in volumes with different shapes and sizes. The most critical part in Injection molding process is design of injection mould. The surface quality, dimensional accuracy, and overall processing efficiency of a product largely depend on the mould design. Injection moulding is a manufacturing process in which plastic material is melted by heat, injected into a mould cavity, and then cooled and solidified to form the final product. The method is appropriate for the mass production of products with complex shapes, and takes a large part in the area of plastic processing. The design of an optimal cooling system and operation conditions of the cooling process are very crucial to the injection molding process.

There are number of parameters during the injection molding related to cooling. In injection moulding, the mould cooling time usually takes up to about 60-80% of the time of the entire cycle shown in Figure 1. A.Agazzi et al. [1] represent the methodology for the design of effective cooling System in injection molding. He suggest an optimization method to determine the temperature distribution on a cooling line to obtain a uniform temperature field in the part which leads to the smallest gradient and the minimal cooling time. Further work will consist in deciding a minimal number of channels needed to match the solution given by the optimal fluid temperature profile. Further D.E. Dimla et al. [2] in his study explain the Design and optimization of conformal cooling channels in Injection moulding tools. This technique led to significant improvements and a general reduction of the cycle time while ameliorating heat transfer.

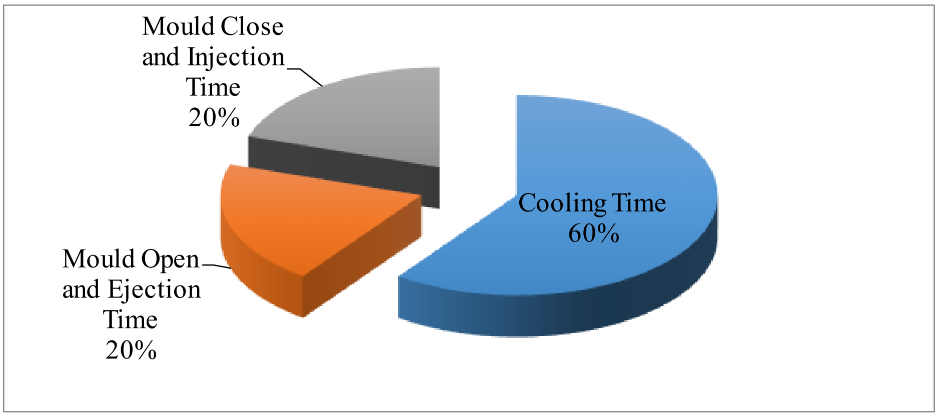

Fig 1:- Pie-chart of Cooling Time

David Homar, et al. [3] in his study Hybrid manufacturing of injection mould tool inserts with conformal cooling channels provides optimal finished products at optimal price. Eli Vandersluis. et al. [4] decreasing the initial mould preheating temperature resulted in an increase in primary solidification rate. However, the solidification rate did not noticeably affect the alloy liquidus, Al-Si eutectic, or solidus temperatures. Rahul vashisht, et al. [5] noticed that the coolanol 45 and oil proved out to be least effective coolant medium whereas pg-1 and ig- 2 proved to be most effective. This coolant performed better than water and also the problems seen with water as coolant medium is eliminated with this coolant. When the hot molten plastic enters the mould cavity, it cools and solidifies by transferring heat through the cooling system [6]. Rahim, Shayfull Zamree Abd, et al. [7] shows that conformal cooling channels reduced warpage in both the X and Y directions by approximately 14% to 54%, and improved cooling time by about 65% compared to conventional straight-drilled cooling channels.

Based on the literature review, four key factors are generally considered to reduce the cooling time in the injection molding process.

- The different material used for manufacturing of mould have different thermal conductivity. The metals with a greater thermal conductivity conduct heat faster and require a shorter cooling time.
- Number, position, and size of cooling channels: The design of cooling channels has a decisive effect on the overall cooling time. If the number of cooling channel are more will cool the mould in short time and the cooling effect better and the shorter the cooling time.
- Quality of coolant: Different coolants have different heat transfer coefficient, specific heat, density and viscosity, and thus, different heat transfer results.
- Coolant flow rate and temperature. The coolant flow rate must reach the turbulent flow to increase the heat transfer effect. Besides, the lower the coolant temperature, the shorter the cooling time.

In the present study, a polycarbonate component with the dimensions as shown in Figure 2 was selected for the cooling study. A cooling channel with a diameter of 5 mm was employed. The channel was positioned 15 mm from the component, extended 25 mm beyond the component, and maintained a centre-to-centre spacing of 15 mm between adjacent cooling channels.

