DEVELOPMENT OF WATER EFFICIENT CUP WASHER

Sibi Raja P (20R240)

Dissertation submitted in partial fulfilment of the requirements for the degree of

BACHELOR OF ENGINEERING

Branch: ROBOTICS AND AUTOMATION

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DEPARTMENT OF ROBOTICS AND AUTOMATION ENGINEERING

PSG COLLEGE OF TECHNOLOGY

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(Internal Examiner) (External Examiner)

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SYNOPSIS

Dishwashers are a modern machinery, reducing manual labour and conserving significant amounts of water annually. Even though they are capable of effectively cleaning a variety of dishes, they have poor efficiency in washing cups alone. In response, cup washers have emerged in the market, utilizing different cleaning mediums such as water and steam. A common limitation of existing cup washers is their inability to accommodate cups of various shapes and sizes, often tailored for specific cup types.

Achieving such versatility can be done with steam or with compressed air in combination with water. The utilization of steam eliminates the need for detergent, owing to its inherent sterilizing properties. To hold down cups of various shapes and sizes under pressure, a mechanism has been developed. The steam must reach all the spots inside the cup leaving no dead spots, otherwise a nozzle design is required to avoid such cases. The development of a universal steam-based cup washer can significantly enhance water efficiency and sustainability in dishwashing practices.

A cup washer that uses minimal amount of water in form of steam is developed, capable of cleaning cups of various shapes and sizes. The important part of the project is the design of the cup washer that can accommodate various cups. The next vital part of the project is the utilisation of the steam boiler to produce steam that will be used to wash cups. In conclusion, using steam as the primary cleaning agent has resulted in a water efficient solution for cleaning cups.

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LIST OF ABBREVIATIONS

S.No.	Abbreviation	Abbreviated Term
1	PSI	Pound per Square Inch
2	ADC	Analog to Digital Conversion
3	RTOS	Real time Operating Systems
4	CMSIS	Common Microcontroller Software Interface Standard
5	LCD	Liquid Crystal Display
6	I2C	Inter Integrated Circuit
7	SMPS	Switch Mode Power Supply
8	SSR	Solid State Relay
9	SCL	Serial Clock
10	SDA	Serial Data
11	SPI	Serial Peripheral Interface
12	UART	Universal Asynchronous Receive and Transmit

CHAPTER 1

INTRODUCTION

The chapter gives an overview of Dishwashers. It discusses the existing problem, objective of the project and the scope of the project.

Dishwashers are now very common in modern kitchens, showing a significant improvement in reducing household work and enhancing work efficiency. Initially developed to reduce the time and effort invested in manual dishwashing, these appliances have evolved from simple designs to sophisticated machines catering to diverse cleaning needs. By automating the cleaning process for dishes, utensils, and cookware through a combination of water, detergent, and advanced technologies, dishwashers have seamlessly become an integral aspect of contemporary living.

Modern dishwashers have the capability to clean dishes effectively while utilizing minimal water and chemicals. Technological advancements in these appliances have significantly reduced both water and energy consumption. They showcase advanced cleaning mechanisms with powerful jets and specialized zones, ensuring optimal stain removal. Moreover, there is a prioritization of energy efficiency through the incorporation of water usage sensors and efficient drying methods, complemented by noise reduction facilitated by advanced insulation. The utilization of durable materials and the integration of easy maintenance features, such as self-cleaning filters, contribute to the longevity of these appliances.

1.1 PROBLEM DEFINITION

Modern dishwashers, while showing significant advancements, are not perfectly tailored for small dishware like cups, cutlery potentially resulting in less efficient cleaning for such items. These dishwashers tend to use more water potentially contributing to increased water consumption. While water and energy-efficient dishwashers are available, they often are unable to clean small dishware’s effectively. Moreover, the use of special detergents containing phosphorus, sodium carbonate, and percarbonate, though effective in cleaning, poses environmental concerns if discharged into water bodies.

Paper cups, once commonly used, are now banned in many states due to the harmful chemicals, such as wax, present in their layers, especially with hot drinks are poured into them. Furthermore, in a workplace not all employees may opt for company-issued coffee cups, preferring to use their own cups, which may vary in shape, size, and material.

1.2 OBJECTIVES OF THE PROJECT

Design and develop a water efficient cup washer that consumes minimal amount of power and also cleans the cup preferably under 30 seconds. To minimize the usage of chemicals used for cleaning the cups.

Develop a universal cup holder design that can hold cups of various height and diameter firmly. The design aims to use heat and steam energy efficiently that reduces any energy wastage to the environment.

1.2 SCOPE OF THE PROJECT

- Cleans one cup at a time, further can be modified accordingly to clean multiple cups at a time
- Clean the cup that are able to fit inside the cup washer and not the cups that are bigger than the washer itself

1.4 ORGANIZATION OF THE REPORT

The report contents are elaborated in chapters as mentioned below,

- Chapter 1 provides a brief introduction of the project
- Chapter 2 researches and analyses the related journals, patents and products related to cup washers and steam dishwashers
- Chapter 3 discusses in detail about Dishwashers and their working
- Chapter 4 gives a detailed view on Cup Washers available in the market
- Chapter 5 explains the methods followed in the project
- Chapter 6 deals with the 3D and electrical design required for the cup washer
- Chapter 7 deals with the implementation and testing of the Cup Washer
- Chapter 8 handles the conclusion of the thesis and the future scope of the project

CHAPTER 2
LITERATURE SURVEY

This chapter discusses a detailed study of the various journals and patents related to dishwashers, cup washers and steam technology in dishwashing.

2.1 LITERATURE SURVEY

2.1.1 D. Johansson, "Reduction of microorganisms in dishwashers with steam" Dissertation, 2017.

The paper, Reduction of microorganisms in dishwashers with steam, by D. Johansson is a dissertation that investigates the use of steam to reduce microorganisms in dishwashers [1]. The paper has provided some concrete facts like steam can be effective in sterilizing bacteria without the use of chemicals. The placement of steam and steam distribution plays a vital role in the time taken to kill the bacteria. The steam nozzle has to be placed at an optimum distance such that the nozzle is not too close or too far from the dishes. If the nozzle is too far the effect of steam is reduced and if the nozzle is too close the cleaning effect is focused on single spot. The downside of using this steam sterilizing method is that it uses more energy compared to normal rinse cycle. This difference in energy is because of the more energy stored in the steam in form of latent heat energy. The research also proved that 2 steam generators increase the speed of sterilizing, reduces the total time taken and provides uniform steam distribution but increases the power consumption.

2.1.2 M. Eklund, "Local disinfection by steam in dishwashers," Dissertation, 2013.

This master's thesis, Local disinfection using steam in a dishwasher, by Marcus Eklund, delves into the potential of steam for localized disinfection within traditional dishwashers [2]. It uses the ISO 15883-1 standard for disinfection in the dishwasher using heat. The idea is to use the 2 factors, heat and time, to calculate an index for the quality of sterilization achieved. The minimum required quality is an A0 value of 600, which can be achieved faster if the temperature is above 80°C. The thesis concludes by highlighting the promising application of steam disinfection in elevating hygiene standards for both domestic and commercial dishwashing. Key takeaways encompass the established efficacy of steam against various microorganisms, the required steam exposure time for a given temperature, the tangible disinfection achieved by the prototype, and the potential for real-world implementation to enhance sanitation practices.

2.1.3 Larsson, “Dishwasher with steam injection: Study of steam as rinse aid in dishwashers,” Dissertation, 2014.

This research, Dishwasher with steam injection: Study of steam as rinse aid in dishwashers, investigates using steam as a rinse aid in dishwashers, potentially replacing traditional rinse aids and saving energy [3]. The study found steam to be effective in removing water spots and hard water mineral deposits, enhancing glossy finish. The for energy producing steam can be reduced by preheating the water and the cleaning chamber. Steam also helps in drying the dishes saving time wasted in the drying cycle. However, some drawbacks exist, like increased energy consumption and non-uniform steam distribution for enclosures that are big and loaded.

2.2 MARKET SURVEY

The cup washer market is currently limited, with only a few companies specializing in the production of cup washers. Among these companies, their offerings are tailored exclusively to specific cup designs, making them unsuitable for use with cups of varying sizes and materials. AUUM, a France-based company, manufactures cup washers exhibit impressive efficiency, capable of cleaning a single cup in under 20 seconds using a mere 100 ml of water. This targeted approach ensures optimal performance and compatibility with the designated cup design.

In addition to AUUM's specialized cup washers, Dayoo presents a versatile solution with its multipurpose steam cleaner. This innovative device is adept at generating hot steam in just 10 seconds, effectively eliminating bacteria. The Dayoo steam cleaner finds application in various contexts, including but not limited to cleaning knives, cutting boards, ovens, microwaves, and bathrooms. Its multifunctionality makes it a valuable tool for maintaining cleanliness and hygiene across diverse settings.

Prahantam, an Indian start-up, specializes in the production of multiple tea cup washers designed to clean up to 15 cups simultaneously. However, it is important to note that this machine is specifically tailored for small tea cups. The manual operation of the machine is required, although the cleaning process itself is automated.

On the other hand, FreshCup introduces an alternative solution with its small dishwashing machine featuring short cycles suitable for cleaning cups, cutlery, and small plates. According to the company, FreshCup can clean three cups simultaneously within a swift 30-second cycle, positioning itself as a potentially market-leading dishwashing machine in terms of speed.

Apart from these products there are a number of companies that manufacture cup rinser which can be fixed in the side of the sink. Bliote is one such company that employs pressurized water to exclusively rinse the interiors of cups without offering cleaning or sterilization functions. It's important to note that Bliote's cup rinser is focused solely on rinsing and does not provide additional cleaning or sterilization features.

Furthermore, there are other companies dedicated to manufacturing mug washers equipped with brushes strategically placed in and around the cup. These brushes play a crucial role in scrubbing, ensuring a thorough cleaning process to maintain the cup's hygiene. Companies like IFB manufacture glass cup washing machines that are specifically designed to cater to the needs of hotels, allowing for the safe and efficient cleaning of multiple glass cups without the risk of breakage. IFB's cup washers provide a reliable solution for maintaining cleanliness and meeting the hygiene standards expected in a hotel environment.

2.3 PATENT SEARCH

2.3.1 Cup Cleaning Device - JP5652684B2

The Japanese patent Cup Cleaning Device, Fig 2.1, relates to a cup washing device, and more specifically the inside and outside surfaces of a large number of cups placed on a main body are washed with purified washing water sprayed at high pressure, and then sterilized with ultraviolet rays along with high temperature steam sprayed at high pressure [5]. It has a drying structure and can quickly and cleanly clean a large number of cups at once, greatly reducing the time and effort required to clean the cups in cafeterias and at home, and improving cup hygiene.

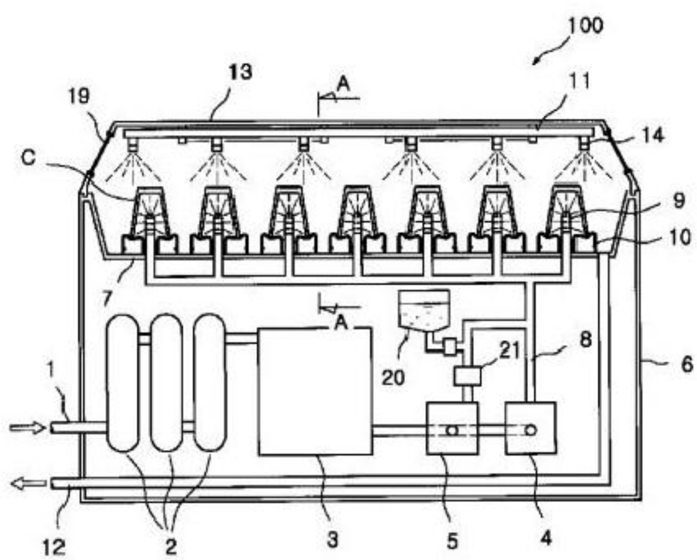
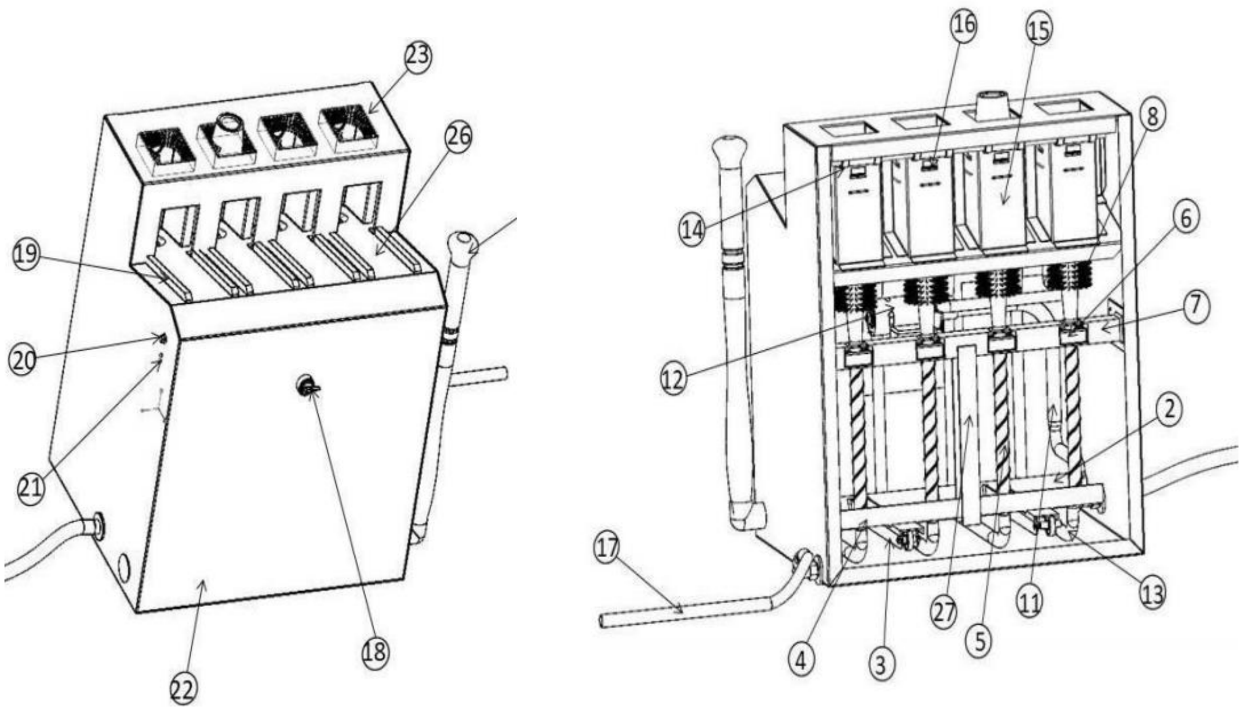


Fig 2.1 Cup Cleaning Device

2.3.2 Cup and Glass Cleaning Device

This Indian patent presents Cup and Glass Cleaning Device. It is a portable and semi-automatic machine having a structure capable of cleaning 15 cups and glasses simultaneously in fast mode by operating a single handle, thus it is a useful machine at tea stalls, hotels, and public areas where the inner and outer surface of the cups are cleaned. The present invention is operated with a single handle by using detergent/Cleaning solutions added into water [4]. Fig 2.2 (a) shows the front view and (b) shows the opened back view of the tea cup washer. The machine incorporates a sliding screw mechanism which helps in moving the brushes up and down, thus cleaning the cups thoroughly. The machine is semi-automated and required human intervention for operating the work flow. Another major disadvantage with this model is that it is capable of washing only chai glasses and not cups of all materials and sizes.



