LAB University of Applied Sciences

Design Principles of a-three-plate cold runner mold

LAB University of Applied Sciences, campus in Lappeenranta

Faculty of Mechanical Engineering

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ABSTRACT

Principle and design of a-three-plate cold runner mold, 47 pages.

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Due to the high consumption by humans for plastic hangers, the study on equipment and process, especially the injection molding machine, to manufacture these products has been attracting the researcher’s attention. To enhance the performance of the machine, some parts of the injection molding should be scrutinized. Generally speaking, the mold of plastic molding plays a crucial role in the process, which can be designed as a hot plate and cold plate. Besides, plastic hangers are produced from Polypropylene – one of the most common polymers in the world. Therefore, the thesis aims to size the three-plate cold runner molding machine to serve the production of the plastic hanger.

To design the practical runner, the theory-based knowledge must be clarified. Therefore, the prioritized aim of the thesis is to calculate the research of theory, especially the theoretical parameters of the runner based on the fundamental background of heat transfer and mass transfer. Thanks to the calculated criteria, the foundation on the parameters of the runner can be achieved and modified to attain the practical model for plastic hanger production.

The calculation and selection of components are implemented thanks to the available data and stock from DME, a Canada-based company who specializes producing details for mold application, based on mathematic methodology. Solidwork is utilized to demonstrate the technical drawing of the machine

Keywords: Cold runner, three plate, design, hangers, Solidworks.

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TERMS AND ABBREVIATION

Bottom plate - It’s the plate used as a support for the mold cavity block, guide pins, bushings, etc.

Cativy is the space inside a mold into which material is injected.

Core pins are used in the plastic molding and die casting dies. They are a fixed component used to create a hold that provides the desired shape in a casting

Core plate The core plate penetrates the cavity position and creates hollow sections in the plastic composition

Ejector pins are pins that are assembled into a mold cavity from the rear as the mold opens to remove the finished part out of the mold.

Ejector plate is a metal plate used to operate ejector pins

Flexural Modulus (FM) depicts the tendency of the material to resist bending

Glass transition is when an amorphous polymer is heated, the temperature at which it changes from a glass to the rubbery form

Impact strength (IS) implies the amount of energy that a material can absorb when the exact load is immediately applied to it

Latent heat of melting is the energy that the materials absorbed from the surrounding to transfer from the solid stage to the liquid stage

Melt Flow Index (MFI) measures the ability of plastics resin to be melted then flows through the mold to form product. Basically, large components require high Melt flow index

Mold and die springs provides the reaction to withstand all deformations of the ejection parts during the removal of final products out of the system

Nusselt number (Nu) reflects the ratio between conduction and convetion process during heat transfer of the process. The more Nusselt number is large, the more convection conducted in the process.

Prandtl number (Pr) illustrates the difference from momentum diffusivity to thermal diffusivity. Prandlt number is also a dimensionless quantity, which can be determined based on several appendix.

Reynold number (Re) is the dimensionless quantity indicating the relationship between flow regime to the velocity of the fluid

Sprue is the feedstock entrance provided in injection molding between the nozzle and cavity or runner system.

Sprue gate is a way through which molten plastic flows from the nozzle to the mold cavity.

Stripper plate is simply a plate that is used to push a product a part off an injection mold core

Sucker is the part used to connect all plates, excepted the bottom plate

Tensile Strength (Nakamura & Igarashi) is a calculation of the force required to pull plastic materials the point where it breaks

Top plate is responsible for holding the feeding system as well as connecting the runner to other parts of the injection machine

1 Introduction

Plastic products play an essential role in our daily life. Noticeably, the production of plastic products accounted for 359 million metric tons in year 2018 (M. Garside, 2018). Due to the exclusive demand for these goods by the human race, the modification and improvement of equipment and technology are essential to keep up with social development. It is noted that plastic products can be produced thanks to multiple machines, including injection, blowing, filming, extrusion, and thus, enhancements of these types of machines are promising. In terms of injection machines, the driving force for its operation is the molding part, which directly affects productivity.

Generally speaking, in plastic injection machine, a runner is the chanel – an intermediate which allows molten plastic to transfer from the nozzle to the cavity. The runner systems can be classified as a hot and cold runner, and subsequently divided into two-plate and three-plate. Undoubtedly, each system illustrates both pros and cons, depending on its ultimate application (Harper, 2006). Among several systems, a three-plate cold runner mold (3P CRM) is considered as the unique technique in the injection process. The proliferation of technology and the emergence of new materials shed light on new designs of 3P CRM, which will be examined in the thesis.

1.1 Objective

The thesis focus on two aspects, the overview of relevant theories used to calculate technical parameters of the runner and the design of practical equipment based on mathematics approach and engineering software.

In terms of the theory field, the information on the worldwide plastic field will be provided. In particular, the evolution of the plastic business, especially in developing nations, is going to be studied. Furthermore, the potential of plastic injection molding will be reseached, and support value information on the technique. The thesis also explains in detail the reason why polypropylene resin was selected as a feedstock for the design of the plastic molding machine (PIM). In addition, patterns of plastic injection moulding machine from desgined from previous researchers will be used as references.

Regarding the practical design, the technical parameters of the machine will be theoretically calculated thanks to the mathematics approach. Fundamentally, the utilization of heat transfer and mass transfer hypothesizes the actual design of the machine. In the subsequent step, an engineering modeling program – will be used to simulate the machine based on parameters caculated from the mathematics approach.

The chance to get access to the procedure of the mechanical design will be brought by the thesis. Fundamentally, perhaps, all equipment can be shaped and designed thanks to the same model called the Engineering design process (EDP). The EDP model, containing seven stages, suggests the procedure to technically design equipment, starting with defining the problem. Afterward, the background research will be implemented, followed by a brainstorm and evaluate the idea. In the subsequent step, developing and prototyping solutions are required before the testing stage. The model will be constantly modified to meet all requirements and then presented to end-users.

1.2 Scope of the thesis

The study was conducted in which the design of other parts of the plastic injection machine was neglected. Besides, some conditions of some empirical equation, including thermodynamic properties of polypropylene, the heat of radiation, etc., were assumed not to be changed during the design.

The thesis attentively focused on the investigation of theory-based knowledge, especially the usage of heat and mass transfer theories to calculate the parameters of the machine. The practical design of the three plates cold runner was also identified based on the data gained from the theory aspect. However, as mentioned, building up theory-based knowledge is the key purpose of the thesis.

2 Literature review

The first discovery of synthetic polymer in 1869 by Hyatt opened doors for the plastic industry. Since the exploration, plastics has been becoming a vital source of all industries, which accelerates the development of a society. The fully synthetic polymer was then invented by Leo Baekeland in 1907, and the successful synthesis became a solid basis for further investigation. During World War II, the pastic production rate of the US increased to an unexpected percentage of 300%, which subsequently became the turning point of the plastic field (Thompson et al., 2009).

Although some undeniable drawbacks of plastic in the modern world are associated with great efforts for alternatives, the plastic industry is forecasted to brilliantly develop in later centuries. However, the growth of worldwide plastic production is not commensurate with overpopulation. For instance, the global plastic manufacture rate accounted for 359 metric tons in 2018, and the worldwide population of this year was estimated at 7.509 billion, which means each person will consume roughly 0.05kg plastic products per year (Ritchie & Roser, 2018) (Division, 2019).

Due to the high demand for plastic products by humans, improvements on the plastic machine has been attracting a great deal of researchers’ attention. Among multiple types of the plastic machine, the injection machine, which was invented in 1872 by John Wesley Hyatt, are making the most generous contribution to the plastic business (HYATT, 1872). The efficiency of this machine highly depends on its operation conditions, including feedstock, temperature, pressure, and cycle time, and the mold. Apparently, innovation can be conducted on designing modern and effective mold, especially the 3P plastic injection machine.

2.1 Overview of the worldwide plastic industry

Plastic products are diverse in their structure, synthesis, and applications. Generally speaking, these products are manufactured based on the primary feedstock in the petrochemical industry, including methane, ethane, propane, butane, benzene, toluene, and xylene. Noticeably, polymers are divided into three groups, comprising plastics, elastomers, and synthetic fibers. Among these types, plastics are successively distinguished as thermoplastics and thermosets (Matar & Hatch, 2001). Crystalline and amorphous plastics are the two major elements of thermoplastics. The classification of polymers are apparently indicated in the following diagram

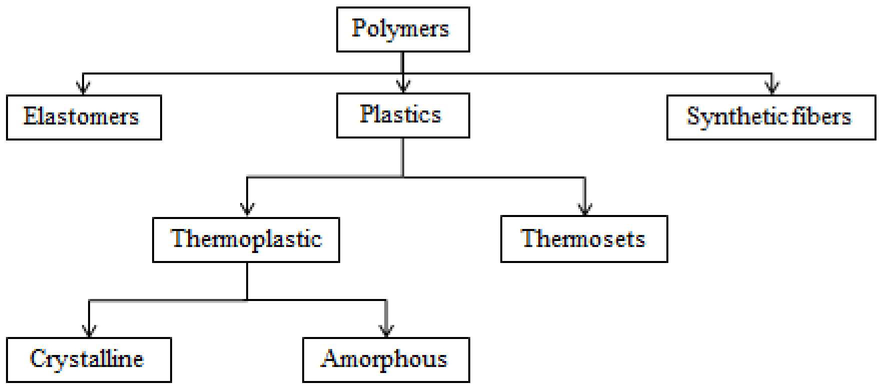


Figure 1. Classification of polymers

2.1.1 Elastomers

Elastomers, also called synthetic rubbers, are high molecular weight polymers thanks to long flexible cross-linked chains, which have low Young's modulus and high failure strain. Owing to this special structure, synthetic rubbers have low crystallinity, high reversible elasticity, and high viscosity. Specifically, these polymers easily recover to its initial structure once forces are not applied. It means that elastomers are extensible under varying conditions of deformation. Representative prototypes of elastomers are styrene, butadiene, isoprene, chloroprene, urethane, etc. The main applications of this type of polymers are belts, wire and cable, industrial appliances, automotive parts, and medical applications (Cheremisinoff & Cheremisinoff, 1993).

