International Journal of Innovation and Industrial Revolution IJIREV
EISSN: 2637-0972
Volume 6 Issue 17 (June 2024) PP. 31-43
DOI 10.35631/IJIREV.617003

INTERNATIONAL JOURNAL OF INNOVATION AND INDUSTRIAL REVOLUTION (IJIREV)
www.ijirev.com

GLOBAL ACADEMIC EXCELLENCE

EFFECTS OF DIFFERENT COOLANT MEDIA ON THE COOLING PERFORMANCE OF INJECTION MOLD PRODUCT

Siti Izamaiera Mohd Azmi[1], Alias Mohd Saman[2*], Ramzyzan Ramly[3]

[1] School of Mechanical Engineering, College of Engineering, UiTM, Malaysia
Email: 2020896834@student.uitm.edu.my
[2] School of Mechanical Engineering, College of Engineering, UiTM, Malaysia
Email: aliasms@uitm.edu.my
[3] School of Mechanical Engineering, College of Engineering, UiTM, Malaysia
Email: ramzyzan@uitm.edu.my
[*] Corresponding Author

Article Info:

Article history:
Received date: 19.10.2023
Revised date: 09.11.2023
Accepted date: 15.05.2024
Published date: 12.06.2024

To cite this document:

Azmi, S. I. M., Saman, A. M., & Ramly, R. (2024). Effects Of Different Coolant Media On The Cooling Performance Of Injection Mold Product. *International Journal of Innovation and Industrial Revolution, 6* (17), 31-43.

DOI: 10.35631/ IJIREV.617003

Abstract:

The injection molding process involves heating a thermoplastic polymer above its melting point and injecting it into a mold. The polymer then cools and solidifies to form the final part. The process consists of four stages: clamping, injection, cooling, and ejection. Among these stages, cooling plays a crucial role as it requires an efficient cooling system to transfer heat from the mold at a consistent rate, ensuring high-quality final products. This project specifically focuses on investigating the impact of different cooling media used in the cooling system for the mold. The aim is to compare the effectiveness of various cooling media on the cooling performance of the injection-molded product. Different types of coolants, including water, oil, or other solution mixtures, have been considered for their ability to reduce or regulate the temperature of the system. CAD modeling was prepared for the case study, along with a pre-designed conformal cooling channel and gating system. After conducting the simulation analysis, water emerged as the most effective coolant, demonstrating superior results compared to other coolant options. The results also highlight the feasibility of using alternative coolants that offer comparable cooling performance.

Keywords:

Cooling Media; Cooling Performance; Cooling System; Injection Molding.

International Journal of Innovation and Industrial Revolution
IJIREV
EISSN: 2637-0972
Volume 6 Issue 17 (June 2024) PP. 31-43
DOI 10.35631/IJIREV.617003

Introduction

The injection molding process requires the use of an injection molding machine, raw plastic material, and a mold. The thermoplastic polymer is heated above its melting point in the injection molding machine, converting the solid polymer into a molten fluid with relatively low viscosity. It is then injected into the mold, where it cools and solidifies into the final part. Cooling constitutes the majority of the production cycle in injection molding. The cooling time during an injection molding process typically represents about two-thirds of the total cycle time (Ching & Chou, 2002). Reducing this time even slightly can significantly enhance production efficiency, allowing for the creation of more products in less time (Poischbeg, 2019). A well-designed cooling system can markedly reduce molding cycle time, boost injection production rates, and lower costs. This includes determining the type of cooling channel to be used and designing them according to factors such as size and pitch, depending on the type of mold material. Improper cooling system design can prolong cooling time, exacerbate warping deformation of plastic products, and result in variations in shrinkage rate and final product temperature (Wang & Cai, 2021).

A suitable cooling medium should be selected to ensure that a minimum cooling time is achieved. Therefore, various types of coolants that can be used to lower or control a system's temperature need to be considered, including water, oil, and other solution mixtures. Water cooling has the benefit of quickly removing a considerable amount of heat since water has a high heat capacity and promptly turns to steam when it enters the heater coils. Since most heat-transfer oils have less than half the heat capacity of water, they are less effective cooling mediums than water. More significantly, these cooling oils do not evaporate at processing temperatures, reducing instability and energy losses (Frankland, 2012).

