# Design and Fabrication of an Autoclave

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## Declaration

I certify that this research work titled "*Design and Fabrication of an Autoclave"* is our own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

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**Language Correctness Certificate**

This thesis has been read by an English expert and is free of typing, syntax, semantic, grammatical and spelling mistakes. Thesis is also according to the format given by the university.

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*Dedicated to my exceptional parents and adored siblings whose tremendous support and cooperation led me to this wonderful accomplishment*

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# CHAPTER 1: INTRODUCTION

The project is to design and manufacture an autoclave for rubber curing. ‘Autoclave is basically a vessel which is designed for the heat treatment of rubber products’. Heat Treatment is a process in which hardness and strength of rubber is increased so that it can be used for useful purposes like making of tires etc.

## 1.1 Background, Scope and Motivation

We wanted to develop a tangible product which would have a discernable impact on industry. This would involve the idea generation of a product and implication of engineering into a viable product which can be used in industry. We explored many ideas for developing a product which can be made for an industry.

Manufacturing Resource Centre (MRC) is a manufacturing department of SMME. We met the head of MRC who expressed the need of MRC for an autoclave for curing of small rubber products. We took this need as an opportunity to develop a product as our final year project which has an application for process industry. So we decided that we would develop an Autoclave for MRC which will be designed according to ASME (American Society of Mechanical Engineers) standards and which will meet desired needs of MRC, keeping the manufacturing costs as minimum as possible.

Our Autoclave is a scaled down version of an industrial autoclave which can be used for curing of rubber products. This is a product which is specifically designed to meet the requirement of our department. Since it is small in size and made from light weight material aluminum so it can be easily moved to any lab where it is need to be used.

## CHAPTER 2: LITERATURE REVIEW

**2.1 ASME STANDARDS:** The ASME Boiler and Pressure Vessel Code (BPVC) is an American Society of Mechanical Engineers (ASME) standard that provides rules for the design, fabrication, and inspection of boilers and pressure vessels. The ASME standards that we required to review for the design of our autoclave were:

**1. ASME Boiler Pressure Vessel Codes Section II – Materials**

**2. ASME Boiler Pressure Vessel Codes Section VIII - Rules for Construction of Pressure Vessels**

- **Division 1**
- **Division 2 - Alternative Rules**
- **Division 3 - Alternative Rules for Construction of High Pressure Vessels**

**2.1.1. ASME Boiler Pressure Vessel Codes Section II – Materials: This section of the ASME consists of 4 parts.**

- **Part A - Ferrous Material**

This part provides material specifications for ferrous materials which are suitable for construction of pressure vessels.

The specifications provide in this part specify mechanical properties, heat treatment etc. The designation of the material specifications starts with **'SA'** and a number which is taken from the ASTM **'A'** specifications.

- **Part B - Nonferrous Material**

This Part provides material specifications for various nonferrous materials which are suitable for construction of pressure vessels.

The specifications provided in this part provide the mechanical properties, heat treatment etc. The designation of the material specifications starts with **'SB'** and a number which is taken from the ASTM **'B'** specifications.

- **Part C - Specifications for Welding Rods, Electrodes, and Filler Metals**

This Part provides mechanical properties, heat treatment for welding rods, filler metals and electrodes used in the pressure vessels construction. The specifications provided in this Part are designated with **'SFA'** and a number which is taken from the American Welding Society (AWS) specifications.

- **Part D - Properties (Customary/Metric)**

This Part provides tables for the stress values, tensile and yield stress values as well as tables for properties of materials.

### 2.1.2. ASME BPVC Section VIII - Rules for Construction of Pressure Vessels

This part has three divisions which provide different requirements and guidance for the construction of pressure vessels under different conditions:

1. **Division 1:** This division provides the mandatory requirements, specific prohibitions and nonmandatory guidance for design of pressure vessels having an internal or external pressure from 15-3000 psi. The important sections of Division that we used for calculations are:

    - **UG-16:** This section provides the general requirements regarding the design of pressure vessels and pressure vessel parts.

- **UG-27:** This section provides the formulas for the design thickness of shell under internal pressure.

- **UG-34:** This section is used to calculate the thickness of flat heads.

