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Predictive maintenance on an autoclave laboratory scale

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Abstract
In this study, defective data from ten autoclaves was analyzed to determine the most frequent cause of issues that substantially contribute to autoclave failure. The findings indicated that voltage and electrical supply fluctuations were the primary cause of the majority of autoclave problems, and a predictive maintenance system based on Matlab software was developed in response to this data.

Keywords: Predicative, maintenance, autoclave, machine learning

Introduction

Establishing an effective equipment maintenance system is one strategy which may significantly promote sustainable laboratory activities, as lab equipment is often the source of significant overall expenses for laboratories across various sectors. This is because the cost of new and repair services for lab equipment are often highly expensive due to the numerous issues related to the lab environment, technicians, and equipment reliability.

The emphasis of laboratory equipment maintenance procedures has changed from corrective to preventive [5], and presently to predictive maintenance. The goal of the maintenance is to minimize equipment downtime and lower associated service costs; as a result, maintaining a predictive maintenance program is crucial [1].

The addition of a thorough predictive maintenance program may and will give accurate information about the working conditional state of the machine this reduce unexpected failures of the equipment and guarantee that repaired equipment is in functionally acceptable condition [2].

One of the issues that requires attention from researchers and developing engineers for lab equipment is emerging the lab equipment maintenance in the system of the digital maintenance, (5th generation), by facilitating the use of machine learning methods for the predicative maintenance, a single device in particular, the autoclave, has been selected to act as an example for the integration of machine learning to lab equipment.

An autoclave laboratory scale is one of the important equipment is a that can be used in a variety of laboratories, including the medical, chemical, and industrial fields.

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, Steam generated from autoclave used as the sterilizing agent, and the pressure inside the device helps to raise the temperature of the steam, which increases its potency for eliminating dangerous biological agents.

Temperature, pressure, and time are frequently used as physical indicators to track the sterilizing process in an autoclave. Some autoclaves additionally feature biological indicators, which are checked for the presence of live microorganisms after the cycle is finished to verify that the sterilization procedure was successful.

Contemporary guidelines and standards for the Autoclave presented in [9].

The using of machine learning for the laboratory autoclave was conducted [6] they were using an artificial intelligence (AI) and mechanical learning methods are used to find the process optimization steps of the autoclave.

Lin and Chin [7] applied CNN and long short term memory (LSTM) models for analysis the processing temperature types of the composite materials. Our goal is to forecast the predictive maintenance system for the autoclave machine to help engineers and technicians to ensure that the machine will continue to operate throughout sterilization.

Autoclave components
The autoclave's main body is the pressure chamber. It is made up of two parts: an outer jacket and an extremely hard and sturdy interior chamber. The area between their two walls is filled with steam that has been heated beyond belief. Frequently has steel as the inner chamber.

Lid or Door: As you might have guessed, in order for the pressure chamber to be usable, it needs to have a lid or door. This can be totally removable for smaller autoclaves, which are essentially pressure cookers anyhow, or it can operate on a hinge for larger autoclaves. The lid would be secured with screws or clamps, and an asbestos washer (a sizable ring around the entrance) would keep the lid airtight.

Pressure gauge: Because working at high pressure is inherently risky, you'll need a way to keep track of the pressure inside the chamber. This is done using the pressure gauge. For smaller cases, it often rests on the lid, while it may be included into larger floor-standing autoclaves. For smaller ones, the meter might be analog, and this is done using the pressure gauge. For smaller cases, it often rests on the lid, while it may be included into larger floor-standing autoclaves. For lesser models, the meter might be analog, whereas for larger models, it can be digital.

