Development of a Sustainable Automated Hand Washing System with an Installed Water Recycling Device

*[1]Kazeem A. Bello, [1]Thomas O. Ayeye, [1]Bukola O. Bolaji and [2]Cordelia O. Omoyi
[1]Department of Mechanical Engineering, Federal University Oye-Ekiti, Nigeria
[2]Department of Mechanical Engineering, University of Calabar, Nigeria
{kazeem.bello|thomas.ayeye|bukola.bolaji}@fuoye.edu.ng |cordeliaochuole@unical.edu.ng

Received: 10-MAR-2023; Reviewed: 29-JUN-2023; Accepted: 30-JUN-2023
http://doi.org/10.46792/fuoyejet.v8i2.1016

ORIGINAL RESEARCH

Abstract- Hand washing has become a new normal in our society to prevent the spread of COVID-19 and other viruses. As a result of the need to comply with World Health Organization (WHO) guidelines on hand washing to reduce the risk of infection transmission, an automated hand washing system with an installed water recycling device was developed. The integration of recycling water ensures effective energy resource management and reduces environmental pollution. The conceptual architectural design of the automated hand washing machine was established using AutoCAD software and the Arduino microcontroller panel. The operation of the hand washing systems consists of assembling relevant sensors to automate the liquid soap, water, hand dryer and sanitiser dispenser. A filtration reactor was used to convert the wastewater to clean water. The clean water is then pumped to the overhead tank by a submersible pump inside the lower tank for reuse. The water treatment was achieved by adding 5g of aqueous $CaCo_3$, and $MgSo_4$ into 1000g of used water. The water samples were then analysed in the laboratory to ascertain their purity, and results were obtained. The purification of the recycled water ranges from 82% to 83%, and the salvage volume of the recovered clean water is 80%. The microcontroller was successful in coordinating the various activities of the automated system. The automatic washing machine will reduce water waste, eliminate environmental pollution and curb disease transmission.

Keywords- Arduino pro-mini, Automation, Hand washing, sustainability, water recycling.

1 Introduction

Water recycling is the process of converting wastewater into water that can be reused for other purposes (Obaideen et al., 2022; Tarpani et al., 2023; Zhang et al. 2022). Reuse may include irrigation of gardens, and agricultural fields or replenishing surface water and groundwater, hand washing etc. The purpose of recycling used water in hand washing machines is to prevent environmental pollution, hazard and natural resources depletion (Filali et al., 2022). Again, automating hand washing machines will help to achieve United Nations Sustainable Development Goals (UNSDG) on innovation, infrastructure and technology.

The importance of hand washing cannot be over-emphasized, particularly in developing nations where eating with hands is a common exercise. The practice of eating with hands poses a great danger of easy transmission of disease among the citizenry (Hamdi, 2022). Therefore, the development of user-friendly hand washing machines will go a long way to curb disease and promote good hygiene (Gondo & Kolawole, 2022). Handshaking is a common way of greeting among friends and colleagues in the workplace which make people vulnerable to virus and bacteria transmission, particularly the during COVID-19 era (Gondo et al., 2022). Therefore, hand washing will prevent the spread of infections, according to the US Centre for Disease Control and Prevention. Dirty or unwashed hands are easy ways of spreading diseases such as colds, flu, ear infections, sore throat, diarrhoea, etc.

*Corresponding Author

Section C- MECHANICAL/MECHATRONICS ENGINEERING & RELATED SCIENCES
Can be cited as:
Bello, K. A, Ayeye, T. O, Bolaji O. B and Omoyi C. O (2023). Development of a Sustainable Automated Hand Washing System with an Installed Water Recycling Device, FUOYE Journal of Engineering and Technology (FUOYEJET), 8(2), 217-222. http://doi.org/10.46792/fuoyejet.v8i2.1016

Regular contact with people, shaking of hands, use of Biomedical equipment in the hospital, Agricultural produce and social interaction also promotes the danger of disease transmission (Smith e al., 2022). Observing regular hand-washing practices would go a long way to diminishing the occurrence of diseases according to the conducted by (Valsamatzi-Panagiotou et al., 2022). The hand washing campaign with soap and the application of sanitiser is a good approach for controlling the spread of the virus that could cause diseases. The acute health disaster brought by COVID-19 is the source of courage to embark on innovative infrastructure that shall help to encourage the practice of hand washing in the University community to help maintain a healthy lifestyle (Bello et al., 2021). This machine can be used in offices, hotels, farms, hospitals, schools, etc. (Mai et al., 2022; Navaratnam et al., 2022). Soap and dryer were incorporated into the design to give the comfort of easy washing away of debris and drying hand before using sanitiser. The machine dispenses both liquid soap and clean water in sequential order during the washing and rinsing cycle and then supplies a warm air current to dry up the completely washed hand.