2.1.2 Syntheric fibers

Synthetic fibers are solid materials synthesized by chemicals, as opposed to natural fibers, which are produced from organisms. This group is characterized by long-chain substances, having a high degree of crystalline. In comparison with elastomers and plastics, synthetic fibers have the lowest elasticity. One of the features of synthetic fibers attracting attention of researchers is the high tensile strength – between 2000 MPa and 4000 MPa, which can be effectively used in clothes production (GR Arpitha et al, 2014). Monomers, such as polyesters, polyamides, polyacrylics, etc., can be used to manufacture synthetic fibers by either step polymerization reaction or chain-addition reaction, depending on the properties of feedstock. Interestingly, applications of synthetic fibers varied from home furnishing, carpeting, automotive fabric to safety apparel and sailcloth (Cook, 1984).

2.1.3 Plastics

As mentioned, plastics comprise thermoplastics and thermoset. The main distinction between the two types is the behavior towards high temperature.

Thermoplastic, also named thermosofting plastics, contains substances that are moldable at a precise temperature and solidify upon cooling. Those types of plastic can change their shape to suit any certain mold conditions, and thus, they are easy to recycle. Particularly, this type of plastic can easily change its phase across the melting and condensation process. Moderate crystallinity, reshaping capabilities, high impact resistance is the main features of thermoplastics. Due to these characteristics, thermoplastic can witness lower elongation, compared to that of elastomers (Matar & Hatch, 2001). Thermoplastics are represented by different compounds, which are listed in the below table

Types of plastics	Representative	Application
Olefins	PP, LDPE, HDPE	Bottles, packaging, bags
Styrenics	PS, ABS	Toys, appliances,
Vinyls	PVC	Pipe, inflatable products
Arcylics	PMMA	Signs, eye lenses, glass

Polytetrafluoroethylene	PTFE	Coatings of cooking ware
Polyamides - Nylon	Nylon 6, Nylon 6-6	Rope, carpets, clothing
Polylactics	PLA	3D printing

Table 1. Types, examples, and applications of thermoplastic (Olabisi & Adewale, 2016)

On the contrary, thermosetting plastic is a term used to emphasize a plastic group that completely decomposes upon heat sources. Fundamentally, thermosetting resin permanently remains in a solid-state during curing – the process used to harden or toughen plastic resins by cross-linking its structure. Therefore, a three-dimensional structure is created, which preferentially leads to outstanding properties of thermosetting compared to that of thermoplastic, especially high resistance to heat degradation and chemical attack. Common thermoset plastics and its applications are polyester resin (fiberglass, protective coatings), polyurethanes (insulating foams, adhesives), epoxy resin (matrix component, electronic encapsulation) (Dodiuk & Goodman, 2013)

According to the report of Plastics Europe organization, the consumption of PP resin held the lion's share at 19.3%, compared to others (PlasticsEurope, 2018). Additionally, the market size of PP accounted for 115.9 billion in 2019 and was forecasted to increase by 3.1% in 2027 . Therefore, PP will be the most popular and vital polymers around the world. In accordance with the market development of PP, the scrutiny on improving and raise the efficiency of PP plastic machines should be implemented. Obviously, PP is selected as the feedstock proving technical parameters for the design of plastic injection machines along with the thesis.

2.2 Manufacture process of plastic products

Overall, the whole processing of plastic products contains three steps, exploitation of raw materials, refining the raw materials into basic feedstocks, monomers and polymers production, and manufacture of plastic products. Raw materials are possibly crude oil, natural gas, or associated gas, which are then separated and distilled into different feedstocks of the petrochemicals industry. These feedstocks can be called monomers – a source to produce polymers in petrochemical plants. It is noted that plastics products are produced by either polymerization or condensation from polymer sources.

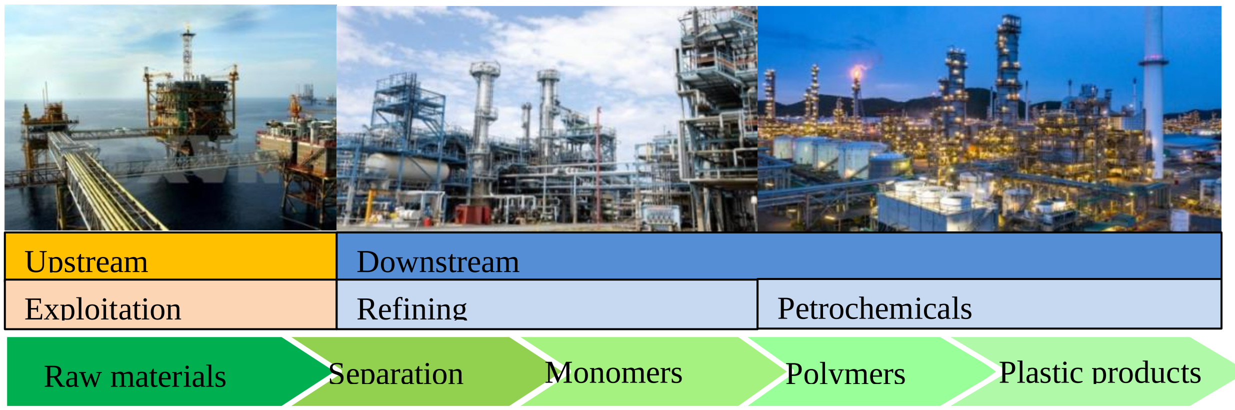


Figure 2. Petrochemical industry chain – Plastic production (Braskem, 2015)

Several types of processes can be conducted to produce plastic goods, including injection molding, blow molding, extrusion process, compression molding, and transfer molding (Harper, 2006). Among these techniques, injection molding is the most popular process in plastic production. Therefore, the injection molding process will be scrutinized in the thesis.

2.3 The injection moulding process

The injection molding process comprises six stages to produce plastic products. Initially, plastic pellets enter the machine by a hopper and then pass through a screw having a series of heating systems. Plastic pellets transfer from the solid to the liquid phase, the resulting fluid is called molten plastic, which is then injected into the mold thanks to different nozzles under high pressure. Once the molten plastic fully fills the mold, the cooling process will be implemented in order to shape the products. Simultaneously, high pressure is will be applied at both moving and fixed platens in order to tighten all parts together during the cooling process. The final products will be reassembled out of the machine after accurate heat will be taken out and precise shapes are achieved (Murti, 2010).

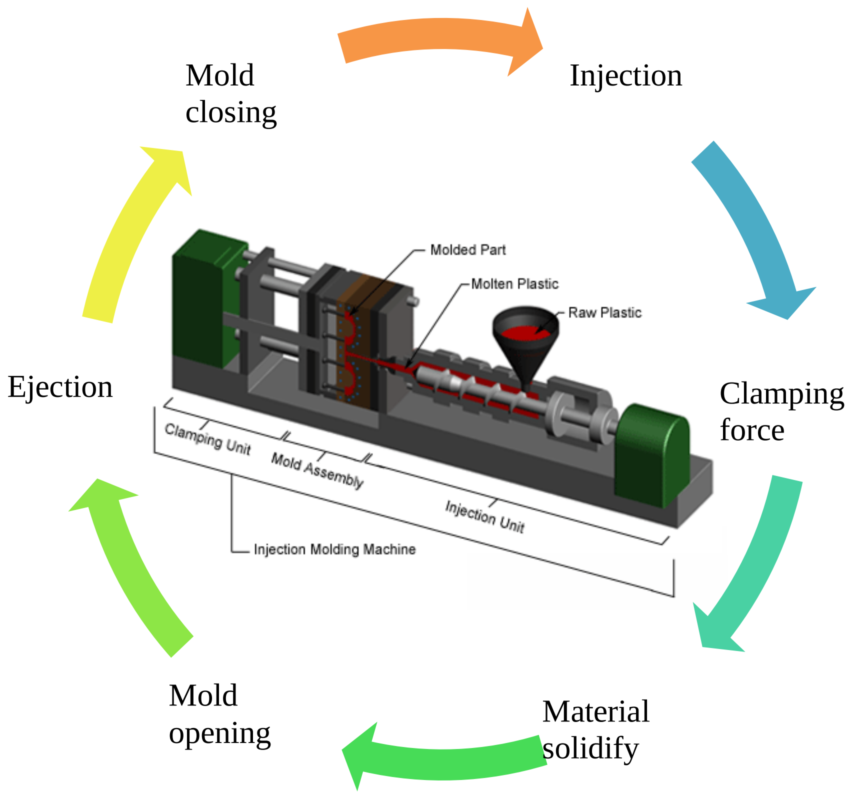


Figure 3. Simulation of injection plastic machine (Murti, 2010)