Release Valve: It goes without saying that there needs to be an automatic pressure release system when working with high pressure, ideally one that also immediately warns you of the excessive pressure. This function is performed by the whistle-doubling release valve. This normally rests on the lid and is gravity-operated.
Safety Valve: On the lids of the majority of autoclaves is an additional safety valve, similar to a good pressure cooker, in case the primary release valve malfunctions. It only erupts as a small piece of firm rubber as opposed to

Methodology
These devices' malfunctions were divided into groups depending on the types of problems and the faulty parts. The defects were first categorized as electrical, mechanical, etc., and the most frequent source of trouble was identified and given priority using a Pareto analysis.
After the autoclave's defective fuses, circuit breakers, switches, control boards, tubing, and valves were replaced, the issues were resolved, leading to the second analysis. After then, these parts were assigned a code.
As indicated in Table 1, the suggested flow chart for the fault problem is based on the physical phenomena that the user experiences, such as no power, no heat, no pressure, temperatures and pressure fluctuations, and temperature and pressure increases or decreases.
The devices that affect and create the fault are shown by the figures of these effects plotted against the defective components.
In order to create a prediction system for the autoclave based on a machine learning algorithm, the defective data was evaluated using Matlab software R2023B to compute the mean and variance.
Autoclave maintenance and troubleshooting Flow chart

Table 1: Proposed defected components

No	Fault type	Proposed defected components
1	No power	Fuse(fs), circuit breaker (ck), switch (sw), control unit, open or short (opsh)
2	No heat	Fuse (fs), circuit breaker (ck), switch (sw), control unit, open or short (opsh), heater
3	No pressure	Fuse (fs), circuit breaker (ck), switch (sw), control unit, valve (vl), blockage (blk), Temp &pressu (gu), leak (lk)
4	Temperature and pressure out of range	Fuse (fs), circuit breaker (ck), switch (sw), valve (vl), blockage (blk), Temp& pressu (gu), leak (lk)

Results and Discussion: A Pareto analysis was performed in order to determine the primary contributing elements to the cause of the issue for the autoclave components. The findings are displayed in Figure 3.
Figure 3 indicates that it's obvious that the power issue dominated the other mechanical issues.

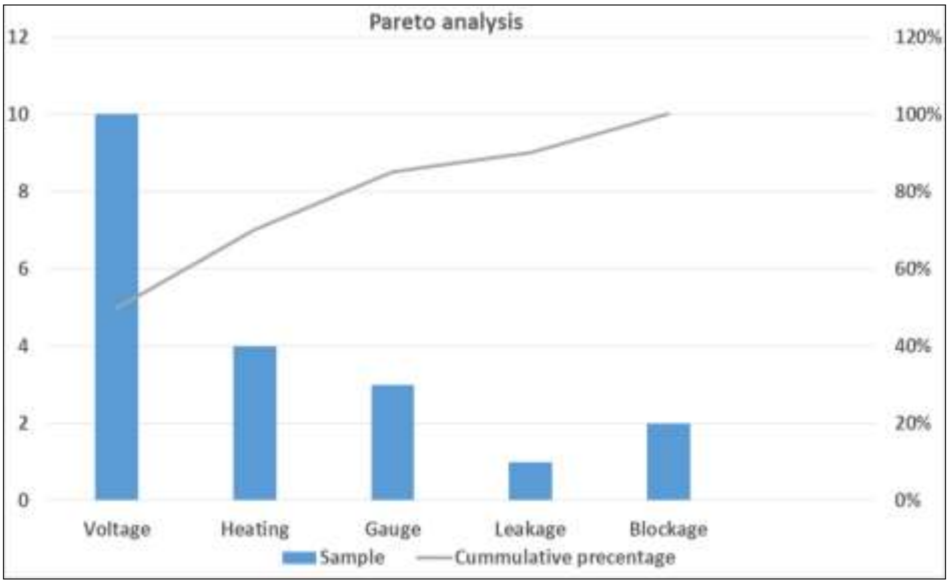

Fig 1: Pareto analysis for the autoclave.

As a consequence, the defects have been classified according to the troubling components, suggesting which devices required greater care during the building or design of an autoclave machine, as illustrated in Figure 4.

