# Design and Construction of an Autoclave

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## ABSTRACT

One of the major problems confronting healthcare professionals is the control of pathogenic organisms. This is because microorganisms are present in our environment and may contaminate healthcare instruments from time to time. An autoclave was designed and constructed to sterilize materials/items used in such healthcare institutions. The autoclave has a liquid capacity of 2 litres and is heated electrically with a 2kw heating-element. The test showed a decrease in the growth of microorganisms at high temperature with a high exposure time.

(Keywords: autoclave, pathogenic organisms, design, engineering, sterilization, health applications, cost effective)



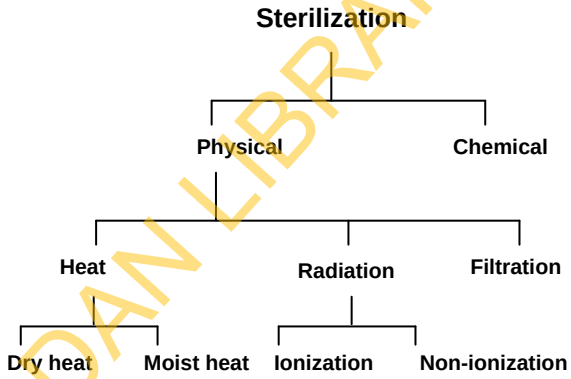


**Figure 1:**Types of Sterilization Method (Source: Olutiola et al, 2000).

## INTRODUCTION

The process whereby microorganisms of all kinds are inactivated, killed, or removed from materials is known as sterilization (Rubbo et. al, 1965). Sterility is the term used in relation to microorganisms to describe the total absence of all life forms in an environment, surface, object, or in an object which may be ingested, such as food, medical, or pharmaceutical products. Thus an object is said to be sterile when it is free of all forms of life. This is an essential pre-requisite for certain categories of pharmaceutical and medicinal products such as injections, infusions and drops, in order to prevent health hazards through contamination by microorganism (Crickshank, 1965).

Sterilization may be undertaken by physical or chemical methods. The method used usually depends on the material to be sterilized. The methods commonly used are shown schematically in Figure 1. Heating is one of the most convenient methods for sterilization. The process whereby water is boiled to 100 C is not effective for sterilization because many spores can survive at this temperature.

Autoclaves are widely used in medical institutions, laboratories, and industries where the quality of reusable items is maintained with respect to infection control. They are, however, not available locally in many developing nations, and many of those in the system are already broken due to lack of indigenous technology and spare parts.

The objective of this research is to design and construct a maintenance-free autoclave that requires little skill to operate and can be readily available for general sterilization purposes.

## LITERATURE REVIEW

The first autoclave was “Chamberland’s Autoclave”. Charles Chamberland, a colleague of Pasteur, built upon Denis Papin’s work. Chamberland invented the autoclave in response to Pasteur’s requirement for a sterilization technique that utilized temperatures higher than 100 C. This was developed between 1876 and 1880.

The major pioneer of the aseptic method of surgery was Professor Von Bergmann of Berlin (1885) who

introduced sterilization by steam into his clinic. In 1886, Ernst Von Bergmann and his associates later learned that steam in itself was inadequate for sterilization. Steam must be under pressure to raise the temperature. Pressure steam sterilizers were later developed to kill resistant spores (Crickshank, 1965).

Bacterial spores are the most resistant of all living organisms because of their capacity to withstand external destructive agents. Although the physical or chemical process by which all pathogenic and non-pathogenic microorganisms, including spores, are destroyed is not absolute, supplies and equipment are considered sterile when necessary conditions have been met during a sterilization process.

**A Steam Sterilizer (Autoclave)**

Under ordinary circumstances, heating water above the boiling temperature in an open vessel is impossible. This is due to extensive evaporation that occurs during boiling. If water is heated in a sealed vessel, it is possible to increase the boiling temperature. An autoclave is a sealed vessel and a large pressure cooker; it operates by using steam under pressure as the sterilizing agent. High pressure enables steam to reach high temperatures, thus increasing its heat content and sterilizing power.

Most of the heating power of steam comes from its latent heat of vaporization. Steam sterilization is the most practicable method for sterilizing reusable medical devices in healthcare institutions because; it has lethality to pathogens, it is rapid; and it is non-toxic. The standard temperature/pressure-time relationship for steam sterilization is 1.05 bar (15 psi), 121 C ($250^0$ F) and 15 minutes (Howard, 2004).

