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Adaptive Cooling Water Control for Sterilizers

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Abstract

This thesis was conducted with the objective of reducing water consumption by optimizing the cooling systems of steam sterilizers. As water is a precious resource with great environmental effects, it is important not to waste it. Consequently, there is a need for a more resource-efficient cooling water system. The project focuses on the development of a system that more efficiently regulates the cooling water utilization by optimizing temperatures. The goal of the project is to achieve a 20% reduction in water consumption of the GSS-91413 model steam sterilizer manufactured by Getinge. In order to achieve the goal, changes were made to the cooling system and control logic of the cooling system. By integrating a proportional valve at the outlet of the cooling system, the system was pressurized with the coolant resulting in greater energy transfer between the condensate and the coolant. The developed control logic incorporates process data combined with an equation-based approach that utilizes temperature data to adjust the proportional valve leading to increased control of the flow of the coolant. As a result, the overall water consumption of the system was reduced by more than 50% while the maximal temperature of the system did not rise more than 1.5%.

Sammanfattning

Detta examensarbete genomfördes med målet att minska vattenförbrukningen genom att optimera kylsystemen i autoklaver. Eftersom vatten är en värdefull resurs med stora miljöeffekter är det viktigt att den inte slösas. Följaktligen finns ett behov av ett mer resurseffektivt kylvattensystem. Projektet fokuserar på utveckling av ett system som mer effektivt reglerar kylvattenutnyttjandet genom att optimera temperaturer. Målet med projektet är att uppnå en 20-procentig minskning av vattenförbrukningen för autoklavmodellen GSS-91413 tillverkad av Getinge. För att nå målet gjordes ändringar i kylsystemet och i kylsystemets styrlogik. Genom att integrera en proportionell ventil vid utloppet av kylsystemet trycksattes systemet med kylvätskan vilket resulterade i större energiöverföring mellan kondensatet och kylvätskan. Den utvecklade styrlogiken inkorporerar processdata kombinerat med ett ekvationsbaserat tillvägagångssätt som använder temperaturdata för att justera proportionalventilen vilket leder till ökad kontroll av kylvätskans flöde. Som ett resultat minskade den totala vattenförbrukningen i systemet med mer än 50% medan systemets maximala temperatur inte steg mer än 1.5%.

Acknowledgments

We extend our heartfelt gratitude to our academic supervisors, Pererik Andreason and Elena Haller, for their insights, guidance, and support throughout the thesis project. We would also like to express our sincere gratitude to Getinge AB for providing us with an opportunity to conduct a thesis within their organization and for providing us with the necessary materials and resources to carry out our research. Furthermore, we would like to extend our thanks to our industrial supervisor at Getinge AB, Robin Eriksson, as well as Mikael Carlsson, Anders Ådin, and all other dedicated staff members at Getinge who contributed their knowledge and assistance.

Contents

1 Introduction

Sterilizers are devices commonly used in hospitals and laboratory research facilities to eliminate microorganisms from various products, including equipment, medical instruments, and waste products. Sterilizing these goods is crucial in preventing contamination caused by microorganisms such as viruses, spores, and bacteria. Multiple sterilizing techniques and mediums exist and are used today. One of those techniques is steam sterilization, which uses heated high-pressure steam. Steam sterilization generates a significant amount of heat which must be adequately cooled before releasing it into the drain to ensure the safety of personnel and material. The cooling of steam is done by circulating it through a heat exchanger together with a cooling medium, usually water. The system that controls the flow of the cooling water must be fast enough to cool down the steam released from the chamber to a specific temperature before it enters the drain. The cooling system should also be as resource efficient as possible due to environmental effects since water is a precious resource and should not be wasted.

1.1 Purpose and Goal

The project aims to develop a system that regulates the cooling water in an autoclave more sparingly without exposing the system to alarming temperatures. The purpose is to cut the total water consumption to reduce the environmental impact of company's machines. The goal of this project is to reduce water consumption by 20%. A new control system will be developed on the GSS-91413 model autoclave to regulate water use and adjust the valve opening according to need instead of set conditions to achieve this goal. The same tests will be performed on the old system and then on the new system to compare the results and evaluate the system.

1.2 Requirements

- The new control system has to accommodate the current code.
- As the new components must adhere to specific standards, a restricted catalog provided by the company's supplier is used.
- The new system is only required to be implemented and tested on the hard goods cycle on the autoclave, thus, limiting the project's performance to the mentioned cycle.

1.3 Delimitations

There are limitations to the project, to narrow the topic to make the goal achievable during the available time.

- Shipping time restricts available components.
- As the space on the autoclave is limited, a water tank for a closed-loop cooling system will not be used.
- The new digital or analog card has to fit in the current electrical cabinet.
- New sensors used for measurements must fit the current piping on the autoclave because the available space is limited as mentioned above.

2 Background

The new cooling control system will be created and tested on the model GSS-91413 steam sterilizer. However, the new system is meant to be applied to numerous types of steam sterilizers produced by the company. The model of the steam sterilizer used in the project is designed for use in biomedical laboratory research. It has a $1.762\,\mathrm{m}^3$ chamber volume and is designed to sterilize a wide range of goods such as laboratory tools, glassware, and liquid containers [1]. It is controlled by a Programmable Logic Controller (PLC) and Input/Output modules to which devices such as temperature sensors can be connected. The control system has its own programming language *IEC 61131-3 Structured Text* [2].

2.1 Sterilization techniques

Four different mediums are used as the most common sterilizer techniques: steam, gamma radiation, hydrogen peroxide gas plasma, and ethylene oxide gas. Their primary use is for the sterilization of medical equipment.

Using steam as a medium is advantageous in terms of toxicity as it is not toxic to humans or the environment. Steam is also preferred regarding time and control as it is generally fast and accessible in terms of control and monitoring. It is destructive to microorganisms and their spores due to its gaseous state and high temperatures. Disadvantages of steam include damage to heat-sensitive instruments and rust if not dried properly. Even though steam is not toxic, it can still cause harm, such as burns, to people and the surroundings if the medium and the sterilized product are not appropriately cooled [3].

2.2 Sterilization process

Sterilization implies the complete eradication of microorganisms, including viruses, bacteria, and spores. For this to be achieved by steam sterilization, the microorganisms must become moistened and be heated above 115 °C. This is usually done by a process consisting of three main phases, the pretreatment phase, the sterilization phase and the post-treatment phase. Temperature and pressure data inside the chamber for a typical sterilization treatment is shown in figure 1. In the pretreatment phase, the air in the chamber is replaced by steam to ensure that all the microorganisms are damp. The sterilization phase heats the steam and goods in the chamber to the sterilizing temperature (usually 134 °C) to eradicate the microorganisms. The post-treatment, the final phase of the process, empties the chamber of steam and dries the goods.

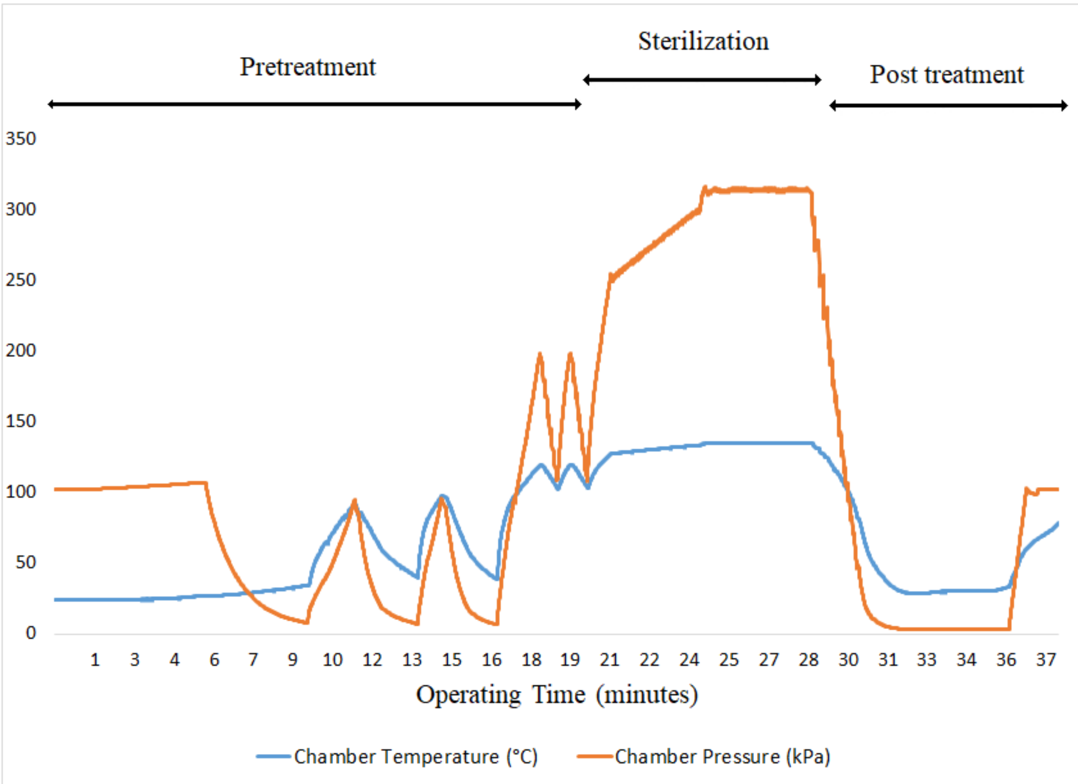


Figure 1: Typical Chamber Pressure and Temperature during the hard goods cycle on the autoclave during pretreatment, sterilization and post-treatment phases.

Steam sterilizers are configured with multiple programs called cycles that are adjusted for certain goods, such as solid goods or containers filled with liquids. Depending on the cycle, the lengths of the three main phases and the rate of pressure and temperature changes may vary. The hard goods cycle, seen in figure 1, is a cycle adjusted for sterilizing solid, non-fragile goods such as laboratory tools and empty plasticware. Hence, the hard goods cycle creates rapid changes in pressure and temperature, leading to quick steam releases to the sterilizer's cooling system.

2.3 Cooling system structure and control logic

In the current cooling system, seen in figure 2, the water flow to the heat exchangers are controlled by two binary valves, one with a smaller flow and one with a larger flow (MIN FV and MAX FV in figure 2). The system uses constant water flow through the smaller throttling by keeping the valve open during the entire operation of the sterilizer. The continuous water flow ensures that the vacuum pump stays cool to allow it to function effectively and ensure that the temperature sensor has enough water flow to measure the temperature of the cooling water at the drain.

