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Modeling and Analysis of Pressure Vessel Relief Valve

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Abstract- *This paper is based on the study of a mechanical device used for regulating pressure in a household pressure cooker, the relation between, amount of thrust generated by the steam on the dead weight and the value of the weight of the dead weight is the factor which decides the exit of the steam from the system. The valve is subjected to a greater amount of temperatures during its operation, hence while designing its component, temperature analysis on the 3D modeled part plays an important role. The paper includes the dimensional and static thermal study of a household pressure regulating valve.*

Keywords- *Mechanical Device, Pressure Cooker, Dead Weight, Valve.*

I.INTRODUCTION

The project includes the design and development of a pressure relief valve used for a pressure cooker. A pressure relief valve is a device designed to protect a pressurized vessel or system during an overpressure. The overpressure or the excess amount of the pressure is relieved to the atmosphere to achieve the maximum allowable working pressure. These pressure valves differ as per the sizes of the pressure cooker. The first safety valve was invented by Denis Papin for his steam digester, an early pressure cooker rather than an engine. The safety valve was indeed designed and used for many years mainly for steam application and distillation. The safety valve was closed using a lever and a movable weight; sliding the weight along the lever enabled to keep the valve in place and regulate the steam pressure (Figure 1).The device works satisfactorily for many years and was commercialized until the beginning of the 20th century [1].

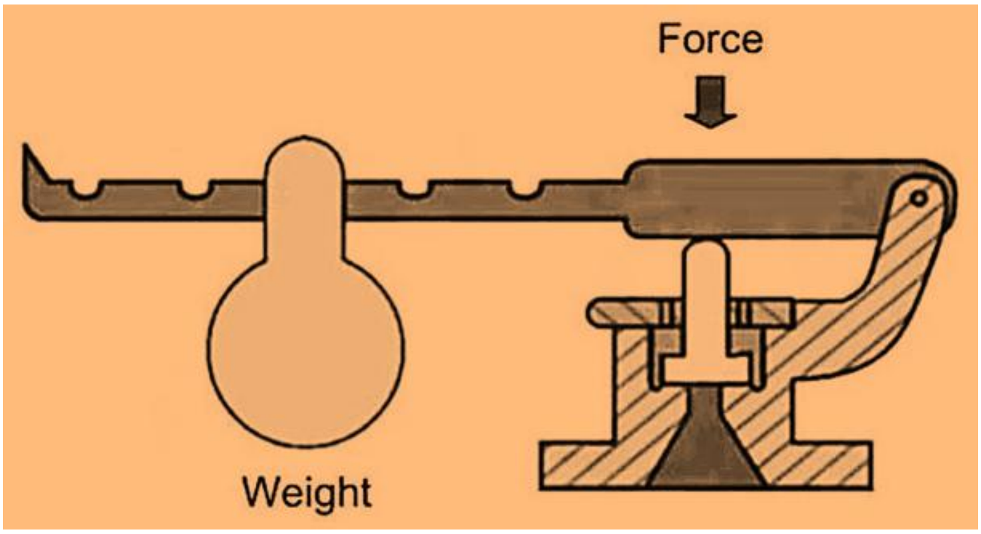

Figure1 Early 20th Century Type Weight-loaded Safety Relief Valve

The investigation includes the design of the dead weight not only includes the dimensional study of the valve, but also the Steady-state thermal analysis, which is one of the important parameters to be considered while designing a body experiencing high temperature and pressure during its operation, the project aims to perform reverse engineering and design the product.

II.OBJECTIVES OF STUDY

The main objective of the project is to achieve the required design, the following point's needs to be fulfilled:

1. To understand and implement the process of the product design.
2. To perform reverse engineering on the component.
3. To perform the calculations and static thermal analysis for the design for the application.

III.WORKING PRINCIPLE

The pressure cooker works on the principle of the Gay-Lussac's law, which states that the pressure at a constant volume of gas is directly proportional to the Kelvin temperature. The function of the pressure relief valve is to maintain the pressure value inside the vessel and release the excess pressure. To achieve this, as the pressure increases, so does the temperature and vice versa. As the volume of the vessel remains constant and the steam temperature rises, the pressure increases, which helps to increase the overall temperature of the vessel, resulting in a reduction in the time required for cooking. When the vapor temperature exceeds a certain value, it increases the pressure, leading to the lifting of the dead weight of the pressure relief valve and thereby decreasing the vapor pressure inside the cooker [6].

