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Optimization of Injection Moulding Process Parameters for Disposable Specimen Collection Containers

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Abstract: Generally, in medical industry, the single use disposable specimen collection containers requirement has vastly increased. The main property of the container is transparency, to achieve this property in the manufacturing industries, uses only virgin polypropylene (PP) material. In the manufacturing process, the products are produced by injection moulding. By properly selecting various parameters which leads to better quality of products. In this work, the aim is to optimize injection moulding process parameters. The parameters selected are injection pressure, melting temperature, cooling time, packing time, and packing pressure. The optimization of the process parameters in injection moulding process by using recycled polypropylene specimen collection containers helps in the production cost, cycle time and virgin material cost.
Keywords: Injection Moulding, PP (Polypropylene), Urine Container, virgin PP, Recycled PP.

I. INTRODUCTION

As for the injection molding machine, several types such as plunger type, plunger preplasticating type, screw preplasticating type and in-line screw type, etc. Have been developed so far, but presently the in-line screw type injection molding machine as shown below figure. The injection molding machine consists of the injection unit and the clamping unit, and their features are described below.

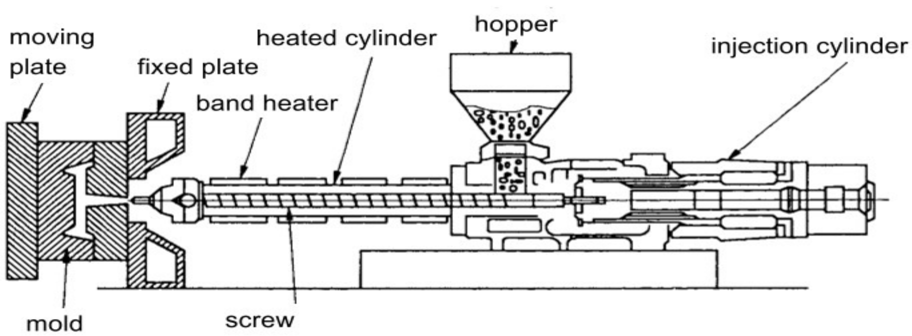

Fig 1: Theory of the in-line screw type injection molding machine

A. Hopper

The hopper is the component where the plastic material is poured before the injection molding process can begin. The hopper usually contains a dryer unit to keep moisture away from the plastic material. It may also have small magnets to prevent any harmful metallic particles from entering the machine. Next, the plastic material is poured into the following major component from the hopper, called the barrel.

B. Barrel

The barrel, or the material tube and barrel, heats the plastic material into a molten state to let plastic flow through the barrel. The screw inside injects the plastic into molds or cavities in the clamping unit. Therefore, the temperature in the barrel needs to be adequately regulated to maintain the appropriate temperature for different types of plastic material. The function of the cylinder is to transport, compact, melt, agitate and press the plastic before it reaches the injection mold.

C. Screw Motion or Reciprocating Screw

Reciprocating screws were created in the mid-1950s, and by 1960 they quickly began to replace the older systems. The advantage of the reciprocating screw design is that it helps manage the temperature of the molten plastic. The screw moves plastic through the barrel. First, as the pellets are fed from the hopper into the barrel, the screw is rotated, driving the material forward while more pellets are added. Second, the flights provide a continuous mixing action that distributes heat evenly throughout the mass. This mixing also helps to purge the mechanism of different materials and any colors left behind from an earlier production run on the same injection molding machine. The reciprocating screw is responsible for providing most heat to the thermoforming plastic. This is because the diameter of the screw decreases as it approaches the tip. As a result, plastic pellets are pulled along by the flights, compressed into a tighter space, and cut by turning flights. This action creates friction that mixes the pellets uniformly and heats them to the proper temperature.

D. Heaters

An injection molding machine can have different types of heaters for maintaining temperatures in conduits and nozzles and heating molds and platens. A heating element can be attached to the barrel and used to melt the hopper's molding material to become liquified material. Some of the different types of injection molding heaters include band heaters, coil/nozzle heaters, cartridge & strip heaters, and insulated cloth heating jackets.

