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AUTOMATIZATION OF CRUISE SHIP'S POTABLE FRESHWATER CIRCULATION CONTROL



MASTER'S THESIS | ABSTRACT

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The aim of the present Master's thesis is to design and implement in a reference ship a fully automatic potable fresh water circulation control system. System design was based on the idea that the potable freshwater circulation control and regulation is based on the water flow and temperature measurement values. The system reads the flow and temperature measurement values from the sensors in real time and based on these measurement values, the system regulates itself to optimal temperature values.

The potable freshwater system was designed in such a way that with these components the regulation of potable freshwater circulation is automated. The development work was carried out through designing and implementing a new automatic fresh water circulation control system that was integrated with the existing fresh water system, to make the water circulation system fully automatized. The development work focused on the automatization of the freshwater circulation system, first in the design phase, then in the negotiation phase with all the parties including the yard, ship owner, supplier and subcontracting companies, ERP and logistics phase, then in the purchase phase, assembly phase, testing phase, commissioning phase and, finally, in the delivery to the ship owner.

As the result of the study, the reference ship now has a working system, that regulates the ship's potable freshwater circulation based on the flow- and temperature measurement values received from the sensors. The system end results show that the temperatures of the returning hot water circulation lines remains hot enough at all times. Hot water circulation lines temperature was a major concern regarding the hot water circulation system, because it has to remain hot enough to ensure the safety of the hot water system. The system makes it easier to commission the potable freshwater system during the ship's building time, because the functioning of the potable freshwater system can be checked from the automation system. The results of the implemented development work also show that it is easier for the ship owner to operate the ship's potable freshwater circulation system and reduce the maintenance and supervision work and, therefore, it produces cost savings for the ship owner. The new automation system developed in this study ensures that the ship's potable hot water is safe and hygienic, because hot water temperatures stays hot enough at all times, and it also minimizes the risk that legionella pneumophila bacteria are able to live in the ship's hot potable water pipelines. The thesis concludes that all efforts made to progress a cruise ship freshwater system automatization are valuable and improve cruise ship water systems for the future.

KEYWORDS:

Shipbuilding, water, circulation, control, automatization

Matti Ojanperä

RISTEILYLAIVAN MAKEAVESIKIERTOJÄRJESTELMÄN HALLINNAN AUTOMATISOINTI

Työn tarkoituksena oli suunnitella ja toteuttaa referenssi laivaan täysautomaattinen makeanveden kierron hallintajärjestelmä. Järjestelmän suunnittelu perustui ajatukselle, että laivan makeavesikierron hallinta perustuu lämpötilan ja virtauksen säätelyyn. Virtaus- ja lämpötila-arvot järjestelmä lukee reaaliajassa antureilta ja näiden arvojen perusteella se säätelee itseään optimaalisiin lämpötila-arvoihin.

Makeavesijärjestelmä suunniteltiin niin, että valittujen komponenttien avulla makeavesikiertojärjestelmä on automatisoitu. Kehitystyö tehtiin suunnittelemalla ja implementoimalla uusi automaattinen makeaveden kierron hallintajärjestelmä, joka integroitiin olemassa olevaan makeavesijärjestelmään. Suunnittelu keskittyi laivan makeavesikiertojärjestelmän automatisointiin, ensin suunnitteluvaiheessa, sen jälkeen neuvotteluissa kaikkien osapuolten kanssa, sen jälkeen integrointi materiaalinhallintajärjestelmään, sitten materiaalien hankintavaiheeseen, järjestelmän asennukseen laivalla, järjestelmän testaukseen, käyttöönottoon ja järjestelmän myyntiin laivavarustamolle.

Työn tuloksena referenssilavassa on nyt toimiva järjestelmä, joka säätelee laivan makeaveden kiertoa antureilta saatavan veden virtaus- ja lämpötila-arvojen mukaisesti. Järjestelmän toteutuksen lopputuloksena on se, että palaavissa kuuman veden kiertolinjoissa kuuman veden lämpötila pysyy riittävän kuumana kaikkina aikoina, ja se oli suuri huolenaihe aikaisemmin kuuman veden järjestelmässä, joka takaa kuuman veden järjestelmän turvallisuuden. Järjestelmä tekee laivan rakennusaikaisen makeavesijärjestelmän käyttöönotosta helpomman, koska järjestelmän toiminta pystytään tarkastamaan automaatiojärjestelmästä. Kehitystyön tulokset tekevät laivan omistajalle laivan makeavesikiertojärjestelmästä helpommin operoitavan ja vähentää huolto ja ylläpitotyötä ja siten tuottaa kustannussäästöjä laivan omistajalle. Kehitystyön uusi automaatiojärjestelmä pitää huolen siitä, että laivan kuumavesi on turvallista ja hygieenistä, koska kuuman veden lämpötilat pysyvät riittävän kuumina kaikkina aikoina, ja myös minimoi riskit, että legionella pneumophila bakteeri pystyisi kehittymään laivan kuuman veden putkistoissa. Kehitystyö johti päätökseen, että kaikki ponnistukset, jotka tehdään kehittämään laivan makeavesijärjestelmien automatisaatiota, ovat arvokkaita ja parantavat laivan makeavesijärjestelmiä tulevaisuutta ajatellen.

ASIASANAT:

Laivanrakennus, makeavesi, kierto, hallinta, automatisointi

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LIST OF ABBREVIATIONS OR SYMBOLS

CEO	Chief executive officer
CGT	Compensated gross tonnage
EU	European union
FW	Fresh water
GDP	Gross domestic product
IMO	International Maritime Organization
USPH	United States public health
WHO	World health organization

1 INTRODUCTION

1.1 Introduction to fresh water systems in cruise ships

Fresh water systems are critical to passengers of cruise ships in many ways: Comfort of showers, toilets, hand wash basins, laundry, spa, restaurants and swimming pools. All these services require water. Fresh water consumers in cruise ships are in the thousands, which makes ships fresh water system diverse and complex. Fresh water system needs to be designed so, that water is always of the right temperature, drinkable and is not contaminated with any living organisms, such as microbes, nor contains toxic amount of chemicals to make water unsafe to drink. Problems that arise with ship's fresh water systems usually relate to hot water taking too long to arrive to consumer, or hot water stagnation or lack of hot water circulation in fresh water pipelines, which both can result to water system contamination with microbes.

