DESIGN, FABRICATION AND PERFORMANCE EVALUATION OF CONTINUOUS OPERATING AUTOCLAVE

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ABSTRACT

Autoclave is a steam sterilizing equipment for destroying the microorganisms at a definite temperature and pressure. The autoclave is widely used to sterilize medical and biological laboratory equipment. Continuous operating autoclave is designed consisting three compartments as sterilization chamber and a common steam producing chamber. The autoclave is designed in such a way that each of three sterilization chamber can be used independently at any time. Steam produced in the common chamber can be supplied and regulated in any sterilization chamber with three individual regulators. Pressure gauges and safety valves are mounted in each chamber to observe the steam pressure and release excessive pressure. Safety valves are so adjusted that it is capable to maintain desire pressure by liberation of steam. The performance study shows that about 105 and 180 minutes are required to reach at desired temperature and pressure when one and two compartments run together. The desired pressure is achieved after 180 minutes without reaching at desired temperature.

Keywords: *Autoclave, continuous operation, design and fabrication, sterilization*

1. INTRODUCTION

Autoclave is an equipment that sterilizes materials by subjecting them at high temperature and steam pressure. An autoclaving is the most effective way of sterilizing medical and scientific equipment. This is also an ideal for sterilizing bio-hazardous waste, surgical dressings, glassware, and various types of microbiological media, liquids, and many other things (Sultana, 2007). When proper conditions and time are employed, no living organisms will survive a trip through an autoclave. An autoclave is a large pressure cooker; it operates by using steam under pressure as the sterilizing agent. High pressures enable steam to reach high temperatures, thus increasing its heat content and killing power. Proper autoclave treatment will inactivate all fungi, bacteria, viruses and also bacterial spores, which can be quite resistant. They are often used in hospitals and laboratories to remove dangerous or potentially hazardous chemicals or compounds.

An autoclave is a large pressure cooker; it operates by using steam under pressure as the sterilizing agent (Woodford, 2009; Howard, 2004). High pressures enable steam to reach high temperatures, thus increasing its heat content and killing power. Steam is able to penetrate objects with cooler temperatures because once the steam contacts a cooler surface it immediately condenses to water, producing a concomitant 1,870 fold decrease in steam volume. This creates negative pressure at the point of condensation and draws more steam to the area (Howard Judelson 2004). Condensations continue so long as the temperature of the condensing surface is less than that of steam. These properties ensure rapid heating of surfaces, good penetration of dense materials, and coagulation of proteins. Moist heat is thought to kill microorganisms by causing coagulation of essential proteins. Death rate is directly proportional to the concentration of microorganisms at any given time.

The time required to kill a known population of microorganisms in a specific suspension at a particular temperature is referred to as thermal death time (TDT). Increasing the temperature decreases TDT, and lowering the temperature increases TDT. Processes conducted at high temperatures for short periods of time are preferred over lower temperatures for longer times. Increased heat causes increased toxicity of metabolic products and toxins. TDT decreases with pronounced acidic or basic pHs. However, fats and oils slow heat penetration and increase TDT (SOP, 2014). Autoclaving is the most effective and most efficient means of sterilization. All autoclaves operate on a time/temperature relationship. These two variables are extremely important. Higher temperatures ensure more rapid killing. Some standard temperatures employed are of 115ºC, 121ºC and 132ºC as well as pressures are of 0.70, 1.0 and 1.86 kg/cm^2 (Jada, 1991; Howard, 2004).

There are various types of autoclaves, such as-industrial autoclave, medical autoclave, laboratory autoclave, etc. All of these autoclaves are batch operating type which has one and only chamber for steam producing and sterilization. In case of biological research laboratory, sequential autoclaving is needed. The commercially available conventional autoclave is not capable to satisfy this continuous sequential autoclaving. The aim of this study is to design, fabricate and performance evaluation of a continuous operating autoclave.

2. METHODOLOGY

2.1 Materials

The material with high pressure resisting capacity is used for the fabrication of the autoclave. To fabricate a low cost autoclave for using in laboratory for research purposes, locally available and less expensive material that has the sufficient strength is chosen to satisfy the required specification.

