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DESIGN OF A LABORATORY POLYURETHANE FOAM RECYCLING MACHINE

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ABSTRACT

This work reports the design of a laboratory polyurethane recycling machine. This machine was designed with the aid of Auto Cad and Inventor software in such way that it can be operated both manually and electrically-in case of power outage. The machine was made up of a mixing chamber which consists of the hopper and mixing drum, and the mixing chamber was sustained by the machine frame. The machine has a compression chamber which consists of the presser, screw and moulding box. The heating chamber of the machine consists of the pressure pot, pressure hoes to enable passage of steam from the pressure pot into the moulding box. Design calculations of the vessels were done with appropriate machine design formula. The assembled parts was also coupled are presented. The design are dimensioned in millimeters (mm), except otherwise stated.

Key words: *machine, pulley, moulding, mixing chamber, hopper.*

1. INTRODUCTION

Polyurethane foam (PUF) from onset has been the major material which mostly serves the purpose of comfort in homes, offices, as sound absorbers in compressors, cushioning materials for automobiles and in the aircraft designing, especially in the upholstery work [1,2]. PUF are formed from the reaction containing at least two isocyanate functional groups R-(N=C=O) with another monomer containing at least two or more hydroxyl groups in the presence of a catalyst system and other additives [3]. Despite its wide application, it was discovered that the waste generated from the production of this product and also the disposal of the used product are highly non-biodegradable, as it does not easily decompose because of its polymeric nature. Ismail et al.[4], observed the draw back in polyurethane foam to be inherited in poor flame retardant characteristics. An investigation on the flame retardant element in PUF as a measure of treatment

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has received attraction from researchers [5]. However, upon an updated information from various foaming company in Nigeria, it was observed that the waste generated from various plants have always been recycled, moreover, most of this recycling are not first done on a small scale in order to know how it will perform on the large scale so as to avoid chemical and energy waste. This reason account for the need of a laboratory polyurethane recycling machine that can be used to carry out simple test of chemical quality, knowing that performing this test on the industrial scale polyurethane recycling machine would lead to wastage of the chemicals hence a need for the laboratory scale polyurethane recycling machine.

Apart from the aim to minimize the waste generated, it was however envisaged that foam produced directly from recycling has very good properties such as resilience and hardness alongside with density as compared to that produced by the continuous process, due to the action of compression and reaction with steam during the recycling process. This makes the foam highly demanded in the orthopedics hospital, in production of very firm mattresses designed to provide maximum support and better weight distribution to gently relieve sleep pressure points that can cause arches and pain. The design of a laboratory polyurethane foam recycling machine was aimed at reducing human (operator) effort, processing time as well as cost of production using suitable engineering materials without compromising the efficiency of the machine.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Materials selection

A number of design factors influence the choice of material for the construction of the polyurethane foam recycling machine to enhance its simplicity, efficiency, reliability, and stability. Table 1 is a representative summary of the components used and their selection criteria.

2.2 Machine design

In this section, details of the design with reference to the parameters of the machine components are described which include: machine frame, mixing chamber, compression chamber, compression plate, shaft, bearings, electric motor, pulley and hopper.

2.2.1 Machine (metal) frame

The skeletal frame works on which other components exerts their weight. It is made of mild steel of dimension 2” x 2” x 1/8” (”- inch) and has the form of a rectangular table.

2.2.2 Mixing chamber

Mixing chamber is made up of the hopper and the mixing drum. Hopper- this is a channel that the polyurethane foam crumbs follows, entering the mixing drum. While the mixing drum is a cylindrically shaped drum where mixing of polyurethane foam crumbs with chemicals is carried out.

2.2.3 Compression chamber

The compression chamber is made up of the compression plate and the molding box. Compression plate exerts pressure on the foam crumbs to help in giving the final product solidity and rigidity. Molding box is where the polyurethane foam crumbs that have been mixed with the chemicals are poured before it is compressed.

