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Design and Fabrication of Plastic Recycling Injection Moulding Machine for Plastic Wastage Recycling In Kenya

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Abstract: ***The purpose of the current work was to design and fabricate plastic recycling injection moulding machine for plastic waste management in Kenya. Using locally available raw materials, the machine was designed, constructed, assembled and tested. Waste plastics were shredded into small pieces and loaded into the hopper where it was heated at 220^{0}C and forced into mould cavity at high pressure by the injection plunger. Material selection was made based on design calculations of injection plunger diameter, number of teeth on pinion and plunger rack, torque, power, angular velocity, number of revolutions and leverage of the machine handle. The various components of the machine were assembled and the constructed machine was tested using high density polyethylene (HDPE). The constructed injection moulding machine produced plastic chair caps from plastic wastes thus saving the country from plastic menace that is currently rampant.***

Keywords: Design, Injection, Fabrication, Plastic Waste, Moulding, Recycling

1. Introduction

The use of plastics for various applications has revolutionalized plastic industries around the globe since they are available, convenient, durable, versatile and cheap leading to excessive consumption and tendency for misuse in many countries of the world. As a result, plastic products industries in Kenya have witnessed rapid growth in the recent past. In Kenya, most products such as sockets, household appliances, eating plates are made of plastic products. The increased amount of plastic wastes generated in Kenya has been facilitated by increasing rate of urbanization. Plastic consumption is high at 24 million plastic per month with half of these proportion ending up in solid waste mainstream [1]. Plastic wastes are responsible for several environmental problems such as visual land pollution (See Fig. 1), blockage of municipal drainage systems and death of aquatic wildlife and livestock whenever these animals ingest the plastics. Poor institutional policy framework on waste management, lack of enforcement or legislatures and laws on plastic waste management, lack of knowledge and awareness by the public, overproduction and overconsumption of plastic as well as inadequate facilities for collection, transportation, separation and disposal of plastic wastes are major factors responsible for plastic waste menace in Kenya [2].

Figure 1: Visual land pollution by PET plastic wastes

The lack of adequate local plastic waste recycling facilities in addition to urbanization, industrialization and population increase have led to multiplication of plastic waste generation in Kenya over the years. Kenya's major towns and cities are experiencing continued problems of plastic wastes with no lasting solution to the menace. The current effort aimed at reducing plastic wastes from dumpsites in major cities and towns include the Green Africa initiative that produces plastic posts from dirty polythenes. These posts are used for fencing, staking and construction purposes as they are durable and pests resistant. This has reduced over-dependence on timber-based products thus saving forests and mitigating the effects of climate change. However, plastic wastes conversion by Green Africa accounts for a small proportion of the country's waste generation. This calls for urgent need for proper and alternative waste management, thus, this research work. The current research work is based on plastic waste management through injection moulding technology. Through this technology, plastic wastes can be recycled thus minimizing the effect of environmental pollution as a result of damping of plastic wastes. The recycling process also produces useful plastic components for domestic and industrial applications. Injection moulding is a method of producing parts with a heat-meltable plastic material using an injection moulding machine. The machine has many advantages such as minimal losses and minimal finishing requirements compared to alternative manufacturing methods [3]. The shape of the final product is controlled by a confined mold cavity [4]. The injection moulding machine has two basic parts, the injection unit, and the clamping unit. Theinjection unitmelts the plastic and conveys the material to the confined chamber or mold while the clamping unitholds the mold in a closed position during injection. This helps in resisting the pressures of the conveying or injection and forming of the material into a desired shape, and then opens after cooling to eject the part from the mold[5]. This is the most commonly used method for recycling thermoplastics. It is based on the ability of thermoplastic material to soften on heating and harden on cooling. The process thus consists essentially of softening the material in a heated cylinder and injecting it under pressure into the mould cavity where it hardens by cooling. Each step is carried out in a separate zone of the same apparatus in the cyclic operation [6].

2. Project System

The main aim of the current work was to design and fabricate a moulding machine for recycling plastic waste in Kenya using the following conceptual design.