In this study, CAD modelling and simulation analysis were employed to investigate systems and strategies, providing an alternative to using real systems, which can be time-consuming and costly. CATIA was utilized to design a 3D model of the product, and the gating system and selected cooling system were designed in Moldflow Adviser prior to running the simulation. During the simulation analysis, different coolant media were employed to analyze their effects on the cooling performance of the injection mold product. The cooling system played a vital role in achieving optimal process cycles for injection molding. By applying cooling mediums such as water, oils, and other solution mixtures, the cooling efficiency could be effectively improved. This study aimed to explore the cooling performance of various coolant media through simulation analysis, identifying which medium offered faster cooling rates, thus enabling shorter cycle times and increased production efficiency. The findings from this study contributed to process optimization and improved productivity.

Literature Review

Injection molding is a crucial process for manufacturing plastic parts, particularly for mass production, as it enables the transformation of raw materials into molded products in a single operation (Hassan, Regnier, Bot, & Defaye, 2009). The six main phases of injection molding—clamping, injection, dwelling, cooling, mold opening, and ejection—each influence the cycle time and process variables. The primary objective of injection molding is to produce parts that meet quality standards, typically characterized by mechanical performance, dimensional accuracy, and appearance (Fernandes, Pontes, Viana, & Gaspar-Cunha, 2016).

International Journal of Innovation and Industrial Revolution
EISSN: 2637-0972
Volume 6 Issue 17 (June 2024) PP. 31-43
DOI 10.35631/IJIREV.617003

Critical factors in plastic injection molding that significantly influence the overall product quality include attributes such as mold temperature, melt temperature, and injection pressure (Jaafar et al., 2020). Vashisht & Kapila (2014) found that cooling plays a pivotal role in the injection molding process, constituting nearly 60% of the total cycle time. Its significance extends beyond mere cycle time reduction; it also exerts a substantial influence on both productivity and the ultimate quality of the end product. The cooling system must possess the capability to efficiently dissipate heat at a rate sufficient for the plastic part to be ejected without incurring distortion (Hassan et al., 2009).

Moreover, research efforts have scrutinized the impacts of various coolant media on the cooling efficiency and product quality of injection molds. The influence of cooling temperature and injection time on product quality concerning the injection molding machine has been analyzed through the finite element method (Pratama, Aminnudin, Pradana, & Afifah, 2021). The researchers discerned that the coolant's temperature significantly affects product quality.

A conventional cooling channel, commonly known as a straight-drilled cooling channel (SDCC), is externally constructed in a linear fashion, featuring a significant coolant pathway within the mold itself (Venkatesh et al., 2017). In a study by Hisham and Saman (2022), diverse cooling channel designs for the mold were evaluated. The conformal cooling channel design emerged as the most favourable option in terms of ejection time, average part temperature, volumetric shrinkage, and deformation. Figure 1 illustrates the conformal cooling channel design.

Molds can now be easily designed using numerical and theoretical methods, thanks to advancements in computer technology. Computational analysis software can predict or directly simulate results, and with many such packaged software available in the market, simulating and testing various parameters and designs has become easier. All this software contributes to increased cost-effectiveness, efficiency, and product quality. Vashisht and Kapila (2014) evaluated various coolants used in conventional cooling channels and compared the results. Other researchers have used computer simulation software to achieve product quality in injection molding while considering variations in coolants to find optimal values, as demonstrated by Pratama et al. (2021).

In the plastic injection industry, water, oil, and ethylene glycol are commonly used as cooling fluids. Water is a frequent choice for mold cooling, but its primary drawback is its potential to induce metal corrosion (Vashisht & Kapila, 2014). As a solution, a combination of water and ethylene glycol is often considered one of the best fluid options. While water provides cooling throughout the mold, ethylene glycol simultaneously prevents corrosion within the cooling channels.

International Journal of Innovation and Industrial Revolution
EISSN: 2637-0972
IJIREV
Volume 6 Issue 17 (June 2024) PP. 31-43
DOI 10.35631/IJIREV.617003

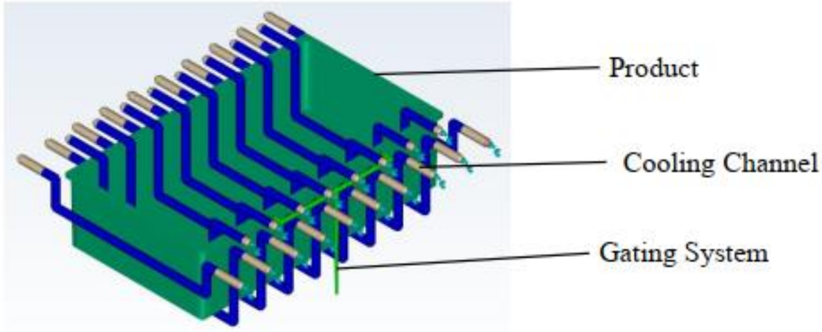

Figure 1: Conformal Cooling Channel Design

Computerized simulation has become indispensable for evaluating cooling channel performance (Nguyen et al. 2023; Kanbur et al. 2022). This tool enables researchers to analyze and demonstrate the benefits of cooling channel systems. In the field of injection mold simulation, abundant literature, and research focus on cooling channels, utilizing various commercial software solutions, including Moldex3D, Moldflow, and Solidworks (Simiyu, Mutua, Muiruri & Ikua, 2023; Wang & Lee,2023; Kuo, Tasi, Hunag & Tseng, 2023)

