

Design, Fabrication and Testing of a Thermoplastic Melt Flow Meter

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Abstract- *The quality of a thermoplastic product is greatly influenced by the quality of the input materials. The characteristics of recycled thermoplastics can be reasonably judged by determining the melt flow pattern. This work developed a thermoplastic melt flow meter for measuring the melt flow rate of thermoplastic materials for production quality control in the plastic industry in Nigeria. The work carried out detailed design analysis, fabrication from locally available materials and tested the melt flow meter.*

Key words- *Design, Melt flow, Thermoplastic, Product quality, Temperature.*

1. Introduction

The quality of a thermoplastic product is a function of the quality of the input materials and the processing conditions. The mechanical properties of the products depend on the melt temperature, injection pressure, clamping pressure and cooling rate (Egbe and Onyekpe, 1991). The processing conditions are known for the virgin thermoplastic materials. Moreover the machines for thermoplastic products have been designed to handle virgin materials and are capable of handling recycled materials with minor changes in the processing conditions. Thermoplastic products are being made from 100% recycled materials and varying mixtures of recycled and virgin materials in Nigeria. The flow characteristics of the recycled plastics are bound to differ from those of the virgin materials due to the presence of plasticizers and some level of degradation. Quality products can only be made when the melt characteristics of the recycled material is known. The focus of this research is to design a unit that will make it possible to determine the melt flow rate of both virgin and recycled thermoplastic materials for the plastic industry in Nigeria.

Sepe (2013) indicated the use of melt flow rate (MFR) as a measure of the viscosity of a thermoplastic material and the extent of degradation. MFR measures resistance to flow and changes in MFR of materials can be used to adjust process parameters in order to maintain the quality of thermoplastic products. Moseley, et al. (2011) calculated the activation energy for viscous flow of

thermoplastic materials from the MFR tests and indicated that the values gave insight into their temperature sensitivities.

Geoffroy, (2004) submitted that the MFR is related to the molecular weight of polymers by a power law, given as;

$$MFR = M_w^{3.4} \quad (1)$$

He concluded that the power factor makes melt flow rate an extremely sensitive tool for measuring small changes in molecular weight. The changes in melt flow rate of recycled polymers gives indication of degradation (Moseley, 2011). Rienzo (2014) indicated that MFR gives good quality control of thermoplastic materials. He submitted that complete rheological characterization of plastic materials is required in order to guaranty the quality of products. Egbe and Adekanye (2016) opined that the needed technology transfer in Nigeria can only be achieved if the country seeks to utilize available technology correctly. The melt flow meter is particularly important in Nigeria because whole products (black jerry cans of varying capacities) are being made from 100% recycled thermoplastic materials of unknown characteristics. In cases where mixtures of recycled and virgin materials are being used, the plastic flow meter will make it possible to seek a mixture with a flow behaviour that yields acceptable mechanical properties.

2. MATERIALS AND METHODS

2.1 Materials

The heating barrel, column, mounting brackets, and piston were made of AISI 1020 (hot rolled) steel. The components of the temperature control unit and heater bands were purchased from local electrical stores. The melt flow meter was tested with virgin and 100% recycled polypropylene materials.

2.2 Design Analysis and Calculations

The plastic melt flow meter consists of a vertical barrel surrounded at the lower part with two heater bands, a piston, a die (an orifice), set of weights, a temperature control unit, an analytical weighing balance, a liver system and a frame (Figure 1). The unit was designed to receive both virgin and recycled materials.

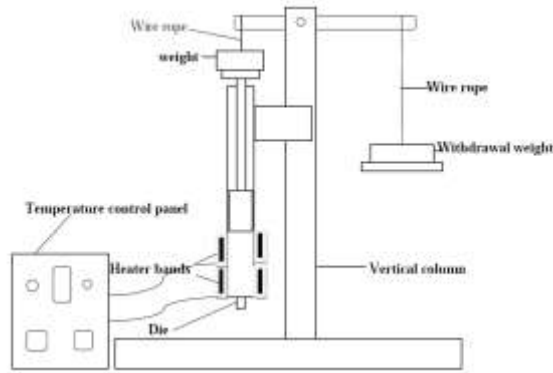


Figure 1: Schematic diagram of the plastic melt flow meter

2.1 The Heating Barrel

The heating barrel was designed to receive 250 grams of plastic material. Available heater bands limit the diameter of heating barrel to about 50mm. Moreover pieces of recycled plastics are generally much larger than virgin pellets, thus barrel diameter of 50mm aids easy charging of recycled plastic. The barrel wall must be capable of withstanding the injection pressure at the operating temperature. Applying the thin wall cylinder expression (Ibrahim et al., 2015), the tangential stress, σ_t is given by,