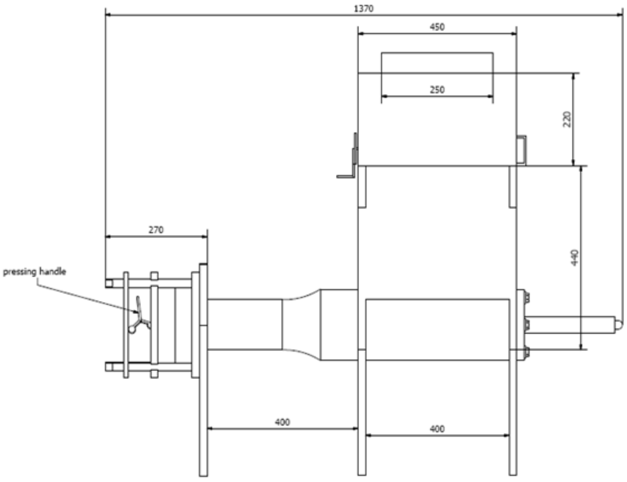

Figure 2: Project System (dimensions in mm)

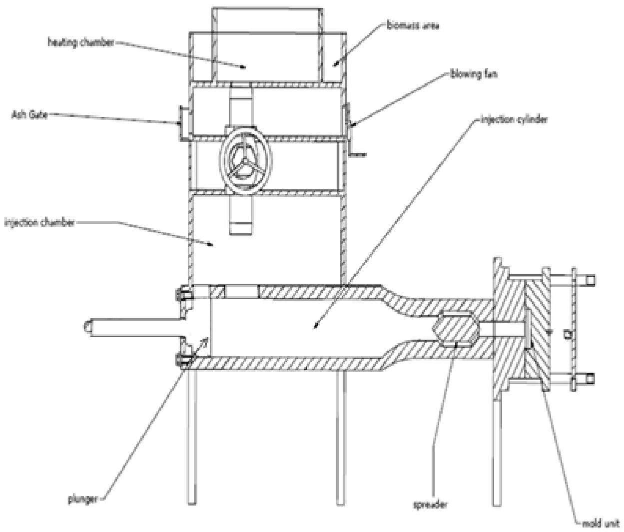

Figure 3: Project Sectional View

2.1 Design Calculations

In this work, design calculations included calculation of the injection plunger diameter, number of teeth required on the plunger rack, motor selection, leverage on the handle and number of teeth needed on the pinion.

2.1.1 Design of injection plunger

(a) Diameter of the plunger rack

The important parameter in the design of injection plunger is the volume of the melt (V) that can be pushed by the plunger from the barrel. This was determined from the diameter, d of the plunger.

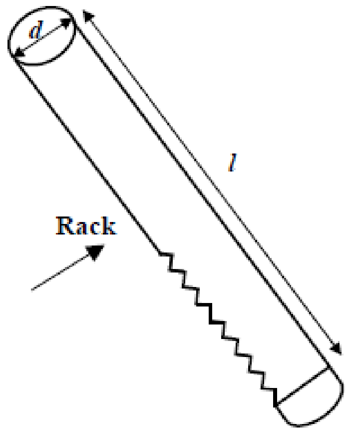

Figure 4: Injection plunger of injection moulding machine

The diameter of the plunger was determined from the relationship;

$$V = \pi r^2 l \qquad (1)$$

where $r = \frac{d}{2}$

Expressing the volume in terms of diameter,

$$V = \pi \frac{d^2}{4} l \qquad (2)$$

The volume of the melt can also be expressed as

$$V = \frac{\text{Mass of the melt}, m}{\text{Density of the melt}, \rho} \qquad (3)$$

Since the Volume of the plunger is constant,

$$\frac{m}{\rho} = \pi \frac{d^2}{4} l \qquad (4)$$

Making d the subject of the formula,

$$d = \sqrt{\frac{4m}{l \pi \rho}} \qquad (5)$$

The laboratory determination of the mass of melt, m = 2.65 kg
Density of the melt resin, ρ = 7900 kg/m3
Length of the plunger, l = 0.85m

Substituting these values in Eq. (5),

The diameter of the plunger = $\sqrt{\frac{4*2.65}{\pi*0.85*7900}}$ = 22 mm

(b) Number of teeth required on pinion (spur gear)

The number of teeth required on the spur gear was determined from Eq. (6).