Methodology

In this study, several coolant media have been identified and selected to be tested in order to find the best coolant for the injection molding process. Two types of software will be used to prepare the 3D model of the product using CATIA, and simulation analysis work will be conducted using Moldflow Adviser software. In this simulation, the gating system and the cooling channels have been added. The properties of coolants, such as density (g/cm3), specific heat (J/kg°C), and thermal conductivity (W/m°C), have also been defined to assess the cooling performance. Data will be collected to compare the effectiveness of different cooling media for the selected case study.

Case Study and Modelling

In this project, computer software was used to create detailed 3D models of physical objects. The selected case study is a plastic tray. The model of the plastic tray is shown in Figure 2. Table 1 presents the material, dimensions, and properties of the product designed in CATIA. The product design takes into consideration injection molding design specifications such as thickness, radii, draft angle, and shrinkage allowance.

ABS is a commonly used thermoplastic material. It is amorphous, meaning it lacks a true melting point, but it exhibits a glass transition temperature around 105°C (Parmar & Sharma, 2017). ABS is valued for its excellent impact resistance and toughness, which are key mechanical properties. Compared to other thermoplastics, ABS has relatively good heat resistance, allowing it to withstand moderate temperatures without significant deformation or degradation

International Journal of Innovation and Industrial Revolution
EISSN: 2637-0972
Volume 6 Issue 17 (June 2024) PP. 31-43
DOI 10.35631/IJIREV.617003

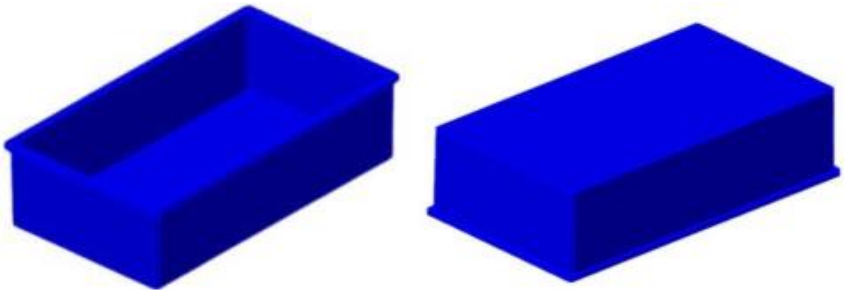

Figure 2: 3D Model of the Product

Table 1: Properties of the Product and Their Descriptions

Properties	Description
Material	Acrylonitrile Butadiene Styrene (ABS)
Overall Size	350mm x 200mm x 90mm
Wall Thickness	5mm
Radius	3mm
Draft Angle	1° draft angle per side
Shrinkage	0.9%
Melt Temperature	230℃
Mold Temperature	60℃

Design of Cooling Channel

The gating system and cooling channel were designed using Moldflow Adviser, based on the product dimensions and the chosen material. The selected cooling channel for this study is a parallel conformal cooling channel with additive cooling lines. The diameter of the cooling channel used is 10mm with a channel distance (pitch) of 40mm, and the depth of the cooling channel is 10mm. Coolant parameters for the cooling simulation were specified, such as a flow rate of 20 liters per minute and a coolant inlet temperature of 25℃.

The sprue gate is the chosen gating system, with two injection points strategically positioned on the product's side to minimize the visibility of resulting blemishes. The gating system and the cooling channel placement are as shown in Figure 1.

Coolants and Its Properties

Table 2 displays various coolants and their properties used in the simulation process, which directly impacts cooling performance. Eight different coolants are introduced into the cooling inlets, each undergoing a series of trials.

To facilitate the simulation, a suitable cooling channel is designed for the product. The simulation encompasses a range of selected coolants, including pure water, oil, pure ethylene glycol, a mixture of 10% ethylene glycol and 90% water, a mixture of 50% ethylene glycol and 50% water, Chevron Coolanol 25, a mixture of 25% Drowfrost fluid and 75% glycol, and a mixture of 50% Drowfrost fluid and 50% glycol. Subsequently, the results will be compared based on various aspects of the product's cooling performance, such as cooling time, ejection time, part temperature, and cooling quality.

