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Research paper

Automated Dirt and Stain Removal Using Soapless Ultrasonic Dishwasher

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Abstract

Dishwashers are starting to become a common sight in households. Due to this fact, there will also be a rise in the demand for soap for dishwashing. An increase in the demand for soap will therefore increase the volume of wastewater produced in each of the current households. Using dishwashing liquid also poses environmental threat. This paper addressed those issues by constructing an automated soapless ultrasonic dishwasher prototype. It was developed using piezoelectric transducers which are set at 28 kHz to maximize the cleaning range. The ultrasonic generator produces waves at 28 kHz to turn on the transducers. The transducers then produce the vibrations which start the ultrasonic cavitation process. The ultrasonic cavitation process is the one mainly responsible for cleaning. The microscopic bubbles produced strike the utensils and subsequently remove dirt and stains. Furthermore, the ultrasonic dishwashing system has a solenoid and ball valve connected to it in order to facilitate automated filling up and draining of water. Tests were carried out to determine the effectivity of the constructed ultrasonic dishwasher prototype which involve subjecting pans, plates and drinking glass to different types of stains to ultrasonic energy. Finally, the optimum time of removal of dirt and stains for a specific type of stain on a specific type of material of the dish wares have been determined.

Keywords: *ultrasonic; cavitation; cleaning tank; piezoelectric transducer; ultrasonic dishwasher; ultrasonic generator*

1. Introduction

Ultrasonic technology finds applications in wireless communication [1], sensing [2], flaw detection [3], soldering and welding [4-5], and medicine [6-7]. Ultrasonic complex vibration welding was used at 20 kHz and 27 kHz in order to overcome the defect caused by sparked metal particles emanated from the welding position [5]. An intelligent online flaw detection was implemented is steel plate production. Fault inspection is done automatically through a multi-channel online ultrasonic flaw detection [8]. An ultrasonic proximity sensor was developed to measure up to 100 cm distance. This sensor can overcome drawbacks of inductive, optical, and inductive sensors [9].

With the different applications of ultrasonic technology just mentioned, the use of ultrasonic in cleaning is the main focus of this paper.

Frequent use of dishwashing soaps, detergents and other cleaning solutions, pose environmental hazard. Our role as engineers and scientists does not stop from promoting technological inventions and innovations. Active participation on environmental preservation should always be our main concern.

Ultrasonication facilitates environmental protection (i.e. refraining from using toxic chemicals in cleaning) contributing to air and water purification [10]. This is the main motivation for the development of different ultrasonic appliances used in cleaning.

A 400W ultrasonic washing machine for cleaning fruits and vegetables was developed using 140 kHz and 80 kHz frequencies [11]. 80% of the pesticides were shown to be removed in 20 minutes using the washing machine. Cleaning fabric through ultrasonic was also developed using an amplifier with varying frequencies. A dual-ended output was also introduced using an H-bridge. By incorporating this on the design, efficient use of power has been achieved [12]. Ultrasonic cleaning has also been applied in surgical and dental instruments in healthcare environment for disinfection and sterilization [13].

The objective of this paper is to create a prototype of an ultrasonic dishwasher that eliminates dirt and stains from pans, plates and drinking wares. While some ultrasonic still use cleaning solutions, the prototype is designed to be earth-friendly veering away from using any kind of soap that will aid the ultrasonic cleaning process.

2. Ultrasonic Cavitation

Ultrasonic cleaning utilizes sound waves with frequencies typically higher than 18 kHz. Millions of microscopic bubbles will then form as frequency sound waves pass through the elastic medium such as solid or liquid. These bubbles will eventually expand and implode when the pressure is high enough, releasing microscopic jets of liquid which gently scrub away the particles on the surface. This active cleaning mechanism is known as the ultrasonic cavitation [14]. The process is shown in Figure 1.

Normally, cavitation is applied on non-elastic mediums such as water. The particles in water will be in a continuous stable transition, as long as the amplitude of the sound is kept low. When the amplitude of the sound increases, the magnitude of the negative pressure increases also. The negative pressure will eventually become high enough to be able to cause the liquid to crack, causing cavitation bubbles near the area of rarefaction [15].