**2. Division 2 - Alternative Rules:** This division provides mandatory requirements, specific prohibitions and nonmandatory guidance for design of pressure vessels having an internal or external pressures upto 10,000 psi.

**3. Division 3 - Alternative Rules for Construction of High PressureVessels**: This division covers the mandatory requirements, for design of pressure vessels having an internal or external pressure which exceeds 10,000 psi.

**2.2 Heat Transfer: There were two types of heat transfer through our shell of autoclave:**

- **Conductive Heat Transfer (through shell of autoclave)**

- **Convective Heat Transfer (Between shell and external environment)**

**2.2.1 <u>Conductive Heat Transfer:</u>** Heat conduction is the transfer of internal energy by collision of particles within a body due to a temperature difference. The diffusing and colliding objects include molecules, electrons, atoms, and phonons. They transfer kinetic and potential energy, which are collectively known as internal energy. Conduction can take place only inside an object or material, between two objects that are in contact with each other.

**2.2.2 <u>Convective Heat Transfer</u>:** Convective heat transfer, often referred to simply as convection, is the transfer of heat from one place to another due to the movement of fluids.

Convection dominates heat transfer in liquids and gases. Convective heat transfer involves the conduction (heat diffusion) and advection (heat transfer by bulk). Convection can be "forced" by movement of a fluid by means other than buoyancy forces (for example, a water pump in an automobile engine). Convection can be "natural" in which buoyancy forces alone are responsible for motion of fluid when the fluid is heated, and this process is called "natural convection" fluid flow.

To calculate the power rating of our heating rods we had to do detailed heat transfer analysis. Since we knew the temperature we had to achieve and the thickness of shell, using these we did the conductive and convective heat transfer analysis to calculate the power rating of our heaters.

We also had to use heat transfer to calculate the thickness of our insulation which was required to minimize the heat loses through the shell.

# CHAPTER 3: INDUSTRIAL VISITS

We had been to two different industries

## 3.1 International Polymer Industries (IPI):

We made a visit to IPI industry which is situated in I-9 Industrial sector. IPI makes rubber so they make extensive use of autoclaves. We visited so that we can get general information regarding the autoclave and there specifications. The autoclave that was being used there were with steam from boiler. The autoclaves that were being used there had high operating pressure and low temperature compared.

## 3.2 Heavy Mechanical Complex (HMC):

HMC is a leading engineering goods manufacturing enterprise in Pakistan located at Taxila. They provide extensive fabrication and machining facility equipped with state of the art technology. All its processing facilities are in-house including Designing, Fabrication, Machining, Heat Treatment, etc. They make pressure vessels and other objects. Visit was specifically made to design department. They told us how they design pressure vessels in industry. They also explain about the materials they choose for making vessel according to requirement. Pressure vessel designs according to specific parameters and with great care. There are standards made to be followed in making pressure vessel. Our industries use ASME standards for making pressure vessel so do we made according to standards.

CHAPTER 4: CALCULATIONS

## 4.1 <u>Design of pressure vessel under internal pressure from ASME standards:</u>

Autoclave is designed according to ASME Standards, different sections of ASME Section 8 has applied here.

For calculating the thickness of shell UG-27 from section 8 has been used.

$$t = \frac{PR}{SE - 0.6P}$$

P = pressure internally exerted (Pa)

R = internal radius (m)

S = allowable stress of aluminum 5450 grade (Pa)

E = joint efficiency

$$t = \frac{1000000 * 0.1524}{(207 * 10^6)(0.7) - (0.6)(1000000)}$$

t = 1.056 mm

Due to non-availability of material we assumed the thickness of material to be 5mm (Al 5450) which was available in market.

For calculating the thickness of head, we apply UG-34 as it's the flat head.

d = diameter

C = a factor depending upon the method of attachment of head, shell dimensions

P = internal design pressure

S = allowable stress of aluminum 5450 grade (Pa)

E = joint efficiency

$$t = d\sqrt{\frac{CP}{SE}}$$

$$t = 0.3048* \sqrt{\frac{0.162*1000000}{\left(207*10^6\right)*0.7}}$$

t = 10.20 mm

Due to non-availability of material we assumed the thickness of material to be 12mm (Aluminum) which was available in market.

**4.2 <u>Calculation of surface temperature</u>**

By considering the fact of achieving 200°C in the inner side of shell, we would have 1600 watts.