(a) Front view **(b) Back view**

Fig 2.2 Cup and Glass Cleaning Device

2.3.3 Tea Cup Washing Apparatus

The disclosed invention [6], Fig 2.3, presents a tea cup washing apparatus designed for effective cleaning using running water. This device employs a two-way cleaning process, featuring a rotary brush on one side with hard bristles and conical nozzles on the other. The twin rotary brush, powered by an AC motor, has small holes allowing running water to pass through.

By manually holding a tea cup or glass against the bristles, the swirling action of the brushes ensures thorough cleaning of the inner surface. Subsequently, the cup is inverted and placed on conical nozzles, allowing vertically flowing running water to achieve a turbulent action for comprehensive inner surface cleaning. A foot pedal, positioned at the bottom, enables manual activation of both the rotary brush rotation and the running water simultaneously. Additionally, a separate foot pedal on the right side operates the water flow through conical nozzles for cups placed in an inverted position.

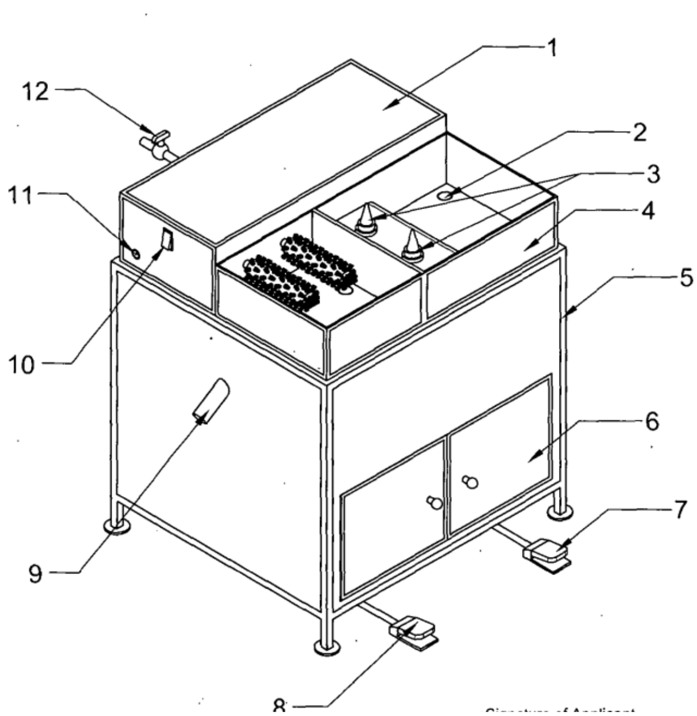
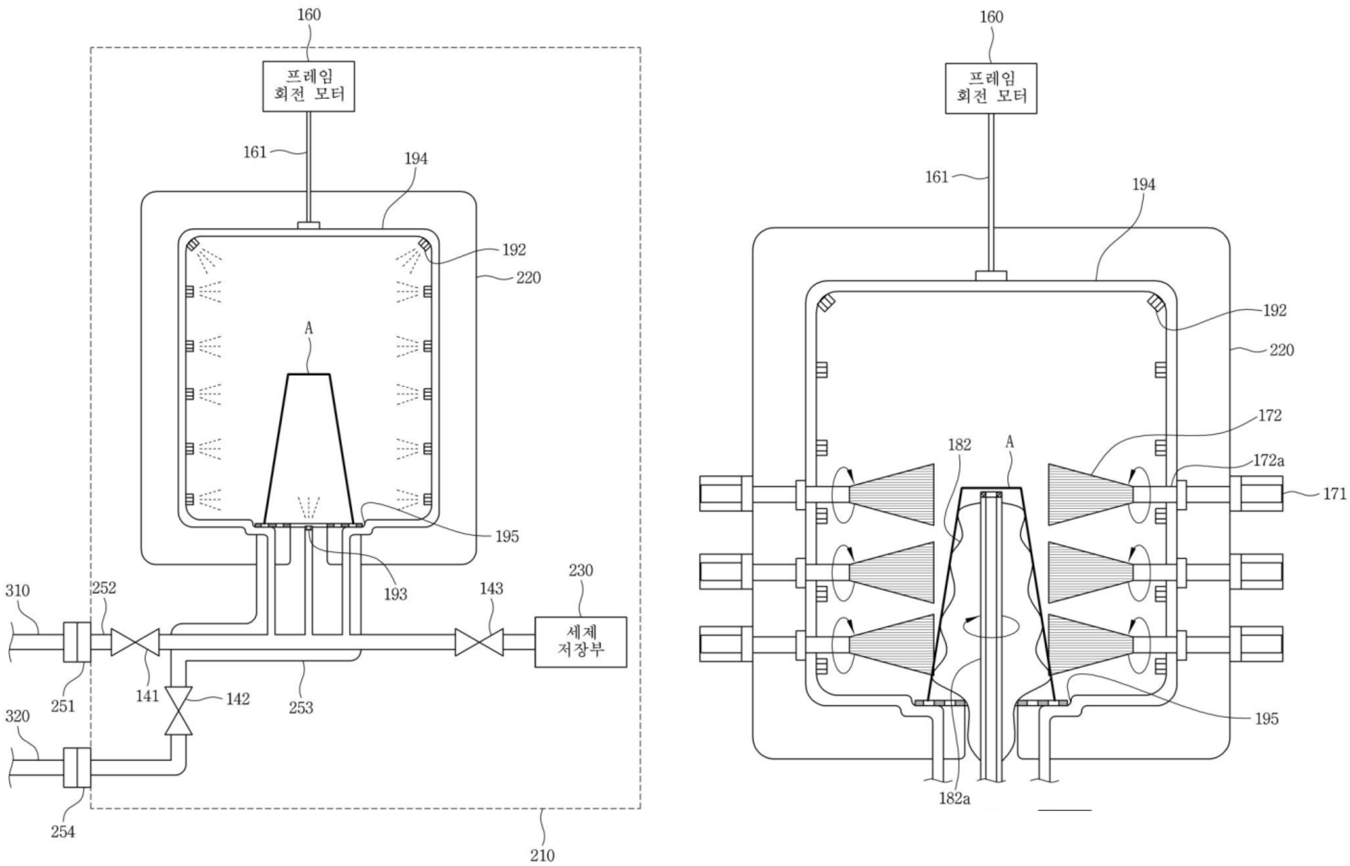


Fig 2.3: Tea Cup Washing Apparatus

2.3.4 Automatic Cup Washer of Compact Type

The described automatic cup washer features a rotating frame propelled by a rotation motor and a support pad with friction protrusions, creating a concave entrance surface for cups [7]. In Fig 2.4 (a) the rotating frame has external nozzles fixed to it for spraying water, and in (b) external brushes for cleaning cup exteriors. The system includes UV lamps in a fixed frame for ultraviolet sterilization, a heater for generating heat, and a fan for heat circulation. The cup is kept stationary on the support pad and only the frame attached with nozzles and brushes rotates. It incorporates three valves: one for supply pipe control, another for draining wastewater, and a third for detergent supply.

The support pad prevents cup slippage with through holes for water discharge and friction protrusions. The central hole in the support pad directs hot air to cup surfaces. The washer efficiently discharges hot air generated by the heater and fan to the storage unit and drain pipe, offering a compact and effective automatic cup washing solution.



(a) Rotating frame with nozzles **(b) rotating frame with cleaning brushes**

Fig 2.4 Automatic Cup Washer

2.4 OUTCOME OF THE LITERATURE SURVEY

- Steam is an effective method to reduce water and chemical consumption in dishwashing
- The temperature and pressure of the steam chamber plays a crucial role in the energy consumption and the time required for cleaning the dishes
- Hot steam, above 120 °c at 1.2 bar, can be used for cleaning and sanitization
- Once in contact with the atmosphere, the cleaning effectiveness of steam drops rapidly
- Maintaining the desired temperature of steam requires a significant amount of energy and sensor to monitor the closed chamber

CHAPTER 3

DISHWASHER

The chapter Dishwasher discusses in detail about the basics of dishwashers, the dishwashing process, advantages and disadvantages.

A dishwasher is a household appliance designed to automate the process of cleaning and sanitizing dishes, utensils, and cookware. It consists of a water pump, heating element, detergent dispenser, and racks or trays to hold the items to be washed. Dishwashers offer several benefits, including time and energy savings compared to handwashing, consistent cleaning performance, and the convenience of freeing up time for other tasks.

3.1 PARAMETERS OF DISHWASHING EFFECTIVENESS

A given dishware can be cleaned using any of the following methods: mechanical action, chemicals or detergents, time and temperature.

1) Mechanical Action - Mechanical action in cleaning involves the application of physical force to remove dirt and contaminants from dishware. This force can be exerted through various means, such as scrubbing, brushing, or agitation. The importance of mechanical action lies in its ability to dislodge particles that may be adhered or stuck to surfaces.

For example, using a brush to scrub a dirty surface increases the mechanical action, aiding in the effective removal of stubborn dirt and stain.

2) Chemicals or Detergents - The use of chemicals or detergents is a fundamental aspect of cleaning processes. These substances are designed to break down, dissolve, or emulsify contaminants, making them easier to remove. Chemicals enhance the cleaning efficiency by altering the chemical nature of the dirt or grease.

For example, using a soap or detergent to wash dishes helps break down grease, allowing it to be rinsed away more effectively. Choosing the right cleaning agent for the specific type of contaminants is crucial for achieving optimal results.

3) Time - Time plays a crucial role in the cleaning process as it represents the duration for which cleaning agents are allowed to act on surfaces. Allowing sufficient time enhances the effectiveness of the chemicals in breaking down and lifting dirt. At the same time allowing the chemicals to sit for too long can also result in undesirable effects such as deposition of a white layer on the surface of the dishware.

For example, using a dishwashing liquid and letting it sit on surfaces for a few minutes before scrubbing gives the cleaning agents the necessary time to work on soap scum, stains, and other residues, resulting in a more thorough cleaning outcome.

4) **Temperature** - Temperature refers to the application of heat during the cleaning process. Higher temperatures generally enhance the activity of cleaning agents. This is because many chemical reactions and the solubility of substances increase with temperature. Heat can also soften or melt certain materials, making them easier to remove.

For example, using hot water to clean greasy dishes not only helps to melt and loosen the grease but also reduces the time taken to wash the dishes, facilitating more efficient cleaning.

3.2 WORKING PRINCIPLE OF DISHWASHERS

First, fresh water enters the water storage tank via the fresh water supply, which is regulated by a solenoid valve. Water is then directed to the water distributor from the water storage and it is channelled into the salt compartment and resins. The salt compartment and resins help in effectively transforming hard water into a soft variant, ensuring optimal cleaning without leaving any unwanted residue on dishware like hard water mineral residue.

After turning the hard water soft, water reaches the tub's base. Water is filled up to a pre-determined level, as measured by the float valve. Subsequently, the circulating pump draws water from the base through the filter and propels it through tubes to both the upper and lower arms. Parts of a typical household dishwasher is shown in the Fig 3.1.

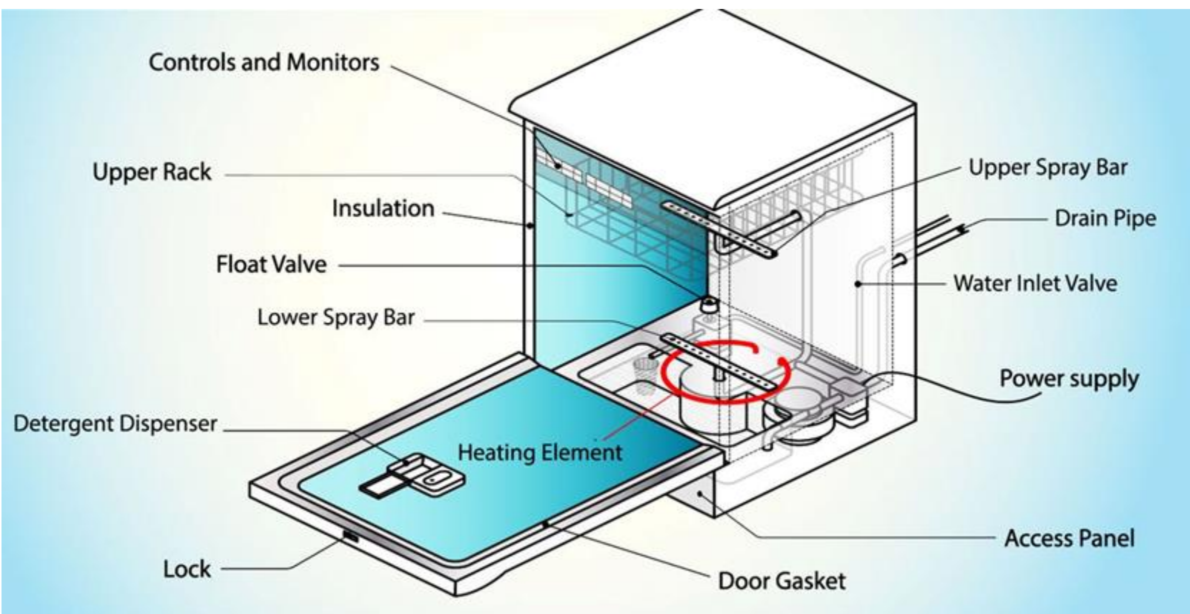


Fig 3.1 Parts of Dishwasher

The arms are a main part of the cleaning process. The lower spray arm, situated at the dishwasher's bottom, rotates during the washing cycle, directing water upward to cleanse the lower rack. Conversely, the upper spray arm, positioned above the upper rack, rotates to spray water downward, ensuring comprehensive coverage for items in the upper rack. These spray arms receive pressurized water from the dishwasher's pump, which is mixed with detergent to effectively clean dishes. Their rotation or movement is designed to cover the entire dishwasher interior, reaching both upper and lower racks. The force and direction of the water expelled through nozzles aid in breaking down food particles and stains. These arms do not have a dedicated motor but exhibit rotation through variable nozzle angles and water pressure acting on the arms.