There have been many cases of *Legionella pneumophila* bacteria affecting passengers in cruise ship's mainly from whirlpools by breathing in aerosols containing water droplets contaminated with *Legionella pneumophila*. There has been 105 ship associated cases of Legionnaires' disease in Europe from 2000 to 2010, and 59 of these cases relate to ship's hot tubs. Legionnaires' disease has 5-30% death rate. (Mouchtouri 2015). Fresh water is distributed with high pressure riser pipes to ring lines after pressure reducing station. Ring lines are usually in every second deck, serving water consumers in same deck and above deck. With over 4000 armatures and over 20 km of pipelines, it is quite complex and vulnerable system. Figure 1 shows simplified principle diagram how fresh water is distributed generally in cruise ship's. Water is distributed from main ring lines in every second deck by taking smaller pipeline branches from main ringlines that serve every water consumer in ship.

SIMPLIFIED CRUISE SHIP'S FRESH WATER DISTRIBUTION SYSTEM PRINCIPLE DIAGRAM

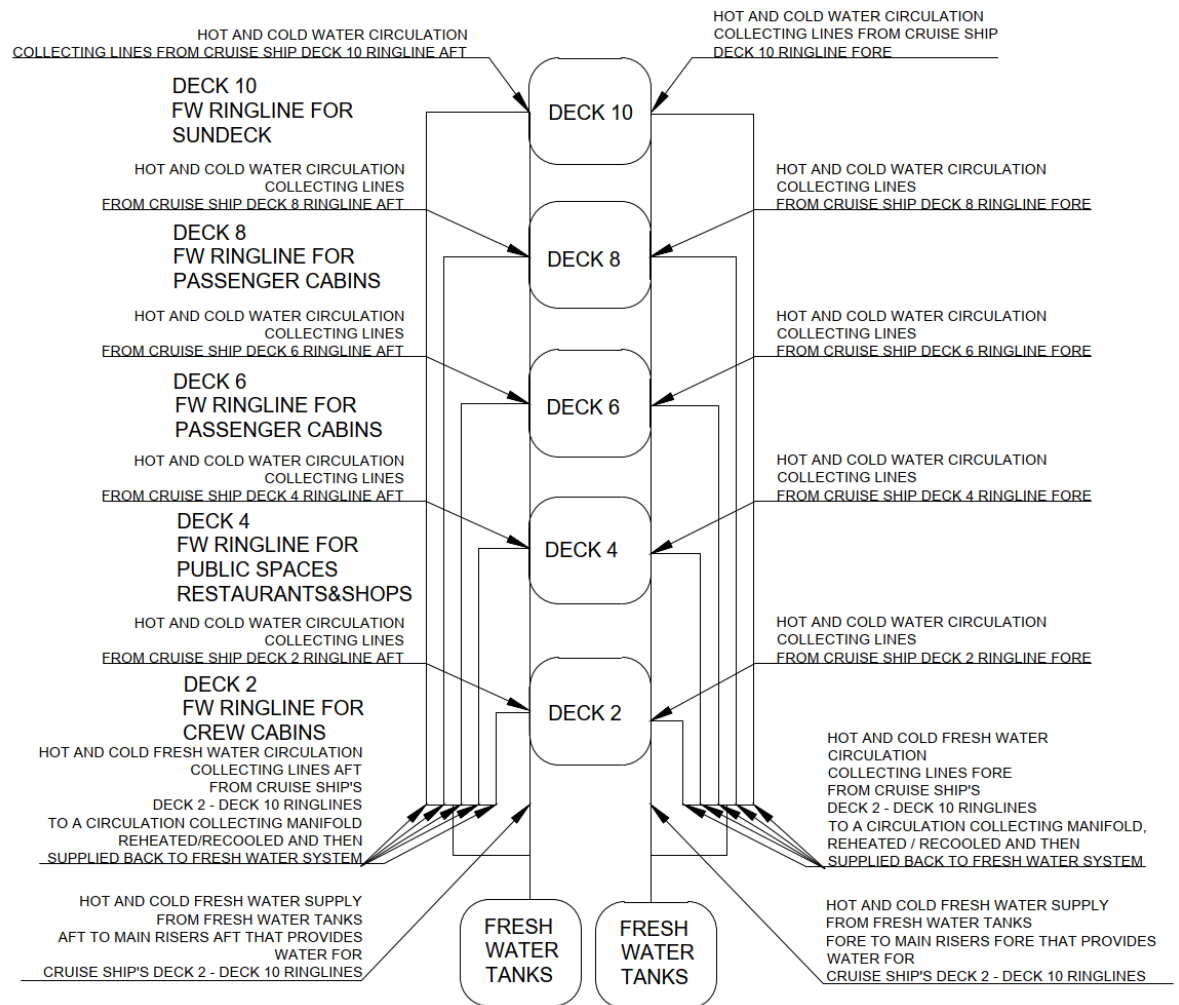


Figure 1 Fresh water system principle diagram

Regulation of fresh water systems is done by several authorities, including United States Public Health USPH, World Health Organization WHO, International Maritime Organization IMO, classification society's such as RINA, and in Finland regulation authorities such as Department of Environmental Control and City of Turku Water Department. (USPH 2018, WHO 2011, WHO 2017)

1.2 Purpose and scope of thesis

Problems in the ship's water systems have been usually related to the water temperature fluctuation, specifically hot water availability and temperature on kitchens and cabins. There came the idea, that a system-level solution is needed to address all these hot water related problems, to save countless of hours of costly after delivery work and warranty claims from the ship owner related to these problems. That is the basis why this thesis work was started, after years of trial and fail, to solve problems related to hot water temperature and availability in cruise ship's. Previously ship's hot water circulation system was fragmented all over the ship, and was very difficult to control and regulate.

A new system is needed to control the whole water circulation system that is always self-regulating, an autonomous system, so there is no need to manually adjust all the regulating valves all over the ship and try to manually find the best balance for the whole system by trial and error, taking many weeks of time and effort from both yard and ship owner personnel to try and correct. That new system is the product of this thesis.

The goal of the thesis is to design and implement an automatic ship's potable fresh water distribution circulation control system. In literature review, there is background information why water circulation, water quality and water hygiene is important in ship's water distribution system, and what are the different methods to ensuring that the water quality and hygiene is taken care of.

In the implementation of the automation system chapter there are described how the automation system was designed, the different components needed to build such a system and data values taken from system.

Purpose and one of the main drivers for this thesis was the challenges with the ship's potable fresh water circulation systems that concern the production, commissioning, design and operation of the circulation systems. The temperatures in returning circulating water lines have been fluctuating, and the calibration of the whole water circulating system has been a big task. Potable water circula-

tion related challenges, for example hot water takes time to arrive to ship's cabins showers or faucets, or the galleys have to wait to get hot water for their operation. The scope of the thesis limits to only designing and implementing an automatic cruise ship's potable fresh water distribution circulation control system. Water quality and hygiene matters are researched in literature review.