IV.METHODOLOGY

a) 3D Model and Part Drawing

Step 1st: Actual part dimensions measurement using a vernier caliper.
Step 2nd: Generating a 3D solid model of each part using NX6 with the dimensions obtained after measurement by vernier caliper.
Step 3rd: Generating of the 2D drawing by the 3D model.
Step 4th: Calculating the tolerance values of each component depending on its type of mating.
Step 5th: Assembly of all components.

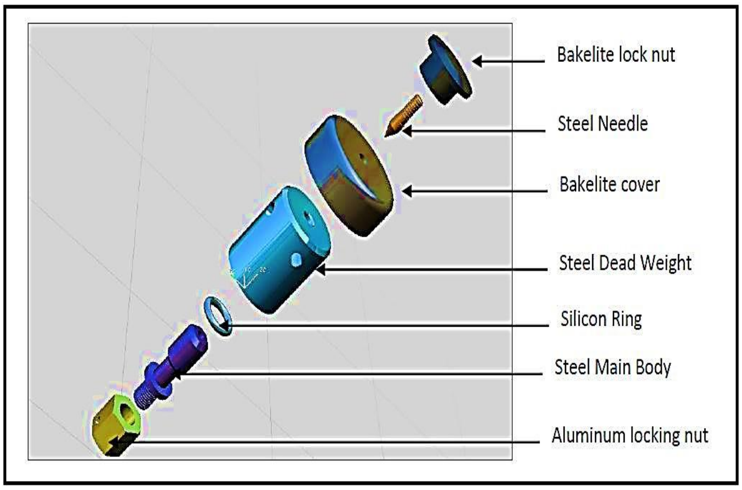

Figure 2 Exploded View of Assembly

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b) 2D Drafting

2D drawings are generated with the help of the 3D model including all necessary tolerances generated with the help of a design data book [5].