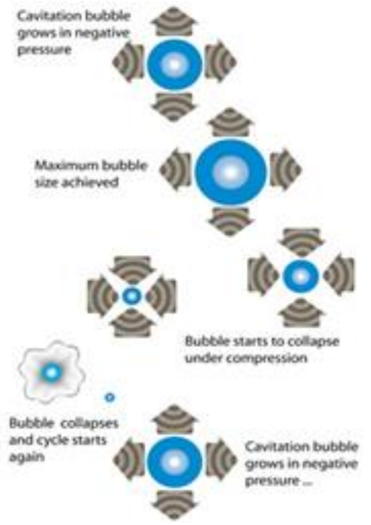

Fig. 1: The cavitation and implosion cycle [16].

3. Design Consideration

There are three basic requirements for an ultrasonic cleaning system, namely: an ultrasonic generator which is a source for electrical energy, a transducer for the conversion of electrical energy to mechanical energy, and the cleaning tank [17]. These basic building blocks are incorporated in the system block diagram as shown in Figure 2. The system is powered by 220Vac, 60 Hz source, which then travels to the solenoid valves necessary for the filling and draining of water from the ultrasonic dishwasher. The ac voltage is also needed to power the water regulator and heater, which are responsible for heating and maintaining the water at the desired temperature of the user. The AC voltage is also required to operate the ultrasonic generator, which is responsible in turning on the transducers. Figure 3 shows how the components of the automation system are connected. The PIC16F84A is used as microcontroller in the system automation block. This microcontroller was used as it is a practical and economical choice when it comes to A/D applications, rather than the PIC16F877A, wherein a lot of input and output ports are wasted.

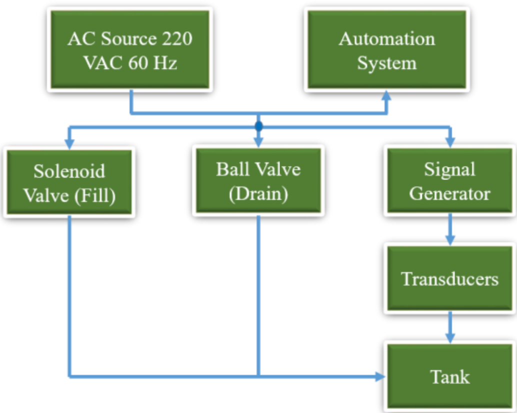

Fig. 2: The block diagram of the dishwashing system.

To power the microcontroller the group needed a voltage of at least 5Vdc. To attain this voltage an ac step down transformer was connected to the 220Vac source. This stepdown transformer converts the 220Vac source down to 12Vac. This power goes through the W10G rectifier so as to convert the ac source into a dc source voltage. High power 10uF capacitors are also connected in parallel with the ac source. This is done so as to remove ripples which causes unnecessary resetting of the microcontroller.

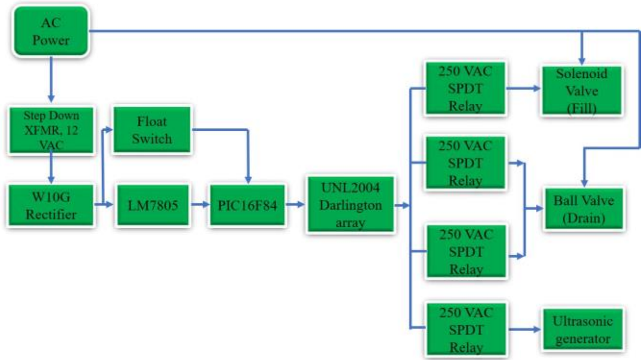

Fig. 3: The connection of the parts for the automation system.

3.1. Control Board

The main controller of the automation system is the control board. This is where the microcontroller is located. The whole board receives power from the 12Vdc regulator which is part of the control panel. The 12Vdc voltage then enters the LM7805 transistor which in turn down converts it in to a 5Vdc voltage. This voltage powers the microcontroller.