Length of shell = 0.6096m

Inner diameter = 0.3048m

Inner radius = 0.1524m

Thickness = 0.005m

Outer diameter = 0.3128m

Outer radius = 0.1564m

Coil efficiency = 0.85

$$\dot{q}_s = \frac{\dot{Q}_s}{2\pi r_2 l}$$

$$\dot{q}_s = \frac{0.85*1600}{2\pi*0.1564*0.6096}$$

$\dot{q}_s$ = 2271.42 $^{W}/_{m^2}$

Assuming 20 % heat loss,

Heat loss will be 454.284 $^{w}/_{m^2}$

$\dot{q}_s$ = 1817.136 $^{w}/_{m^2}$

**4.3 Heat Calculation:**

$\frac{d}{dr}(r\frac{dT}{dr}) = 0$

$-k\frac{dT(r_1)}{dr} = h\,[T_\infty - T(r_1)]$

$k\frac{dT(r_2)}{dr} = \dot{q}_s$

$\frac{rdT}{dr} = C_1$

$\frac{dT}{dr} = \frac{C_1}{r}$

$T(r) = C_1 lnr + C_2$

$r = r_2$

$\frac{kC_1}{r_2} = \dot{q}_s$

$C_1 = \frac{\dot{q}_s r_2}{k}$

Now putting r = $r_1$

$\frac{-kC_1}{r} = h\,[T_\infty - (C_1 lnr_1 + C_2)]$

$C_2 = T_\infty - [\,lnr_1 - \frac{k}{hr_1}\,]\,C_1$

as $C_1 = \frac{\dot{q}_s r_2}{k}$

$C_2 = T_\infty$ - [ $lnr_1$- $\frac{k}{hr_1}$ ] $\frac{\dot{q}_s r_2}{k}$

T($r$) = $C_1 lnr$ + $T_\infty$ - [ $lnr_1$ - $\frac{k}{hr_1}$ ] $C_1$

T($r$) = $T_\infty$+ [ $lnr$ - $lnr_1$ + $\frac{k}{hr_1}$ ] $C_1$

T($r$) = $T_\infty$+ [ $lnr$ - $lnr_1$ + $\frac{k}{hr_1}$ ] $\frac{\dot{q}_s r_2}{k}$

Putting values,

$$T(r) = 200°C + [\ ln\frac{r_2}{r_1} + \frac{167 W/m^2\ °C}{15 W/m^2 * 0.1524}\ ] * [\ \frac{0.1564m * 1817.136 W/m^2}{167\ W/m°C *\ 0.1524m}\ ]$$

T($r$) = 200°$C$ + 124.36°$C$

T($r$) = 324°$C$

Here, surface temperature is 324°$C$ which is less than melting temperature of aluminum 5450 grade (650°$C$).

## 4.4 <u>Insulation thickness calculation:</u>

For losses not more than 20%

$\dot{q}_s$ = 454.3 $W/m^2$

Heat flux per unit length = 454.3 * 0.6096

Heat flux per unit length =Q= 277.83 $\frac{w}{m}$

$$Q = 2\pi kl * \frac{T_1 - T_\infty}{ln\frac{r_2}{r_1}}$$

$T_\infty$ = ambient temperature = 25℃

k = heating coefficient of glass wool

$$277.83 = 2 * 3.14 * 0.085 * 0.6096 * \frac{324.5-25}{ln\frac{r_2}{r_1}}$$

$r_2$ = 0.188m

Thickness of insulation = $r_2 - r_1$

t = 0.0316 m

t = 31.6 mm

t = 1.25 inch

## Longitudinal Stress:

$$\sigma_L = \frac{PR}{2t}$$

P = pressure exerted inside the vessel

R = radius of vessel

t = thickness of vessel

$$\sigma_L = \frac{1000000*0.3048}{2*0.005}$$

$\sigma_L =$ 15.2 MPa

## Hoop Stress:

$$\sigma_H = \frac{\sigma_L}{2}$$

$\sigma_H =$ 7.6 MPa

# CHAPTER 5: OPERATIONS

Operations involve in making shell and head are:

## 5.1 <u>Cutting :</u>

Shear cutting machine was used for the cutting of Aluminum Alloy sheet of 5mm thickness measuring 24*38 inch. Shear cutting machine cuts the stock without the formation of chips.