As can be seen from Figure 3., the cycle starts with the withdrawal of the platen parts, followed by the isolating of the mold assembly. In the subsequent stage, polymer pellets transfer continuously into the molten – liquid phase thanks to heat source from along with the screw. The molten plastics, afterward, enters the mold by different nozzles, and fully filled the mold. The cooling process is implemented to convert the molten phase into solid, and final products are collected with precise shape. Particularly, the precision of the shape is primarily assessed by its conformability to the contour of the mold. (Murti, 2010). Regarding the melting process, there are three stages, including the fill stage, the pack stage, and the hold stage (Altenbach, Naumenko, & Zhilin, 2003)

In the fill stage, molten plastics having a high thermal energy state entered the system. Owing to high pressure and temperature, the viscosity of the fluid decreases, and thus, it is fed forward the screw, a speader before entering the mold cavity. Theoretically, the efficiency of the process is evaluated based on the injection rate – a rate at which the plunger moves forward, pressure, and cycle time. During the next stage, melted plastic cools down and shrinks, and therefore will not fully fill up the mold cavity. Therefore, the pack stage is implemented to compensate for the shortage in order to guarantee the precision of the final products. It is clear that all parts are not completely sealed to one another, and molten plastics can overflow and leak back through the gate. The hold stage operates based on the pressure difference principle, in which forces are utilized to prevent the unforwarded internal reflux of the molten resin. Sometimes, the second and third stages are merged into one phase, called a combined holding stage (Rosato & Rosato, 2012).

According to Figure 4 there are three parts of one injection molding machine, including the injection unit, molding unit, and clamping unit. Among other components, hopper, screw, barrel, injection nozzles, and mold are the fundamentally necessary parts.

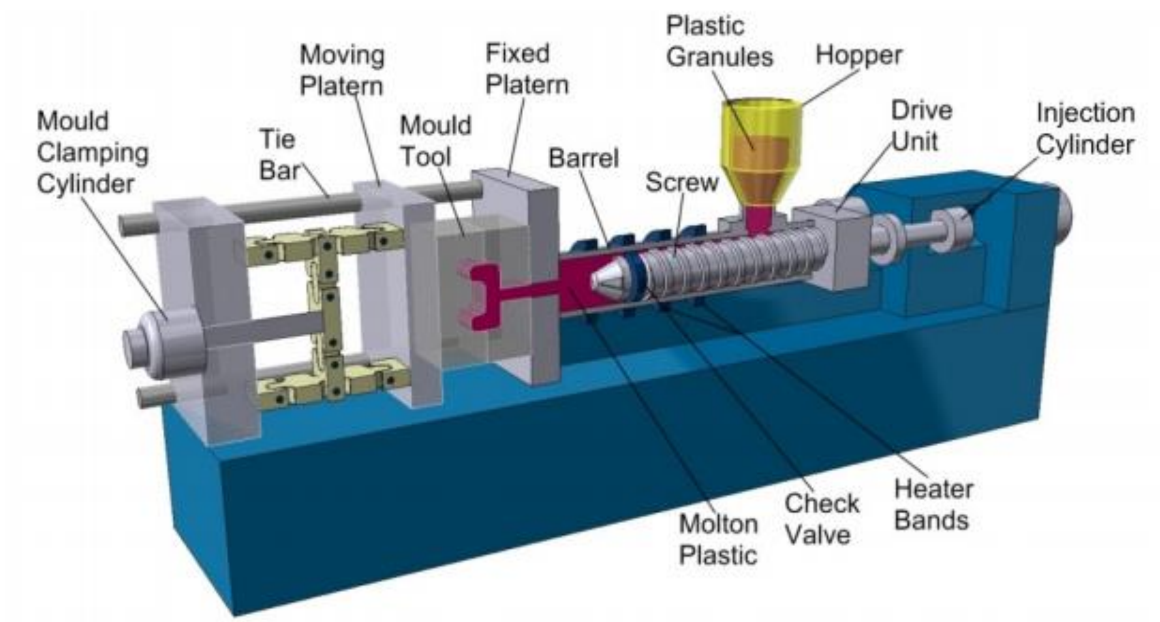


Figure 4. Injection molding machine illustration (Asia, 2018)

Hopper links to two pipelines and a pump. The injection machine frequently consumes plastic under pellet or chip form. Therefore, one pipeline is connected to the plastic bag, and the other is fixed to the pump. These materials are pneumatically transported and contained in the hopper. Thanks to the continuous movement of the screw, plastics pellets enter the barrel by gravity. The screw has three parts, including feeding, compression, and meetering, in which plastics are melt along with the body of the screw. Specifically, pellets remain its initial solid phase during the feeding zone, then partially transfers into the molten phase at the next zone, and completely becomes liquid phase once entering the melting zone (Lindt, 1976)

One of the advantages of the screw is the mixing effect that assists the homogeneous phase of molten plastic. The barrel supplies energy to the system, and thus, plastic pellets are heated and change its phase. Thanks to multiple heating bands distributed along the barrel, heat transfer is maintained and the efficiency of the system remains unchanged. Virtually, a mold is an important element of PIM, which decides the shape of the products (Haley, 2009).

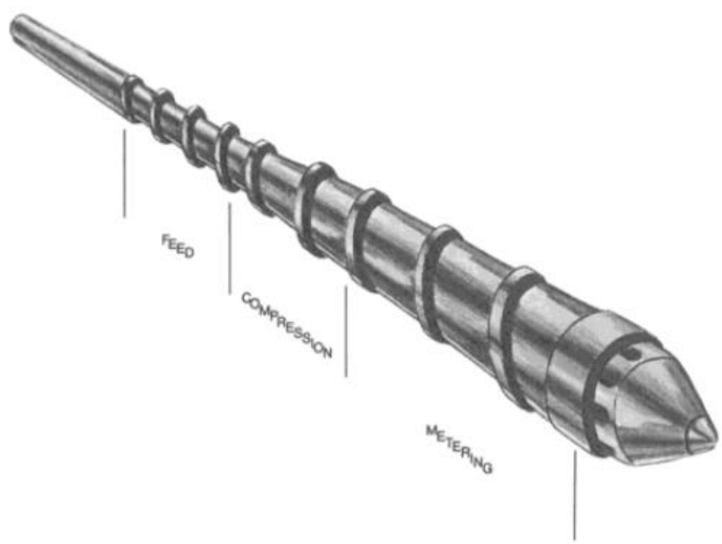


Figure 5. Three zones of the screw in plastic injection machine (Rosato & Rosato, 2012)

Obviously, each PIM might have similar elements, such as hopper, barrel, screw, but differs in the mold. It is a complex and expensive device and requires periodical maintenance. There are four main parts of mold, including a sprue, a runner, a cavity gate, and a cavity (Note, 2020)**.**

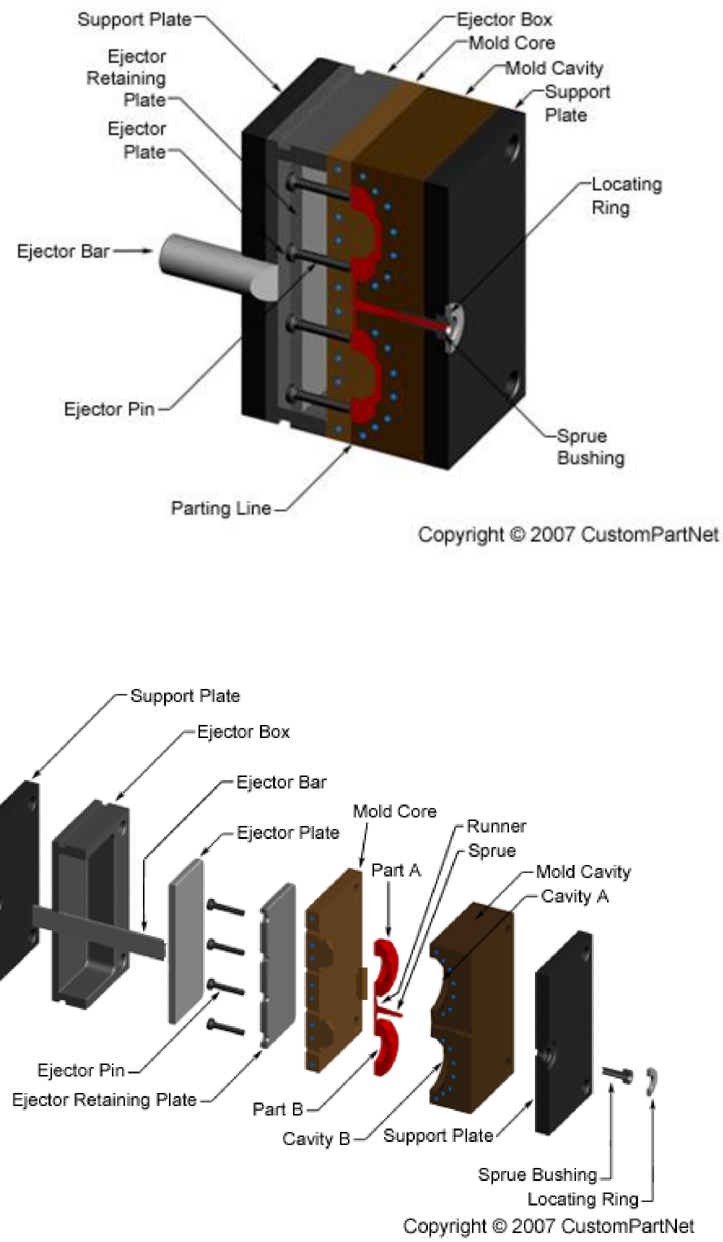


Figure 6. Structure of mold in (CustomPartner, 2017)

In order to inject the molten plastic from nozzles into the runner, a sprue acts as a channel that allows this phenomenon. Afterward, the melt transfers across a runner, followed by passing through the gate to enter the cavity. The usage of the runner is not required for the single-cavity mold, in which molten plastic is injected directly into the cavity without passing through the runner. However, single-cavity is not common these days, and thus, the use of different runner types attracts the attention of researchers. Runners are divided into two parts, including runner and cold runner, and then subsequently classified based on its number of the plate (Rosato & Rosato, 2012).

