

Research Article

Design and Simulation of Screw Flow in a Prototype Injection Molding Machine Using Recycled Polypropylene

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Abstract: Plastic waste is currently still a serious problem for society due to the lack of sensitivity to environmental problems and the impact of careless disposal of plastic waste in many places. The injection molding process on industry scale often faces obstacles such as machines that have not worked efficiently, injection capacity that is unable to fill the mold completely, and the emergence of product defects due to plastic flow that begins to freeze before the entire cavity is completely filled. This study aims to design and simulate a prototype injection molding machine with a capacity of 4 tensile test specimens (total volume 28.5 cm³) in order to overcome these problems and to adjust the practicum needs of mechanical engineering students. The design process is carried out with SolidWorks software for 3D design, as well as flow simulation using SolidWorks Plastics and Flow Simulation with recycled Polypropylene (PP) material at melting temperature ± 230 ° C and injection pressure ± 5.3 MPa. The design results in a machine with dimensions of 1273 × 400 × 826 mm equipped with main components in the form of a frame, electric motor and gearbox, hopper, body safety, wheels, piston cylinder, control panel, heater, screw with barrel, and mold. SolidWorks Plastics simulation shows that the plastic flow fills the mold evenly with a filling time of 10.93 seconds, cycle time of 83.94 seconds, and maximum pressure of 5.38 MPa in the gate area, while Flow Simulation simulation shows a spiral flow pattern from the hopper to the end of the mold without backflow, with a mass flow rate of 0.0227 kg/sec and an average pressure of 97.765 Pa. These results prove that the design and simulation can improve process efficiency and mold quality.

Keywords: Design; Flow Simulation; Polypropylene recycle; Prototype Injection moulding; Screw.

1. Introduction

According to (Kazmer, 2016), design simulation in injection molding is very important for identifying potential errors in mechanical and thermal systems prior to production, thereby reducing the risk of product defects and improving process efficiency. In addition, (Groover, 2019) also emphasizes that the use of simulation in manufacturing engineering can help analyze structural and thermal aspects, ensuring that the resulting design is more optimal and in line with production requirements. However, in the context of this project, one of the main issues that has not been addressed in previous designs is the lack of simulation of the mechanical movement of the machine and the flow of recycled plastic fluid. Without in-depth analysis, it is difficult to ensure that the injection system can flow plastic optimally without obstacles or premature freezing that could cause product failure. Therefore, machine motion simulation and fluid flow analysis are necessary to achieve a more effective and efficient design. If these simulations are conducted from the early stages of design, potential issues can be identified earlier, allowing the design to be improved before entering the physical manufacturing and testing phases.

Simulations using SolidWorks software will be conducted to ensure that this new tool can actually operate as intended and be used properly. SolidWorks is one of the most widely used 3D simulation and design software among students, enabling virtual analysis to support design and simulation. With SolidWorks, important parameters such as motion analysis and mold design can be performed to analyze pneumatic motion systems and molding systems

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(Munandar, 2020). Additionally, the use of flow simulation in SolidWorks enables analysis of plastic fluid flow during the injection process, allowing evaluation of flow patterns and the possibility of premature freezing in the mold cavity. With this simulation, design can be further optimized to ensure more even material distribution and reduce the risk of defects in the final product. The mechanical and thermal analysis features of SolidWorks software can predict material behavior, operating pressure, and the durability of designed components. Therefore, the use of SolidWorks software in simulation (Dassault Systèmes, 2021) can enhance design efficiency and prevent errors that could potentially cause functional failures before the tool is manufactured.

2. State of The Art

(Gusniar, 2018) Plastic waste is a serious problem in Indonesia. In 2015, the Ministry of Environment recorded an increase in waste accumulation reaching 175,000 tons/day, 15% of which was plastic waste. Various studies have been conducted to transform plastic waste into more useful products, such as the production of paving blocks made from plastic waste. One type of plastic waste, HDPE (High-Density Polyethylene), is converted into hexagonal paving blocks measuring 50 x 50 x 20 using an injection molding machine. The average compressive strength test result exceeded the minimum standard for C-grade paving blocks intended for pedestrians, which is 220,858 kg/cm², compared to the standard compressive strength of 127,460 kg/cm² (SNI 03-0691-1996).

Design of the Tipipiel One Machine for Processing Plastic Waste into Plastic Pellets Using the Pelletizing Method (Syarafina, 2022). The success of the Tipipiel One machine can be seen from the quality of the plastic pellets produced by the machine. The optimal temperature for melting Polyethylene Terephthalate (PET) plastic waste using the Tipipiel One machine is 200°C. The machine's capacity is 0.08 kg/hour due to the small size of the barrel. The electrical energy required for the "Tipipiel One" machine to operate for 8 hours is 9.372 kWh. With the "Tipipiel One" machine, it is hoped that the accumulation of waste in the environment can be reduced and environmental pollution caused by plastic waste can be prevented.

2.1. Polypropylene Recycle Materials

The plastic pellets to be used are polypropylene (PP) with a melting point of 200-300 °C or 392-572 °F (Mujiarto I, 2015). This type of plastic was chosen for several reasons, including its heat resistance, good flexibility, which makes it easy to recycle and reshape into various products, and its availability. Thermoplastics can melt at a certain temperature; the melting point of thermoplastics can be seen in Table 1 below.

