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Development of a Mixer for Polyurethane (Foam) Waste Recycling Machine

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Abstract: *A Laboratory sized polyurethane (foam) mixer was designed and fabricated for the recycling of old foams and foam wastes generated in the foam production industries during production. It was observed that the waste generated from various foam plants are so enormous and there is need to recycle them. Also, old and discarded foams are serious source of environmental concerns because they are not bio-degradable. However, most of the recycling are being carried out by big companies on a large scale because of the size and cost of recycling machineries involved. This had always excluded cottage industries from participating in recycling process thereby putting much burden on the big industries in recycling both the generated wastes and old foams. There is need to develop a small polyurethane (foam) crumbs mixing machine for recycling of foams that can be used by any industry, whether big or cottage; and that can also be used to carry out simple test of chemical quality, which would have been done with larger machines that could have led to wastage of the chemicals and time. It has been discovered that foam produced directly from this recycling process has very good properties such as resilience and hardness alongside with high `density as a result of compression and curing with steam during the recycling process as compared to those produced by the normal continuous process. This makes the foam manufactured from recycled materials in high demand in orthopaedics foams, in production of very firm mattresses designed to provide maximum support and better weight distribution to gently relieve sleeping pressure points that can cause aches and pains. These foams are also useful as industrial lagging/insulation materials in refrigeration and air conditioning systems. The mixing machine is made up of a mixing chamber which consists of the hopper and the mixing blade on a shaft; the foam crumbs mixing chamber is supported by the machine frame made of square hollow mild steel pipes. The machine was put to test after fabrication for performance evaluation and the capacity of the machine was determine for different scenarios. It was discovered during the testing that the density of the product increases with the increasing weight of the chemical due to compression and curing. The tests showed that the products from the machine was in good comparison with the ones produced by industrial machines.*

Keywords: *Lagging/insulation materials, Mixing machine, Orthopaedics, Polyurethane Foams, Recycling machine.*

1. INTRODUCTION

Polyurethanes were discovered around 1937 by Professor Dr. Otto Bayer (1902-1982) and his co-workers at IG Farben in Leverkusen, Germany [1, 2]. Polyurethanes had some significant benefits over other existing brand of plastics that were made either by polymerizing olefins or poly-condensation. Initially, the production was mainly fibres and flexible foams. Also, polyurethanes were applied to some extent, as aircraft coating during World War II [3]. Polyurethanes were in different texture and aesthetics. Polyurethanes were used variedly for different purposes, such as coatings and adhesives, shoe soles, mattresses and thermal insulation. However, they have their basic composition basically the same. During World War II, polyurethanes were widely used as a replacement for rubber, which was very expensive and difficult to source because of the war. Several polyurethane applications and uses were developed, involving coatings of different kinds, airplane finishes as well as special resistant clothing. After the war, polyurethanes had applications in adhesives, elastomers and rigid foams and, later in flexible cushioning foams like those being used today. Most people are not familiar with polyurethane materials because when they are in use, they are hidden from the sights by other materials covering their surfaces. It is hard to imagine life without polyurethanes today. Polyurethane materials produce lots of wastes and rejects during production and after their useful lives because they are used widely in many areas. Wastes generated during its production processes were estimated to be about 15% [4]. China is one of the highest producers and consumer of polyurethanes. China's production output had been rising steadily and peaked at 7.5 million tons in 2011; 60% of which was polyurethane foam, with about 675,000 tons of polyurethane foam as wastes [4]. The foam wastes mainly come from the production process of leftover materials and