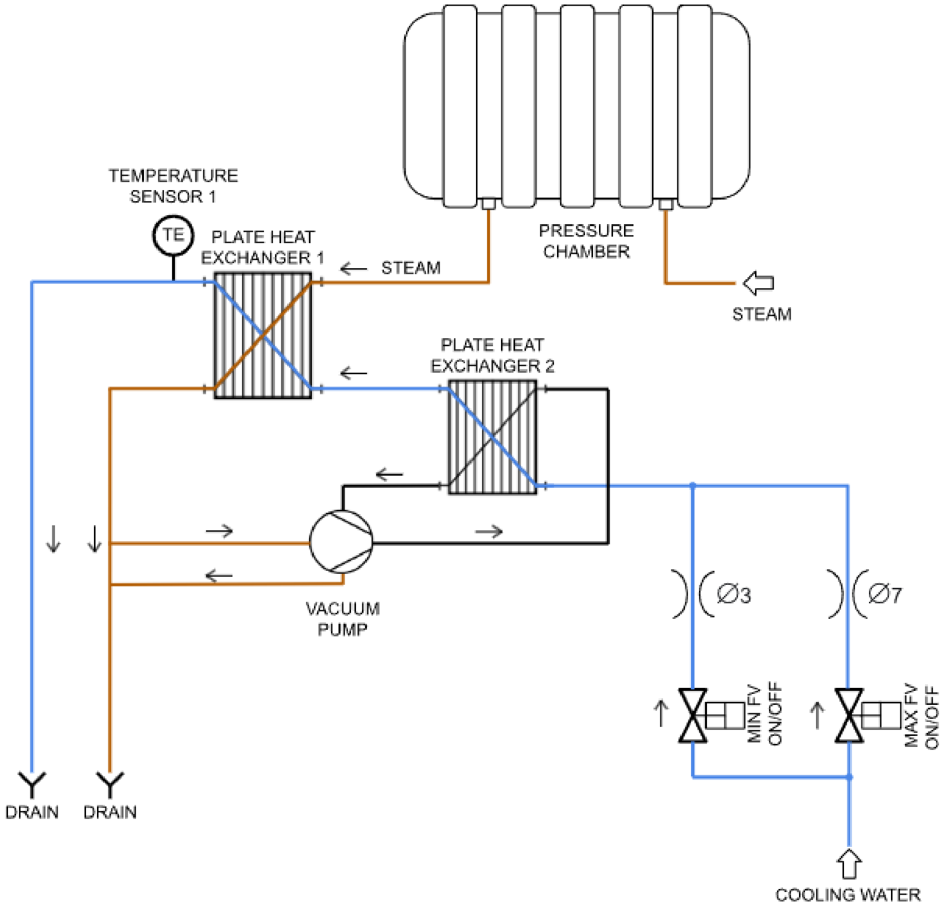


Figure 2: A simplified P&I diagram of the steam (orange-colored piping) being discharged from the pressure chamber inside the autoclave, to be cooled in the heat exchanger, using cooling water (blue-colored piping).

While the minimum throttling valve remains open, the larger throttling valve opens and closes to regulate the temperature of drained water when larger amounts of steam are released from the chamber. The logic of the valve control, described by figure 3, opens or closes the large throttling valve depending on two factors. The first factor is the temperature measured by the temperature sensor two at the drain seen in figure 2. The valve opens if the measured condensate temperature at the drain reaches 60 °C. The second factor is a flag that is set by stages in different cycles. If the flag is set, the large throttling valve opens. In the hard goods cycle, the flag is set during the negative pressure pulses seen in figure 1 caused by the vacuum pump in the pretreatment and post-treatment phases.

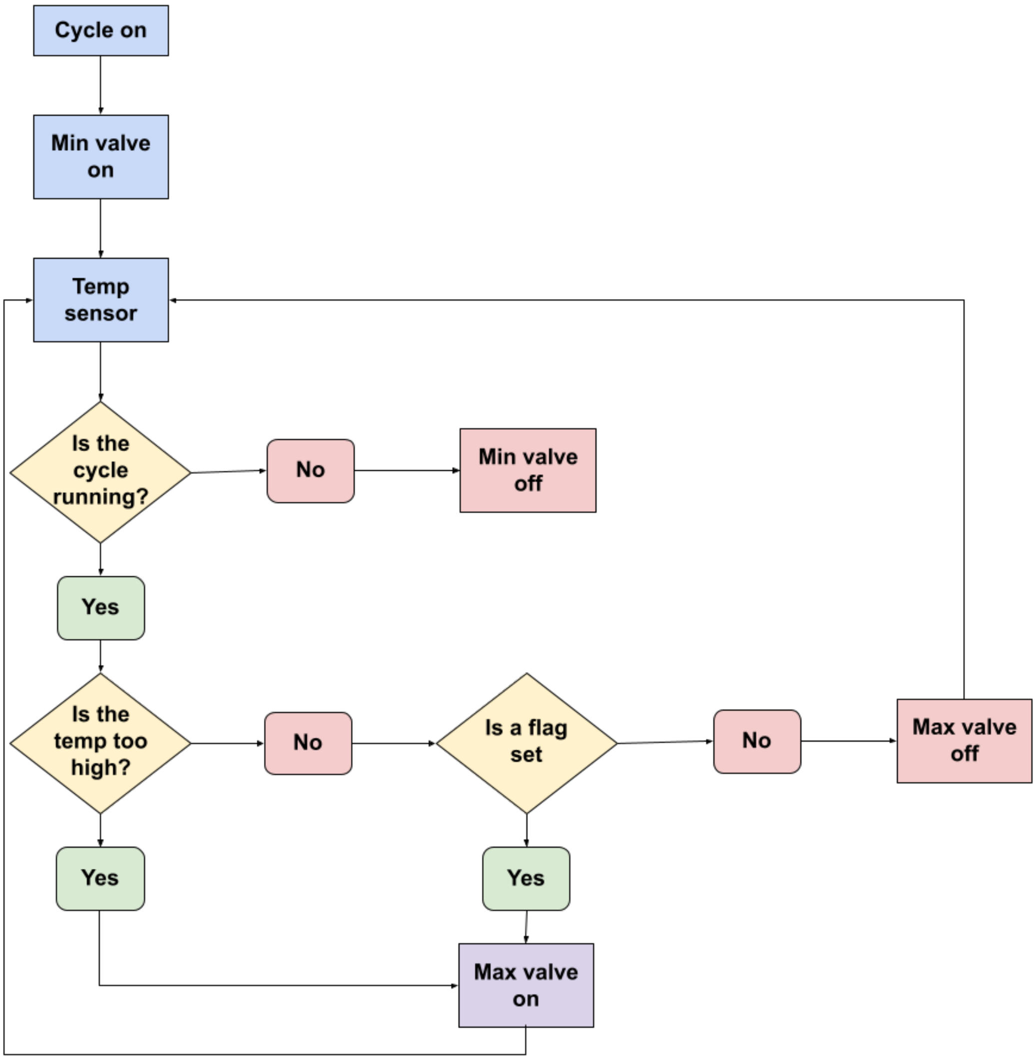


Figure 3: Flowchart of the current cooling system control logic.

2.4 Earlier measurements

The measurements done earlier by the company show cooling system water consumption of a hard goods cycle, which lasted approximately 38 minutes, to be $0.545\,\mathrm{m}^3$ with a 159kg steel tool load. From observations of the water flow at the inlet of the cooling system, it is noted that it only uses two cooling levels: The low level, where the minimum throttle valve is the only one open, and the high level, where both minimum and maximum throttle valves are simultaneously used. In this process, approximately 60% of consumed water passes through the minimum throttle valve, which is open during the entire machine operation except for the start of the cycle, as seen in figure 4.

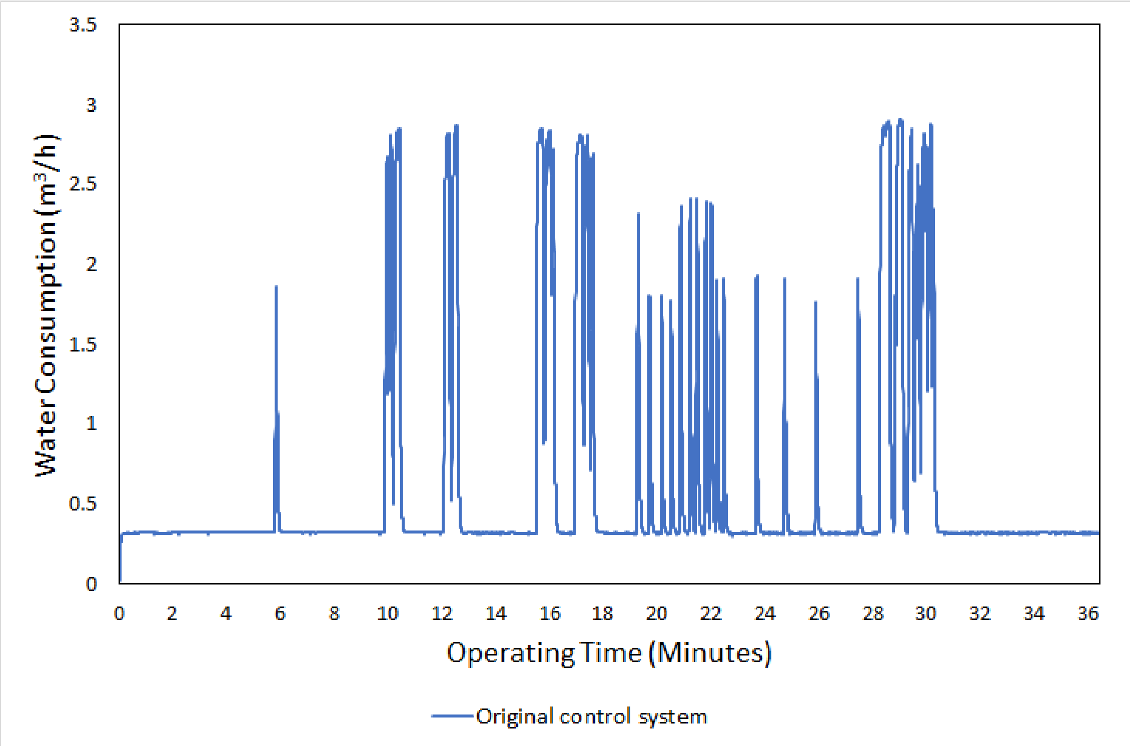


Figure 4: Water flow during hard good cycle on the autoclave, measured earlier by the company.

2.5 Valves

While the vacuum pump needs a coolant flow to operate efficiently, it does not operate during the entire sterilization process, nor does it need cooling during nonoperational periods. The cooling water drain temperature sensor requires a small water flow to measure the temperature. However, in certain parts of the autoclave sterilization process, no steam is released from the chamber, meaning a minimal flow would suffice. The current cooling system uses two digital valves to control the flow of the coolant, meaning there are only three possible flow rates that can be created:

- Minimum, when only the small valve is open.
- Medium, when only the large valve is open.
- Maximum, when both the small and large valve is open.

However, the autoclave currently uses only the minimum and maximum flow. The lowest flow rate of these three is measured to be approximately 8.5 l/min which is unnecessarily much if the vacuum pump is not operational and no steam from the chamber is released. These three flow rates can also be wasteful if the drain temperature is slightly above a certain level, and only a slightly larger water flow would be sufficient. By replacing the current two digital valves with one proportional valve, the water flow could be changed more precisely. Meaning that when water flow is only needed for measuring the temperature, it could be lowered to the minimum. The change in drain water temperature could also be met with a proportional amount of the coolant leading to less waste of coolant when switching flow rates.

2.6 Heat transfer

The cooling system of the machine incorporates two brazed plate heat exchangers, as illustrated in 2. These heat exchangers play distinct roles in the cooling process. The first heat exchanger, denoted as Plate Heat Exchanger 1, is responsible for cooling down the steam. It possesses 30 plates and a heat transfer area of 2.646m^2. The second heat exchanger, referred to as Plate Heat Exchanger 2, is used to cool the vacuum pump ring water. It features a heat transfer area of 0.919m^2 distributed over 26 plates.

3 Control Theory

3.1 Digital and PID control comparison

Silva et al. compare two temperature control methods of a cooling systems condenser [4]. The study was done on a fluid condenser cooled by fan-created airflow. They evaluated and compared the binary control of fans with the PID control of the fans. The evaluations of these two methods showed that the PID control method outperformed the digital method. The PID-regulated system consumed 26.31% less current, keeping temperatures lower and more stable. Concluding, the PID-controlled system was able to maintain the desired temperature more accurately and hence be more energy efficient.

The study by Silva et al. concludes that a PID controller offers more efficient and accurate regulation of cooling medium [4]. Even if the study is done on an air-cooled system, the basic principles of the system and the conclusions can be applied to the water-cooling system. However, for the GSS system used in this thesis, system identification was not possible to perform as not enough data could be isolated from the earlier measurements. The use of a PID controller would also require additional information on the control signal, for which the company would be required to install an additional temperature sensor and a pressure sensor for measuring the cooling water on each machine. Thus, a PID controller is not used.

