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EFFECT OF EPOXY RESIN IN FABRICATED RESIN TRANSFER MOLDING

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Abstract

Polymer composites becomes the most important and versatile theme of research. Production of the same implies the method of compression molding, injection molding, hand lay-up method etc. in this chapter, we specifically deal with resin transfer molding and their important parameters for manufacturing polymer composites. Two pistons with reverse motion mechanism are provided for resin flow process. Whereas, the separate hopper used for hardener flow process. Finally the mixing of resin and hardener is done by pneumatic gun setup.

Keywords: Polymer Composites, Resin Transfer molding, Preform Thickness.

INTRODUCTION

RTM is a vacuum-assisted, resin transfer process with a flexible solid counter tool for the B-side surface compression. This process yields increased laminate compression, a high glass-to-resin ratio, and outstanding strength-to-weight characteristics [1]. RTM parts have two finished surfaces.

Reinforcement mat or woven roving is placed in the mold, which is then closed and clamped. Catalyzed, low-viscosity resin is pumped in under pressure, displacing the air and venting it at the edges, until the mold is filled. Molds for this low-pressure system are usually made from composite or nickel shell-faced composite construction.

Suitable for medium volume production of larger components, resin transfer molding is usually considered an intermediate process between the relatively slow spray-up with lower tooling costs and the faster compression molding methods with higher tooling costs [2].

The classic RTM process uses a wide range of thermally activated resins, but due to the low cost, polyesters are the most commonly used resins in RTM[3]. Other resins used include epoxies, vinyl esters, acrylic/polyester hybrids, acrylamide resins, and methyl methacrylate vinyl esters. These thermally activated resin systems do not react appreciably at the initial resin storage temperature and rely on the heated mold walls to accelerate the chemical reaction [4]. As a result, the filling times for RTM can be as long as 15 min, and the cycle time can be of hour or longer, depending on the resin and application. Slow injection and reaction rates of some RTM systems can be used to achieve excellent impregnation of complex shaped parts [5]. In addition, the low viscosity of the resin and the slow injection rate result in low injection-pressure and clamp-force requirements. As a result, RTM allows the use of so-called *soft tools* (e.g., wood backing epoxy molds or aluminum molds), which require significantly lower investments compared to competitive manufacturing systems. Because of the relatively long cycle time, RTM is generally limited to a low-volume production (i.e., less than 10,000 parts). The figure shows an RTM setup classification of processes.

OPEN MOLD PROCESSES:

1. Family of FRP shaping processes that use a single positive or negative mold surface to produce laminated FRP structures

2. The starting materials (resins, fibers, mats, and woven roving's) are applied to the mold in layers, building up to the desired thickness

3. This is followed by curing and part removal Common resins are unsaturated polyesters and epoxies, using fiberglass as the reinforcement.

OPEN MOLD FRP PROCESSES:

1. Hand lay-up

2. Spray-up

3. Vacuum Bagging –uses hand-lay-up, uses atmospheric pressure to compact laminate.

4. Automated tape-laying machines

The differences are in the methods of applying the laminations to the mold, alternative curing techniques, and other differences

CLOSED MOLD PROCESS:

Resin Transfer Molding:

Resin transfer molding (RTM) is a closed mold manufacturing process. Finished parts are made by introducing polyester or vinyl ester resins into closed molds containing fiberglass, carbon or other reinforcements [6].

Whether your process is traditional RTM, Light RTM, Vacuum Infusion Process (VIP), Closed Cavity Bag Molding (CCBM), or other similar process, Glass Craft offers a complete line of RTM systems to fit your application.

Process of Resin transfer molding:

1. Performing

2. Mold filling and Curing

3. Post Curing

4. Releasing

RESIN SYSTEMS:

Common resin systems used in advanced composites include polyesters, vinyl-esters, epoxies and thermoplastics [7].

Epoxy resin systems tend to be the most versatile, but are expensive and have environmental concerns associated with them. Thermoplastic resin systems are the toughest of the resin systems, but they are highly viscous and are not suited to processing by either hand lay-up or RTM[8].

Polyester and vinyl-ester resins have low viscosities, are more benign environmentally than epoxies and tend to be the least expensive[9]. Epoxies, vinyl-esters and polyesters are all commonly used in wind turbine blade manufacture[10].