The simulation was carried on the Mold-Flow software as shown in Figure 3. The cooling simulation was carried out using the following process parameters:

- Coolant flow rate: 20 L/min
- Coolant inlet temperature: 25°C
- Gate type: Pin gate
- Runner type: Rectangular runner

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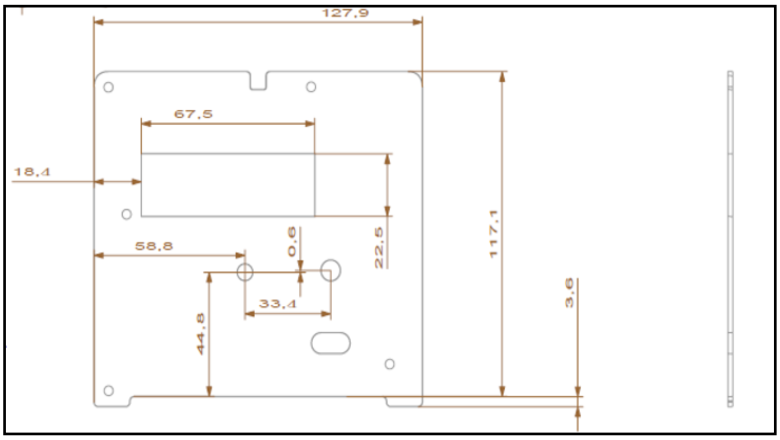

Fig.2 Component Drawing

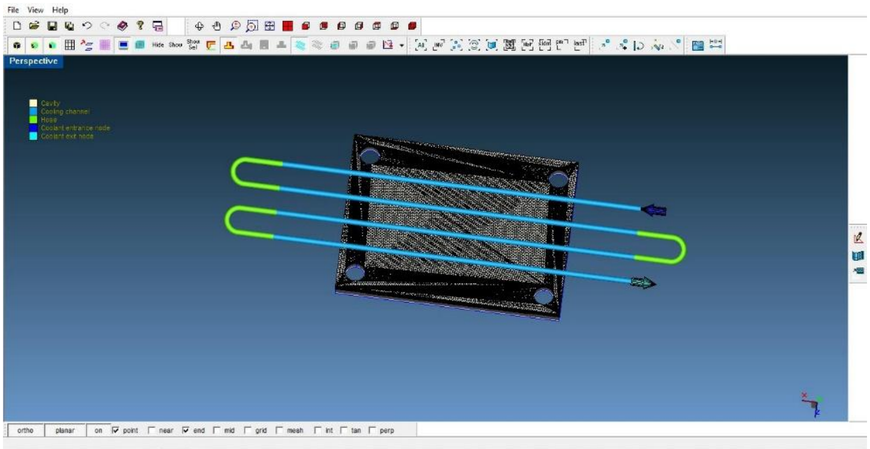

Fig.3 Mold-Flow simulation

The injection molding process comprises the injection, cooling and hardening of molten plastic components into a mould. The technology is well suited to the mass manufacture of complex-shaped goods, and it is widely used in the field of plastic processing. The moulding process relies heavily on the design of an optimal cooling system and the operation parameters of the cooling process. During the injection moulding process, there are a number of cooling parameters to consider. The mould cooling time in injection moulding is typically around 60%-80% of the total cycle time [8]. For mould cooling, water is commonly utilised. Water has the significant disadvantage of corroding metal. Clean water (H20) has a boiling point of 100 degrees Celsius, but because of the minerals in tap water (magnesium, calcium, and chlorine), it can only reach 85 degrees Celsius. These salts build up over time (the same whitish gunk we see at the bottom of kettles), clogging our mould cooling channels and putting a strain on the line and pump. This causes the cooling lines to fail, lowering the cooling efficiency. When water boils, it expands and releases gases that have been dissolved in it. The expansion of a gas due to heat is far greater than that of a liquid, and this expansion causes pressure to build up. It has the potential to destroy machine components. To avoid this, a coolant with a solution to the aforementioned problem is required.

II. EXPERIMENTAL DISCUSSION AND RESULTS

To simplify the complex nature of the cooling process, the following assumptions were made during the cooling stage of this research:

- Because the physical properties of mould materials do not change significantly as a result of temperature and pressure, they are treated as constants.
- The coolant and mould material are supposed to absorb all of the energy generated by the plastic materials.
- The cooling channel wall temperature is considered to be constant.
- It is believed that both the mould and the plastic material have their own consistent temperature throughout the first stage, and that the plastic substance contains no solid parts.

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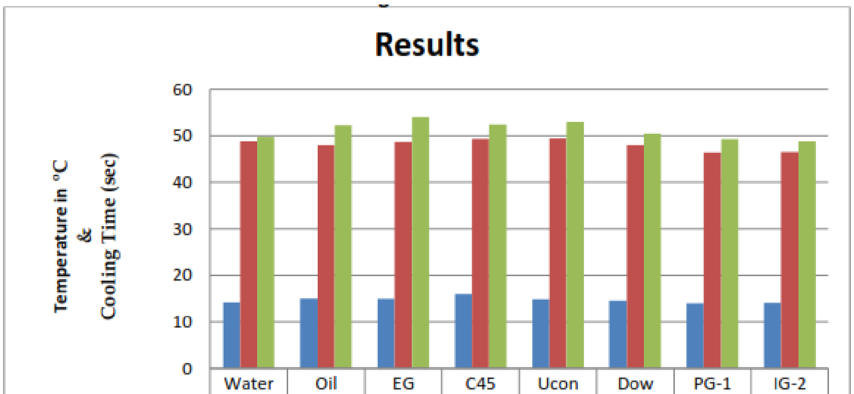
- Inside the mould cavity, the pressure is believed to be constant. As a result, the influence of boundary layer pressure reduction is neglected, during the solidification process, the volume of plastic material remains constant.
- Without accounting for boundary layer displacement, the solidification latent heat is estimated as part of the specific heat.
- Throughout the whole cooling phase, the plastic material is assumed to be in a static state. As a result, the flow-induced thermal effect is neglected.
- In this study, the heat influence of the crystallisation process is not taken into account.
- The cooling simulation does not take into account the feeding system; only the interaction with the cooling channel and component is taken into account.

