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Research Article

# Optimization of Process Parameters using Full Factorial Design in Injection Molding of Polypropylene

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**Abstract:** Injection molding process is widely used in industry for manufacturing of various kinds of products made of plastics. It is a fundamental polymer processing practice in plastic industry. In this process various optimization techniques are used to improve the product quality. Process parameters play a vital role in injection molding and have an effect on the worth of the product made up of different plastics. Along with molding conditions,plastic properties have a significant impact on the quality of plastic products in injection molding and optimised parameters enhance the quality of product and shrink the cycle time. In this research paper, the optimization of process parameters is implemented for polypropylene to manufacture a pharmaceutical cup. The technique applied for optimizing molding parameters is full factorial design. Analysis of Variance (ANOVA) technique is applied in Minitab software to find the significance of each parameter. Selected parameters like total time, injection pressure, injection temperature and mould's temperature are taken and analyzed during experimentation and best applicable combination of these parameters is set to get the desired results. The results obtained after performing experiments suggest that total time and mould temperature are significant factors in shaping the product's quality.

**Keywords:** Polypropylene, Injection Molding Process, Parameters Optimization, Surface Roughness, Full Factorial Design.

## 1. INTRODUCTION

Due to the global competition, industry is striving to produce high quality products to end customers. Industries are using different approaches to fulfil the market demands. Injection molding is one such industry that is using injection molding process to manufacture quality products. Industrialists use plastic injection molding machines with various kinds of plastics such as polyethylene, polyvinyl chloride, polypropylene, high-density polyethylene, polystyrene, and other engineering plastics etc. The foremost advantage of injection molding is its ability to mass production and once the setup cost is being paid then manufacturing in injection molding per unit is extremely low. Scrape rates in injection molding is very less as compared to traditional machining like CNC machining cut large amount of extra material which is wasted. In injection molding repetitiveness is a big advantage in which identical parts can be produced in large numbers. To smooth the progress of molding process, components to be injection moulded are very watchfully designed. And for this, material of mould, material of parts, desired features and shapes of components and characteristics of moulding machine needs to be considered. The versatility and usefulness of injection molding is enhanced by design considerations. Apart from material characteristics, the optimization of process parameters is a key to high quality products in this industry.

## 2. LITERATURE REVEIW

Several researchers worked on injection molding machine and proposed different methods to optimize its parameters for different products made up of different materials. M. V. Kavade and S. D. Kadam [1] deployed Taguchi method for optimization of parameters of injection molding machine for polypropylene and considered barrel temperature, holding time, injection speed, coolant flow rate, injection pressure, cooling time, and

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holding pressure as input variables for response variable that is productivity. Hyoungjun Moon et al. [2] studied parameters of injection molding of display front panel by using Taguchi method and analyzed packing pressure and cooling pattern to solve deflection problem in panels. Subodh Tomar et al, [3] performed research on parametric process of injection molding using a H200mk Grade of polypropylene. Molding parameters considered and analyzed by these researchers were injection temperature, holding pressure, injection speed, injection pressure, cooling time, holding time and polypropylene tensile property was considered as a response variable.

Likewise, Hasan Oktemand and co-researchers [4] used Taguchi optimization method for a thin-shell part in unearthing plastic injection molding process parameters. Different parameters were tried to reduce the warpage problem. This problem is linked to shrinkage variation dependent of unlike parameters during manufacturing of thin-shell plastic tools. Rajalingam et al, [5] determined best possible molding parameters by deploying two level factorial design with center points. They considered injection speed, mould temperature, injection pressure that significantly effects asking price of production, demand of production, quality, and productivity in injection molding industry.

Babur [6] in plastic injection molding helped in determining the influence of two parameters such as mould materials and shot parameters on mechanical characteristics of Acrylonitrile-butadiene-styrene (ABS). Factors taken into consideration were melt temperature, injection pressureand cooling time. And for mechanical properties of ABS, Taguchi method was deployed to estimate the signal to noise ratio. The result of parameters on mechanical properties was established using Analysis of variance. Kuo Ming et al, [7] did work on the effects of processing parameters on lenses optical quality at some stage in injection molding process. And they revealed that the key process parameters that ha an impact on the waviness of surface is a temperature called melt temperature, followed by injection pressure, mould temperature and packing pressure.