Table 1 *- Summary of the material(s) employed for the construction of the machine as well as the criteria for their selection.*

S/N	COMPONENT	SUITABLE ENGINEERING MATERIALS	CRITERIA FOR MATERIAL SELECTION	MATERIAL SELECTED
1	Machine frame	Mild steel,high speed steel, galvanized steel, stainless steel, wood, angle iron or pipe	Strength, cost, stability/rigidity	Mild steel angle iron
2	Hopper	Mild steel, galvanized steel, high speed steel, cast iron, stainless steel sheet	Strength, corrosion and acidic reaction resistance, workability, lightness, cost	Mild steel
3	Mixing chamber	Mild steel, galvanized steel, high speed steel, cast iron, stainless steel sheet	Strength, corrosion and acidic reaction resistance, workability, lightness, cost	Galvanized steel
4	Mixing rods	Mild steel, galvanized steel, high speed steel, cast iron,	Strength, corrosion and acidic reaction resistance, workability, lightness, cost, formability /forgeability	Mild steel
5	Compression chamber	Mild steel, galvanized steel, high speed steel, cast iron, stainless steel sheet	Strength, corrosion and acidic reaction resistance, workability, lightness, cost	Galvanized steel
6	Cover	Mild steel, galvanized steel, high speed steel, cast iron, stainless steel sheet	Strength, corrosion and acidic reaction resistance, workability, lightness, cost	Galvanized steel
7	Pulley(s)	Mild steel, high speed carbon steel, galvanized steel, stainless steel, cast iron	Strength, workability, reliability, cost, wear resistance	Mild steel
8	Belt	Rubber, leather	Flexibility, strength, wear resistance, availability	Rubber
9	Shaft	Mild steel, cast iron, high speed steel, galvanized steel, stainless steel	Cost, reliability, workability, wear resistance, strength	Mild steel
10	Bearings	Pillow journal bearing, thrust Bearing	Axial and radial load resistance	Pillow journal bearing
11	Pressure pot (autoclave)	Aluminium or Stainless steel.	Corrosion, heat and weather resistance.	Stainless steel pot.

2.2.4 Bearing

The effectiveness and smooth operation of the machine largely depends on the bearings. The journal pillow bearing number 207 of internal diameter of 35 mm was used as a result of its capability to withstand the thrust and axial loading of the shaft of the machine. The journal of the pillow bearing was bolted to the machine (metal) frame.

2.2.5 Machine drive

The drive of the machine is the coupling effect of electric motor, v-belt and pulley(s). The electric motor is mounted directly on the machine support via bolts and nuts, and power is transmitted from the electric motor to the shaft via the pulley and v-belt arrangement.

2.2.6 Pressure vessel or autoclave

Pressure vessels (cylinders or tanks) are used to store fluids under pressure. The fluid being stored may undergo a change of state inside the pressure vessel as in the case of steam boilers.