Fluid cooled moulds are the primary source of cooling, with ethylene glycol and water as the most common used fluid mixture. The water provides the cooling as it flows through the mould taking heat out of the mould. The ethylene glycol prevents rust from forming inside the mould cooling piping and helps to keep the mould at a steady temperature during manufacturing use. Air cooled mould are not frequently used as they take a long time to reduce the heat in the injection mould via heat transfer dissipation to the surrounding air. If the surround environment for the injection molding machine and mould itself is kept cold, that can increase the amount of heat shed to the air. That may also require additional operating expense to cool that space. The study was conducted on a plastic component made of polycarbonate. In addition to water, seven alternative coolants were selected to evaluate their performance and compare their effectiveness in reducing the cooling time during the injection moulding process. The experimental trials were carried out as described below, and the corresponding comparison of the cooling times, mould and part temperature is presented in Figure 4.

- **Trial 1 Water:** Water when used as the coolant, the cooling time from simulation came out to be 14.19 sec. Moreover the mold temperature came out to be 46.86°C and part temperature came out as 50.74°C.
- **Trial 2 Oil:** Oil when used as the coolant, the cooling time from simulation came out to be 14.65 sec. Moreover the mold temperature came out to be 48.99°C and part temperature came out as 53.21°C.
- **Trial 3 Ethyl Glycol(Pure):** Pure ethyl glycol when used as the coolant, the cooling time from simulation came out to be 14.44 sec. Moreover the mold temperature came out to be 47.64°C and part temperature came out as 51.96°C.
- **Trial 4 Coolanol 45:Chevron** : Chevron when used as the coolant, the cooling time from simulation came out to be 15.60 sec. Moreover the mold temperature came out to be 48.32 °C and part temperature came out as 52.37°C.
- **Trial 5 Ucon Heat Transfer Fluid 500**: Union Carbide when used as the coolant, the cooling time from simulation came out to be 14.98 sec. Moreover the mold temperature came out to be 47.43°C and part temperature came out as 50.94°C.
- **Trial 6 Dowfrost HD**: Dow Chemical when used as the coolant, the cooling time from simulation came out to be 14.39 sec. Moreover the mold temperature came out to be 46.92°C and part temperature came out as 50.78°C.
- **Trial 7 PG-1**: When used as the coolant, the cooling time from simulation came out to be 14.09 sec. Moreover the mold temperature came out to be 46.21°C and part temperature came out as 49.27°C.
- **Trial 8 IG-2**: When used as the coolant, the cooling time from simulation came out to be 14.26 sec. Moreover the mold temperature came out to be 46.58°C and part temperature came out as 49.48°C.



	Water	Oil	EG	C45	Ucon	Dow	PG-1	IG-2
Cooling Time (sec)	14.21	15.01	14.96	15.95	14.86	14.57	14.02	14.11
Mould Temp (°C)	48.86	47.91	48.64	49.32	49.43	47.92	46.39	46.47
Part Temp (°C)	49.74	52.21	53.96	52.39	52.94	50.44	49.28	48.86

Fig.4 Comparison of CoolingTime, Mould and Part Temperature

It was observed that both the simulation and experimental results indicate that Multitherm PG-1 exhibits the lowest cooling time, while Coolanol 45 shows the highest cooling time among the eight tested coolants, as presented in Table 1.

Table 1: Theoretical and Experimental Results of Cooling Time

Trial	Coolant	Theoretical Cooling Time	Experimental Cooling Time
1	Water	14.21	14.19
2	Oil	15.01	14.65
3	Ethyl Glycol	14.96	14.44
4	Coolanol 45	15.95	**15.60**
5	Ucon Heat Transfer Fluid 500	14.86	14.98
6	Dowfrost HD	14.47	14.39
7	PG-1: Multitherm	14.02	**14.09**
8	IG-2: Multitherm	14.11	14.26

III. CONCLUSION

From this research, it is concluded that the choice of coolant significantly affects the overall cooling time in the injection moulding process. Although advanced coolants improve cooling performance, they also increase production cost. However, they can be effectively used to control and optimize the cooling stage in industry applications. Among all tested coolants, Multitherm PG-1 showed the fastest cooling time of 14.09 seconds. A maximum difference of 1.51 seconds was observed compared to other coolants, which is significant in mass production. Multitherm PG-1 also outperformed water, eliminating issues such as cooling channel blockage. In addition, it resulted in lower mould and part temperatures compared to water. The average temperature reductions were approximately 3.94°C for the mould and 2.78°C for the part. Overall, Coolanol 45 and oil showed the least effective performance, while Multitherm PG-1 and IG-2 were the most efficient coolants.

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