Generally, resin systems are processed as liquids. Resin systems cure by either forming cross-linked polymer chains, thermosets, or by making very long, entangled polymer chains, thermoplastics[11]. Epoxy, polyester and vinyl-ester resins fall into the thermoset category. The cure time of a resin system is very important to both RTM and Hand lay-up. Resin systems have to remain liquid long enough to fill the mold and properly wet out the fibers[12]. The working time of a resin is referred to as the gel time. Gel times of fifteen minutes to one hour are common for most systems used for both RTM and hand lay-up.

RTM Injection Setup

RTM is a closed mold process. First, dry reinforcing fibers are placed in a two-sided mold. The mold is then sealed, and at this time, it is common to pull a vacuum. A vacuum helps eliminate void formation during injection since the resin does not need to push air out of the mold[13]. The resin is then mixed to initiate curing and injected under pressure.

Resin viscosity is critical to the RTM process. Injection times are limited and the fiber mats have a very low permeability. If pressures get too high, the fibers will be moved by the resin, commonly called fiber wash. Low viscosities decrease injection times and lower the risk of fiber wash [14]. It is possible to process resins with viscosities up to 1000 cP. In practice, however, most RTM resin systems have viscosities less than 500 cP, with ideal resin viscosities in the 100 to 200 cP range [15].

Basic equations for flow of the liquid resin:

The basic equations for flow of the liquid resin through the spaces in the mats are described in this section. Generally, resin systems are modeled as Newtonian fluids with constant density and viscosity so the Navier-Stokes equation is valid.

$$\rho \frac{Du}{Dt} = -\nabla P + \mu \nabla^2 u + \rho g = \nabla P + \mu \nabla^2 u$$

Where ρ is the density, u is the velocity of the fluid, t is time, P is the pressure, μ is the viscosity of resin and g is the acceleration due to gravity [16].

PROBLEM DEFINITION AND PROPOSED CONCEPTS

That Resin transfer molding (RTM) machine is used for manufacturing large sizes of components with a huge setup of machinery and the electrical devices are used like Motor, pump etc,

To overcome that difficulty, we design the same machinery equipments with new mechanisms in smaller sizes to reduce cost and for making small components with same strength and properties as large RTM machine

But now, the whole system is works under Pneumatic where the compressor is used to run the system.

So the electrical source is fully eliminated here and also reduced cost of the machine. components description

The major components used in this proposed design of Resin Transfer Molding are described below with the materials that are suitable for the particular component.

PISTON:

Piston is a disk or cylindrical part tightly fitting and moving within a cylinder, either to compress or move a fluid collected in the cylinder, as air or water, or to transform energy imparted by a fluid entering or expanding inside the cylinder, as compressed air, explosive gases, or steam, into a rectilinear motion usually transformed into rotary motion by means of a connecting rod.

Dimensions:

1. Piston Cap : Square – 43x43x43x43mm (2 no's)
2. Cylinder dia : 37mm
3. Piston Rod : 108mm
4. Total length : 198mm

MATERIAL USED

1. Piston : Stainless steel
2. Cylinder : Aluminium
3. Cylinder Cap : Cast Iron

Stainless steel:

1. Stainless steel is most commonly used for their corrosion resistance.

2. It used for high temperature properties

Aluminium:

1. It has low density and Low weight but high strength.

2. Aluminium can be easily machined.

Cast Iron:

1. It includes Tensile strength, compressive strength, and Shear modulus of Rupture.

2. Has a brittle property.

AGITATOR

Agitators are devices that are used to stir or mix fluids, especially liquids, which is one of the basic mechanical process engineering operations. Essentially, agitators are used for the homogenization of liquids or liquid-solid mixtures by generating horizontal and vertical flows. These flows are generated by rotating agitator blades.

Dimensions:

1. Height of the Agitator : 155mm
2. Major diameter : 158mm
3. Minor diameter : 85mm
4. Height of the Gun : 155mm
5. Height of the rod (blade) : 12mm
6. Thickness of the blade : 3mm

Material Used:

1. Agitator : Stainless steel
2. Blades : Mild steel

1. Stainless Steel

1. Stainless steel is most commonly used for their corrosion resistance.

2. It used for high temperature properties

2. Mild Steel:

1. Mild steel can be machined and shaped easily.

PNEUMATIC GUN (OR) AIR GUN:

An air gun is any kind of small arms that propels projectiles by means of mechanically pressurized air or other gas (shooting involves no chemical reaction), in contrast to explosive propellant of a firearm (shooting involves an exothermic chemical reaction). The description of pneumatic gun is as follows.