Scope of thesis include only ship's fresh water systems circulation control system, because that is the solution needed to overcome the problems faced previously with the unavailability of hot water and too low hot water temperature for passenger cabins and galleys.

1.3 Outline of thesis

Thesis contains six chapters: the introduction, fresh water systems onboard ships, design of the automatic water flow system, commissioning the automation system, findings and discussion and conclusions. The introduction chapter describes the main drivers for thesis.

The literature review, fresh water systems onboard ships, describes theory behind the subject of the thesis, why it is so important to have circulating water at right temperature in the ship's potable fresh water distribution system, and what other important factors effect ship's water quality and hygiene. Design of the automatic water flow system describes the design of the automation system, the components used to build automation system, analysis of the function of the automation system on cruise ship. Commissioning the automation system describes how commissioning was done and commissioning test results. Findings and discussion reflects the results of thesis.

Finally the last chapter is conclusions, that describes the findings of the function analysis of the automation system on cruise ship, and suggests further future improvements for more efficient use of the ship's automatic circulation regulation system and the communication of the system with other systems in ship. Limitations of thesis include laboratory water chemistry, all other ship's systems are excluded from thesis for example water sewage systems.

2 FRESH WATER ONBOARD SHIPS

2.1 Fresh water regulation

Ship's fresh water distribution system is in many ways similar to a small city's fresh water distribution system. In a large cruise ship there can be 10 000 people on board, that all need approximately 140 liters of fresh water per day, for showering, toilet use and hand washing, mainly for the passenger cabins. Other services that need water onboard a ship are laundrying, swimming pools, whirlpools, restaurants and galleys for example.

Circulation of the water is important, specially for the hot water, because if there would be no circulation of the hot water in ship's fresh water distribution system, hot water would not stay hot and the availability of hot water would be worse, one would have to wait longer periods of time for the hot water to arrive to destination. Also if hot water temperatures would be lower than 50 degrees Celsius, that would enable the hot water system to contaminate with bacteria and biofilm. Most known problem of this phenomena being the legionnaire's disease, that can be deadly specially to elderly people, taking a shower for example, and inhaling the legionella pneumophila bacteria from the air water droplets to their lungs.

Water quality in ship is based on many factors, such as water temperatures, water flow and stagnant water, water acidity / alkality measured by water pH, water hardness, water mineralization, water hygiene, water contamination, and water chemicals. Water temperature problems usually relate to hot water temperature being lower than 50 degrees Celsius, because if hot water temperature gets lower than 50 degrees Celsius, bacteria, living micro-organisms and biofilm can contaminate the ship's water system. Water flow and stagnant water problems relate to dead end's and too long hot water pipelines without circulation of

the ship's water piping system. Water being too hard or too soft usually relate from either bunkering too hard water from the shore or water being too soft, when ship's water treatment is not handled properly. Water mineralization being out of balance relate to water treatment process not being handled properly by the ship's operating staff. Water hygiene and water contamination relates usually either to water chlorine levels being too low or the hot water temperature being consistently too low in parts of the ships, due to lack of circulation. Water chemical issues relate to toxic chemicals residing in ship's water systems.

Solution for water temperature problems is to improve ship's hot water circulation system. Solution for water pH problems is to implement educational courses for ship's operating staff teaching ship's fresh water system functions and practical aspects of maintaining the ship's water treatment system. Solution for water hardness and water mineralization problems is avoid bunkering hard water from shore connections and educating the ship's staff to properly maintain ship's water treatment plants. Solution for water hygiene and water contamination problems is to improve ship's hot water circulation, either by adding more circulation lines to hot water system or improving the hot water circulation system function for example by automatization. Also ship's staff needs to understand how the ship's water treatment works, different courses can be held for the staff to improve the knowledge of the function of the ship's water treatment plants. Solution for the water chemical problems is to regularly flush the whole ship's fresh water distribution system.

2.2 Fresh water circulation principles

Most common threats to ship's fresh water system hygiene related to fresh water circulation are typically stagnation of water in pipelines, which means that the fresh water in pipelines does not flow correctly, lack of hot water in cabins and galleys, or hot water takes too long time to arrive at the desired destination, and temperature problems mainly in hot water system, which makes the temperature conditions more favorable to bacteria growth, for example *Legionella pneumophila*. Prevention depends on good maintenance of water systems. Figure 2 shows the principle of water circulation. Principle of water circulation is that water from ship's main ringline ends are collected to lower decks and regulated there. Figure 3 shows why hot water circulation control is important because low hot water temperatures enable micro-organisms, biofilm and bacteria to multiply and contaminate ship's water systems.

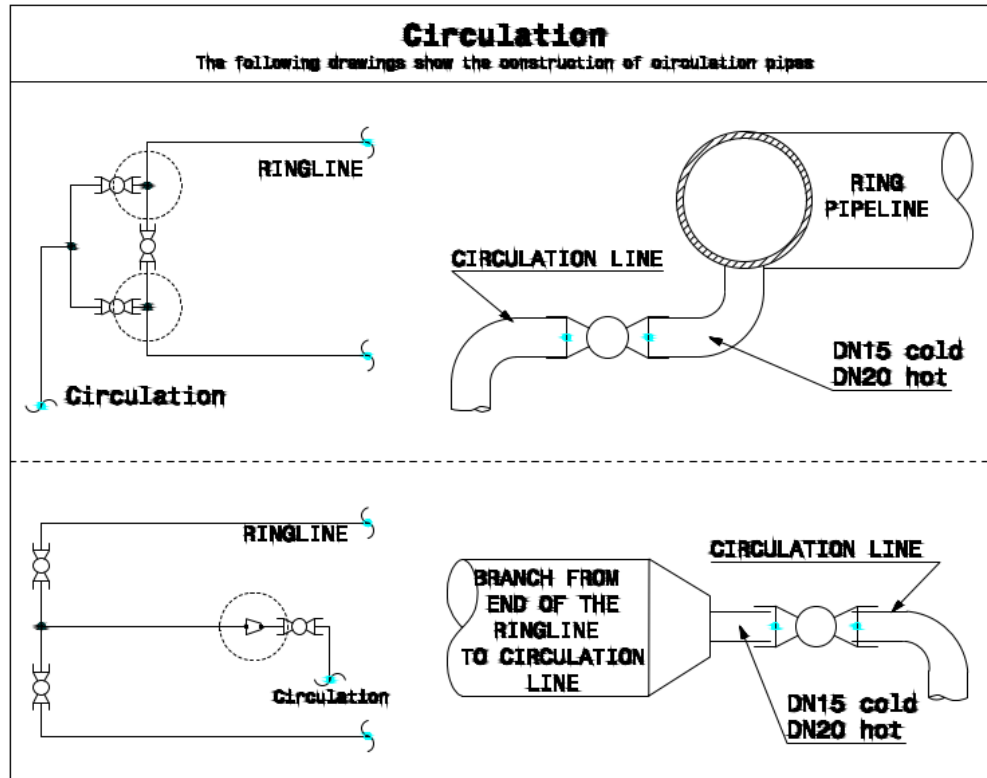


Figure 2 principle of water circulation

Ring lines are usually in every second deck and are usually in the cabin corridors, and circulation lines are usually connected to these ring lines. This makes sure that the fresh water does not stagnate in the dead ends, but flows back to the circulating main pipelines, and effectively cancels any fresh water stagnation.

