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Design and Fabrication of Mini-Injection Moulding Machine for Small-to-Medium Scale Plastic Processing

Nwadinobi, C.P. [*1]**, Ezeaku, I.I.**[1] **and Ugwu, V.**[2]
[1]Department of Mechanical Engineering, Abia State University, Uturu, Abia State, Nigeria.
[2]Department of Mechanical Engineering, Abia State Polytechnic, Aba, Abia State, Nigeria.
*Corresponding author's email: chibundop@gmail.com

Abstract
This paper presents the design process and manufacturing of plastic injection moulding machine that is inexpensive and for use in the production industry for producing small size plastic products. The components of the machine are the hopper, screw, the barrel assembly, and the injection nozzle. The machine is a batch processing machine and fabricated using locally sourced materials. The machine was tested with polypropylene (pp) and Acrylonitrile Butadiene Styrene (ABS) materials. Temperatures of 200°C and 300°C were used to test the rate of melting of the plastic grains and their fluidity. The performance test of the machine indicated average throughput and injection efficiency, of 261.04kg/hr and 92.2% respectively at a displacement time of 0.0353hr. Therefore, this innovation is recommended for small scale plastic industries. The production cost implication of this machine considering bought out components, material cost, job cost (machining and non-machining) is approximately fifty-four thousand, eight hundred and twenty naira only (₦54,820).

Keywords: *Injection moulding, Design, Plastics, Throughput, Injection efficiency*
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1. Introduction

Plastic moulding operates with the concept of placing a polymer in a molten state into a mould cavity so that the polymer can take the required shape. This is achieved with the help of alternating temperature and pressure. Moulding of plastics can be done through blow moulding, injection moulding, rotational moulding and compression moulding (John, 2009). This work will concentrate on injection moulding. Injection moulding has enjoyed sustained growth since its beginnings in the late 1800s till date (Melick, 1995; Singha and Vermaa, 2016). The implementation of the injection moulding technique as a means of plastic production has evolved from the production of simple products like combs and buttons to major consumer, industrial, medical, and aerospace products (Yi-qi *et al.*, 2013; Siregar *et al.*, 2017). Plastic injection moulding is one of the most popular methods for the manufacturing of plastic components. By using the injection moulding machine wide variety of products can be manufactured such as children's toys, chair caps, mobile panels, plastic cups, bottle caps, water bottles and water pipes, chemical drums, TV cabinets, refrigerator stands, dustbins, and others. The advantages of plastic injection moulding machine process include good surface finish of the product can be produced, less scrap and flashes are produced, and the process has relatively low labour costs.

According to Samson (2011), injection moulding is a method of forming a plastic product from pellets or powdered thermoplastics. This is achieved by feeding the material through the machine component known as the hopper through to a heated chamber. This is aimed at making it soft and thereafter force the material into the mould by the use of the screw. In this whole process, pressure should be retained until the material is hardened and ready to be removed from the mould. This technique appears to be the most common and preferred form of producing plastic products with any complexity and size.

In Nigeria, the cost of the imported plastic injection moulding machine is quite high due to foreign currency exchange. There is also high maintenance cost for the imported products, thus making it difficult for small scale manufacturers to afford the imported plastic moulding machine. The foreign plastic injection moulding machine consumes much electric current thereby making the industry pay more for power consumption which afterward increases their overall cost of production. In addition, the foreign plastic injection moulding machine has complex mechanisms thereby require expertise to fix or carry out maintenance on it. However, this research work intends to find a solution to these challenges. It involves simplified design which can be produced locally with the attendant benefits. This work is aimed at the design and fabrication of a manually actuated plastic injection moulding machine that can melt plastic grains and pressurizes the molten plastic material into mould cavity so that when solidified gives out the exact shape or product of the mould cavity. This is expected to produce a machine cheap and economical for use by small scale plastic industries. This machinery is affordable to those working in the informal sector; less complex and hence easy to operate and cheap to maintain.