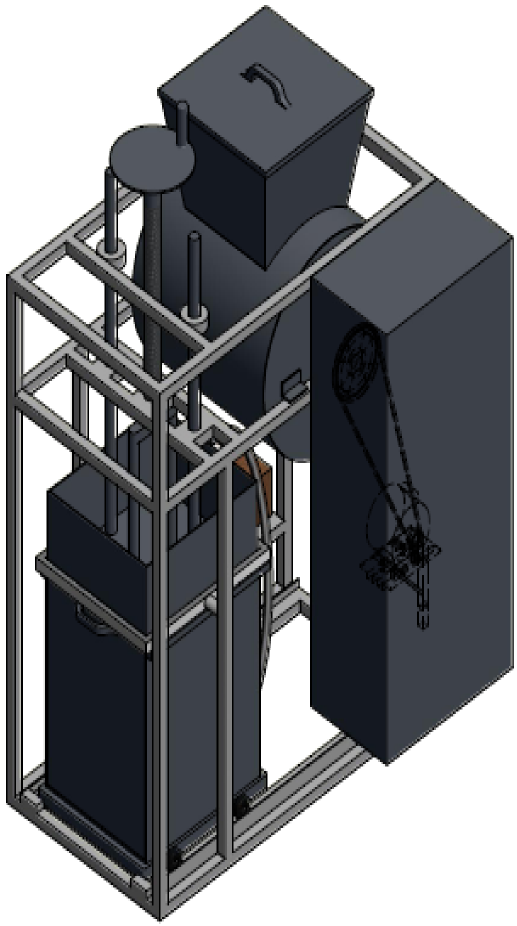

Fig.1 *- Isometric drawing of the machine*

3. RESULTS AND DISCUSSION

3.1 Design Calculation

Determination of the area and volume of the mixing chamber - the mixing chamber is made up of the hopper and the mixing drum.

3.1.1 Hopper

The hopper is in the shape of a truncated pyramid and each side having the shape of an isosceles trapezoid.
Area of a truncated pyramid is given as:

$$A = 2(a+b)\sqrt{\left(\frac{a+b}{2}\right)^2 + h^2} \tag{1}$$

Where *a* and *b* are the lengths of the parallel sides and *h* is the height of the truncated pyramid .i.e. *a*= 42 cm, *b*= 27 cm, *c*= 33 cm as *h* is unknown.
To find the height of the pyramid taking a section along the upper and lower diagonal of the truncated pyramid as shown below.
Using the Pythagoras theorem we can find the length of the diagonals, *Z* is 59.4 cm. However, for the lower diagonal, Z' is 45.3 cm. Bringing out the isosceles trapezoid to calculate the height of the pyramid, *h* is 30 cm.
Substituting *a*, *b*, and *h* into equation (1), we have that *A* is 4501 cm^{2}.
Volume of the hopper V_h = volume of truncated pyramid [6].

$$V_h = \frac{1}{3}\left(a^2 + 2ab + b^2\right)\pi h \tag{2}$$

Substituting the values of a, b and h into equation 2 gives V_h= 129810.61 cm^3

3.1.2 Mixing drum calculation

The details of the mixing drum, the area of mixing drum A_d= area of a cylinder
Surface area of cylinder

$$A_d = 2\pi r^2 + 2\pi rh \tag{3}$$

As *r* =27cm, *h* = 52 cm, substituting these into equation 3 gives A_d = 13404 cm^2. Also, volume of mixing drum = volume of a cylinder

$$V_d = \pi r^2 h \tag{4}$$

Upon substitution into equation 4, we have V_d = 119106 cm^3

3.1.2.1 Mixing chamber calculation

The total area of mixing chamber = area of hopper + area of mixing drum, area of hopper = 41435 cm^2, area of mixing drum = 13404 cm^2.

Total area of mixing chamber = 4501 + 13404 = 17905 cm^2

Total volume of mixing chamber is eqaul to the volume of hopper = volume of mixing drum Volume of hopper = 129810.61 cm^3

Volume of mixing drum = 119106 cm^3

Total volume of mixing chamber = 248916.61 cm^3

3.1.3 Compression chamber calculation

The compression chamber is made up of the area and volume of the molding box. The total surface area is 13342 cm^2, as the volume of molding box is

$$L \ x \ B \ x \ H \tag{5}$$

Where L= 55 cm, B=46 cm and H= 41cm, substituting into equation 5 gives V = 103730 cm^3

3.1.4 Determination of belt and pulley

Belt design considerations

Akinnuli et al. [7] stated that speed ratio is given by

$$\frac{N_1}{N_2} = \frac{D_2}{D_1} \tag{6}$$

Where N_1 is speed of the driver pulley = 1400 rpm, N_2 is speed of the driven pulley (uknown), D_1 is diameter of the driver pulley is 42 mm, and D_2 is diameter of the driven pulley = 175 mm. Replacing given values in Eq. 6, it follow that speed of the driven pulley is $\mathbf{N_2}$ = 336 rpm.