Table 1. Thermoplastic Melting Temperature [4]

Material	Pure	Recycle
Temperature	°C	°C
ABS	180-240	170-230
Acetal	185-225	175-220
Acrylic	180-250	170-240
Nylon	260-290	245-280
Poly Carbonat	280-310	270-305
LDPE	160-240	155-235
HDPE	200-280	190-270
PP	200-300	190-290
PS	180-260	179-250
PVC	160-180	100-170

2.2 Injection Moulding Development

Design and construction of an injection molding machine unit for the production of thread cones with a capacity of 1 piece (Feriansyah, 2023). The results of the thread cone tool design show that this tool is capable of withstanding loads of up to 51.9 kg on the frame, producing good thread cone products at a melting temperature of 180°C, has a low frame flexibility level, and has an appropriate plastic melt flow rate. "Manufacturing of an Injection Molding Machine Unit for Producing Underarm Crutch Pads from Polypropylene Material" [10]. In the production of this injection unit, a barrel capacity of 137.444 cm³ was obtained.

The parameters that need to be considered are the dimensions of each part of the tool, temperature, pressure, and time. In this study, the most suitable molding parameters were also determined, namely injection pressure of 150 bar and melt temperature of 200°C. Material testing was then conducted, with density testing yielding a result of 0.89 g/cm³ and hardness testing yielding a result of 75.6 Shore D.

3. Research Method

The research method used was the engineering design method (Susanto RE, 2022), which began with the data collection stage (observational study and literature study), followed by the machine component planning stage (selection, determination, and calculation of components based on appropriate criteria), and continued with the design stage, which included the measurements that had been carried out in the planning stage. The final stage is the machine/prototype manufacturing process. This research was conducted up to the dimensional design stage (shown in Figure 1) (Riswan Eko Wahyu Susanto, 2023), followed by simulations (there are many simulations for each part/component) of several components, one of which is Flow Simulation in the Screw Injection system. The design and simulation were carried out using SolidWorks on the injection molding machine prototype.

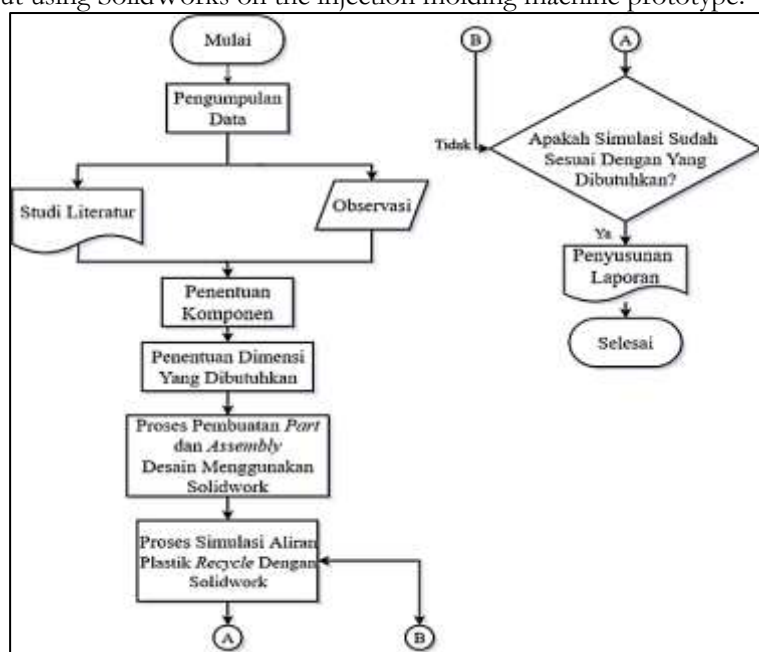


Figure 1. Research Flow Chart (Engineering Design + Flow Simulation)

3.1. Design Determination Parameters

Before starting the design process, various technical and functional parameters were identified as the basis for machine design decisions. These parameters were obtained from product specifications, plastic material characteristics, SolidWorks Plastics simulations, and local manufacturing limitations. The parameters in question are described as follows:

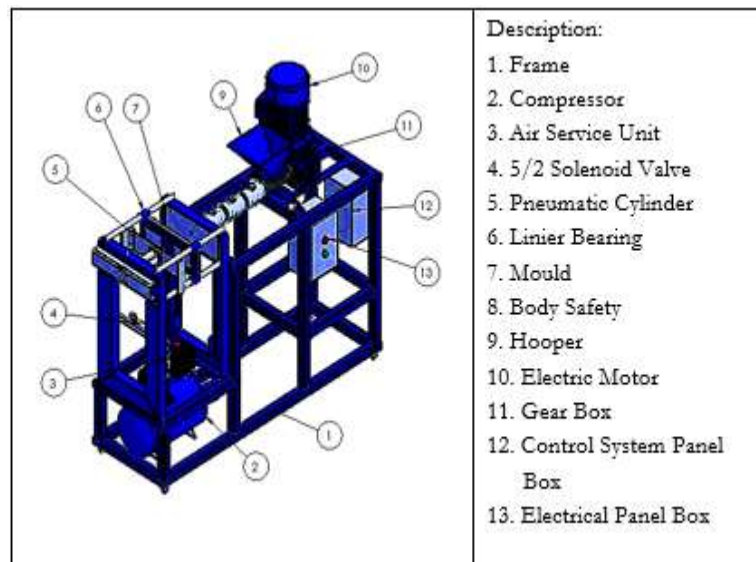


Figure 2. Desain Awal Prototype Injection Moulding

Table 2. Design Determination Parameters

No	Parameter	Value / Consideration	Functions in Design
1	Machine Functions	Print 4 tensile test specimens	Determining the number of cavities and mold capacity
2	Volume Total Cetakan	28,5 cm ³	Determining barrel capacity and screw size
3	Product Material	Polypropylene (PP) recycle	Determining melting point and viscosity
4	Melting Temperature of PP	±230 °C	Determining heating power and temperature control systems
5	Mold Temperature	±70 °C	Ensuring the plastic freezing process
6	Maximum Injection Pressure	±48 bar / 5,3 MPa	Determining the strength of the frame structure and locking system
7	Plastic Fluid Flow Velocity	±2,8 cm ³ /s	Determining nozzle design and filling efficiency
8	Filling Time	±10 seconds	Determining screw speed and work cycle
9	Screw type	Right-hand helical thread, Ø32.4 mm	Adjusting flow volume and mold length
10	Screw Length	612 mm	Mendukung proses plastisasi penuh
11	Frame Material	40 × 40 mm hollow steel	Menopang tekanan dan getaran injeksi
12	Heater	Band heater Ø80,25 mm	Menghasilkan suhu merata sepanjang barrel
13	Automatic Control	Arduino + switch panel	Mengendalikan pemanas dan motor secara presisi
14	Operator Safety (K3)	Heater cover body safety	Protecting against the risk of burns
15	Cost and Availability of Components	Use local materials (iron, Arduino, etc.)	Reducing production costs without compromising functionality