Number of teeth required on pinion

$$= \frac{\pi * \text{diameter of pitch cirle}}{\text{Circular pitch distance}} \quad (6)$$

Where diameter of the pitch circle = 76 mm and circular pitch distance = 6 mm/tooth

The number of teeth on the pinion = $\frac{76 * \pi}{6}$ = 39.79 ≅ 40 teeth

(c) Number of teeth required on the plunger rack

The number of teeth on the plunger rack was determined from Eq. (7).

Number of teeth required on the plunger rack

$$= \frac{\text{plunger expected length of travel}}{\text{Circular pitch distance}} \quad (7)$$

Where the expected travel length of the plunger

$$= \frac{\text{length of plunger}}{5} = \frac{850}{5} = 170 \text{ mm}$$

Therefore, required number of teeth on the rack

$$= \frac{170}{6} = 28 \text{ teeth}$$

(d) Motor selection

In order to select a motor appropriate for the injection moulding machine for recycling plastic, the angular velocity ω was determined from Eq. (8).

$$\omega = \frac{v}{rs} \quad (8)$$

Where r_s is radius of motor shaft and v is injection linear velocity which have been established in literature as v = 0.161 m/s while r_s = 12 mm = 0.012 m[7].

Therefore, angular velocity of the motor, ω = $\frac{0.161}{0.012}$ = 13.4 rad/s

Using the angular velocity, the number of revolutions (N) of the motor was determined from Eq. (9).

$$N = \frac{60\omega}{2\pi} \quad (9)$$

$$N = \frac{60*13.4}{2\pi} = 1263.9 \text{ rpm} \cong 1264 \text{ rpm}$$

This is within the range as most electric motors operate between 500-3,000 revolutions per minute (rpm)[8].

The torque (T) and power of the motor were determined from Eq. (10) and Eq. (11) respectively.

$$T = Fr_s \quad (10)$$

Where F is turning force of motor shaft, the value of F for G.80 type electric motor shaft = 0.112N. Therefore, torque, T = 0.112 * 0.012 = 0.00134 Nm

$$P = T\omega \quad (11)$$

= 0.00134 * 134
= 0.17956 Kw
P = 0.18Kw

(e) Leverage of the handle

Based on previous work by Joseph [9], the leverage of the handle of the designed injection moulding machine (M_L) was determined from Eq. 12.

$$M_L = m_h g d_1 \quad (12)$$

Where m_h is mass of the platen as determined in the laboratory measurement, m_h = 5.06 kg, g is acceleration due to gravity, g = 9.81 m/s^2 and d_1 represent the distance in which the handle moves in the plate, d1 = one fifth of the total length of the plunger = $^1/_5$ * 0.85 = 170 mm = 0.17 m.

The leverage of machine handle

= 5.06 * 9.81 * 0.17
= 8.44 J

2.1.2 Design of heating chamber

This is where heating is supplied to melt the mixture of the shredded plastics and additives using biomass as a fuel.

(a) Energy balance in the heating chamber

It was assumed that the combustion rate of the biomass mixture as well as the mixing rate between air and the biomass is infinitely fast so that vertically upward moving lump of high temperature (T_f) is uniformly distributed between stagnated region and the vessel surfaces. The study neglected the heat losses due to chemically incomplete combustion.