2. Materials and methods

2.1 Principles of operation

The principle of injection moulding is very simple. The injection moulding process stages start with the feeding of polymer (in the form of granules, beads or powder) through the hopper. The hopper functions as the inlet point and holder of the raw materials. The plastic pellets raw materials are then fed from the hopper to the barrel through gravity. The barrel is a housing that gives support to the screw and consists of heater bands that function as heat source for each section of the barrel. The screw, also known as the reciprocating screw is used in compressing, melting and conveying the plastic material. The screw consists of three zones: the feeding zone, the compressing/transition zone, and the metering zone. In the feeding zone, there is no change to the orientation of the plastic materials and are transferred to the next zone which is the transition zone. In this zone, melting of the pellets occur and the molten plastics are transferred to the next zone which is the metering zone. Here, the molten material is ready for injection. Also, there is the nozzle, with the main function of connecting the barrel to the sprue bush. This forms a seal between the mould and the barrel. It is essential that the nozzle temperature should be set to the materials melting temperature, depending on the recommendation (Rosato *et al.*, 2000). After injection, pressure is applied to both platens of the injection moulding machine (moving and fixed platens) to hold the mould tool together until after cooling and solidification. After this process, the product gets its shape and the two platens are moved away from each other to separate the mould tool which is known as mould opening. Finally, the moulded product is ejected or removed from the mould marking the end of the process (Siregar *et al.,* 2017).

2.2 Design consideration and fabrication of the injection moulding machine

The substantial considerations for the design of the injection moulding machine include design concepts, design specification, design calculations, and choice of material. The machine was designed to be simple and hence easy to operate and cheap to maintain. The fabrication process includes metal cutting, welding of the parts and assembling. The components of the machine are hopper, screw, barrel assembly, and injection nozzle.

2.3 Description of the machine

The injection moulding machine is designed for small scale industries purposes with main considerations as follows: inexpensive, small size, capable of producing a small number of products for prototype testing, able to accommodate up to medium size specimens, and have a standard operational procedure. The pictorial view of the plastic injection machine is as presented in Fig. 1. Fig. 2 shows a sectional view of the machine.

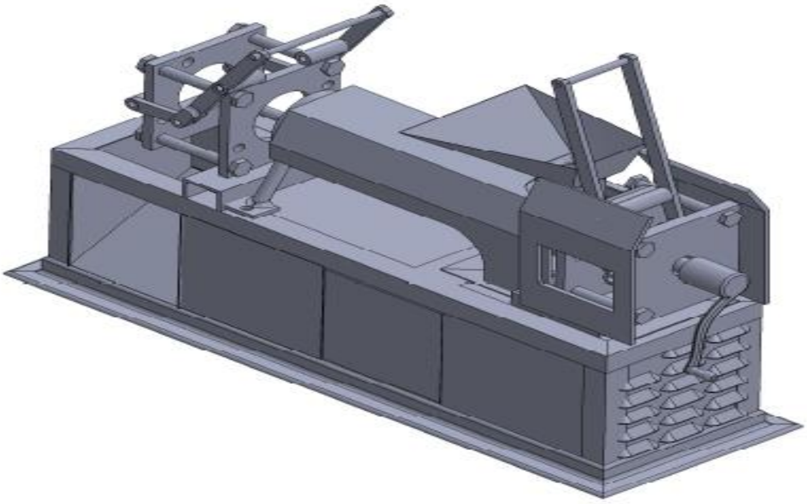

Fig. 1: Diagram of the plastic injection machine

ITEM NO.	PART NUMBER	QTY.
1	Injection fixed plating	1
2	Barell	1
3	Injection movable plating	1
4	Plating dwell pine	8
5	Plating dwell pine nut	8
6	Fixed mold Plating	1
7	Movable mold Plating	1
8	Screw rotating handle	1
9	Slied clampin	2
10	Nozzle3	1
11	Topido flow valve	1
12	Topido look valve	1
13	Topido ring	1
14	Screw	1
15	Injection push bar extention	2
16	Injection push bar	2
17	Injecting Handle	1
18	Plating push bar	2
19	Plating push bar extention	2
20	Plating Handle	1
21	Hoper	1
22	Table	1
23	barrel guard	1
24	Discharge	1
25	Housing	1
26	Panel	1

