Review of Historical Development of Autoclave towards healthcare sector

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Abstract

Autoclave is a machine used to carry out industrial and scientific processes requiring elevated temperature and pressure in relation to ambient pressure and/or temperature. The name autoclave indicates a self-closing vessel with internal pressure sealing its joints, but many autoclaves are kept closed by external mechanical means.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 steam digester, a prototype of the autoclave that is better known now as a pressure cooker, was invented by French-born physicist Denis Papin in 1679. It wasn't until 1879 that the French microbiologist Charles Chamberland created a new version called the autoclave to be used in medical applications. Most healthcare facilities, however, have medium or large autoclave machines in their Sterile Processing Department (SPD) which can process 15-20 trays of instruments per cycle or even up to 625 lbs of instruments per cycle depending on size. This research presented an overview of autoclave, the types, and applications, working principles and improvement in the system over the past decades. The findings showed that maintaining a temperature of 121° C for at least 30 minutes by using saturated steam under at least 15 psi of pressure is vital to maximize the efficiency o autoclave during sanitization of tools.

Keyword: Autoclaves, steam sterilizers, pathogenic organisms, health applications

1. Introduction

An autoclave is a machine that uses steam under pressure to kill harmful bacteria, viruses, fungi, and spores on items that are placed inside a pressure vessel. It is also known as steam sterilizers.The items to be sterilized are placed inside a pressure vessel, commonly referred to as the chamber. The items are heated to an appropriate sterilization temperature for a given amount of time. The autoclave is considered a more effective method of sterilization as it is based on moist heat sterilization.The moisture in the steam efficiently transfers heat to the items to destroy the protein structure of the bacteria and spores.The name comes from Greek auto-, ultimately meaning self and Latin clavis meaning key, thus a self-locking device.

The autoclave is generally used to disinfect anything that needs to be free of microorganisms. It can decontaminate solids, liquids, hollow items and instruments of varying shapes depending on the type of autoclave and its size. Autoclaves are used in medical applications to perform sterilization and in the food and chemical industries. In healthcare, the term "autoclave" is typically used as the nomenclature to describe a Steam Sterilizer.

ANSI/AAMI, which provides standards and guidelines for the processing of medical devices, refers to autoclaves for healthcare specifically as Steam Sterilizers. Most healthcare facilities, however, have medium or large autoclave machines in their Sterile Processing Department (SPD) which can process 15-20 trays of instruments per cycle or even up to 625 lbs of instruments per cycle depending on size, (Trenton, et al., 2015)

The size of the sterilizer will vary based on the capacity needed for the area where the autoclave will be used. The autoclave must be large enough to hold at least one supply cylinder, if these are used, and must be maintained to ensure correct operation. Steam quality problems can cause sterilization failure in even the most carefully maintained autoclave; thus, institutional support in the form of proper installation, maintenance, and repair of building steam supplies is an important factor in successful facility operation. We also recommend that, if at all possible, the facility have an autoclave dedicated to its own use and that only trained facility personnel operate it, so as to avoid conflicts and delays in daily use as well as maintenance and repairs. It also is advisable to identify a backup autoclave that has the necessary capabilities and monitor it regularly, even if it is rarely used.

2. Literature Review: Invention

The autoclave was invented by Charles Chamberland in 1879, although a precursor known as the steam digester was created by Denis Papin in 1679, which is a prototype of the autoclave that is better known now as a pressure cooker. However, this was used solely for culinary purposes until Chamberland's work. Papin called his product the "the marmite de Papin, or the "Papin Digester",(Howard, 2004). Dr. Charles Chamberland took an interest in inventing tools and machines, after obtaining a doctorate in physical sciences in 1879. His thesis, titled “Recherches sur l’origine et le développement des organismes microscopiques,” translated as “Research on the origin and development of microscopic organisms,” was the first step that led to him to investigate sterilization techniques, ultimately inventing the autoclave in response to Pasteur’s requirement for a sterilization technique that utilized temperatures higher than 100 C