Steam is able to penetrate objects with cooler temperature because once the steam contacts a cooler surface, it immediately condenses to water, producing a replacement in folds, thereby resulting in decrease in steam volume. This creates negative pressure at the point of condensation and draws more steam to the area for further condensation. This condensation continues so long as the temperature at the condensing surface is less than that of steam present, until temperature equilibrium is obtained; and a saturated steam environment in formed.

The more moisture present, the more heat can be carried, so steam is one of the most effective carriers of heat (Howard, 2004). Moist heat kills microorganisms by causing coagulation of essential proteins structures that are nucleus and cytoplasmic membrane inclusive, rendering the cell non-viable.

The rate at which bacterial cells are thermally inactivated depends on the temperature and time of heat exposure.

**Types of Steam Sterilizers**

Sterilizers designed to use steam under pressure as the sterilizing agent frequently are referred to as AUTOCLAVE. Steam sterilizers are available in many sizes ranging from portable countertop to the fixed room-size sterilizers. The loading of items/materials into the sterilization chamber also serves as bases for different types of classification, namely; vertical loading and horizontal loading. The major yardstick for categorizing the steam sterilizer is the mechanism behind their air removal process from the sterilization chamber.

**CAPACITY DESIGN**

Dimension of sterilizing cylinder = 0.3m diameter and 0.4m length

Dimension of perforated cylinder = 0.27m diameter and 0.32m length

Volume of the sterilizing cylinder;

$v = \pi r^2 h$ **(1)**

$v = \pi (0.15)^2 \times 0.4$
$v = 0.028m^3$

Density of stainless steel used for the cylinder = $7930kg/m^3$

Mass of the cylinder
$m = \rho v$ **(2)**

$m = 7930 \times 0.028$
$= 224.22kg$

Weight of sterilizing cylinder;
$w = mg$ **(3)**

$= 224.22 \times 9.81$
$= 2199.59N$

Volume of the perforated container

$v = \pi r^2 h$ **(4)**

$= \pi(0.135)^2 \times 0.32$
$= 0.018m^3$

Mass of the perforated container:

$m = \rho v$ **(5)**

Density of the stainless steel = 7930kg/m$^3$
m = 7930 x 0.018
m = 142.74kg

Weight of the perforated container
w = mg
= 142.74 x 9.81
= 1400.27N

The volume of water supplied
$V = \pi r^2 h$ ;

where r = 0.15m, h = 0.04m
$V = \pi (0.15)^2 \times 0.04$
V = 0.0028m$^3$

Mass of the water supplied
$M = \rho v$

Density of the water = 1000kg/m$^3$
M = 1000 x 0.0028
= 2.827kg

Weight of the water
w = mg
= 2.827 x 9.81
= 27.737N

**FRAME DESIGN**

Dead loads = Wc + Wp + Ww

where Wc = Weight of the sterilizing cylinder
= 2199.59N

Wp = weight of the perforated container
= 1400.27N

Ww = weight of the water
=27.737N

Dead loads = 2199.59 + 1400.27 + 27.727
= 3627.59N

Assuming weight is equally distributed on 4 stands.
∴ Weight on a stand = $\frac{\text{dead load}}{4}$

$= \frac{3627.59}{4}$

Downward force on stand = 906.89N

Area of channel of angle iron:

$A_{ch} = \frac{f}{\sigma}$ x factor of safety (Surendra & Singh, 1982)
where T = shear stress of angle iron material = 68MN/m$^2$ (hardened steel)

$\therefore A_{ch} = \frac{906.89N}{68 \times 10^6 N/m^2}$

$= 1.33 \times 10^{-6} m^2$

∴ Dimension chosen are 21 x 21mm of stainless steel pipe

**Wall Thickness Determination**

For a given internal pressure p, the maximum stress developed in the shell should not exceed the permissible tensile stress $\sigma_t$ of the material.

Recall;
$\sigma_c = 2\sigma_L$

and $\sigma_c$ is not to exceed $\sigma_t$
$\therefore \sigma_c \leq \sigma_t$

From the above, it is obvious that the cylinder is a thin one, because the cylinder is required to operate under pressure of 30MN/m$^2$, and 250MN/m$^2$ operations require thick cylinders (Surendra, 1982).