Wei Guo et al. [8] did research on the influence of processing factors on molding process in microcellular injection molding. And for decreasing advance dimensional accuracy and weight of plastic goods, temperature, time and gas controlling were considered. Alireza and Mohammad [9] carried out research on optimization in plastic injection molding process with the help of IWO algorithm and statistical methods. They were successful in finding the impacts of different process parameters or treatments in the form of packing time, melting temperature, and pressure on polystyrene (PS) and polypropylene(PP). Mustafa Kurt et al, [10] did experimental analysis of plastic molding, in which the they investigated the effect of mould temperature and the pressure inside cavity on quality of end products. Full factorial design is a common experimental designs which was used for warpage values consequent to training data [11]. Similarly, various researchers have researched on the process parameters of injection molding machine for different materials and used new techniques.

Till date, significant research work has been carried in the area of injection molding process. However, research studies on specific plastic materials are scarce. Local manufacturers in Peshawar (Pakistan) were facing surface roughness issue in products of polypropylene and there was no optimization technique applied on it to resolve the issue. Polypropylene is a thermoplastic polymer and is widely used in packaging and labelling, plastic parts, textile and reusable containers of different types and automotive components. It is unusually resistant to many acids and bases. In this research, parametric optimization of injection molding machine is done for polypropylene. For this material, four input variables such as, injection temperature, total time, mould temperature, and injection pressure are used to find the response variable. In the factorial design, best feasible grouping of the four parameters is obtained for a product fabricated of polypropylene having superior surface smoothness that can be utilized in local industry for better quality products.

The rest of the paper is ordered as follows: Section 3 depicts the proposed method while section 4 presents the design and manufacturing of mould. Section 5 illustrates the experimental setup in this study. Section 6 presents the results obtained from the experiments and section 7 discusses the significance of the approach and the interpretation of the results obtained. In the end, Section 8 and 9 sum up and concludes the paper.

## 3. MATERIALS AND METHODS

In this study full factorial design is used to study the effects of several factors that must have a certain response. During experiments, varying levels of factors and their interactions are used at the same time to get the results.

### 3.1. Selected Parameters

In this research, four parameters are selected in our analysis. Those four parameters are injection temperature, injection pressure, mould's temperature and total time. Next, three levels of each variable are considered, which resulted in eighty one (81) runs (number of experiments). Surface roughness acted as a response or reaction variable. And for selected input variables and a response variable, Analysis of Variance (ANOVA) technique is deployed for testing. ANOVA is being applied in Minitab specifically to find the significance of each parameter and its relationship with other parameters.

Cutting tool speed and feed of the cutting tool are not considered as process parameters in the ANOVA because they are used in the manufacturing of mould design and not used in the production of plastic products.

### 3.2. Multilevel Factorial Design

Full factorial design technique is used to get the required experiments that are being performed and is shown in Table 1.

In Table 1, the factors 4 means that there are four factors and the experiments are run for 81 times. Replicates 1 propose that every experiment or test will be done only once and for each parameter, numbers of levels taken into consideration are three. Four factors and levels of each factor is shown in Table 2.

The required determined experiments using full factorial design were executed on vertical plastic injection molding machine. Surface roughness tests were carried out on a device called surface roughness tester. Appendix 1 provides the details regarding input variables and surface roughness. After getting surface roughness values from products using surface roughness tester for conducted experiments, Analysis of Variance is applied in Minitab software to determine significant factors from the above declared four factors i.e. injection temperature, total time, mould temperature and injection pressure. On the basis of generated results from Minitab, best feasible combination of parameters/treatments is selected for this material i.e. polypropylene.

### 3.3. Mould Modeling & Fabrication

Mould is used when large numbers of parts are to be produced. To fulfil complete product development, mould has also been modelled and fabricated. Modeling of a mould has been done using CREO software. The objective of modelling a mould is to learn the basics of mould making, creation of mould models and to assemble the work pieces into the mould.