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product scraps. Polyurethane foam has small density of about 30 kg/m³, therefore, it will occupy a lot of space during. Since it is difficult to bio-degrade, it remains in the environment for a very long time thereby causing adverse effect in the environment. Therefore, pollution by polyurethane foam wastes can be curbed efficiently by recycling. Polyurethanes could be recycled physically by directly reusing polyurethane wastes without applying chemicals or chemically by degradation principle. Polyurethane wastes will gradually depolymerize to original reactant or another oligomer and even small molecule organic compound [5]. Seymour & Kauffman [3] reported that commercial availability of Poly-isocyanates and the production of flexible polyurethane foam using toluene diisocyanate (TDI) and polyester polyols were in 1952 and 1954 respectively. These materials were also utilized to produce other products including rigid foams, gum rubber, and elastomers. Production of linear fibers were from hexamethylene diisocyanate (HDI) and 1,4-Butanediol (BDO). According to Seymour & Kauffman, DuPont introduced polyether polyols in 1956, which was made from poly (tetramethylene ether) glycol, and BASF while poly-alkylene glycols were being sold by Dow Chemical starting from 1957 [3]. Polyether polyols became more popular because they were cheaper, easier to handle and were also more water-resistant than polyester polyols. At that time, Union Carbide and Mobay, a joint venture between U.S. Monsanto and Bayer, also started manufacturing polyurethane chemicals. Flexible polyurethane foams produced in 1960 were in excess of 45,000 metric tons. Polyurethane rigid foams were used as high-performance insulation materials because of the availability of chloro-fluoro-alkane blowing agents, as well as inexpensive polyether polyols, and methylene diphenyl diisocyanate (MDI). Urethane-modified polyisocyanurate rigid foams were introduced in 1967, which offered better thermal stability and flame propagation resistance. Automotive interior safety components, including instrument and door panels, were produced by back-filling thermoplastic skins with semi-rigid foam in the 1960s. Bayer exhibited an all-plastic car in Düsseldorf, Germany in 1969. Some of this car parts, such as the fascia and body panels, were produced using different process, the reaction injection moulding (RIM), which the reactants were mixed and then injected into a mould to dry. Reinforced RIM (RRIM) was produced with the addition of fillers, such as milled glass, mica, and processed mineral fibres. This gave improvements in flexural modulus (stiffness), reduction in coefficient of thermal expansion and improved thermal stability. The first plastic-body automobile in the United States, the Pontiac Fiero, was manufactured using RRIM technology in 1983. The stiffness was improved by adding pre-placed glass mats into the RIM mould cavity, which is known generally as resin injection moulding, or structural RIM (SRIM). Water-blown microcellular flexible foams were used to mould gaskets for automotive panels and air-filter seals, instead of PVC polymers starting in the early 1980s. Polyurethane foams are now being used in high-temperature oil-filter applications because of its high popularity in the automotive realm [6]. Polyurethanes are polymers composed of organic units joined by carbamate (urethane) links. Polyurethane polymers are basically and mostly formed by reacting a di- or tri-isocyanate with a polyol. Polyurethanes are classed as alternating copolymers because they contain two types of monomers which polymerize one after the other. On the average, Isocyanates and polyols used to make polyurethanes contain two or more functional groups per molecule. Polyurethanes are being used in the manufacture of many products such as high-resilience foam seating, rigid foam insulation panels, microcellular foam seals and gaskets, durable elastomeric wheels and tires (including roller coaster, escalator, shopping cart, elevator, and skateboard wheels), automotive suspension bushings, electrical potting compounds, high-performance adhesives, surface coatings and surface sealants, synthetic fibers (e.g., Spandex), carpet underlay, hard-plastic parts (e.g. electronic instruments), condoms, and hoses [7]. In 1995, the largest US market share of polyurethanes were taken by flexible and rigid foams, with 48% and 28% respectively followed by about 8% for polyurethane elastomers and about 16% for other applications, which added up to around 1640 Mt (million tonnes) in the US in 1995. At that time North America represented around 30-35 % of the world total consumption, with the remainder in Western Europe (around 40 %), the Far East (around 15%) and the rest of the world (around 10-15 percent). This put the total worldwide polyurethane consumption to around 6000 Metric tons for 1995, which corresponded to about 5% of the total plastics consumption [8]. Besides recovery and recycling of the polyurethane waste, there could be other options, such as land filling or exporting. Land filling of polyurethane wastes is still a very common practice in most places around the world. Also, exporting of polyurethane foams is still occur. In year 2000 about 60,000 tons of polyurethane foam production waste was exported from Europe to the US for recycling to making carpet underlay by re-bonding [9]. Wastes generated over the years from the polyurethane foam production that found their ways into the environment by disposal were found not to be biodegradable. This has attracted the attention of chemical engineer professionals on how to properly handle the recycling of the wastes generated during production and consumption of polyurethane foams [10]. Recovery and recycling of polyurethane waste can be categorized into three methods as reported in Weigand [11]: Mechanical recycling, Feedstock recycling and energy recovery. Adhesive pressing [11] is a type of mechanical recycling method whereby scraps of polyurethane foams are shredded into particles and eventually coated with a binder, and bonded in a heated press with steam curing. This can be done to a lot of plastics wastes and this is a short route to many semi-finished and finished products. This is one of the oldest methods of recycling flexible polyurethane foams which makes possible the production of many other products such as mats, carpet underlay, sports hall floor coverings, heat and automotive sound insulation. Mechanical mixers are integral part of recycling process which will be used to mix the foam crumbs wastes with binding agents for homogenous mixture. Traditional mixing technique such as stirrers were being used in the past, but mixers had evolved with the invention of electronics and motors, and these are some of the most preferred methods for mixing and stirring chemicals now. Those traditional methods in past, asides from being tedious and time consuming, mixing of amorphous materials, solid-state pellets, and others in solvents resulted in inhomogeneous products most of the time [12]. Mechanical mixers using hand driven gear systems were designed in early 1900s to overcome earlier limitations. Miniaturization of electrically driven motors in early