3.2. Relay Board

The relay board is the secondary component of the automation system. The single pole, double throw (SPDT) relays, which are used in controlling the solenoid valves, are located here. The QIANJI-JQC3F relay is utilized in the relay board. This is chosen since it is able to control the 220Vac solenoid using an actuating voltage of only 12Vdc. The ULN2004 IC is used as the supply for the actuating voltage of the relay. This is necessary due to the fact that the output voltage of the PIC microcontroller would not be sufficient to successfully actuate the relays, which are controlling the solenoid valves. The ULN is composed of high current and high power Darlington arrays which can amplify the input voltage. Once the input from the microcontroller enters the ULN2004, it is amplified to a voltage that can actuate the relays, thus allowing current to flow on the normally open port of the relay. In these normally open ports, the solenoid valves and the ultrasonic cleaner are connected.

3.3. Voltage Source

The transformer is directly connected to the AC source of 220VAC. After being down converted to 9VAC, it passes through the W10G bridge rectifier, the bridge rectifier converts the AC voltage in to DC voltage. The solenoid valves are directly connected to the AC source, since they do not require the conversion of the voltage. For the microcontroller, once the voltage has been converted in to a DC voltage, it enters the LM7805 which down converts the energy in to 5V, this is the necessary voltage for the microcontroller.

3.4. The Transducers

The number of transducers is determined based on the tank size itself, where it can as much as possible cover the whole area beneath the tank. The power of each transducer is also determined based on the appropriate power required to achieve ultrasonic cleaning. In this case, 17 pieces of ultrasonic transducers can be accommodated for a tank size of 400mm x 300mm x 175mm (Lx W x H) and drainage. Figure 4 below specifies the type of transducer used.

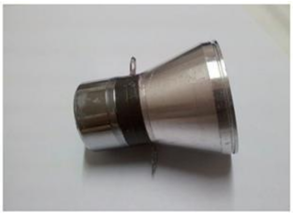

Fig. 4: UCE-UT-2850 PZT-4(UCE Ultrasonic Co. Ltd.).

3.5. The tank

The cleaning tank (See Figure 5) was fabricated using Type 304 stainless steel. Type 304 is the popular stainless steel type because of its corrosion resistance and formability property. The cleaning tank has dimensions of 400 (length) x 300 (width) x 175 mm (height) and 2 mm thickness. 2 mm is the chosen optimum thickness to prevent ultrasonic erosion but can still perform ultrasonic cavitation. Cleaning tank will house the different components included in the system, like: the fill and drain outlet; and the rack to hold the utensils in place. The basket rack will have the same material as the cleaning tank to prevent corrosion. The tank is supported by a four-legged cylindrical bases which balance the whole tank. The legs are made of polyethylene to provide enough support whenever solution is poured in the tank. The length of the two legs differs by 1 centimeter from each other. The tank is tilted in such a way that water will be drained effectively. Also, the height of the leg gives enough spacing from the ground. The tank is also incorporated with a gutter. The gutter provides runaway for the water overflows. The actual photo of the tank is shown in Figure 6.

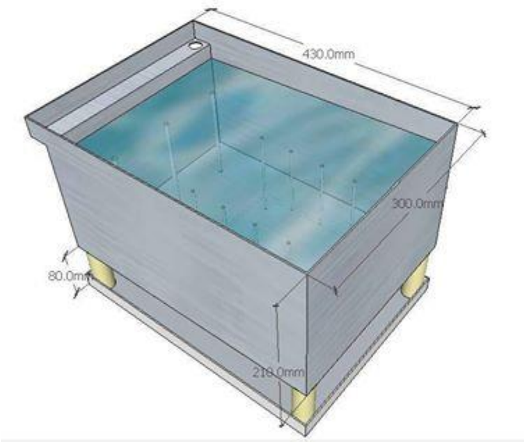

Fig. 5: The tank design and its dimensions.

Fig. 6: The photo of the stainless cleaning tank.

3.6. The Control Panel

The control panel (See Figure 8) is composed of five main buttons, namely: light, medium, heavy, start and stop buttons.

Fig. 8: The photo of the actual control panel.