**Table 1.** MINITAB results using full factorial design

| Sr. No | Full factorial design | |
|---|---|---|
| 1 | Factors: 4 | Number of levels: 3 |
| 2 | Total runs: 81 | Replicates: 1 |

**Table 2**. Factors and selected levels

| Sr. No | | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| 1 | Injection Pressure | 45 | 50 | 55 |
| 2 | Injection Temperature | 190 | 200 | 210 |
| 3 | Mould temperature | 50 | 65 | 80 |
| 4 | Total Time | 40 | 45 | 50 |

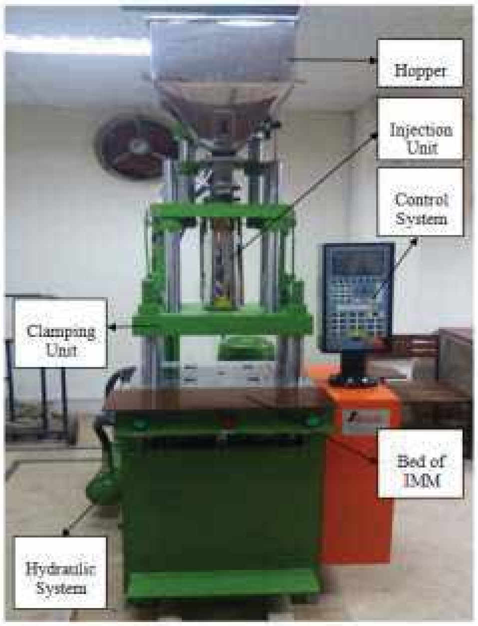


**Fig. 1.** Vertical plastic injection molding machine

Keeping in view the specifications and bed of injection molding machine, models of different plates are generated and then drawing of each plate is developed in CREO. The same drawings are then interacted with CNC five-axis machine through programs already generated from the drawings. Manufacturing of a mould in itself on CNC machine is a very difficult job. After programs communication with CNC five-axis machine, different process parameters are selected. Cutter diameter is taken as 20 mm while two process parameters are specifically paid attention. Cutting tool's speed is taken as 800 rpm while feed of cutting tool is taken as 100 mm/min as shown in Table 3. During removal of additional material, speed and feed of cutting tool is maintained constant as variations in speed and feed causes vibrations in various parts of a machine. The material of manufactured mould is mild steel which is generally used in market and the reason of selecting mild steel is the feasibility of this particular material in the market. Different views or phases of a mould in injection molding process can be seen in Fig. 2.

**Table 3**. Two process parameters and their values

| Sr. No | | | |
|---|---|---|---|
| 1 | Parameter 1 | Speed | 800 rpm |
| 2 | Parameter 2 | Feed | 100 mm/min |

### 3.4. Experimental Setup

The equipment on which parametric study is carried out is plastic injection molding machine (vertical) shown in Fig. 1. Each and every part of a machine has been labelled.

Injection molding process cycle is completed in four stages namely clamping, injection, cooling and ejection. Three stages of injection molding process have been shown in Fig. 2.

After performing experiments, picture of one of the product (Pharmaceutical cup) and surface roughness measuring tool used for measuring surface roughness of each and every product has been shown in Fig. 3.

Surface roughness taken over here is basically the arithmetic mean of the absolute values of the profile divergences or deviations from the mean bar, and it is represented by Ra.


**Fig. 2.** Different Phases of Injection Molding Process

**Fig. 3.** Surface Roughness Tester and Final Product (Pharmaceutical Cup)

## 4. RESULTS

The concluding results that are achieved from ANOVA using Minitab software by getting rid of all the insignificant process parameters are given in Table 4.

Referring to p-values given in Table 4 of analysis of variance, it is clear that these values are below 0.05. Hence, it is obvious that with more than 95% of confidence we can litigate that $C_3$ and $C_4$ (Mould Temperature and Total Time) are the significant factors and response variable (surface roughness) changes with these two factors. Hence, we reject the null hypothesis. The reason behind the insignificance of injection pressure and injection temperature ($C_1$ and $C_2$) is that the range between the first and the last level is very less and if injection pressure and injection temperature is taken less than the first level or greater than the final level, it will affect the response variable greatly and there will be chances of their significance.

Graph is drawn (Fig. 4) for all experiments and their corresponding surface roughness depicted in Appendix 1. It can be seen that random variation of combination of all the above mentioned parameters causes a general trend in surface roughness. Hence, increase or decrease of surface roughness of a product is random.