2.1.1 Steel vessel

An MS cylindrical housing pipe of 82 cm long and 60 cm diameter with desired thickness is taken from the strength of material laboratory of the Department of Civil Engineering of RUET. The strengths of the material and welded joint of the pipe are testing with the help of UTM in the SM laboratory. A MS plate of desired thickness is also collected from laboratory and tested for using in pressure vessel to make bottom and partition wall of steam and sterilization chambers. The collar and lid of the pressure vessel is also made with the MS plate.

2.1.2 Water heater

A commercially available water heater, which is usually used for water heating in a water bath in winter season, is purchased from the local market. The capacity of the heater is 2000 W.

2.1.3 Safety valve

Safety valve is a valve mechanism for the automatic release of pressure from a boiler, pressure vessel or the other system when the pressure or temperature exceeds limits. Commercially available adjustable safety valve used in steam boiler is purchased from the local market.

2.1.4 Pressure gauge

Pressure gauge is a device which shows the value of pressure in different conditions. This device will help the equipment to show its pressure condition. By observing the value the design pressure is maintained. Commercially available pressure gauge with the capacity of 10 kg/cm^2 is purchased from local market.

2.1.5 Gasket

A gasket is a mechanical seal that fills the space between two mating surfaces generally to prevent leakage from or into the joined objects whiles under compression. Gaskets are produced by cutting sheet materials, such as gasket paper, rubber, silicone, metal, cork, neoprene or a plastic polymer. It is usually desirable that gasket be made from a material that is to some degree yielding such that it is able to deform and tightly fill the space it is designed for, including any sight irregularities. A rubber sheet is used to make gasket in required shapes and sizes.

2.2 Methodology

The size of the vessel is selected based on required volume and diameter. The length of the vessel is calculated. The longitudinal and hoof stress developed on vessel wall due to steam pressure are calculated. The strength of selected material for fabrication is determined in the laboratory. The required wall thickness is calculated for withstanding the developed pressure. A cylindrical housing pipe is taken from the laboratory and selected for using as vessel considering the strength and wall thickness. The fabrication of autoclave is done according to design. A bottom plate of required thickness is attached by welding. Three lids are designed for closing the three separate sterilization chambers. A collar at the top edge of the vessel is attached for placing lid properly. A gasket is place on the collar for making the lid leak proof. A water heater, pressure gauge, safety valve, thermometer, outlet valve for washing and cleaning of vessel are purchased from market and fixed as per design. Finally, the fabricated autoclave is operated to evaluate the performance in the laboratory.

3. DESIGN, FABRICATION AND PERFORMANCE STUDY

3.1 Design of Autoclave

The total height of the autoclave chamber is considered to be 82 cm with the diameter of 60 cm. The height of the steam chamber is of 30 cm at the bottom portion. The seam producing chamber is designed as two-third volume will be filled with water. About six liter water can be poured in the steam chamber. A water heater is set at 25 mm above from the bottom. The steam chamber and sterilization chamber are separated completely by welding a plate at 30 cm height. Three sterilization chambers are made by dividing in equal three pats by fixing steel plate vertically. The interior angle of each compartment is 120^{o}. Three independent lids are connected for three compartments. Three baskets are made of similar shape for ease of handling of sterilized materials. The pressure gauges and safety valves are fixed at the side of the each steam and sterilization chambers. Steam is supplied in each sterilization compartment individually from out side. Three regulating valves are connected in each steam supply lines. An outlet for cleaning is placed at the bottom of the vessel. A six inch high stand is attached with the vessel. Insulation system is not provided considering the cost of insulation. A schematic diagram is shown in Figure 1.