An automated hand washing machine can eliminate contagious diseases; for instance, in a manual type hand washing machine, to turn on/off the tap, you need to make use of your hands. In that case, your hands or fingers would be infected with any virus left by the previous user if he or she is infected with a disease. With the automatic type, you will not only use the water with ease but also avoid any possible contact with any contagious disease. Many studies had been done on automated handwashing machines (Koondhar et al., 2022), (Vignesh et al., 2019), (Sibiri et al, 2020) as documented in various literature, however, this study is unique because it incorporates the recirculation of used hand washing by using CaCO3 and MgSO4 and CACO3 chemicals. This will eliminate the threat to humans, livestock and ecosystems that could result from water scarcity. Again, recirculation of used hand washing water will reduce environmental pollution and preserve the depletion of natural resources in line with the United Nations Sustainable Developments Goals (UNSDG) (Jama-Rodzeńska et al., 2021). The automated washing machine will reduce the waste of water, eliminate environmental pollution and curb disease transmission.

2 METHODOLOGY

2.1 MATERIALS

The materials used for this experimental study were carefully selected as listed below:

- Arduino pro-mini
- IR Proximity sensor
- Solenoid valve
- Relay module
- Ultrasonic sensor
- Water pump
- Water house
- Water tanks
- Purified water container

The assembly of materials were assembled and controlled by an Arduino Pro Mini microcontroller board based on the ATmega328. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analogues inputs, an onboard resonator, a reset button, and holes for mounting pin headers. A six-pin header can be connected to an FTDI cable breakout board to provide USB power and communication to the board. The Arduino Pro Mini is intended for semi-permanent installation in objects or exhibitions. The board comes without pre-mounted headers, allowing the use of various types of connectors or direct soldering of wires.

2.2 METHODS

Hand washing machine with an inbuilt water recycling system requires some level of purification for the water to be re-used over and over again. This is in line with sustainable development goals to effectively manage the ecosystem, and pollution and reduce natural depletion. Figure 1 shows the setup and control mechanism for the automated hand washing machine. The single hand washing station consists of an overhead tank which supplies water by gravity, a soap container, a hand dryer station and a sanitiser container. The operating systems are completely automated by using the selected sensors and transducers. The washing machine flow chart is depicted in Figure 1. 1 Kg of water was mixed with varying quantities of blended $CaCO_3$ and $MgSO_4$ chemicals at 5g, 10g, and 15 g. Three different experimental trials were carried out as shown in Table 1.

The samples of the trials namely sample A, B and C were sent to the laboratory for the purpose of determining the optimal quantity of blended used $CaCO_3$ and $MgSO_4$ that is best suitable to achieve the higher purified recycled water. The clean water was then flowed through the filter by gravity to a water collector while the remaining debris in the used water collector is discharged to a waste chamber attached to the used water collector. The clean water is then pumped to the overhead tank to be reused. This circle continues until the water in the overhead tank is replenished whenever it is necessary to compensate for the water shortage. The performance evaluation was carried out on the machine to ascertain the level of acceptance by the users compared to other alternative hand washing machine, the running cost and the overall reliability was also determined.