3.2. Determination of Simulation Parameters for Dimensions and Materials

Before conducting simulations on the design results, the initial data used as a reference in the simulation process must first be determined. This data includes material type and injection parameters. The initial data is obtained from literature studies and technical specifications of the components used in the design. For each process, a simulation will be conducted using SolidWorks Plastic software to analyze plastic material flow during the filling process, pressure and temperature distribution within the mold cavity, and the potential occurrence of defects such as weld lines, air traps, and cavity voids.

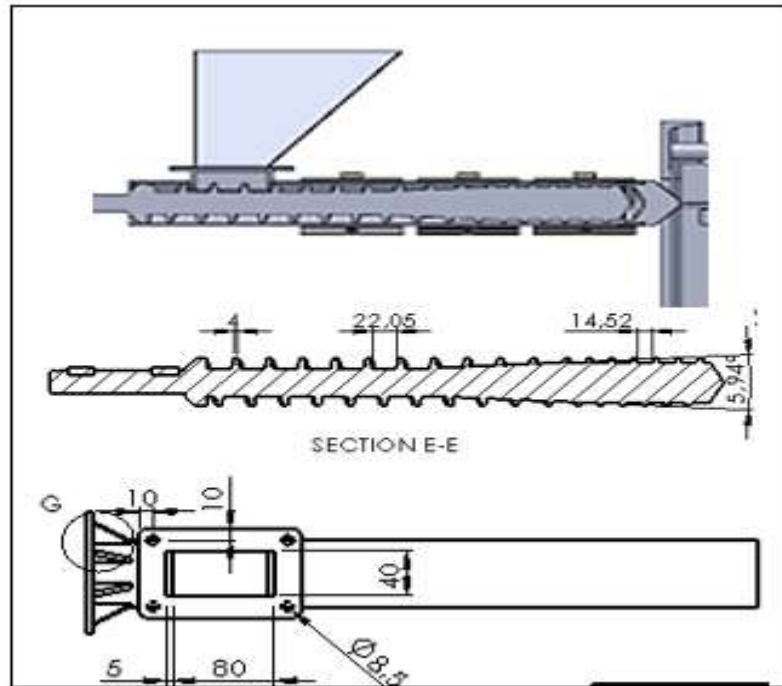


Figure 3. Screw injection design to be simulated

Table 3. Material flow simulation [4]

No	Parameter	Value / Description
1	Material Name	Polypropylene (PP)
2	Melting temperature of pure PP	200–300 °C
3	Melting temperature of recycled PP	190–290 °C

4. Results and Discussions

The following results and discussion briefly describe the results of the design of the components of the Injection Molding prototype with simulations concentrated on screw injection flow simulation, which is the part that drives and presses the plastic material to be molded.

4.1. Injection Molding Component Design Results

The design process was carried out in stages, beginning with the initial design, determination of components, selection and calculation of components and component materials, and ending with the final drawings complete with dimensions and component materials. The following components are available: frame structure, transmission system, and injection system.

- Frame, the machine frame is designed from 40×40 mm hollow steel profiles with a total height of 790 mm, a length of 1240 mm, and a width of 400 mm. The frame is divided into three main compartments, each 360 mm wide, with an additional compartment on the left side that is 360 mm wide and 500 mm high. On the sides, the height is divided into 460 mm (top) and 210 mm (bottom). Bolt holes with diameters of 10 mm and 16 mm are provided on the top as mounting points, with spacing between features such as 87 mm, 85 mm, 62 mm, and 35 mm according to the requirements of the component mounts. All joints are welded to ensure structural rigidity and stability during operation.
- Hopper, the hopper is designed in an inverted trapezoidal shape with a total height of ± 181 mm, an upper mouth width of 180 mm, and a lower width of 80 mm. The angle of the side walls is 65° , while the front side has an angle of 49° . The distance between mounting holes on the mounting plate is 71.76 mm, with a hole diameter of $\text{Ø}8.5$ mm and an edge radius of R5. This hopper serves as an inlet for plastic material into the barrel and is designed to facilitate material flow by gravity.
- Front Mold Support Frame, this component is a front mold support frame with total dimensions of $345 \text{ mm} \times 680 \text{ mm}$ and a thickness of 40.64 mm, the same as the rear

mold support frame. There are four mounting holes with a diameter of $\text{Ø}10.0$ mm, as well as an internal cavity with a width of 192.60 mm for the mold mounting. The internal profile is equipped with a chamfer and a radius of R6.86 mm to ensure precise mounting. The half-circle holes with a radius of R35 mm serve as access paths for opening and closing the nozzle.