1. It is fully operated by means of Air.
2. More pressure.
3. RPM: 1500
4. Equal Clamping of blades in the mixer.

NON RETURN VALVE

A non-return valve allows a medium to flow in only one direction. A non-return valve is fitted to ensure that a medium flows through a pipe in the right direction, where pressure conditions may otherwise cause reversed flow.

The description and details of the non-return valve used here is explained below

The material used for non-return valve is Gun Metal Casted

Gun metal:

1. Very good sliding properties.
2. Wear resistant.
3. Cavitation resistant.

CONNECTORS

A simple device that physically links, couples, or connects, two things together. A male connector has pins that fit into the sockets, or receptacles, of a female connector, as the connectors mate. A male connector sometimes is referred to as a plug, and a female connector as a jack.

A simple device that physically links, couples, or connects, two things together. A male connector has pins that fit into the sockets, or receptacles, of a female connector, as the connectors mate. A male connector sometimes is referred to as a plug, and a female connector as a jack.

Dimensions:

1. Major diameter : 158mm
2. Minor diameter : 85mm
3. Thickness : 15mm
4. Thread pitch : 9.5 pitch

HOSES:

A hose is a flexible hollow tube designed to carry fluids from one location to another. Hoses are also sometimes called pipes (the word pipe usually refers to a rigid tube, whereas a hose is usually a flexible one), or more generally tubing. The shape of a hose is usually cylindrical (having a circular cross section).

Hose design is based on a combination of application and performance. Common factors are size, pressure rating, weight, length, straight hose or coil hose, and chemical compatibility.

Dimensions:

1. Pneumatic Hose dia : 5mm
2. Hydraulic Hose dia : 8mm

CALCULATIONS FOR THE PROPOSED DESIGN

CYLINDER AREA:

1. Cap end area (A) = Bore dia x 0.7854

= 1.2598 x 0.7854

= 1.2465inch2

2. Net rod end area =

(bore dia^2-rod dia^2) x0.7854

=1.259^2- 0.4724^2 x 0.7854

=1.0696inch^2

3. Force extend =Cap end area x PSI

=1.2465 x 43.50

=54.22 N

4. Force Retracts =Net rod end area x PSI

=1.0696 x 43.50

=46.52 N

5. Force Regeneration=Rod area x PSI

=0.1753 x 43.50

=7.625 N

CYLINDER SPEED:

1. Gallons per inch (GPI)=AREA/231

=1.2456/231

=5.3961 x10^{-3} GPI

=3.4011 x10^{-7} m^3/sec

2. Inches per minute (IPM)

= (Stroke length x 60) / (Stroke Time)

= (4.0559 x 60)/1.35

=188.97 IPM

3. Inches per second (IPS)

= (Stroke length) / (Stroke time)

= (4.089) /1.35

=3 IPS

4. (I) Flow rate in GPM

=GPI x IPM

=4.630 x10^{-3} x 188.97

=5.520 x10^{-5} m^3/sec

(II) Flow rate in IPM

=GPM / GPI

= (0.9657)/ (5.3961 x10^{-3})

=188.96 IPM

CYLINDER ROD END INTENSIFICATION:

1. Single rod end cylinder

= (Cylinder bore (A)) / (Cylinder Net rod end (A))

(RATIO)=1.2465/1.0696

=1.165

2. Cylinder velocity

= (231 x flow rate (GPM)) / (12 x 60 x net area (sq.in))

= (231 x 0.8750)/ (12 x 60 x 1.0696)

=0.2526 feet/sec

3. Volume

= (π/4 x d^2) x (Stroke)/231

= (π/4 x 1.259^2) x (4.25)/231

= 0.022 gallons of fluid

AGITATOR:

1. Vessel diameter =120mm

2. Liquid level =50mm

3. Shaft speed =720rpm

4. Blade diameter =6mm

5. Volume =h x π x r^2/3

=155 x π x 60x60/3

=584.33 x $10^3$$mm^3$

6. Equivalent diameter=4v/π

= (4 x 584.33 x 10^3)/π

=0.090613 m

7. Reynolds Number =d^2 x N x ρ/M

=0.006^2 x 720 x 8940/ (500 x 10^3)