1950s with the evolution of power & control electronics brought about mixers such as magnetic stirrers and centrifuges. Also, the development of small size Alternating Current (AC) motors in the early 1960s and 1970s, and the design of new types of shakers, mixers, stirrers and temperature-controlled equipment and instruments developed specifically for use in chemical and biological laboratories. This led to a new kind of industry that is scientific instrumentation manufacturers [13, 14]. The mixers require different variations of standard and some, special components for their purposes. Combinations of different components such as mixer power, impeller size, speed of rotation, and length of shaft makes the mechanical design of mixers different. A mixer should be mechanically designed to cope with external forces within its material limit. There is need for proper mechanical design which includes the selection of appropriate components, such as electric motors, bearings, and vanes, and the sizing of components, such as mixer drum, shafts, etc. The objectives of this paper are to design, fabricate and test a small (laboratory) scale polyurethane (foam) mixing machine for recycling of polyurethane wastes. Also, samples of the recycled foams will be produced and tested for the purpose of validating the design. This machine will be a welcome development for the industry operators in that they can also perform their test at a smaller scale with a small machine that can conserve materials during testing. It will have cost more on materials had the test been performed on a larger machine.

2.0 MATERIALS AND METHODOLOGY

2.1 Material selection process

Effective and efficient machine operations is very important for proficiency and profitability. For effective operation of this machine, the materials were properly selected with careful consideration and balance between cost, materials' availability, mechanical properties, processing and environmental concern.

2.1.1) The Frame support: The frame support is shown in Figure 1. This supports the entire machine component such as the mixing chamber, the presser and the mould. A suitable engineering material, hollow structural section (squared pipe), made of mild steel was considered such that will meet the standard of budget, availability, rigidity, high strength, weldability was selected.

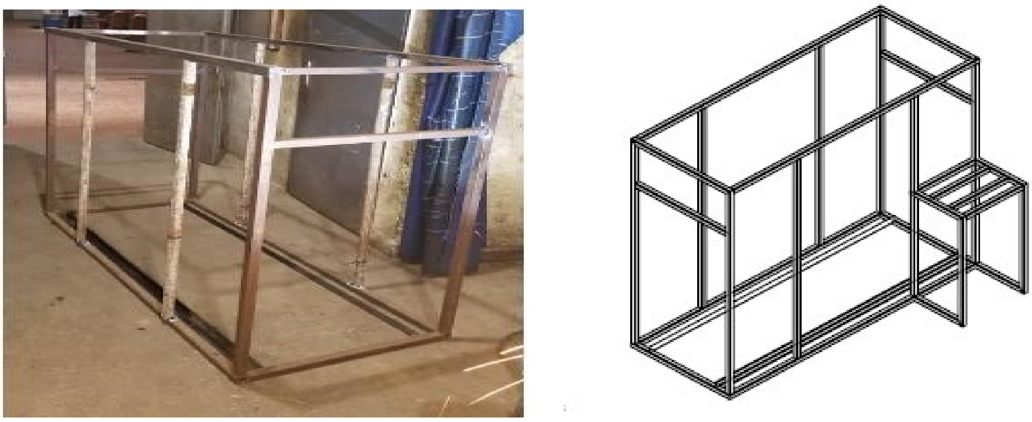

Figure 1: Machine frame

2.1.2) The Mixing Drum with the Hopper: The mixing drum with the hopper is shown in Figure 2. The mixing drum is a cylindrical container that houses the foam crumps and the mixing blade. The hopper is the entrance through which the crumps is fed into the mixing drum and an opening at the bottom through which the mixture is discharged. The materials used for this part was galvanized steel, considering cost, availability, rigidity, fatigue strength, fracture toughness, weldability, corrosion and acidic reaction resistance, lightness, wear and other properties.