After this two Aluminum Alloy plates of 12mm thickness measuring 15*15 inch were cut on shear cutting machine for head formation.

## 5.2 <u>Bending:</u>

Bending is done on plate rolling machine that rolled aluminum sheet into round shaped. Rolling is done to make a cylindrical shell precisely of 12 inches diameter. The flat metal plate is placed in the machine on either side and "pre-bent" on the same side. The Side-Rolls do the work of bending for aluminum sheet.

## 5.3 <u>Surface Welding:</u>

Joining technology plays an important role in the successful application of aluminum alloys. $CO_2$ surface welding for joining the two ends of sheet has been done precisely. The cylindrical shell was welded to make the cylinder air tight.

Surface welding of one 12 mm plate (12 inches diameter) to the down side of shell and flange welded to the top side of shell.

# CHAPTER 6: TESTING AND SPECIFICATION

## 6.1 Operation Testing:

We successfully tested our autoclave by heating the autoclave up to 200°C and pressure of 2 bars. The temperature was reached within approximately 2 minutes.

## 6.2 Specifications:

| | |
|---|---|
| Shell Thickness | 5mm |
| Head Thickness | 12mm |
| Shell Diameter | 1 ft |
| Shell length | 2ft |
| Design Temperature | 350°C |
| Design Pressure | 10 bar |
| Operating Temperature | 250°C |
| Operating Pressure | 5 bar |
| Power Input (Watts) | 1600 W |

The operating temperature can be increased by introducing heating rods of more power since the material we have used can sustain temperature up to 600°C.

## 6.3 Temperature and Pressure Control:

For controlling the temperature we have used a thermostat (0-300). There is also emergency circuit breaker. Pressure is controlled through a pressure valve which is attached to the inlet of compressor to the shell. Temperature and Pressure gauges are also provided for the user to observe the operation. Heat proof wires were used for the connections of electric rods inside the shell. To make the holes we used silicone sealing.

# CHAPTER 7: COMPONENTS OF AUTOCLAVE AND TEMPERATURE DISTRIBUTION

**Engineering Drawings:**

**7.1 Table**: A table was manufactured for the support of autoclave. The material used for autoclave was Mild Steel. All dimensions are in inches.

Engineering Model:

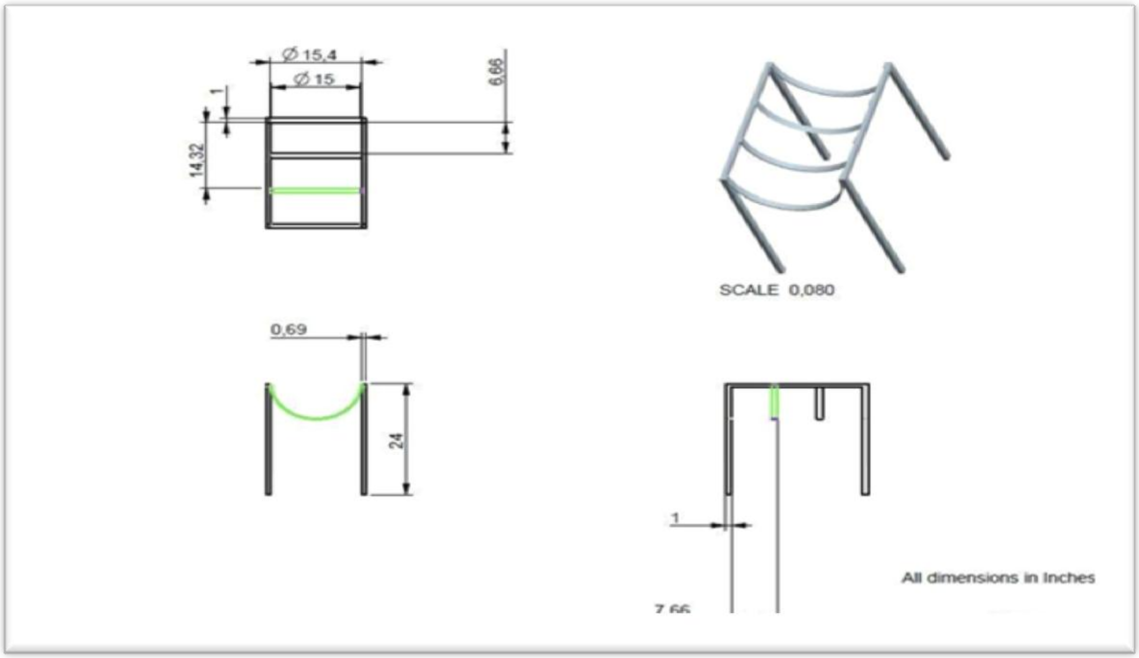


Fig 7.1.1

Actual Part:

Fig 7.1.2

Manufacturing Operations:

- Cutting
- Bending
- Welding

**7.2 Shell:** The shell of autoclave was made of 5mm thick Aluminum Alloy 5450 sheet. The diameter of shell is 12 inch and length of shell is 24 inch.

Engineering Model:

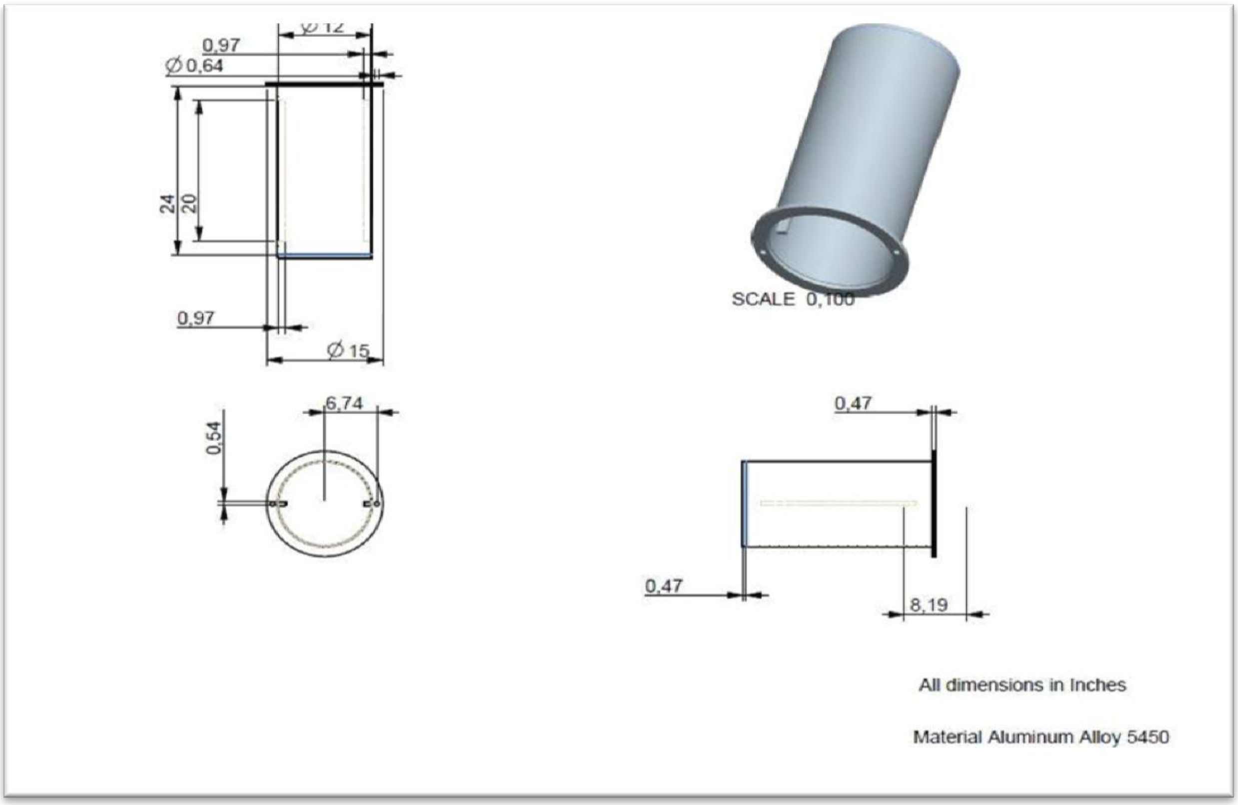


Fig 7.2.1

Actual Part:

Fig 7.2.2

Operations Required:

- Sheet Cutting
- Rolling
- Welding

**7.3 Head:** Two heads for the shell of autoclave were formed from 12mm thick Aluminum Alloy 5450 Plate. One head is fixed to the autoclave, while the other which is being used as opening is attached by a flnage to shell.