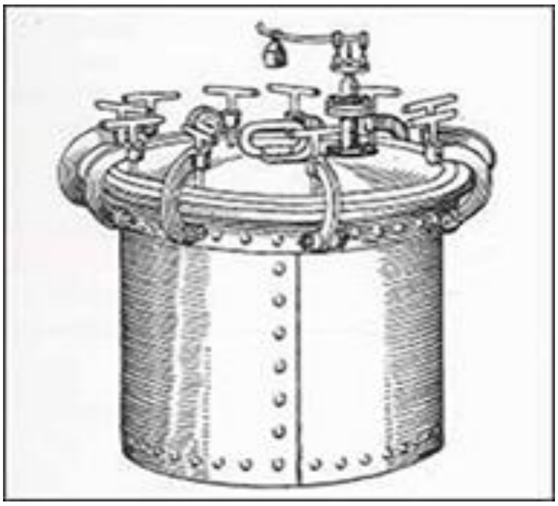

Figure 1: The first steam sterilizer (Alexander, 2023)

Denis Papin was a medical doctor with his MD in 1669 from the University of Angers, before he left for Paris to begin a career in science under the direction of Christiaan Huygens, working on an air pump, then moving to London in 1675 to work with Robert Boyle and Robert Hooke. Though much of his work was centred on air pumps, he would also go on to invent a “steam digester” that basically acted as a pressure cooker with a safety valve. The digester looked like a potbellied stove, consisting of a metal cylinder with a glass vessel. The cylinder could be filled with water equal to the difference in volume between the glass container and the cylinder itself, with meat and liquid placed inside the container, then sealed. Heat was applied from a fire under the cylinder, with a safety valve to remove excess steam once the inside had reached a high enough pressure. Papin eventually published a detailed account of his digester in 1681 in an article titled, "A new digester or engine for softening bones, containing a description of its make and use" (Alexander, 2023).

3. Construction of Autoclave

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

The source of steam generation in the chamber is through the electrical means. The water is heated by the boiler, thereby producing steam. 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 2: An Autoclave (Palenik, et al. 1999)

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, (Festus, 2007).

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).

3.1 Basic Components of Autoclave:

For the autoclave machine to do its job, all the components must work properly. The ability to identify these components makes it easier to maintain the machine (Michael, 2021). Here is a list of the main component parts that make up an autoclave:

- **The Chamber:** The vessel is made from stainless steel. This is the main part of the autoclave, where the items are placed for sterilization. They can vary in size, from 100L to 3000L and have an inner chamber as well as an outer. The size of the chamber varies and selected based on the motive of use. This outer chamber is generally known as a 'jacket', which is filled with steam to reduce sterilization time. The electric heater is placed beneath the chamber. The electric heater working principle is similar to geezer. The electric heater start heating it causes boiling of water. The user needs to maintain the water level as per the marking. Less water may cause burning and more water may lead to enter water in the experimental material, (Sangha, 2020).

- **The Door:** The vessel mouth is covered by lid or door, which is also made from stainless steel. The purpose of the front door of the autoclave is to seal off the outside atmosphere. This allows the items inside the chamber to be sterilized properly. A lock and a door seal secure the contents and prevent leakage.

- **The Safety Valve:** A pipe at the bottom of the cylinder feeds steam into the chamber at a higher atmospheric temperature. This increased pressure raises the temperature by 20 degrees centigrade higher than the normal boiling point of water. Therefore, a safety valve is fitted to stop the pressure inside the chamber exceeding a pre-set maximum temperature. Their function is to avoid catastrophic accident especially when pressure inside the chamber is uncontrollable.

- **The Thermostat:** Once the desired temperature has been reached, a thermostat starts off a timer. The timer is usually set to 15-20 minutes, depending on the contamination level of the materials inside the autoclave. The way in which they have been loaded into the chamber will also have an effect on the timing.