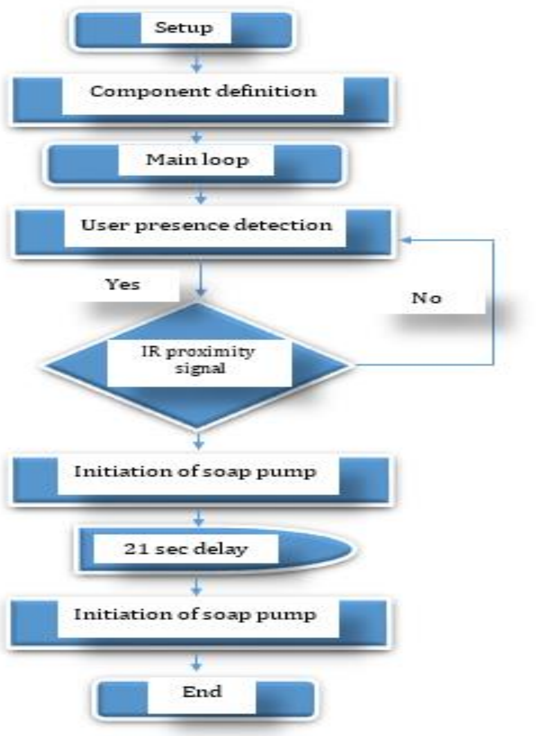

Fig.1: Hand washing machine control Flow Chart

2.3 DESIGN CALCULATIONS

The cylindrical water storage tanks were carefully selected based on the calculated design below. Thus, the volume of the tank is calculated as follows:

$$v = \pi r^2 h \qquad (1)$$

Where r = radius of the tank in m, h = height of the tank in m, $v = \pi(0.23)^2(0.24)$

$$v = \pi \times 0.0529 \times 0.24 = 0.039 \text{ m}^3$$

2.4 DETERMINATION OF POSSIBLE NUMBERS OF WASH IN A FULL TANK

The quantity of water dispensed by the hand washing machine was collected and measured using a digital weight scale to be 250 g of water. From the volume of the storage tank which is 0.039 m^3 and the density of water which is 997 kg/m^3, the mass of the storage tank can be calculated as:

$$D = \frac{m}{v} \qquad (2)$$

Where m = mass of water in kg, v = volume in m^3, d = density of water in kg/m^3

$$997 = \frac{m}{0.045}, m = 997 \times 0.039 = 38.8\text{kg}$$

Therefore, the number of washes for a full tank is calculated thus;

$$\frac{mass\ of\ water\ in\ the\ storage\ tank}{mass\ of\ despensed\ water} \qquad (3)$$

http://doi.org/10.46792/fuoyejet.v8i2.1016 http://journal.engineering.fuoye.edu.ng/

Table 1. Experimental trial tests for varying quantities of CaCO3 and MgSO4 on used water

Sample	5g of $CaCO_3$ and 5g of $MgSO_4$	10g of $CaCO_3$ and 5g of $MgSO_4$	5g of $CaCO_3$ and 10g of $MgSO_4$	15g of $CaCO_3$ and 5g of $MgSO_4$	5g of $CaCO_3$ and 15g of $MgSO_4$	10g of $CaCO_3$ and 15g of $MgSO_4$	15g of $CaCO_3$ and 10g of $MgSO_4$
A	% of H_2O purification	% of H_2O purification	% of H_2O purification	% of H_2O purification	% of H_2O purification	% of H_2O purification	% of H_2O purification
B	% of H_2O purification	% of H_2O purification	% of H_2O purification	% of H_2O purification	% of H_2O purification	% of H_2O purification	% of H_2O purification
C	% of H_2O purification	% of H_2O purification	% of H_2O purification	% of H_2O purification	% of H_2O purification	% of H_2O purification	% of H_2O purification

$\frac{38.8}{0.25}$ = The number of washes without recycling is 155 times.