The hot runner operates based on the high-temperature principle, in which the runner keeps its temperature higher than the melting point of the plastic. The runner is placed internally in the mold and possibly heated by diverse heating sources, such as coils, cartridge heaters, heating rods, heating bands, etc. Due to the high temperature, some scraps might appear during the process and should be eliminated. Additionally, high energy consumption, expensive maintenance expense, and difficult color controllability are also some drawbacks of the hot runner. Hot runner plate, by contract, benefits the process by offering fast cycle time, low pressure, and high adaptability to large parts.

There are two types of hot runner – insulated system and heated system. The insulated system, also called the unheated system, comprises large passages that allow each injection shot having a similar heat transfer rate so that molten flow remains unchanged. It is noted that the volume of the runner must be larger than that of the cavity to control the amount of each shot, even excessive rate. Heated systems are divided into internal and external heated systems. The internal approach designs a series of heat transfer by a probe or torpedo located inside the passages, while that of external one is done by a cartridge-heated manifold installed externally in the passages (SIMTEC, 2015)

In comparison with the hot runner, the cold runner is more simple with the presence of plates, cavity, and the core. The main operating principle of the cold runner is the low-temperature, in which the runner is not exposed to heat and acts as a distribution channel to deliver molten plastic into the cavity. Simultaneously, the cold runner system also takes the energy of sprue and gate along with the molded part. Generally speaking, a two-plate cold runner and three-plate cold runner are the main types of cold runners. In terms of the former, the sprue and the runner system are fixed into final products.

The separation between products and mold is implemented thanks to an ejection system. The three-plate runner, as its name revealed, comprises three parts, including the stationary plate, the middle plate, and the movable plate. The structure allows runners and components to be located in different parting planes, and thus, disassembly can be easily implemented. During the operation of the mold, the middle part is separated out of the stationary, which subsequently leads to the elimination of the sprue from two plates. (Moayyedian, 2019)

It is noted that each type has its benefits and drawbacks. However, the three-plate cold runner can be an alternative for the hot runner. Besides, the cold runner is supposed to have a lower cost, compared with the hot runner system. In order to cut down on maintenance expenses and energy costs, the cold runner should be developed. Additionally, the appearance of temperative sensitive polymers challenged the hot runner system due to the degradation and decomposition of these materials.

3 Parameters of the mold

This chapter will focus on the mathematic-based calculation approach to work out necessary parameters of the cold runner. The chapter starts with the selection of feedstock of the process – the type of polymer, followed by choosing the input data for heat balance and mass balance so that the required dimensions of the mold can be approximated.

3.1 Material

In the modern world, all countries have been witnessing the high consumption of hangers to keep pace with the apparel industry. Although the plastic industry currently faces a crisis from the majority of people due to its unexpected impact on the environment, the utilization of plastic cannot be ignored under any circumstances even that a hanger takes even a millenium to decompose (BBC, 2019). Therefore, humans are raising their awareness in the recycling of plastic hanger. However, hardly ever do famous and luxury brands refer to using recyclable plastic products. According to the estimation of Roland Mouret – a hanger designer who was in charge of London Fashion Week, there were merely 20 % of designers choosing recycled plastic hangers for their collection (BBC, 2019). The importance of the garment hanger industry is still recognized.

As mentioned, polypropylene was chosen as feedstock for the process. The polymer can be classified into three group, including homo, random, and block copolymer, which differs from their properties as well as manufacturing method. Generally speaking, homopolypropylene completely contains 100 % of polypropylene, while that of random and blockcopolymer are produced in the presence of polypropylene and ethylene. Thermodynamic properties of PP are illustrated in the below table.

Properties	Unit	Value
Melting point	°C	150-170
Density		0.905
Thermal diffusivity	°C	0.65
Decomposition temperature	°C	>300
Coeff.therm.expansion	$\mu m/mK$	100
Molecular weight	kg/mol	>200000
Thermoconductivity	W/mK	0.24
Laten heat (Heat of melting)	kJ/kgK	1.95

Table 2. Thermodynamic properties of PP (Osswald & Hernández-Ortiz, 2006; Thermopedia, 2011)

Among three types, Homo grade has varied applications. Homopropylene can be used to manufacture woven bags, oral products, films, etc. Depending on process, additives, each type of Homo produced from different producers has its unique properties illustrated in the Technical Data Sheet (TDS). It is noted that four characteristics name melting index, tensile strength, impact strength, and flexural modulus, which directly affects to production rate, toughness, stiffness, and flexibility, respectively, of PP resin (Tusch, 1966). Homo can also be used to produce hangers through injection method to serve the apparel industry. Therefore, the thesis focus on the design of PIM using PP as feedstock to produce hangers.

3.2 Input

In order to calculate the technical parameters of the 3P CRM, the following data will be utilized based on technical data sheet of PP Homo 1100K of APC

Parameter	Unit	Value
Flowrate		
Hot feed	kg/s	0.004
Cool feed (water)		
Cycle time	s	50
Temperature of hot fluid		
Molten PP before enter	^{o}C	180
Final product		40
Temperature of cold fluid		
Water in temperature	^{o}C	20
Water out temperature		40

Table 3. Input of mathematic calculation (Maung Myint, 2018)

Manufacture: Mainetti	
Parameter	
Length (cm)	30
Width (mm)	20
Height (mm)	20
Weight (g)	50
Density (g/cm^3)	0.905
Volume (cm^3)	54.945

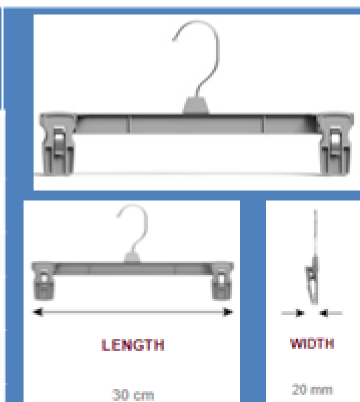


Figure 7. Technical parameters of hangers produced by Mainetti (Mainetti, 2020)

Assume that the intermediate thickness is $\sigma = 2\ (\mathrm{mm})$, according to the given information, total surface area of the product *S* can be calculated by the ratio between volume of molten plastic *V* and the intermediate thickness (Moayyedian, 2019)

$$S = \frac{V}{\sigma} = \frac{54.945\ cm^3}{0.2\ cm} = 274.725\ \mathrm{cm}^2 = 27472.5\ mm^2 \text{ (1)}$$

Among different type of gate section, the circular cross section are chosen in the thesis.

The gate diamater will be identified in the below equation (Moayyedian, 2019)

$$d = c_1 \times c_2 \times \sqrt[4]{S} = 0.294 \times 0.7 \times \sqrt[4]{27472.5} = 2.65mm \text{ (2)}$$

where $c_1 = 0.294$ and $c_2 = 0.7$ are the imperical factors, which were selected based on the inter thickness and type of material (PP).

Runner diameter of the machine can be achieved through the formula (Moayyedian, 2019)

$$D = \frac{\sqrt{w} \times \sqrt[4]{L}}{3.7} = \frac{\sqrt{50} \times \sqrt[4]{1200}}{3.7} = 22.5\ mm \text{ (3)}$$

Choose the diameter at 25.4mm, which is appproximately to 1” pipe

The maximun stress of polypropylene is $\tau = 0.25\mathrm{MPa}$, pressure drop of the equipment is

$$P = \frac{2\tau L}{r} = \frac{2(n\dot{\gamma})L}{r} = \frac{2L}{r} = \frac{2(0.25MPa) \times 1200 \times 10^{-3} m}{12.25 \times 10^{-3} m} = 48.98\ MPa\ < 70MPa \text{ (4)}$$

The standard maximum pressure drop of the runner is 70 MPa. Hence, the calculated pressure drop must be less than 70 MPa.

Therefore, the designed gate diameter and the runner diameter is 2.65mm and 25.4mm, respectively. The selected diameter of the runner can help the machine run well without any damages due to overpressure.

3.3 Heat balance

To calculate the heat transfer of the process, temperature profile is be described in Figure 7.