International Journal of Innovation and Industrial Revolution
EISSN: 2637-0972
IJIREV
Volume 6 Issue 17 (June 2024) PP. 31-43
DOI 10.35631/IJIREV.617003

Traditionally, ethylene glycol has been the preferred choice for cooling in plastic injection molding, offering both efficient cooling and freeze protection. Its exceptional heat transfer properties enable it to endure lower temperatures without freezing, rendering it suitable for cold weather conditions. Chevron Coolanol, developed by Chevron Lubricants, is a branded engine coolant explicitly engineered to provide efficient cooling and heat transfer in diverse cooling systems. It is available in a pre-diluted, ready-to-use form as both a coolant and antifreeze. This coolant was selected for the simulation to evaluate its effectiveness in plastic injection molding.

Drowfrost fluid is a heat transfer fluid based on propylene glycol, commonly employed in industrial applications. It offers excellent freeze protection, operating effectively below -60ºF and providing burst protection below -100ºF. The fluid contains specialized corrosion inhibitors, which prevent HVAC pipes from corroding without causing fouling.

No	Coolant	Coolant Density (g/cm3)	Specific Heat (J/kg°C)	Thermal Conductivity (W/m°C)
1	Oil	0.836	2250	0.136
2	Water (Pure)	0.988	4180	0.643
3	Ethylene Glycol 10% + Water 90%	1.011	4060	0.576
4	Ethylene Glycol 50% + Water 50%	1.064	3336	0.413
5	Chevron Coolanol 25	0.875	2008	0.128
6	Drowfrost Fluid 25% + Glycol 75%	1.034	3131	0.274
7	Drowfrost Fluid 50% + Glycol 50%	1.026	3629	0.368
8	Ethylene Glycol (Pure)	1.117	2382	0.249

Table 2: Different Coolant with their Properties

Results and Discussion

The simulation of the injection moulding process with cooling channels was conducted using eight different types of coolant. In this simulation, four variants of cooling performance were assessed, including cooling quality, cooling time variance, part temperature, and the time it takes to reach ejection temperature.

The cooling quality result is the percentage of the quality product in the cooling process which the cooling has been distributed uniformly to the molded part. The result shows where heat tends to stay in a part because of existing cooling circuits, part shape and thickness. The cooling time variance in injection molding pertains to the distinction between the time required for polymer solidification in a specific section of the part and the average solidification time across the entire part.

On the other hand, the part temperature results relate to the forecasted temperature distribution within the molded component during its cooling and solidification phase. This result displays the mean temperature at the boundary of the part, situated on the part's side of the part/mold interface, throughout the entire molding cycle. Additionally, the time it takes to reach the

International Journal of Innovation and Industrial Revolution
IJIREV
EISSN: 2637-0972
Volume 6 Issue 17 (June 2024) PP. 31-43
DOI 10.35631/IJIREV.617003
ejection temperature signifies the elapsed time from the beginning of the filling phase to reach the temperature necessary for ejection. This interval ensures that the part has undergone sufficient cooling and stabilization to preserve its form and quality during the ejection process. Figure 3 displays four different outcomes assessing the performance of water as a coolant. The cooling quality results are visually represented, showcasing a part with distinct regions in green, yellow, and red. The green sections signify efficient cooling, while the yellow areas represent moderate cooling, and the red portions indicate inadequate cooling. The graphical representation highlights that most of the part receives effective cooling. However, there are regions along the inner right and left walls where cooling appears less effective, likely due to an improper arrangement of the cooling channel system in those areas.

The outcome from the cooling time variance analysis reveals that four vertical edges of the part take a longer time to solidify. These specific areas are displayed in shades of red and yellow, in contrast to the predominantly blue regions on the part. This discrepancy may be attributed to the increased thickness in these regions and the influence of the cooling channel on the cooling process. Examining the part temperature results, it becomes evident that there are specific hot spot locations on the part. These hot spots are indicated by the red coloration and are notably concentrated at the four internal edges of the part. When assessing the time required to reach ejection temperature, we observe uniform freezing of the part overall. However, it is worth noting that the left and right-side walls exhibit a slightly longer cooling time.

Table 3 provides a summary of the cooling performance of eight different coolant types, showcasing the highest value achieved for each specific coolant performance parameter. This format facilitates a straightforward comparison between the coolant options.