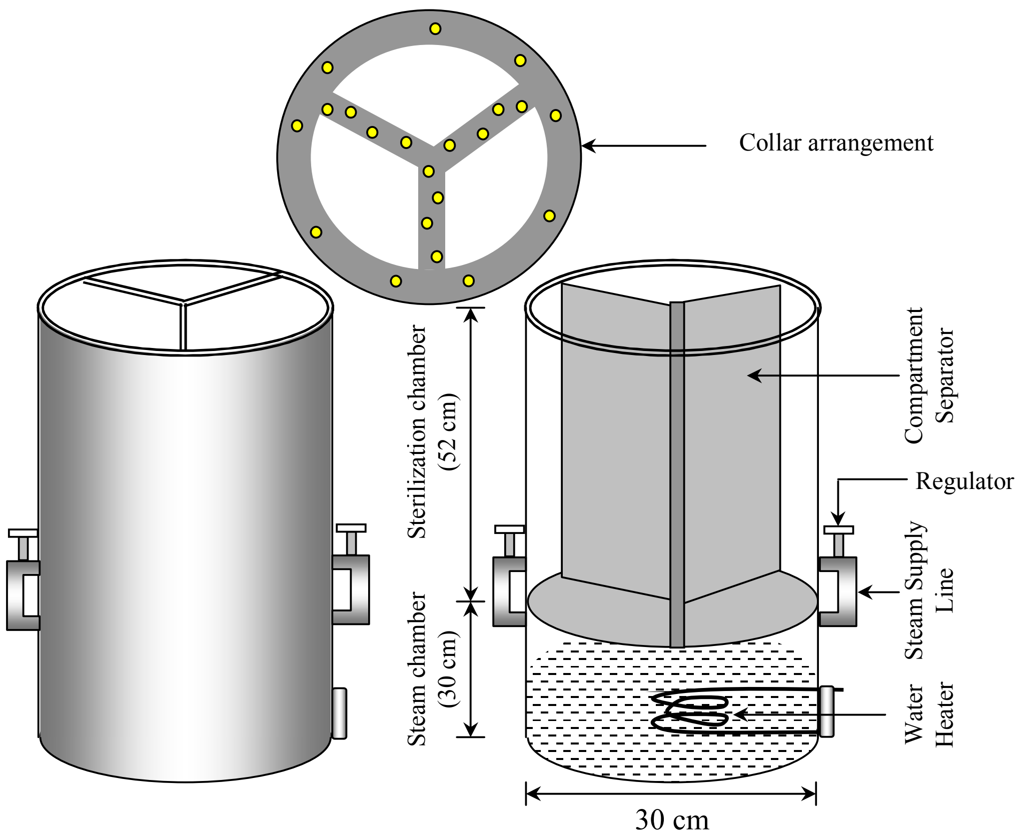

Figure 1: Schematic diagram of continuous operating autoclave

3.1.1 Analysis of developed stress

Longitudinal and transverse stresses are developed in cylindrical pipe when filled with fluid (steam) that must be resisted by the used material. The longitudinal stress and transverse stress of section can be determined by using the equation $\sigma_l = \frac{PD}{4t}$ and $\sigma_t = \frac{PD}{2t}$.

The working pressure inside the autoclave is considered to be of 2 kg/cm^2 (19.62 N/cm^2) and wall thickness is 0.52 cm. Therefore, developed longitudinal stress and transverse stress (hoof stress) are estimated to be of 0.6 KN/cm^2 and 1.2 KN/cm^2, respectively.

3.1.2 Determination of material strength

The testing specimens are prepared by cutting from the housing pipe available in laboratory. The testing specimens are cut in transverse direction from welded joint portion and in longitudinal direction from plane portion. The width and thickness of the specimens prepared from welded portion are 2.23 cm and 0.59 cm, respectively while, width and thickness of the specimens prepared from plane portion are 1.32 cm and 0.52 cm, respectively. The applied load at yield point is measured with the help of Universal Testing Machine. The average load is found to be of 45 KN and 32.3 KN for welded and plane specimens, respectively. The corresponding yield strength of the material is calculated to be of 33.16 KN/cm^2 (3.32×10^5 Kpa) and 47.06 KN/cm^2 (4.71×10^5 Kpa) which are absolutely higher than that of the developed stress. Thus the vessel thickness is considered to be sufficient.