Thin cylinders have working stress ranging from 5MN/m$^2$ to 30MN/m$^2$ (Ibid.).

$\therefore \sigma_c = \frac{Pr}{h}$
where h = wall thickness

P = pressure = 1.05 bar ≡ 0.103MPa at 121$^0$C
(Source: steam table)

$h = \frac{pr}{\sigma_c}$

Taking, $\sigma_c = 5MN/m^2$

$h = \frac{0.103 \times 10^6 \times 0.15}{5 \times 10^6}$
$= 0.00309m$
$\approx 0.003m$

Hence, the thickness of the pressure vessel used = 0.003m.

The cylinder wall is 0.003m thick and the internal diameter of the cylinder is 0.3m. The ratio $\frac{t}{d} = .01$ which is less than 0.1, hence the thin-cylinder design must be used (Hall, A. S. et al, 1980).

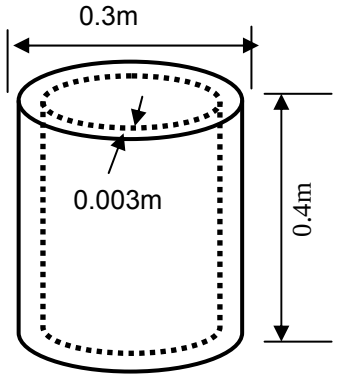


**Figure 2:** Sterilization Cylinder and Inner Container.

## CONSTRUCTION PROCEDURES AND TESTING

The autoclave comprises the frame, sterilization cylinder, stainless steel lid, inner container, immersion heater, control valve (air escape valve), pressure relief valve, and the temperature control unit. The frame provides support for all other components to be assembled. A square pipe, 21mm x 21mm, made of stainless steel was used, putting into consideration the load carrying capacity of this material that can withstand the weight of the components to be included.

The sterilization cylinder is the heart of the autoclave, where the sterilization of materials is carried out. Stainless steel sheet of 3mm thickness was formed into a cylinder with a 45mm ϕ hole made to accommodate the heater.

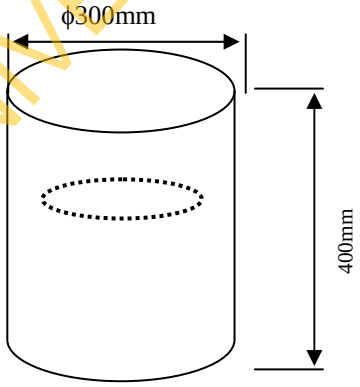


**Figure 3:** Sterilization Cylinder.

The open end of the sterilization cylinder was covered by a lid which is air tight in order to prevent the escape of steam which is generated in the sterilization chamber.

A stainless steel sheet of 1mm of thickness net was formed into a cylinder using a rolling machine. The container was closed at one end and opened on the other to accommodate the items to be sterilized through vertical loading approach.

The removable inner container was provided with 4 legs to serve as a support and also to raise the container above the volume of water supplied.

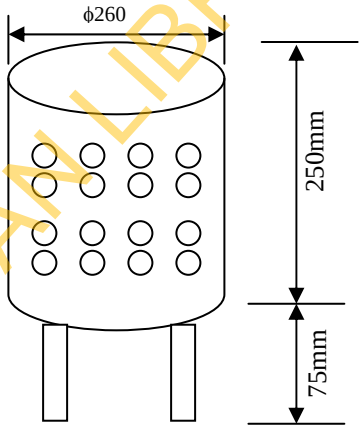


**Figure 4:** Perforated Inner Container.

The source of steam generation in the chamber is through the electrical means. The water is heated by the boiler, thereby producing steam. The power capacity of the heater is 2000 watts, which is capable of generating steam throughout the required duration.

It was noted from the literature that the presence of air in the sterilization chamber reduces the penetrating effect of the steam on the material to be sterilized. The control valve serves as a vacuum pump which is manually operated to remove air presence in the chamber during sterilization. The control valve through the help of the flexible pipe performs its role effectively. This is attached to the lid using a 10- gauge stainless steel electrode. Safety of the device is very important because it operates at high pressure due to increases in temperature. Hence, to avoid rupture of the device, a pressure relief valve was welded to the lid.