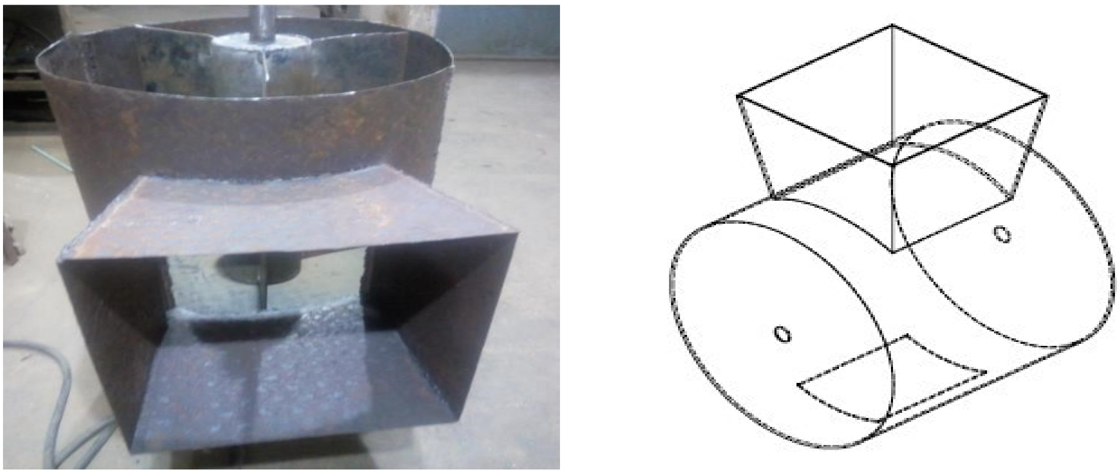

Figure 2: Mixing Drum with the hopper

2.1.3) Mixer hub: The Mixer hub shown in Figure 3 carries three-vane mixing blade angled at 120^0 to each other. During the selection process, different shapes such as square, rectangular and circular pipe were considered but a hollow structural section (round pipe) galvanized steel was used. The mixer vane, also shown in Figure 3, is the major mixing part, rotating with the hub to mix both the binding chemical and the foam crumps homogeneously. During the selection process we considered suitable engineering materials such as mild steel, high speed steel, galvanized steel and stainless steel, however, after considering cost, availability, rigidity, fatigue strength, fracture toughness, weldability, corrosion and acidic reaction resistance, lightness, wear and other properties. We decided to select mild steel plate.

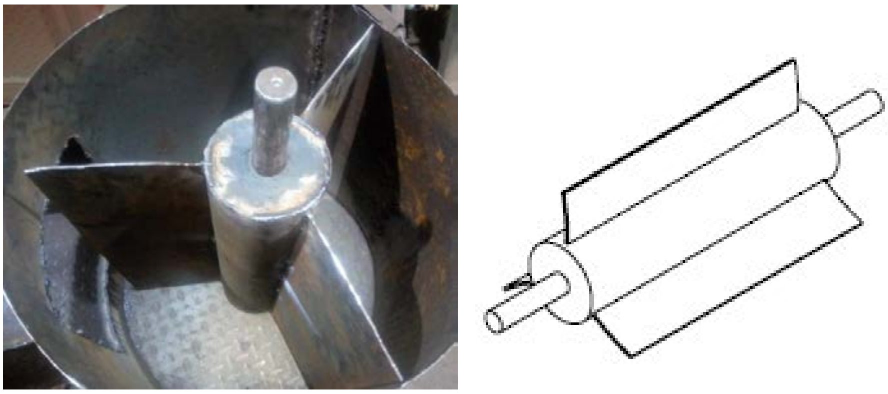

Figure 3: Mixer

2.1.4) Mixing shaft: This is the component that rotate the mixer via power transmission from the electric motor. During the selection process, suitable engineering materials such as mild steel, high speed steel, galvanized steel and stainless steel, were all put into consideration, however, after considering cost, availability, rigidity, shear resistance, fatigue strength, fracture toughness, weldability, corrosion and acidic reaction resistance, lightness, wear and other properties. Mild steel rod was eventually selected for the mixing shaft.

2.1.5) Belt: A belt shown in Figure 4, is a loop of flexible material used to link together two or more rotating shafts mechanically. Rubber belt drive was selected after considering the cost and other factors

2.1.6) Bearing: A bearing is a machine element that constrains relative movement to the desired motion and reduces friction between moving parts. This is attached to the Mixing shaft at both ends for frictionless motion. Two pillow block bearing were used since it is used for a rotating shaft with the help of compatible bearings and various accessories.

2.1.7) Pulley and electric motor: Figure 4 below shows a pulley of size A with an external diameter 160mm, to ensure a ratio of 1:2 speed transmission from the electric motor to the mixer and internal diameter 75mm was selected to fit into the shaft. The pulley was attached to one end of the shaft and connected to 3hp gear electric motor via A43 belt.

Figure 4: Pulley and Electric motor

2.2 Methodology

The section is about the method of achieving the design and construction of the mixing machine.

2.2.1) Design calculation: This section is devoted to the design calculations of various parts of the assembly.

Design of the Hopper: The hopper is in the shape of a truncated pyramid and each side having the shape of an isosceles trapezoid as shown in the Figure 5 below.