3.1.5 Determination of belt speed and belt tension

The speed of the belt is given as;

$$V = \frac{\pi N_1 D_2}{60} \tag{7}$$

Substituting the values of N_1, D_1 and π respectively, we have the belt speed to be V =3.08 m/s. According to Khurmi and Gupta [8], the length of an open belt is given as;

$$L = \frac{\pi}{2}(D_1 + D_2) + 2C + \frac{(D_1 + D_2)^2}{4C} \tag{8}$$

where C is distance between the two pulleys.

Using the relation from [7], C = 540 mm. Substituting values for D_1, D_2 and C in equation 8,we have L= 1442.79 mm. Hence, the length of the belt = 1.443 m.

Let:
T_1 - Belt tension on the tight side, T_2 - Belt tension on the slack side, M - Mass of the belt, V - Speed of the belt and α =Angle of wrap of the belt, then mass of v-belt is :

$$M = Density\ x\ Length\ x\ Area \tag{9}$$

Here, longer width of V-belt is W_1=12.5 mm, shorter width of V-belt W_2 = 7.2 mm, and thickness of V-belt is t = 8 mm.
Assuming a cut section through the v-belt, it forms a trapezoidal shape and area of a trapezoid is given as:

$$A = \left(\frac{W_1 + W_2}{2} \right) \cdot t \tag{10}$$

Where W_1 and W_2 are the lengths of the parallel sides of the trapezoid and t is the height of the trapezoid. Substituting the values of W_1, W_2 and t in equation 10, gives Area of v-belt = 0.0000788 m^2.

From Khurmi and Gupta [8], the density of a convass V-belt is given by 1220 kg/m^3. By substitution values in Eq.9, we have the mass of V-belt, M = 0.14 kg. Centrifugal tension is determined by:

$$T_c = Mass\ x\ (Velocity)^2 \tag{11}$$

By substituting, we have T_c = 1.328 N

Allowable stress of the belt is σ = 2.4 MPa, as the maximum tension in the belt is:

$$T_b = \sigma\ x\ Area \tag{12}$$

Hence, T_b = 189.12 N

The tension on the tight side of the belt is given as:

$$T_1 = T_b - T_c \tag{13}$$

i.e. T_1 = 187.792N

For an open belt drive;

$$sin\ \alpha = \frac{D_2 - D_1}{2C} \tag{14}$$

Substituting for D_1, D_2 and C in equation 15 gives the value of α =7.07°

3.1.6 Determination of the angle of contact, tension on the slack side of the belt and power transmitted

The angle of lap/contact (θ) is the angle between the two pulleys of different diameter connected by an open belt. Angle of lap on the smaller pulley;

$$\theta = \frac{(180 - 2\alpha)\pi}{180} \tag{15}$$

Hence, θ = 2. 896 rad.

To calculate the tension on the slack side of the belt, T_2, the relation below is utilize [8].

$$2.3\log\left(\frac{T_1}{T_2}\right) = \mu\theta \tag{16}$$

Coefficient of friction, μ was taken as 0.20. Substituting the values of μ, θ, and T_1 into equation 16, gives T_2 as 105 N.

The torque (T_L) on the shaft of the driven pulley is given as :

$$T_L = \frac{(T_1 - T_2)D_2}{2} \tag{17}$$

Substituting for the values of T_1, T_2 and D_1 in equation 18 above, we have T_L = 7.3 N. Thus, the Power transmitted can be deduce from the relation below

$$P = (T_1 - T_2)V \tag{18}$$

Upon computation, $P = 255.33\ W$.

3.1.7 Calculation of the shaft parameters

Volume of the shaft is:

$$V_s = \pi r^2 L \tag{19}$$

For radius of shaft = 2.8 cm, length of shaft = 74.3cm, we get volume of the shaft 0.00183 m^3.