The first wash cycle is known as pre-wash. Pre-wash helps in removing large dirt particles and loosens other hard stains. This cycle uses normal freshwater from water storage tank and forces the water onto dishes using the spray arms. The pre-wash is a short cycle that uses minimal amount of water. Once the cycle is completed the dirty water is drained and new a set of fresh water is taken in from the water storage.

In the second wash cycle, the heating element activates and at the same time detergent is added. The dishwashing detergent is usually in the shape of tabs, which is introduced into the water bottom automatically at the right time. The second wash is the longest cycle of the dishwashing process, the spray arms forces pressurized hot water mixed with detergent for about 40 minutes or more depending on the users wish.

The third and the final wash cycle is rinsing. The rinsing cycle removes any detergent or stains left on the dishes in the second cycle. Normally hot water is used for rinsing cycle while some dishwashers use rinsing aid which serves the same purpose as hot water rinse and also additionally help in sanitizing the dishes. As the washing cycle concludes, water exits the system by passing through a steel wire mesh and subsequently filtering out, completing the seamless operation of this sophisticated appliance.

The heating element used in the dishwasher may take the form of a tube and shell heat exchanger or a heating coil immersed at the tub's bottom. Heating coil is a straight forward method that uses more energy and is not much efficient. Tube and shell heat exchangers, in Fig 3.2, are very efficient as they preheat the next set of water in the previous cycle. Heat exchangers usually transfer heat energy from one fluid to another through means of contact of the heated element and the desired fluid. The heated element is passed through tubes that are wound multiple times and the fluid to be heated is passed through the shell that is placed around the tube winding. Continuous temperature monitoring ensures the maintenance of the desired temperature.

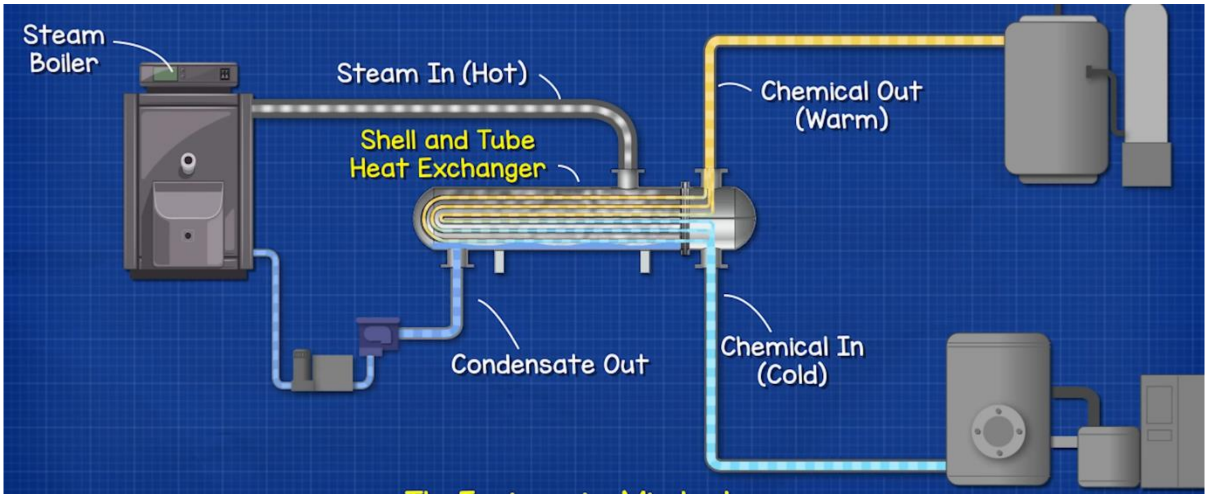


Fig 3.2 Flow of Tube and Shell heat exchanger

3.3 DETERGENTS AND RINSE AID

Dishwashing detergents contains various chemicals like alkalis, bleach, enzymes, fillers, solvants, complex binders, surfactants and perfume. Alkalis help in raising the pH value of the water and can break down fats and proteins. These fats and proteins present on the surface of the dishware are hard to remove because of their organic nature. Alkalis break down and loses the adhesion of these organic traces which can be easily washed away. Bleach is used to counteract color coatings on the dishes and complex binders help in increasing the effectiveness of the detergent.

The detergents being so helpful in the cleaning process can cause major environmental issues like alkalis released in large quantities in water bodies results in poor purification process of the water bodies. Bleach contains sodium hypochlorite which is toxic to aquatic life organisms. Complex binders are also environmentally hazardous components.

Rinse aid, which is added during the final rinse of the rinsing process, reduces the surface tension of the water, which makes it easier to run off the dishes. This is good because the dishes dry faster and lime deposits from hardwater are reduced or completely eliminated. Hard water contains a large amount of dissolved minerals, and after the third wash cycle once the water evaporates on the dishes, a white film of so-called lime deposits forms, which can be difficult to remove and reducing the glossiness of the dishwares.

Rinse aid is a mixture of synthetic chemicals, one of which is non-ionic surfactants. All surfactants used in cleaning agents must be biodegradable. Surfactants are a collective name for substances whose function is to lower the surface tension in liquids. As surfactants possess this property, it means that they are almost always toxic to aquatic organisms and are environmentally hazardous.

3.4 PROBLEMS WITH DISHWASHERS

Dishwashers, while offering convenience, come with some considerable downsides. Firstly, they are not tailor-made for small dishwares, often leading to less efficient cleaning for items of small size. Additionally, despite their automated nature, dishwashers tend to use more water, even for cutleries and smaller dishware, contributing to higher water consumption compared to manual washing. Moreover, water and energy-efficient dishwasher models, which aim to address environmental concerns, come at a higher cost.

Over time, some dishwashers may emit unpleasant odours, posing a hygiene concern. Furthermore, the use of special detergents containing phosphorus, sodium carbonate, and percarbonate raises environmental issues, particularly in terms of water bodies health. These drawbacks highlight the need for careful consideration of the environmental impact and suitability for specific dishware sizes when opting for dishwasher usage.

Dishwashers are household appliances designed to automate the process of washing dishes efficiently by minimizing the use of water and energy. Dishwashers are intelligently engineered so as to provide proper cleaning and sanitization. However, dishwashers are not efficient for use in small-scale coffee shops and IT offices, as only cups need to be cleaned. Hence cup washers are invented which is discussed in the next chapter.

CHAPTER 4
CUP WASHERS

This chapter discusses the various existing technologies and products relating to Cup Washing and discuss their advantages and disadvantages.

Cup washers are dishwashers, that are specifically designed to clean tea, coffee, wine, soft drinks cups, mugs or glasses. The current market for such cup washers is pretty much non-existent, nevertheless there are lots patents for cup washer models and there are already few products in the market. The primary goal of such cup washers is to clean a large number of cups in a short time automatically improving health and sanitization.

4.1 CUP WASHERS IN MARKET

4.1.1 AUUM

Auum is a France based company that aims to eliminate the use of one-time paper cups in a workplace like IT offices. “Glasses are cleaned, disinfected, and dried in a record time of less than 10 seconds. It provides an instant cleaning experience” so claims the company. The Auum is redesigned with existing technologies to reduce water consumption and use no chemicals for cleaning glasses.

The glass cup is encapsulated between two surfaces, Fig 4.1 (a), to provide a very precise cleaning. Seven nozzles inject steam at high pressure and high temperature on the glass. Six seconds later, the steam supply stops, and a high-speed turbinated air flow is sent over the glass to dry it and cool the cup [9].

Once the boiling temperature of water is reached, it changes from liquid to gas. Once it turns to steam it can condense again very quickly to the contact of a cold air flow. Small particles of liquid water remain suspended in the steam. This mixture of liquid and gaseous water is called wet steam. The Auum-S, is based on dry steam technology. This patented technology heats the steam to over 140 °C (284 °F), high above the boiling temperature of 100°C (212 °F). By increasing the thermal energy of the steam, we can obtain new properties and high performances using a very small amount of water. Auum-S has 7 steam jets which eject a pressurized mixture of 93% dry air and 7% water steam, for a total of less than 20 ml per cleaning cycle. The appearance of the Auum cup washer during the cleaning cycle is shown in the Fig 4.1 (b). The cup is encapsulated by upper and lower cleaning part that is closed and sealed during washing.

(a) Cup Placed – Machine OFF **(b) Cup Washing – Machine ON**

Fig 4.1 The Auum Cup Washer

Table 4.1 Specifications of the Auum Cup Washer

SPECIFICATION	
Water tank	1.6 L
Drain pan	1.6 L
Cycle time	10/20 seconds
Technology	Dry steam
Temperature	140 °c
Water consumption	20.7 ml
Energy	4 Wh/cycle
Detergent	none
Dimensions	57 x 41 x 38.2 cm
Weight	32 kg

Table 4.1 gives the important specifications of the Auum cup washer. The dry steam technology is helpful in reducing the amount of water consumed and effective cleaning is possible because of temperature going upto 140 °c.

The downside of such great cup washer is that it is capable of cleaning only the Bodum glasses specially made for Auum. It is a double walled glass, provides heat insulation properties. Auum claims that the cup was designed by Bodum in such a way that it provides an optimal cleaning experiance. Moreover, the Auum cupwasher is capable of cleaning only one cup at a time.

4.1.2 PRAHANTAM

The Prahantam, Fig 4.2, is an Indian based tea glass cleaning machine made for Tea Stalls, Cafes & Canteens providing Rapid Cup & Glass washing experience. The mission of the Prahantam tea glass washer is to promote reusable cups & glasses to avoid harmful paper cups. The machine is capable of cleaning upto 9 glasses at a time by means of mechanical scrubbing action. The company claims that it takes only 2-3 seconds to wash a single glass cup. The old model is patented (Cup and Glass Cleaning device) and is semi-automated with a manually operated handle. The handle helps in taking the tea glass in, washing them and pushes it up and out [10]. Fig 4.2 (a) shows the old model of the tea glass washer, capable of cleaning only 2 glasses at a time. Fig 4.2 (b) shows the new updated model of the tea glass washer that is capable of cleaning upto 15 cups at a single time.

(a) Old model **(b) New Model**

Fig 4.2 Prahantam Tea Glass washer

The Prahantam looks like a perfect choice for washing the Indian coffee and Chai glasses, which they are for tea stalls and hotels, but for workplaces like IT offices this is not the best option. It ensures hygiene but comparatively uses more water and detergent for a washing cycle.

4.1.3 DAYOO STEAM CLEANER DISHWASHER

The Dayoo, Fig 4.3 (a), is a portable dishwasher that cleans and sanitizes dishes using a high-pressure steam jet. Dayoo's high-pressure jet, which uses a spray of tiny water droplets heated to 221 °F (105 °C) to clean dirt off plates in seconds without soaking, soaping, scrubbing, or even getting hands dirty or greasy, is designed to make cleaning utensils faster, more effective, and less expensive to operate shown in Fig 4.3 (b).

The heated steam efficiently removes grease and food residues from plates and utensils, while the aerated nozzle conserves water compared to standard faucets. A wall-mounted module pressurizes and heats the water, with a hand-held shower used for spraying and cleaning utensils. The system is equipped with a single stepless dial for adjusting water pressure and a trigger on the hand-held shower for activating the hot steam. Dayoo can heat water up to temperatures of 221 °F and remains safe to handle with bare hands as long as the users handle is 4 inches away from the nozzle [11].

(a) The Dayoo steam cleaner

(b) operating the steam cleaner by hand

Fig 4.3 Dayoo Steam washer

Table 4.2 Specifications of the Dayoo Steam Dishwasher Easy Steamer

SPECIFICATION	
Water tank	1.2 L
Steam Discharge Flow	45-120 ml/min
Steam Pressure	0.3 MPa (3 bar)
Technology	Wet pressurized steam
Temperature	105 °c
Detergent	none
Power	1800 W
Dimensions	411 x 200 x 155.5 mm
Weight	2.35 kg

Table 4.2 gives the specifications of the steam dishwasher. The important features to be observed here are the steam discharge flow, working pressure, technology used and the temperature of the steam. The steam pressure is vital for the proper cleaning of the dishware.

4.1.4 CUP RINSER

Cup rinsers are devices commonly used in cafes, bars, and restaurants to quickly and efficiently rinse glasses and cups. They typically consist of a small basin with a water jet or spray nozzle positioned above it. When a glass or cup is pressed down onto a platform, a stream of water is released, rinsing the inside of the vessel. This helps to remove any dust, debris, or residues, ensuring that the glassware is clean and ready for use. Cup rinsers are often integrated into the workflow of drink preparation, making it easier for staff to maintain cleanliness and hygiene standards [13].

Cup rinsers provide convenience but come with limitations. They are effective for rinsing but not for thorough cleaning, raising hygiene concerns. Additionally, they do not clean the exterior of the cup, which is a significant drawback, especially in Indian tea shops. In Fig 4.4 (a), the cup rinser is depicted, highlighting its limitation in cleaning only the inside of the cup while leaving the brim of the cups inadequately cleaned. Fig 4.4 (b) shows the nozzles of the cup rinsers through which high force water gushes out spreading at various angles resulting in effective rinsing.

(a) Operating the Cup Rinser

(b) Nozzle Design for Cup Rinser

Fig. 4.4 Cup Rinser

There are very few cup washers in the market and each have their own advantage and disadvantage. The Auum cup washer utilizes the best technology and completes the cycle with less amount of water and time. But it lacks the ability to clean cups of various sizes and shapes.

The Prahantam is one of the best solutions for Indian chai and coffee glasses as it claims to finish a cycle within 2-3 seconds. The company has gained momentum since it introduced itself to the shark tank and the got multiple investments. However, the machine is not capable of being used in the workplaces and uses more water and chemicals compared with Auum and Dayoo.

The Dayoo steam dishwasher utilizes low wet pressurized steam for cleaning dishes, bathrooms, floors and all kinds of stuff. It provides excellent high speed cleaning experience with low water usage. The advantage is the technology it uses and the disadvantage being the need to use it manually with hands for steaming. This technology can be replicated for building a cup washer, for which the approach and methodology is presented in the next chapter.