E. Nozzle

The nozzle is an injection molding component located at the bottom of the machine's ejector system. It pushes liquified plastic out of the barrel and into the mold. The nozzle rests against a surface on the mold called the sprue bushing and locating ring, which helps center the nozzle on the mold. Today, nozzles can provide a variety of functions, including filtering, mixing, and shut-off of melt flow. Nozzle filters can minimize the clogging of gates and hot runner tips from foreign material or contamination in the melt stream. Mixing nozzles can enhance the dispersion and mixing of additives, improving molded part quality while reducing the volume and cost of additives. Shut-off nozzles can reduce drool in injection molding operations where the press is frequently disengaged from the mold, such as in many two-shot molding applications.

F. Extraction Pins or Ejector Pins

Ejector pins are vital in creating parts. They are an essential component of the ejection system in molds, which determines the outcome of products in an injection molding process. The metal injection mold comprises two parts: A and B sides. After the molten material in the mold is cooled, both parts are separated to remove the solid plastic. Injection molds are built so that when they are opened, the A-side half is lifted, leaving the formed part and the B-side. Extraction pins are found on the B-side half of the injection mold, where they push the formed part out of the mold (or extract it). The pin mark is commonly imprinted on finished products as a dent. There are many types of ejector pins. Through-hard ejector pins are heat-treated to ensure consistency in the hardness through the diameter of the pin. A case-hardened ejector pin is much harder than the through-hard pins and is suitable for die casting ejection systems. A black ejector pin is coated with a black surface treatment, allowing it to self-lubricate and withstand high temperatures up to 1000°C.

G. Split Molds

In injection molding, a parting line is where two halves of a mold meet when closed, especially on a split mold. The plastic product created by the injection mold is divided into two parts, and the line separating the two mold haves are called parting lines. Split molds are one type of injection mold, where the jaws form the mold cavity. The jaws are injected diagonally on the nozzle side and are then moved on the diagonal to the outside when the mold opens with a pull tab. Then the injection molded part is released.
The jaws can also be guided on the ejector side. They are then moved, during or after opening the mold, mostly with hydraulic cylinders or mechanically using springs or air.

II. INJECTION MOULDING PROCESS

A. Working Of Injection Moulding Machine

The injection molding process begins with the gravity feeding of polyolefin pellets from a hopper into the plastic ting/injection unit of the molding machine. Heat and pressure are applied to the polyolefin resin, causing it to melt and flow. The melt is injected under high pressure into the mold. 11 Pressure is maintained on the material in the cavity until it cools and solidifies.

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When the part temperatures have been reduced sufficiently below the material's distortion temperature, the mold opens, and the part is ejected. The complete process is called a molding cycle. The period between the start of the injection of the melt into the mold cavity and the opening of the mold is called the clamp close time. The total injection cycle time consists of the clamp close time plus the time required to open the mold, eject the part, and close the mold again. There are four basic components to an injection molding machine:

1) Injection

Plunger injection units were the first types used for injection molding, but their use today is quite limited. Schematic cross-section of a typical plunger (or ram or piston) injection molding system the reciprocating screw injection molded is the most common molding machine in use today for moulding polyolefins. The injection unit mixes, plasticated and injects a thermoplastic melt into a closed mold. The reciprocating screw accomplishes this in the following manner:

a) The injection cycle starts with the screw in the forward position.
b) Initially, the screw begins to rotate in the heated barrel. Resin pellets are forced by this action to move forward through the channels of the screw.
c) As the pellets move forward, they are tumbled, mixed, and gradually compressed together as the screw channels become shallower. The section of the screw nearest the hopper is called the feed section, in which no compression takes place.
d) As the pellets travel down the barrel, they are heated by friction and the heat conducted from the external electric heater bands. The friction is caused by the pellets sliding against themselves and the inner wall of the barrel and the screw surface. The heat from the friction and conduction causes the pellets to melt. The majority of the melting occurs in the transition section of the screw, where compression of the polymer is taking place as the root diameter of the screw is increased.
e) Next, the melted polymer is further mixed and homogenized in the metering section of the screw. In the metering section of the screw, the root diameter has reached its maximum, and no further compression takes place.
f) The polymer melt flows in front of the screw tip and the pressure produced by the build-up of polymer in front of the screw causes the screw to be pushed backward in the barrel as it continues to rotate.
g) The screw stops turning when the volume of melt produced ahead of the screw tip is sufficient to completely fill the mold cavity and runner system (the channels leading to the mold cavity). This amount of material is called the shot size and the period during which the screw rotates is called the screw recovery time.
h) The screw is then forced forward, injecting the melt into the mold. This is called the injection stage.