Engineering Model:

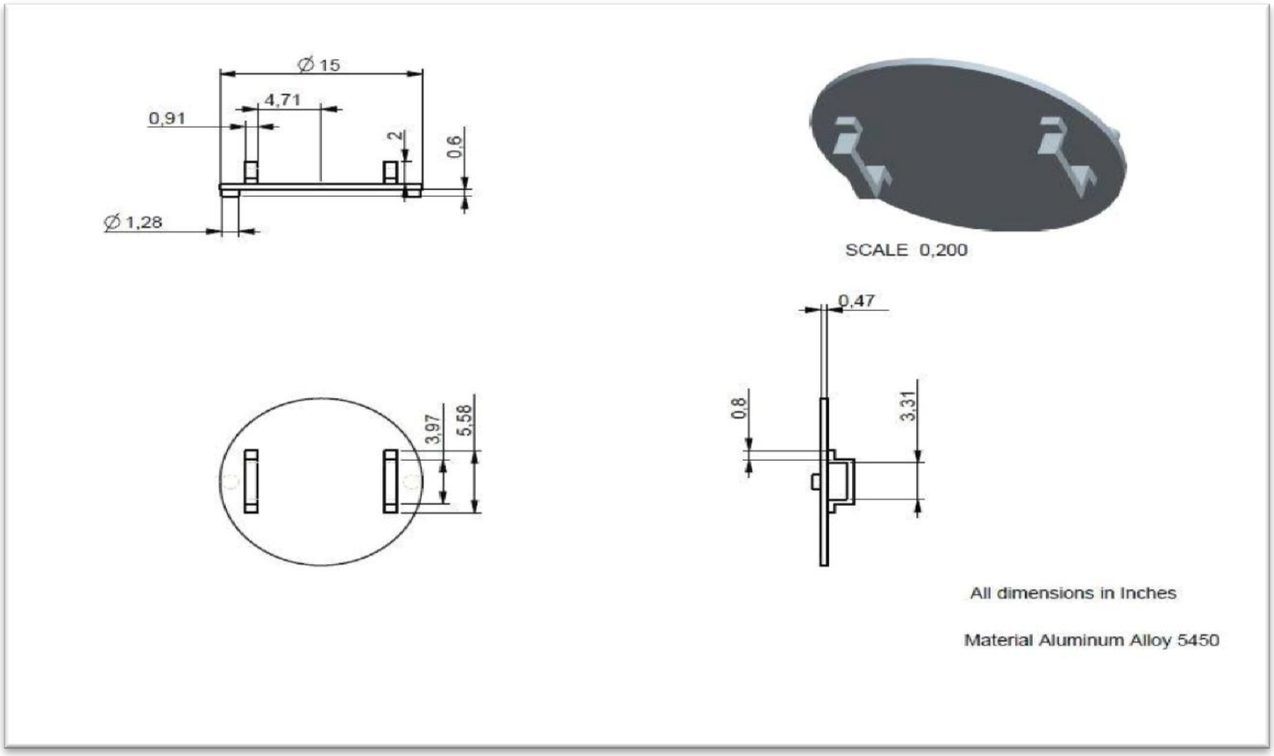


Fig 7.3.1

Actual Part:

Fig 7.3.2

Operations Required:

- Turning Operation (Lathe Machine)
- Drilling

**7.4 Control Panel:** Control System consists of different electric elements:

- Thermostat (0-300ºC)
- Relay magnetic Contactor (20 A)
- Circuit Breaker (10A)
- Temperature Gauge (0- 300ºC)
- Pressure Gauge
- Pressure Valve

Temperature Gauge is attached with opening and Pressure Gauge is with other fixed end of shell. Circuit Breaker, Relay and Thermostat are with the circuit Board fixed on table.