International Journal of Innovation and Industrial Revolution
IJIREV
EISSN: 2637-0972
Volume 6 Issue 17 (June 2024) PP. 31-43
DOI 10.35631/IJIREV.617003

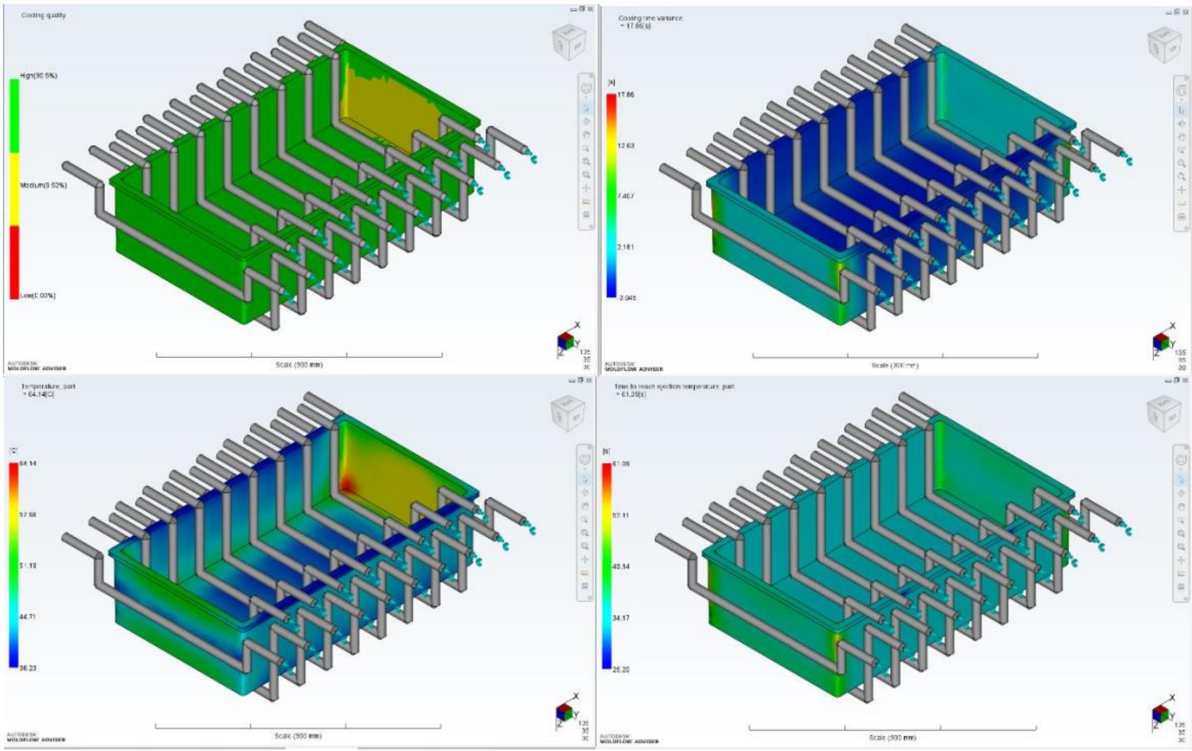

Figure 3: Cooling Performance Results (Water)
(a) Cooling Quality (b) Cooling Time Variance (c) Part Temperature
(d) Time to reach Ejection Temperature

Table 3: Different Coolant with their Cooling Performance

No	Coolant	Ref.	Cooling Quality (%)	Cooling Time (s)	Part Temperature (℃)	Time to Reach Ejection Temperature (s)
1	Oil	Oil	90.1	18.0	61.7	65.8
2	Water (Pure)	Water	90.5	17.9	61.1	64.1
3	Ethylene Glycol 10% + Water 90%	Glycol 10%	90.4	17.9	61.3	64.5
4	Ethylene Glycol 50% + Water 50%	Glycol 50%	89.9	18.5	62.7	67.4
5	Chevron Coolanol 25	Chevron 25	88.4	21.0	69.5	78.1
6	Drowfrost Fluid 25% + Glycol 75%	DF25-Glycol75	87.9	21.8	71.8	81.0
7	Drowfrost Fluid 50% + Glycol 50%	DF25-Glycol 75	89.6	18.9	63.9	69.5
8	Ethylene Glycol (Pure)	Glycol	82.0	88.7	190.0	106.4

Figure 4 displays the cooling quality results for various coolant media. Water exhibits the highest cooling quality percentage at 90.5%, followed closely by a mixture of Ethylene Glycol 10% + Water 90%, which only differs by 0.1%. A higher percentage in cooling quality signifies that the molded part achieves excellent cooling distribution, ensuring that the final product is

International Journal of Innovation and Industrial Revolution
EISSN: 2637-0972
Volume 6 Issue 17 (June 2024) PP. 31-43
DOI 10.35631/IJIREV.617003
formed perfectly and meets the required specifications. In contrast, pure ethylene glycol has the lowest cooling quality percentage at 82%. This lower percentage implies that the molded part requires a longer time to complete the injection molding cycle, potentially leading to issues such as warpage and product deformities.