2) Clamping

There are three basic types of injection molding machine clamps: mechanical, also called toggle units, hydraulic and a combination of these called hydromechanical clamps. Toggle clamps, which are less expensive to build, are most widely used on small tonnage machines (typically, less than 500 tons). The toggle action can best be understood by looking at your arm when it is bent at the elbow and then when it is fully extended. In the toggle clamp, a hydraulic cylinder moves the unit’s crosshead forward, extending the toggle links and pushing the platen forward. The mechanical advantage is low as the clamp opens or closes, which permits rapid clamp movement. This action slows and the mechanical advantage increases as the platen reaches the mold-close position. The slow speed is important for mold protection. Full clamp pressure is reached when the linkage is fully extended. To adjust the toggle clamp to different mold heights, the entire toggle mechanism and moving platen assembly are moved along tie rods.

The position of the toggle mechanism depends on where the mold closes when the toggle is at full extension. The toggle opens when hydraulic pressure is applied to the opposite side of the clamp cylinder. Hydraulic clamps generally are used on injection molding machines in the 150 ton to 1,000+ ton clamp tonnage range. In this type of clamp, hydraulic oil is used to move the platen through the full closing and opening strokes. The fluid is metered into a reservoir behind the main ram. At first quite rapid, the oil flow is slowed as the ram reaches the mold-close position in order to protect. Toggle clamping system. Hydraulic clamping system 16 mold. An oil fill valve closes when the mold is closed. The area behind the ram is then pressurized to build full clamp tonnage. To open the mold, the oil valve is first partially opened to smoothly open the mold. Once the mold halves are separated, the clamp accelerates to a fast open speed. Mold set-up is much easier with a hydraulic clamp than with a toggle clamp since hydraulic clamp tonnage can be reached anywhere along the clamp stroke. Mold set-up is accomplished by setting the clamp position from the machine’s control center. Hydromechanical clamps are commonly used on very large injection molding machines, i.e., over 1000 tons. In the hydromechanical clamp, a hydraulically actuated toggle mechanism pushes the moving platen at high speed to a point where the mold halves are nearly closed. A mechanical locking plate or links prevent rearward movement during final build-up to full clamp tonnage. Short-stroke hydraulic cylinders are used to move the platen the final short closing distance and develop full clamp tonnage.

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3) Injection Molds

There are many types of injection molds and tooling in use today, such as two-plate, three-plate, and stack molds. Two and three-plate molds are more commonly used for heavy wall and non-packaging products. Both cold and hot-runner systems are used for two and three-plate molds. All stack molds use a hot manifold to convey the melt to the cavities. Each mold component must be machined and finished to exact dimensions with very tight tolerances and must be heat-treated to be able to withstand very high injection and clamp pressures. Injection molds are the most expensive molds used in plastics processing with very long lead times required for their design and fabrication. Every mold must be tested and debugged to prove out the ejection system, cooling and/or heating system and operating components before it is placed in production.