CHAPTER 5
METHODOLOGY

This chapter discusses the process involved in cleaning the cup and gives a detailed explanation of the modules and components used in the prototype of the cup washer.

5.1 BLOCK DIAGRAM

The block diagram, Fig 5.1, consists of three main sections: steam boiler module, detergent storage module and the steam outlet control module. The steam boiler uses a diaphragm pump to pump outside water into the steam boiler through a non-return valve.

The most important part of the setup is the steam boiler module. The steam boiler mainly depends on three sensors for its proper and safe operation. The sensors used here are temperature, pressure and water level sensor. The pressure sensor is used to monitor the steam pressure and maintain the pressure at a desired pressure level of 20 – 23 PSI. At this pressure level the water temperature is usually around 120 degrees Celsius. This high-water temperature and pressure ensure proper and a hygiene cleaning experience. If the pressure drops below 20 PSI the heater is turned ON and turned OFF above 23 PSI.

The temperature sensor is used to validate the temperature and pressure relation, as the water heats up, the temperature rises, and the pressure within the closed chamber should also increase. Meaning that temperature and pressure are directly related to each other, for a given temperature the pressure inside the closed chamber must be within the range. The water level sensor is used to monitor the water level inside the steam boiler. If the sensor returns an ADC value less than the pre-set value, the controller turns ON the diaphragm pump and pumps IN water until the water level reaches the pre-determined level.

In succession to the steam boiler a single steam outlet is taken, in which a solenoid valve is connected to access the detergent storage whenever needed. The detergent storage is accessed only during the wash/detergent soak cycle and is kept closed during the remaining time. The steam outlet control module is used to direct the steam either to the outer nozzle or to the inner nozzle.

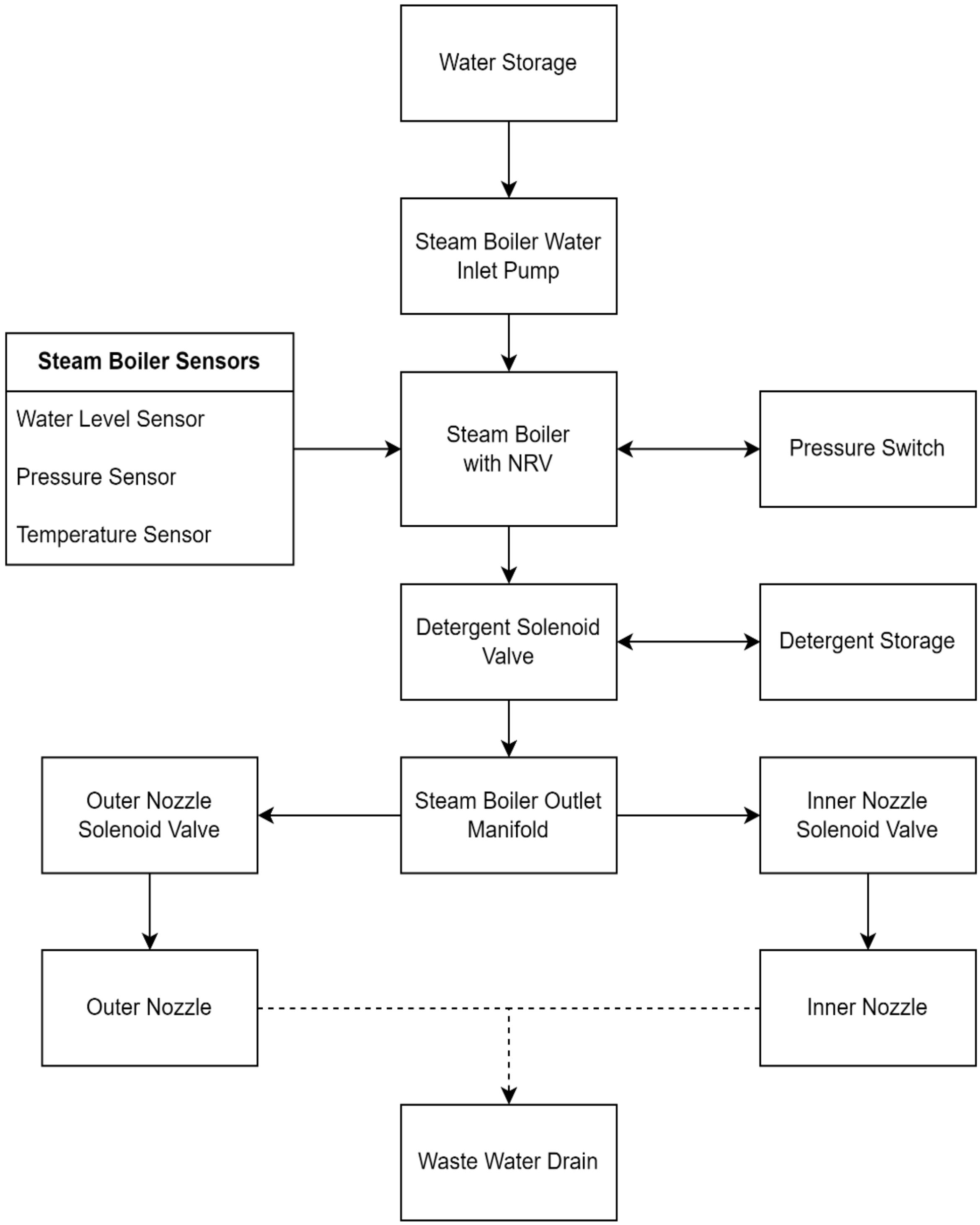


Fig 5.1 Block Diagram

5.2 PROCESS FLOW

In machine start-up, once the machine is powered, it automatically begins to check the steam boiler conditions through the sensors mentioned earlier. It is important to note that the steam can only be taken if the temperature and pressure are above a certain level, this is because below that specified level of temperature steam wouldn't exist. If button is pressed in such a state, the valve would open but there would be no steam out.

The controller program is implemented with RTOS so that all the process are monitored in real time and no tasks miss their deadline [12]. The tasks keep a track of the sensor readings and performs actions according to the received ADC values. Once all the steam boiler conditions are met and the user presses the button, the steam exits the boiler through dedicated piping to the manifold. The manifold has two outlets: one for inner nozzle and the other outlet for outer cleaning nozzle. The steam out through these pipes are controlled through solenoid valve.

During the cleaning cycle either the inner nozzle is opened or the outer nozzle is set to open. This is done not to drastically reduce the pressure inside the steam boiler during the cleaning cycle. The other way to prevent sudden pressure drop is to increase the pressure maintained inside the chamber. The steam boilers pressure can be adjusted using the microcontrollers program.

First of all, the cup is placed upside down such that the cups mouth rests on the inclined portion of the support base. The machine is programmed to run 3 controlled cycles to wash the cup more effectively. The first cycle is the pre-wash cycle, this helps in removing most of the large visible dirt's and stains in the cup. This process takes the most time among the three other cycles.

The second cycle is the detergent wash cycle. The negative pressure created from the steam flow is used to suck the liquid detergent from the detergent storage chamber. Once the first cycle is over the detergent solenoid valve is opened for few seconds and closed soon after. The liquid detergent is let to sit on the cup for few seconds. During this waiting time, the outer surface of the cup is washed whose solenoid was shut off until now. The outer cups washing duration is comparatively shorter, considering that usually there isn't much dirt on the outer part of the cup.

After a very short waiting time the third and the final cycle begins. The aim of this cycle is to wash away all the detergent on the cup. This cycle acts as the rinsing cycle, similar to dishwashers third cycle. Apart from rinsing the cup it also helps in giving a glossy finish to the cup without any hard water or milk fat/protein stains. The high temperature steam naturally kills any germs/bacteria and acts as a disinfecting agent. All the wastewater drains after every cycle without interrupting the cleaning process. The process flow is shown in the Fig 5.2.

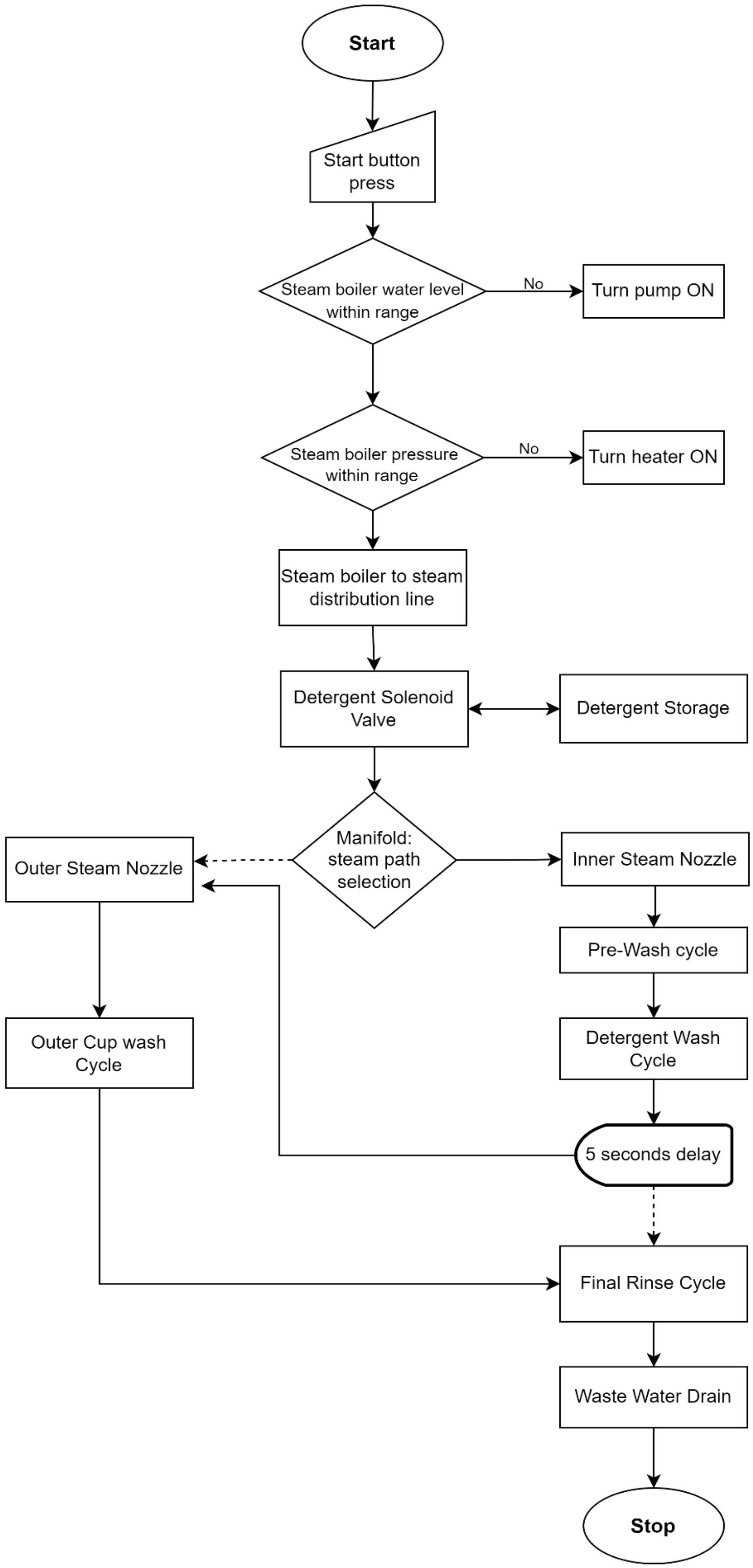


Fig 5.2 Process Flow

To immobilize the cup at a single point during the washing cycle, a compression spring is placed on the lid of the cup-washer. The spring is carefully selected and designed in such a way that it must be capable of holding cups of various sizes and heights. The springs tension must also be considered as any compression on the spring over 50 - 70% reduces the springs life over time. Therefore, to improve the effectiveness of steam cleaning and springs life the overall height of the cup-washer is reduced as much as possible.

As mentioned earlier the sensors are monitored in real-time using RTOS(CMSIS) to maintain the steam boilers condition so that there is steam available all the time. If the pressure drops below the specified range, the heating coil is turned ON inside the steam boiler and heats the water. This heating of water produces steam and automatically increases the pressure contained inside a closed chamber. If water level drops below the set limit, it turns on the water pump and forces the water through the one-way valve fixed at the steam boilers end. This ensures that there is water flow only into the boiler and not out of the boiler under pressure.

The Fig 5.3 shows the working flow of the steam boiler module. The setup also has a pressure gauge and pressure switch to monitor the pressure of the steam built inside the steam boiler. The pressure gauge is a mechanical instrument helpful in monitoring the pressure inside the steam boiler. The pressure gauge has a range of 0 – 30 PSI above which the gauge will get permanently damaged and can no longer be used again. So, the pressure must be maintained below 30 PSI at any cost. This can be achieved with the help of pressure switch.

Pressure switch is an electro-mechanical device used to turn ON and OFF the heater depending on the program and the pressure inside the steam boiler. If the pressure is below the set level (20 PSI) the controller turns ON the SSR by turning ON the relay, once the set maximum pressure is reached the controller turn OFF the SSR by turning OFF the relay. In case of some kind failure in the sensor the controller may not turn OFF the heater at the set level (23 PSI), this is where the pressure switch comes into picture. The pressure switch is usually set at a pressure little more than the pressure set in the program, say 25 PSI. In case of pressure sensor failure, the pressure switch automatically turns OFF the heater at 25 PSI.

The water level sensor uses the principle of conductivity to measure the water level. In more accurate terms the water level sensor either indicates a high state or low state depending on whether the water is touching both the rods (high level), or the water is not touching either of the rods (low level). Water passes electricity when current is applied into it. Water conducts current with some voltage losses, but it is enough to get the water level reading. The water level sensor must always show a non-zero value in order to turn ON the heater, otherwise the water pump for the steam boiler is turned ON.