- Back Mold Support Frame, This support frame has total dimensions of 345 mm \times 680 mm with a profile thickness of 40.64 mm. The inside of the frame has a support cavity with an opening width of 192.60 mm.
- Transmission system, The electric motor has total dimensions of 323 mm in length, 200 mm in height, and ± 172 mm in width. The main shaft diameter is $\text{Ø}25$ mm with a shaft length of 47 mm. The horizontal mounting hole spacing is 130 mm and the vertical spacing is 121.77 mm, with a bolt hole diameter of $\text{Ø}11$ mm. This motor is designed as the main drive for the screw in the injection system. The gearbox has total dimensions of 191 mm in length, 167 mm in width, and 200 mm in height. The input shaft diameter is $\text{Ø}25$ mm, while the output shaft hole diameter is $\text{Ø}30$ mm. The distance between the horizontal mounting holes is 114.1 mm and the vertical mounting holes is 128 mm. This gearbox is used as a speed reducer from the electric motor to the screw, with flange-shaped mounts for precise integration.
- Injection system. The screw has a total length of 612 mm with a main thread diameter of $\text{Ø}32.4$ mm and a rear shaft diameter of $\text{Ø}25$ mm. The threaded section is approximately 452 mm long with a right-hand helical thread. The end of the screw has a 45° tapered profile and a support diameter of $\text{Ø}22.05$ mm. This component functions as the main driver of plastic material toward the nozzle during the injection process.

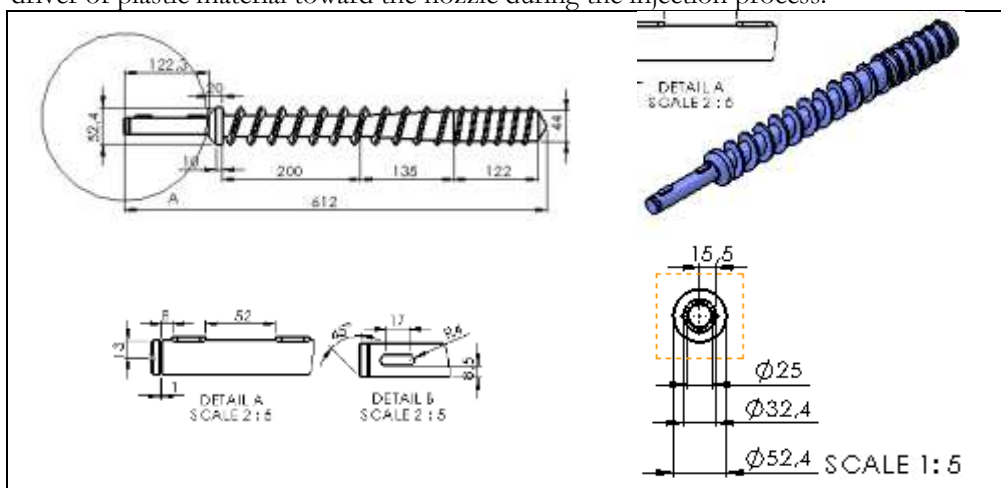
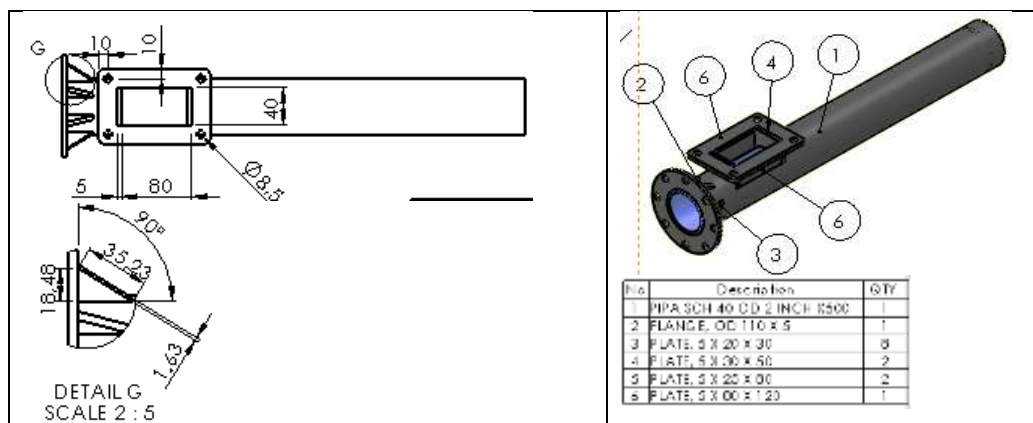


Figure 4. Screw Injection

The barrel has a total length of 500 mm and an outer diameter of $\text{Ø}60.3$ mm, using a SCH 40 OD 2-inch pipe. The front section is equipped with a $\text{Ø}110$ mm flange with a thickness of 5 mm as a connection mount to the nozzle. A reinforcement plate mount is arranged on the underside along a length of 120 mm to support the barrel on the frame. This component functions as a plastic melting chamber before being pushed toward the mold by the screw.



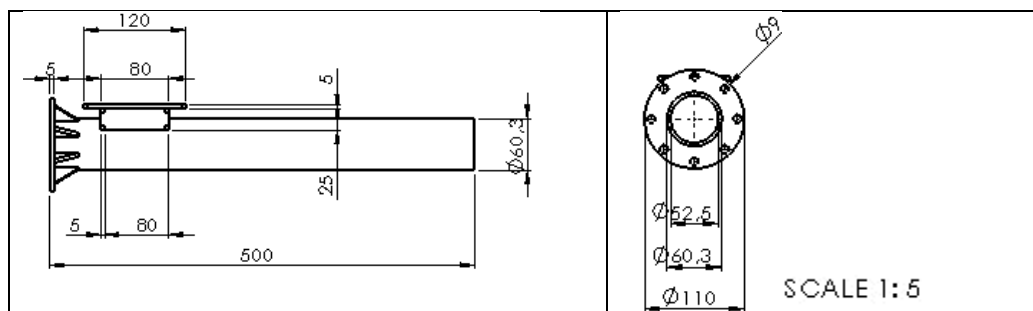


Figure 5. Barrel Injection Design

The band heater is designed in a cylindrical shape with an inner diameter of $\text{Ø}80.25$ mm and a height of 73.79 mm, matching the outer dimensions of the barrel. There is a 20×20 mm box mount on the top for electrical connections. Two $\text{Ø}8$ mm locking bolts are installed at the bottom as clamps to the barrel, with a clamp curvature radius of R2.04 mm. This component is used to generate even heat on the barrel surface during the plastic melting process.