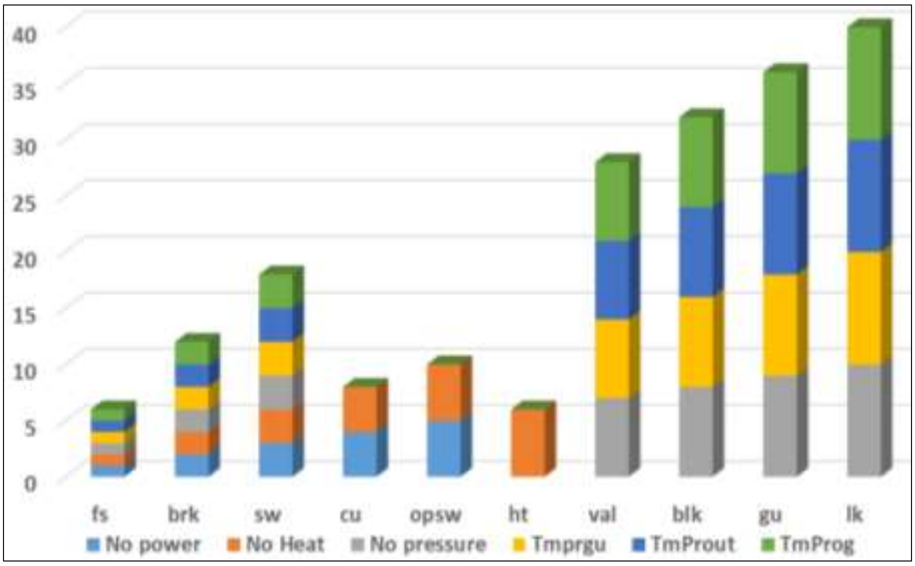

Fig 2: Faults and defective components in the Autoclave.

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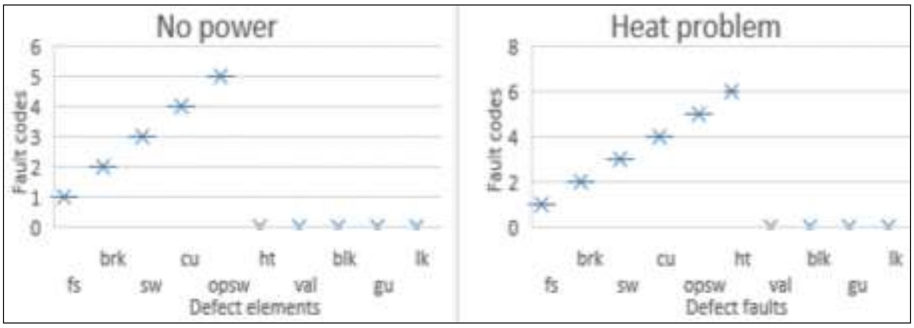

Fig 3: The power and Heat problems and associated defected components

The heat problem related the power issues as showed in the figure 5b, therefore it is the diagram seen similar to the power, the difference only in the

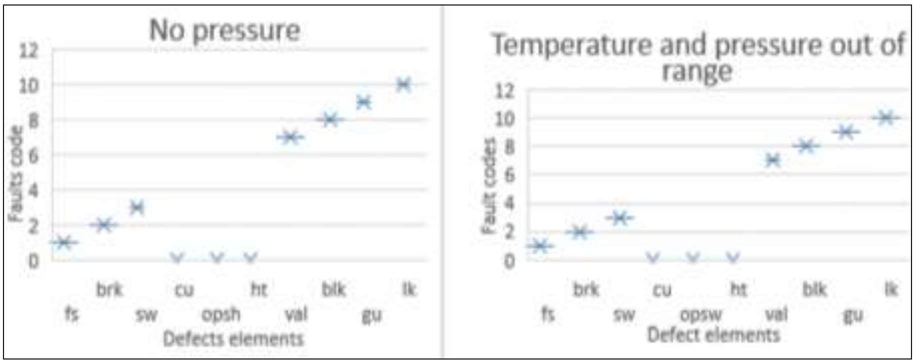

Fig 4: The figure, a no pressure problem and b showed temperature and pressure out of desired range.

The pressure and temperature problems looking like the same due to the correlation between their components, the pressure problem may be caused by fuse blown, circuit breaker, solenoid valve, blocking tube and leakage.

The continuous cleaning of chamber and tubing in additional to the stable source of electricity is play a significant role in the continuous operation of the autoclave and increase the life time of the machine.

The predicative maintenance proposed to satisfy the requirements of sustain operation of the machine with minimum maintenance cost and long life time.