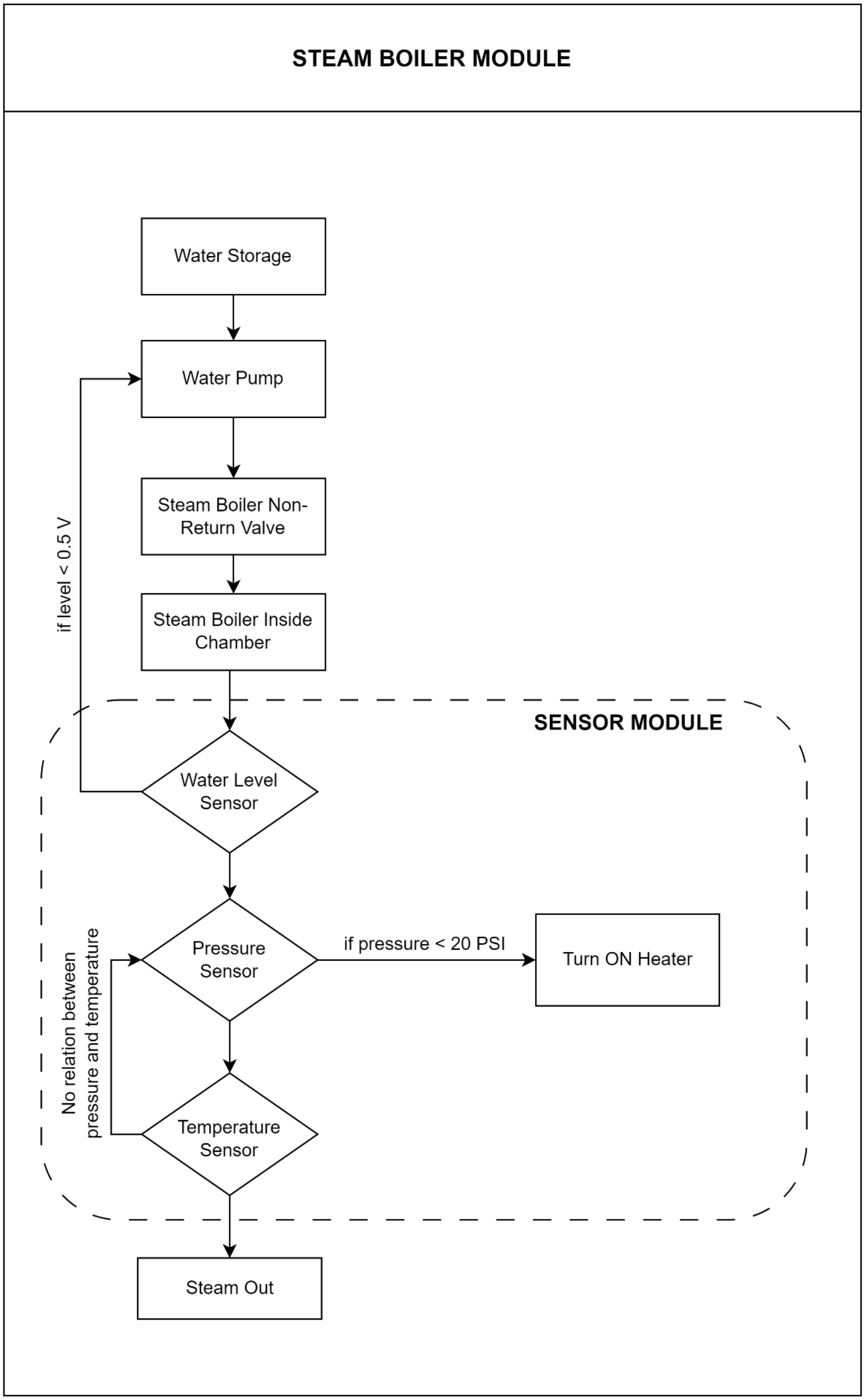


Fig 5.3 Working Flow of Steam Boiler Module

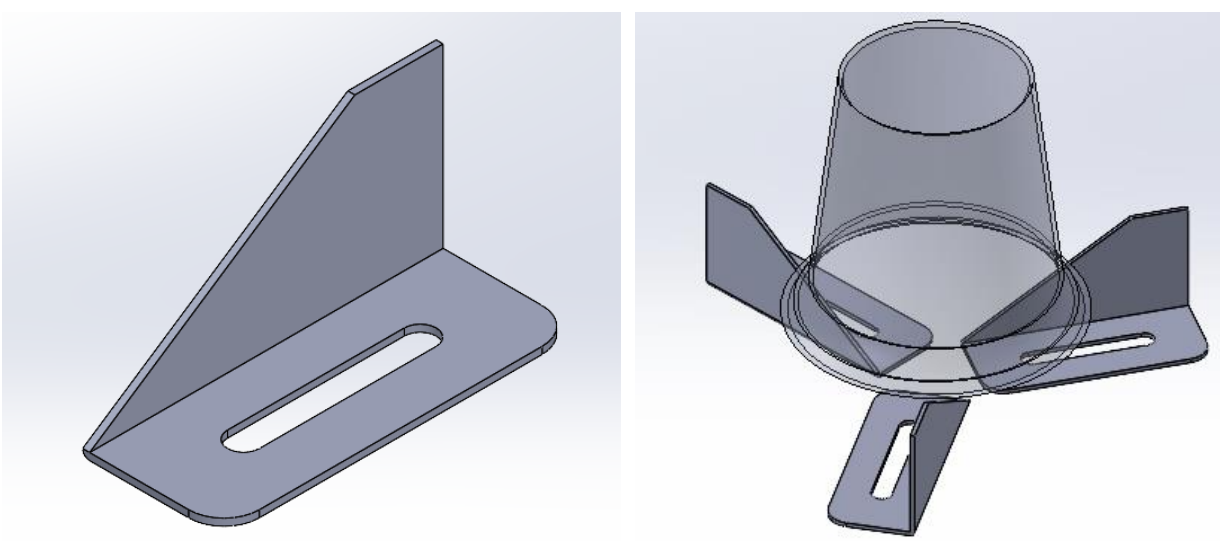
CHAPTER 6

CAD DESIGN AND ELECTRICAL DESIGN

This chapter presents with the CAD modelling and the circuitry that is implemented in the cup-washer. It gives an elaborate view on the design of various parts of cup washer and the electrical components.

6.1 CAD DESIGN

The 3D design was created using Solidworks 2022 software. The resulting design prioritizes the ease of acquiring the necessary parts in a short span of time. The main challenge in the design of the cup washer is the universal design that must be capable of holding various cup sizes (cup of different height and diameter). Fig 6.1 (a) depicts a design for the cup holder, with the cup positioned upside down so that its mouth rests on the inclined surface shown in Fig 6.1 (b). This design, Fig 6.1 (b), helps in immobilizing cups of different diameters and holds the cups rigidly. The slots cut out from the cup holder is useful in testing the effect of steam on the cup that is to be placed at various height adjustments made from it. The inclined part of the cup holder is too rough for glass cups and thus a thin layer of silicon coating is applied on top of the inclined part to give a soft cushion. The silicon used is capable of withstanding high temperatures and does not deform when it comes in contact with steam.



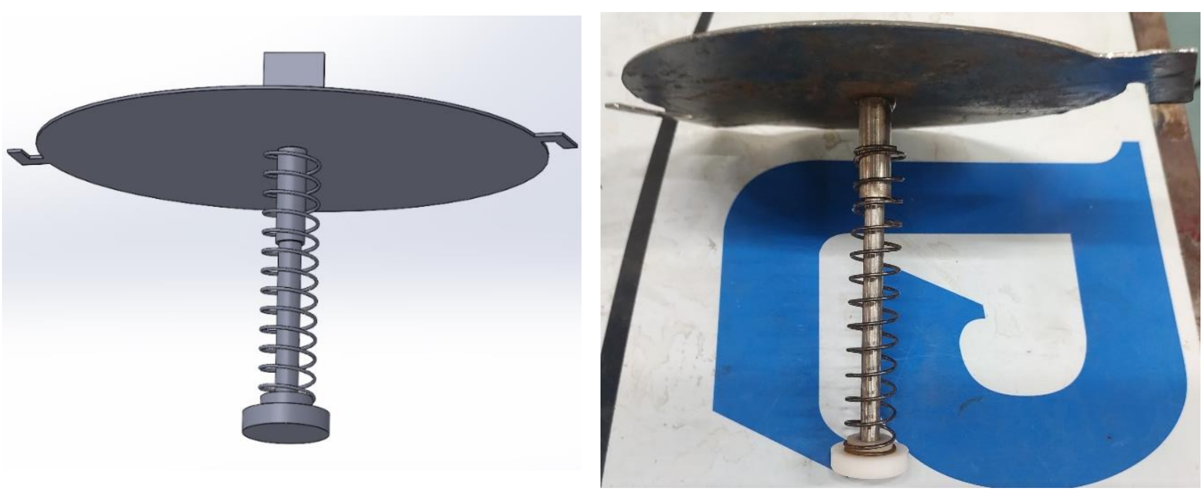
(a) Individual Slot Design **(b) Assembled Slot Concept**

Fig 6.1 Cup Holder Design

Implementing only the Cup Holder presents a problem: high-pressure steam causes the cup to be thrown off due to the pressure. To prevent such an undesirable case a spring support has to be developed. The spring rests on the bottom side of the cup which is placed upside down. The spring must also touch the bottom of the smaller cup and the larger cup. So, a compression spring of length 100 mm, thickness 1.2 mm and 20 mm diameter are designed that has enough tension to hold the cups in place without damaging the cups.

The design of the spring support is shown in the Fig 6.2. The plate is capable of sliding up and down the rod, Fig 6.2 (a), while the spring is coiled around the rod. The end of the rod is fixed with polypropylene. Fig 6.2 (b) shows the developed polypropylene base that directly comes in contact with the bottom of the cup. Polypropylene is used as it is soft on the cup and does not damage the cup. The cups are placed upside down so as to facilitate water drain from the cups after washing them.

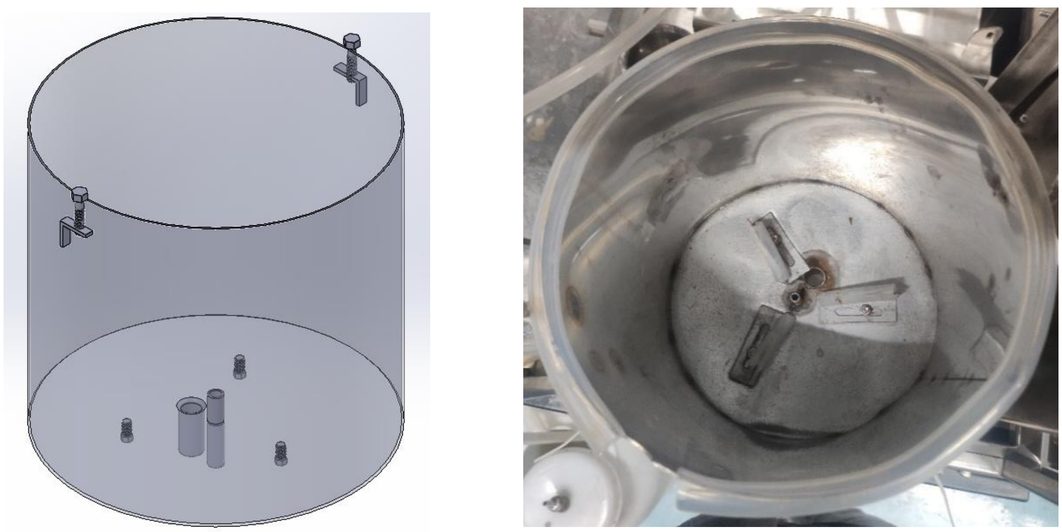
(a) Top View of Lid with Spring Support Below



(b) Bottom View of Lid with Polypropylene Stopper at End of Spring Support

Fig 6.2 Spring Support

The three inclined cup holders are placed 120° apart, Fig 6.3 (a), and the position of the three cup holders can be adjusted using the M4 nuts and bolts. By bringing the cup holders closer it is possible to get more steam coverage and it is possible to clean the places that are closer to the mouth of the cup, but by doing so the variety of cup sizes it can accommodate greatly reduces. If the cup holders are moved backwards, the effective height of the cup is reduced and it is possible to accommodate cups of various sizes. But if the cup holders are moved back too much, then small cups cannot be accommodated on the inclined surface of the cup holder. Fig 6.3 (b) shows the bottom view of the body of the cup washer, the small pipe is used for steam inlet and the bigger pipe is used to drain the dirt from the washer.

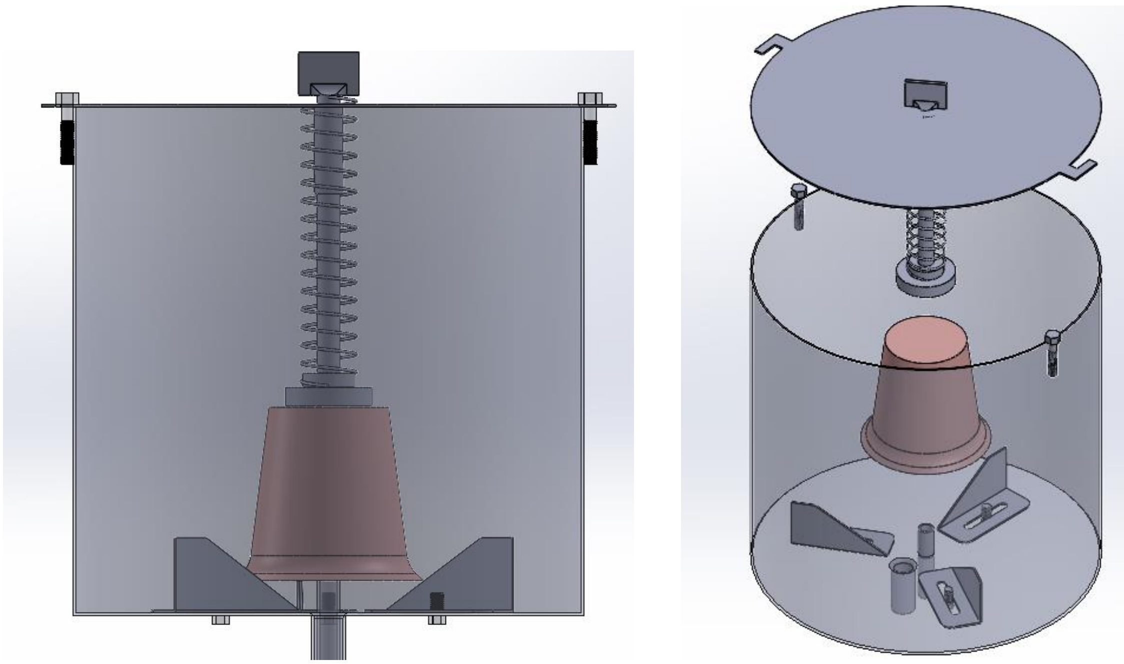


(a) isometric CAD model view (left) and implemented cup washer (right)

(b) tilted bottom CAD model view (left) and implemented cup washer (right)

Fig 6.3 Body of The Cup-Washer

The completely assembled 3D model of cup washer is shown in the Fig 6.4. First the cup is placed upside down on the cup holder and then the lid is placed carefully on top of the cup washer such that the spring holder's polypropylene bottom lies on top of the cup as shown in the first image of Fig 6.4 (a). The lid is rotated and locked in place without any movement. The steam is passed through the smaller pipe for cleaning. Fig 6.4 (b) shows the cup washer accommodating cups of two different types and holding the cups in place firmly.