Adding circulation pipelines to avoid stagnant water: Another effective way to avoid stagnant water in fresh water system pipelines is to connect dedicated circulation pipelines to areas that do not have good quality of water recirculation, for example in lower deck crew cabin areas. In crew cabin areas for example, It is good fresh water system design practice that we make loops for areas in lower crew cabin areas, and connect dedicated fresh water cold and hot circulation pipelines to these loops, which in turn connects to the main circulation pipelines, so that the circulation in these pipelines that brings hot and cold water to

crew cabin showers, faucets and toilets, is always flowing, and the temperature is always correct (Wikipedia 2022).

Without hydraulic alignment

+GF+

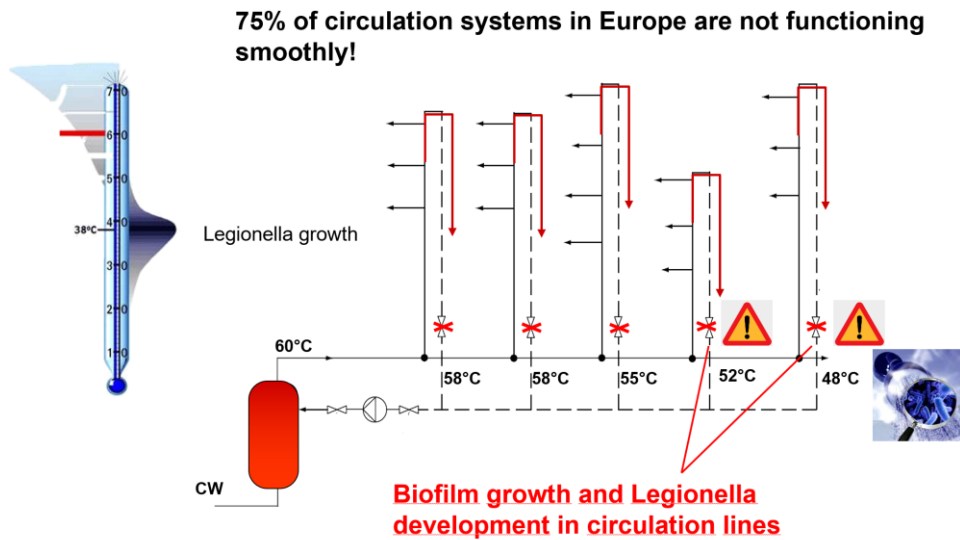


Figure 3 Why hot water circulation control is important (Georg Fischer GmbH 2021)

2.3 Fresh water quality

Fresh water quality is monitored closely by the ship owner at all times. Ship's fresh water quality correlated to fresh water circulation is related to parameters of fresh water temperature and flow. By monitoring fresh water temperature and flow, the ship owner can be satisfied that the distributed circulating fresh water quality is in order. Control of the ship's fresh water circulation system gives the ship owner added value, if the ship owner can monitor in the temperature and flow values of every circulating fresh water pipeline separately, and see the how the whole fresh water distribution circulation system in the ship is functioning.

2.3.1 Prevention of legionella in drinking water system

Legionnaire disease, form of pneumonia caused by the bacillus *Legionella pneumophila*. The first symptoms legionnaire disease general malaise and headache, followed by high fever, often accompanied by chills. Coughing, shortness of breath, pleurisy-like pain and abdominal distress are common. Figure 4 shows cases of legionellosis in Europe in years 1993-2013.

Legionellosis in Europe in years 1993-2013

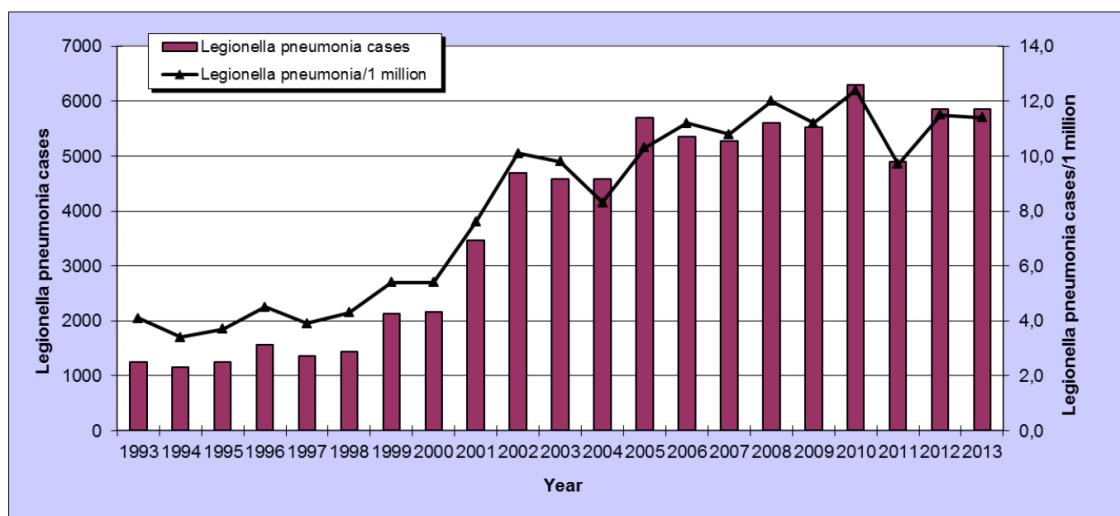


Figure 4 Legionellosis in Europe in years 1993-2013 (ECDC, 2015)

Prevention of legionella pneumophila bacteria from growing in ship's drinking water system pipelines is handled by various means, for example, super chlorination of the whole ship's fresh water system pipelines, or by monitoring and controlling whole ship's fresh water system pipelines water temperatures and flow. In figure 5 is shown how legionella pneumophila bacteria can live and grow in biofilm (Encyclopediabritannica 2021).