4) Control System

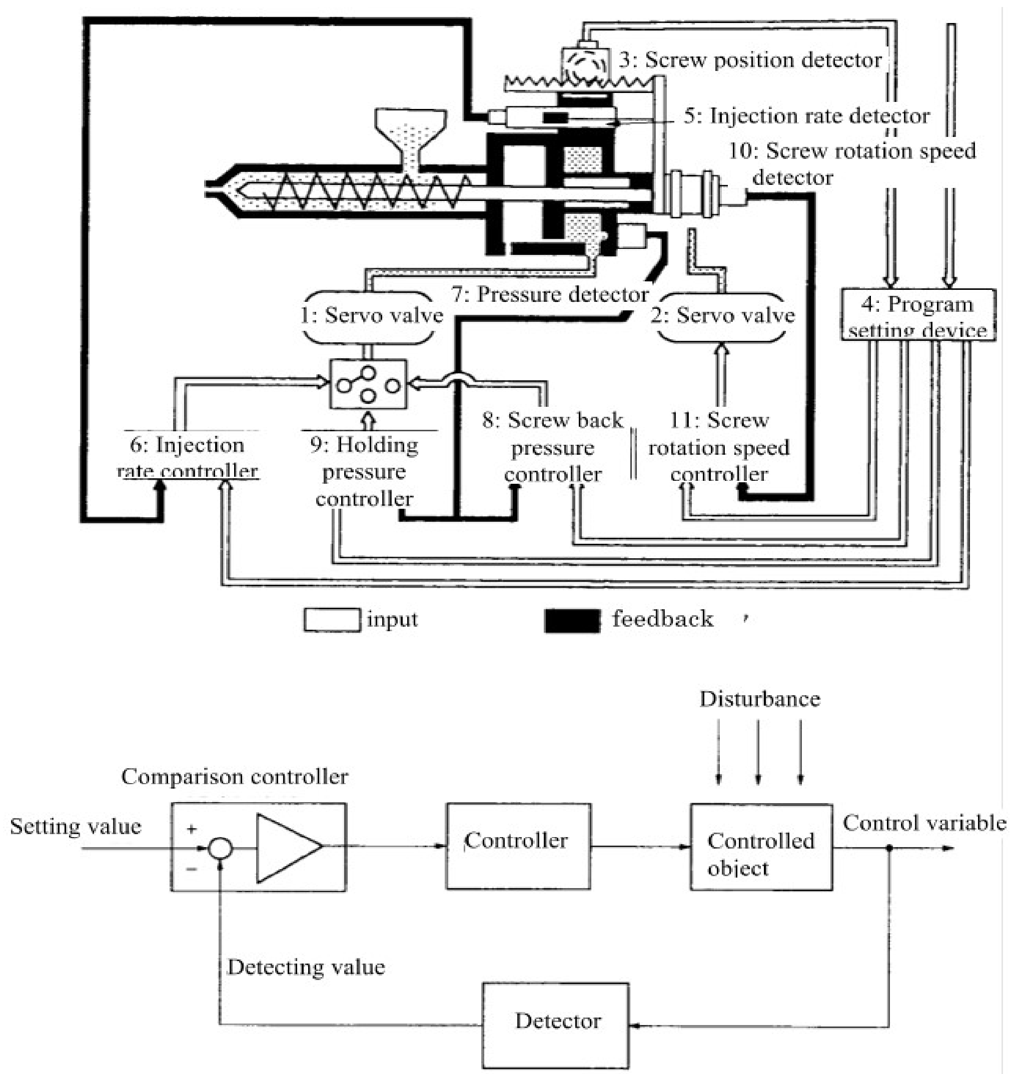


Fig 2: Injection Molding Control System

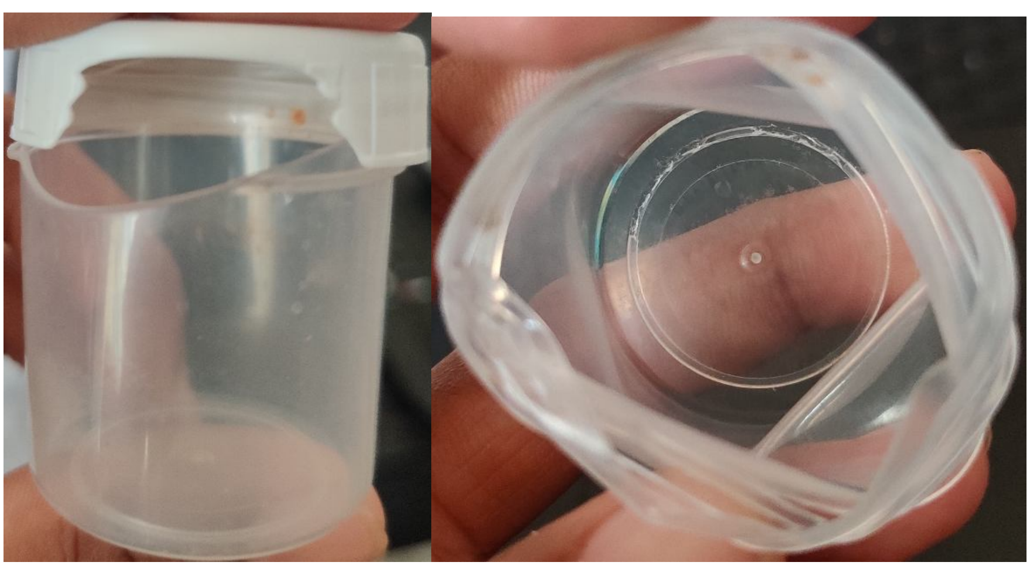
A control System for an injection molding machine performs a molding cycle. The molding cycle includes a filling process for controlling an advancing motion of a Screw of the injection molding machine, and a hold press Process for controlling a pressure of a molten resin after the filling process. The control System includes retracting Speed limit
means for limiting a retracting Speed of the Screw to a predetermined retracting Speed limit value after a pressure control in the hold press process begins.