**Figure 5:** Aerial View of the Autoclave with the Inner Container (Olaoye, 2007).

This is the unit that is responsible for the effective functioning of the device. The temperature control regulates flow of current to the element/heater. It is incorporated with a circuit breaker which helps the system to "cut – off" after reaching a pre – set temperature in which sensor is attached.

The temperature controller provided maintains the temperature at the preset value for a preset time before tripping. The corresponding pressure value of preset temperature is shown on the manometer and the device is well controlled with respect to any preset condition of operation.

**Performance Testing**

The recommended operating conditions for the steam autoclave for heat sensitive instruments are 121 C to 124 C at 1.1 to 1.25 bar pressure, for a minimum of 15 minutes, or 134 C to 137 C at 2.1 to 2.3 bar pressure, for a minimum of 3 minutes. A cycle of 126 C to 129 C at 1.4 to 1.6 bar pressure for 10 minutes is also recommended by some manufacturers (Palenik, et al. 1999).

Tests were carried out using the autoclave. A surgical instrument, the kidney dish, was used to determine the effectiveness and efficiency of the device. Mixed growth of five different microorganisms was placed on the kidney dish and it was autoclaved. The sterilizer was operated for 2, 4, 6, 8, 10 and 12 minutes at 1.25 bar before it was stopped. At every interval of 20 C of autoclaving, a swab was taken and cultured in a medium. A blood agar culture was used.

Commencing the experiment, at constant time of 2 minutes for the first test, swab was taken with cotton wool at interval of 20 C temperature, starting with 40 C to 120 C, and this was cultured for 3-days and the result was observed.

At time T = 2 minutes, the kidney dish was tested at 40, 60, 80, 100, and 120 C. The procedure was repeated for the specified time interval mentioned above and the corresponding microorganism growth was noted.

