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DESIGN AND FABRICATION OF BENCH SCALE EQUIPMENT FOR THE PRODUCTION OF STYROFOAM ADHESIVE

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ABSTRACT

Design and fabrication of bench scale equipment for the production of styrofoam adhesive. The design and fabrication was carried out by applying various workshop processes and techniques. Stainless steel was chosen to be used for the reactor because it is resistant to corrosion and has greater strength at high temperature. The equipment is capable of mixing and agitating of 0.00458 m^3 volume of solid – liquid mixtures at a reactor residence time of 1.53 s. The reactor was powered by 2.56 watts' electric motor and operated at 100 rpm. The production test of the styrofoam adhesive was successfully carried out base on raw material compositions, the flow behaviour of the adhesives produced is pseudo plastic which is non Newtonian fluid.

KEY WORDS: *Styrofoam, adhesive, reactor, synthetic solvent*

1.0 INTRODUCTION

Adhesives is the general term used for substance capable of holding material together by surface attachment to provide some form of geometric continuity. Adhesives may come from either natural or synthetic sources and it is cure (harden) by either evaporating a solvent or by chemical reactions that occur between two or more constituents **[1].**

Adhesive is a compound that adheres or bonds particles together. Adhesives are produced from either natural or synthetic sources. Some adhesives produce extremely strong bonds and are becoming increasingly important in the modern construction industry. Resin is a natural or synthetic compound which is highly viscous in its natural state and hardens with treatment. Typically, resin is soluble in alcohol but not in water and is also used as varnishes and adhesives.

Styrofoam is a lightweight plastics material normally thrown away after been used during ceremonies, occasions and after other materials being packaged were removed. However, the intention to use styrofoam comes from the fact that it is environmental unfriendly solid waste materials, non-biodegradable and readily soluble in acetone but insoluble in water **[2].**

The reactor/vessel in which the process takes place is the key unit operations equipment in most of chemical process industries, the design of reactors vessel is therefore crucial to the success of the industrial operation. The research is aimed to design and fabricate bench scale equipment for the production of styrofoam adhesives.

The design is primarily concerned with the main mechanical features commonly. The size reduction devices which is manually operated, screw conveyor that conveys the styrofoam to the reactor and the mechanical agitation devices that comprises of Vessel and Impellers.

It is useful to consider some common problems encountered in production of the adhesives, the problems are:

- How to design and select reactor equipment for a given duty
- How to assess whether reactor is suitable for a particular application

How to deduce the most satisfactory arrangement for a large unit from experiments which is small units?

It is therefore important to appreciate that over mixing may often be undesirable because it may result in both excessive energy consumption and impaired product quality in mixing, there are two types of problems to be considered — how to design and select mixing equipment for a given duty, and how to assess whether a mixer is suitable for a particular application **[3].** The following aspects should be considered for mixing processes:

i. Similarity criteria
ii. Flow patterns
iii. Power consumption
iv. Rate of mixing and mixing time
v. The range of mixing equipment available and its selection.

1.1 SIMILARITY CRITERIA OFSTIRRED VESSELS

One of the problems confronting the designers of mixing equipment is that of deducing the most satisfactory arrangement for a large unit from experiments with small units. In order to achieve the same kind of flow pattern in two units, geometrical, kinematic, and dynamic similarity and identical boundary conditions must be maintained.

For similarity in two mixing systems, it is important to achieve geometric, kinematic and dynamic similarity **[3].**

The geometric similarity prevails between two systems of different sizes if all counterpart length dimensions have a constant ratio. Thus the following ratios must be the same in two systems:

$$\frac{D_T}{D}; \quad \frac{D_T}{D}; \quad \frac{W_B}{D}; \quad \frac{W}{D}; \quad \frac{H}{D} \qquad (1)$$

However, the kinematic similarity exists in two geometrically similar units when the velocities at corresponding points have a constant ratio. Also, the paths of fluid motion (flow patterns) must be alike.

The dynamic similarity occurs in two geometrically similar units of different sizes if all corresponding forces at counterpart locations have a constant ratio. It is necessary here to distinguish between the various types of force: inertial, gravitational, viscous, surface tension and other forms, such as normal stresses in the case of viscoelastic non-Newtonian liquids **[3, 4].** Some or all of these forms may be significant in a mixing vessel.