$$\sigma_t = \frac{pr}{t} \quad (2)$$

where p = internal pressure, r = inside radius of cylinder and t = cylinder wall thickness. Moseley et al. (2011) reported the use of a maximum mass of 9.9 kg for MFR test. The materials covered in that report have melt temperature that range between 55.1°C and 105.5°C. However regularly used polymers may have melt temperatures above 200 °C and the mass required for attainment of adequate flow could be much higher than 9.9 kg. Thus a mass of 20kg was considered for initial design. The pressure resulting from application of this load in a barrel of 50mm diameter is,

$$p = \frac{F}{A} = \frac{20 \times 9.81}{\pi d^2} \times 4 = \frac{784.8}{\pi (0.05)^2} =$$

99923.84 Pa.

Applying this pressure for available material ($\sigma_y = 207\text{MPa}$ for AISI 1020 (hot rolled) steel) and a design factor of 8, because of temperature, yields,

$$\sigma_t = \frac{207 \times 10^6}{8} = \frac{pr}{t} = \frac{99923.84 \times 0.025}{t}$$

Therefore the wall thickness, $t = \frac{99923.84 \times 0.025 \times 8}{207 \times 10^6} = 0.0965\text{mm}$.

This thickness is much less than the wall thickness of a standard 50mm hot rolled steel pipe. Thus the 50mm diameter steel pipe selected was used for the heating barrel.

2.2 Vertical Column

The heating barrel is mounted on a vertical column via welded bracket and the fulcrum of the lever system is also mounted on the column as shown in Figure 1. The load transferred through the bracket is the sum of weight of the heating barrel, piston, heater bands and test weight. It was found to be 245.25 N. Though the withdrawal mass is expected to be lower than the test mass, the same value was used for both in the initial column design. Thus reaction at the lever is given by,

$$R = (2 \times 20 + 5)9.81 = 441.45 \text{ N}$$

The column is essentially free at the top and fixed at the base. Circular steel pipes are readily available for this component. The column should not buckle under a load of $441.45 \text{ N} + 245.25 \text{ N} = 686.7 \text{ N}$. Applying Euler's expression for long column,

$$P_c = \frac{2\pi^2 EI}{L^2} \quad (3)$$

where P_c = critical load, E = modulus of elasticity, I = second area moment of inertia, and L = length of the column. Geometric considerations indicate that L cannot be shorter than 600mm and E of AISI 1020 (hot rolled) steel is $207 \times 10^9 \text{ Pa}$. The ratio of outside diameter (D) to internal diameter (d) of a standard American pipe (50mm diameter grade no 40) is 1.53 (Shegley, 2005). This implies that $D = 1.53d$. The second moment of inertia for a hollow circular column is given by,

$$I = \frac{\pi}{64} (D^4 - d^4) = \frac{\pi}{64} (1.153^4 - 1)d^4 = 0.03766d^4 \quad (4)$$

Substituting into equation (3) yields,

$$\frac{686.7 \times N}{0.6^2} = \frac{2 \times \pi^2 \times 207 \times 10^9}{0.6^2} \times 0.037666 d^4$$

where N is the design factor and is taken as 3 for this design. Calculating yields internal diameter of 8.33 mm and outside diameter of 9.6 mm.