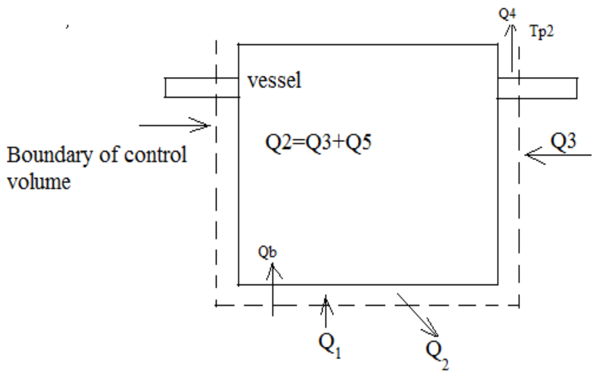

Figure 5: Energy balance of heating chamber

$$Q_1 = Q_2 + Q_3 + Q_4 \quad (13)$$

Where Q_1 is total heat carried into the control volume; Q_2 are heat losses from the control volume; Q_3 is heat absorbed by the heated vessel; Q_4 is heat losses by flue gases at temperature T_{P2} and Q_5 is heat carried out with the flue gases at temperature T_{P2} in the control volume at the bottom edge of the vessel before coming in contact with the lateral surface of vessel.

$$Q_1 = M_g \times C_p (T_{p1} - T_\infty) \quad (14)$$

Heating chamber efficiency = $\frac{Q_b + Q_5}{Q_1}$ where Q_b is the heat absorbed by the vessel surfaces

(b) Heat conduction in the heat chamber

This is the transfer of heat through metal this as the heat is transferred from the heating chamber to the vessel to melt the mixture.

Using Fourier's law

$$Q = \frac{KA\,\Delta T}{x} \quad (15)$$

Where by K= coefficient of conductivity of the wall material (KW/mK)

ΔT = Temperature difference, x wall thickness
A= Wall area normal to heat flow, m^2
K for steel = 50W/Mk
Thickness for steel plate (x) = 2mm
Area = 0.22 x 0.25 = 0.055M^2
T_2 = Temperature of plastic mixture 25°C
T_1 = Temperature of the heating from biomass 450°C

$$Q = \frac{50 \times 0.055 \times (450-25)}{0.002} = 584.4\text{kJ/kg}$$

2.2 Material selection

The materials used for the design of the machine were selected based on cost, mechanical, metallurgical and designed properties such as weldability, machinability and formability. The properties of materials affect construction and joining process. The main materials used in the construction of the machine were mild steel, medium and high carbon steel. The major construction techniques used in producing the machine include cutting, machining, welding operations, assembly and finishing.

Figure 6: Fabricated injection moulding machine

3. Results and Discussions

A model of plastic recycling injection moulding machine was fabricated and tested. The project used high density polyethylene (HDPE) materials in testing the constructed machine as HDPE is very tough at low temperatures, excellent chemical resistance and ease to process. HDPE material in small sizes was fed into the hopper. Using the heater bands, the barrel of the machine was heated for one hour to attain the highest temperature of 220^{0}C at which the material melted into liquid. Using the handle, the mould was closed allowing the injection plunger to force the molten material under high pressure to the mould cavity where it cooled into required end-product. The constructed machine produced plastic chair caps from plastic wastes.The mould cavity of the machine can be changed to desired shapes and sizes to produce other plastic products such as containers, mobile phone parts and bottle caps. The volume v of plastic melt in the injection chamber was controlled by a limit switch. Whenever the volume of the material reaches maximum level, the limit switch shuts off the plunger and the electric motor. However, during moulding process some problems were encountered. First, some molten plastic product was not fully injected. This can be attributed to either starting the injection process before the material reaching the necessary temperature or melt temperature being too low to completely melt HDPE plastic materials. Also, there was the problem of sinks on the product as a result of too high melt temperature resulting into insufficient cooling of the mould [10].

4. Conclusion

In this work, plastic recycling injection moulding machine was successfully designed, constructed and tested for plastic waste management in Kenya. The testing of the machine concluded that strict adherence of operational procedures of the machines affects the efficiency and practicability of the machine. Heating HDPE material at 220^{0}C completely melted the material. The molten material was forced under high pressure by the injection plunger into the mould cavity where it cooled to desired shape. Due to environmental awareness and economic importance of HDPE, the government of Kenya as well as environmental institutions and research centres should sensitize the public on the importance of recycling plastic wastes through injection moulding technology. The government should further invest in this technology to help in recycling plastic wastes as well as provide jobs for millions of unemployed youth. Hence the implementation of this project by the government will result into environmental and economic benefits.

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