1.2 POWER CONSUMPTION IN STIRRED VESSELS

Power consumption is perhaps the most important parameter in the design of stirred vessels. Because of the very different flow patterns and mixing mechanisms involved, it is convenient to consider power consumption in low and high viscosity systems separately.

For low viscosity liquids, high-speed propellers of diameter about one-third that of the vessel are suitable, running at 10-25 Hz.

For the mixing of highly viscous and non-Newtonian fluids it is usually necessary to use specially designed impellers involving close clearances with the vessel walls; these are discussed in a later section. High-speed stirring with small impellers merely wastefully dissipates energy at the central portion of the vessel **[4].** For geometrically similar systems, these ratios must be equal,and the functional relationship between the power number and the other dimensionlessgroups reduces to:

$$Np = f(Re, Fr) \qquad (2)$$

The simplest form of the function in equation above is a power law, giving:

$$Np = K' Re^b Fr^c \qquad (3)$$

where the values of K', b and c are dependent upon type of impeller/vessel arrangement and the flow regime, that is laminar, transition or turbulent, prevailing in the mixing vessel.

1.3 FLOW PATTERNS IN STIRREDTANKS

A qualitative picture of the flow field created by an impeller in a mixing vessel in a single- phase liquid is useful in establishing whether there are stagnant or dead regions in the vessel, and whether or not particles are likely to be suspended. In addition, the efficiency of mixing equipment, as well as product quality, are influenced by the flow patterns prevailing in the vessel. The flow patterns for single phase, Newtonian and non-Newtonian liquids in tanks agitated by various types of impeller should also be considered. Equation 4 and 5 can be used as correlations in the determination of flow pattern **[4].**

$$R_e = \frac{ID^2 N\rho}{\mu} \quad (4)$$

$$F_r = \frac{N^2 D}{g} \quad (5)$$

1.4 RATE AND TIME FOR MIXING

The main mechanical features of mixing and its range of applications depend upon mechanical agitation, vessels, baffles and impellers. Before considering rate of mixing and mixing time, it is necessary to have some means of assessing the quality of a mixture, which is the product of a mixing operation because of the wide scope and range of mixing problems **[5].**The residence time (τ) for the reactor vessel depends on the conditions selected. Equation 6 can be applied for therelation between residence time and the other pertinent variable.

$$\tau = \frac{1}{s} = C_{A0}\, {}^{V}/F_{A0} \quad (6)$$

2.0 MATERIALS AND METHODS

2.1 MATERIALS SELECTION

The factors to be considered for selection of materials are; the function of the equipment, strength and durability of the materials, materials of mating parts, method of manufacturing and finishing and accuracy required **[6]**

2.1.1 List of Materials

The major raw materials are styrofoam, gum arabic, ethanol, gasoline, silica gel, bolts and nuts, carbon steel sheet, mild steel angle bar, stainless steel sheet, stainless steel rod and other fabrication tools.

2.2 DESIGN PROCEDURE

The design and fabrication of the reactor was done in such a way that the component parts could be dismantled for maintenance and easier operation.

2.2.1 Determination of Reactor Volume

Where H = 0.18m and D_t = 0.18m

$$V = \pi[Dt/2]^2\ H \quad (7)$$

$$V = \pi[0.18/2]^2 \times 0.18 = 0.004581\ m^3$$

$Approx = 5\, litres$

2.2.2 Impeller Design [ID]

$$ID = \frac{Dt}{3} \tag{8}$$

$$ID = \frac{0.18}{3} = 0.06m$$

2.2.3 Position of Impeller in the Tank

$$\frac{ZA}{Dt} = \frac{1}{3} \tag{9}$$

$$\frac{ZA}{Dt} = \frac{0.18}{3} = 0.06 \text{ m}$$

2.2.4 Impeller Width[W]

$$\frac{W}{Dt} = \frac{1}{5} \tag{10}$$

$$W = \frac{0.18 \times 1}{5} = 0.036\, m$$

2.3 SCALE U-UP OF STIRREDVESSEL

2.3.1 Dimensional Similarity

Equation (1) was applied to determine geometrical and dynamic similarity. However, kinematic similarity exists if two geometrically have similar ratio.

$$\frac{D_T}{D}; \quad \frac{D_T}{D}; \quad \frac{W_B}{D}; \quad \frac{W}{D}; \quad \frac{H}{D} \tag{11}$$

For Geometrical Similarity

$$\frac{Dt}{ID} = \frac{0.18}{0.06} = 3, \quad \frac{H}{ID} = \frac{0.18}{0.06} = 3, \frac{ZA}{ID} = \frac{0.06}{0.06} = 1 \quad and\ \frac{W}{D} = \frac{0.037}{0.06} = 0.62$$

Therefore, the above ratios showkinematic similarity exists in two geometrically similar units.