The maximum and minimum surface roughness that has been measured is 21.5 µm and 0.12 µm respectively and is obtained from experiment 5 and

**Table 4.** ANOVA Results

| Analysis of Variance | |
|---|---|
| Source | P-Value |
| $C_3$ (Mould Temperature) | 0.018 |
| $C_4$ (Total Time) | 0.012 |

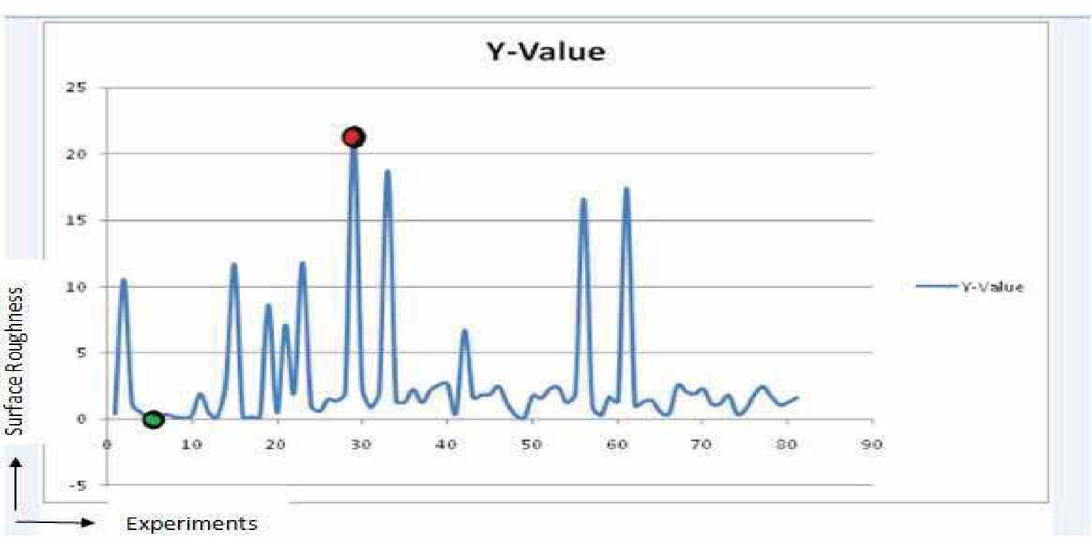


**Fig. 4.** Surface Roughness for the entire experiments

**Table 5.** The Best and worst case of process parameters and responses for polypropylene

| Sr. No | Factor 1 | Factor 2 | Factor 3 | Factor 4 | Response |
|---|---|---|---|---|---|
| | Pressure (Bar) | Temperature (Ċ) | Mould Temperature (Ċ) | Total Time (Sec) | Surface Roughness (μm) |
| Exp 5 | 45 | 190 | 65 | 40 | 0.12 |
| Exp 29 | 50 | 210 | 80 | 45 | 21.5 |

experiment 29 as shown in table 5. These values are also represented by red and green dots in Fig. 4.

Table 5 shows the best and worst cases of combination of process parameters and the resulting response variable. It is also evident from the best and worst cases that the difference between the surface roughness values is very large. Hence research can also be carried out on effect of mould material and mould surface roughness. In this case the mould used was made of mild steel which is largely used in local industry.

## 5. DISCUSSION

Injection molding has always been a challenging and demanding process to produce good quality products with low cost. With stiff competition in injection molding business, deploying the trial and error approach to establish the optimal process parametersis not good enough. Local manufacturer's in plastic injection molding (PIM) industry was facing problems of surface roughness and no design process and optimization techniques was applied to address the issue. As a consequence, product waste percentage was very high and final products quality was not up to the mark.

Setting of process variables and their optimization is very vital to enhance the worth of the moulded products. However, optimization of input parameters is not a simple task, because it usually depends on various factors, such as product design, mould surface finish, the molding machine and molding material etc [12]. Minute modifications of molding conditions may enhance a considerable jolt to the plastic's features. Several experimental research works were carried out to study the impact of the injection molding process parameters on the features of moulded products and their respective defects [13].