PHASE 1: Practical heat transfer coefficient based on heat transfer equation

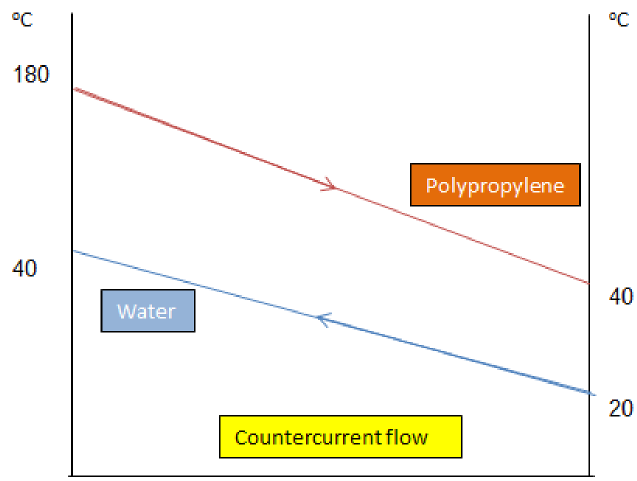


Figure 8. Temperature profile of hot and cold side (Maung Myint, 2018)

Assuming that the mass flowrate of the process is equal to the mass of the product and each product consumes $50g$ PP polymer. Therefore, the molten flowrate of PP can be calculated

$\dot{m}_h$: mass flowrate of polypropylene enters the machine

Cycle time: the length time to produce one product in the injection machine

$$\dot{m}_h = \frac{m_{product}}{Cycle\ time} \times Number\ of\ cativy = 50g \times \frac{1}{50s} \times 2 = 0.002(\frac{kg}{s}) \quad (5)$$

The heat balance of hot feed and cool feed is indicated in the following equation can be identified once the $\dot{m}_h$: mass flowrate of polypropylene enters the machine, C_{ph}: specific heat of the hot feed – molten polypropylene (kJ/kgK) and ΔT_h: temperature difference between hot feed in and out (^oC) is known.

The heat balance of hot feed and cool feed is indicated in the following equation

$$Q_1 = Q_2 = \dot{m}_h \times C_{ph} \times \Delta T_h = \dot{m}_h \times C_{ph} \times (T_{h1} - T_{h2}) \text{ (6)}$$

Therefore, required flowrate of the coolant – water used in the system

where: $\Delta H_{melting}$ is the latent heat of melting (kJ/kg)

$$Q_1 = \dot{m}_h \times C_{ph} \times (T_{h1} - T_{h2}) + \dot{m}_h \times \Delta H_{melting} = \dot{m}_c \times C_{pc} \times (T_{c1} - T_{c2}) \text{ (7) (Altenbach et al.)}$$

$$\leftrightarrow 0.002 \times 1.95 \times 1000 \times (180 - 40) + 0.002 \times 210000 = \dot{m}_c \times 4.187 \times (40 - 20)$$

$$\Rightarrow \dot{m}_c = 11.5 \frac{g}{s} = 0.0115 \frac{kg}{s} = 41.4 \frac{kg}{h} \ (water)$$

Since $Q_1 = 0.002 \times 1.95 \times 1000 \times (180 - 40) + 0.002 \times 210000 = 966\ (W)$ (8)

Additionally, heat of the process can also be calculated by the below formula

$$Q = U \times A \times \Delta T_{LMTD} \ \text{(Rohsenow, } Hartnett, \& \ Cho, \text{1998)}$$

Logarithmic mean temperature difference of the system can be calculated as followed

$$\Delta T_{LMTD} = \frac{(T_{h1} - T_{c2}) - (T_{h2} - T_{c1})}{\ln\left(\frac{T_{h1} - T_{c2}}{T_{h2} - T_{c1}}\right)} = \frac{(180 - 40) - (40 - 20)}{\ln\left(\frac{180 - 40}{40 - 20}\right)} = 61.67℃ \text{ (9) (Cartaxo \& Fernandes, 2011)}$$

The heat transfer is used to work out the dimensions of the process based on method of iterative calculation. Hence, the dimensions will be constantly modified until the error between U_1 and U_2 is less than 5%.

Choose the length and width of the runner of 1200mm and 700mm, respectively. Hence, the heat transfer surface area accounts for

$$A = L \times W = 1200 \times 700 \times 10^{-6} = 0.84\ (m^2) \text{ (10)}$$

The overall heat transfer coefficient can be calculated by the following formula (practice)

$$Q = U \times A \times \Delta T_{LMTD} \text{ (11) (Rohsenow, } Hartnett, \& \ Cho, 1998)$$

$$\rightarrow \mathrm{U} = \frac{Q}{A \times \Delta T_{LMTD}} = \frac{966}{0.84 \times 61.67} = 18.65 \left(\frac{W}{m^2K}\right)$$

Therefore, the practical heat transfer coefficient of the system $U_1 = 18.65 \left(\frac{W}{m^2K}\right)$

PHASE 2: Theoretical heat transfer coefficient based on emperical equation

The calculations used to approximate the theorical heat transfer coefficient inquire the input data. Those parameters can be implied thanks to the temperature of the substance. Assume that all parameters are not affected to the change of the temperature. Thus, all data will be demonstrated in the below table.

The thermodynamic properties of chemical substances were revealed and used widely thanks to the research of Burnham et al (1969)

Properties	Symbol	Unit	Hot side (Polypropylene)		Cold side (Water)	
			In	Out	In	Out
Temperature	T	℃	180	40	20	40
Pressure	P	MPa	533	102	1	1
Flowrate	$\dot{m}$	kg/s	0.002	0.002	0.0115	0.0115
Density	ρ	kg/m^3	910	910	1000	1000
Specific heat	C_P	kJ/kg℃	1.95	1.95	4.187	4.187
Thermal conductivity	k	W/mK	0.24	0.24	0.59	0.59
Viscosity	μ	cP	150.9	150.9	100.2	100.2

Table 4. Parameter of hot side and cold side (In-Out) (Burnham, Holloway, & Davis, 1969)

Properties	Symbol	Unit	At wall	
			Hot	Cold
Temperature	T	℃	110	30
Specific heat	C_P	kJ/kg℃	4.22	1.95
Thermal conductivity	k	W/mK	0.06	0.24
Viscosity	μ	cP	150.9	79.7

Table 5. Parameter of hot side and cold side (At wall) (Burnham, Holloway, & Davis, 1969)

Convection coefficient of molten polypropylene

Velocity of molten polypropylene at the gate

$$v = \frac{\dot{m}}{\rho \times A} = \frac{\dot{m}}{\rho \times \frac{\pi \times d(gate)^2}{4}} = \frac{0.002}{910 \times \frac{\pi \times 0.00265^2}{4}} = 0.398\ \left(\frac{m}{s}\right) (12)$$

The calculation approach based on emperical equations can be achieved thanks to the relationships among dimensionless parameters, including Reynolds number, Prandtl number, and also Nusselt number.

Reynold number emphasized the flow regime of the process. The flow regime of the process directly affects to the behavior of the fluid. And thus, the calculation of Reynolds number must be calculated. Prandtl number is used to indicate the momentum diffusity of the fluid, which illustrates the correlance among heat convection and heat conduction, whereas Nusselt number reflects the ratio between conduction and convection process during heat transfer of the process. The more Nusselt number is large, the more convection conducted in the process. It is noted that Nusselt number is usually defined thanks to the emperical equations, which can be selected through the flow regime. To identify the flow regime, the value of Reynolds number is the foundation.

The relationship betweet Nusselt number and Reynold numbers can be illustrated in the following emperical equations

$Nu = 0.0004Re^{1.3}$ $(3000 < Re < 15000, Turbulent\ flow)$ (Nakamura & Igarashi, 2004)

Regarding the thesis, Reynolds number of hot fluid can be calculated by the following formula

$$Re = \frac{\rho v d}{\mu} = \frac{910kgm^{-3} \times 0.398ms^{-1} \times 1.2m}{150.9 \times 10^{-3}Pas^{-1}} = 2885.10 \quad (13)$$

(Rehm, Schubert, Haghshenas, Paknejad, & Hughes, 2013)

Prandtl number of the hot fluid

$$Pr = \frac{\mu C_p}{k} = \frac{150.9 \times 10^{-3}Pas^{-1} \times 1.95 \times 1000J/kg℃}{0.24W/mK} = 1.23 \quad (14)$$ (Rapp, 2016)

Prandtl number of the hot fluid at wall

$$Pr_w = \frac{\mu C_p}{k} = \frac{150.9 \times 10^{-3}Pas^{-1} \times 4.22 \times 1000J/kg℃}{0.06W/mK} = 0.011 \quad (15)$$ (Rapp, 2016)

Based on calculated data, Nulselt number of the hot fluid is worked out (16)

$$Nu = 0.045 \times Re^{0.8} \times Pr^{0.43} \times \left(\frac{Pr}{Pr_w}\right)^{0.25} = 0.045 \times 2885.1^{0.8} \times 1.23^{0.43} \times \left(\frac{1.23}{0.011}\right)^{0.25} = 93$$

Hence, the convection transfer coefficient of the hot fluid

$$h_h = \frac{Nu \times k}{L} = \frac{93 \times 0.024W/mK}{1.2m} = 18.59 \left(\frac{W}{m^2K}\right) \quad (17)$$