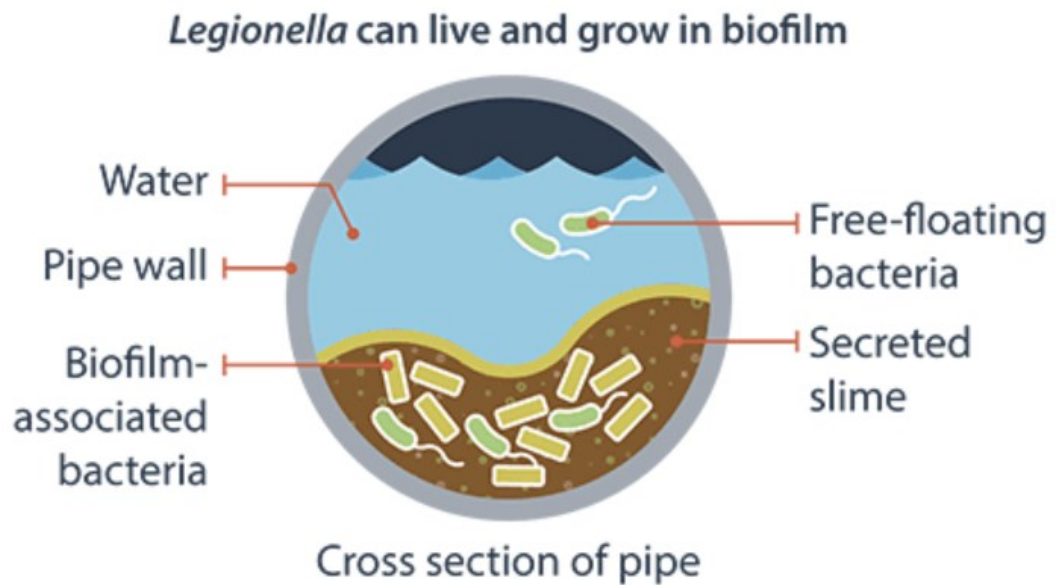


Figure 5 Legionella can live and grow in biofilm (NBCI, 2013)

2.3.2 Prevention of biofilm and stagnant water in drinking water system

Prevention of biofilm in drinking water is based on many factors. Such factors include but are not limited to: Chlorine concentration in fresh water, water temperature, free phosphorus in drinking water, type of pipe material, water flow velocity, water pH, water hardness, nutrients and organic matter in water (Encyclopediabritannica 2021).

Biofilm prevention methods in drinking water pipes include regularly cleaning the pipes, avoiding dead ends in the piping and assure a good flow at all times, choosing piping material, polyethylene pipes are prone to biofilm formation whereas copper piping is less sensitive to biofilm formation. (Disarm project, EU, 2020)

2.3.3 Use of chlorine for disinfection of drinking water

Chlorination and boiling are the most common water and wastewater disinfection processes in use throughout the world. It is also used in emergencies when other, more sophisticated methods of disinfection are not available. Prior to the development of chlorination, boiling was the principal method used to kill pathogenic organisms. Chlorination of drinking water over 5 parts per million makes the drinking water toxic to human health.

Chlorination has become the most common type of water and wastewater disinfection. It should be noted that it is designed to kill harmful organisms, and generally does not result in sterile water, free of all microorganisms. Two types of processes are generally used: hypochlorination, employing a chemical feed pump to inject a calcium or sodium hypochlorite solution, and gas chlorination using compressed chlorine gas. (DUNCAN 2009, AWWA 2009)

2.3.4 Thermal disinfection of drinking water

Hot water distribution is a critical factor, if the hot water temperature is constantly regulated and monitored, pathogens such as legionella have no chance of survival.

For safe protection, high water temperature of >55 °C are necessary. Hot water temperature of 55-60 °C is necessary for hygienic heated water, keeping within this range is also considered the optimum temperature range for energy efficient operation. Safe protection with hot water temperature over 55 °C, where Legionella dies within 5-6 hours. Perfect temperature for legionella growth is between 20 and 45 °C.

Boiling is a very simple method of water disinfection. Heating water to a high temperature, 100 °C, kills most of the pathogenic organisms, particularly viruses and bacteria causing waterborne diseases. In order for boiling to be most effective, the water must boil for at least 20 minutes. (DUNCAN 2009, AWWA 2009)

According to DVGW worksheet W551, a minimum of 60 °C temperature must be reached in the hot water storage tank. This ensures the required supply temperature is maintained and pathogens are killed. In order to realize the even distribution of water temperature, a controlled flow through all the pipes of the drinking water installation is necessary. As different components have different pressure losses, the differential pressures of the individual hot water pipes must be determined and adjusted in the pipe network. (AWWA 2009)

3 DESIGN OF THE AUTOMATIC WATER FLOW SYSTEM

3.1 Design of the automation system

Design of the automation system started with the idea, how would it be possible to automatize the potable fresh water circulation control, which would benefit both the yard and the owner. Yard would benefit from the easy commissioning of the fresh water circulation system, also from the building time data that would be available regarding the real-time flow and temperature values that would be uploaded from the system.

Design started by considering different options about component selections. There are many companies that have different solutions. The logical choice is to compare the functions of the different solutions and select the one that best suites needed end results. Full automatization of water circulation system being required, that limits solution providers to only a few suppliers.

Design would be implemented as practically as possible, to make the water circulation system fully automatized. Together with all the partners, yard commissioning staff, electrical design team, ship owner personnel and different subcontractors the work was carried on. First in design phase, then negotiation phase with all the parties including yard, ship owner, supplier and subcontracting companies, ERP and logistics phase, then purchase phase, assembly phase, testing phase, testing and commissioning phase results and documents can be seen clearly in figures 10 and 11, pages 29 and 30, where are shown variations in temperature in the returning circulating cold and hot pipelines as a diagram, that is downloaded from the automation system, commissioning phase and finally delivery to ship owner. Design started in 2019 June, fully functioning system delivery to ship owner 2020 October.

In design phase, the supplier was first selected. In negotiation phase prices, modification costs and technical specifications had to be negotiated with yard

HVAC and electrical design teams, with yard's HVAC commissioning team, with ship owner's technical and management teams, with supplier and with two turn-key-subcontracting companies. In ERP and logistics phase, the components are defined in the yard's ERP system and the delivery times are defined with the supplier company. In the purchase phase, materials and components are purchased based on the information imported from yard's ERP system with purchase order. In the assembly phase, after the space is built for the automation system, pipes, components and armatures are assembled. In testing phase, function of all components from automation system is checked and verified, the system is tested and the test results were encouraging, but the fresh water distribution system was not installed completely in the ship at the time of the testing phase, so the results of the hot water system were not satisfactory at that time. In the commissioning phase, all parameters are set up to the automation system, and verified that everything is working as it should, and that the system is ready to be delivered to ship owner. Just before the automation system delivery to ship owner, results were taken out of the system, and the results can be seen in chapter 4.2. System measurement values. The final delivery to ship owner, automation system is sold to ship owner.