Figure 5 illustrates a comparative graph that examines the variance in cooling times and the time required to reach ejection temperature for eight different coolant types. The results indicate that pure water and a mixture comprising 10% ethylene glycol and 90% water offer the most efficient cooling, resulting in relatively shorter cooling durations. Among these coolant options, the top performers are pure water and the 10% Ethylene Glycol + 90% Water mixture, both demonstrating a commendable cooling time of 17.9 seconds. Furthermore, both pure water and the Ethylene Glycol 10% + Water 90% mixture exhibit minimal differences in the time required to reach ejection temperature, underlining their effectiveness in cooling.

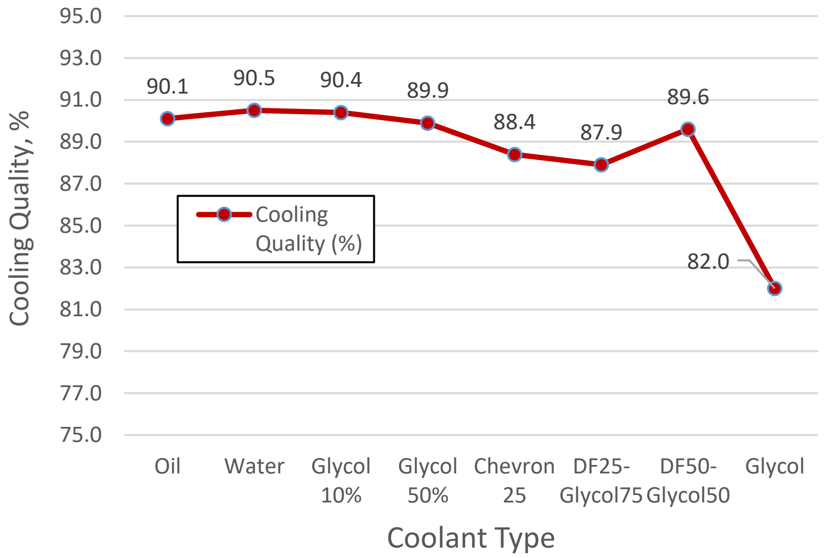

Figure 4: Cooling Quality for Varies Coolant Media

International Journal of Innovation and Industrial Revolution
EISSN: 2637-0972
IJIREV
Volume 6 Issue 17 (June 2024) PP. 31-43
DOI 10.35631/IJIREV.617003

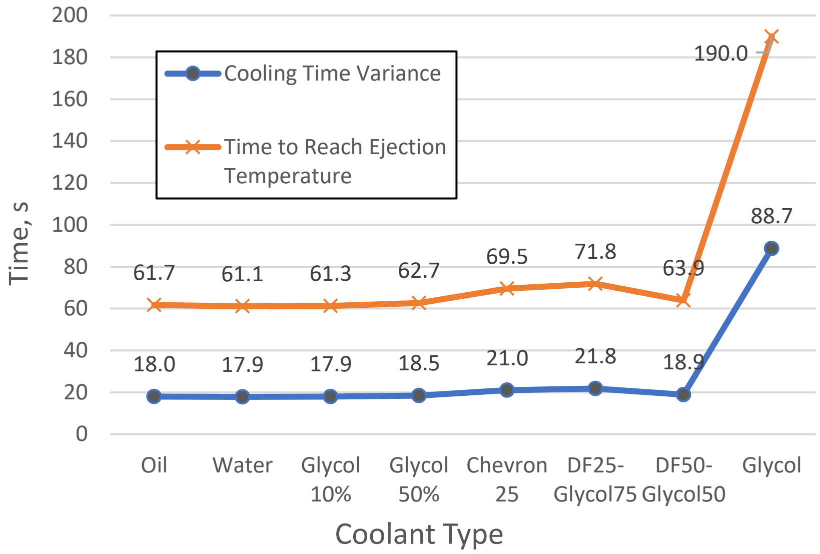

Figure 5: Cooling Time Variance and Time to Reach Ejection Temperature for Varies Coolant Media

Figure 6 presents a comparative graph of part temperatures for eight distinct coolants. Among them, the pure ethylene glycol coolant demonstrates the poorest cooling performance as it exhibits the highest part temperature in comparison to the other tested coolants. Notably, both the chevron coolanol 25 coolant and the Drowfrost Fluid 25% + Glycol 75% coolant show elevated part temperatures when contrasted with water-based coolants. Meanwhile, the Drowfrost Fluid 50% + Glycol 50 mixture displays respectable cooling performance, as depicted in Figure 6, but still registers slightly higher part temperatures than the water-based alternatives.