=463.4496

8. Tip Speed =π x d x w m/s

=π x 0.006 x 720

=13.57 m/s

9. Pumping Rate =Nq x n x D^3

=0.87 x 720 x 0.006^3

=1.3530 x $10^{(-4)}$ m^3/s

10. Power drawn =Np x ρ x N^3 x D^5 kW

=357.6 x 890 x 720^3 x 0.006^5

=9.2787 kW

11. Power / Volume Ratio

=0.8616/0.58436

=1.447

12. Froude Number $=N^2 x D/g$

$=720^2$ x 0.006/9.81

=317.064

13. Bulk Volume =4 x Q x (π x T (Eq^2))

=4 x 6.68 x $10^{(-6)}$

(π x 0.0966^2)

= 7.6063 x $10^{(-6)}$ m/s

4. Power Number = (P x g)/ (3 x N $^{(3)}$ x D x a^5)

= (0.8463 x 9.81)/

(3 x $720^{(3)}$ x 0.006 x 10^5)

=0357.6

15. Power required

= (KT x $π^3$ x D x a^5 x ρ)/gc

= (0.32 x 720^3 x 0.06^5 x 8940)/9.81

= 0.846 kW

RESIN SIDE:

Epoxy properties:

1. Viscosity = 500cps

2. Density = 8940 kg/m^3

3. Fluid pressure = (Force (pounds))/ (Unit area (in^2))

Note= (m x volume)/ (time taken (s))

=0.143850/1.227

=0.1165 N/in^2

4. Discharge = (Area) x (Velocity)

Note: v=Displacement/ (time taken (s))

= 1.227 x 0.850

= 1.043 in^3/sec

= 26.50 mm^3/sec

= 0.0265 m^3/sec

= 420.0335 GPM

5. Velocity through cylinder in feet/second:

= (0.320833 x GPM (Flow through conduct))/ (Internal area of conduct (in^2))

= (0.320833 x 420.0335)/1.227

=109.829 FPS

6. Extra resin required to fill a volume:

= (PSI x Volume (in^3))/250000

= (43.5 x 4.637)/250000

= 8.06 x $10^{(-6)}$ in^3

7. Specific gravity of a fluid=(Density of Resin)/(Density of water)

=8940/1000

=8.940 kg/m^3

8. Push force = PSI x 3.1415 x b^2/4 lbs

=14.5 x 3 x 3.1415 x 0.032^2/4 lbs

=1.0932 KN

9. Pull force

= (14.5 x 3 x 3.1415 x $(0.032^2-0.012^2)$)/4

=0.03006 KN

10. Theoretical thrust (cylinder)

= eff area (sq.cm) x press (bar) x 10

= π/4 $x3.2^2$ x 3 x 10

= 241.274 KN

CONSTRUCTION AND EXPERIMENTAL PROCEDURE

Initially two hoppers were placed separately to fill Resin and Catalyst. A double acting cylinder (A) and piston arrangement is placed below of the hoppers. The cylinder is fitted with connectors and suitable control valves. Beside of the cylinder-A, the agitator is placed where the outlet of the piston is connected to the major diameter of the agitator. Below the agitator, a pneumatic gun is placed and tightened with spindle blades of the agitator. The gun is used to drive the blades. The agitator has an outlet which is connected to another double acting cylinder (B) of inlet. The outlet of the cylinder (B) is connected to nozzle. The both port B of cylinders is connected by the pneumatic hose from the 5/2 DC valve, which changes the flow of direction by means of lever. The both port A of cylinders is connected by means of T-Connector through hydraulic hoses. The link is which the square rod of 390mm is connected to both ends of the piston rods. The slotted of 7.6mm at both ends which slights the link and tends to move the piston rods extract and retracts. The experimental procedure follows step by step.

1. Initially the system starts with pneumatic system where the compressor used.

2. The Air enters through the 5/2 valve and the piston A will move leftwards ideally.

3. Now the link which is connected to the end of piston rod A creates an opposite motion, which tends to move the piston B towards rightward.

4. By changing the lever, the supply of air will be change piston A to piston B.

5. So the Piston B moves leftward direction and that makes the piston A to move in rightward direction. Now the piston A, pull the resin inside from the hoppers.

6. Now again, the direction is to be change and piston A should move towards left side.

7. The resin is delivering through a pipe to an agitator from the piston A, where simultaneously the harder flows inside the Agitator from separate hopper.

8. So, the agitator has a separate line from the compressor which is connected to the pneumatic gun.

9. The pneumatic gun spindle is tightened to the agitator blades, so the blades rotate by means of pneumatic gun when air is supplied.