System process description: First fresh water circulation function was disputed, and all components related to fresh water circulation was re-examined. Elements needed for full fresh water circulation automatization were analyzed. It was clear that fresh water circulation manifolds are good idea concerning the automatization of the fresh water circulation system, because all the equipments and components needed for fresh water circulation automatization could be placed physically near each other and therefore cabling, testing, commissioning and other functions could be easily done when one does not need to run all around the ship to for example, check if all the valves are functioning correctly temperature-wise. Components needed to be changed to different ones, so that the whole fresh water circulation system could be automatized. These new components were then designed to the fresh water distribution diagrams, to support full automatization of the fresh water circulation system.

System measurement sensors are temperature sensors integrated in smart valves and external flow volume sensors. System alarms are set for hot water circulation returning pipelines smart valves temperature sensors. Data is stored in Master and can be accessed with smartphone or laptop computer via bluetooth connection.

Owner would benefit from the easy maintenance of fresh water circulations system. Owner would also benefit from the data of the temperature and flow volumes of fresh water circulation. Temperature and flow values can be monitored straight from the system at all times. This valuable data would make it possible for the ship owner to optimize the water consumption for hot potable water system.

3.2 Components used in the automation system

3.2.1 Central control unit, Master

Control for the system, for the execution, programming, recording, monitoring and data logging of drinking water installations, hydraulic balancing of hot and cold drinking water systems with line regulating valves. Automatic detection of the valves for hydraulic balancing, and also type and serial number. Central control unit is shown in figure 6.

Central control unit, also known as Master, is a control unit that controls with two cable sets up to 50 different valve's functions.

Master recognizes in the commissioning phase each single valve and sensor ID-marking and type, and connects components to the function related to each.

System is instantly ready to use, because all equipments have their readily programmed factory settings.

Regulation is done by controlling the circulation controllers with electric motor driven actuators opening value, from 0 – 100 percent. That controls the flow volume of individual water pipelines.

3.2.2 Circulation controller

The circulation valve regulates the flow rate by permanently reading the water temperature with the help of an immersed temperature sensor. The measured values are processed by the controller. If a deviation from nominal temperature is detected, the circulation valve regulates the flow rate by opening or closing the valve until the set point temperature is reached. This is done by means of an actuator.

Water temperature readings are permanently taken by the valves, the values are passed on to the master. The valves are activated dependent on preprogrammed parameters. During commissioning, all valves are automatically detected by the master by their ID. Circulation valve have adjustable leakage flow rate when the valve is closed, higher linearity and more precise regulation thanks to special cone profile. Circulation valve applications are: Hydraulic calibration and maintenance flushing once a week.

Circulation controller temperature curve is shown in figure 6. Circulation controller pressure loss per flow volume curve is show in figure 7 where can be seen that pressure loss is depending on the size of the valve and the flow volume of circulating water. Circulation valve does hydraulic balancing and rinsing and flushing operations, has a fast actuator and a motor with encoder, has integrated flow regulator and temperature sensor. Controller is connected to every device, controller recognizes with which device type it is connected, for example legiotherm valves or sensors. Controller has light display and controller is largely maintenance free.

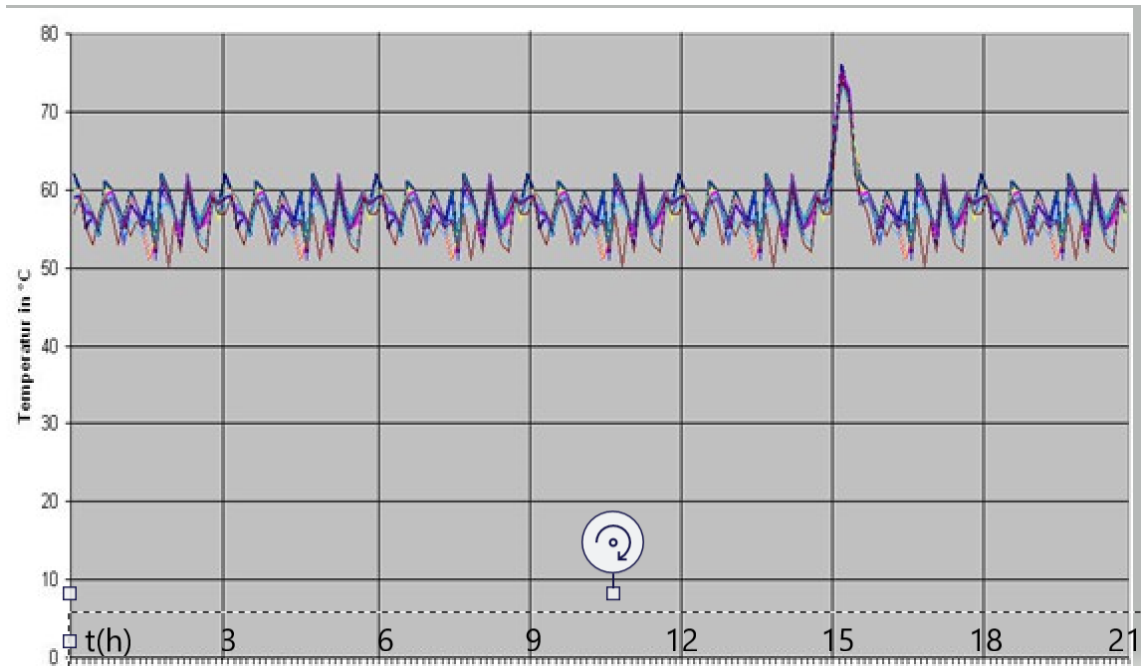


Figure 6 Circulation controller temperature curve, each color represents a different period of measurement (Georg Fischer GmbH, 2021)