B. Defects In Plastic Injection Molding

However, all defects can avoid and removed by proper selection and optimization of process parameters.

Table 1: Effect of Injection Molding Parameters on Product Quality

DEFECT	ADJUSTMENT FOR PARAMETER SETTINGS
Poor surface finish	Increase shot size Increase injection pressure and speed Increase melt temperature Increase mold temperature Increase cycle time
Flash	Decrease melt temperature Decrease injection pressure Decrease cycle time Improve mold venting Increased clamp pressure
Weld lines	Increase injection pressure Increase packing duration and pressure Increase melt temperature Increase mold temperature
Sinks or Voids	Increase injection pressure Increase packing duration and pressure Increase melt temperature Decrease mold temperature
Warpage	Increase mold temperature Increase injection pressure and velocity Increase packing duration and pressure



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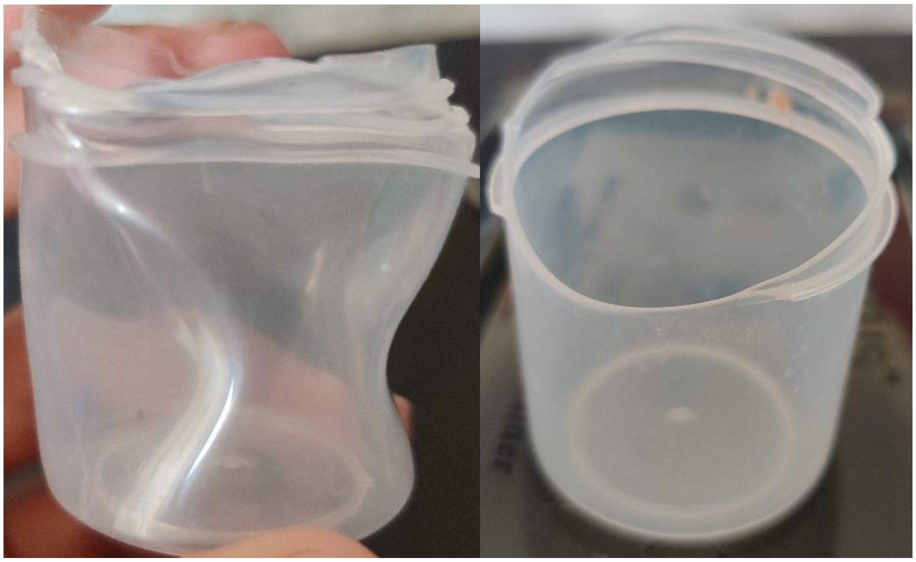

Fig 3: Defects of Products on various parameters

The value of shrinkage is different for different type of plastic materials, in some plastics, it may be zero and others it may little or in some, it may be higher in degrees. The value of tolerance in molded parts is mainly determined by the predicted value of shrinkage rightly. It's hard to control and predict shrinkage because it is not isotropic always. The amount of shrinkage is depending upon following causes:

- Uneven cooling
- Non-uniform volumetric shrinkage
- Anisotropic material behaviors
- Differential thermal strain

From above table, its show effect of varies process parameters on shrinkage. Shrinkage is increased with increasing in melt temperature, mold temperature, and part thickness but in the case of increasing packing pressure and packing duration it is decreasing. With increasing of injection rate, the first shrinkage reduced, but slowly it is increasing.

C. Selection Of The Injection Moulding Parameters And Their Levels

A large number of process variable affect the quality of products made by injection moulding process. The process parameters that will influence the results of the experiments have to be recognized before starting the experiments to ease the further analysis in DOE as these parameters will contribute to the variations of results and influence the results due to the adjustments of parameters. All the parameters involved during injection moulding process can be grouped into three basic categories: temperature, pressure, time. Temperature is the most important of the process parameters, followed by pressure, time. However, these parameters are mutually interdependent and changing one requires the adjustment of the other parameters as well.

To visualize the effect of process parameters on the impact strengths of PP Container, following parameters were selected: injection pressure, melting temperature, cooling time, packing time, and packing pressure. Other parameters such as injection pressure (120 bars) and cooling time (4 – 5 s) were kept constant during the experimentation. Keeping in view the importance of the main process parameters and their effect on the performance characteristics, working range of each parameter was carefully chosen to produce the PP Containers of acceptable quality. Each parameter level was then selected carefully, and the experiments were performed as per the Taguchi L9 orthogonal array.