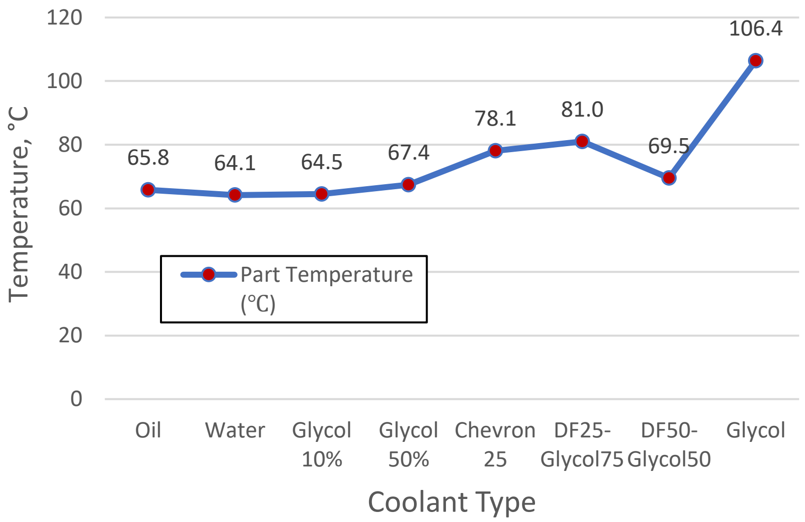

Figure 6: Part Temperature for Varies Coolant Media

International Journal of Innovation and Industrial Revolution
EISSN: 2637-0972
IJIREV
Volume 6 Issue 17 (June 2024) PP. 31-43
DOI 10.35631/IJIREV.617003

The cooling performance of a coolant is determined by its properties, as indicated in Table 2. Through simulation analysis, water has been identified as the optimal coolant due to its highest thermal conductivity. This high thermal conductivity is crucial for efficient heat absorption and transfer from the mold. In addition to the mentioned coolant properties, other criteria that require emphasis include temperature control. Maintaining precise temperature control for the coolant medium is of utmost importance. This ensures consistent cooling and prevents issues such as warping or uneven shrinkage in the molded part.

Additionally, the flow rate of the coolant medium through the cooling channels in the mold also affects heat transfer efficiency. Sufficient flow rate allows the coolant to effectively carry away heat, preventing hot spots and promoting uniform cooling. In order to achieve the best cooling performance, the coolant medium should possess a high heat capacity. This allows it to absorb and store a significant amount of heat without experiencing drastic temperature fluctuations. This property enables the coolant to maintain a stable temperature and sustain the cooling process.

Compatibility with the materials being molded is another important consideration. The coolant medium should not chemically react with the materials or cause any degradation or contamination of the molded parts. Lastly, adherence to environmental regulations and guidelines, particularly regarding disposal or recycling, is crucial for the chosen coolant medium.

In summary, to optimize cooling performance in plastic injection molding, the ideal coolant should possess high thermal conductivity, the ability to maintain a controlled temperature, sufficient flow rate, high heat capacity, compatibility with materials, and compliance with environmental regulations.

Conclusion

In conclusion, this study successfully accomplished its main objective, which was to investigate the cooling efficiency of different coolant media. Water emerged as the most effective coolant, demonstrating superior results compared to other coolant options. The results also highlight the feasibility of using alternative coolants that offer comparable cooling performance. Furthermore, this research highlights the potential for an alternative coolant to be employed, provided it offers equivalent cooling performance to that of water. The study illustrates the feasibility of using an alternate coolant that can provide a comparable level of cooling performance to water. For instance, a mixture of water and 10% ethylene glycol yields nearly identical performance while offering corrosion resistance characteristics.

Thus, this study contributes to the understanding of how coolant media affect cooling performance in injection moulding. The result offers practical insights for manufacturers to optimize cooling processes, thereby enhancing product quality, efficiency, and cost-effectiveness. By identifying cost-saving measures through the adoption of alternative coolants, it contributes to economic growth within the manufacturing sector. In the future, research should explore alternative coolants' durability, environmental impact, and interaction with materials, alongside exploring innovative cooling strategies. Collaboration between academia and industry is vital for progress.