*L*ateral Area, $LA = 0.402$ m^2

*S*urface Area, $SA = LA + a^2 + b^2 = 0.683$ m^2

Volume of the hopper= volume of truncated pyramid

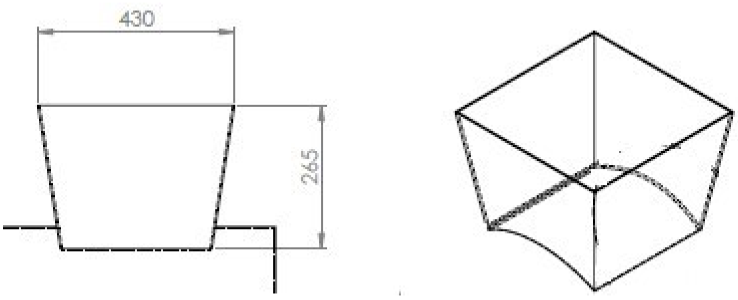

Figure 5: The hopper design

$V = 1/3 * (a^2 + ab + b^2)*h$ [15]

$V = 1/3 * (0.43^2 + 0.43(0.31) + 0.31^2) * 0.265$

$V = 0.0366m^3 = 36.7$ litres

Design of the mixing drum: Figure 6 is the schematic design of the mixer blade. To get the Volume of space within the Mixing drum that will accommodate the foam wastes crumbs, it is important to know the volume of mixer (hub and blade) in the mixing drum and the volume of the mixing drum itself.

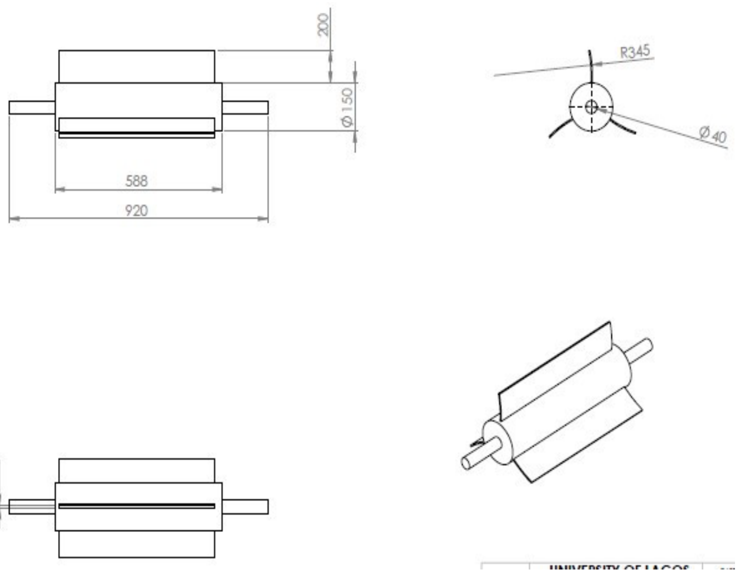

Figure 6: The drawing of the mixer blade

The volume of the mixer is therefore calculated thus [16]:

Volume of the Mixer, $V_{mixer} = V_{hub} + V_{blade}$

Where V_{hub} is the Volume of hub

V_{blade} is the Volume of blade.

Since the hub is cylindrical shape with diameter of 0.15m with height 0.6m, V_{hub} is therefore calculated thus:

Volume of hub: The volume of the hub is calculated thus:

$$V_{hub} = \pi r^2 h$$

$$Where\ r\ is\ the\ radius\ of\ hub, r_{hub} = \frac{d_{hub}}{2}$$

$$Since\ diameter\ of\ hub, d_{hub} = 0.15m, \quad radius\ of\ hub, r_{hub} = \frac{0.15}{2} = 0.075$$

$$V_{hub} = 3.142 \times 0.075^2 \times 0.6 = 0.0106m^3$$

Volume of blade: Since the blade is cuboid in shape with length 0.550m, breadth 0.2m and thickness (height) 0.004m, V_{blade} is therefore calculated thus:

$$V_{blade} = L_{blade} \times B_{blade} \times H_{blade}$$

$$V_{blade} = 0.550 \times 0.2 \times 0.004 = 0.00044 m^3$$

Since we have three blades around the hub in the mixing drum total volume of blade is therefore:

$$V_{blade\ total} = 3\,(V_{blade}) = 3 \times 0.00044 = 0.00132 m^3$$

Therefore,

$$\textbf{Volume of Mixer}, V_{mixer} = V_{hub} + V_{blade\ total} = 0.0106 + 0.00132 = 0.01192 m^3$$