2.4 DETERMINATION OF FLOWPATTERN

Equations 4 and 5 was applied in the determination of flow pattern of the mixture

$$R_e = \frac{ID^2 N\rho}{\mu}$$

$$= \frac{0.06^2 \times 1.7H_Z \times 1860}{54 \times 10^{-3}} = 210.8$$

$$F_r = \frac{N^2 \text{D}}{g}$$

$$= \frac{1.7^2 \times 0.06}{9.81} = 0.01768$$

2.5 DETERMINATION OFREACTOR VESSEL RESIDENCE TIME (τ)

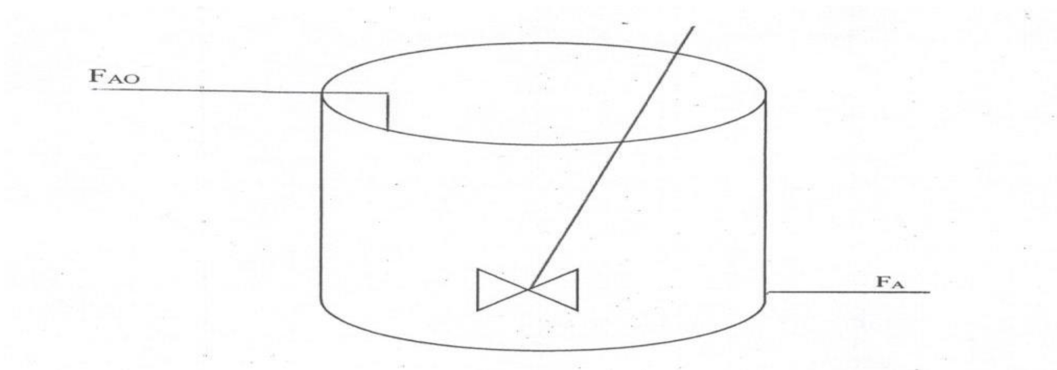

Figure 1: Reactor vessel

Equation (6) was used in determining residence time (τ) for the reactor vessel

$$\tau = V\frac{C_{AO}}{F_{AO}} \quad (6)$$

From Ideal gas equation given as:

$$P\,V = n\,R\,T \quad (11)$$

$$P = \frac{n}{v}RT \quad (12)$$

Where $C = \frac{n}{v}$

In this case $C_{AO} = \frac{P_{AO}}{RT}$ (13)

P_{AO} = 101.3 KN/m^2 $R = 8.314\ KJ/Kmol\ k$, $T = 37 + 273 = 310\ k$

Substitute the above parameters into equation 13

$$C_{AO} = \frac{101.3\ KN/m^2}{8.314\,kj/kmol\,k\ \times 310\,k} = 0.039\ kmol/m^3$$

F_{AO} = Area $\times$ Volume (14)

$$A = \frac{\pi D^2}{4} \quad (15)$$

$$A = \frac{\pi(0.18)^2}{4} = 0.025\,m^2$$

Where volume = 0.004581m^2

F_{AO} = 0.004581 $\times$ 0.025 = 0.000117m

$$\tau = \frac{VC_{AO}}{F_{AO}} = \frac{0.004581 \times 0.039}{0.000117} = 1.53\ S$$

2.6 FABRICATION PROCEDURES

The fabrication process was by applying various workshop processes depending on their property and places of use. The basic process involved were machining, fitting and welding (permanent joining).

2.6.1 Fabrication of the Frame

The frame was the rigid and main structure of the machine-it was made from mild steel. The mild steel was cut off in to ten different pairs, out of which three were of the same length, and six were of different length while the remaining one is for middle support. Two holes were drilled on the opposite side of the flat bar of (49 X 3) mm. one hole was attached with angle bars, whereas the other hole accommodate the clamp that tighten the motor, which will be mounted on the reactor cover.