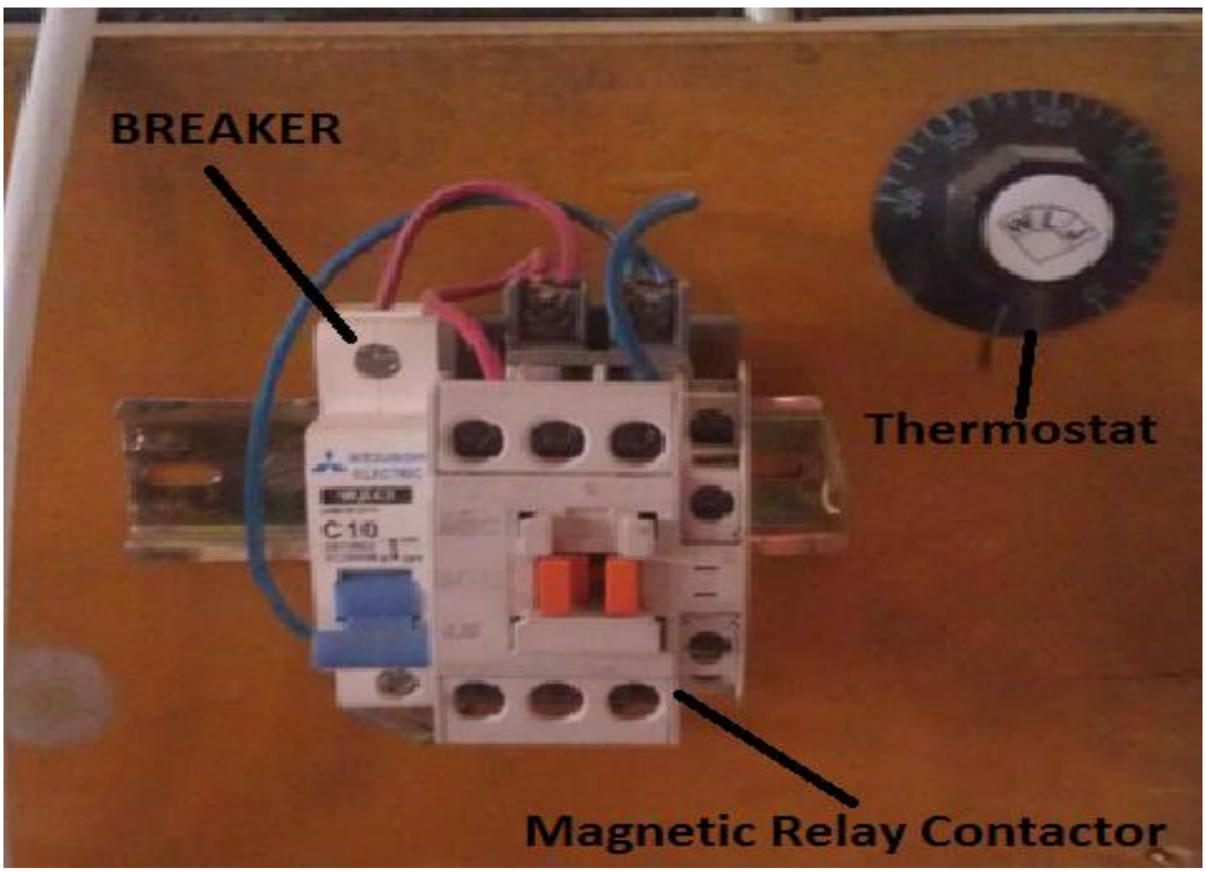


Fig 7.4.1

## 7.5 Temperature Distribution Analysis:

The red locations show the point of attachment of electric rod to the shell. Each rod has the power input of 400 watts; the surface temperature of electric roads was experimentally detected using infrared thermometer. We use that surface temperature 300ºC to detect temperature distribution throughout the shell.