10. Both resin and hardener stirring well inside the tank and the outlet of the tank is given to the inlet of piston B.

11. So again the direction changes connected link mechanism which tends to pull the resin + hardener combination inside the piston B.

12. Again the direction changes, piston pushes the fluid through a nozzle which is connected at outlet of piston B and the cycle repeats.

MERITS

1. Accuracy and Surface finish

2. Mass Production

3. No air entrapment if properly designed (tooling, perform, and resin)

4. Low tooling cost / short tooling lead times.

5. Close dimensional tolerances can be maintained (given proper clamping and mold closure)

6. Very large and complex shapes can be made efficiently.

7. Cost Reduction.

RESULTS AND DISCUSSION

The process initially started by using epoxy resin, but the viscosity of the fluid is about 500cps. So we found some difficulties in flow of resin and the timings while doing trial and error method. So after some observations and analysis we decided to work on the same resin but which the cylinder port and valves diameters are increased.

Again the process started with the epoxy resin which is 500cps and with respected hardener. The same trial and error method applied on the epoxy-hardener combination and observations are taken in various aspects.

Now the flow and the timing is quiet match for our machine setup as which we planned to implement. So the setup can be used for the resin with is below 500cps.

The following observations are made and studied at 18^{o}c weather condition.

CONCLUSIONS

As we discuss in the problem definition, the cost of RTM machine setup is high and the equipment has motor and pumps. But this RTM eliminates some sources like motors and pumps to reduce cost. Instead of motor and pump, we include pistons, Pneumatic gun, links and compressor setup to feed the system.

By mixing the epoxy with hardener with different ratios, we observed the variations in before curing and after curing. Finally we observed the better curing in the ratio 180-54ml of 60sec.

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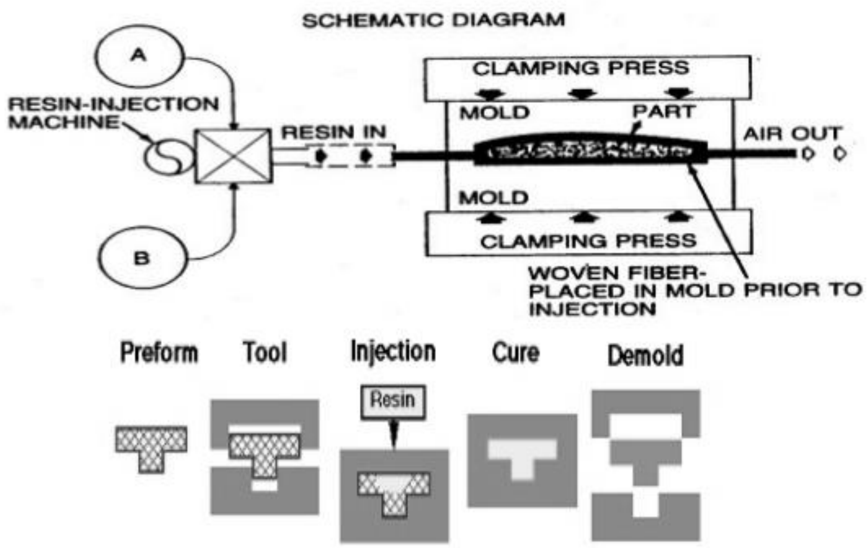