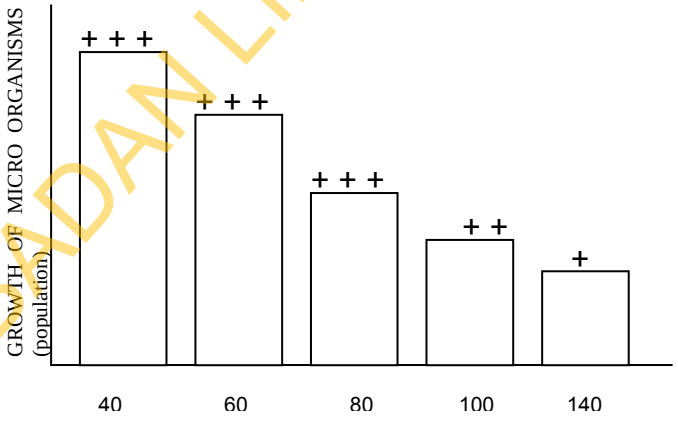


**Figure 6:** All Parts Un-Sterile at time T = 2 Minutes.

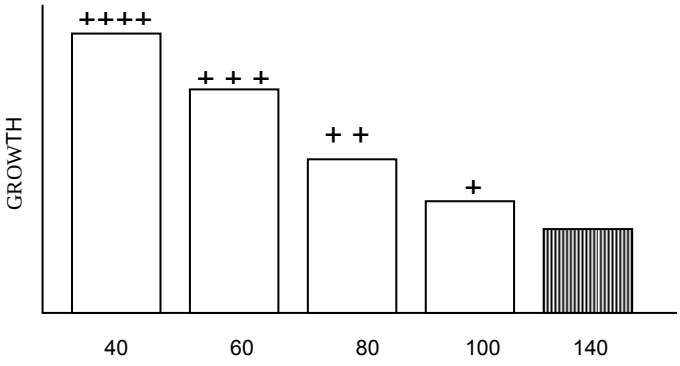


**Figure 7:** A Region is Sterile at time T = 4 Minutes.

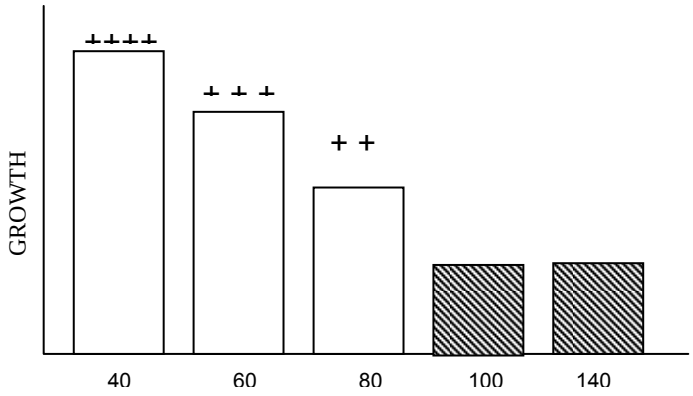


**Figure 8:** Two Regions Sterile at time T = 6 Minutes.

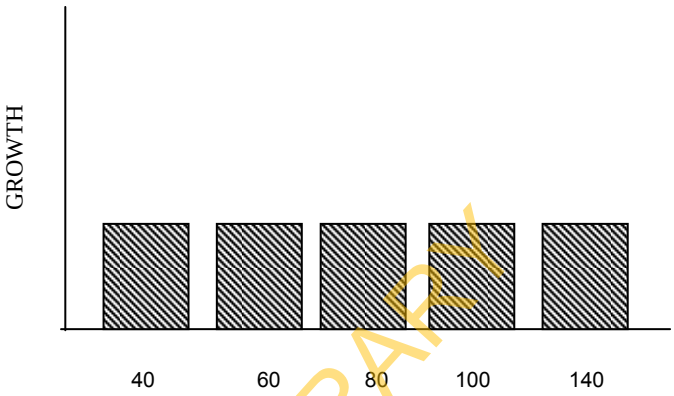


**Figure 11:** All Regions Sterile at time T = 12 Minutes.

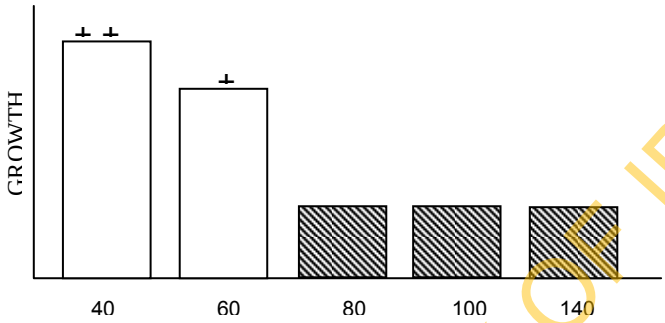


**Figure 9:** Three Regions Sterile at time T = 8 Minutes.

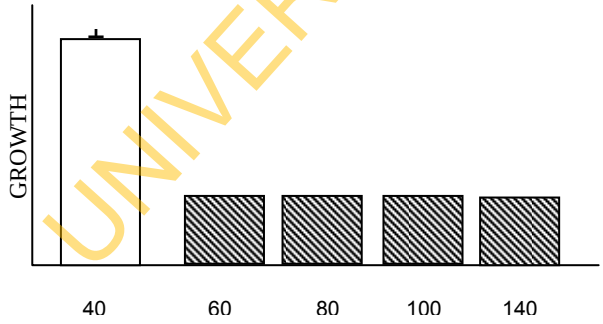


**Figure 10:** Four Regions Sterile at time T = 10 Minutes.

## RESULTS AND DISCUSSION

From the experiment presented here, it was observed that a decrease in the population of microorganisms followed an exponential power. The increase in the temperature of the autoclave reduced the growth of the microorganism by ten fold.

The microorganisms used were heat resistant organisms which could only be destroyed at higher temperatures - the more the exposure time and the higher the temperature, the less the presence of these microorganisms. At the first stage (Figure 6), none of the regions on the kidney dish was sterilized, and this showed that the exposure time was too small for effective sterilization. With higher temperatures and increased soaking time, the presence of microorganisms was reduced drastically (see Figures 7 to 10). Finally, all the regions were sterile after 12 minutes (Figure 11).

The above results show that the designed autoclave meets the European Standard BS EN 554:1994.

## CONCLUSION

The autoclave was designed and constructed from locally available materials to make the cost of purchase affordable and to control infectious diseases.

The device has a high potential for sterilizing items both wrapped and un-wrapped. The result of the test carried out shows that for sterilization to be

more effective and efficient, higher temperature is required together with more time of exposure.

A satisfactory result was achieved when the operating temperature was set at 120 C for 12 minutes. We therefore conclude that the rate at which microorganisms are thermally killed depends on the temperature, pressure, and time of heat exposure.

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