3.2 Fuzzy Controller

The study aimed to design a fuzzy logic control with the Mamdani model for temperature control of a heating and cooling water system [5]. IF-THEN rules are the basis of the logic control and are used for mapping the input and output.

This study is based on a closed pipes system, which recycles the water in separate coils for hot and cold water. The two inputs for the controller are temperature and its time derivative, while the output is the streaming water ratio. A microcontroller on the servomotor then controls the valve based on the output. Abduljabar [5] differentiates between three steps, all determined by different experts, for the fuzzy logic control:

- The base rules are set
- The relation between the input and output is determined
- Fuzzification and defuzzification, where the inputs are converted to a fuzzy value and the outputs are converted to a crisp set.

By using a fuzzy control system the study results in an optimized method for the functionality of the conditioning system.

While the study by Abduljabar applies fuzzy logic control successfully, a decision not to utilize it in the project was made due to the application of a fuzzy controller and its time demanding process in terms of design, implementation, and tuning. Considering the available resources and project constraints, it was concluded that pursuing this approach would have been less time-efficient compared to the alternative proportional control method.

3.3 MINLP model

The article presents a mixed-integer nonlinear programming (MINLP) model for the optimal design of integral cooling water systems regarding economic factors. The model uses all the provided components to optimize their design by modeling them simultaneously, obtaining an optimal cooling water system. The model results in a proposed superstructure optimized regarding economic factors [8].

The MINLP model was used to optimize the cooling system in regard to economics. However, the general use of it pertains to optimization and can thus be used to optimize the water use of cooling systems. All variables and facts must be known for the model to work [8]. As mentioned above, not all variables are known as the system extends beyond just cooling the steam released from the sterilizer as it depends on multiple processes during the ‘hard goods’ cycle. Furthermore, it is computationally demanding and requires software not available for this thesis. As this solution is too complex, it is not used.

3.4 Water re-circulation

A possible solution is water re-circulation, which is described in this article. The system described in the paper comprises a network of cooling water towers and heat exchangers, their superstructure makeup. Mathematical optimization formulation focuses on the superstructure exploring all potential water reuse opportunities. The solution was to reduce the inlet flow rates of the cooling towers, which, according to the study, implies an increased heat load handled by the cooling towers [9].
Even though heat exchangers are used in both the system described in the article and the system described in this thesis, the requirements are different as their solution was to reduce the flow rates at the inlet of the cooling towers, which also implied an increased heat

load handled by the cooling towers [9]. The solution presented in the paper is not suitable as the vacuum pump used for the current system is sensitive to temperature increases. The new system explored in this thesis aims at adaptivity to ensure temperatures are regulated according to need. Thus, reusing cooling water within acceptable temperatures is an option when designing the new system. As mentioned in the introduction, there is not enough place to use a tank for reusing the cooling water. However, because the cooling water only flows in one way, through both heat exchangers, there is no need for the mathematical optimization formulation as the re-circulation could potentially be redirected through either

- heat exchanger 2, illustrated in figure 2, or
- both heat exchangers

As the cooling water system depends on temperature sensor 1 in figure 2, a flow is required for accurate readings. Thus, if water is to be reused, the ability to create a flow is essential.

3.5 Once-through cooling system

This study [10] describes six different possible cooling systems used for an oil refinery:

- once-through cooling water system,
- once-through cooling water system with a closed secondary water loop
- recirculating cooling water system with an open cooling tower
- recirculating cooling water system with an open cooling tower and a closed secondary water loop
- direct air-cooled system
- air-cooled system with a closed secondary water loop

Most of the cooling is needed for process streams in heat exchangers. The process stream fluid has a required end temperature of about 45 °C, dropping from approximately 150 °C. The calculations from this study were based on a throughput of 20000 ton/day Arabian light crude, a type of oil. The study concludes that using an air-cooled system offers the best outcome as it is regarded as the most environmentally friendly and among the least costly systems. However, comparing the energy consumption of the seven different explored systems indicates that the second most environmentally friendly system would be the once-through cooling water system with a total of 3500 kW in energy consumption, compared to the 2000 kW needed for the air-cooled system [10].

The temperature drop in the study resembles the one in this thesis, as described above in the background. The temperature of the steam is about 134 °C in the chamber, and has to be cooled below 65 °C before exiting into the drain. The starting temperature of the cooling water used in the study may differ, but the conclusion is still applicable. The calculations in this study were based on considerably higher volumes of fluid than the volumes used by the sterilizer, leading to smaller margins than those produced by this study. Part of the solution of this thesis pertains to the accessibility of the results to be used by the company in the future. Thus, an air-cooled system would be challenging to incorporate into the current system design as it requires considerably more space and additional instrumentation and is therefore not favorable and thus excluded. The second best option presented by the study is the once–through cooling water system. As a closed loop cooling water system was also studied but used 2000 kW more than the open system, a closed loop will not be a part of the thesis's solution. Therefore, the best solution in regard to the sterilizer is a once-through cooling system similar to the current one. As mentioned in the requirements, a closed loop system using a tank is not possible due to lack of space.

3.6 LMTD

Logarithmic Mean Temperature Difference (LMTD) is a vital parameter in cooling systems, and it represents the average temperature difference between hot and cold fluids in a heat exchanger. LMTD helps estimate heat transfer rates, surface area requirements, and overall efficiency. In cooling systems, LMTD determines heat exchanger effectiveness by considering temperature variations along the heat transfer surface, and it aids in the optimization of the design [11]. Regrettably, the absence of additional sensors to measure the cooling water temperature at the heat exchanger's inlet made it impossible to determine this parameter. As a consequence, the use of the Logarithmic Mean Temperature Difference (LMTD) method was precluded.

4 Method

4.1 System Considerations

After analyzing the data provided by the company, also presented in figure 4, it is determined that the majority of water that can be saved is excreted by the constant flow of the minimum valve. Turning both digital valves off when the system does not require cooling would result in the most significant amount of water-savings. However, as seen in figure 2, and previously explained, the cooling water first passes the heat exchanger of the vacuum pump. As such, the vacuum pump requires there to be at least some water passing through the pipes. This indicates that the new valve/valves still ought to have a constant flow, but possibly more restricted than the current minimum throttle can produce. A possible solution would be to add one more digital valve, with a smaller throttle than the current minimum. The smallest possible diameter that can be used for this purpose is 1.5mm. The system would increase in complexity in regard to both software and hardware as the number of combinations for a minimum, medium and maximum throttling is $2^3 - 1 = 7$. The software implementation would require longer code and more testing since the seven different levels would have to be set specifically using if-statements. Determining what valves to use would also require extensive testing with so many different combinations and should be based on a thorough analysis of the system which would require extensive resources regarding both personnel and material. Thus, this solution is regarded as unnecessarily complicated.

The current valves are placed at the inlet, restricting the water flowing in. Another possible solution is to place the valve at the outlet, which restricts the water flow out of the system, causing an accumulation of water inside the piping system. This solution ensures the constant presence of water in the system, either a flow when the valve is open or a still water build-up when the valve is closed, ensuring more energy can be transferred from the steam since water has a higher specific heat capacity than air. Though the advantage of this solution allows the valve to be closed and keep the water still, the disadvantage pertains to the temperature sensor. When there is a build-up of water in the system, the increase of temperature in the piping is not linear, instead, it is specific to the place of origin, where the temperature increase. Even though the temperature sensor is placed as close to the heat exchanger as possible, it still leaves room for uncertainty. Thus, pulsing is used. Pulsing is used as a safety measure to ensure that the correct temperature is recorded by creating a temporary flow when opening the valve for a couple of seconds and then closing it again. The ratio of seconds for opening and closing the valve is determined by testing it, as described in the results.

The choice of using the temperature of warmed up coolant as feedback to the system instead of using steam temperature was done due to two reasons. The first one is that the piping that leads condensed steam to the vacuum pump and to the drain, as seen in figure 2, consists of steel pipes. This means that the thermometer could only be placed in the center of the pipe with available components leading to a false temperature reading if the level of fluid was lower than the thermometer. The second reason for choosing the warmed-up coolant temperature as system feedback is the efficiency of the heat exchanger (Plate Heat Exchanger 1) seen in figure 2. Measured temperatures of cooling water and condensed steam temperatures in tests conducted by the company, seen in figure 5, show that the temperature of heated cooling water always surpasses the temperature of the condensed steam when larger amounts of steam are released into the cooling system.

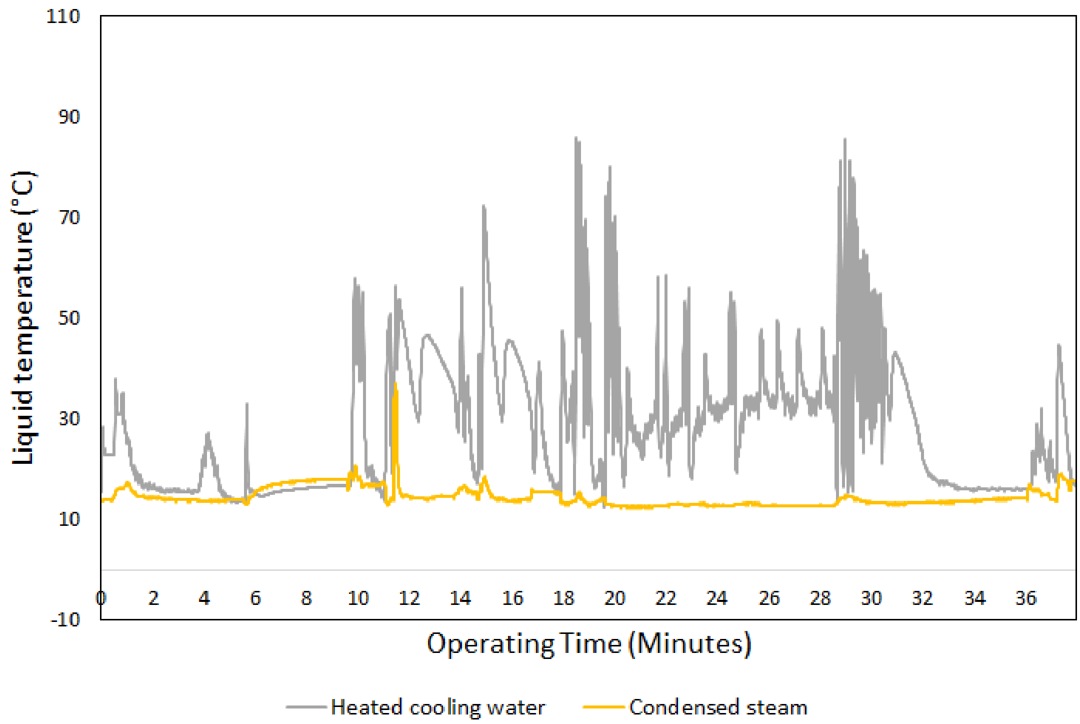


Figure 5: Temperature comparison of heated up cooling water and condensed steam from measurements conducted by the company.