2.6.2 Fabrication of components

The impeller was made up of stainless steel to avoid corrosion, 0.06m diameter impeller was cut followed by twist drilling of holes to accommodate the stirrer with the aid of bolts and nuts.

Five (5.0) litres volume of stainless steel vessel was fabricated by apply workshop techniques and 20mm diameter hole was drilled at the button of the vessel, where the tap was fitted for discharging the mixtures.

At the end all components were collected, jointing, fitted and some permanently welded parts were assembled together for the bench scale equipment.

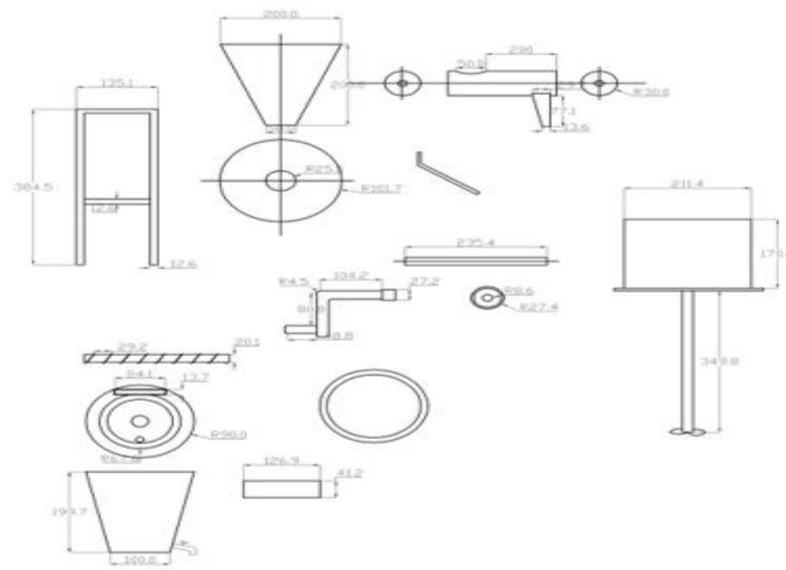

Figure 2: Component drawings

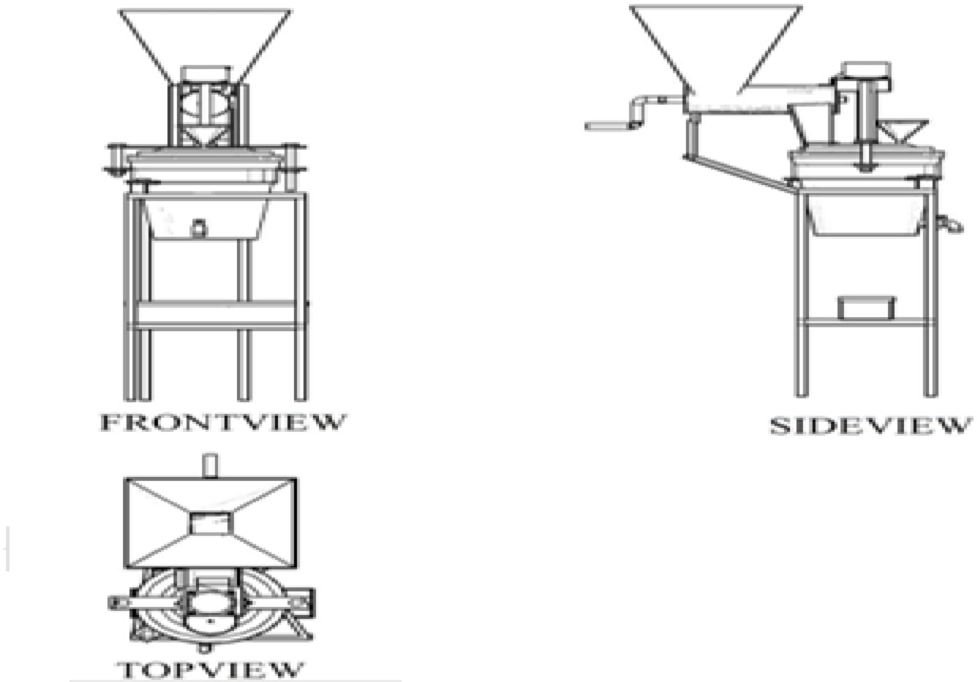

Figure: 3 Isometric View

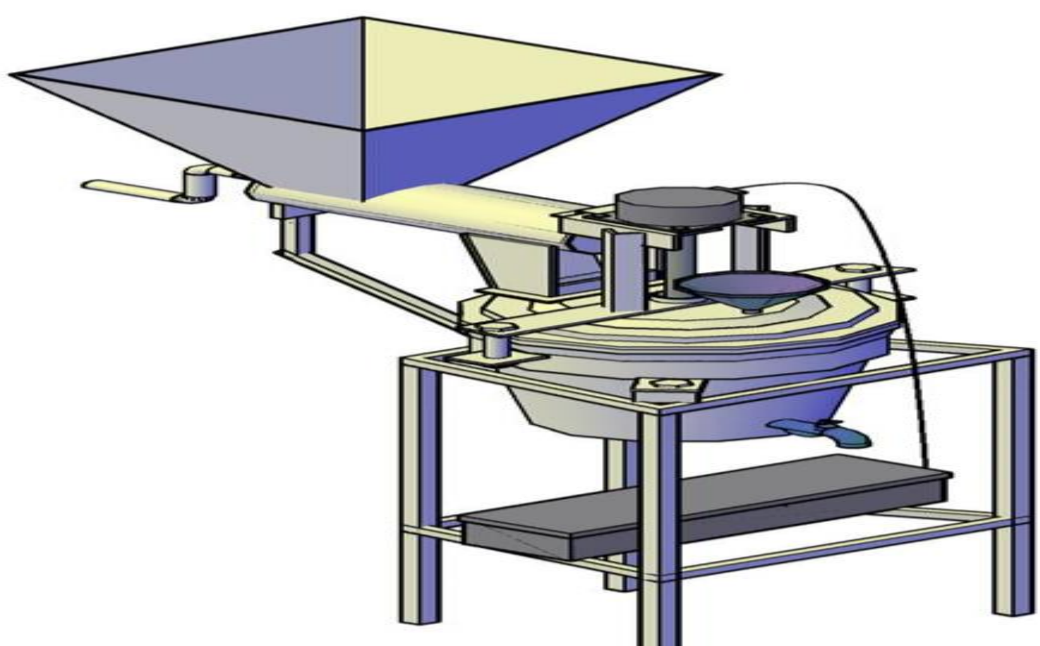

Figure: 4 Complete Bench Scale Assembly View

4.0 DISCUSSION OF RESULT

The design and fabrication of bench scale equipment for the production of styrofoam adhesive was done; by all the available materials and various factors were considered for the selection of the materials for fabrication. The fabrication was done by applying various workshop processes and techniques depending on their properties and method of operations. Stainless steel was chosen to be used for the reactor, because it is resistant to corrosion and has greater strength at high temperature. The reactor was powered by 2.56 watts' electric motor and also agitate at 100 rpm. During agitation the impeller continues to generate high velocity streams resulting into uniform mixing The bench scale adhesive equipment is relatively simple device adaptable to a small-scale laboratory set ups and it needs little auxiliary instrumentation and flexible when operating This equipment is capable of mixing and agitating of 0.00458 m^2 volume at reactor residence time of 1.53sand finally this equipment can also be used for other mixing that are viscous.The flow behavior of the adhesives produced is pseudoplastic which is non Newtonian fluid.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The bench scale adhesive equipment is relatively simple device adaptable to a small-scale laboratory set ups and it needs little auxiliary instrumentation and flexible when operating This equipment is capable of mixing and agitating five litres of solid – liquid mixtures at a time and other mixing that are viscous.

5.1RECOMMENDATION

The bench scale equipment is capable of mixing high viscous liquids, and recommended for industrial requirement and to be scale up with mathematical simulation. Finally, every user of this equipment should adhere to the following important consideration:

Inspection, safety, and maintenance given to the bench scale equipment as follows:

- The equipment vessel was designed only for Agitation and mixing of solid – liquid or liquid – liquid.
- The equipment vessel should be thoroughly washed before commence further operation.
- The electrical devices (electrical motor, switch regulator) operational guidance should be adhere.

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