- **Pressure gauge andPressure releasing unit/whistle:** It is present on the upper surface of lid. Its function is to indicate the level of pressure that is produced during autoclaving. It is vital part because it allows us to visually see the rise of pressure and alert for any forthcoming mishap hence it ensures the safety. The whistle is placed on top of the surface of the lid, just like pressure cooker. The whistle allows us to release the pressure whenever required.

- **Wastewater cooler:** Many autoclaves will have a system that cools any wastewater before it enters the drain. This is often done to avoid damage to the drain piping at the laboratory.

3.2 Sterilization Cycles

This refers to the process that removes kills or deactivates microorganisms and unicellular eukaryotic organisms present in or on a specific surface, object, or fluid. There are four standard sterilization cycles: gravity, pre-vacuum, liquids, and flash (also known as immediate use). The table 1 showed the cycles in greater detail.

Table 1: Cycles of sterilization and applications

Basic cycles	Description	Typical application
Gravity	The most basic sterilization cycle. Stem displaces air in the chamber by gravity through a dry port	Glass ware, unwrapped goods, waste, utensil, rebags
Pre-vacuum and post vacuum	Air is mechanically removed from the chamber and load through series of vacuum and pressure pulses. This allows the steams to penetrate porous areas of the load that culdnot otherwise be reaches with simple gravity displacement	Wrapped goods, packs, animal cage bedding, cages, porous materials, redbags
Liquid	Gravity cycle with a slower exhause rate to minimize oil over	Media, LB broth, water, etc
Immediate use/flas (health care sterilizers only)	High temperyure cycle for a shorter period of time	Unwrapped goods

The sterilization of materials as in table1 uses steam and pressure is a dependable procedure for the destruction of all forms of microbial life. However, the autoclave must be properly used and understood to be effective. Do not assume that merely pushing the button on an autoclave will result in the proper sterilization of your materials, (Howard, 2004). Some autoclaves also have the ability to perform specialty cycles designed to avoid damage to delicate goods that need to be sterilized but would be damaged or destroyed by the rapid changes in temperature and pressure in a normal cycle. These specialty cycles include much longer cycles at lower temperatures, steam-air mix cycles with special pressure controls to avoid breaking sealed test tubes, and cycles that use special instrumentation to ensure full sterilization temperature is achieved (Amit, 2007).

According to Sangha (2020), three factors are critical to ensuring successful steam sterilization in an autoclave: time, temperature and steam quality. To meet these requirements there are three phases to the autoclave process (Sangha, 2020):

1. **Conditioning Phase (C):** Air inhibits sterilization and must be removed from the chamber during the first phase of the sterilization cycle known as conditioning. In dynamic air removal-type steam sterilizers, the air can be removed from the chamber using a vacuum system. It can also be removed without a vacuum system using a series of steam flushes and pressure pulses. Gravity-type sterilizers use steam to displace the air in the chamber and force the air down the sterilizer drain.

2. **Exposure Phase (S):** After the air is removed, the sterilizer drain closes and steam is continuously admitted into the chamber, rapidly increasing the pressure and temperature inside to a predetermined level. The cycle enters the exposure phase and items are held at the sterilization temperature for a fixed amount of time required to sterilize them.
3. **Exhaust Phase (E):** During the final phase of the cycle, exhaust, the sterilizer drain is opened and steam is removed, depressurizing the vessel and allowing the items in the load to dry.

Quality steam is vital to a successful autoclave sterilization process. The steam used for sterilization should be composed of 97% steam (vapor) and 3% moisture (liquid water). This ratio is recommended for the most efficient heat transfer. When the steam moisture content is less than 3%, the steam is described as superheated (or dry). Superheated steam is too dry for efficient heat transfer and is ineffective for steam sterilization.