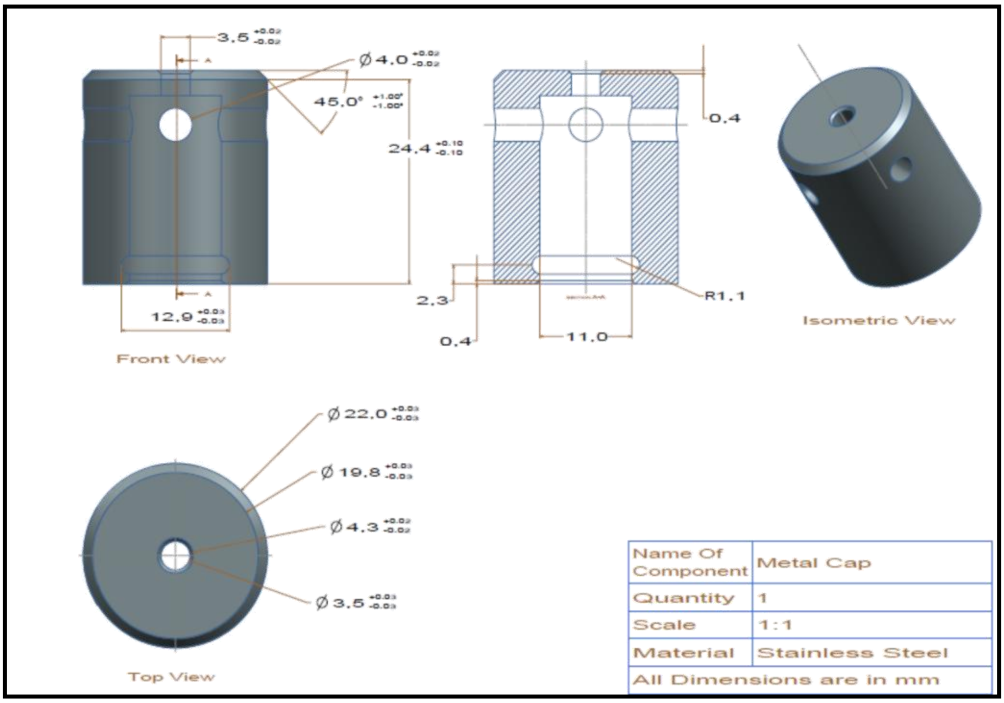

Figure 3 Design of Dead Weight

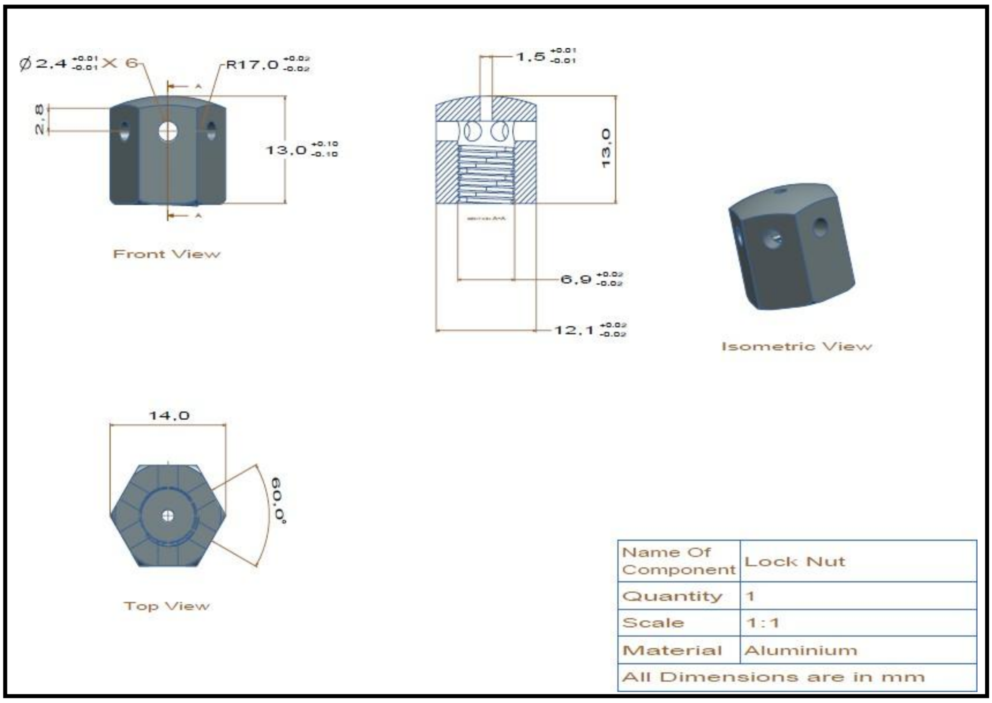

Figure 4 Design of Locking Nut

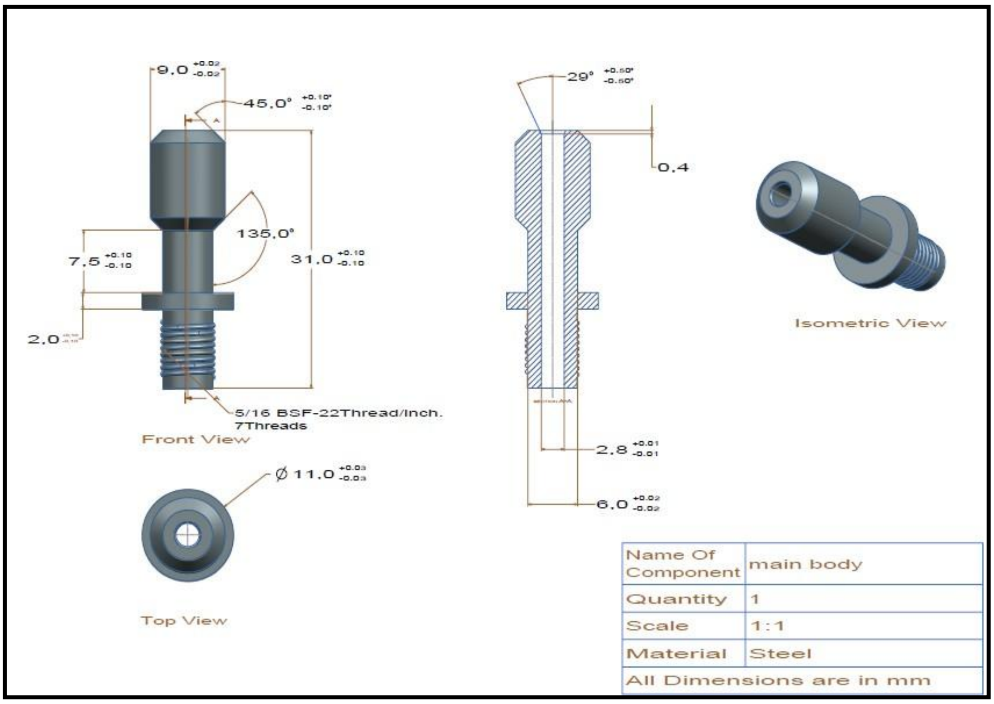

Figure 5 Design of Main Body

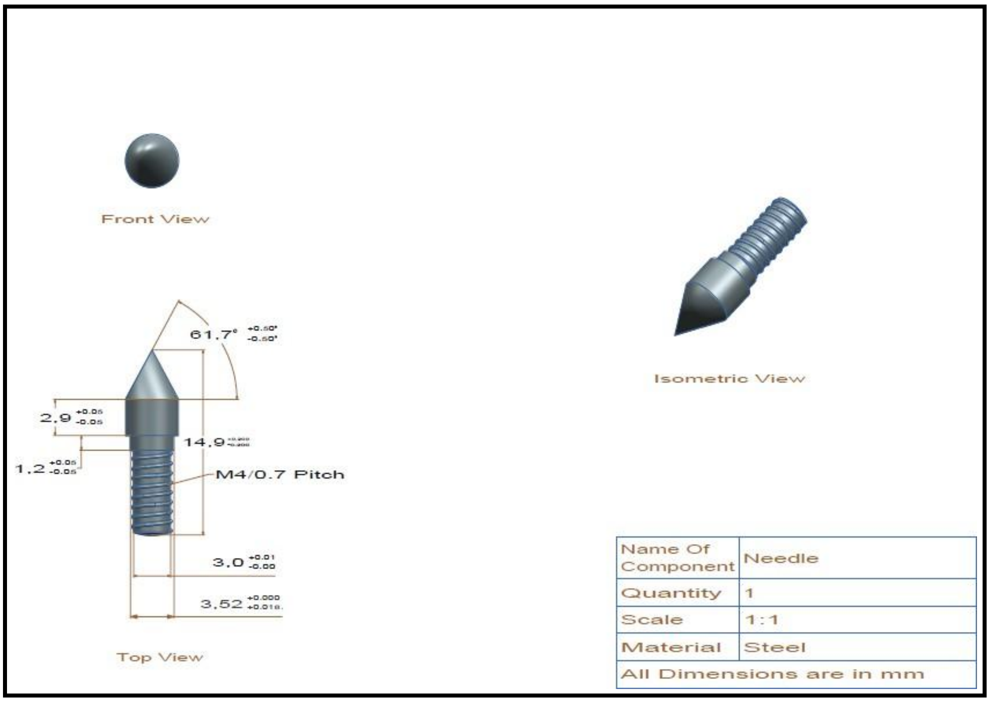