Acknowledgements
The authors would like to express their sincere gratitude to Universiti Teknologi MARA (UiTM) for funding the publication of this project.

References

Ching, Z. L., & Chou, M. H. (2002). *Design of the cooling channels in nonrectangular plastic flat injection mold*. Journal of Manufacturing Systems, 21(3), 167–186. https://doi.org/10.1016/S0278-6125(02)80160-1

Fernandes, C., Pontes, A. J., Viana, J. C., & Gaspar-Cunha, A. (2016). *Modeling and optimization of the injection molding process: A review*. Advances in Polymer Technology, 37(2), 429–449.

Frankland, J. (2012). *Water, oil, air, or none?* Plastic Technology. Gardner Business Media, Inc.

Hassan, H., Regnier, N., Bot, C. L., & Defaye, G. (2009). *3D study of cooling system effect on the heat transfer during polymer injection molding.* International Journal of Thermal Sciences, 49(1), 161–169.

Hisham, M., & Saman, A. M. (2022). *Evaluation of cooling channels design for plastic injection mold*. In Enabling Industry 4.0 through Advances in Manufacturing and Materials. Lecture Notes in Mechanical Engineering. Springer, Singapore.

Jaafar, R., Arep, H., Mohamad, E., Abd Razak, J., Arfauz A Rahman, M., & Yuniarti, R. (2020). *Analysis on volumetric shrinkage of plastic food container made from an injection molding process*. Journal of Engineering and Management in Industrial System, 8(2), 22–31. https://doi.org/10.21776/ub.jemis.2020.008.02.3

Kanbur, B. B., Zhou, Y., Shen, S., Wong, K. H., Chen, C., Shocket, A., & Duan, F. (2022). *Metal additive manufacturing of conformal cooling channels in plastic injection molds with high number of design variables*. Materials Today Proceedings, 70, 541–547.

Kuo, C.-C., Tasi, Q.-Z., Hunag, S.-H., & Tseng, S.-F. (2023). *Development of an injection mold with high energy efficiency of vulcanization for liquid silicone rubber injection molding of the fisheye optical lens*. Polymers, 15, 2869.

Nguyen, V.-T., Minh, P. S., Uyen, T. M. T., Do, T. T., Ha, N. C., & Nguyen, V. T. T. (2023). *Conformal cooling channel design for improving temperature distribution on the cavity surface in the injection molding process*. Polymers, 15, 2793.

Parmar, K., & Sharma, M. (2017). *Preparation and characterization of ternary blend polystyrene, acrylonitrile butadiene styrene and CaCO3*. International Journal of Advance Research and Innovative Ideas in Education (IJARIIE), 3(2).

Poischbeg, M. (2019). *Choosing the right cooling method is the key to cycle time reduction*. SEA-LECT Plastics / Plastic Injection Molding. Retrieved from https://sealectplastics.com

Pratama, R. A. A., Aminnudin, Pradana, Y. R. A., & Afifah, N. (2021). *Analysis of coolant temperature and injection time effect on the product quality in injection moulding using the Finite Element Method (FEM)*. IOP Conference Series: Materials Science and Engineering, 1034(1), 012097.

Simiyu, L. W., Mutua, J. M., Muiruri, P. I., & Ikua, B. W. (2023). *Optimization of polygonal cross-sectioned conformal cooling channels in injection molding*. International Journal of Interactive Design and Manufacturing, 1–17.

Vashisht, R., & Kapila, A. (2014). *A comparative study of coolants based on the cooling time of injection molding.* International Journal of Emerging Technology and Advanced Engineering, 4(6), 830–834.

International Journal of Innovation and Industrial Revolution
EISSN: 2637-0972
IJIREV
Volume 6 Issue 17 (June 2024) PP. 31-43
DOI 10.35631/IJIREV.617003
Venkatesh, G., Ravi Kumar, Y., & Raghavendra, G. (2017). *Comparison of straight line to conformal cooling channel in injection molding.* Materials Today: Proceedings, 4(2), 1167–1173. https://doi.org/10.1016/j.matpr.2017.01.133

Wang, B., & Cai, A. (2021). *Influence of mold design and injection parameters on warpage deformation of thin-walled plastic parts*. Polimery, 66, 283–292.

Wang, Y., & Lee, C. (2023). *Design and optimization of conformal cooling channels for increasing cooling efficiency in injection molding*. Applied Sciences, 13, 7437.