Figure 1. RTM process

CLASSIFICATION OF PROCESS

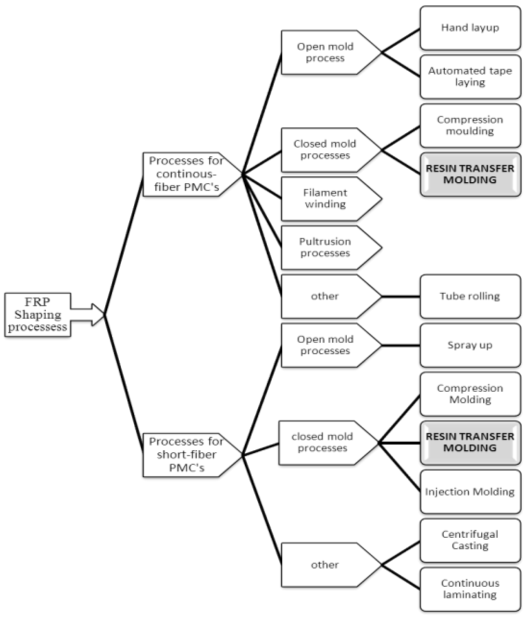

Figure 2 Classification of Process

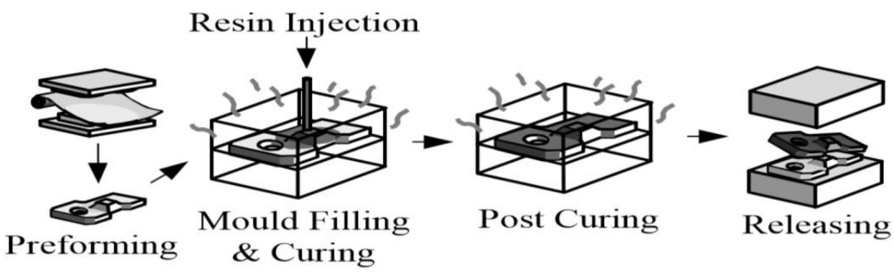

Figure 3 Process in RTM

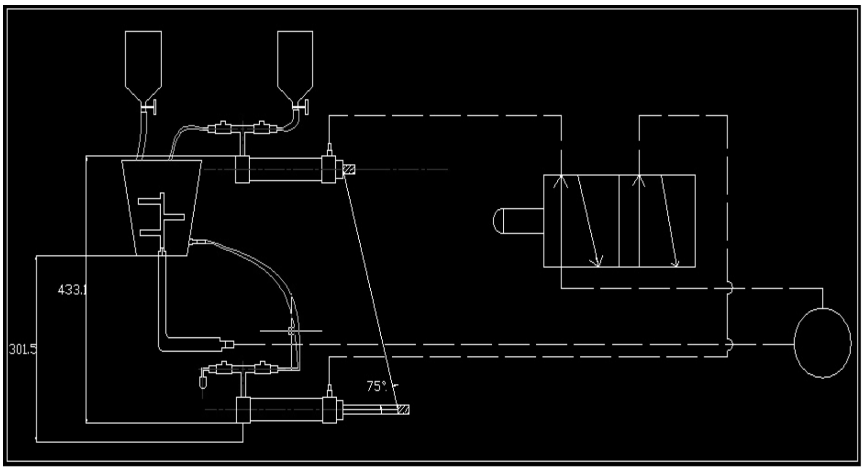

Figure 4 Proposed Design of RTM Set up

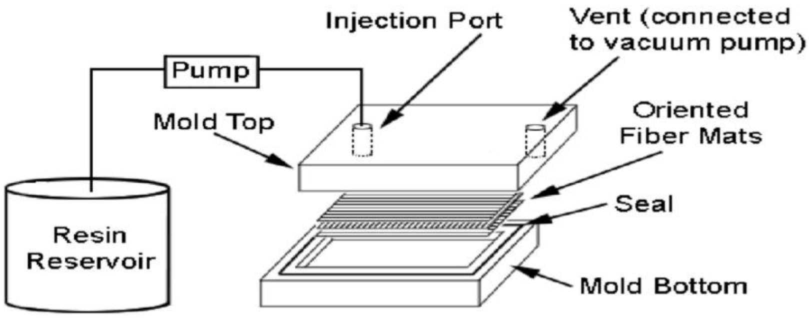

Figure 3 RTM Injection Setup.