4.2 Mathematical Controller Function

The aim is to develop a function with a linear relationship. A linear relationship is desired due to the possibility of optimizing the function using an exponent. The exponent will be used to control the speed of the equation, i.e. the speed of the cooling water flow, which is used to cool the condensate. As the system is sensitive when the temperature rises above a particular temperature, Tc, this will be the point at which the coefficient, k, will be equal to 1, i.e., 100%. The system does not require cooling until it reaches a certain temperature, Tok. Therefore, the equation does not need to produce a positive value below Tok, as the valve should be closed. Thus, a linear function, equation 1, is sought with the perimeters defined in equations 2 and 3.

$$k = m \cdot T + c \tag{1}$$

$$k(T_{ok}) = 0 \tag{2}$$

$$k(T_c) = 1 \tag{3}$$

The boundaries are then used and substituted as variables in the equations 1 through 7 below.

$$k(T_{ok}) = m \cdot T_{ok} + c \tag{4}$$

$$0 = m \cdot T_{ok} + c \tag{5}$$

$$k(T_c) = m \cdot T_c + c \tag{6}$$

$$1 = m \cdot T_c + c \tag{7}$$

Equation 5 is subtracted by 7 to eliminate 'c', the y-intercept, to find the gradient m, derived in equations 8 through 10.

$$0 - 1 = m \cdot T_{ok} + c - (m \cdot T_c + c) \tag{8}$$

$$-1 = m(T_{ok} - T_c) \tag{9}$$

$$m = \frac{1}{T_c - T_{ok}} \tag{10}$$

The gradient from equation 10 is then used to derive the y-intercept, as seen below in equation 11 through 13, resulting in equation 14.

$$0 = m \cdot T_{ok} + c \tag{11}$$

$$0 = \frac{1}{T_c - T_{ok}} \cdot T_{ok} + c \tag{12}$$

$$0 = \frac{T_{ok}}{T_c - T_{ok}} + c \tag{13}$$

$$c = -\frac{T_{ok}}{T_c - T_{ok}} \tag{14}$$

A k-value can now be calculated using the equation of a straight line, equation 1, and substituting the derived gradient and y-intercept from equation 10 and 14 above.

$$k = m \cdot T + c \tag{15}$$

$$k = \frac{1}{T_c - T_{ok}} \cdot T - \frac{T_{ok}}{T_c - T_{ok}} \tag{16}$$

$$k = \frac{T}{T_c - T_{ok}} - \frac{T_{ok}}{T_c - T_{ok}} \tag{17}$$

$$k = \frac{T - T_{ok}}{T_c - T_{ok}} \tag{18}$$

Equation 18 can be rewritten as equation 19.

$$k = 1 - \frac{T_c - T}{T_c - T_{ok}} \tag{19}$$

The advantage of the latter pertains to the exponent 'n'. An exponent will result in a faster-acting linear equation for equation 20, moving the point at which the equation results in a fully opened valve.

$$k = (\frac{T - T_{ok}}{T_c - T_{ok}})^n \tag{20}$$

$$k = 1 - (\frac{T_c - T}{T_c - T_{ok}})^n \tag{21}$$

This means that equation 3 will be false, as seen in figure 6.

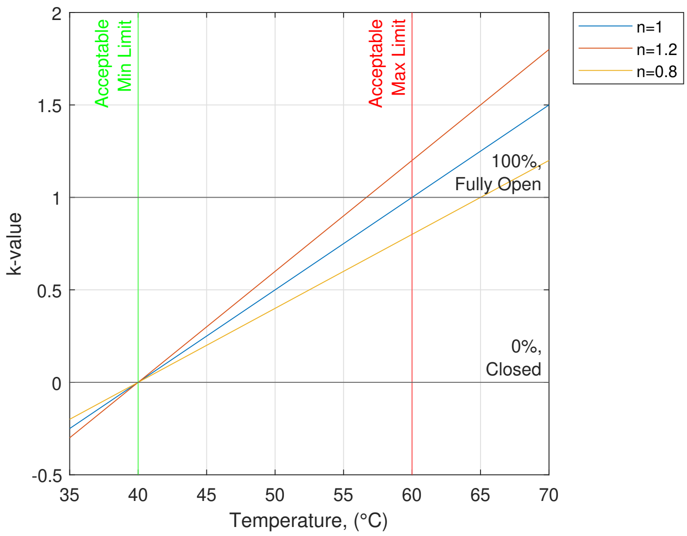


Figure 6: A graph displaying the behavior of equation 20 for different n-values. All three n-values generate a straight line while differing in regards to the y-intercept for when the valve is supposed to be fully opened.

Equation 3 being false negates the purpose of the exponent and equation as mathematical control function. If the exponent in equation 21 is used instead, the perimeter will still be true but result in exponential equations for which the speed can be controlled, as seen in figure 7.

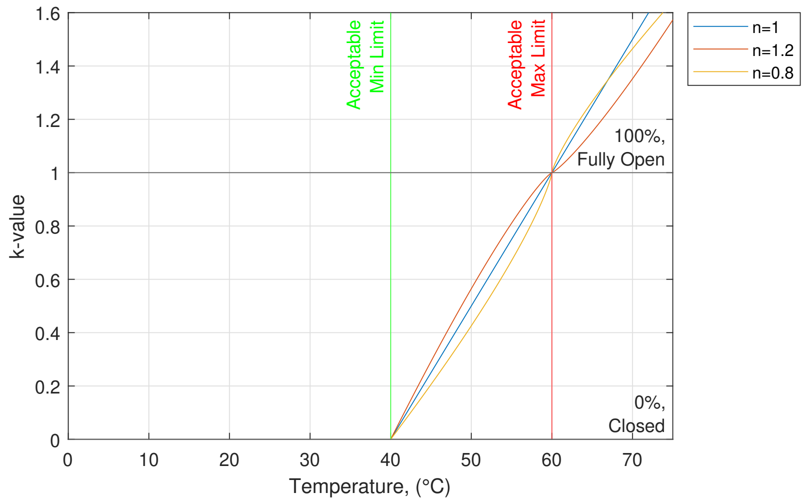


Figure 7: A graph displaying the behavior of the equation for different n-values. The k-value starts to increase after the temperature reaches 40°C. The starting point and end-point, i.e., interceptions, are the same, independent of the exponent. The minimum and maximum temperature limits are included for reference, along with the k-value, ranging from 0 to 1.

The result of equation 21 is k, which is a decimal value, from 0 to 1, that is later converted to a percentage, from 0% to 100%. Two of the variables, Tok and Tc, are predefined as they are the temperature limits of the system. The third variable, T, is the measured temperature of the cooling water after it has gone through both heat exchangers.

4.3 Hardware

4.3.1 Valve

The proportional valve used to regulate the flow of the coolant is GEMÜ 554 (554/25/D-9-9-5-1-1 A575) 2/2-way angle seat globe control valve with nominal size DN25 and flow factor (Kv) of $15\mathrm{m}^3\,\mathrm{h}^{-1}$. The valve is equipped with a GEMÜ RS004 linear regulating cone, creating a linear proportion between the percentage of valve stroke and the percentage of the flow factor [6]. The valve regulation is conducted by GEMÜ 1434 µPos (1434-000-Z-1-A-14-1-00-01-030) electro-pneumatic positioner. The control input to the positioner, consisting of a current in the range of $4\,\mathrm{mA}$ to $20\,\mathrm{mA}$ corresponds to a linearly proportional stroke percentage of the valve, which the positioner controls with air pressure by a direct pneumatic connection between the two components [7].The valve was originally delivered with a non-linear regulating cone, but due to the lack of markings on the cone, it was not possible to determine its model and, thus, how it behaves. The cone behavior could have been tested by measuring the water flow during machine operation and comparing it to the stroke of the valve. However, the testing of the cone would shorten already limited testing time, and a linear cone was ordered instead to ensure total control of the valve. With a linear cone, a linear equation can then be used and keep the linear characteristics of the system. It can also be controlled by an exponential function. In this case, a non-linear cone would interfere with the optimization of the value since two non-linear factors increase the complexity of the system. The range of analog valves is limited during the opening of the valve. The flow is not linear at the beginning of opening the valve. Instead, a jump from 0% to an unknown percentage is recorded. The unknown percentage, the minimum level at which the proportional valve could open, is determined by testing it with different percentages manually set on the display on the autoclave.

4.3.2 Sensors

The measurement of water consumption of the cooling system in the autoclave is done by a Bürkert Type 8081 QN 6.0 , see Appendix A, ultrasonic flowmeter. The flowmeter uses the transit time method to determine the fluid flow speed and can measure in the range of $0.036\,\mathrm{m}^3\,\mathrm{h}^{-1}$ to $12\,\mathrm{m}^3\,\mathrm{h}^{-1}$ with a maximal measurement deviation of ±4% at the lowest flow rate and minimal measurement deviation of $\pm 2\%$ at the highest flow rate. The company provided two Pentronic Pt100 (5306050-002) platinum resistance thermometers for measuring the temperature in the cooling system. One of the thermometers measures the cooling water temperature (Temperature Sensor 1) after the heat exchanger that cools down the steam, and the second thermometer measures the temperature of the condensed steam at the drain (Temperature Sensor 2), as seen in figure 2. The measuring range of the thermometers is $0\,°C$ to $140\,°C$ with a response time T90 < 5s, as seen in Appendix B.

4.4 PLC programming using B&R

This particular autoclave is controlled with software from B&R, which is programmed using a PLC with structured text, *IEC 61131-3 Structured Text*. It is based on a template created by the company. The template has essential functions enabling the machine to run all required cycles. The PLC is imported into the machine when the code is completed. Adjustments to the code are made either directly while connected to the machine or by making corrections while using *Automation Studio*. *Automation studio* is a software that simulates the code using a virtual machine, *VMware Workstation Pro* [12].

4.5 System evaluation

The evaluation of the systems will be conducted by running the hard goods machine cycle on both the existing and the new cooling systems. In this process, the PLC is going to log and store the data emitted by the sensors each 100ms. Subsequently, the obtained data will be analyzed using Microsoft Excel to asses the performance and the effectiveness of the cooling system variations. In addition to the data collection and comparison process, an analysis of the acquired dataset will be conducted to identify any correlations or trends within the measured parameters.

5 Results

5.1 System Considerations

As mentioned above, it is determined that the most amount of water can be saved from the constant flow through the minimum throttling. Because the system, including pipes and heat exchanger, had to have at least small amounts of water, the two valves at the inlet could not be closed for period of time. One possible solution, previously described in the method, required three digital valves which result in seven different flow combinations. This solution is considered unnecessarily complex as extensive testing and simulations would be required to determine possible throttling diameters, even though seven different flows would probably suffice and save water. Instead the other solution of placing the valve at the outlet is used.

Valves at the outlet let water out of the system, instead of in. This will keep the system pressurized as nothing but the output valve constricts the flow into the system. By choosing an analog valve, it can be controlled by the k-value derived from equation 21, derived in the method. The pressure within the system that is caused by the closed analog valve, deters any flow. To obtain accurate temperature data from the temperature sensor, pulsing is used. The pulsing will be explained later in the method.

5.2 Hardware implementation

In order to enable other personnel to conduct other tests on the autoclave and to reduce the assembly and disassembly time of the parts, it was agreed with the company not to remove the digital valves from the autoclave. The digital valves, placed at the start of the cooling system, were instead to be kept open during the testing by the software. However, due to the performance limitations of the proportional valve, the digital valves were used in the system to reduce water flow further. The position of the proportional valve and the sensors was not affected by the digital valves, as seen in figure 8.

Personnel from the company's electrical department updated the sterilizer's electrical diagram, which is a graphical representation of the sterilizer's electrical circuits. The new diagram, containing the proportional valve, flowmeter, and cable connections for the two components, was used in the project to connect the valve to the correct electrical outlets and the PLC analog input and output cards. The thermometer was connected to the input of the PLC using instructions from the electric diagram on the existing thermometers in the machine.