The weight of the shaft for the mass of the shaft 7.839 kg and material density ρ = 4283.6 kg/ is F_s= 76.8 N. Mass of wheel/pulley = 0.89 kg, weight of wheel/pulley = 8.7 N.
Total weight of mixing rods= 1.36 N (each weighing 0.139 kg)

3.1.8 Determination of the power required to drive pulley and shaft

Weight of pulley F_p= 8.7N, Radius of pulley = 87.5 mm, and Number of revolution N=23.33 s^{-1}, as the Angular velocity is $\omega = 2\pi N = 146.5\ rad/s$. Linear velocity of the pulles can be calculated from [9] as:

$$v = r\omega = 182\ m/s \tag{20}$$

Power required to drive the pulley is

$$P_p = F \cdot v = 0.16\ kW \tag{21}$$

Also, using Eq.21, we get that power required to drive the shaft is *Ps* = 0.34 kW (Weight of shaft = 76.8 N, radius of shaft, r = 0.030 m and Velocity = 4.39 m/s).
The ttotal required power is *Pt* = 0,51 kW

3.1.9 Determination of compression screw

Date regarding screw geometry are as follows: Length of screw = 54 cm, external diameter of screw, d = 42 mm, internal (core) diameter of screw, d_1 = 31.3 mm, Pitch, $P = d - d_1$ =10.7 mm, Mean diameter, d_m = 36.65 mm.

The relationship between the helix angle α pitch and mean diameter d_m is expressed by [10]

$$\tan\alpha = \frac{P}{\pi d_m} \tag{22}$$

Substituting corresponding values into equation 30, we get α =5.3 °.

The torque (M_t) required to overcome friction between the screw and nut is given by

$$M_t = W \cdot \tan(\alpha + \theta)\frac{d_m}{2} \tag{23}$$

where: μ=0.12 - coefficient of friction, and θ = 6.84° ($\mu = \tan\theta$) – friction angle.

Mass of foam crumbs = 5 kg, Mass of chemicals = 1 kg, which gives Total weight (W) = 58.8 N.

Substituting W, α, d_m, and θ into equations 23, we have Mt = 0.232 Nm.

Efficiency

$$\eta = \frac{\tan\alpha}{\tan(\alpha + \theta)} \tag{24}$$

4. CONCLUSION

A laboratory polyurethane foam recycling machine has been designed with details on the parameters few of which are, the hopper, the auto clave, the shaft, the compression chamber and the mixing rods. The challenge in disposing polyurethane foam as land fill or exporting it as waste can be resolve with the use of a recycling machine. Hence, the design was factored so as to allow for either manual control or electrical control mechanism.

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KONSTRUKCIJA LABORATORIJSKOG POSTROJENJA ZA RECIKLAŽU POLIURETANSKE PENE

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REZIME

Poliuretanska pena (PUF) je materijal koji ima široku primenu za razne vrste pakovanja u kućanstvu, administraciji i industriji, zatim kao absorber zvuka u kompresorima i drugim mašinama/uredjajima koji proizvode buku, kao amortizujući materijal u auto i avio industriji itd.
Uprkos svojoj širokoj primeni ustanovljeno je da je otpad nastao proizvodnjom ovog proizvoda kao i odlaganje upotrebljenog proizvoda veoma ne-biorazgradiv process tj. da se zbog svoje polimerne prirode ne može se lako i brzo razgraditi. Zbog toga postoji potreba za efikasnom reciklažom PUF pene. Ovaj rad prikazuje konstrukciju jednog takvog postrojenja za tu vrstu reciklaže.
Postrojenje je konstruisano pomoću AutoCad i Inventor softvera, a može funkcionisati ručno kao i na električni pogon. Glavni delovi postrojenja su komora za mešanje, komora za sabijanje i komora za zagrevanje. Komora za mešanje se sastoji od kontejnera sa levkom i bubnja za mešanje. Ova komora je fiksirana za kućište mašine. Komora za sabijanje sadrži pritiskivač, zavojno vreteno i kalup. Komora za zagrevanje mašine sastoji se od potisnog lonca i potisnih kanala koji omogućavaju prolaz vodene pare iz potisnog lonca u kalupe.
U radu je konkretno elaboriran jedan primer proračuna datog postrojenja.Proračun je izvršen na bazi relevantne metodologije.
Klljične reči: *mašina, kotur, brizganje, komora za mešanje, levak*