In this study or research paper, four parameters are selected for the analysis while surface roughness acted as a response variable. The experiments were performed on injection molding machine(vertical machine). After getting surface roughness values for each and every experiment, analysis of variance is applied in Minitab software to determine significant factors from the four selected input factors i.e. Temperature, time, pressure, and mould temperature. After interpretation of results obtained from Minitab, best feasible blend of input parameters is chosen for polypropylene. While performing the required number of experiments best and worst cases of surface roughness were achieved (as shown in Table 4). Furthermore, it can be observed that the surface roughness varied with the variation of these parameters and mould temperature and total time are the significant process parameters during experimentation.

Local industry making plastic products will benefit from the product and process development using latest tools employed in this project. It is an observation that the local industry is not using the scientific tools for their products made by injection molding process. Mould material would certainly have an impact on the mechanical properties of the products. Different mould materials behave differently during fabrication and if the quality of the mould cavity is not good enogh during manufacturing, it would certainly leed to quality problems during production of plastic products.

## 6. CONCLUSIONS

This research work has been conducted that aims to optimize the process parameters and position the best viable integration of selected process parameters. From the results in ANOVA , it has been observed that mould temperature and total time are the significant process parameters (shown in Table 4) and the minimum surface roughness value that has been measured for these parameters is 0.12 (shown in Table 5). Results showthat the best likely combination of parameters for polypropylene's with better surface smoothness is 45 bar, 190 Ċ, 65 Ċ, 40 sec for pressure, temperature, mould temperature and total time respectively (Experiment 5).

As most of the moulds used locally are imported from different countries which increase the final cost of plastic products, that's why mould designed and manufactured locally will benefit local customers, suppliers and manufacturers with minimum cost. So reducing the burden on foreign exchange by indigenous product development locally.

## 7. FUTURE PROSPECTS

Till date, a number of researchers worked on injection molding machine and large number of parameters were optimized to obtain a product with good quality and reasonable cost. Furthermore, future research work can be carried out by changing the mould material and its impact on surface finish of final product using injection molding machine. A comparative analysis of using other mould materials , its design and manufacturing process can be carried out for optimized results.

Likewise, material of plastic products might also be changed to find the impact of optimization on the parameters of the molding machine. Research can be taken into consideration in future related to bio-degradable polypropylene as it can be bio-degradable, if enhance bio decompositions (EBD).

## 8. ACKNOWLEDGMENT

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## Supplementary Data

APPENDIX 1. Combination of four process parameters and response variable(surface roughness)

| Sr. No | Variable 1 | Variable 2 | Variable 3 | Variable 4 | Response Variable |
|---|---|---|---|---|---|
| | Injection Pressure (Bar) | Injection Temperature (Ċ) | Mould's Temperature (Ċ) | Total Time (Sec) | Surface Roughness (μm) |
| 1 | 50 | 200 | 50 | 45 | 0.45 |
| 2 | 50 | 190 | 50 | 45 | 10.52 |
| 3 | 55 | 190 | 65 | 45 | 1.23 |
| 4 | 45 | 190 | 80 | 40 | 0.545 |
| 5 | 45 | 190 | 65 | 40 | 0.12 |
| 6 | 55 | 200 | 50 | 40 | 0.225 |
| 7 | 55 | 210 | 50 | 50 | 0.38 |
| 8 | 50 | 210 | 65 | 45 | 0.2 |
| 9 | 45 | 210 | 80 | 45 | 0.13 |
| 10 | 50 | 210 | 65 | 40 | 0.285 |
| 11 | 45 | 210 | 50 | 45 | 1.91 |
| 12 | 55 | 190 | 65 | 50 | 0.52 |
| 13 | 45 | 210 | 65 | 45 | 0.21 |
| 14 | 55 | 190 | 50 | 50 | 2.74 |
| 15 | 50 | 200 | 50 | 50 | 11.675 |
| 16 | 55 | 190 | 80 | 50 | 0.23 |
| 17 | 45 | 210 | 50 | 50 | 0.22 |
| 18 | 55 | 200 | 65 | 50 | 0.238 |
| 19 | 55 | 200 | 65 | 45 | 8.62 |
| 20 | 55 | 200 | 65 | 40 | 0.52 |
| 21 | 55 | 190 | 80 | 45 | 7.125 |
| 22 | 55 | 210 | 50 | 45 | 1.97 |
| 23 | 55 | 210 | 65 | 45 | 11.79 |
| 24 | 45 | 190 | 50 | 50 | 1.04 |
| 25 | 55 | 200 | 80 | 40 | 0.6 |
| 26 | 45 | 210 | 80 | 50 | 1.5 |
| 27 | 50 | 210 | 50 | 40 | 1.4 |
| 28 | 55 | 210 | 80 | 45 | 2 |
| 29 | 50 | 210 | 50 | 45 | 21.5 |
| 30 | 55 | 210 | 65 | 40 | 2.37 |
| 31 | 45 | 200 | 80 | 40 | 0.9 |
| 32 | 50 | 190 | 80 | 40 | 2.09 |
| 33 | 50 | 200 | 50 | 40 | 18.693 |
| 34 | 50 | 190 | 80 | 45 | 1.39 |
| 35 | 45 | 210 | 65 | 40 | 1.29 |
| 36 | 50 | 190 | 50 | 40 | 2.27 |
| 37 | 50 | 190 | 50 | 50 | 1.27 |
| 38 | 50 | 210 | 80 | 50 | 2.2 |
| 39 | 55 | 200 | 80 | 50 | 2.6 |