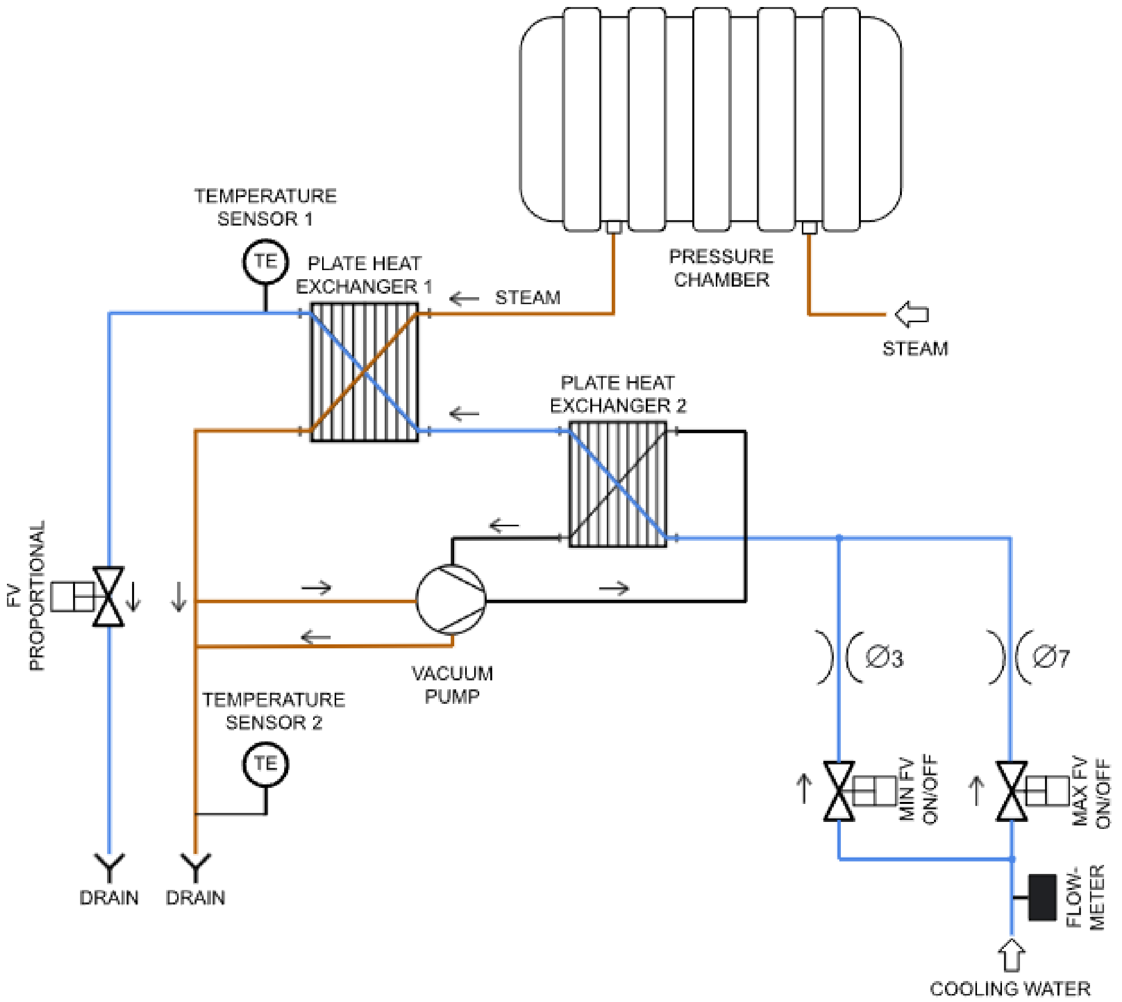


Figure 8: A simplified P&I diagram of the cooling system containing both digital valves and the added proportional valve, temperature sensor and flowmeter.

In order to change the equal percentage cone to the linear regulating cone, the valve had to be pressurized by applying the pressured air to the inlet of the valve in order to release tension from the spring that keeps the valve closed during non-operational periods. After dismantling and exchanging the cone, the valve was assembled and connected to the piping between the heat exchanger and the drain using glands seals.

5.2.1 Component performance tests

Before the start of the measurements a set of tests was conducted in order to confirm that the flowmeter and the proportional valve work as intended. The test of the accuracy of the flowmeter was done by manually opening the valves and measuring the needed time to fill a $0.1 m^3$ container. The result of the test was a 3% difference between the value provided by the flowmeter and the manually measured one, but it was assessed as acceptable since the manufacturer of the flowmeter provides the maximal measurement deviation of ±4% in the datasheet of the product. The function of the proportional valve was tested by gradually opening the valve using the machine's inbuilt control panel while monitoring the water flow. Testing of the proportional valve led to the conclusion that the cooling water starts flowing through the valve when the valve is set to at least 22% open. However, the water flow at the minimal opening point of the valve varied depending if the valve was raised or lowered to that position. If the valve position was raised 10% to 22%, water flow was measured to be approximately $0.5\,\mathrm{m^3\,h^{-1}}$. If the valve position was lowered, for example, from 30% to 22%, the measured flow was $1.125\,\mathrm{m^3\,h^{-1}}$. However, the maximum flow of the water through the system, which was limited by the throttling on the digital valves, was not affected by the closing or opening and was approximately $2.4\,\mathrm{m^3\,h^{-1}}$ when the proportional valve was 30% open.

5.3 Measurements of water consumption

The measurements of the cooling system were conducted on the hard goods machine cycles without a load, i.e., with an empty chamber. The readings of the selected variables were logged by the PLC in intervals of $100\,\mathrm{ms}$ during the entire machine operation, which lasts approximately $35\,\mathrm{min}$ for each cycle. During the cycles, the pressure of the cooling water was $(3.7 \pm 0.4)\,\mathrm{bar}$. Two hard goods test cycles were run on the original cooling system to have up-to-date system behavior information for comparison with the new system. During these two cycles, the proportional valve was pressurized by an external air supply to be kept fully open and not interfere with the measurements. Six testing cycles with different characteristics were conducted for the new cooling system, and due to the time limitation, these cycles could not be repeated. During the tests, the temperature of the vacuum pump had to be regularly checked to ensure that the pump does not get overheated and create a risk for steam building. The temperature control was done manually by hand since welded piping connected to the pump prevents the emplacement of a thermometer. However, in the first of the six tests, the system's cooling was insufficient to keep the vacuum pump cool enough to lower the chamber pressure to the required valve, and the test had to be aborted.

Different ratios for the pulsing were tested. The pulsing is a safety measure to ensure that the correct temperature is recorded. As no flow will occur while the valve is closed, thus pressurizing the system, the accumulation of temperature of the cooling water within the pipes will be specific to the point where the heat of the condensate is absorbed. As this point can change it is not determined. The place or the temperature sensor is fixed, unless manually changed. Therefore a flow is required for an accurate reading. The potential flow has to be balanced by the water use. The first ratio was 10s on and 10s off. This is determined to be too wasteful, as the correct temperature can be recorded in a shorter interval than 10s. The next test had a ratio of 9s off and 1s on. This does not result in any pulsing since the time to open the valve is insufficient. Instead, 2s open was tested, resulting in a similar conclusion. The time is insufficient to open and close the valve but results in a limited flow, which is not enough for a correct temperature sensor reading. The final ratio is 9s closed and 3s open which is illustrated in figure 9. The period for which the valve is closed is considered sufficient in terms of required accuracy.

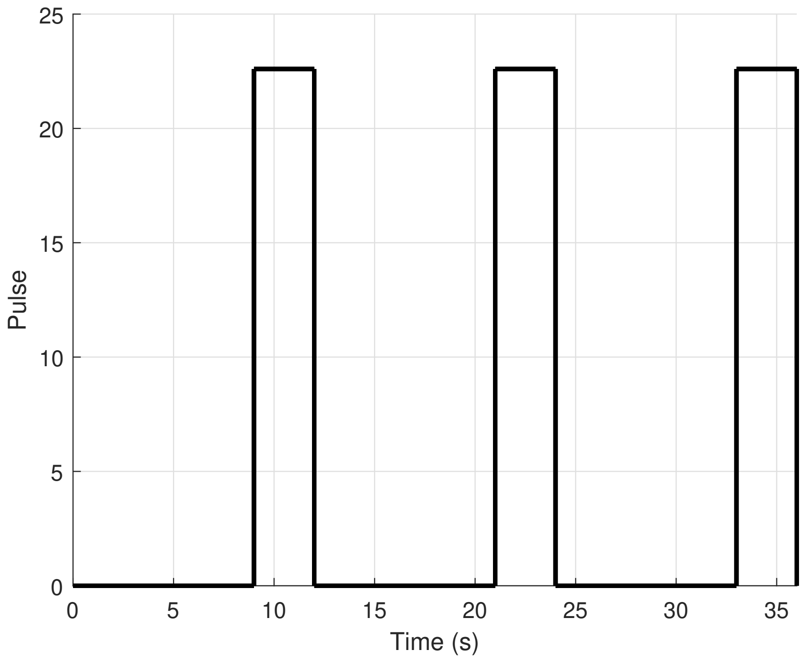


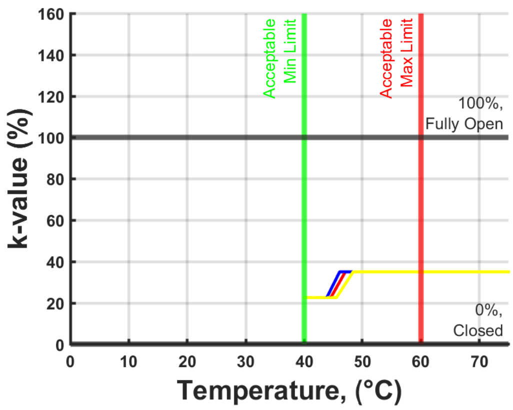
Figure 9: Illustrating 36 seconds of pulsing.

The minimum level at which the valve consistently opens is determined to be 22%. The differed depending on if it was set starting at a higher percentage or lower. Ex, if the starting percentage is 65 and then followed by 21%, it might open, but if the valve is closed, i.e., at 0%, and then adjusted to 21%, it will not necessarily open. Therefore, 22% was chosen as a minimum level. This percentage was then adjusted to 22.6% after the program was stuck at 22% without opening the valve. During this time, the program was stuck in a loop where pulsing could not occur since the valve was controlled by the k-value. The closed valve resulted in incorrect temperature measurements because there was no flow, and the spot-specific heating of the cooling water occurred at a distance that could not reach the sensor. The time it took for the cooling water the heat up was insufficient. The k-value was derived from the analog's minimum level as it was actually lower than 22% but higher than 0%. This further delayed response to the system as it would take too long for the system to heat up enough for the percentage to change to a higher value. Therefore, the cycle was aborted, and the new minimum value was chosen.

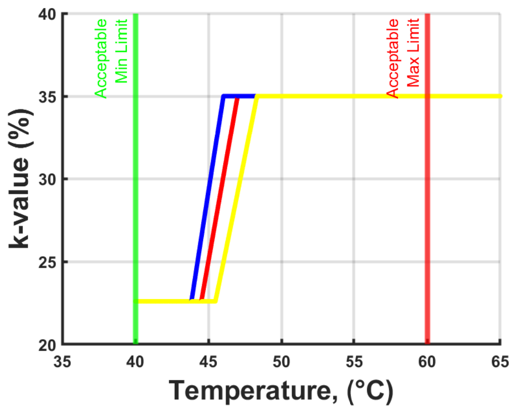
Further, the temperature at which the previous system automatically used the maximum flow is increased as the system can tolerate higher temperatures. The original value was 50°C, while the new temperature is 60°C. To compensate for the change and safely regulate the system, the temperature boundaries by which the k-value is calculated are determined to be 40 and 60°C.

5.3.1 Mathematical Controller Function Implementation

In theory, equation 21 can be used to control the valve from 0% to 100%. However, hardware restrictions are imposed on the analog valve as mentioned above. The range of use is from 22.6% instead of 0%. There is also no need to open the valve 100% as the current systems maximum flow is achieved at a 30% opening of the valve. As a security measure, the valve will be restricted at 35% instead of 30%. These restrictions will be implemented on equation 21 using software, and will result in the behaviour illustrated in figure 10a and 10b.



(a) An overall view of the implemented equation.



(b) A closer view of the temperature range at which the implemented equation 21 acts.

Figure 10: The behaviour of the implemented mathematical controller function from equation 21. The blue line represent n=1.2, red for n=1 while the yellow depicts n=0.8.

The exponents were chosen to deviate 20% from the linear equation of n=1, i.e., n=0.8 and n=1.2. As the machine is complex and parts can overheat if not cooled properly, further deviations from the linear equation, equation 21, were excluded. In theory, the lowest water consumption is expected from n=0.8 as that is the slowest function with the widest range of temperatures, given that the system can handle hgiher overall temperatures.