3.3 Working Principle of an Autoclave

The autoclave works on the principle of moist heat sterilization where steam under pressure is used to sterilize the material present inside the chamber. The high pressure increases the boiling point of water and thus helps achieve a higher temperature for sterilization. Water usually boils at 100°C under normal atmospheric pressure (760 mm of Hg); however, the boiling point of water increases if the pressure is to be increased. Similarly, the high pressure also facilitates the rapid penetration of heat into deeper parts of the material, and moisture present in the steam causes the coagulation of proteins causing an irreversible loss of function and activity of microbes.Before beginning to use the autoclave, it should be checked for any items left from the previous cycle and a sufficient amount of water is then put inside the chamber.

In general, an autoclave is run at a temperature of 121° C for at least 30 minutes by using saturated steam under at least 15 psi of pressure. This principle is employed in an autoclave where the water boils at 121°C at the pressure of 15 psi or 775 mm of Hg. When this steam comes in contact with the surface, it kills the microbes by giving off latent heat. The condensed liquid ensures the moist killing of the microbes.

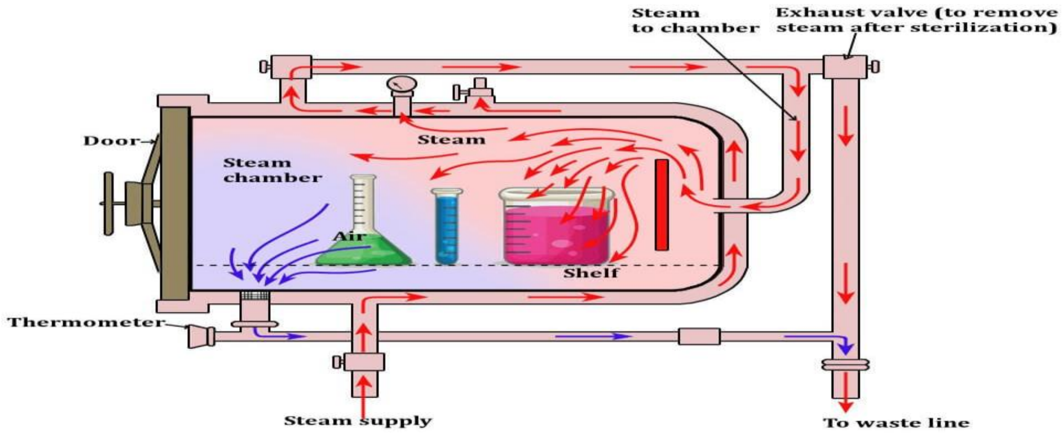

Figure 3: Autoclave Principle or Working (Anupama,2023)

Once the sterilization phase is completed (which depends on the level of contamination of material inside), the pressure is released from the inside of the chamber through the whistle. The pressure inside the chamber is then restored back to the ambient pressure while the components inside remain hot for some time (Anupama, 2023).

Precautions: According Anupama, 2023, Autoclaves are pretty simple to use, there are certain rules of precautions to be followed while operating an autoclave. Some of the important precautions to be followed while running an autoclave are:

- Autoclaves should not be used to sterilize water-proof or water-resistant substances like oil or powders.
- The autoclave should not be overcrowded, and the materials should be loaded in a way that ensures sufficient penetration of articles by the steam.
- To ensure sufficient penetration, articles should be wrapped in something that allows penetration by steam, and materials like aluminum foils should not be used.
- The items placed inside the chamber should not touch the sides or top of the chamber.
- Attempts to open the lid when the autoclave is working should never be made.
- Liquid components should never be autoclaved in sealed containers.
- The liquid inside the containers should only be filled 2/3rd of the total volume to prevent the spilling of the liquid.
- Plastic or polyethylene trays or containers should not be used as they might melt and damage the autoclave.
- Besides, never autoclave flammable, reactive, corrosive, toxic, or radioactive materials, household bleach, or paraffin-embedded tissue.
- The paper should not be placed directly inside an autoclave as it is a combustible substance. It should be autoclaved in a waste bag on a bio bag setting to prevent fire.