Convection coefficient of cold fluid

Velocity of cold fluid – water

$$v = \frac{\dot{m}}{\rho \times A} = \frac{\dot{m}}{\rho \times \frac{\pi \times d(gate)^2}{4}} = \frac{0.0015}{1000 \times \frac{\pi \times 0.008^2}{4}} = 0.229 \left(\frac{m}{s}\right) \approx 0.23 \left(\frac{m}{s}\right) \quad (18)$$

Reynolds number of cold fluid can be calculated by the following formula

$$Re = \frac{\rho v d}{\mu} = \frac{1000kgm^{-3} \times 0.23ms^{-1} \times 0.008m}{100.2 \times 10^{-3}Pas^{-1}} = 1833.23 \quad (19)$$ (Rehm et al., 2013)

Prandtl number of the cold fluid

$$Pr = \frac{\mu C_p}{k} = \frac{100.2\times10^{-3}Pas^{-1}\times4.187\times1000J/kg℃}{0.59W/mK} = 7.15 \text{ (20) (Rapp, 2016)}$$

Prandtl number of the cold fluid at wall

$$Pr_w = \frac{\mu C_p}{k} = \frac{79.7\times10^{-3}Pas^{-1}\times4.187\times1000J/kg℃}{0.603W/mK} = 0.55 \text{ (21) (Rapp, 2016)}$$

Based on calculated data, Nusselt number of the cold fluid is worked out (21)

$$Nu = 0.045 \times Re^{0.8} \times Pr^{0.43} \times \left(\frac{Pr}{Pr_w}\right)^{0.25} = 0.045 \times 1833^{0.8} \times 7.15^{0.43} \times \left(\frac{7.15}{0.55}\right)^{0.25} = 81.10$$

Hence, the convection transfer coefficient of the cold fluid

$$h_c = \frac{Nu\times k}{L} = \frac{81.10\times0.59W/mK}{0.008m} = 5941.79\ \left(\frac{W}{m^2K}\right) \text{ (22)}$$

Choose the thickness of 2mm, and 304 stainless steel is chosen as the material the overall heat transfer coefficient can be calculated as below

$$\frac{1}{\mathrm{U}} = \frac{1}{h_h} + \frac{1}{h_c} + \frac{\delta}{k_{304steel}} \text{ (23)}$$

$$\mathrm{U}_2 = \left(\frac{1}{h_h} + \frac{1}{h_c} + \frac{\delta}{k}\right)^{-1} = \left(\frac{1}{18.59} + \frac{1}{5941.79} + \frac{0.002}{60}\right)^{-1} = 18.52$$

The error between theory calculation and practical calculation is

$$\Delta U = \frac{\mathrm{U}_1-\mathrm{U}_2}{\mathrm{U}_1} = \frac{18.65-18.52}{18.65} = 0.68\% < 5\% \text{ (24)}$$

Therefore, the chosen parameter is favorable for the machine (Rohsenow, Hartnett, & Cho, 1998)

3.4 Design of the components of the PIM mold

This part will focus on the selection of several details of the runner thanks to input data and available commercial parts supplied by DME – a company that specializes in runner's parts production. In some cases, the commercial details, including some pins, will be selected thanks to the handbook of DME. Then, these parts will be modified to suit the runner.

3.4.1 Sprue - Sprue bush and Locating ring

Due to the suitability and popularity of sprue gate for product made from polypropylene, this type of gate is selected in the design. In order to design the sprue gate, technical parameters, including the nozzle exit diameter, diameter of the sprue orifices, and the diameter of the sprue gate must be calculated.

The diameter of the sprue orifices is calculated thanks to the mass flow rate and velocity of the molten polypropylene if its velocity is assumed unchanged, which is selected at

$$d = \sqrt{\frac{4\dot{m}}{\pi \rho v}} = \sqrt{\frac{4 \times 0.002 kgs^{-1}}{\pi \times 910 kgm^{-3} \times 0.4 ms^{-1}}} = 2.64\ (mm)$$ (25) (Mechanicalengblog, 2019)

The nozzle exit diameter is less than 1mm, compared to the diameter of the sprue orifices

$$d_v = d - 1 = 2.64 - 1 = 1.64\ (mm)$$ (26) (Mechanicalengblog, 2019)

The relationship between the diameter of the sprue gate and the thickness of the hanger is demonstrated in the below equation

$$D_{sprue} = t + 1.5 = 2 + 1.5 = 3.5\ (mm)$$ (27) (Mechanicalengblog, 2019)

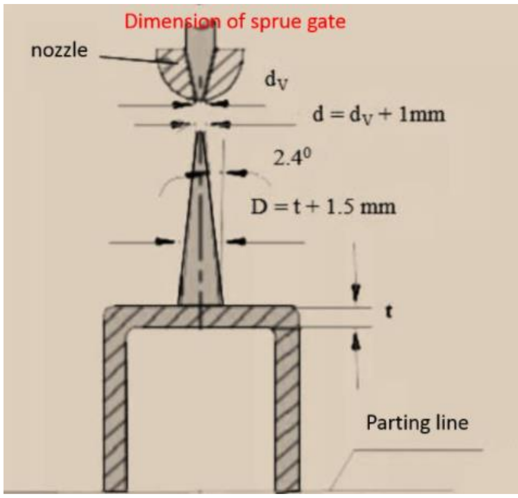
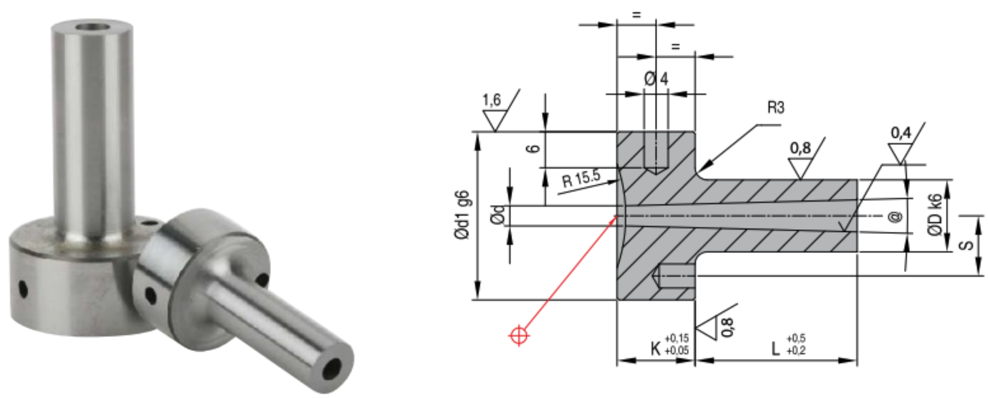


Figure 9. Dimensions of the sprue gate (Mechanicalengblog, 2019)

Regarding sprue bush, diameter of the sprue is the criteria to choose bush type



DHR 076 D X L x d REF @ 1°	DHR 76 D X L x d REF @ 2°	DHR 77 D X L x d REF @ 3°	d	d1	K	L	D	S
	DHR 76 12x22x2,5x15,5		2,5	28	13	22	12	11
DHR 076 12x27x2,5x15,5	DHR 76 12x27x2,5x15,5					27		
DHR 076 12x36x2,5x15,5	DHR 76 12x36x2,5x15,5					36		
DHR 076 12x46x2,5x15,5	DHR 76 12x46x2,5x15,5					46		
	DHR 76 12x22x3,5x15,5		3,5	28	13	22	12	11
DHR 076 12x27x3,5x15,5	DHR 76 12x27x3,5x15,5					27		
DHR 076 12x36x3,5x15,5	DHR 76 12x36x3,5x15,5					36		
DHR 076 12x46x3,5x15,5	DHR 76 12x46x3,5x15,5					46		
DHR 076 12x56x3,5x15,5	DHR 76 12x56x3,5x15,5					56		

Figure 10. Sprue bush illustration and dimension (DME, 2018)

The diameter of the sprue is 3.5mm, therefore the “AR” type – having straingth shape for feedstock input which is demonstrated in the above figure, is suitable for the machine due to the similar standard diameter ($O = \frac{5}{32} inch$). The length of the sprue bush is

$$L_{sprue\ bush} = 1\frac{13}{16}\ (inch) = 46.04\ (mm)$$

The height of the sprue is equal to to the length of the bush

$$H_{sprue} = L_{sprue\ bush} = 46.04\ (mm)$$

3.4.2 Cavity mold

The length from the runner to the cavity can be chosen at 75mm according to the research of Ruskatkas and co-workers (Rutkauskas & Bargelis, 2007).