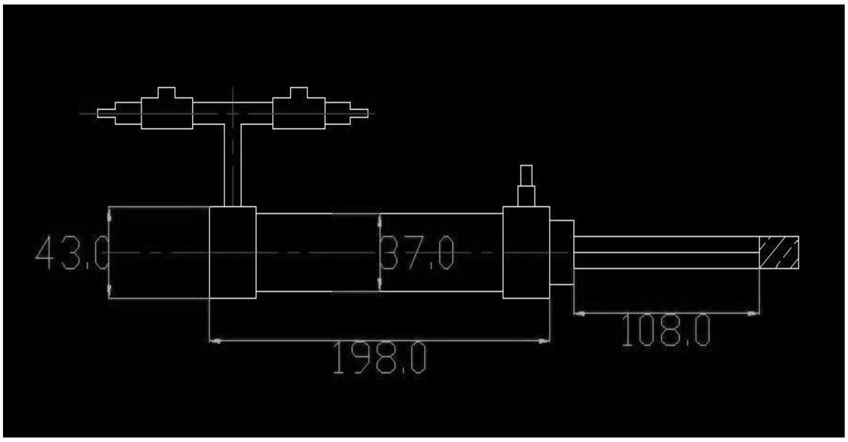

Figure 5 Piston - Cylinder with Connector

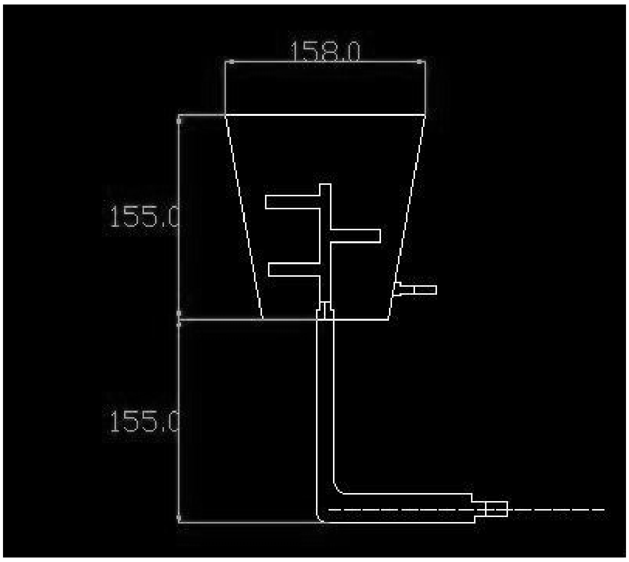

Figure 6 Agitator With Air Gun

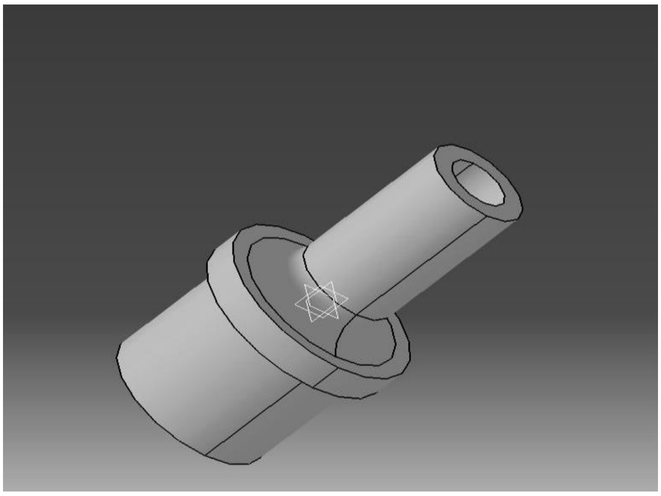

Figure 7 Connectors.

Graph on the above observations.

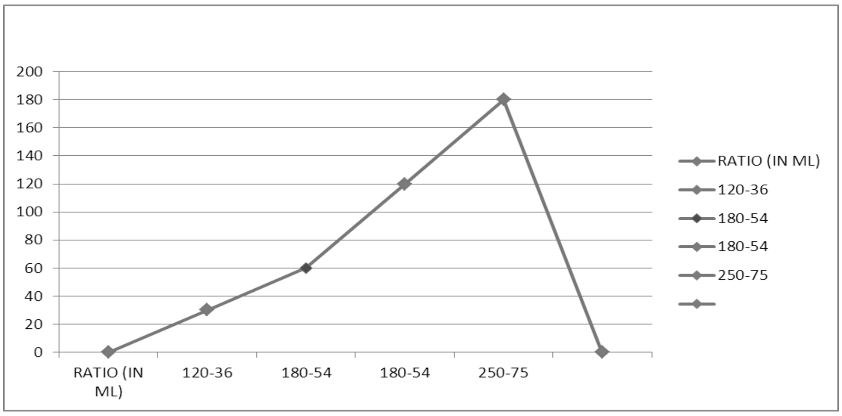

Figure 8 Ratio and time

Figure 9 Before Curing

Figure 9 After Curing

Table 1 Agitator - Details

AGITATOR MODELS	APPLICATION
Paddle flat blades	Solid Mix, slurry
Counter rotation paddles	Paste mix
Tumbling	Blending
Disk and cone	Polymers and dispersion preparation
Free shaft suspension	Sugar process
Impeller type	Emulsion preparations
Turbine again straight blades	Liquid and gas reaction
Slotted rotating disc	Powder and cosmetics

Table 2 Ratio and time

Resin-hardener Ratio (ml)	Time (sec)
120-36	30
180-54	60
180-54	180
250-75	120