Figure 6 Design of Needle

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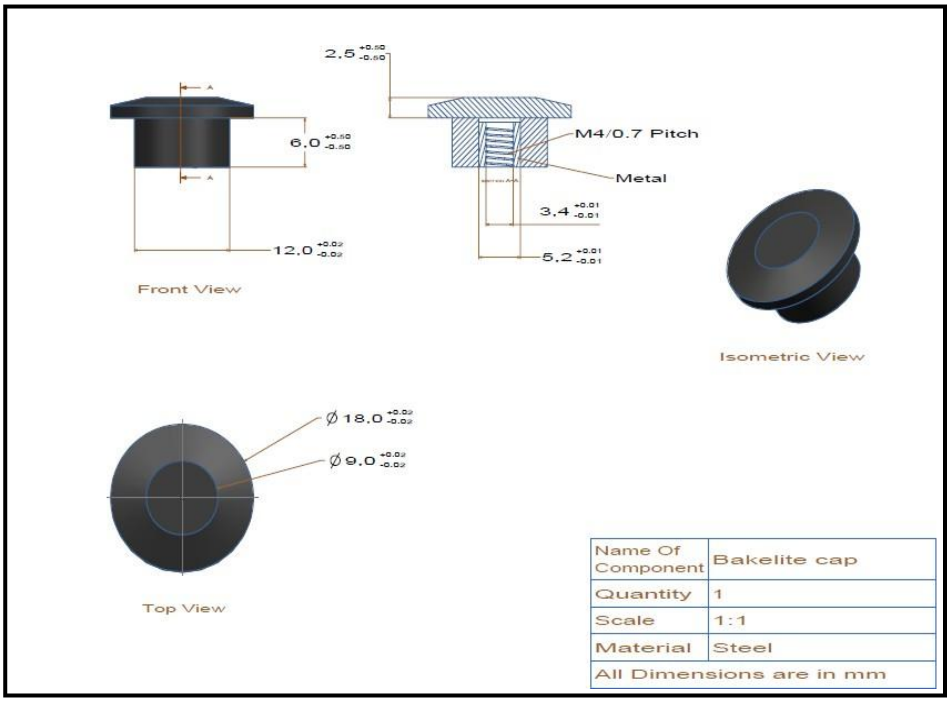

Figure 7 Design of Bakelite Cover

c) Selection of Materials for Components

1. Steel

Application: Deadweight, main body, needle.