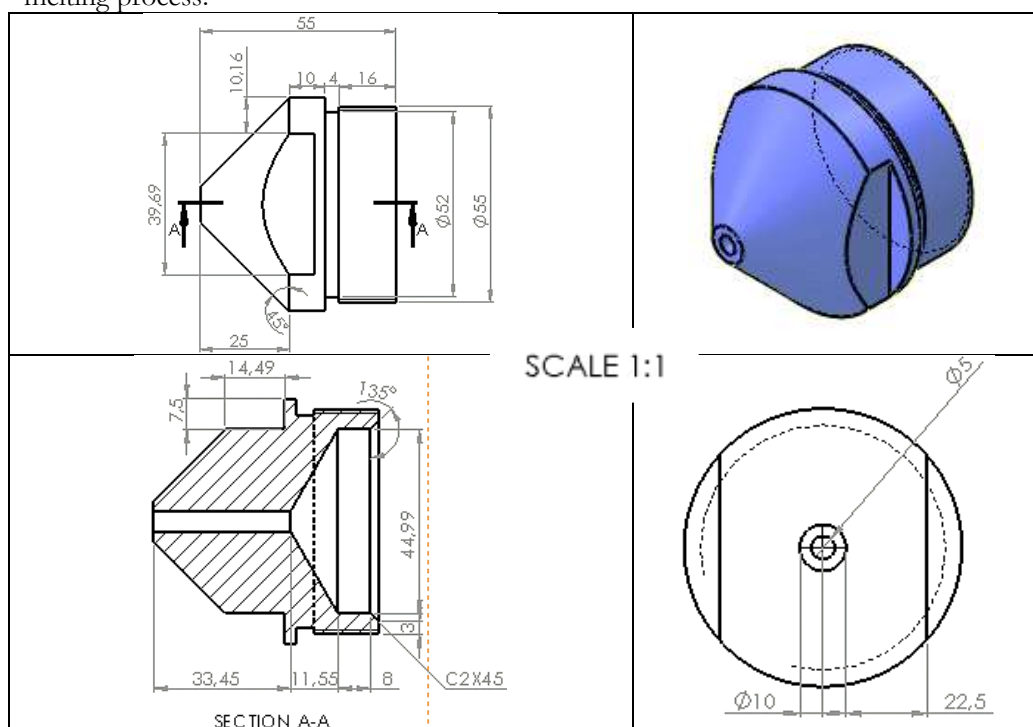


Figure 6. Nozzle Injection Design

The nozzle has a total length of 55 mm with an outer diameter of $\text{Ø}52$ mm. The front section is conical with an angle of 135° , and the length of the cone is ± 33 mm. The diameter of the main flow hole is $\text{Ø}10$ mm and ends with an outlet diameter of $\text{Ø}2.5$ mm. There is an internal mounting groove with a depth of 8 mm and a chamfer $\text{C}2 \times 45^\circ$ to ensure precise connection with the barrel. This nozzle serves as the final channel for the flow of molten plastic into the mold.

4.2. Results of the Simulation Process Flow on Screw Injection

Before simulating the design results, the initial data used as a reference in the simulation process must first be determined. This data includes the type of material and injection parameters. The initial data is obtained from literature studies and technical specifications of the components used in the design. The material used in the screw injection is polypropylene (PP), with a density of 0.91 g/cm^3 and a non-Newtonian fluid type.

4.2.1. Determination of Flow Simulation Parameters in Screw Injection

In the prototype injection molding machine with a capacity of 4 test specimens per process, a simulation will be conducted using SolidWorks Flow Simulation software to

determine material flow and pressure distribution. The design of the tool can be seen in the injection screw image above. In the initial simulation data, several tools are used. These tools include [7] screw dimensions, barrel dimensions, and nozzle dimensions. This geometric data serves as the primary reference for mesh generation and material flow during the simulation. The detailed dimensions and geometric characteristics of the part are shown in Table 2, while the 2D and 3D models of the part can be viewed in Figures 4, 5, and 6. The following is the description data of the simulated part.

Table 4 Part Dimension

No	Component Name	Value / Description
1	Screw	Length = 612 mm, Thread Diameter = 52,4 mm
2	Barrel	Length = 500 mm, Inner Diameter = 52,5 mm
3	Nozzle	Length = 55 mm, Diameter = 5 mm

The flow simulation steps applied to the screw extruder system using SolidWorks software consist of the following stages:

- Activate the Flow Simulation menu on the Screw Extruder by opening the product file that has been created, then changing the interface to Flow Simulation, then selecting “Display Manager” in the “Tree” menu.
- Selecting the Wizard-Unit System, in the first step of the Wizard-Unit System setup, which displays the unit system options. Figure 3.62 Wizard Unit System. Several unit systems are available: COS, FPS, IPS, NMM, SI, and USA, all of which are predefined. The currently selected system is “SI (m-k-g-s)”.
- Selecting Wizard-Analysis type, the next step is “Wizard – Analysis Type” which displays the analysis types that can be performed. Users can choose between ‘Internal’ or ‘External’ as the analysis type and use the rotation type. In this step, Internal analysis type is selected.
- Select Default Fluid, Wizard-Default Fluid” which displays a list of fluids available for analysis. The next step is to add a new fluid using the “Add” button or remove unnecessary fluids using the “Remove” button. Below the fluid list, there is a “Project Fluids” section that displays the fluids selected for the current project, with “Polypropylene” as the default fluid.
- Setting Initial Conditions, the next step is to set the parameter values. The image shows that the simulation to be performed is a flow simulation with a pressure of 101325 Pa and a temperature of 293.2 K.