| | | | | | |
|---|---|---|---|---|---|
| 40 | 55 | 200 | 50 | 50 | 2.67 |
| 41 | 45 | 190 | 65 | 50 | 0.5 |
| 42 | 45 | 200 | 50 | 45 | 6.71 |
| 43 | 55 | 210 | 80 | 40 | 1.65 |
| 44 | 45 | 190 | 80 | 45 | 1.85 |
| 45 | 55 | 200 | 80 | 45 | 1.89 |
| 46 | 50 | 200 | 65 | 40 | 2.49 |
| 47 | 45 | 200 | 80 | 50 | 1.19 |
| 48 | 55 | 210 | 65 | 50 | 0.34 |
| 49 | 50 | 210 | 65 | 50 | 0.14 |
| 50 | 50 | 190 | 65 | 40 | 1.77 |
| 51 | 50 | 190 | 80 | 50 | 1.59 |
| 52 | 55 | 190 | 65 | 50 | 2.29 |
| 53 | 50 | 190 | 80 | 40 | 2.4 |
| 54 | 50 | 190 | 50 | 45 | 1.25 |
| 55 | 50 | 190 | 65 | 45 | 1.95 |
| 56 | 55 | 190 | 50 | 45 | 16.574 |
| 57 | 45 | 200 | 65 | 50 | 1 |
| 58 | 50 | 210 | 50 | 50 | 0.3 |
| 59 | 50 | 200 | 65 | 45 | 1.7 |
| 60 | 45 | 190 | 50 | 40 | 1.35 |
| 61 | 50 | 200 | 50 | 45 | 17.39 |
| 62 | 50 | 210 | 50 | 45 | 1.071 |
| 63 | 50 | 210 | 65 | 40 | 1.34 |
| 64 | 50 | 200 | 80 | 45 | 1.42 |
| 65 | 50 | 210 | 50 | 50 | 0.54 |
| 66 | 50 | 200 | 80 | 50 | 0.44 |
| 67 | 45 | 190 | 80 | 40 | 2.57 |
| 68 | 45 | 190 | 50 | 45 | 2.072 |
| 69 | 45 | 190 | 50 | 40 | 1.932 |
| 70 | 45 | 200 | 65 | 45 | 2.3 |
| 71 | 50 | 200 | 80 | 50 | 1.17 |
| 72 | 45 | 210 | 80 | 45 | 1.2 |
| 73 | 45 | 210 | 65 | 40 | 1.81 |
| 74 | 55 | 210 | 80 | 50 | 0.4 |
| 75 | 55 | 190 | 80 | 40 | 0.8 |
| 76 | 50 | 210 | 80 | 40 | 1.874 |
| 77 | 55 | 190 | 65 | 40 | 2.48 |
| 78 | 45 | 200 | 50 | 50 | 1.693 |
| 79 | 50 | 190 | 65 | 50 | 1.1 |
| 80 | 50 | 190 | 65 | 50 | 1.3 |
| 81 | 45 | 200 | 80 | 40 | 1.654 |