(a) 3D Model Showing the Assembly of Cup and Spring Support to Hold the Cup

(b) Implemented Cup Washer Holding Cups of Different Types

Fig 6.4 Assembled Cup Washer

6.1 ELECTRICAL COMPONENTS AND THEIR SPECIFICATIONS

Table 6.1 Electrical Components Bill of Materials

S.No.	NAME	SPECIFICATION	QUANTITY (Nos.)
1	STM32 F103C8T6	32 bit, 73 MHz, 64 kb/20 kb, 5 V/3.3 V, 40 pins	1
2	Relay module	4 Channel 5 V – 24 VDC	1
3	LCD with I2C module	16x02, VCC 5 V	1
4	Pressure sensor	5 V, 30 PSI, 12-bit resolution	1
5	Temperature sensor (MAX6675)	12 bit, SPI, max 1024 °c, precision 0.25 °c	1
6	Water level sensor	5 V, 2 wire	1
7	Diaphragm pump	24 V, 60 W, 5 bar, 4 L/min	1
8	Solid State Relay	4-20 mA	1
9	2 Way Solenoid Valve	24 V, Normally Closed	1
10	Heating coil	2000 W	1
11	SMPS	12 V / 24 V	1
12	Pushbutton	4 pin tactile	2

Table 6.1 gives the bill of materials of the electrical components used in the development of the cup-washer. The most important component in the list is the controller STM32 F103C8T6. The temperature, pressure and water level sensor also play a vital role in the proper functioning of the steam boiler.

The STM32 "Blue Pill" development board is built around the STM32F103C8T6 microcontroller, featuring a 72 MHz ARM Cortex-M3 core. It offers up to 64 KB of Flash memory and 20 KB of SRAM for program and data storage, respectively. With a rich set of peripherals including 37 GPIO pins, 3 UART, 2 SPI, 2 I2C, 10 ADC pins, and 1 CAN communication, it suits a variety of applications. Clock management is versatile, supporting internal RC oscillators, external clocks, and PLLs [14]. These details can be obtained from the pinout diagram given in the Fig 6.5. The functions of every single pin in a microcontroller can be obtained from the pinout diagram of the respective microcontroller.

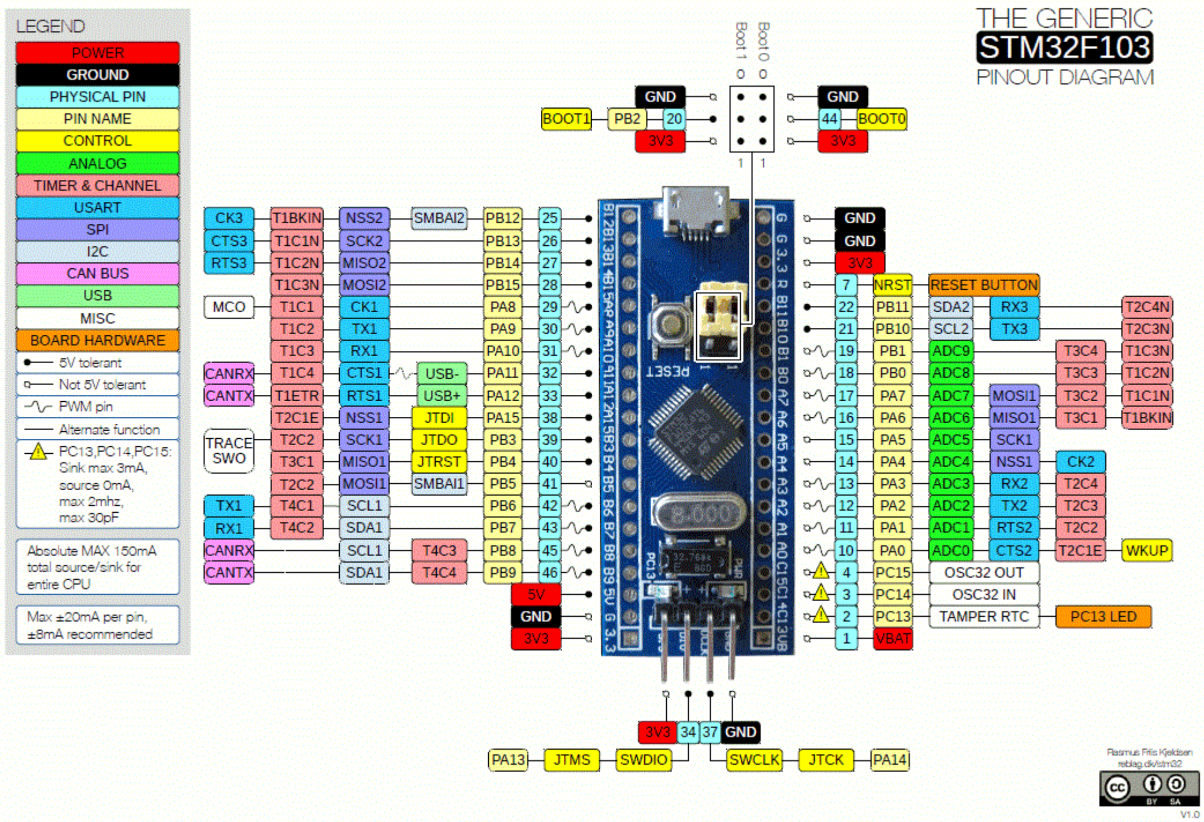


Fig 6.5 Blue Pill pinout diagram

The controller can be programmed using Arduino IDE or the STM32 Cube IDE. It is best advised to go with the STM32 Cube IDE as it provided by the microcontroller developer and comes with a lot of features for easier pin configuration. The programming is done with the HAL abstraction layer as it is user friendly and comes along with lot of features for sensor integration. It supports multi file handling allowing effective troubleshooting during runtime. FREERTOS is implemented with the CMSIS layer, that simplifies user interface and reduces confusion during programming.

The next important part of the electrical design is the sensor integration inside the steam boiler. The three major sensors used in the steam boiler are pressure, temperature and water level sensor. These sensors output an ADC value of 12-bit resolution (values ranging from 0 - 4095), these values can then be converted to voltage values using conversion formula. The sensors usually have lot of noise in their readings which disturbs the effective performance of the whole system. Therefore, special circuits have to be designed to eliminate any noises in the output, this is achieved by developing op-amp circuits or buying a sensor module that already has op-amp in it.

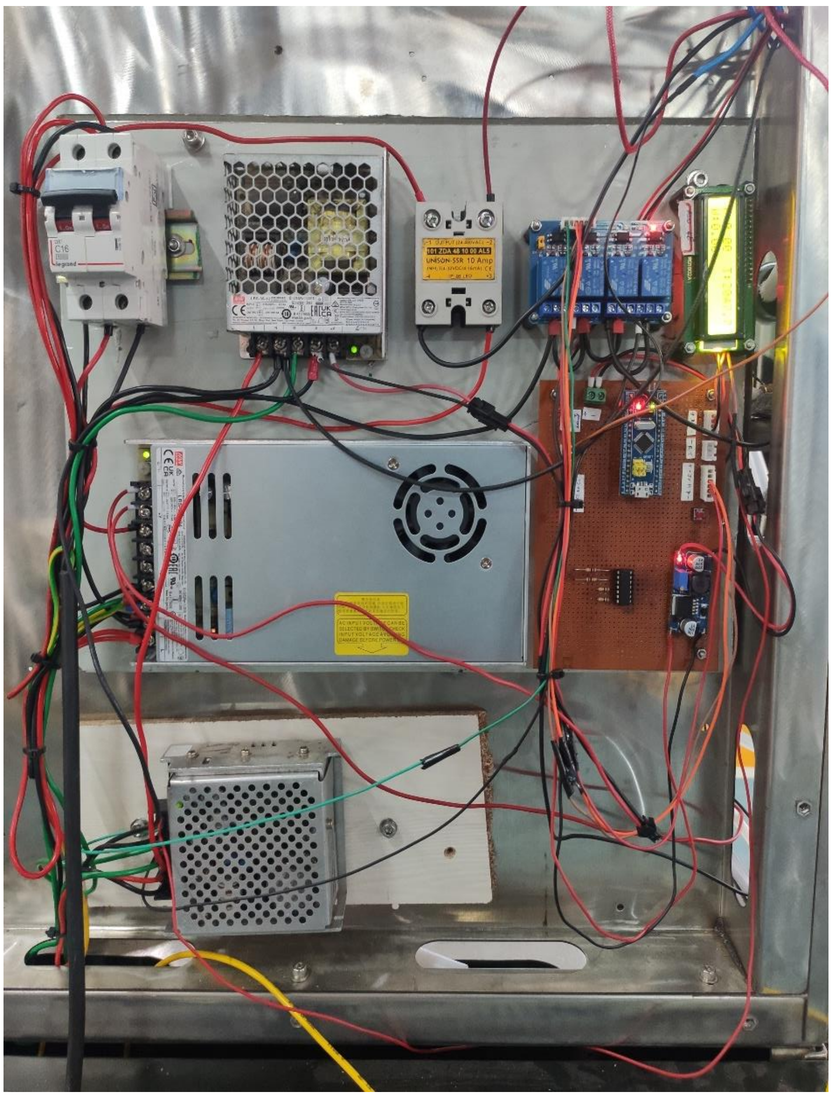
The 3.3 V pressure sensor uses LM324 module, as the module supports 3.3 V operation. Meanwhile the temperature sensor uses MAX6675 module. It is a K Type thermocouple Sensor with 12-bit resolution, communicates using SPI, supports a maximum of 1024 °c, and has a precision of 0.25 °c [15]. It has an internal integrated cold junction compensation circuit with an operating voltage (VDC) of 3 to 5.5 V. The water level sensor uses 3.3 V and has plain ADC conversion similar to pressure sensor.

To control the pump, heater and solenoid valve signals are sent from the microcontroller, since the microcontroller is capable of only providing 3.3 V output signals relays are used to control the outputs. The relays are 5 V operated and thus ground control is chosen for the switching operation. That is, instead of grounding the components and using 3.3 V as trigger signal, we supply 3.3 V to the components beforehand and we use ground (0 V) as the trigger to operate. In simpler terms we use inverse logic to control the output operations. Using this we get 24 V trigger signal on the output end of the relay that'll be connected to pump, heater and solenoid valve.

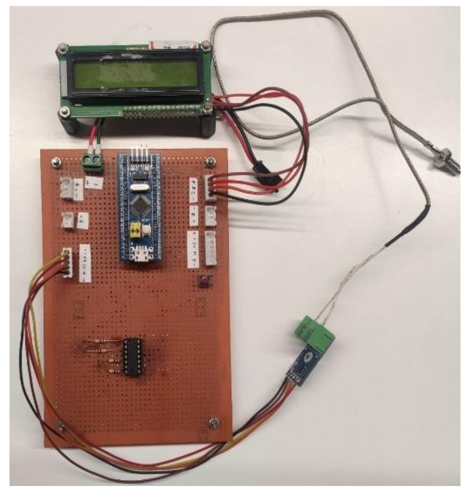
The pump and the solenoid valve are operated at a voltage rating of 24 V only. But on the other hand, the heating coil needs a 2000 W supply. Thus, to control such high current and voltage operations we use a solid-state relay (SSR). Another important feature of this solid-state relay is its ability to control the power it works at, say it can work at 1000 W, 1500 W or 2000 W, but this feature is not utilised here. Further development on this washer can use this SSR to its full potential.

The diaphragm pump is used to push water into the steam boiler which is constantly operating under pressure. But it also necessary to note that the amount of water required for the steam boiler operation is very minimal and the pump is used not used much often. The pump has an operating voltage of 24 V and 60 W power. It is capable of operating under a maximum pressure of 5 bar (~75 PSI) and can pump up to 4 L /min. It is the perfect pump for the operation.

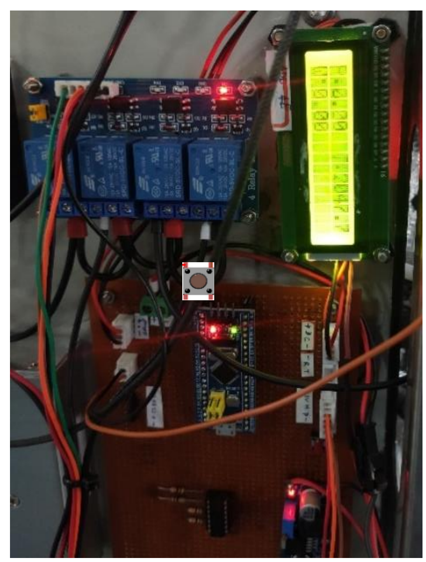
The 16x02 LCD module is used to display the sensor readings from the steam boiler in real time. To reduce the number of GPIO pins used by the LCD module an I2C interface has been used. Using this interface module, we can cut short nearly 1/4th of pins used without I2C communication. The LCD commands are written in a separate file so as to maintain a proper coding format. The LCD module takes 5 V as input power and two other wires for serial communication using I2C (SCL and SDA). Fig 6.6 (a) shows the actual implementation of the circuit. The bluepill microcontroller is soldered onto a dot board and sensors are connected to the dot board through male pin connectors as shown in Fig 6.6 (b). The Fig 6.6 (c) shows the controller and the LCD panel during the machine runtime.



(a) Implementation of the complete electrical circuit



(b) Controller board on dot board



(c) LCD and controller in ON state

Fig 6.6 Implemented Control Board

The Fig 6.7 gives a visual representation of the Cup Washer's circuit diagram. Ground control is implemented in the circuit to enable faster control.