4.2.2. Boundary Conditions for Screw Injection

Boundary conditions are time conditions specified in a differential function that is solved systematically. At this stage, boundary conditions are determined, such as setting the inlet and outlet.

1. Input boundary condition

In applying boundary conditions, the steps begin with selecting the hopper connection face as the input point with a volume flow input type. The volume flow value is set at 0.0462 m³/sec based on previous calculations. The selection of the face on the hopper connection is an important step because this area plays a major role in the distribution of incoming flow. By setting this input, the simulation or analysis is expected to accurately reflect real-world conditions. The results of these boundary condition application steps will provide deep insights into flow behavior within the screw and can be used to improve the design or optimize the system as a whole.

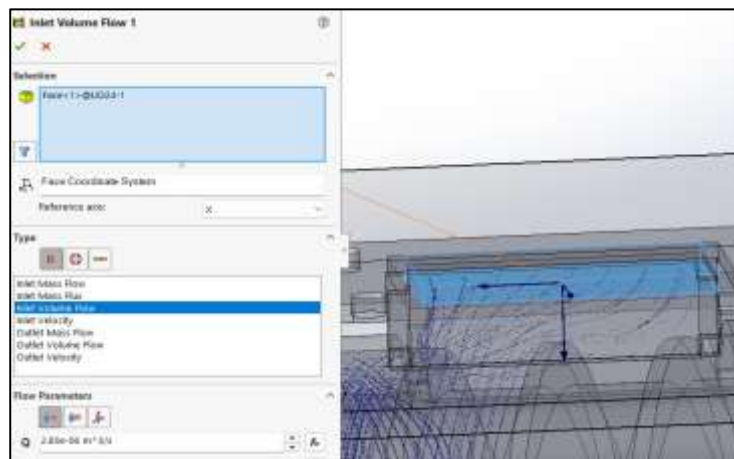


Figure 7. Input Boundary Condition

2. Output boundary conditions

The steps begin by setting the front of the chamber as the input point with a calculated value of 101352 Pa at a temperature of 293.2 K or 20°C.

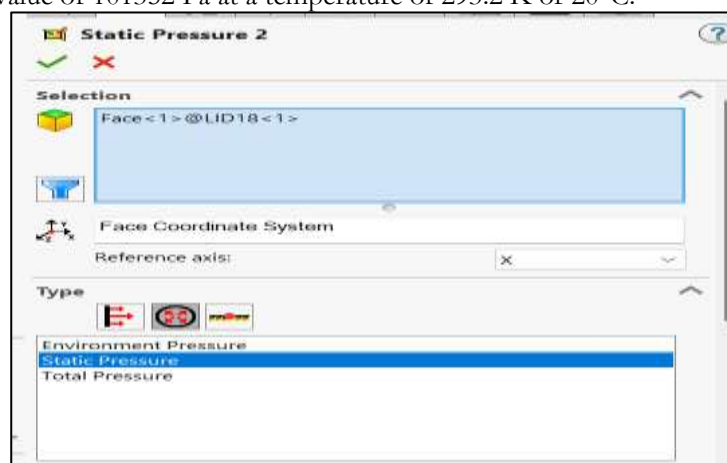


Figure 8. Output Boundary Condition

4.2.3. Setting Goals for Screw Injection

The following are the goals that have been set for the SolidWorks Flow Simulation application in the charcoal briquette extrusion process, from the housing to the mold. These goals were specifically selected to monitor the main parameters related to the performance of non-Newtonian fluid flow in the screw extruder. These settings include Average static pressure, Average flow velocity, Volume flow rate, and Mass flow rate. This approach is designed to provide accurate monitoring of pressure distribution, velocity distribution, and actual production capacity in the form of mass and volume flow rates exiting the mold. With this configuration, fluid flow performance analysis can be conducted comprehensively from the hopper inlet to the die outlet.

4.2.4. Meshing on Screw Injection

The next step in the simulation is to set up the mesh. The mesh serves to divide the flow domain into small elements that enable the software to calculate fluid variables numerically in each element. In this process, a combination of Global Mesh and Local Mesh is used. Global Mesh is applied to provide a uniform distribution of elements throughout the simulation domain, ensuring comprehensive mesh coverage of the housing, screw, and other fluid spaces. Local Mesh is used specifically in critical areas that require a higher level of accuracy, such as around the rotating screw and mold areas. The use of Local Mesh aims to make calculations in areas with complex geometry or sharp velocity and pressure gradients more accurate without overburdening the entire domain with an excessive number of elements. With this combination, the simulation is expected to produce accurate data while remaining computationally efficient.

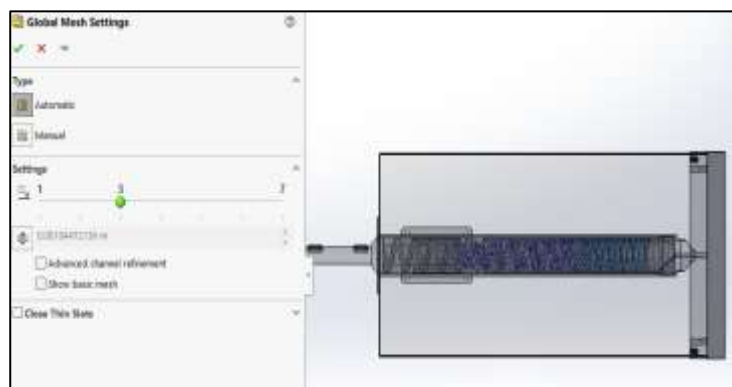


Figure 9. Global Mesh Setting

4.2.5. Solver Process in Screw Injection

Once all parameters and conditions have been specified above, run the simulation by clicking “Run.” SolidWorks flow simulation will process the data and calculate the solution based on the specified numerical method.