The distance between two cavity is kept at 200mm, and the cavity has the parameter illustrated in the below table

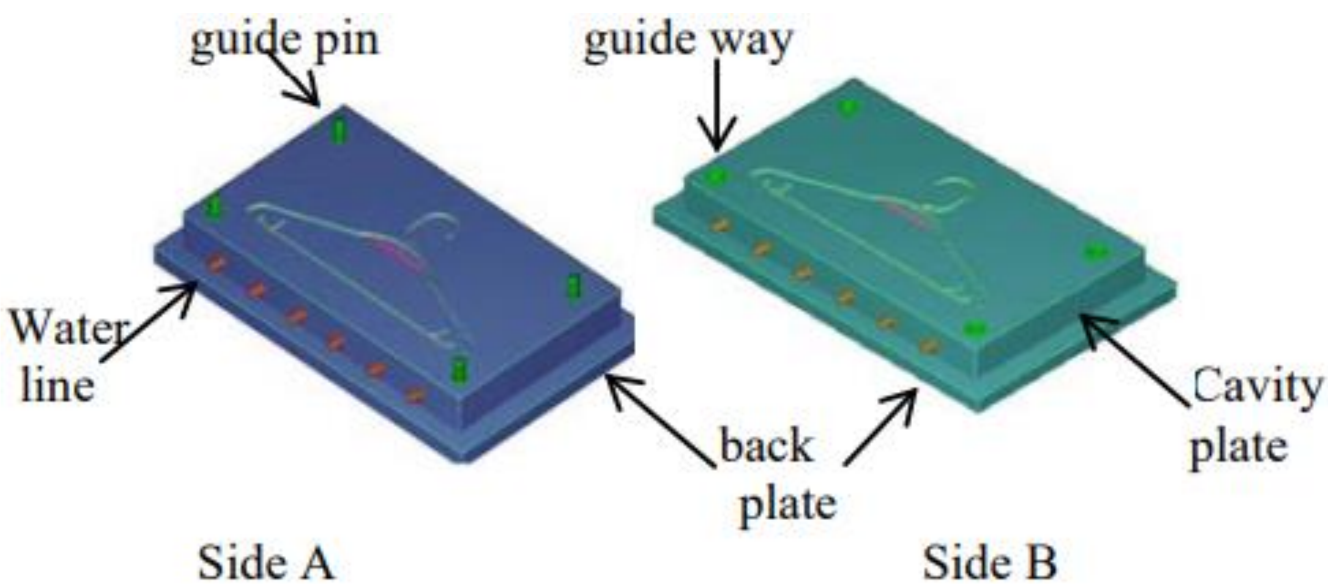


Figure 11. 3D Molding design of the mold (Maung Maung Myint, 2018)

To cover the product, the $L \times W \times H$ of the cavity is designed at

$600 \times 350 \times 50$ because the heat transfer area has $L \times W$ of 1200×700

The thickness of the cavity plate is equal to its height, 50mm.

3.4.3 Runner system

As calculated, the runner diameter is 25.4mm, and the 1” pipe is sized for the system.The distance from the sprue to two cavity is 550mm, which is similar the length of the runner system.

3.4.4 Sucker

Choose the sucker pin having parameter as below

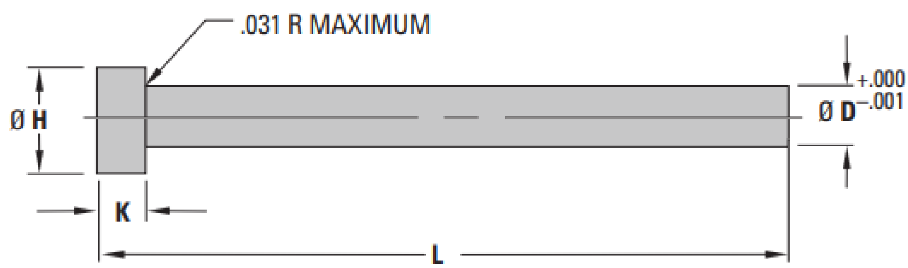


Figure 12. Dimensions of sucker pin (DME, 2018)

Type: CX17M

Head diameter:$H_s = 0.437\ (inch) = 11.1\ (mm)$

Head thickness: $K = 0.187\ (inch) = 4.75\ (mm)$

Pin diameter: $D_{pin} = 0.25\ (inch) = 6.35\ (mm)$

Pin length: $L_{pin} = 3(inch) = 76.2\ (mm)$

Total thickness of the top plate and runner stripper plate must be higher than the length of the sucker pin to disassemble the sprue

$$\delta_{total} = \delta_{top\,plate} + \delta_{stripper\,plate} = 46.04 + x > 76.2mm \rightarrow x > 30.16mm$$

Choose the thickness of the stripper plate at 35mm.

3.4.5 Ejector part

Ejector part comprises ejector plate, ejector back plate, ejector bush, ejector push pin, and ejector pin. Ejector plate and ejector bush have the same dimensions to that of tip plate and bottom plate. Thus, the dimensions are $L \times W = 1300 \times 300$

In terms of ejector pin, the total thickness of three layers, including core plate and cavity plate accounts for

$$\delta_{ejector} = \delta_{core} + \delta_{cavity} = 7 + 50 = 57\ (mm)$$

Besides, due to the separation of the top plate and the runner stripper plate during the ejection stage, ejector pins must have an extra length to compensate for the reassemble

$$\delta_{actual} = \delta_{ejector} + 35 = 57 + 35 = 92\ (mm)$$

There fore, the length of the ejector pin should be higher than 92 mm. According to the appendix of DME, the parameters of the ejector pin are

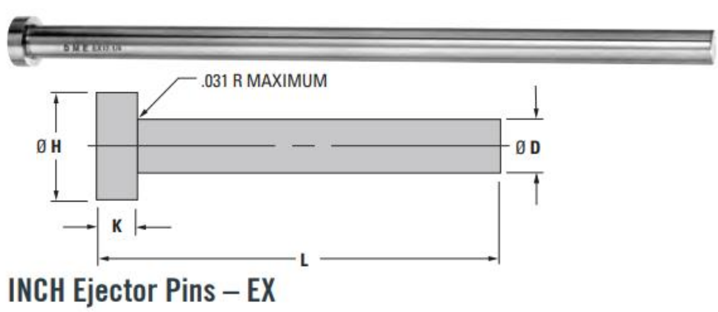


Figure 13. Dimensions of ejector pin (DME, 2018)

Type: EX17M6

Head diameter: $H_s = 0.25\ (inch) = 6.35\ (mm)$

Head thickness: $K = 0.125\ (inch) = 3.18\ (mm)$

Pin diameter: $D_{pin} = \frac{9}{64}\ (inch) = 3.57\ (mm)$

Pin length: $L_{ejector} = 6\ (inch) = 152{,}4\ (mm)$

The ejector pin having the length of 10inch will be purchased and cut to required length

The pin length has the value of 180 (mm), therefore, the thickness of the support plate can be worked out: $\delta_{support} = L_{ejector} - \delta_{actual} = 152{,}4 - 92 = 60{,}4\ (mm)$

3.4.6 Pull rod (Core pin)

Pull rod functions the connection among 5 layers, including core plate, top plate, runner stripper plate, cavity plate, and support plate. The length of the core pin must be equal or higher than the total thickness of five layers.

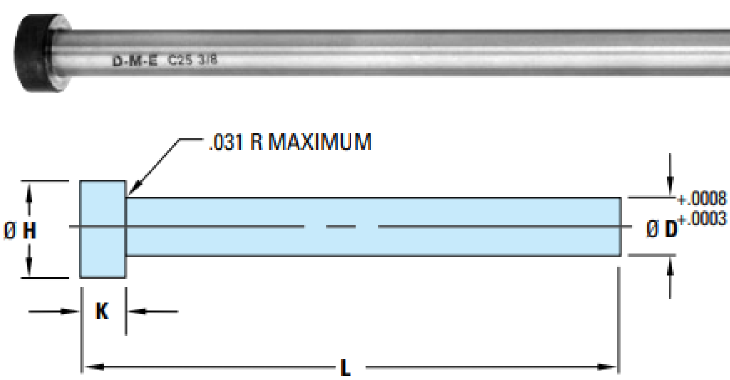


Figure 14. Dimensions of core pin (DME, 2018)

Type: CX41M

The total thickness of five layers is

$$\delta_{pull} = 7 + 50 + 35 + 50 + 60{,}4 = 202{,}4\ (mm$$

According to the standard of the DME, the pin has the length of 10 inch. Hence, the 10 inch pin will be used in the design.

Therefore, the length of the pull rod is chosen at 10 inch (254mm). Technical parameters of the core pin – type C41M are provided as below (DME, 2018)

Head diameter:$H_s = 1\ (inch) = 25.4\ (mm)$

Head thickness: $K = 0.25\ (inch) = 6.35\ (mm)$

Pin diameter: $D_{core} = \frac{3}{4}\ (inch) = 19.005\ (mm)$

Pin length: $L_{core} = 10\ (inch) = 254.0\ (mm)$

3.4.7 Cooling system

Cooling system uses water as an coolant. In order to maintain the velocity of water, sizing the diameter of the pipe is vital. The flowrate of water is $\dot{m_{water}} = 0.0115\text{m}/s$ which is calculated according to the heat balance. Velocity of water flow remains unchanged at 0.23m/s. Thus, the diameter of the pipe can be formulated as following

$$d_{pipe} = \sqrt{\frac{4\dot{m}}{\pi v \rho}} = \sqrt{\frac{4 \times 0.0115}{0.23 \times 1000 \times \pi}} = 0.008\ (m)$$

Choose the pipe having diameter of 0.008 m. Other parameters are illustrated in the below table

Parameter	Symbol	Unit	Value
Diameter	d_{pipe}	mm	8
Outside diameter	OD	mm	13.7
Wall thickness	δ_{pipe}	mm	3.023
Inside diameter	ID	mm	7.654
Pipe weight	m_{pipe}	kg/m	0.794
Water weight	m_{water}	kg/m	0.046

Table 6. Dimensions of water pipe in cooling system

The length of the pipe is half the width of the machine. Hence, $L_{pipe} = 150\ (mm)$

Pipe in and pipe out have the same diamater and is ran in U-shape. During the cooling process, water constantly enters the system and flow across the mold. The heat is be taken out of the system thanks to the pipe arranged in a U-shape underneath the mold. The inlet of the pipe is arranged opposite to the outlet.