5.4 PLC programming implementation using B&R

The previous code was written to control two digital valves. These valves are open by default in the new code. The valves are kept for two reasons:

- For practical purposes, dismantling the digital valves is time-consuming and impractical as the machine is used for testing and will require these valves after the tests associated with this project have been completed.
- For flow control, the lowest flow of the analog valve is higher than optimal. The flow can be restricted by closing the bigger digital valve, thus, saving water when a bigger flow is unnecessary.

The code is constructed using three scenarios with the following priority:

1. Flags
2. Regulation
3. Pulsing

When a high condensate flow is expected and requires maximal cooling, flags are specified for different phases and conditions during the cycle. The flags used were already specified in the code.

Control is achieved by applying the k-value calculated from equation 21. However, as mentioned above, the maximum flow of the digital valve is measured to be 30% of the maximum flow of the analog valve. As such, 35% is used to scale down the k-value derived from equation 21. Thus, the scaling is implemented because of the bigger size of the analog valve, compared to the digital valves.

It is implemented when the temperature needs to be adjusted, but the flags which require a maximum flow are not set. Any k-value above 0 and below 22.6 is automatically changed to 22.6% since that is the minimum for the valve. If neither of the conditions above are met, i.e., when the system does not need cooling, pulsing is required to measure the temperature of the cooling water accurately. During this period, the valve will be closed for 9 s and then open for 3 s. The valve opens after nine seconds instead of pulsing as soon as the third scenario is reached. This distinction is made to save water by not pulsing immediately after the system reaches an acceptable temperature since the recorded temperature will be accurate, considering the valve has just been closed.

The logic is described in figure 11. The system runs in a loop. The temperature sensor placed by the output on the heat exchanger to measure the cooling water regulates the system. It is continuously updated while the autoclave is on. The k-value is then calculated based on that temperature. The digital valves will be turned on by default to allow maximum flow if needed. The three scenarios are then defined using if-statements.

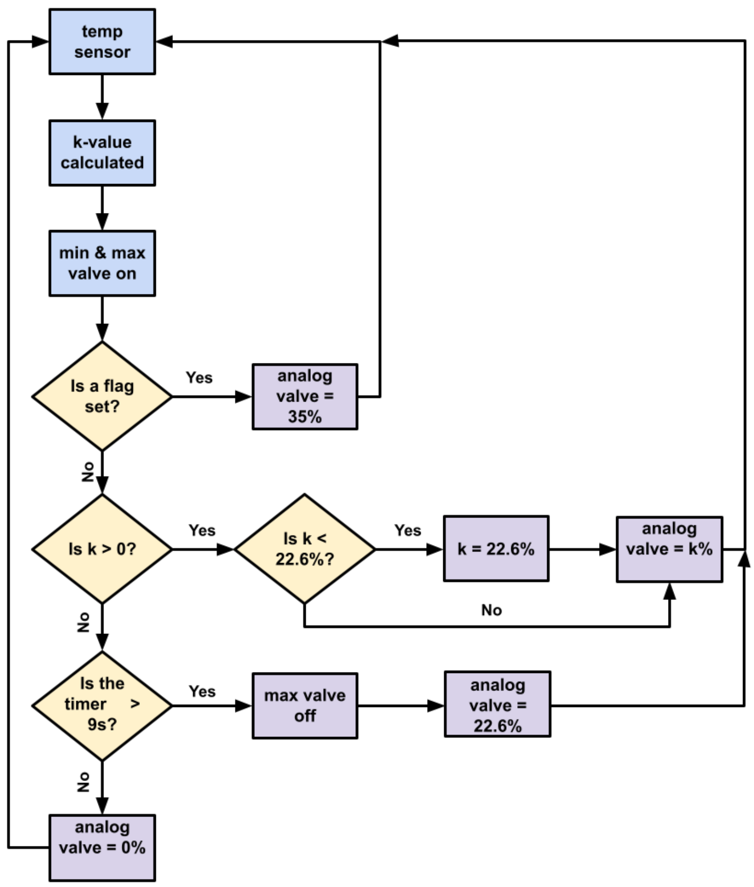


Figure 11: Flowchart of the new cooling system control logic. The temperature is updated in every loop, to calculate a new k-value. The k-value and the flags that were defined by the company are the basis for the decisions and actions within the if-statements represented in the flowchart.

5.5 System performance and water consumption

The measured water consumption of the company's cooling system during the 'hard goods' cycle on the autoclave showed that the total amount of water used by the cooling system during the cycle was $0.366\,m^3$. During this cycle, the temperature of the condenser, or the cooling water, reached a maximum temperature of 106.6 °C. The measurements done on the new cooling system showed a reduction in water consumption by $53 \pm 1\%$ with a slight rise in the maximum temperature of the cooling water. The measurements showed that control logic that used the equation with exponent n=0.8 consumed the least amount of water, $0.1717\,m^3$, but also lasted the shortest amount of time. During this cycle, coolant reached 106.7 °C, 0.1 °C higher than the company's cooling system, as seen in table 1.

Table 1: Comparison of tested performance of control systems in which lower maximal cooling water temperature is preferred.

Test system:	Original	n=1	n=0.8	n=1.2
Cycle time:	36 min	32 min	31 min	35 min
Total water consumption:	$0.366m^3$	$0.172m^3$	$0.1717m^3$	$0.1741m^3$
Maximal condensate temperature (TE2):	19°C	20.2°C	21°C	19.3°C
Average condensate temperature (TE2):	14.6°C	15.7°C	16.1°C	15°C
Maximal cooling water temperature (TE1):	106.6°C	107.7°C	106.7°C	108°C
Average cooling water temperature (TE1):	24.9°C	31.5°C	30°C	33°C

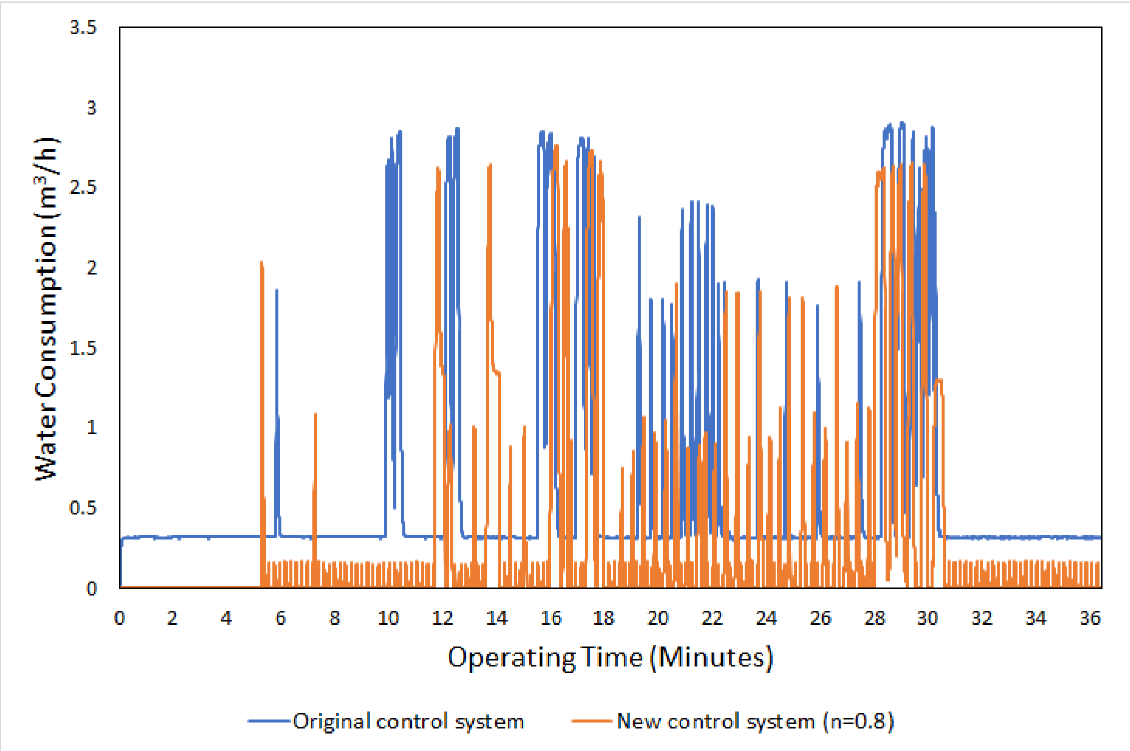


Figure 12: Waterflow comparison between company's cooling system and the new cooling system with n=0.8 equation.

While the new cooling system with exponent n=8 uses 0.1943 m^3 less cooling water than the company's cooling system during the measured hard goods cycle, seen in figure 12, the length of these two cycles are not equivalent. The difference in the length of the cycles can also be seen in figure 13 in a comparison of the new cooling system with control logic using equations with exponents n=1 and n=1.2. The system with exponent n=1 used 0.172m^3 water and reached a maximum temperature of 107.7°C during the cycle that lasted 32 minutes. The cycle of the system with exponent n=1.2 lasted 35 minutes and used 0.1741m^3 water while reaching the maximum temperature of 108°C.

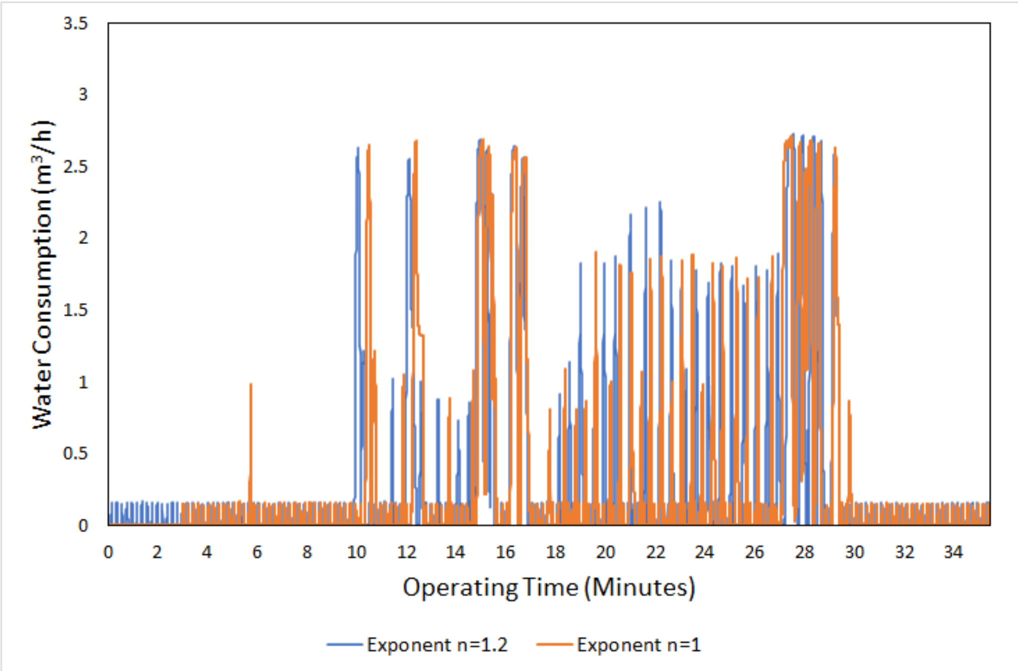


Figure 13: Waterflow comparison of systems with exponents n=0.8 and n=1.2 in control logic equation.