4.3. Discussion of CFD Simulation Results on Screw Injection

In the simulation process of liquid/paste polypropylene flow in a screw injection system using SolidWorks-Flow Simulation 2023, flow parameters were set with a volume flow rate of $1.8914 \times 10^{-5} \text{ m}^3/\text{sec}$. The briquette paste flows from the hopper through the screw until it exits the mold. Several key outputs were obtained from the simulation results. The mass flow rate was 0.0226973 kg/sec, which, when converted, yields a production rate of approximately 81.7 kg/hour.

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value	Progress [%]	Use In Convergence	Delta	Criteria
SG Volume Flow Rate 1	[m ³ /s]	-1,22678E-14	2,45979E-16	-1,34887E-14	1,55352E-14	100	Yes	1,53848E-15	2,86629E-08

Figure 10. Screw Injection Simulation Results

In Figure 10, the average static pressure is 97.765 Pa. The average flow velocity is $1.20 \times 10^{-5} \text{ m}/\text{sec}$, indicating a slow flow characteristic consistent with the properties of a non-Newtonian paste with high viscosity. The simulation ran until convergence was achieved with small delta and error values, so the results can be considered stable and valid for use as a reference for system performance.

4.3.1. Flow Path in Injection / Extruders Screw

Viewing flow trajectories is the process of visualizing the path or pattern of fluid movement in a flow simulation using software such as SolidWorks flow simulation. Here are the steps for creating flow trajectories:

1. Selecting Results Flow Trajectories

The steps to create flow trajectories begin by clicking “Insert Flow Trajectories” in the software used. After that, a flow trajectory settings display will appear, allowing users to adjust various parameters related to fluid flow. In this settings display, users can select the flow source, such as inlet or outlet, determine the number of particles to be tracked, and set visualization parameters such as color, speed, and flow direction.

2. Setting Trajectory Parameters

When setting trajectory parameters, the first step is to determine the number of particles to be tracked in the simulation. This number of particles can be adjusted to obtain a more detailed or more general picture of the fluid flow. At this step, select the outlet face with the arrow visual type.

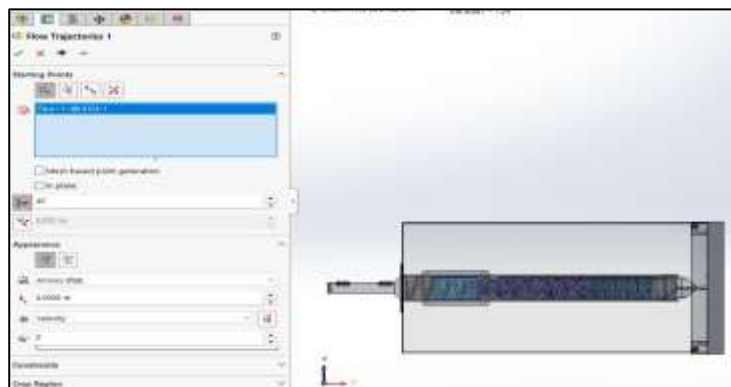


Figure 11. Setting Trajectory Parameters

3. Flow Trajectory Results

In the flow trajectory results, the flow velocity of the briquette paste from the hopper to the mold can be visualized as shown in the following figure:

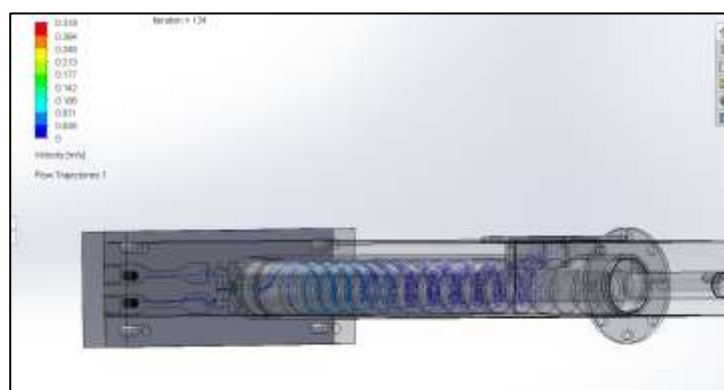


Figure 12. Flow Trajectory Inlet Section

In Figure 12, in screw injection, the flow pattern follows the direction of the screw thread in a spiral toward the tip of the mold. The colors on the arrows illustrate variations in speed, where the speed is relatively higher in the area near the thread and slows down as it approaches the outlet due to friction resistance and increased pressure.

Visualization of the flow trajectory inside the screw injection/conveyor provides an overview of the spiral pattern of fluid flow resulting from the movement of the screw. Based on the simulation results, there are no reverse flow arrows, so backflow or dead zones are not found in that area. This indicates that the flow moves according to the design, with low but stable velocity, maintaining even material distribution to the mold.