Bending load can occur as a result of inaccuracy in fabrication. When that happens it is desired to have zero tension at the base of the column. The surface bending stress at the base due to eccentric mounting, e , is,

$$\sigma_{\text{base}} = \pm \frac{PessecKL}{I} \quad (5)$$

where P is the load, e is eccentricity, s is half the depth of section in the plane of bending, $K^2 = (P/EI)$, I is second area moment of inertia and L is the length of the column. For zero tensile stress,

$$-\frac{P}{A} + \frac{PessecKL}{I} = 0 \quad (6)$$

This implies that $Sec\ KL = \frac{I}{Ase}$ (7)

To check the capacity of the column to sustain eccentric load resulting from imperfection in fabrication the calculated values for the column obtained were substituted into Equation (7).

$$Sec\ KL = \frac{180.576}{17.8844 \times 8.8 \times e} = \frac{2.10351154}{e}$$

However sec KL must be greater than one if K has real value and it implies that e should be less than or equal to 2.1 mm. Limiting eccentricity to 2mm and substituting gave a K value of 0.5251. The allowable critical load for zero tension at the base is,

$$P_c = K^2 \times E \times I \quad (8)$$

Substituting D= 9.6 mm, d = 8.33, E = 207x10⁹ and K = 0.5251 yielded a critical load of

$$P_c = 0.5251^2 \times 207 \times 10^9 \times 180.575 \times 10^{-12} = 10.3\ N$$

This load is much below 686.7 N when there is perfect fabrication. The column was redesigned to allow some level of eccentricity. The eccentricity of 2mm allowed for in above calculation is in a ratio of 4.8 to diameter d. Maintaining the same ratio of D:d, the second moment of inertia becomes, 0.037666d⁴, area A becomes, 0.2587d² and s = 0.5765d. Substituting into Equation (7) yields

$$Sec\ KL = \frac{0.037666\ d^4}{0.2587\ d^2 \times 0.5765\ d} \times \frac{4.8}{d} = 1.21226$$

$$KL = 0.60076$$

Therefore K = 1.0013. Substituting back into Equation (8) and maintaining a design factor of 3 yields,

$$686.7 \times 3 = K^2 \times E \times I = 1.0013^2 \times 207 \times 10^9 \times 0.037666d^4$$

Therefore d = 22.66mm and D = 26.124mm. The nearest standard American pipe was used. It has an outside diameter of 26.7mm and internal diameter of 19.79mm.

2.3 Fabrication of Melt Flow Rate Meter

The processes employed in fabrication of the melt flow rate meter involved marking of pipe for the barrel and cutting to size, machining of a cover plate and welding. Other machining operations such as turning, drilling and welding were adopted in making the piston, lever unit, column, mounting brackets and the frame. The temperature control unit was assembled locally in the Department of Electrical and Electronic Engineering.

2.4 Testing Method

The heating system of the equipment was switched on and allowed to heat up for one and half hours with the temperature control set to 230°C. Three sets of 250 g virgin polypropylene were weighed with a laboratory weighing machine. One set of sample was added and the unit was allowed to heat to a steady barrel temperature of 230°C after another 20minutes.

A load of 2kg was placed on the piston. The stopper on the die was pulled out, while simultaneously a stop watch was switched on. A cutter was used to stop the flow after every two minutes. The extrudates were allowed to cool and weighed.

3. Results and Discussion

Table 1 presents the results for the melt flow of virgin polypropylene and Table 2 present that for 100% recycled polypropylene. The melt flow rate (MFR) for virgin was calculated to be 20g/10 minutes and that for 100% recycled polypropylene was 40g/10 minutes. This wide difference between the MFR of the virgin material and 100% recycled PP occurred as a result of the presence of plasticizers in the recycled material and a small effect of degradation of the material. The effectiveness of using the developed plastic melt flow meter for characterizing the input materials for thermoplastic production has been established.

Table 1: Melt flow of 100% virgin PP

S/No	Time(m)	Melt Flow(g)
1	2	4
2	4	8
3	6	12
4	8	16
5	10	20

Table 2: Melt flow of 100% recycled PP

S/No	Time(m)	Melt flow (g)
1	2	8
2	4	16
3	6	24
4	8	32
5	10	40

4. Conclusion

The design, fabrication and testing of a thermoplastic flow meter has been carried out in this work. The remarkable difference between the MFR of virgin polypropylene and that of one hundred per cent recycled polypropylene indicates that plastic industries using varying ratios of recycled materials

need the melt flow meter for monitoring the behaviour of production input materials.

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