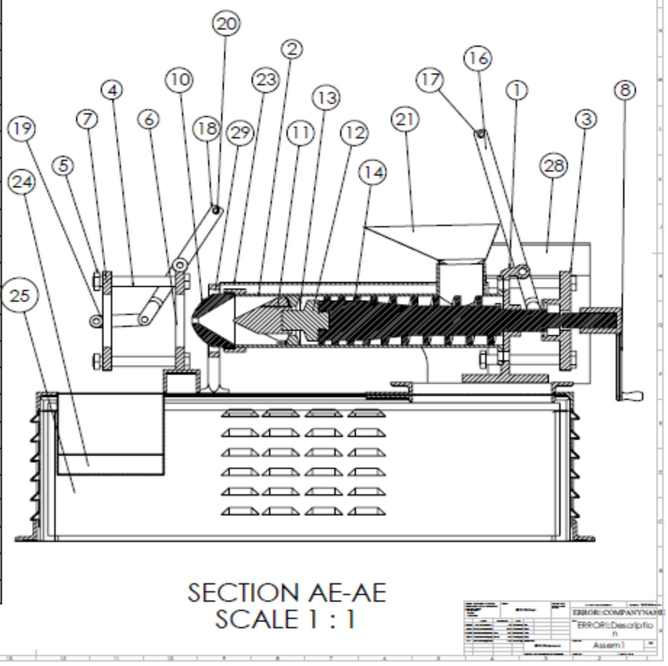

Fig. 2: Sectional view of the plastic injection machine

The hopper is fabricated with 3mm flat metal sheet, this part helps direct the plastic grains into the barrel for melting and injecting. A circular pipe of 55mm internal diameter was used for the construction of the plastic injection moulding barrel, where the screw is given 0.1mm tolerance so it can rotate and move linearly in the barrel. Also, 55mm thick shaft was used to construct the plastic injection moulding screw by threading operation in a lathe machine. The torpedo consists of an assembly of valve and a locking ring for preventing backward movement during the injection process. These parts were constructed by machining using a lathe machine. In addition, the injection nozzle was fabricated. This part is connected to the end of the barrel in which the molten materials come out from and then go into the mould cavity. The platen is constructed from a flat metal sheet. Next is the heater band which is an electric device that generates the amount of heat required to melt the plastic grains, it is of different sizes and capacities. The type used is called the Mica heater band. The selection of the heater band depends on the amount of heat needed in a system. Mica heater bands provide excellent thermal conductivity. These bands are basically of mica insulator a nickel-chrome resistant ribbon wire. Mica bands are capable of attaining a temperature up to 90^{o}F and a normal watt density of 20-45W on a barrel. This rotating handle was constructed with a circular pipe. Its function is to help in rotating the screw manual by hand. The frame was also constructed with angle iron bars, which act as support and carrier for the other machine components. Fig. 3 presents a detailed drawing of the components of the injection moulding machine.