The cycle length difference depends on the varying heat-up time of the autoclave. The heat-up time is affected by the temperature of the autoclave, which depends on how long time has passed since the machine was operating. However, the heat-up phase of the machine does not emit any steam into the cooling system meaning that the water consumption during the time difference between uneven heat-up phases is linearly proportional to the time. The measured average consumption of a pulse, $0.0001m^3$, means that the machine consumes approximately $0.0005m^3$ per minute while pulsing which is $0.0046m^3$ less than the constant minimum flow on the original system. Normalizing the lengths of heat-up phases and, thus, the lengths of the cycles led to a change in water consumption of the systems. As seen in 2 the system with exponent n=1 consumes $0.1736m^3$, which is $0.0001m^3$ less than system with exponent n=0.8 and $0.0009m^3$ less than system with exponent n=1.2 when equally long.

Table 2: Comparison of performance of control systems with normalized and equal length cycles.

Test system:	Original	n=1	n=0.8	n=1.2
Cycle time:	36 min	32 min	31 min	35 min
Cycle time difference:	N/A	4 min	5 min	1 min
Normalized water consumption:	$0.366m^3$	$0.1736m^3$	$0.1737m^3$	$0.1745m^3$

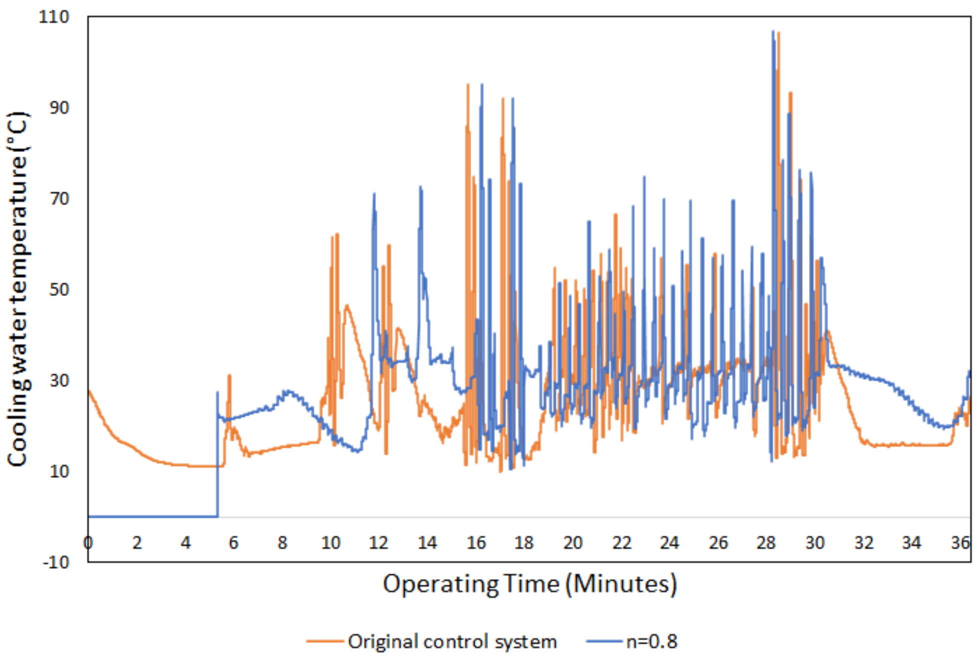


Figure 14: Comparison of the cooling water temperatures, measured by the temperature sensor, in the original system and system with exponent n=0.8 in control logic equation.

The temperature of cooling water during the cycle was generally higher in the new cooling system. As seen in figure 14, the temperature of the system that uses the equation with exponent n=0.8 reaches temperatures over 70°C approximately twice as often as the company's system. However, due to the distance between the thermometer and the drain, at which the cooling water exits, the temperature is significantly lower. During the testing of n=0.8 system, a thermometer connected to a multimeter was placed at the drain, and the temperature measured by it reached a maximum temperature of 80 °C, which can be compared to the maximum temperature of 106.7°C measured by the temperature sensor.

6 Discussion

The overall outcomes of the project are highly satisfactory. Notably, all three solutions substantially reduced cooling water consumption, with an average saving of approximately 0.19m^3 per cycle or 50%, which is noticeably higher than the set goal of 20%. The exponent value of n=0.8 was expected to perform the best, which it did. However, the three different solutions with different exponents had minor and nearly insignificant differences in results leading to difficult performance comparison between these solutions.

Because the tests were performed without a load, i.e., with an empty chamber, this is considered a weakness. There are only a few situations in which the chamber would be empty in reality. The water consumption is higher when the program is run with a load, therefore further tests should be performed measuring water consumption using different loads to establish a more reliable result. In theory, the saving should increase even further with a load partly because of the allowed temperature increase from 50°C to 60°C, since larger amounts of condensate are expected and thus, higher temperatures. The higher temperatures will be combated using the equation rather than automatically using the maximum flow. As it was only tested on the hard goods program, the generalizability of the results can only be speculated upon, even though the solution resulted in a 53% reduction, and can therefore be considered a great success. However, the new system is easily applicable to other programs as well.

Further testing is required to improve this system and also gather data for customers if the implementation of this new system is considered. This process is very time consuming and wasteful. A simulator would therefore prove valuable to test different hypotheses before implementing them. It was not implemented during this thesis because of the time constraints, but could potentially be created using *Automation Studio*.

Limitations pertaining to the reliability of the result are worth mentioning, as only one cycle was run for each exponent. The result might therefore vary. It is also important to note that the machine needs to warm up before the program can start. This standby time will also impact water consumption, as seen in the results. The effect of the standby time can not be properly documented due to the limited testing.

With further improvements, the system could be tested without the limitation imposed by the digital valve throttlings. A higher volume of water could be efficiently released throughout the system, effectively encountering the releases of large steam quantities.

This, in turn, would contribute to the reduction of peaks in system temperatures, resulting in more even and controlled temperatures. The equation might thus be utilized to a larger extent if the flow could be increased, as certain flags could be replaced for the system to be more dependent on the cooling water temperature calculated using the equation.

An alternative approach could also be tested by reducing the cooling water consumption by reducing the heat exchanger's size and efficiency, which would result in a more balanced energy distribution from the steam to the cooling water. This would promote equal temperatures between the two fluids, reducing the requirement for coolant. The downsized heat exchanger can be integrated with either the company's existing system or the system developed within the scope of this project.

6.1 Valve

Despite the outcome of achieved water savings with the provided proportional valve, it is noteworthy that utilizing a smaller valve would present a more optimal solution. Utilizing a smaller valve would likely offer enhanced precision in control, cost-effectiveness, and minimized utilization of raw materials used in manufacturing. Using a smaller nominal diameter valve could also eliminate the need for pulsing in the control system. A lower constant flow of $0.024\,\mathrm{m^3\,h^{-1}}$ could be released through the valve, reducing both energy consumption and wear on the valve. Releasing a steady flow of the cooling water instead of pulsing would improve efficiency by reducing the air consumption of the pneumatic valve and therefore reduce the compressor's energy consumption. It would likely increase system longevity and reduce the amount of maintenance due to the less wear of the valve caused by less movement. However, this is debatable as a constant flow could still be more wasteful than pulsing, even if the flow is minimized. The placement of the proportional valve at the outlet of the system also presents certain drawbacks. Firstly, if a leak occurs, it leads to persistent system leakage. Secondly, maintenance and replacement of components become more challenging due to pressurized water in the system. However, these concerns can be addressed by incorporating a manual shut-off valve at the inlet of the cooling water.

6.2 Mathematical Controller Function

The equation can be further optimized. The current result indicates a significant improvement in the new system compared to the original one. However, the effect of the exponent, n, used in the equation is debatable as the difference between the best, n=1, and the worst, n=1.2, is 0.21 L. Further testing, and repeated testing, would provide more insight into the significance of the exponent, as well as optimize it.

6.3 Pulsing Ratio

The current pulsing ratio, 9-3, is the product of testing the minimum time needed for a significant amount of water to pass through the system for a correct reading of the temperature. The minimum amount of time needed for the valve to open and close, and release enough water is 3s. With a differently sized valve, this might vary and has to be tested. Though, the period during which the valve is closed can be considered as universal but has to be decided considering the maximum time for which the system can be exposed to alarming temperatures.

6.4 Environmental impact

The environmental factor creates the basis for this project. A new, more robust system significantly decreases the environmental impact. The new system's potential is consequential, not only to the company but also to its customers. A 53% reduction in water consumption is significant as the company performs daily tests of its machines. Getinge Sterilization AB has a worldwide customer basis. A considerable part of the world has a water shortage. The reduction can improve the quality of life for a lot of people as water is vital for survival. It is even more significant as drinking sanitary water is used as cooling water.

The machine has a guarantee of 20000 cycles during it's life-cycle. If it is run with an empty chamber it would equal 7320 m^3. With a 53% savings rate, there would be a 38 796 m^3 reduction in cooling water. The company estimates a full load to equal 13 200 m^3 during its life-cycle, which would comparably save 6996 m^3 with the same savings rate. That equals 2.8 Olympic swimming pools, or a lifetime supply of water for two average Swedes who use 140 L of water a day [13]. The same saving would provide 14 average African families a lifelong supply of sanitary water as they consume about 18.9 L a day [14]. It is a fair comparison as the company has customers all over the world.

The heated cooling water or steam could be utilized to heat the building during colder months, instead of discharging it, which would decrease the environmental impact of the company even further as multiple machines are tested every day.

6.5 Comparison of other results

The university study conducted by Delphine Faugeroux can be compared to the results in this thesis. As seen in table 3, the autoclave used by the university consumes marginally less water even though the machine has a smaller chamber and shorter cycle [15]. However, there is no specification of what the water in the study is used for, it could cover more than the cooling system. The data in this thesis refers to the cooling system only, not measuring the amount of steam used in the chamber.

Table 3: Comparison of two autoclaves, one used by the University of California, the other the machine used in this thesis [15].

Machine:	University of California	GSS-91413
Chamber capacity:	$0.500\,m^3$	$1.762\,m^3$
System:	No single pass cooling water	Once-through system
Cycle length:	15-20min	31 min
Water consumption/cycle:	$0.1703\,m^3$	$0.1717\,m^3$

The access to information in regard to specific amounts of cooling water is very limited. Therefore, only this study can be used for comparison. A larger chamber uses more steam than a smaller one, therefore more cooling water is needed to cool the larger amount of steam released by the larger chamber. Assuming the data provided by the University of California exclusively includes the cooling water system, our results could be considered superior as the chamber size is significantly larger on the machine used in this thesis, even though the overall use is $0.0014\,m^3$ higher in this thesis.

6.6 Conclusion

The goal of this project was to reduce water consumption by 20%. As the new system consumes 53% less water, not only has the goal been achieved, but the new system has excelled and shows great promise if implemented in new machines. In terms of the 'hard goods' program that lasts longer than 30 min, 194 L are saved for each time it is run. More tests should be run to establish generalizability, even though the results are promising, and considered a success for the intended purpose.

The results were achieved by using an analog valve at the outlet instead of the digital valves at the inlet. The system will be pressurized during all times as the valve is placed on the outlet, letting water out of the system, instead of into the system. The analog valve is controlled using equation 21, a mathematical control function. While the valve is closed for temperatures below 40°C, pulsing is used to createa flow for accurate temperature readings. The solution is tested on the machine, *Gss-91413*, provided by the company. The edited software from *Automation Studio* is transfered to the PLC on the autoclave.

The requirements stated in the beginning of the thesis are met as:

- The new control system accommodates the old one.
- New parts adhere to the standards set by the company, by chosing an available component.
- Results are a success in regards to the ’hard goods’ cycle.

As a conclusion, the goal of a 20% cooling water reduction was a achieved as the new data indicates an 53% reduction.

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8 Appendices

8.1 Appendix A: Bürkert Type 8081, Operating Instructions

1 DESCRIPTION

4.4. Area of application

The ultrasonic flow rate transmitter type 8081 is intended for the measurement of water flow rates which may be slightly charged with contaminants.

4.5. General description

4.5.1. Design

The 8081 ultrasonic flow rate transmitter consists of an electronic module and a brass fitting with a built-in measuring tube. When combined with a controller and a control loop, it enables a control loop to be established.