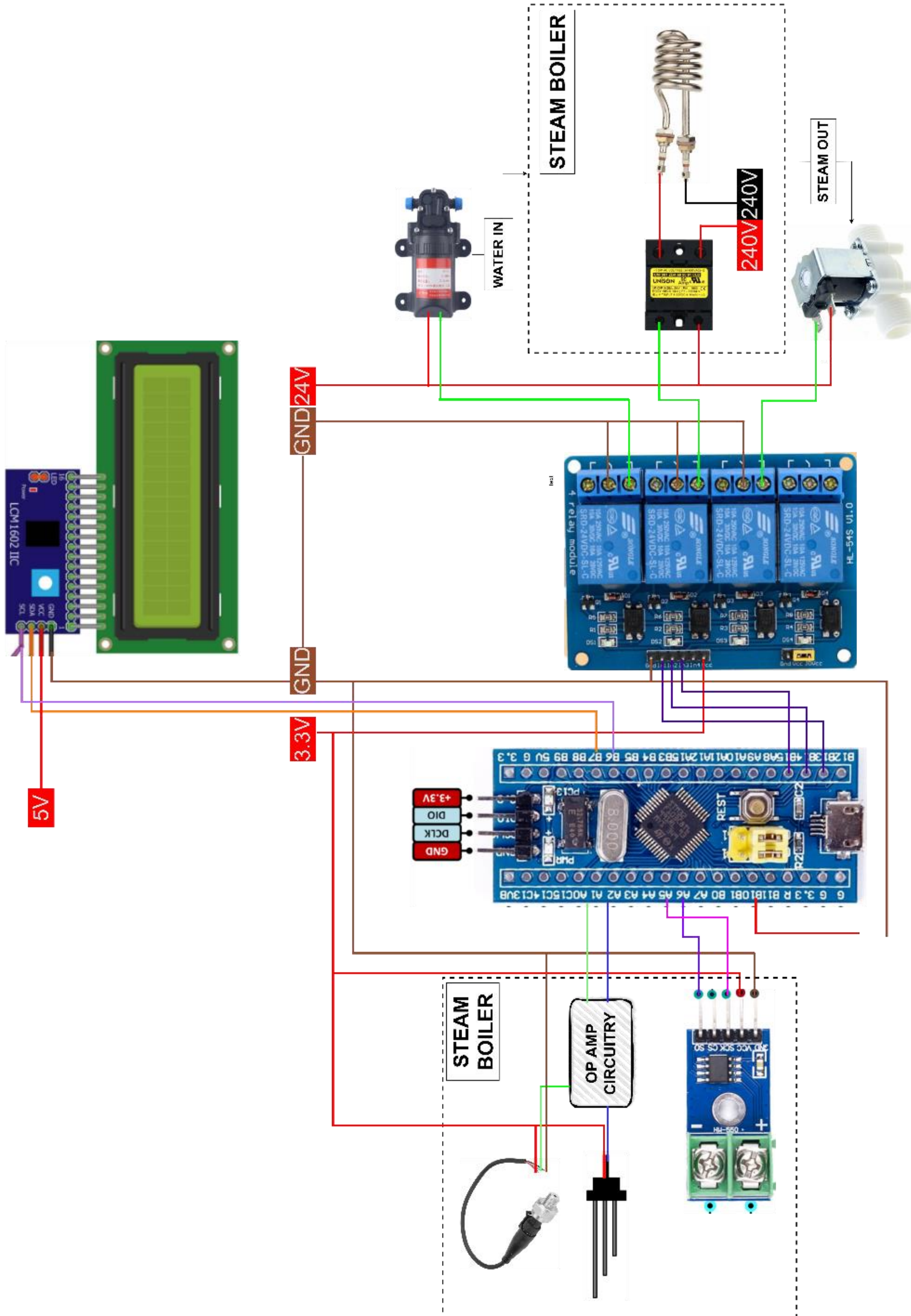


Fig 6.7 Cup-Washer Circuit Diagram

CHAPTER 7

IMPLEMENTATION AND TESTING

This chapter addresses the challenges encountered in the implementation and integration of hardware and software components, as well as the limitations in the approaches utilized and the strategies employed to mitigate them.

7.1 STEAM ONLY CUP WASHER

The initial and primary idea of the cup washing apparatus is to wash the cups using only steam. This is performed by running multiple cycles with different parameters such as pressure, time of exposure to steam and the gap between two steam cycles. The important factors that were observed in this testing is the amount of water used, pressure drop range, leftover stain, smell of cup and glossiness. The initial and final pressure is also noted as it is necessary to operate the cup washer at high pressure as possible. This is because at high temperature and pressure cleaning is found to be more effective for the same given amount of time.

Operating at high pressure in a given temperature is highly desirable. Wanting to increase the pressure results in higher temperature meaning the cups are very difficult to handle after cleaning. This is because the cups absorb the heat from the steam and as a result it becomes very difficult to handle the cup after cleaning.

A standard coffee tumbler was chosen for testing the performance of the cup washer. Even if the cup washer is capable of cleaning cups of various sizes, a cup of single type was chosen to only evaluate the performance of the cup washer and nothing else. The image of the tumbler is attached below in Fig 7.1.

Fig 7.1 Cup Used for Testing

Table 7.1 Observed Readings with Steam only as Washing Agent

S.No.	Time of steam applied (delay between)	Initial Pressure (In PSI)	Final Pressure (In PSI)	Amount of water used (approx.)	Remarks
1	10	21	18.75	11 ml	Cleans better than 5 sec cycles. Less stains with milk smell
2	10+5(3)	21	17.5	17 ml	Milk smell, stains same as in 10 sec
3	10+10(5)	22	17.5	14 ml	Average cleaning with milk smell and coffee stains
4	10+10+5(5+5)	21	16.75	17 ml	Same effect as the 20 sec cycle with milk smell
5	10+10+10(5+5)	21	16	18 ml	Fair cleaning with milk smell and light coffee stains

A tabulation was made to observe the drop in pressure from the start of cycle to the end as shown in table 7.1. The “amount of water used” here mentions the amount of water collected at the end of the steam out. It is important to note that the actual amount of water used is usually a little more to the observed reading, this is because of the losses of the steam to the atmosphere.

Advantages:

- Uses very less amount of water compared to traditional methods of handwashing
- Cleans the cups (partially) without manual intervention
- Latent heat energy stored in steam acts as the mechanical scrubbing agent
- Removes majority of the dirt and the stains

Drawbacks:

- Smell of milk exists in all the cases
- Cups are very hot after cleaning and cannot be touched with bare hands
- Coffee stains exist here and there, mainly near the mouth of the cup
    - This is because there is no nozzle used in these tests

Images of the tumblers before and after washing with only steam is given in the Fig 7.2.

BEFORE **AFTER**

(a) Cup cleaned for 10 seconds

(b) Cup cleaned for 20 seconds

(c) Cup cleaned for 30 seconds

Fig 7.2 Before and After Steam Cleaning

Conclusion:

This test case scenario has some very important takeaways, for example it has given a clear idea on the effect of steam in washing cups. It is very clear that using only steam for cleaning removes major part of the dirt using very little amount of water. However, using only steam is not a complete solution as it partially cleans the cup on its own and doesn't clean at the cups mouth. On top of that, after cleaning, the cups give out the odour of milk which is a very undesirable and it indicates that the cups are not properly cleaned.

7.2 STEAM AND DETERGENT CUP WASHER

The basic idea of washing the cup only with steam had its own advantages and disadvantages. Using the advantages from the previous scenario of using steam, the only possible solution to eliminate the milk odour is to use some sort of chemical. The chemical chosen for this purpose is an alkali-based chemical, that can break down milk fats and proteins thus eliminating the smell of milk from the cups.

Table 7.2 Observed Readings with Steam and Detergent as Washing Agent

S.No.	Time of steam applied (In seconds)	Initial pressure (In PSI)	Final pressure (In PSI)	Remarks
1	5+5	21	18	Heavy chemical smell with high chemical deposits
2	5+5+5	21	17.5	Slight milk smell with zero traces of coffee stains and considerable traces of chemicals
3	10+5+5	22.75	18.5	Zero coffee stains, mild milk smell and visible chemical stains
4	10+5+10	23	18	Very less milk smell and visible chemical deposits inside cup

The readings of the test with steam and detergent are noted down in table 7.2. Best cleaning with less milk odour and coffee stains is observed in the longest cycle of 25 seconds.

Advantages:

- Less water usage
- Zero coffee stains after washing
- Reduced milk smell and stains
- Reduced effective steam application time

Drawbacks:

- Visible chemical deposits
- Slight chemical smell
- Increased waiting time for the chemical to soak
- The cups get too hot and damages the glass cups due to excess heat

Images of the tumblers before and after washing with steam and detergent is given in the Fig 7.3.

(a) 25 second wash cycle (before and after)

(b) 30 second wash cycle (before and after)

Fig 7.3 Before and After Steam with Detergent Cleaning

Conclusion:

The key change in the second test scenario is the usage of chemicals. The chemical was administered through syringe, as shown in Fig 7.4, because it was needed to use only a very little amount of the alkali. The amount of chemical used in the tests were 1 ml. The chemical was manually passed through a syringe for a duration of only 5 seconds in all cases, with the tube sealed to prevent any leakage at the syringe insertion point.

Fig 7.4 Syringe Setup in Path of Steam

The second test scenario has shown crucial improvement in comparison to the first case. The first major improvement is the elimination of milk odour and its traces, which is a major part in the cleaning process. Elimination of the milk odour gives a sense of more proper and thorough cleaning. The second point is the complete elimination of the coffee stains. Since the detergent application time is only 5 seconds, which can be reduced to 3 seconds, the usage of steam is reduced.

Major drawbacks in both the test scenarios 1 and 2 is the overheating of the cups when the steam is directly applied to the cups. Direct application of steam to the cups without the use of nozzle ensures a wide range of cleaning but also overheats the cups. This overheating is not an issue in tumblers but is a major issue in case of chai glasses. The glasses get fragile due to a sudden change in temperature from a hot environment to atmosphere temperature and cracks. To prevent such damages in future, silicon is added to the inclined part of the cup support, which acts as a cushion to the glasses mouth.

7.3 STEAM WITH DETERGENT AND WATER CUP WASHER

To overcome the problem of overheating of cups, few test runs with additional water supply in the path of steam was used. The water is manually controlled and turned on only during the last cycle for rinsing. This purpose of this is to try and reduce the temperature of the cup after steam washing.

Table 7.3 Observed Readings with Steam, Detergent and Water as Washing Agent

S.No.	Time of Steam Applied (In seconds)	Initial Pressure (In PSI)	Final Pressure (In PSI)	Remarks
1	10+5+10	22.50	18.50	Good spotless cleaning, with no smell of chemical or milk
2	10+5+10	23.00	18.25	Zero stains with no bad odour
3	10+5+5+5	21.5	16.50	Very hot cup, spotless cleaning

Table 7.3 gives the readings observed from using steam, detergent and water as the washing agents. In the third test the steam still remains as the primary cleaning agent aided by detergent for eliminating milk odour and water for cooling the cup while rinsing the detergent at the same time. The takeaway from this tabulation is that water is necessary to rinse the cup thoroughly and eliminate the trace of any unwanted odour. Eventhough water was used in cleaning the cup, in comparison to traditional cup washing methods the water usage is less.

Advantages:

- Zero coffee stains after washing
- Zero milk smell and stains
- Spotless cleaning
- Uniformly cleans all the surface of the cup

Drawbacks:

- Increased waiting time for the chemical to soak
- Uses more water than previous methods
- Water becomes mandatory for rinsing of chemical

The before and after images of the cup washed with steam, detergent and water cycle is shown in the Fig 7.4. It is evident from the images that all the spots of the coffee cup are thoroughly cleaned. This method even cleans the brim of the cup without any trace of coffee or chemical stains. The only major drawback faced in this method is increased usage of water. Sometimes the odour of milk was not completely removed despite using water.

Fig 7.4 Before and After Steam, Detergent and Water Cleaning

CHAPTER 8

CONCLUSION AND FUTURE SCOPE

Steam by nature is very hot and spreads widely if forced through a nozzle. This is helpful in cleaning the major parts of the cup but not entirely clean the cups. Moreover, steam alone is not sufficient in producing satisfactory results as it is difficult to breakdown milk fats and proteins through only steam. Thus, alkali-based chemicals have to be used which can be very helpful in breaking down fats and proteins in the expense of less steam.

The steam cup washer is successful as it cleans the cup with minimal amount of water compared to traditional washing methods. Even at the worst-case scenario, third test case, the water consumption is not more than 150ml of water. The third test was not necessary for tumblers but was necessary for fragile cups like glasses.

The placement of the cup also plays a vital role in the effective cleaning of the cup. If the cup is placed too close to the nozzle, the steam doesn’t spread widely and is focused on only one spot, resulting in poor cleaning. This is the reason the cup washer was unable to clean the mouth of the tumbler in many tests. The poor cleaning performance at the cups mouth can be rectified by placing the cups at just the right height. This is not user friendly, so a nozzle design that can clean all the parts of the cup was required.

Among all the tests performed, the test that returned more consistent results was the third test case, tests that were run with water. The best cleaning cycle is 10 seconds steam + 3 seconds wait + 5 seconds steam with detergent + 7 seconds wait + final water rinse along with steam. The delays in between the cycle also plays a crucial role as it helps in regaining the pressure drop during steam out.

8.1 FUTURE SCOPE

The future scope of this project includes further exploration in implementing a simpler design that enables the user to have an easier access to the cups. The design also needs some kind of ventilation that’ll make the cups easier to handle after the cleaning cycle as the current method returns an overheated cup. The selection of material also plays a crucial role, this is because the materials are continuously exposed to steam, water and chemicals thus resulting in corrosion and rusting of metals.

The cup washer currently cleans one cup at a time, which is not applicable in day-to-day life as there will be a need to clean multiple cups at a time in shops and pantries. The cup washer holds potential for cleaning multiple cups at a time using minimal amount of water in a record-breaking time. With further research in the same topic can yield outstanding results with time.

The cup washer as of now only cleans the inner part of the cup, but by adding nozzle to the walls of the cup washer it'll be possible to clean the outer part of the cups. Many innovations can be brought into the machine with various functionalities, such as reducing the wash cycle for light stains or a reduced cleaning temperature for more fragile cups or use steam more effectively through proper nozzle design.