3.4 Development: Types of Autoclave

Over time, new autoclave technology has been developed including pre-vacuum cycles in 1958, and steam-flush pressure-pulse in 1987 allowing the science to evolve into the autoclaves, or steam sterilizers, used in hospitals today.

According to celitron.com (website), there are many different aspects that can be used as a basis for the categorization of the different types of autoclaves, and some of these aspects may overlap with each other.In most cases, steam sterilizers can be differentiated by:

1. function
2. class
3. size (capacity)

Figure 4: Types of autoclave (Anupama,2023)

1). Categorized by Function: All autoclaves use high-temperature and high-pressure steam to sterilize medical equipment and waste. Their function indicates how they should be loaded, and force in the steam in their chamber to sterilize the instruments inside as in table 2.

Table 2: categories of autoclave by functions

Vertical autoclaves	Horizontal autoclaves	Gravity displacement autoclaves	Pre-vacuum (prevac) autoclaves
These types of autoclaves are loaded by opening their top lid, especially suited for laboratory use or in smaller clinics with cramped spaces. As such, they also have a smaller capacity chamber.	Front-loading steam sterilizers with a larger capacity chamber. When available space is not an issue, and you need to treat many loads a day, this one is exceptional for reducing the strain on medical staff.	One of the most common types of autoclave that relies on using dense steam to force out the air from the machine's chamber. They are suitable for the treatment of basic loads like flat surgical tools and certain types of bio-hazardous waste but are not as versatile as pre-vacuum autoclaves.	This type of autoclave uses a vacuum pump to remove all the air from the autoclave's chamber, allowing for better steam penetration, and the sterilization of more materials and complex loads such as medical textile products, porous loads, larger pieces of equipment, and even objects made from high-density polyethylene like the syringes of sharps and pipette tips.

2). Categorized by Class: A more clear-cut way of categorizing the different types of autoclave machines. A steam sterilizer's class indicates how versatile it is: in other words, it shows what kind of loads can be treated with it as in table 3.

Table 3: categories of autoclave by classes

Class N autoclaves	Class S autoclaves	Class B autoclaves
These are essentially simple, gravity displacement autoclaves that only remove a certain portion of the air inside the machine's chamber. Designed for the treatment of simpler loads like flat medical tools.	Another type of gravity displacement autoclave that uses a wall of dense steam, but by repeating the process 3 times, it can actually extract all the air from the chamber, and as such, it can already treat bagged instruments and porous loads. Still less versatile and not as fast a class B autoclave though.	Premium pre-vacuum autoclaves that can sterilize the most materials and are also much faster at doing so by removing all the air from their chamber with a powerful vacuum pump. Some models make the best out of modern technology and operate with a completely automated process: this ease-of-use and effectiveness make them very attractive for all kinds of medical facilities.

3). Categorized by Size (Capacity): Here is a categorization that is pretty straightforward, but it certainly does not make it less important to consider. Autoclave size is also a key factor that needs to be taken into account: the right choice here depends on the amount of waste your facility needs to be treated each day, as well as the amount of available space you have as in table 4.

Table 4: Categories of autoclave by sizes

Large steam sterilizers	Medium-sized steam sterilizers	Small (benchtop) steam sterilizers
The capacity of these types of autoclaves usually ranges between 110 to 880 liters. Ideal for large medical facilities like hospitals that generate a notable amount of waste each day and needs to use a lot of medical tools and equipment to treat patients.	The capacity of these types of autoclaves usually ranges between 75 to 200 liters. An excellent choice for dental and other clinics, biotechnological applications, or for operating theatres in hospitals.	The capacity of these types of autoclaves usually moves around 25 liters. These compact steam sterilizers are perfectly suited for smaller facilities with limited available space, and who do not need to sterilize as many medical tools each day.