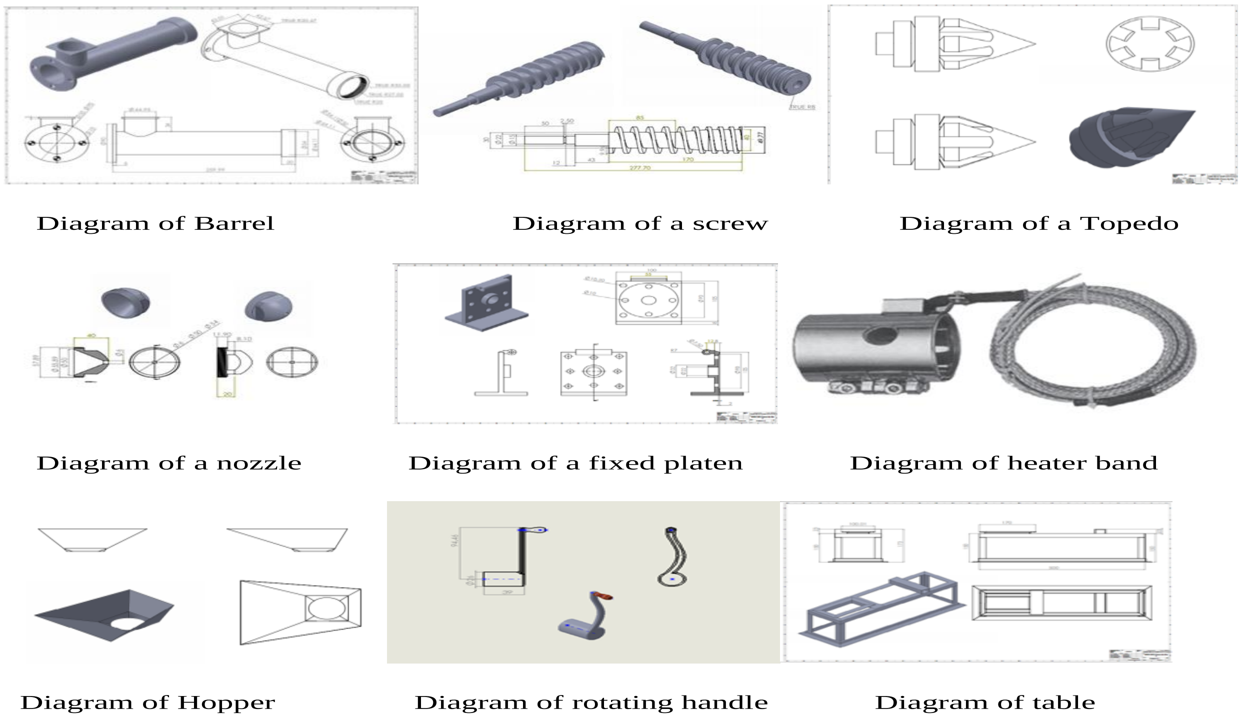

Fig. 3: Detailed drawing of injection moulding machine component

2.4 Design analysis of the plastic injection machine

The machine was designed for safe use, ease of operation at low maintenance cost. The components of the plastic injection machine are as follows: feed hopper, screw, barrel and feed throat, heating elements, frame/stand, bearing assembly and temperature controller.

2.4.1 Design of injection screw conveyor

One important component of the machine is the injection screw also known as the reciprocating screw used in compressing, melting and conveying the plastic material. The screw is a cylindrical rod with constant outside diameter. The screw rotates within the barrel. As the screw rotates, it forces the plastic materials in the channel forward which is heated, melted and the molten material will be ready for injection. Injection mould screw of 55mm was employed with the following parameters models as recommended by Rauwendaal (2013):

Total length of screw $(L) = 10D$ (1)

Length of feeding zone section $(L_f) = 2D$ (2)

Length of transition zone section $(L_t) = 3D$ (3)

Length of melting zone section $(L_m) = L - (L_f + L_t)$ (4)

Helix angle $(\varphi) = 18^{o}$ (5)

Flight pitch $= D/2$ (6)

Flight width $= 0.1D$ (7)

From the equations given, the total length of screw (L) was obtained as 550mm, length of feeding zone section (L_f) as 110mm, length of transition zone section (L_t) as 165mm, length of melting zone section (L_m) as 275mm, helix angle (φ) as 18o, flight pitch as 27.5mm and flight width as 5.5mm.

2.4.2 Determination of barrel dimension

Total length of barrel (L_b) = 600mm

Barrel Internal diameter = D + R_c (8)

where, Screw diameter D = 55mm, Rc = Radial clearance (mm) of 0.1mm

Thickness of barrel = 5mm

Thus, External diameter of barrel = Int. Dia. of barrel + (2×thickness of barrel) = 65.1mm.