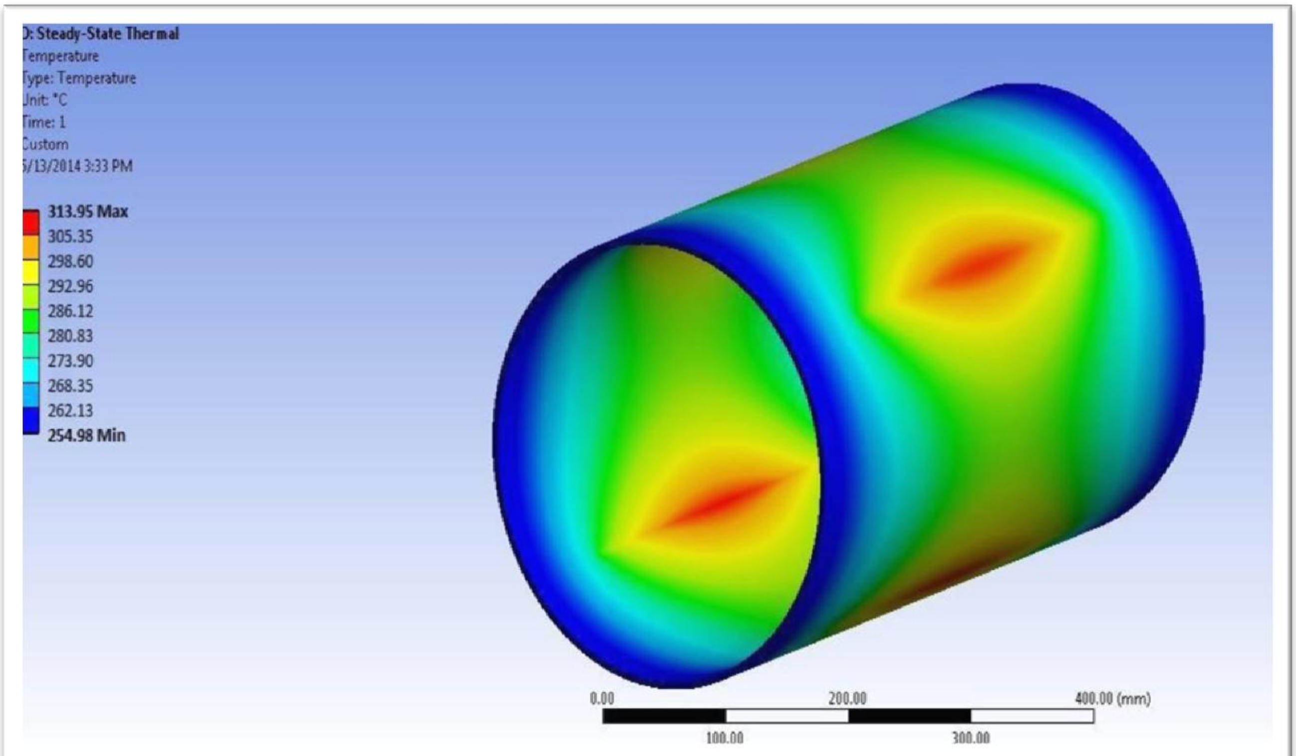


Fig 7.5.1

# CHAPTER 8: IMPROVEMENTS AND CONCLUSION

**Improvements:**

**Cooling System:**

To make the operation of autoclave safe for the user a cooling system can be installed around the autoclave. The cooling system could be of two types:

- Addition of another shell (cooling jacket) around the shell of an autoclave in which cooling water will be circulated by a pump
- Twisting copper pipes around the autoclave in which cooling water will be circulated by pump

**Heating Flexibility:**

The operating temperature of the autoclave can be increased according to the requirement by using heating elements of more power. The material that we have used for the autoclave can sustain a temperature of 600ºC.

**Door Opening Improvement:**

At the moment we are using a circular plate which is attached to the shell with the flange using clamps as the opening to the autoclave. The door can be improved using right hand horizontal swing hinge. Locking ring can also be positioned over the shell extension; it would create immediate positive sealing.

## Conclusion:

Making product which will have a positive impact in the industry is not an easy task. During product development there were many factors which were under considerations including material selection and market survey for making cheapest and viable strong product.

We achieved most of the goals that we had set when we started our project. There is always room for improvement, and we believe that certain modifications can make our autoclave more user friendly.

## Overall Product:

Fig 8.1

## References :


- http://en.wikipedia.org/wiki/ASME_Boiler_and_Pressure_Vessel_Code_(BPVC)
- http://en.wikipedia.org/wiki/Heat_transfer
- http://thelibraryofmanufacturing.com/sheetmetal_cutting.html
- http://en.wikipedia.org/wiki/Machining