The volume of mixing drum: Figure 7 below is the design of the mixing drum. Since the mixing drum is a cylindrical shape with diameter 0.615m and height 0.61m, The Volume of Mixing drum, $V_{mixing\ drum}$ is calculated thus:

$$V_{mixing\ drum} = \pi r^2 h$$

$$Where\ r\ is\ the\ radius\ of\ mixing\ drum\ , r_{mixing\ drum} = \frac{d_{mixing\ drum}}{2}$$

$$Since\ diameter\ of\ mixing\ drum, d_{mixing\ drum} = 0.615m,$$

$$radius\ of\ mixing\ drum, r_{mixing\ drum} = \frac{0.615}{2} = 0.3075m$$

$$V_{mixing\ drum} = 3.142 \times 0.3075^2 \times 0.610 = 0.1812\, m^3$$

The volume of space for crumbs within the mixing drum is therefore:

$V_{crumbs\ space} = V_{mixing\ drum} – V_{mixer}$

Where $V_{mixing\ drum} = 0.1812$

$V_{mixer} = 0.01192\ m^3$

$V_{crumbs} = 0.1812 – 0.01192 = 0.1693\ m^3$ or 169.3 litres - this is the maximum space (volume) of the mixing drum by implications, the maximum volume of foam crumbs that can be mixed at once.

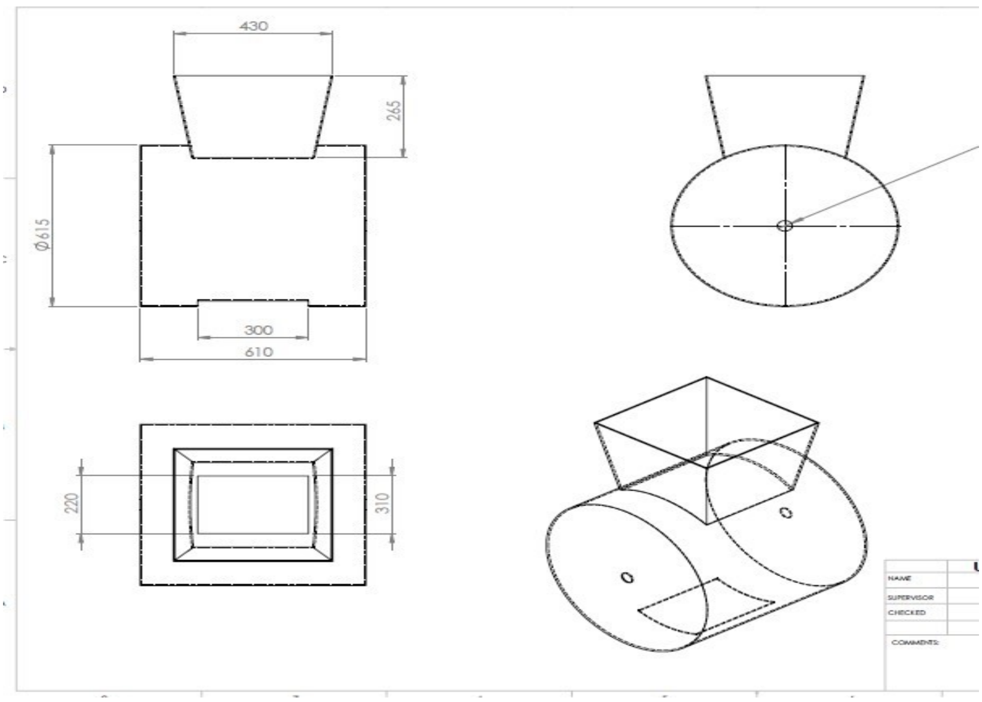

Figure 7: Mixing drum design

2.2.2) The Construction: The construction of some essentials parts of the machine is discussed.