Vol. of barrel, $V = \pi \times R^2 \times L$ (9)

where, R = barrel radius of 27.55; L = barrel length of 600 and π = 3.142

Note: The volume of the mould cavity must be less than the maximum volume of the injection machine.

2.4.3 Design of the hopper

Mild steel was selected for the construction of the feed hopper and a trapezoidal-shape selected for hopper for better material feed with volume of 9408cm^3. The hopper base is constructed to fit the barrel wall. The trapezoidal shaped hopper has a height of 28cm, top width of 20cm, top length of 30cm, bottom width of 4cm, bottom length of 6cm, and wall thickness of 0.3cm, as shown in Fig. 3.

Vol. of hopper = $\left(\frac{1}{2}(a+b)h\right)h$ (10)

2.4.4 Determination of mass and volumetric flow rate

Mass flow rate was calculated using Equation (11) (Harold and Giles, 2005):

Mass flowrate = $D^2 \times N \times h \times \rho_{buik}$ (11)

Volumetric flowrate = $v_z \times w \times h$ (12)

v_z(Channel Velocity) = π ×D ×Ncosφ (13)

where *W*= Metering channel width, *h* = Metering channel depth, *D* = Screw diameter, *N* = Screw speed, φ = Helix angle, and ρ_{buik}= Bulk density.

2.4.5 Determination of total flow output from barrel

In most practical situations, the total output is the combination of drag flow and pressure flow and neglecting the leakage flow term. In addition, the pressure gradient is often considered as linear. Thus, total output was calculated using Equation (14) (Jassim *et al.*, 2016):

$$Q_T = \frac{1}{2}\pi^2 D^2 N h sin\varphi cos\varphi - \frac{\pi D h^3 (sin\varphi)^2}{12\eta}\frac{P}{L} \quad (14)$$

where Q_T = Total output, D = Diameter of the screw, N = Screw revolution (rpm), h = Channel depth of the screw (m), φ = Helix angle of screw, L = Length of the screw (m), P = Operation pressure (Pa), and η =Viscosity (Pa.s).

2.4.6 Determination of heat transfer through barrel

Rate of heat transfer from the external surface to the internal surface of the barrel in the cylinder is expressed as (Shigley, 2006; Eastop and McConkey, 2009):

$$Q = \frac{2\pi K(T_1 - T_2)}{In\left(\frac{R_2}{R_1}\right)} \quad (15)$$

where Q = Amount of heat transfer (W), R_1 = Inner cylinder radius (m), R_2 = Outer cylinder radius (m), (T_1 – T_2) = Temperature difference (^{0}C), and K = Proportionality constant known as Thermal conductivity (W/m^{o}C).

The general steps involved in the fabrication process of the plastic injection machine is as shown below:

Metal cutting

↓

Welding and Machining of parts

↓

Assembling of parts

↓

Finished machine

3. Results and discussion

3.1 Performance evaluation

Test parameters of melting time with temperature was tested and a simple mould was fabricated and the machine was tested with polypropylene (pp) and Acrylonitrile Butadiene Styrene (ABS) materials. The plastic injection machine was feed with plastic grains through the hopper. Its rotating handle was rotated for the grains to travel forward. The heat generated by the heater band to the barrel was sufficient to melt the plastic grains and then the injection lever was then pulled for the injection of molten plastic out from barrel into the mould cavity. The machine was connected to electric power to power the heater bands and heat up the barrel through which the plastic material passed to the nozzle where it was pressurised into mould cavity and it was also super-heated before getting to the nozzle in order to enhance injection pressure and to avoid cold short before getting into mould cavity. The machine temperature controller was set at 200°C and then 300°C for the experimental runs undertaken. For the temperature measurements, a thermocouple was used.

Fig. 4 presents the effect of initial barrel temperature on the material output temperature using pp which has a melting point of 160°C. The duration of time taken for plastic material grain to travel from the hopper to the nozzle was tested with respect to machine temperature at times ranging from 10secs to 30secs. The rate of displacement of plastic grains was dependent on the rotating speed of the screw, thus when the screw handle is rotated faster the plastic grains then moved at a faster rate through the barrel. Besides, the longer the material stays in the barrel, the more heat it gains and there is increased temperature.