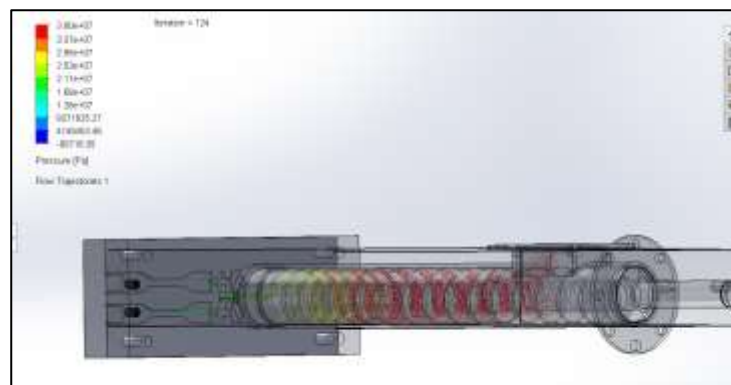


Figure 13 Flow Trajectories Screw Section

Based on the analysis of the overall flow trajectory results, no backflow was found along the screw injection/conveyor or at the outlet, there were no dead zones that could potentially cause blockages, the spiral flow pattern in the screw showed that the screw design was effective in pushing the material into the mold, and the fluid velocity and pressure were well distributed in accordance with the simulation design.

5. Comparison

Testing was conducted virtually using SolidWorks Plastics and SolidWorks Flow Simulation modules to evaluate the performance of the injection molding machine prototype design prior to the physical manufacturing stage. These simulations aimed to determine the flow distribution, pressure, velocity, and cavity filling quality to ensure compliance with the specified design parameters. The simulation test results were then analyzed (D, 2011), (Dominick V, 2000) to ensure that the plastic material could fill the entire mold without defects, as well as to ensure that the screw, barrel, and injection system designs were functioning optimally.

Table 5. Simulation criteria

No	Criteria for Successful Simulation	Results
1	Cavity filled completely during filling time < 15 second	10,93 seconds
2	Maximum injection pressure < 6 MPa (≈ 48 bar \pm tolerance).	5,38 MPa
3	Density distribution ≥ 0.75 g/cm ³ throughout the cavity area.	0,78–0,93 g/cm ³
4	Backflow in the flow of material from the hopper to the mold.	No Backflow
5	The mass flow rate supports a mold volume of 28.5 cm ³ within the planned filling time.	0,0227 kg/s

Based on the above criteria, the SolidWorks Plastics simulation results show that the filling time of 10.93 seconds meets the target (<15 seconds). The maximum pressure of 5.38 MPa is below the design limit (6 MPa), ensuring safety regarding frame strength and mold locking. The material density of 0.78–0.93 g/cm³ also meets the requirements, indicating that the cavity is fully filled without voids.

Table 6. SolidWorks Plastics & Flow Simulation Results

No	Parameter	Value	Unit	Simulation [14]
1	Fill Time	10,93	second	SolidWorks Plastics
2	Cycle Time	83,94	Second	SolidWorks Plastics
3	Peak Pressure	5,38	MPa	SolidWorks Plastics
4	Density after packing	0,78 – 0,93	g/cm ³	SolidWorks Plastics
5	Mass debit	0,0227	kg/s	Flow Simulation
6	Average static pressure	97,765	Pa	Flow Simulation
7	Average flow velocity	$1,20 \times 10^{-5}$	m/s	Flow Simulation
8	Flow pattern	Spiral, without backflow	-	Flow Simulation

From Flow Simulation, the mass flow rate of 0.0227 kg/s corresponds to the mold volume requirements, while the spiral flow pattern without backflow ensures that the material is evenly distributed. The average static pressure of 97.765 Pa and flow velocity of 1.20×10^{-5} m/s indicate a stable flow process. Overall, the simulation meets all success criteria, proving that the injection molding machine design is suitable for producing optimal molds.

6. Conclusions

Based on the results of the design that has been created, it can be concluded that the injection system design with machine dimensions of 1200 mm x 400 mm x 790 mm has components consisting of an injection screw with a diameter of 52.4 mm and a length of 612 mm, a barrel with an inner diameter of 56 mm and a length of 500 mm, a nozzle hole with a diameter of 5 mm, and four ASTM tensile test specimens. The material used for the injection screw is S45C with a hard chrome finish, the barrel uses mild steel pipe schedule 40, and the molding die is made of cast aluminum. The results of the injection system calculations are as follows: for the screw section, the screw capacity is 101.93 cm³, screw travel speed is 0.214 m/sec, and injection rate is 11.381 sec for the barrel section, the barrel volume is 1230.88 cm³, the wear limit is 0.19 cm, while the maximum limit is 0.7 cm, so it is deemed safe or suitable for use. The heater section has a power of 0.580 kW or 580 W. The nozzle cross-sectional area is 0.19625 cm². Based on the design and simulation results, a prototype injection molding machine with a capacity of 4 tensile test specimens (total volume 28.5 cm³) was simulated using generic polypropylene material. The material has a melting

temperature of 230°C, a mold temperature of 70°C, an injection pressure of 48 bar, an average melt viscosity of $\sim 500 \text{ Pa}\cdot\text{s}$ within the relevant shear rate range, and an average flow rate of $2.85 \text{ cm}^3/\text{sec}$. The simulation results show that the plastic flow begins to distribute from the gate to the runner and cavity gradually. The SolidWorks Plastics simulation results indicate that the filling time of 10.93 seconds meets the target. The maximum pressure of 5.38 MPa is below the design limit, ensuring safety regarding frame strength and mold locking. The material density of $0.78\text{--}0.93 \text{ g/cm}^3$ also meets the requirements, indicating that the cavity is completely filled without voids. Flow simulation shows a mass flow rate of 0.0227 kg/sec , which aligns with the mold volume requirements. The spiral flow pattern without backflow ensures the material is distributed evenly. The average static pressure of $97,765 \text{ Pa}$ and flow velocity of $1.20 \times 10^{-5} \text{ m/sec}$ indicate a stable flow process. Overall, the simulation meets all success criteria, proving that the screw injection molding machine design is suitable for producing optimal molds at points far from the gate. Material solidification occurs more quickly, potentially causing short shots or weld lines if flow velocity is not optimal. Temperature, pressure, and injection velocity settings must be carefully adjusted to ensure the cavity is fully filled before the material solidifies.

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