Properties of Steel:

i. High elasticity (200Gpa)
ii. Corrosion resistance
iii. High melting point (1510^{0}C)

The above components are subjected to heat and steam pressure.

2. Aluminum

Application: Locking nut.

Properties of Aluminum:

i. Corrosion resistance
ii. Lightweight (2.7g/cm^3)
iii. Nontoxic
iv. High melting point (660^{0}C)

3. Bakelite

Application: Bakelite lock nut, cover.

Properties of Bakelite:

i. Can easily be moulded into any complicated shape
ii. Resistant to heat (0.2W/mK)

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d) Temperature, Pressure, Weight Relationship

Mathematical calculation to find maximum dead weight lifting pressure is given as follows:

Mass of dead weight (m) = 64.5gm = 0.0645 kg (actual weight) Main body inner diameter (d) = 2.8 mm Gravitational force (g) = 9.81 m/sec^2

$$Area(A) = \frac{\pi}{4}d^2 = \frac{\pi}{4}2.8^2 = 6.15mm^2 \quad (1)$$

By formula,

$$mass(m) \times gravity(g) = Pressure\ force(P) \times area(A)$$

$$0.0645 \times 9.81 = P \times 6.15 \quad (2)$$

P=0.1028 N/mm^2= 1.028 bar.

This is the working pressure of pressure cookers to lift the dead weight, 1.028 bar steam pressure is required.

V.STATIC THERMAL ANALYSIS

The maximum working steam temperature in this application is 120^{0}C, so the steady-state temperature flow in the components is represented below with the help of Ansys. The analysis is performed on the components which are subjected to steam.

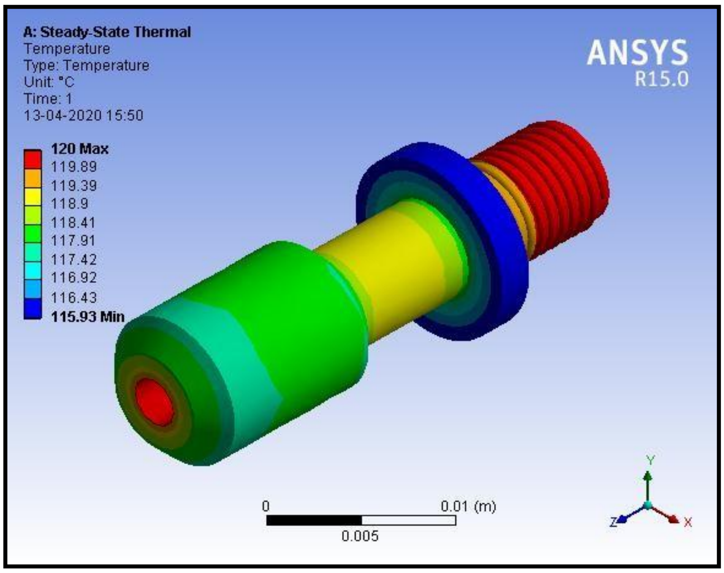

Figure 8 Temperature Flow in the Main Body

The main body made up of stainless steel experiences a maximum temperature of 120^{0}C inside its hollow passage from which the steam passes. Considering the conduction of heat through the body and convection of heat from the external surface, and the thermal coefficient of stainless steel as 50 W/mK the flow of temperature is represented as shown in the Figure 8.

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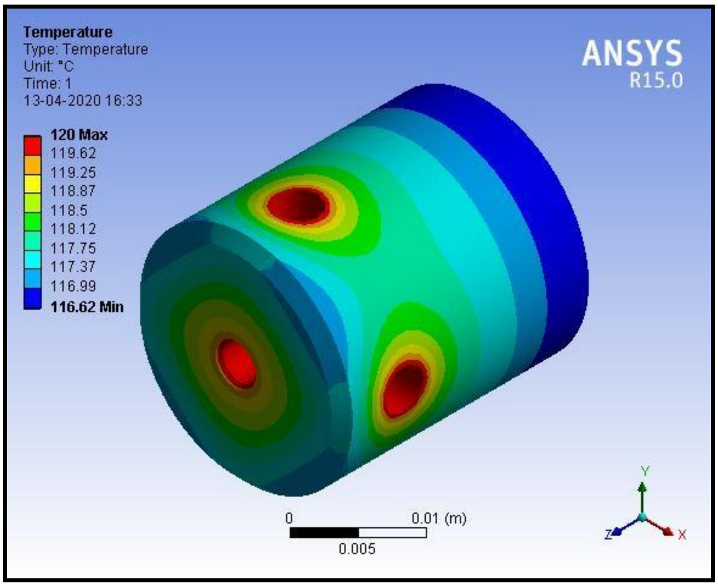