3.4.8 Mold and Die Springs

The mold and die springs can be designed based on the applied force to lift the ejection push pins. Therefore, all parameters of the spring depend on the force as well as the distance in which the pin travelles.

All parameters of the mold can be achieved once the ejection force is defined. The ejection force is calculated based on the total surface that the mold contacts to the cavity and the Young's Modulus of the polyme which illustrates the elascity of the polymer. Other factors, including coefficient of friction, which is used to demonstrate the degree of friction between two materials as well as the thermal expansion cofficiency, which shows the expansion of polymers corresponding to temperature increase, are also mentioned in the equation. Thus, the ejection force can be calculated based on the following formula (Walsh's plastic consulting, 2015)

Where, $F_b$is the ejection force applied to the system (N)

A is the total surface area of moulding in contact with cavity or core, in line of draw (mm^2)

E is the Young's Modulus of the polymer

μ is coefficient of friction, PP on steel (Shen, Chen, & Jiang, 1999)

m is Poisson's ratio (Shen et al., 1999)

d is the diameter of a circle whose circumference is equal to the total projected perimeter of the moulding (mm)

The perimeter is $C = L \times W = 300 \times 20 = 6000mm$. Therefore, $d = \frac{C}{2\pi} = 955mm$

α is the coefficient of linear expansion of the polymer (mm/°C) (Toolbox, 2003)

Δt is equal to (polymer softening temperature) minus (mould tool temperature)

t is average wall thickness of part (mm)

$$F_b = \frac{EA\mu\alpha\Delta t}{\frac{d}{2t}\left(1 - \frac{m}{2}\right)} \text{(Walsh's plastic consulting, 2015)}$$

Hence

$$F_b = \frac{1550MPa \times \frac{\pi \times 6.35^2}{4} mm^2 \times 0.15 \times 72 \times 10^{-4} mm℃^{-1} \times (260 - 40)℃}{\frac{1910mm}{2 \times 20mm}\left(1 - \frac{0.32}{2}\right)} = 72.6N$$

The rod has the diameter of 7.9mm. Therefore, the springs will be selected based on the parameters of the rod diameter of 8.7mm and applied force is 72.6N. According to the table of mole and die springs for medium duty, the free length is 25.4mm (DME, 2018) and the hold diameter is 16mm.

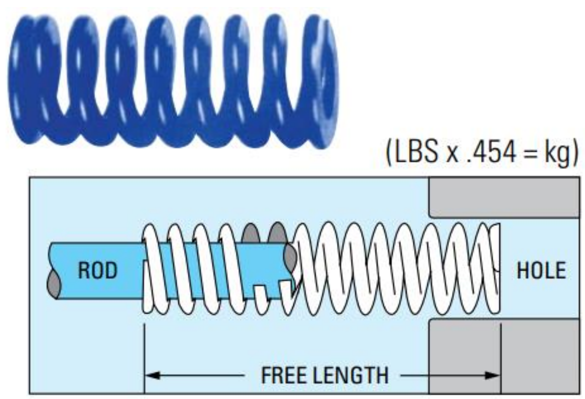


Figure 15. Dimensions of the springs (DME, 2018)

3.4.9 The bottom plate and top plate

The bottom plate has the relatively similar dimensions to the top plate because two plates are combined directly to each other. Both of the plates are used to cover the inside plates as well as protect the equipment.

Therefore, the size of the bottom plate is 1500 x 650 x 50

3.5 Summary on the parameters and designs

All the necessary information of the cold runner will be illustrated in the below table

Part	Parameter	Material	Value (mm)	Symbol
Top plate	Top plate			
	LengthxWidthxHeight	Stainless steel	1500x650x50	$L \times W \times H$
	Sprue			
	Sprue orifices diameter		2.64	d
	Sprue diameter		3.50	D_{sprue}
	Nozzle exit diameter		1.64	d_v
	Height of the sprue		46.03	H
	Length of the bush		46.03	$L_{sprue\ bush}$
	Sucker			
	Head diameter		11.1	H_s
	Head thickness		4.75	K
	Pin diameter		6.35	D_{spin}
	Pin length		76.2	L_{spin}
Ejection plate	Cavity		600x350x50	
	Cavity thickness		50	δ_{cavity}
	Ejector plate			
	Ejector thickness		57	$\delta_{ejector}$
	Ejector pin			$H_{ejector}$
	Head diameter		6.35	K
	Head thickness		3.18	D_{pin}

	Pin diameter Pin length		3.57 180	L_{pin}
Core plate	Core plate Core plate thickness Stripper plate Stripper plate thickness Support plate Support plate thickness Core pin Head diameter Head thickness Pin diameter Pin length		800x650x7 7 1300x650x35 35 1300x650x60.4 60.4 12.7 6.35 7.9375 254.0	$\delta_{core\ plate}$ $\delta_{stripper}$ $\delta_{support}$ H_{core} K D_{core} L_{core}
Cooling system	Coolant Water Pipeline Diameter of the pipe Outside diameter Wall thickness Inside diameter Pipe weight Pipe in – Pipe out		8 13.7 7.654 0.794 0.046	d_{pipe} OD δ_{pipe} ID m_{pipe}
Mold and Die Springs	Free length Hole diameter	Rubber	24.5 16	
Bottom plate	Bottom plate LengthxWidthxHeight		1500x650x50	$L \times W \times H$

Table 7. Summarized table of the design devices in the 3P PIM

4 Results and Discussions

On the one hand, the thesis successfully simulated the three-plate cold runner for a plastic injection machine. The principles of heat transfer and mass transfer were clarified, which gear us towards solid knowledge of how to calculate theoretical factors of the real design.

Thanks to the heat transfer, the energy balance was achieved associated with the energy consumption of the equipment. The equipment consumed roughly one thousand Watt which was calculated based on the equation (8) respectively.

It is true that the thesis also has several limits, which should be improved to obtain a higher accuracy of the real design. Firstly, the thermodynamic of the fluids, including molten PP and water should be clarified. During the heat transfer, the temperature of hot fluid continuously changed, and thus, several thermodynamic parameters were modified corresponding to this adjustment. For instance, viscosity, density, specific heat are the three factors having a dependency relationship to temperature. However, the thesis ignored these changes due to the complexity of calculation once those problems were mentioned. Secondly, most chemical processing underwent two design phases, including static and dynamic simulation. The thesis illustrated the static process of PP during plastic molding and neglected the dynamic process. In order to effectively simulate the process, a dynamic process should be approached thanks to some software, including Unisim, Aspen HYSYS, etc. Specifically, the Mold Flow system can be utilized to facilitate the dynamic process (Wang, Xie, Yang, & Ding, 2010). Wang et al investigated the simulation of semi-crystalline PP in the injection molding machine, then worked out the impact of temperature on volume and pressure of molten PP during the process. These programs can make a great contribution to enhance the reliability of the thesis.

Another obstacle to the thesis is the lack of stability calculation although the equipment was also considered the pressure vessel. The calculation of durability also correlated to the sizing of some details, including bolt, nut, etc., especially the thickness of the equipment. Therefore, the study on pressure balance is crucial to increase the accuracy of the calculation. The more thicknesses of the equipment are determined, the more further factors, including the economic possibility, hydraulic testing, and lifespan of the runner are justified.

Besides, the selection of some pins were not completely accurate due to a lack of input data, which subsequently leads to inconsistency among some parts of the machine. For instance, some pins are too small compared to the whole machine.

Last but not least, the location of pins – parts used to connect different layers of the runner – was not clearly described in the thesis. It is noted that the locations of pins directly affected the performance of the equipment. Nevertheless, as mentioned, due to the delimitation of calculation on equipment durability, the distance between some details, such as core pin, suckers, ejector pin, etc., were not fully investigated. Those parts were primarily selected based on the thickness of the runner's layers as well as the available assembling in the market.

5 Conclusions

In comparison with other plastic grades, PP is considered as one of the most versatile polymers, which can be applied in a variety of industries. The demand for PP has been increasing, and thus, industries related to PP have been accelerated. It is noted that not only the process but also the equipment's efficiency must be improved and innovated to keep up with the high consumption of PP. Among several types of the plastics production process, injection is the popular one. Therefore, raising the performance of the plastic injection molding machine should be prioritized.

The design of three plate cold runner molding machines can tackle the high consumption of plastic products in the twenty-first century. Particularly, the clothing and apparel industry sheds light on the massive production of garment hangers to keep pace with the display and protection of clothes.

The thesis successfully sized the equipment with capable dimensions, which can be practically manufactured on an industrial scale. Besides, details and other utilities were measurable and favorable to the system.

The technical drawing of the machine was clarified, which creates the basis for the machinery construction stage. The drawing also provided the necessary dimensions of the machine, which was calculated based on heat and mass transfer theories. There were two molds in the runner, which can produce 120 hangers in an hour. The total length witch and height of the 3P CRM are 1500mm, 300mm, and 50mm, respectively.

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