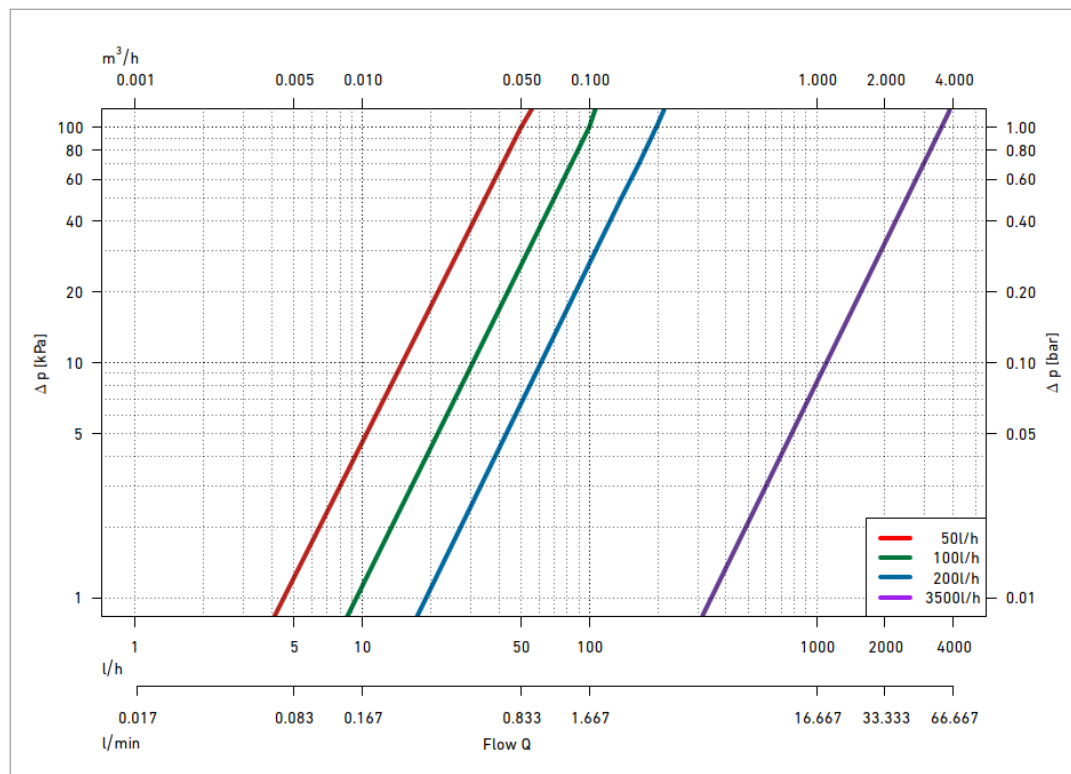


Figure 7 Circulation controller pressure loss per flow volume curve, pressure loss varying between 1 - 100 kPa, red line for DN10, green line for DN15, blue line DN20 and violet line for DN25 (Georg Fischer GmbH,2021)

3.2.3 Flow Sensor

Flow sensor is a measurement value receptor for the capturing of the volume flow of liquids. Flow sensor must be connected to a controller and is automatically identified as an external flow sensor upon the start of the master. Flow rate of the sensors can be read out on the master in liters per hour. Captures flow rates from 0 to 3600 litres per hour. In figure 8 is shown flow sensor pressure loss per flow volume curve. In figure 9 is shown flow sensor photo. Flow sensor sends signal to master with 4-20 mA DC current signals.

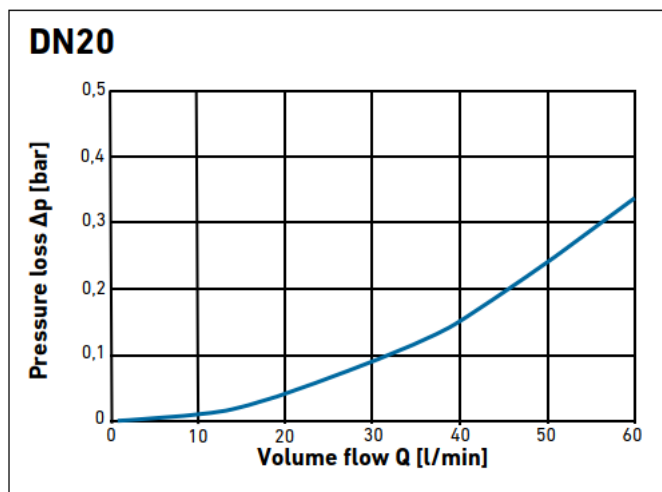


Figure 8 Flow sensor pressure loss per flow volume curve (Georg Fischer GmbH, 2021)



Figure 9 Flow sensor (Georg Fischer GmbH, 2021)

3.3 Commissioning of the automation system

The circulation pipelines and components and armatures had been installed on both circulation manifolds, configuration of the system started. In Configuration phase, components were named properly, updates were installed to all the masters to update all the masters software to latest version and alarms were set to the automation system. When configuration was done, testing of the system began.

3.3.1 System measurement values

System measurement values for cold circulating water system can be seen from figure 10.

Valve Internal Temperature Sensor(s)

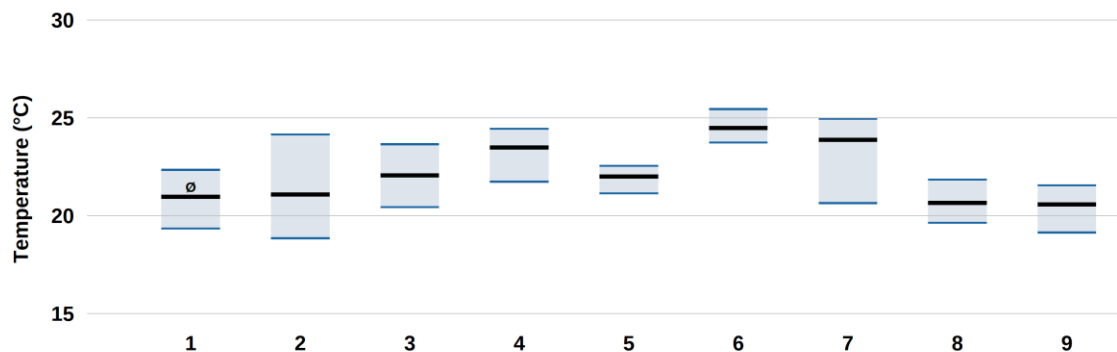


Figure 10 Cold water circulation system temperature measurement values from valve internal temperature sensors during 5.10.-12.10.2020.

System measurement values for hot circulating water system can be seen from figure 11.