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Program Code:

```
#include "cmsis_os.h"
#include "main.h"
#include "FreeRTOS.h"
#include "stm32f1xx_hal.h"
#include "CupWasherControlMain.h"
#include "PressureMap.h"
#include "string.h"
#include "stdio.h"
#include "LCD_Display.h"
#include "semphr.h"
#include "task.h"
#include "event_groups.h"
#include "timers.h"
#include "FreeRTOSConfig.h"

extern UART_HandleTypeDef huart1;
extern ADC_HandleTypeDef hadc1;
extern DMA_HandleTypeDef hdma_adc1;

uint8_t StatusBuffer[30];
uint8_t tx_buf[50];
uint16_t adcDMAbuffer[2] = {0};
uint16_t PressureSensorADCValue;
uint16_t TemperatureSensorADCValue;
uint16_t WaterLevelSensorADCValue;
uint8_t TemperatureValue;
float TempVal = 0;
float PressureValue;
float WaterLevelValue;
uint8_t count = 0;
char lcd_pressure_buf[20] = {0};
char lcd_temp_buf[20] = {0};
char lcd_wl_buf[20] = {0};
```

```
osThreadId_t WaterPumpControl_Handler;
osThreadId_t SteamBoilerPressureControl_Handler;
osThreadId_t MainTask_Handler;
osThreadId_t LCD_Handler;
static TimerHandle_t timer_1 =NULL;

static const osThreadAttr_t WaterPumpControl_Attributes = {
  .name = "WaterPumpControl",
  .stack_size = 1024,
  .priority = (osPriority_t) osPriorityNormal,
};

static const osThreadAttr_t SteamBoilerPressureControl_Attributes = {
  .name = "SteamBoilerPressureControl",
  .stack_size = 1024,
  .priority = (osPriority_t) osPriorityNormal,
};

static const osThreadAttr_t MainTask_Attributes = {
  .name = "MainTask",
  .stack_size = 1024,
  .priority = (osPriority_t) osPriorityNormal,
};

static const osThreadAttr_t LCD_Display_Attributes = {
  .name = "LCD_Display",
  .stack_size = 1024,
  .priority = (osPriority_t) osPriorityNormal,
};


static void WaterPumpControl();
static void SteamBoilerPressureControl();
static void MainTask();
```

```
static void LCDDisplay();
static void SVOffCallback(TimerHandle_t xTimer);
extern float Max6675_Read_Temp();

void WasherControlMain()
{

	WaterPumpControl_Handler = osThreadNew(WaterPumpControl, NULL,
&WaterPumpControl_Attributes);
	SteamBoilerPressureControl_Handler = osThreadNew(SteamBoilerPressureControl,
NULL, &SteamBoilerPressureControl_Attributes);
	MainTask_Handler = osThreadNew(MainTask, NULL, &MainTask_Attributes);
	LCD_Handler = osThreadNew(LCDDisplay, NULL, &LCD_Display_Attributes);
	timer_1 = xTimerCreate("timer_1", 5000 , pdFALSE, 0,  SVOffCallback);

	//Debug log for verifying task creation
	if(WaterPumpControl_Handler != NULL)
	{
		strcpy((char*)StatusBuffer,"\nWater Pump Control created\r\n");
		HAL_UART_Transmit(&huart1, StatusBuffer, strlen((char *)StatusBuffer),
HAL_MAX_DELAY);
	}

	if(SteamBoilerPressureControl_Handler != NULL)
	{
		strcpy((char*)StatusBuffer,"Pressure Control created\r\n");
		HAL_UART_Transmit(&huart1, StatusBuffer, strlen((char *)StatusBuffer),
HAL_MAX_DELAY);
	}

	if(MainTask_Handler != NULL)
	{
		strcpy((char*)StatusBuffer,"Main Task Control created\r\n");
```

```
			HAL_UART_Transmit(&huart1, StatusBuffer, strlen((char *)StatusBuffer),
HAL_MAX_DELAY);
		}

		if(LCD_Handler != NULL)
		{
			strcpy((char*)StatusBuffer,"LCD Display created\r\n");
			HAL_UART_Transmit(&huart1, StatusBuffer, strlen((char *)StatusBuffer),
HAL_MAX_DELAY);
		}

		if(timer_1 != NULL)
		{
			strcpy((char*)StatusBuffer,"Timer created\r\n");
			HAL_UART_Transmit(&huart1, StatusBuffer, strlen((char *)StatusBuffer),
HAL_MAX_DELAY);
		}

		osDelay(10);
		osKernelStart();
		while(1)
		{
			osDelay(10);
		}
}

static void WaterPumpControl()
{
		//first get the water level from sensor
		// if() water level is low then TURN ON PUMP until level is satisfied

		HAL_ADC_Start_DMA(&hadc1, (uint32_t *)adcDMAbuffer, 2);
		while(1)
		{
```

```
		osDelay(100);
		PressureSensorADCValue = adcDMAbuffer[0];			//A1 PIN
		WaterLevelSensorADCValue = adcDMAbuffer[1];		//A2 PIN
		TempVal = Max6675_Read_Temp();
//		osDelay(10);

		WaterLevelValue = (WaterLevelSensorADCValue * 3.3) / 4096 ;

		if(WaterLevelValue < 0.3)
		{
			count++;
			if((WaterLevelValue < 0.3) && (count == 17))
			{
				HAL_GPIO_WritePin(GPIOB, GPIO_PIN_13,
GPIO_PIN_RESET);	//Pump ON
				count = 0;
				PumpOnCount++;
			}
		}
		else
		{
			HAL_GPIO_WritePin(GPIOB, GPIO_PIN_13, GPIO_PIN_SET);	//Pump
OFF
		}
		osDelay(500);
	}

}

static void SteamBoilerPressureControl()
{
	//get the pressure value from pressure sensor
		//use mapping to convert the pressure range
	//if pressure <(17-19 PSI) TURN ON HEATING ELEMENT
```

```
	while(1)
	{

		osDelay(100);
		TempVal = Max6675_Read_Temp();

		for (uint16_t index = 0; pressureLookUpTable[index].endADCValue !=
INVALID_PRESSURE_SENSOR_ADC_VALUE ; ++index)
		{
		  if ((PressureSensorADCValue >= pressureLookUpTable[index].startADCValue)
&& (PressureSensorADCValue <= pressureLookUpTable[index].endADCValue))
		  {
			PressureValue = pressureLookUpTable[index].pressure;
		  }
		}

		if(PressureValue <= 19)
		{
			if(WaterLevelValue != 0 )
			{
				numcount++;
				if(numcount == 800)
				{
					HAL_GPIO_WritePin(GPIOB, GPIO_PIN_14,
GPIO_PIN_RESET);  //Heater ON
					numcount = 0;
				}
			}
			else
			{
				HAL_GPIO_WritePin(GPIOB, GPIO_PIN_14, GPIO_PIN_SET);
	//Heater OFF
			}
```

```
            }
            else if(PressureValue > 23)
            {
                  HAL_GPIO_WritePin(GPIOB, GPIO_PIN_14, GPIO_PIN_SET);
      //Heater OFF
            }

            osDelay(10);
      }//end while
}//end steam boiler pressure control

void LCDDisplay()
{
      lcd_init();
      lcd_clear();

      while(1)
      {
            lcd_put_cur(0, 0);
            sprintf((char *)lcd_pressure_buf,"P:%.2f", PressureValue);
            lcd_send_string(lcd_pressure_buf);
            lcd_put_cur(0, 8);
            sprintf((char *)lcd_temp_buf,"T:%.2f", TempVal);
            lcd_send_string(lcd_temp_buf);
            lcd_put_cur(1, 0);
            sprintf((char *)lcd_wl_buf,"W:%.2f", WaterLevelValue);
            lcd_send_string(lcd_wl_buf);



            sprintf((char*)tx_buf,"\nTemperatureValue :%.2f \r\n",TempVal);
            HAL_UART_Transmit(&huart1, tx_buf, strlen((char*)tx_buf),100);
            sprintf((char*)tx_buf,"adcVal : %d pressureValue :%.2f
\r\n",PressureSensorADCValue,PressureValue);
            HAL_UART_Transmit(&huart1, tx_buf, strlen((char*)tx_buf),100);
```

```
		sprintf((char*)tx_buf,"adcVal : %d Waterlvl :%.2f
\r\n",WaterLevelSensorADCValue,WaterLevelValue);
		HAL_UART_Transmit(&huart1, tx_buf, strlen((char*)tx_buf),100);
		osDelay(100);
	}
}

static void MainTask()
{
	//if Steam ON button is pressed open valve and hold
	//if Steam OFF button is pressed close valve and hold

	while(1)
	{
		osDelay(20);

			if( HAL_GPIO_ReadPin(GPIOB, GPIO_PIN_10) == GPIO_PIN_RESET )
	//User button press
			{
				if(xTimerStart(timer_1, 0) == pdPASS)
				{
					HAL_GPIO_WritePin(GPIOB,
GPIO_PIN_15,GPIO_PIN_RESET);
				}
			}
	}
}


static void SVOffCallback(TimerHandle_t xTimer)
{

//	strcpy((char*)StatusBuffer,"\n****Timer OFF Invoked**** \r\n");
```

```
//	HAL_UART_Transmit(&huart1, StatusBuffer, strlen((char *)StatusBuffer),
HAL_MAX_DELAY);
	HAL_GPIO_WritePin(GPIOB, GPIO_PIN_15,GPIO_PIN_SET);
}
```

MAX 6675.h code:

```
#include"MAX6675.h"
#include "cmsis_os.h"
extern SPI_HandleTypeDef hspi1;

// ------------------- Variables ----------------
_Bool TCF=0;                            // Thermocouple Connection acknowledge Flag
uint8_t DATARX[2];                      // Raw Data from MAX6675
float Temp=0;                           // Temperature Variable

// ------------------- Functions ----------------
float Max6675_Read_Temp(void)
{
HAL_GPIO_WritePin(SSPORT,SSPIN,GPIO_PIN_RESET);      // Low State for SPI
Communication
HAL_SPI_Receive(&hspi1,DATARX,1,50);                 // DATA Transfer
HAL_GPIO_WritePin(SSPORT,SSPIN,GPIO_PIN_SET);        // High State for SPI
Communication
TCF=(((DATARX[0]|(DATARX[1]<<8))>>2)& 0x0001);       // State of Connecting
Temp=((((DATARX[0]|DATARX[1]<<8)))>>3);              // Temperature Data Extraction
Temp*=0.25;                                          // Data to Centigrade Conversation
osDelay(300);                                        // Waits for Chip Ready(according to Datasheet, the max
time for conversion is 220ms)
return Temp;
}
```

MAX 6675 code:

```
#include"MAX6675.h"
#include "cmsis_os.h"
extern SPI_HandleTypeDef hspi1;

// ------------------- Variables ----------------
_Bool TCF=0;                                    // Thermocouple Connection acknowledge Flag
uint8_t DATARX[2];                              // Raw Data from MAX6675
float Temp=0;                                   // Temperature Variable


// ------------------- Functions ----------------
float Max6675_Read_Temp(void)
{
HAL_GPIO_WritePin(SSPORT,SSPIN,GPIO_PIN_RESET);       // Low State for SPI
Communication
HAL_SPI_Receive(&hspi1,DATARX,1,50);                  // DATA Transfer
HAL_GPIO_WritePin(SSPORT,SSPIN,GPIO_PIN_SET);         // High State for SPI
Communication
TCF=(((DATARX[0]|(DATARX[1]<<8))>>2)& 0x0001);        // State of Connecting
Temp=((((DATARX[0]|DATARX[1]<<8)))>>3);               // Temperature Data Extraction
Temp*=0.25;                                     // Data to Centigrade Conversation
osDelay(300);                                   // Waits for Chip Ready(according to Datasheet, the max
time for conversion is 220ms)
return Temp;
}
```

LCD_Display.c code:

```
#include "LCD_Display.h"
#include "cmsis_os.h"
```

```
extern I2C_HandleTypeDef hi2c1;

#define SLAVE_ADDRESS_LCD 0x4E
extern uint8_t tx_buf[50];

void lcd_send_cmd (char cmd)
{
  char data_u, data_l;
        uint8_t data_t[4];
        data_u = (cmd&0xf0);
        data_l = ((cmd<<4)&0xf0);
        data_t[0] = data_u|0x0C;  //en=1, rs=0
        data_t[1] = data_u|0x08;  //en=0, rs=0
        data_t[2] = data_l|0x0C;  //en=1, rs=0
        data_t[3] = data_l|0x08;  //en=0, rs=0
        HAL_I2C_Master_Transmit (&hi2c1, SLAVE_ADDRESS_LCD,(uint8_t *) data_t, 4, 100);
}

void lcd_send_data (char data)
{
        char data_u, data_l;
        uint8_t data_t[4];
        data_u = (data&0xf0);
        data_l = ((data<<4)&0xf0);
        data_t[0] = data_u|0x0D;  //en=1, rs=0
        data_t[1] = data_u|0x09;  //en=0, rs=0
        data_t[2] = data_l|0x0D;  //en=1, rs=0
        data_t[3] = data_l|0x09;  //en=0, rs=0
        HAL_I2C_Master_Transmit (&hi2c1, SLAVE_ADDRESS_LCD,(uint8_t *) data_t, 4, 100);
}

void lcd_clear (void)
{
        lcd_send_cmd (0x80);          //Force cursor to the beginning ( 1st line)
```

```
            for (int i=0; i<70; i++)
            {
                        lcd_send_data (' ');
            }
}

void lcd_put_cur(int row, int col)
{
    switch (row)
    {
        case 0:
            col |= 0x80;     //Force cursor to the beginning ( 1st line)
            break;
        case 1:
            col |= 0xC0;     //Force cursor to the beginning ( 2nd line)
            break;
    }

    lcd_send_cmd (col);
}
void lcd_init (void)
{
            // 4 bit initialisation
            osDelay(50);  // wait for >40ms
            lcd_send_cmd (0x30);
            osDelay(5);  // wait for >4.1ms
            lcd_send_cmd (0x30);
            osDelay(1);  // wait for >100us
            lcd_send_cmd (0x30);
            osDelay(10);
            lcd_send_cmd (0x20);  // 4bit mode
            osDelay(10);
  // dislay initialisation
```

```
	lcd_send_cmd (0x28); // Function set --> DL=0 (4 bit mode), N = 1 (2 line display) F = 0 
(5x8 characters)
	osDelay(1);
	lcd_send_cmd (0x08); //Display on/off control --> D=0,C=0, B=0  ---> display off
	osDelay(1);
	lcd_send_cmd (0x01);  // clear display
	osDelay(1);
	osDelay(1);
	lcd_send_cmd (0x06); //Entry mode set --> I/D = 1 (increment cursor) & S = 0 (no shift)
	osDelay(1);
	lcd_send_cmd (0x0C); //Display on/off control --> D = 1, C and B = 0. (Cursor and blink, 
last two bits)
	osDelay(1);
}
void lcd_send_string (char *str)
{
	while (*str) lcd_send_data (*str++);
}
```