4. **Improvement in technology**

Autoclaves may be considered ancient devices by the standards of modern science, but this does not mean that autoclaves lack innovation, especially when it comes to controls, cloud connectivity, and ecological impact. Over the years, several milestones have been achieved that have fundamentally improved the steam sterilization method. Sterilization, as a specific discipline, has been with us for approximately 120 years, since the invention of the steam autoclave by Charles Chamberland in 1879. Since that time, we have seen progressive refinement in steam sterilizers: from the early, manually operated equipment to modern microprocessor-controlled, automatic machines. Although the efficiency, reliability, and performance monitoring of modern equipment is continually improving, the fundamental process remains essentially the same, (David, 1998). The autoclave is now a fixture of almost every research and healthcare institution, from biological labs to dental offices and hospitals. Since their conception, they've come a long way, incorporating new features and other recent technological advancements. This includes touch screen pads, internal temperature and pressure sensors, printers that deliver status reports, and auto-locking mechanisms on newly purchased autoclaves. Some models come with Ethernet ports and WiFi connectivity that help optimize updating processes and allow users to perform remote maintenance and remotely control the instrument. Crucially, the materials used to produce the autoclave are now made to be resistant to corrosion, ensuring their longevity. Even label technology has adapted, with an entire array of specialized products that resist autoclaving and other forms of sterilization, all of which can be adapted to nearly any laboratory environment. The steam autoclave isn't one of the more complex instruments you can buy.

However, its utility in sterilizing tools and consumables is nearly unparalleled throughout the science and medical world, making it one of the most important inventions of the last several hundred years. As mentioned earlier, autoclave controls have advanced greatly in the age of computers, progressing from manual controls and simple timers to computer automation that minimizes or eliminates entirely the need for user input. Computerized controls have also led to advances in data control, record keeping, and remote monitoring via mobile devices. Autoclaves with automatic printers that record data for the purpose of verifying successful sterilization have now been replaced by new autoclaves that connect to the cloud to store cycle records on the internet. Another trend in autoclave design is sustainability. Autoclaves are a major source of water and energy consumption, both in laboratories and hospitals. In recognition of this, many manufacturers have found innovative ways to reduce autoclaves' environmental impact. Green autoclaves that reduce or even fully recycle the water consumed by a sterilizer in some cases, from 1,500 gallons a day to less than one gallon a day are critical to create an environmentally friendly laboratory. Control systems that automatically turn the autoclave when not in use can also significantly reduce energy use in some cases, from 80 kilowatt-hours per day to 20 kilowatt-hours per day (Amit Gupta**,** 2007). Alongside consistent temperature, equal pressure is crucial for ensuring ideal sterilization, especially within the medical industry. For optimal performance, it's crucial to keep in mind that uniform temperature depends on the size, shape, and material of the tool that's being treated inside the autoclave.

5. Contribution to Knowledge

This research work gives point by point information on the beginning, advancement and history of the Autoclaves. The priority of this research is to establish uniform temperature and pressure controls, i.e. to say that Autoclaves operate at high temperature and pressure in order to kill microorganisms and spores, while autoclave manufacturers are continually devising new technologies to improve their heating systems.

6. Conclusion

Autoclaves make use of steam sterilisation that is grounded in pressure, temperature and time, all of which work together to kill all signs of microbial life, especially those that are resistant to boiling water and powerful detergents. There are various types of autoclaves, but they all function the same way. Take all the necessary precautions when carrying out autoclaving procedures, and make sure that you have an experienced technician to help guide you through this process. A notable recent and increasingly popular application of autoclaves is the pre-disposal treatment and sterilization of waste material, such as pathogenic hospital waste. To be effective, the autoclave must reach and maintain a temperature of 121° C for at least 30 minutes by using saturated steam under at least 15 psi of pressure. Increased cycle time may be necessary depending upon the make-up and volume of the load. The rate of exhaust will depend upon the nature of the load. Dry material can be treated in a fast exhaust cycle, while liquids and biological waste require slow exhaust to prevent boiling over of super-heated liquids.

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