The control panel is designed in a way that each button has a 5V source connected to it. This power comes from the LM7805. Each button is also connected in series with a specific port on the microcontroller. The light load is connected to the first port, the medium button is connected to the second port, and so on. The connection is made in such a way that when a button is pressed a voltage is sent to the microcontroller. Using the analog-to-digital capability of the microcontroller, eventhough the voltage is below 5V, it can still be read and can be converted in to a digital high value. The microcontroller then activates the output port corresponding to the input port which receives the input signal. The complete ultrasonic dishwasher prototype is shown in Figure 7.

Fig. 7: The prototype of the ultrasonic dishwasher.

4. Results and Discussion

The prototype of the ultrasonic dishwasher system is basically made up of a tank with transducers implanted beneath it. These transducers are connected in parallel and powered up by an ultrasonic generator. In this system, dish wares and drinking wares are submerged into the tank and positioned to be resting on poles specifically designed inside the tank. Once the dishware is carefully positioned in the tank, the ultrasonic generator is turned on to power up the transducers beneath the tank until the cleaning is done.

In order to determine the standard duration for ultrasonic cleaning for a particular stain, three modes of cleaning are carried out, namely: light, medium and heavy modes. Light mode operation is applied for easily removed stains like soy sauce. Medium mode operation applies for stains such as hardened rice, dried catsup, and butter. Lastly, heavy mode applies for stains like oil and burnt ingredients. The list of stains for a particular type of dishwares are shown in Table 1.

Table 1: List of Stains and Dishwares Considered in the Experiment

Dishware	Type of Stains	Material of Dishware
Cooking Pans	Burnt grease, burnt sugar	Stainless steel
Dining Plates	Butter, Hardened Rice, Ketchup, Soy Sauce	Ceramic, glass, Stainless steel
Drinking wares	Chocolate, Coffee	Ceramic, Glass, Stainless Steel

The summary of the cleaning time for each type of stain is shown in Table 2.

Table 2: Summary for time of stain removal for three trials

Type of dishware	Type of stain	Material	Time of Stain Removal (mins.)		
			Trial 1	Trial 2	Trial 3
Cooking Pans	Burnt grease and sugar	Stainless	60	20	60
Dining Plates	Butter	Ceramic	12	14	14
		Glass	12	22	14
		Stainless	26	26	14
	Hardened Rice	Ceramic	30	26	30
		Glass	30	22	26
		Stainless	20	30	24
	Ketchup	Ceramic	12	14	14
		Glass	20	24	28
		Stainless	18	12	14
	Soy Sauce	Ceramic	2	2	2
		Glass	2	2	2
		Stainless	2	2	2
Drinking wares	Chocolate	Ceramic	2	2	2
		Glass	2	2	2
		Stainless	6	6	6
	Coffee	Ceramic	4	6	6
		Glass	4	4	4
		Stainless	4	6	4

Burnt grease and sugar were determined to be the most difficult stain to be removed. Cleaning durations for butter, hardened rice and ketchup stains were found to be more uniform. Lastly, liquid-based stains like soy sauce, chocolate and coffee were found to be the easiest stains to be removed.
Therefore, light mode can be set to 10 minutes, medium mode to 30 minutes and heavy mode to 60 minutes.

5. Conclusion

Based on the data that have been gathered, it can be concluded that ultrasonic technology can be used in dishwashing. Liquid-based stains were easily removed because of its non-viscous property. Stains that are oil-based like grease and butter were also removed. However, oil-based stains float on the water surface which led the group to incorporate an overflow system. The overflow system removes the floating stains that remained after ultrasonic cleaning. Lastly, stains like burnt sugar and hardened rice were found to be removed despite of its adhesiveness, though it took longer time.
This research proves that with the right use of ultrasonic frequency and basic guidelines in achieving maximum cavitation (i.e. degassing), stain and odor from basic food condiments can be removed from the dishwares. Also, through the testing done wherein several types of stains were mixed to simulate the stains produced on utensils after eating in normal households, it can be concluded that ultrasonic technology can be applied in cleaning daily dish wares. Moreover, ultrasonic dishwashing is proven to be effective with the use of water only as the medium inside the tank. This discovery would help in reducing pollution made to the aquatic environment.

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