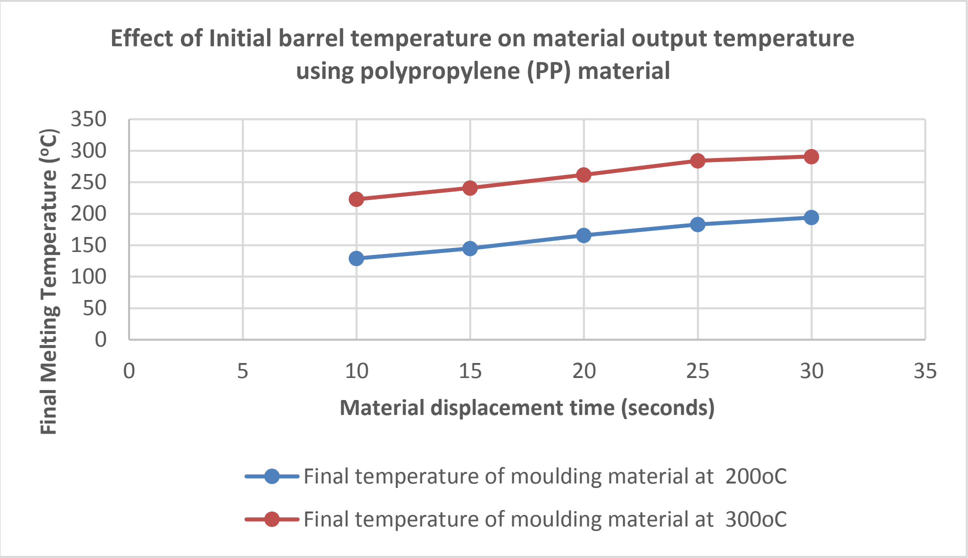

Fig. 4: Melting temperature test using polypropylene (PP) material

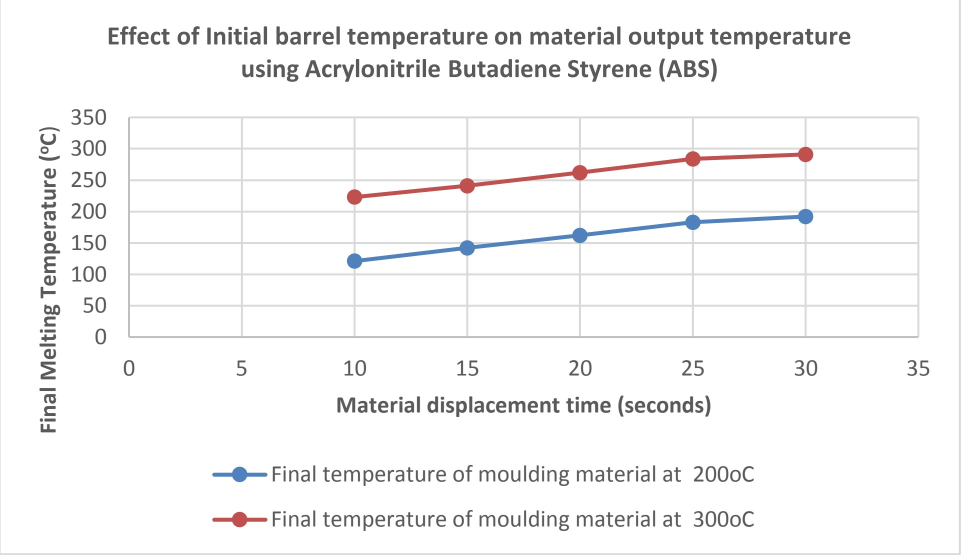

Fig. 5: Melting temperature test using Acrylonitrile Butadiene Styrene (ABS) material

In addition, ABS was also used which has a melting point of 105°C. From the result obtained as shown in Fig. 5, it was observed that when the machine heating system is set to a higher temperature the rate of melting of the plastic grains became faster and discharges at high temperature thus retaining its fluidity.