The electrical connection is made via a 5-pin M12 fixed connector.

The transmitter features, depending on the version:

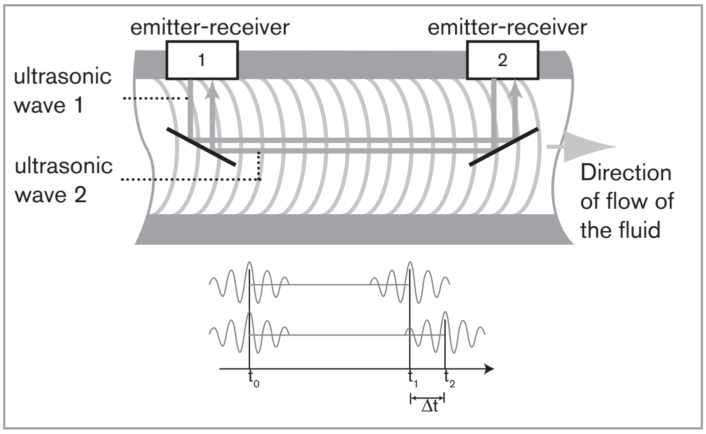
- a pulse output or
- a pulse output and a 4...20 mA current output;

Each version is available for 5 different flow rate ranges:

- model QN 0.6 DN15: 0.06 to 20 l/min
  (nominal flow rate 0.6 m³/h namely 10 l/min)
- model QN 1.5 DN15: 0.1 to 50 l/min
  (nominal flow rate 1.5 m³/h namely 25 l/min)
- model QN 2.5 DN20: 0.16 to 82 l/min
  (nominal flow rate 2.5 m³/h namely 41 l/min)
- model QN 3.5 DN25: 0.6 to 116 l/min
  (nominal flow rate 3.5 m³/h namely 58 l/min)
- model QN 6 DN25: 1 to 200 l/min
  (nominal flow rate 6 m³/h namely 100 l/min)

4.5.2. Measuring item and principle

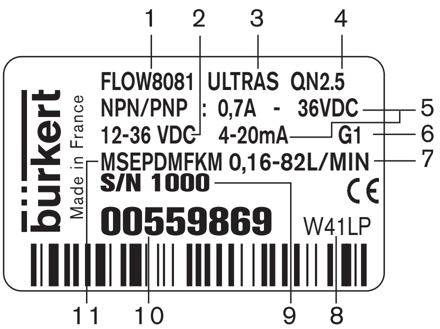
The 8081 flow meter is based on the transit time method. This consists in measuring the transit times of the sound from emitter 1 to receiver 2 and from emitter 2 to receiver 1 and subsequently comparing both values. The calculated transist time difference is directly proportional to the flow speed of the fluid.



The electronic module then delivers a pulse signal proportional to the volume or an industry-standard 4...20 mA signal, proportional to the flow rate or to the temperature.

4.6. Description of the name plate

1. Measured quantity, type of flow meter
2. Supply voltage
3. Measuring principle
4. Nominal flow rate
5. Output data
6. Process connection
7. Flow rate range
8. Manufacturing code
9. Serial number
10. Article number
11. Materials: housing, seal



5. TECHNICAL DATA

5.1. Conditions of use

Ambient temperature:	+5...+55 °C
Storage temperature:	+5...+55 °C
Air humidity:	< 80 %, not condensated
Protection rating:	IP65 with cable plug plugged-in and tightened

5.2. Conformity to standards and directives

The applied standards, which verify conformity with the EU directives, can be found on the EU-type examination certificate and/or the EU declaration of conformity (if applicable).

5.3. Conformity to the pressure equipment directive

- Make sure that the device materials are compatible with the fluid.
- Make sure that the pipe DN is adapted for the device.
- Observe the fluid nominal pressure (PN) for the device. The nominal pressure (PN) is given by the device manufacturer.

The device conforms to Article 4, Paragraph 1 of the Pressure Equipment Directive 2014/68/EU under the following conditions:

- Device used on a piping (PS = maximum admissible pressure; DN = nominal diameter of the pipe)

Type of fluid	Conditions
Fluid group 1, Article 4, Paragraph 1.c.i	Forbidden
Fluid group 2, Article 4, Paragraph 1.c.i	DN ≤ 32 or PSxDN ≤ 1000 bar
Fluid group 1, Article 4, Paragraph 1.c.ii	Forbidden
Fluid group 2, Article 4, Paragraph 1.c.ii	DN ≤ 200 or PS ≤ 10 bar or PSxDN ≤ 5000 bar

5.4. General technical data

5.4.1. Mechanical data

Item	Material
Housing, cover	PPS
Seal in contact with the environment	Silicone
M12 connector	PA
Fitting	Brass
Measuring tube	PES
Seal in contact with the fluid	EPDM, FKM

5.4.2. Dimensions

→ Please refer to the technical data sheets related to the device at: country.burkert.com

5.4.3. Fluid data

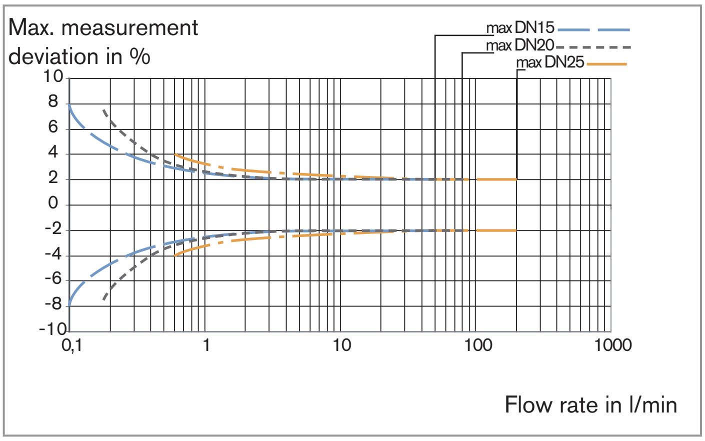
Pipe diameter	DN15 to DN25
Type of fluid	water (or neutral liquids on request)
Fluid temperature	+5...+90 °C
Fluid pressure	PN 16
Measuring range	0.06...200 l/min

Accuracy (see curves on next page)	± (0.01 % of Full Scale* +2 % of measured value) [1)]
Repeatability	1 % of measured value
Measuring element	2 ultrasound emitter-receiver cells

** Full Scale, see measuring range on the diagram of measurement accuracy.*

[1)] *Reference conditions: fluid = water, water and ambient temperatures = 20 °C*

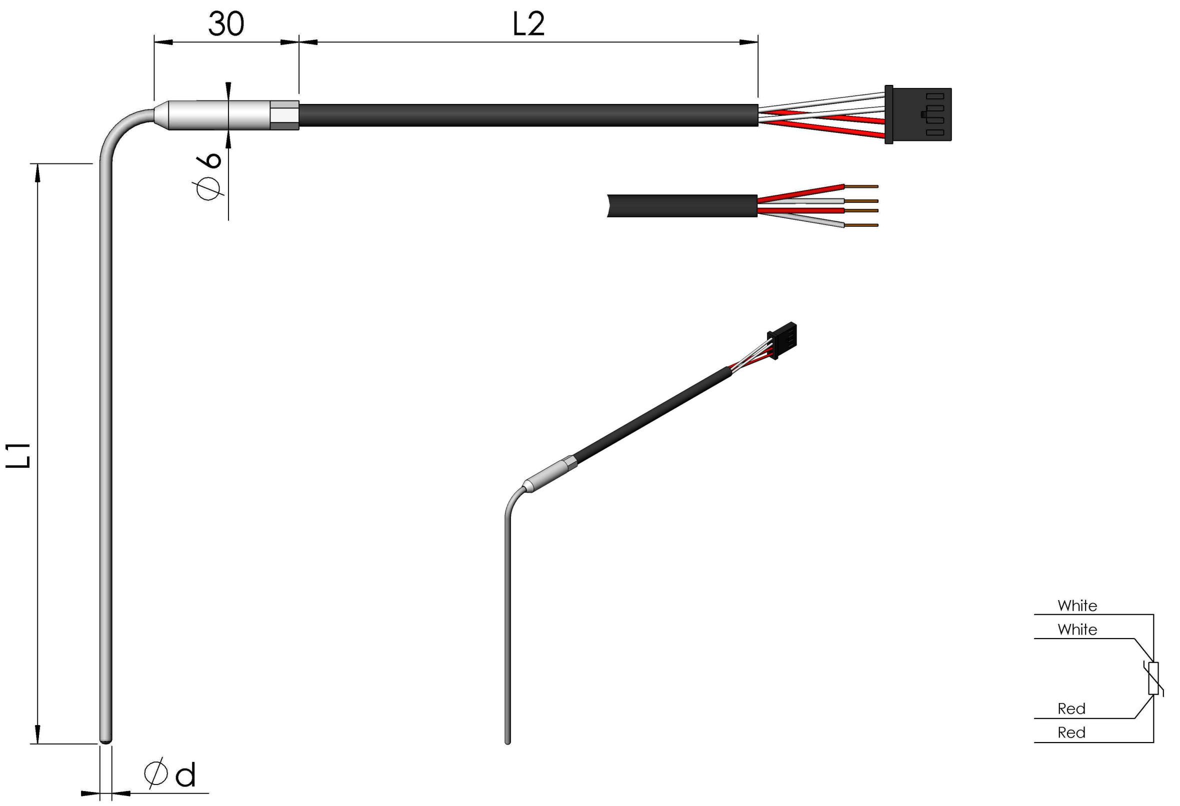
Measurement accuracy



5.4.4. Electrical data

Supply voltage (V+)		12...36 V DC
Current consumption		▪ Own consumption: < 4 mA ▪ Consumption with load: < 1 A
Pulse output (transistor)	▪ version without current output	▪ NPN as default setting; (PNP on request), open collector, 5 mA min., 700 mA max., NPN output: 0,2...36 V DC
	▪ version with current output	▪ PNP as default setting; (on request: NPN for the pulse output and sinking mode for the current output), open collector, 5 mA min., 700 mA max., PNP output: supply voltage (V+) If QN=0.6 or 1.5: 1 pulse corresponds to a volume V = 0.002 l (K factor = 500 pulse/litre) If QN=2.5 or 3.5: 1 pulse corresponds to a volume V = 0.005 l (K factor = 200 pulse/litre) If QN=6: 1 pulse corresponds to a volume V = 0.01 l (K factor = 100 pulse/litre)

8.2 Appendix B: Pentronic, Pt100 sensors for steam sterilizers (auto-clves)



Pt100 sensors for steam sterilizers (autoclaves)

Design
Pt100 detector mounted in protection tube.

Application area
Temperature measurements of process media in steam sterilizers (autoclaves).

Temperature range
Probe: -0 to +140 °C
Cable: -5 to +80 °C

Pressure range
Not applicable

Response time
T_{90} <5 sec when tested in water acc. to IEC60751.

Sensing element
Pt100 detector, IEC60751 class A.

Protection tube
Stainless steel EN 1.4404/1.4435 (316L)

Signal connection
4-wire connection
Housing: AMP 280359
Terminals: AMP 280530-2
Leads: 4x0.25mm^2 tinned copper.
Lead insulation: PVC
Braid: Tinned copper
Overall insulation: PVC

Certificate
Output (0°C): EN10204 3.1
Material (protection tube): EN10204 2.1

Handling
The sensor is to be handled with care and is not to be exposed to mechanical or thermal shock. The protection tube is not to be deformed or bent.

Getinge Part No	Pentronic Part No	Ød (mm)	L1 (mm)	L2 (mm)	AMP-connector
470802170	5306040-000	2.5	120	5000	Yes
470802102	5306050-005	3	350	5000	No
470802103	5306050-001	3	260	5000	Yes
470802104	5306050-002	3	120	8000	Yes
470802105	5306050-003	3	170	5000	Yes
470802111	5306050-004	3	70	3000	Yes

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