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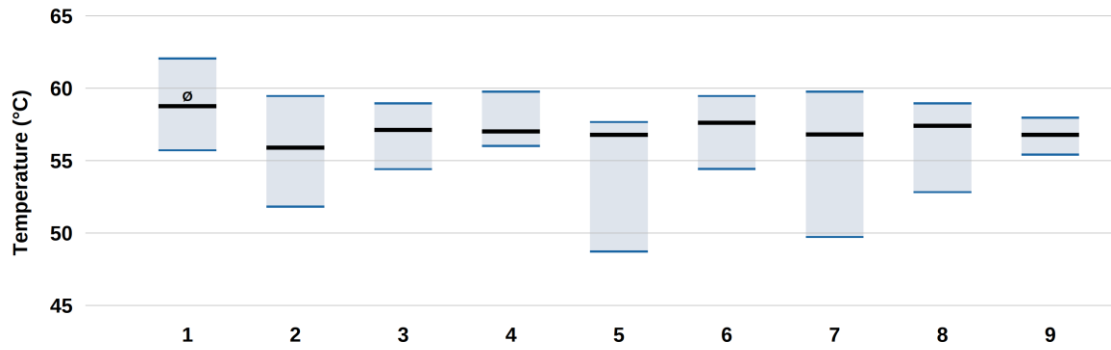


Figure 11 Hot water circulation system temperature measurement values from valve internal temperature sensors during 5.10.-12.10.2020.

4 FINDINGS AND DISCUSSION

Findings

4.1 Results

A fully automated system of cruise ship's fresh water circulation control was designed and implemented in the cruise ship fresh water system. The results are satisfactory, hot water temperature values from returning hot water circulation lines are between 50 – 57 degrees Celsius. Growth of harmful bacteria can be controlled through basic measures e.g. maintaining water outside the range at which *Legionella* proliferate, i.e. $> 50\text{ }^{\circ}\text{C}$ for hot water. Poor temperature control can occur in hot water systems in long branch mains and dead ends (i.e. lengths of pipe, closed at one end, through which no water passes)" (USPH 2018, WHO 2017).

Hot water needs to be $> 50\text{ }^{\circ}\text{C}$, so that no harmful bacteria may grow on pipe surfaces, and not acceptable concerning human health issues caused by drinking water onboard ship when ship's water system may be contaminated by slowly growing microbes and bacteria in water systems due to lower than 50 degrees Celsius temperature in hot fresh water system in ship (USPH 2018, WHO 2017).

4.2 Trustworthiness of the results

The results can be monitored onboard reference ship from the ship's own automation system in real-time. If there are problems related to the automation system, for example too low hot water system circulation returning lines temperature, below 50 degrees Celsius, these problems can be seen at any time from the ship's own automation system in engine control room, no separate temperature meters were used to compare temperatures with the automation system

given temperatures. The whole automation system can be monitored with the ship's automation system through ship's engine control room, so that makes the results trustworthy, because the results can be monitored at all times in full transparency, and if problems arise, they can be directly pointed out and communicated with the yard. User experience, comments and feedback from yard HVAC commissioning staff has been mostly positive and as one yard HVAC expert said "Automation system has been a great help in the ship's fresh water system commissioning".

4.3 Implications

Implications of this thesis are related to cruise ship's design and production, particularly in automatization of cruise ship's technical systems, including fresh water system. With connecting more of the technical systems to the ship's automation system, the systems on ship can be made intelligent, the systems can interrelate with every other system, and all of the ship's systems can be more intelligently controlled and monitored.

4.4 Discussion

It is not an easy task to try to automatize ship's different systems, but it is a worthwhile task, because it benefits all parties included.

Automatization benefits the ship owner, because it makes maintenance of the systems easier, it makes all the data available from the ship's automation system, it reduces maintenance costs, and it improves the quality of the system, in this case it improves the quality of water in the fresh water system, for example ensuring that passengers get warm water from cabins showers in short time.

Automatization benefits the shipbuilding yard, because it makes easier to commission the system, and reduces commissioning work hours. It also benefits the yard as yards technological references and talents improve, and yard gains quality added value, also this improves the chance for the yard to get new ship orders, because the high technology skills and ship overall quality is known as top grade.

Automatization of the ship's systems benefits also the subcontractor and network companies, because it adds to the know-how and references of these network companies. These companies learn how to use new technologies, and it adds to the value of these companies, as their technology and know-how product portfolio increases, and they can get new contracts based on these references and technology skills.

The problem was solved through designing and implementing a new automatic fresh water circulation control system that was integrated with the existing fresh water system. The process of implementing new fully automatic fresh water circulation control system in the ship took over 1 and ½ years to complete, from designing, to negotiating with all parties, collaborating with yard other design teams and turnkey subcontractors.

The system is self-regulating, and the values can be monitored from the ship's engine control room, so that ship owner can verify, that all temperatures in ship's fresh water system are as they should be. A new, fully automatic fresh water circulation control system was designed and built on board reference ship. Results, as stated by the yard's fresh water system commissioning staff and ship owner's technical experts, are satisfactory.

To continue the ship's fresh water system's automatization work, there are a lot of practical applications to be made. More sensor's are needed to know how the whole fresh water system works all over the ship. When the sensor's are connected to ship's own automation system, the values can be monitored from engine control room. The designing and building of a new system, a fully automatic fresh water circulation control system, on board reference ship, is a practical application in it's own right.

5 CONCLUSIONS

5.1 Summary

The aim of the thesis was to design and implement in reference ship fully automatic potable fresh water circulation control system. System design was based on the idea that ship's potable fresh water circulation control and regulation is based on waters flow and temperature measurement values. The system reads flow and temperature measurement values from the sensors and based on these measurement values the system regulates itself to optimal temperature values.

The potable fresh water system was designed so that with these components the regulation of potable fresh water circulation is automated. The development work was done through designing and implementing a new automatic fresh water circulation control system that was integrated with the existing fresh water system, to make water circulation system fully automatized. First in design phase, then negotiation phase with all the parties including yard, ship owner, supplier and subcontracting companies, ERP and logistics phase, then purchase phase, assembly phase, testing phase, commissioning phase and delivery to shipping company.

Result is that reference ship now has a working system, that regulates the ship's potable fresh water circulation based on the flow- and temperature measurement values received from the sensors. The system makes it easier to commission the ship's building time potable fresh water circulation system and reduces the maintenance and supervision work and therefore produces cost savings for the ship owner. This development works new automation system makes sure that the ship's potable hot water is safe and hygienic, and also minimi-

zes the risk that legionella pneumophila bacteria is able to live in ship's hot potable water pipelines. The thesis concludes that all efforts made to progress cruise ship fresh water system automatization are valuable to improve cruise ship water systems for the future.

5.2 Recommendations and directions for further research and development

Logically, next step in development and research should be broader automatization of cruise ship's fresh water system, as this thesis work is a successful proof that automatization can be done in smaller scale systems, in this case the fresh water circulation regulation system. The next step would be to analyze the whole fresh water system, how could it be further automatized and how the whole system and the data of the system could be connected to cruise ship's automation system.

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