The injection machine performance was further tested by the evaluation of the Machine injection efficiency (IE) and Throughput (TP). The performance test was carried out after the fabrication and assembly of the machine. The machine was fed with samples of equal-weighted mass of the plastic materials used through the hopper per time. A stopwatch was used to record the time taken for the processing of each experimental batch.

$$Machine\ injection\ efficiency, IE\ (\%) = \frac{Output\ mass\ from\ injection\ machine, O_m\ (kg)}{Input\ mass\ of\ plastic\ pellets, I_m\ (kg)} \quad (16)$$

$$Throughput, TP\ (kg/hr) = \frac{Output\ mass\ from\ injection\ machine, O_m\ (kg)}{Time\ taken, T\ (hr)} \quad (17)$$

Table 1: Performance test responses for the Injection machine

Experimental runs	Input mass (I_m) (kg)	Time taken (T) (hr)	Output mass (O_m) (kg)	Machine injection efficiency (IE) (%)	Throughput (TP) (kg/hr)
1	10	0.0347	9.7	97	279.5
2	10	0.0356	8.6	86	241.6
3	10	0.0356	9.5	95	266.9
4	10	0.0350	9.4	94	268.6
5	10	0.0358	8.9	89	248.6
Average	**10**	**0.0353**	**9.22**	**92.2**	**261.04**

Table 2: Injection machine production cost

Description	Material	Size	Quantity	Unit Price (₦)	Total Price (₦)
Barrel	Circular pipe	Θ50mm x 3000	1	2000	2000
Screw	Shaft	Θ60mm x 277mm	1	2500	2500
Nozzle	Shaft	Θ40mm x 70mm	1	500	500
Topedo	Shaft	Θ60mm x 350mm	1	3500	3500
Plating block	Flat metal block	120mm x 120mm x 8mm	4	600	2400
Plating pin	Mill steel pin	10mm x 150mm	8	300	2400
Plating handle	Mill steel plat bare	10mm x 300mm x 5mm	4	200	800
Plating handle hinges	Mill steel pipe	Θ6mm x 100mm	1	200	200
Plating handle hinges	Mill steel rod	5mm x 100mm	1	200	200
Rotating handle	Cast iron	200mm	1	1000	1000
Table	Angle iron	1″ x 8ft	2	1000	2000
M5 Align bolt	Mill steel	20mm	10	50	500
M12 Nut	Mill steel		16	20	320
Heater Bands			3	3000	9000
Temperature controller			1	6000	6000
Thermos couple			1	1000	1000
Power breaker switch			1	500	500
Construction and Labour					15000
Miscellaneous					5000
Total					**54,820**

Fig. 6: Pictorial view of the fabricated injection machine

3.2 Production cost of the fabricated injection machine

The production cost of the Fabricated Injection Machine (Fig. 6) is as shown in Table 2. The total cost presented include the machine construction cost; material cost and miscellaneous expenses. This cost of production for the plastic injection moulding machine is relatively effective and affordable for a small to medium scale production start-up.

4. Conclusions

A mini injection moulding machine for Plastic Processing was designed and fabricated which melts and injects (pressurizes) molting materials into mould cavities with ease. This machine is inexpensive and can be used as learning equipment in school or laboratories and also could be used in the production industry for producing small size plastic products. The components design of the machine was properly undertaken and fabrication followed by assembling of the parts. The machine was tested with polypropylene (pp) and Acrylonitrile Butadiene Styrene (ABS) materials. Temperatures of 200ºC and 300ºC were used to test the rate of melting of the plastic grains and their fluidity. Performance test of the machine indicated average throughput and injection efficiency of 261.04kg/hr and 92.2% respectively at displacement time of 0.0353hr, average input and output masses of 10kg and 9.22kg respectively. Therefore, this innovation is recommended for small-scale plastic manufacturing industries.

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