3.2 Fabrication

The fabrication part is very important in machine. The main vessel is fabricated according to design shape by jointing the bottom plate by welding with cylindrical MS pipe. The steam producing chamber and sterilization chamber are separated by connecting another plate at 12 inch height from bottom by nut and bolt with proper sealing gasket. A heater is attached with this vessel in the steam producing chamber before connecting the chamber separator. The heater capacity of 2000W is used. The sterilization chamber is divided into three compartments with three vertical plates by welding as shown in Figure 1. Safety valves are connected in each chamber for releasing excessive pressure created in the vessel. To maintain the design pressure and safety ness valves play vital role. Then to monitor the steam pressure, a pressure gauge is also attached with the machine. A collar is welded at the top end of the vessel to facilitate the connection of three separate lids of each compartment. Gaskets are used between the contact face of the collar and lids to make it leak proof. The nut and bolts are used to attach the cover with vessel. Two handles are also attached with the vessel to carry the autoclave easily from one place to another. Steam supply lines are connected with controlling regulators through out side from steam chamber to sterilization chambers.

3.3 Performance Evaluation

The performance of the newly designed and fabricated autoclave is evaluated for pressure and temperature. Performance evaluation is done through three steps test: at the first step, all three sterilization compartments run together, in second step, two sterilization compartments run together and in third step, only one sterilization compartment runs by opening the respective steam supply regulators. The performance evaluation is performed successfully for three hours in each step. The changes of pressure inside the vessel and surface temperature of the vessel wall (temperature difference between inside and out side wall is neglected for simplification of experiment) are observed during the run. The change of pressure and temperature are observed at an interval of 15 minutes for evaluating the performance of fabricated autoclave. The obtained results are represented in Figure 2.

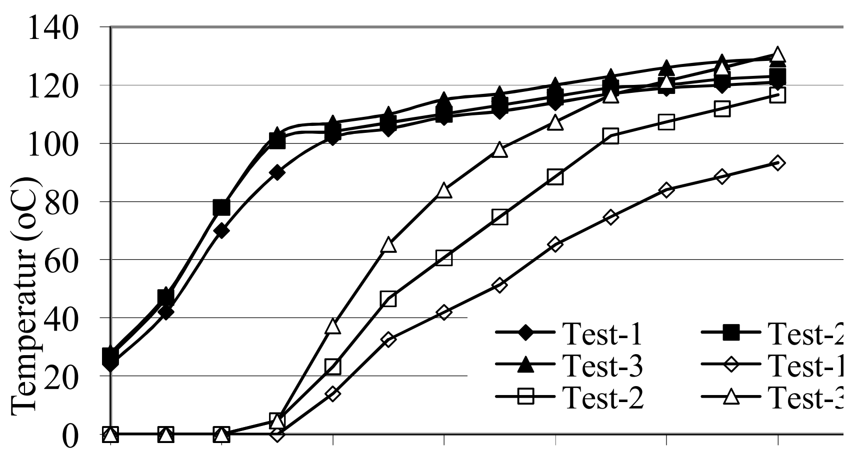

Figure 2: Variation of Temperature and Pressure with time

The figure shows that the pressure is not appeared in any compartment up to 45 minutes in test-1 and temperature is 90°C while in test-2 and test-3 pressure are initiated at temperature 101°C and 103°C, respectively. It is observed that the temperature increased rapidly up to boiling point by 45 minutes and then rate of increment became slow. Then the pressure is increasing due to gradual increasing of steam production. The highest pressure of 2.8 psi is observed at 129°C after 180 minutes in case of single compartment operation. However, maximum required temperature of 132°C is not achieved in any case by three hours. Furthermore, the first and second standard temperatures and pressures are obtained after 105 minutes and 180 minutes, respectively in every operational condition.

Again from figure, it is observe that the rate of increase of pressure becomes slow after around 120 minutes. It might be due to the ending of steam production in absence of enough water in side the vessel. The lowest pressure is found in each compartment in test-1 when three compartments run together. On the other hand, the highest pressure is found in test-3 when only one compartment runs while intermediate pressure is found in test-2 when two compartments run together. It is also observed that the duration to reach the desired pressure is very long which should be within 30 minutes. It might be obtained by using higher heating capacity water heater.

4. CONCLUSIONS

The fabricated autoclave runs successfully. It took much time to reach at the expected pressure. The desired performance could be improved by introducing high capacity water heater. Eventually, the design and fabrication of continuous operating autoclave are successfully achieved and further study needs to achieve desire improvement.

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