The Polyurethane mixing machine consists of the Frame and mixing drum. This machine was constructed by assembling fabricated parts/components of the machine via several joining (such as welding, use of fasteners, etc.) methods and techniques based on the material function, expected life of the components, as well as the operation of the entire machine. The fabrication is in accordance with standard fabrication procedures such as measurement, marking out, cutting, machining, forging, bending, drilling, joining (temporary and/or permanent joint) and finishing operations such as smoothening with emery cloth and grinding machine and painting. The frame as shown in Figure 1 was made with a hollow structural section (square pipe) of 30 mm x 30 mm with thickness of 1.5 mm. The square pipe was cut and joined permanently by welding to form a frame of height 1355 mm above the ground, length 1710 mm and breadth 680 mm. Four circular hollow structural section of diameter 30mm and thickness 3mm was also introduced to the frame at four points to support and balance the load exerted on the frame by the mixer and the presser. The mixing drum as shown in Figure 2 was made with galvanized sheet of 1.5 mm thickness cut and folded to form a cylindrical hollow shape of diameter 615 mm and height 610 mm. A square shaped discharge channel was cut underneath the drum with dimension 365 mm by 365 mm. Figure 3 is a hopper with a squared base of 310 mm x 310 mm, squared top 430 mm x 430 mm and height of 265mm was fabricated and positioned at the center of the curved surface of the mixing drum. The Mixer shown in figure 4 contains the blade, the hub and the shaft. The two ends of a 75 mm diameter and length 920 mm round shaft known as the mixing shaft was machined on the lathe to step turn the diameter to 40 mm at 160 mm from both ends in other to accommodate the hub and sit at the centre of the mixing drum. The mixing hub was made with a 3 mm thick cylindrical hollow structural section of external diameter 150 mm, internal diameter 76 mm and length 600 mm, the mixing hub was then welded to the centre of the mixing shaft after which three number 4 mm thick mixing plate of length 550 mm and height 200 mm was attached as the mixing blade on the hub at an angle 120^0 to each other. After which the mixer was centralized into the mixing drum and the whole component was mounted on the frame via two self-centred pillow bearings of internal diameter 75 mm at both ends. Figure 5 below is a pulley of size A with an external diameter 160 mm was selected to ensure a ratio of 2:1 speed transmission from the electric motor and internal diameter 75 mm was selected to fit into the shaft. The pulley was attached to one end of the shaft and connected to 3 hp electric motor via A43 belt.

2.2.3) Theoretical Framework:

For foam crumbs of density 13kg/m³ and mass 3kg

$$Since, Volume = \frac{mass}{density}$$

$$Volume_{density\ 13}, V_{13} = \frac{3}{13} = 0.2308m^3$$

Table 1 below shows the values of volume of foam densities at different masses. It can be seen that if the mass of foam crumbs to be charged into the mixing drum is 6kg, none of the foam densities can be charged into the mixing drum as the least volume is 0.17m^3 which is the same as the $V_{crumbs\ space}$. If the mass of foam crumbs to be charged is 5kg, only foam density 36kg/m^3 can be charged into the mixing drum. If the mass of foam crumbs to be charged is 4kg, only densities 25kg/m^3 and 36kg/m^3 can be charged into the mixing drum. If the mass of foam crumbs to be charged is 3kg, densities 13kg/m^3, 16kg/m^3 and 18kg/m^3 can be charged into the mixing drum. If the mass of foam crumbs to be charged into the mixing drum is 2kg and below, all densities of foam can be charged into the mixing drum.

Table1: Volume of the different foam crumb densities at varied masses.

Density (kg/m3)	Volume (m^3) at 1 kg	Volume (m^3) at 2 kg	Volume (m^3) at 3 kg	Volume (m^3) at 4 kg	Volume (m^3) at 5 kg	Volume (m^3) at 6 kg
13	0.08	0.15	0.23	0.31	0.38	0.46
16	0.06	0.13	0.19	0.25	0.31	0.38
18	0.06	0.11	0.17	0.22	0.28	0.33
20	0.05	0.10	0.15	0.20	0.25	0.30
22	0.05	0.09	0.14	0.18	0.23	0.27
25	0.04	0.08	0.12	0.16	0.20	0.24
36	0.03	0.06	0.08	0.11	0.14	0.17

Mass of different density of foam crumbs acceptable in the mixing drum: Since it is concluded that at mass 3 kg not all density of foam crumps can be fed into the mixing drum because at densities 13 kg/m^3, 16 kg/m^3 and 18 kg/m^3 the volume of crumbs will be too much for the space in the mixing drum. This therefore makes it important to calculate the mass of each density of foam at 15% less of the $V_{crumbs\ space}$ 0.17 m^3.

Volume of available crumbs' space, $V_{crumbs'\ space} = 0.1411\ m^3 = 141.1$ litres

Volume permissible for free mixer rotation: 10% clearance was given in the mixing drum to create clearance for smooth and ease of operation of the mixer.

Permissible Volume, $V_{permissible} = V_{crumbs'\ space} - (10\%\ of\ V_{crumbs'\ space})$

$= 0.17 - (0.1 \times 0.17) = 0.153\ m^3$

Actual mass of acceptable foam crumbs in the mixing drum is therefore calculated as

Mass = density X Volume.

Table 2 below shows the acceptable mass of all the densities that can be contained in the mixing drum without any clog to rotation of the mixer.