III.EXPERIMENTATION

A. Materials

Polypropylene (Isofil H 40 C2 F NAT), obtained from PT. Trias Sentosa Manufacturing

Sidoarjo, and constituting 40% calcium carbonate, was the polymer material used in the experiment. The material is quite popular owing to its cheapness and appropriate for use in any application and is quite commonly used in manufacturing products in the automotive industry: dashboard components, medical containers, fans, ductwork, among others. Since the material was stored properly, there was no need for drying it. Polypropylene’s properties are presented in Table 2.

Table 2: Properties of polypropylene

Physical properties	Value
Tensile strength	0.95 - 1.30 N/mm2
Notched impact strength	3.0 - 30.0 Kj/m2
Thermal coefficient of expansion	100 - 150 E-06
Max. continued use temperature	80 oC (176 oF)
Melting point	160 oC (320 oF)
Glass transition temp. (atactic)	-20 oC (-4 oF)
Glass transition temp. (isotactic)	100 oC (212 oF)
Density	0.905 g/cm3

B. Experiment Equipment and Mould

The injection molding machine used in this experiment is Haitian Plastics Machinery MA2000 with the Pump capacity of 22 KW, injection pressure of 1540 bar. The mould used in the experiment is manufactured with the steel. The term generally refers to the whole assembly of parts that make up the section of the moulding equipment in which the parts are formed.

Fig 4: Polypropylene used

The material used in this experiment is polypropylene (PP). The polypropylene has many Variants, but the material used in this process is homopolymer polypropylene of H110MA grade. The electronic weighing machine is used for Weight measurement after plastic injection molding process. The weighing machine used for the experiment is electronic type having the weight limit 0.01 gm. to 200gm.

C. Experimental Method

Experiments are taken to study the effects of different process parameters in polypropylene injection molding machine. The orthogonal experiment method (Taguchi method) is conducted to arrange experiments. The Taguchi method is well-known technique that provides a systematic and efficient methodology for process optimisation. It has been widely used for product design and process optimisation worldwide. Using the orthogonal experiment method, results of experiments can be analysed. Each parameter at levels 3 was considered. The parameters shown in below Table 3.

Table 3: shows the injection moulding parameters and their levels

Factor	Parameter	Unit	Level 1	Level 2	Level 3
A	Melting Temperature	oC	215	220	225
B	Injection Pressure	Bar	350	450	550

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Fig 5: Final product

IV. RESULTS AND DISCUSSIONS

Experiments were performed by making Urine container products with a bottom diameter of 35 mm and top diameter of 35 mm. The materials used were Polypropylene material (PP). Machine used was a plastic molding machine branded Haitian Plastics Machinery MA2000 with a capacity of 200 Tons. From the results of the Central Composite experimental design used, it looked that almost all these factors had a significant influence. The model approaches were full quadratic models which meant to include linear models and their interactions. In the linear model, the injection speed and time factors showed retaining significant influence, whereas the quadratic model injection pressure, injection temperature, injection speed and retention time also had a significant influence.

Besides, in the interaction of two factors, the interaction effect of the injection pressure and injection temperature also had a significant influence. The results are recorded and observations of each product either with the senses or by means of a magnifying glass to detect defects in the product. The proportion of defects was calculated by comparing the number of defective products for every 10 performed replicates for the types of defects that arised among others in the form of bubbles, the dimensions of which did not match, a hole and other small defects. As shown in the following figures.

Fig 6: The product of PIM: Urine Container

V. CONCLUSIONS

The main objective of this research work is to identify parameters which affects the performance of the Urine Container and determine an effective method to incorporate the critical performance factor into an equation in order formulate a suitable performance rating method and recycling plastic can reduce consumption of energy. The effect of recycled PP and virgin PP on impact strength optimal values of process parameters was analyzed. The optimal amounts of mixture components to produce recycled plastic products are determined. As the results of doing systematic experimentation, using mixture experiments, the quality of recycled plastic products can be improved and becomes more robust to variations at the optimal operating settings. The results have proven that the manufacturer can use these settings of recycled PP and virgin PP to produce quality products with low cost (quality depends on source as some recycled content qualities can be very high) and environmental impact reduction.

In this work, the effect of using pre-consumer PP scraps (which can be collected during Urine Container production process), as an alternative to post-consumer recycling, mixed with virgin Urine Container PP on static and long-term mechanical properties is studied. Samples were prepared by blending virgin PP with various contents of recycled PP.

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