Figure 9 Temperature Flow in Dead Weight

The internal area of the dead weight which is exposed to the high temperature up to 120^0C, and the material is stainless steel hence the thermal conductivity coefficient is considered as 50 W/Mk.

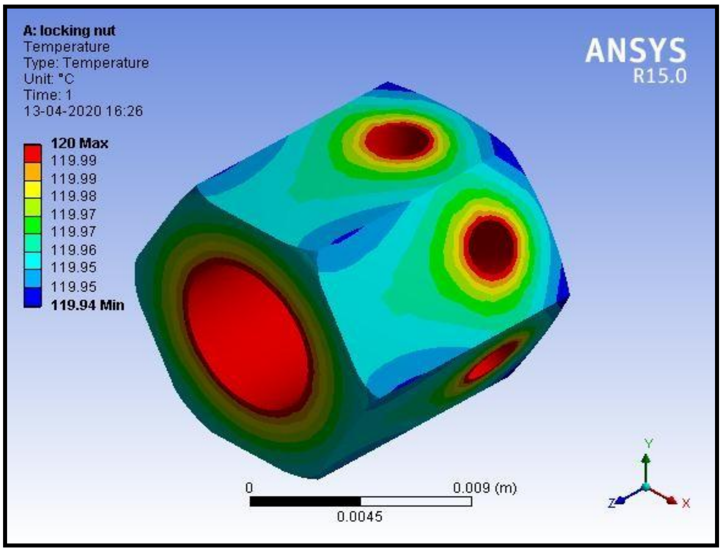

Figure 10 Temperature Flow in Locking Nut

As locking nut is the part which directly comes in contact with the steam, is exposed to maximum temperatures, hence the material used for this component is aluminum which has a high thermal conductivity coefficient (205W/mK).Considering the time required for a pressure cooker of capacity 3 liters, 180 seconds are required to raise the temperature to 120^0C of the component due to a rise in temperature of the steam generated by boiling of water on a high flame.

The below graph is plotted to represent the time and temperature relationship in all the components, the temperature flow is linear.

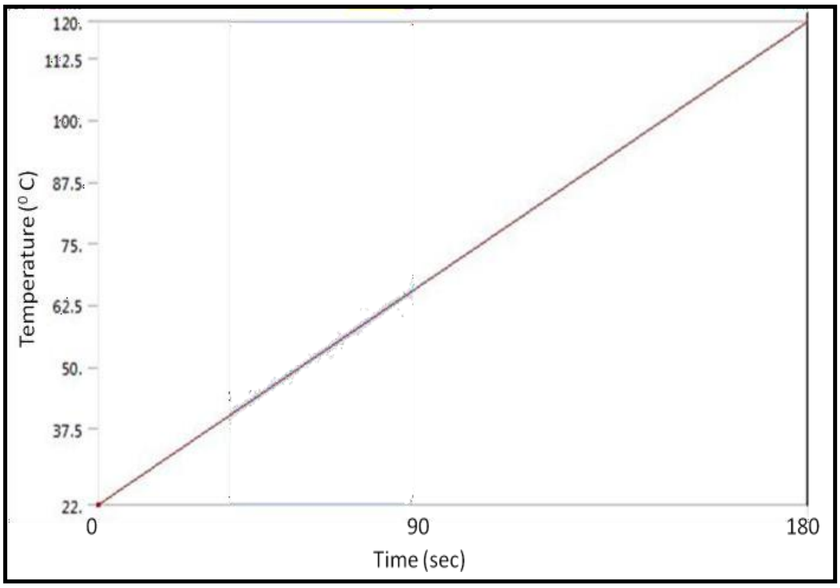

Figure 11 Time-Temperature Relationship

VI.CONCLUSION

The project includes understanding the working, and successful completion of reverse engineering of a pressure relief valve including modeling, drafting and analysis, the 3D modeling, and drafting are completed using Unigraphics NX 6.0 and the steady-state temperature analysis is completed with the help of Ansys Workbench V15.0. This investigation provides the temperate flow and the relationship between time and temperature.

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