Mixing proportion of foam crumbs for the available space in the mixing drum: Since it is not all the densities of foam crumbs that can be fed into the mixing drum, estimation of the mixing proportion of the various densities is necessary. Percentage of proportion of mass of each densities were determined as follows:

Total mass of all the mixtures = 2.0 + 2.4 + 2.7 + 3.1 + 3.4 + 3.8 + 5.5 = 22.9 kg

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$$percentage\ proportion = \frac{mass\ of\ each\ density}{total\ mass\ of\ all\ densities} \times 100$$

Table 2: Actual mass of acceptable foam crumb of each density in the mixing drum at 0.1524 m^3 volume

Density (kg/m^3)	Mass (kg)
13	2.0
16	2.4
18	2.7
20	3.1
22	3.4
25	3.8
36	5.5

Mass proportions of each densities of foam crumps: to be fed into the mixing drum at once to attain 3 kg of foam crumbs are calculated thus as shown below and tabulated in Table 3 below.:

$$mass\ proportion = \frac{percentage\ proportion}{100} \times total\ mass\ to\ be\ charged\ into\ the\ drum$$

$$Volume\ proportion = \frac{mass\ proportion}{density}$$

Table 3: mass proportion of foam crumbs mixture that are fed into the mixing chamber

Density (kg/m^3)	Mass (kg)
13	0.26
16	0.31
18	0.35
20	0.41
22	0.45
25	0.50
36	0.72
Total	**3**

3.0 RESULTS AND DISCUSSIONS

3.1 Results

The polyurethane (foam) mixing machine was constructed, tested, observed and evaluated using foam of different densities as mentioned earlier.

3.1.1 Description of machine operations and testing

Figure 8 below shows the mixing drum. The process of recycling of polyurethane foam with this machine begins from sourcing of waste and old foams of different densities which is then loaded into a shredder to reduce the size. The shredder produces crumbs at the rate of about 10 kg per hour. The shredded crumbs are then fed into the mixing drum which has capacity to hold about 6 kg of crumbs, however for the sake of this experiment, only 3 kg of crumbs is charged into the drum to allow for clearance and higher efficiency. Thereafter, the electric motor is powered on to begin the agitation of the crumbs while the prepolymer binder is added gradually until homogeneity of the mixture (prepolymer and crumbs) is attained, this process takes about 10 minutes. During the mixing process the steam boiler will be powered on make the steam ready to supply for bonding. The moulding box is brought under the mixing drum via a travelling rail after which the mixing drum is opened underneath to discharge the foam crumbs as the stirrer continues to rotate, after the discharge, the moulding box returns to the compression section of the machine where the mixture is compressed while curing with steam.

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Figure 9: The Mixing Drum

3.2 Discussion

Testing of the Mixing drum was done with the foam crumbs fed into the mixing drum. The crumbs were fed at random without considering the density but volume. Therefore, it is important to know the volume of different density of foam crumbs that can be fed into the mixing drum at any time. Also, it is important to know the volume of each densities of foam crumbs that can be charged into the mixing drum when combined with other densities of foam crumbs as well. For this experiment, seven (7) different densities of foam crumbs that were combined were; 13 kg/m^3, 16 kg/m^3, 18 kg/m^3, 20 kg/m^3, 22 kg/m^3, 25 kg/m^3, 36 kg/m^3. Three different mixtures were made as samples. The composition of the mixtures are shown in Table 4 below. From the observation in Table 3, it is discovered that the more the chemicals charged, the denser the product becomes as illustrated in sample 1 compared to sample 2. Sample 2 and 4 were of the same composition.

Table 4: The materials fed into the mixing drum

Samples	Crumbs (kg)	Chemicals (kg)	Total materials charged (kg)	Steam charged(kg)
Sample 1	3	2.4	5.4	2.5
Sample 2	3	1.2	4.2	2.5
Sample 3	1.5	1.2	2.7	2.5
Sample 4	3	1.2	4.2	2.5

4.0 CONCLUSION

A mixing drum for a laboratory size polyurethane foam recycling machine was designed, developed and tested. Table 5 below shows the comparative sizes of the industrial mixing drum (mixer) and the laboratory scale mixing drum. One of the aims of the project is to develop a laboratory sized recycling machine to reduce the loss that will be incurred when using the industrial recycling machine for chemical test. This has been achieved since the final product was found comparative with the product from the industrial recycling machine.

Table 5: Comparison of the industrial machine to the laboratory machine developed

Components and materials	Industrial Machine	Laboratory Size	Reduction ratio
Mixer volume	6.7 m^3	0.1524 m^3	43.9:1
Mould Volume	8.325 m^3	0.223 m^3	37:1
Crumbs used	130 kg	3 kg	43.3:1
Chemical used	20 kg	0.46 kg	43.3:1
Density obtained	100 – 250 kg/m^3	100 – 250 kg/m^3	1:1

It has been successfully demonstrated that foam recycling can be done even at the back yard of as a cottage industry to earn good income for the unemployed in converting of waste to wealth. Although, earlier works has been done on the industrial recycling machine, this work has simplified the greatly dealt with numerous challenges that are usually encountered when using the industrial machine for the same purpose.

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