Data used for the predication of the system is given in the table 1, to analysis the data, the predication logarithm used for the predication of the system as shown below:

Table 1: Data used to calculate the predication system

Fault type	Variable	Dataset	Mean (µ)	Variance (δ)
No power	X1	[1 2 3 4 5 0 0 0 0 0]	1.5	3.611
No Heat	X2	[1 2 3 4 5 6 0 0 0 0]	2.1	5.211
No pressure	X3	[1 2 3 0 0 0 7 8 9 10]	4	16.44
Temperature &pressure not stable	X4	[1 2 3 0 0 0 7 8 9 10]	4	16.44

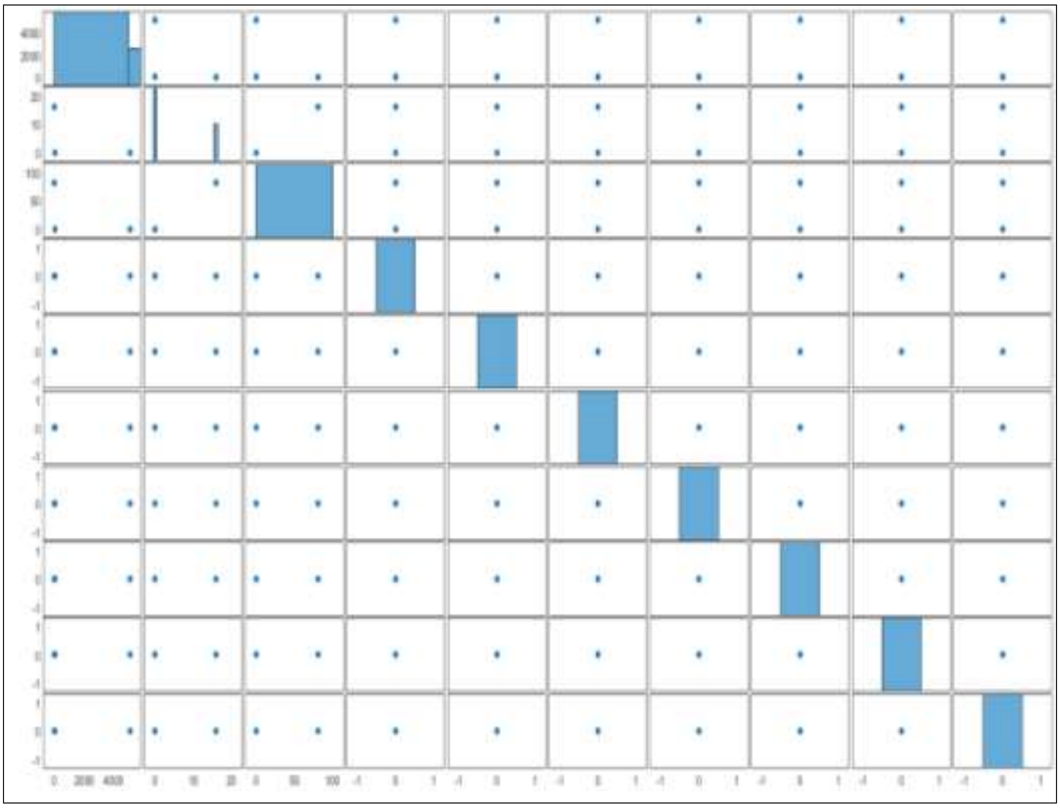

Fig 5: The validation of the predicated system for the Autoclave

The equation used to predict the system given by

Predication(X) = (x1, µ1, δ1) * (x2, µ2, δ2) * (x3, µ3, δ3) * (x4, µ4, δ4). The matlab software version R2023b used to calculate the matrix and plot the predication output results as given in figure (7). Computational and mathematical approach to forecast the results according to historical maintenance records using a predictive maintenance model. The training data set, as shown in Figure (7), is created utilizing iterative process models in Matlab. It is subsequently verified and validated to evaluate the accuracy of the system, as indicated in Figure 7.

Conclusion

The analysis of the autoclave faults and problems identified that the power issues as the most dominant mechanical problems. It emphasizes the importance of addressing these problematic components during the construction or design phase of autoclave machines.

The paper proposes predictive maintenance as a solution to ensure continuous machine operation with reduced maintenance costs and a longer lifespan. The accuracy of the predictive maintenance system is evaluated through verification and validation processes, this evaluation helps assess the reliability and effectiveness of the system in improving maintenance practices.

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