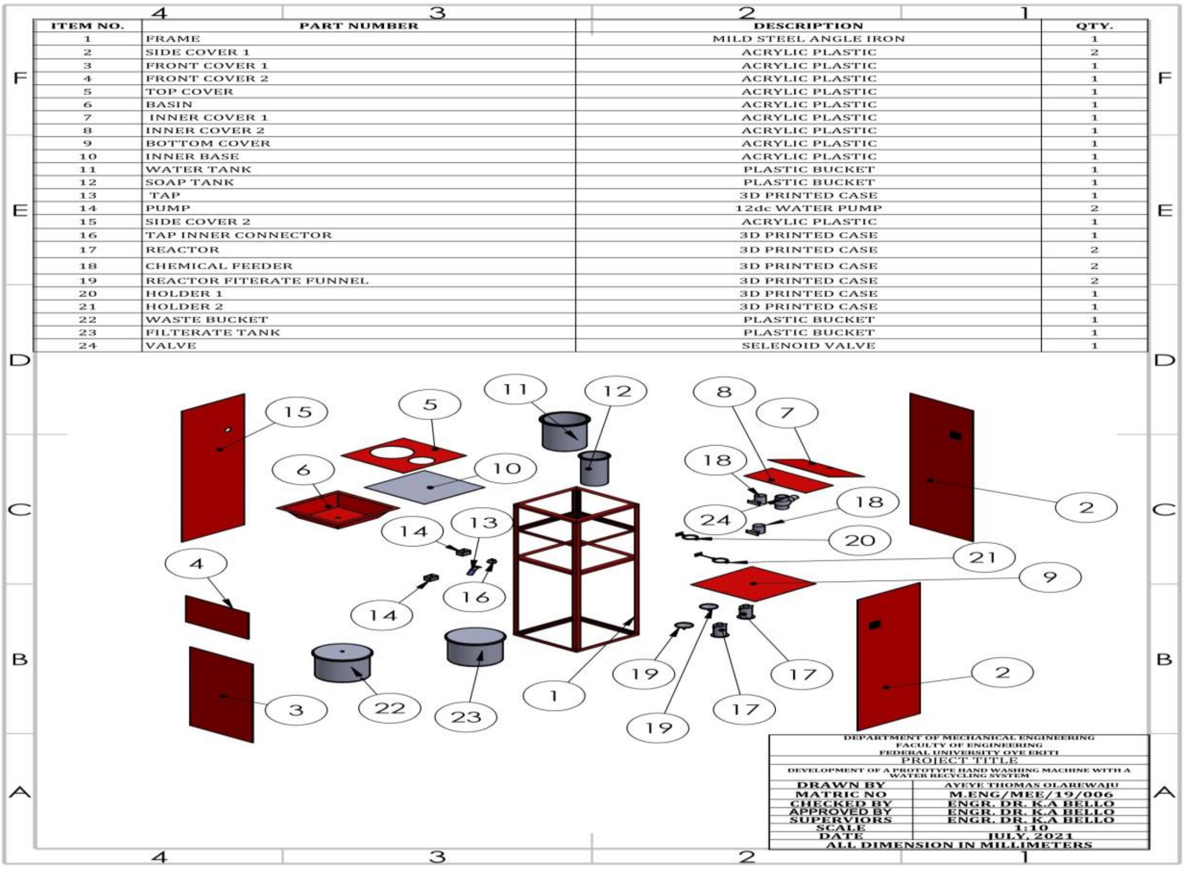

Fig. 2: Exploded diagram of the Hand Washing Water Recycling Machine

Figure 2 depicted the exploded diagram of the automated hand washing machine with integrated water recycling application techniques. Figures 3, 4, and 5 represented the Auto CAD geometric design of the automated hand washing machine components in a standard form. Figure 6 is the block diagram of the automated hand washing machine. Figure 7 depicted the architecture of the developed automated washing machine

3 Results and Discussion

Hand washing machine with an inbuilt water recycling system needs some level of purification before the used water can be re-used again and again for sustainable of water resources. Therefore, experimental tests were carried out to optimize the blend of $CaCO_3$ and $MgSO_4$ quantities that were needed to determine the highest purified recycled water. Varying quantities of $CaCO_3$ and $MgSO_4$ were dissolved in the used 1Kg of used water collected from the hand washing machine as shown in table 2. The blended samples were taken to the laboratory to determine the level of water purification. The 3 experimental test results obtained from the laboratory analyses were recorded as shown in Table 2.

It was observed that the recycled water purity decreases as the ratio of the chemicals increases. Table 2 shows that ratio 1:1 of $CaCO_3$ and $MgSO_4$ gave the better outcome of water purifications. Therefore, 5g of the ratio of $CaCO_3$ and $MgSO_4$ system was adopted for this study. The result obtained in this study is similar to the previous studies (Flaaen, Hortaçsu et al., 2020; Satria et al., 2022). The performance evaluation was carried out on the hand washing machine to determine the acceptable level for the users, the running cost and the overall reliability of the system.

http://doi.org/10.46792/fuoyejet.v8i2.1016 http://journal.engineering.fuoye.edu.ng/

The washing machine was mounted at the front of the faculty of engineering, Federal University Oye Ekiti, Nigeria. It was tested for 5 weeks and the results recorded were shown in Table 3. The number of users increases which each passing week because of the level of awareness and satisfaction derived from the machine. The running cost reduces with the increase in the number of users. This makes the machine cost-effective and cheap to operate. It was also observed that the percentage of recycled water is constant at the highest recovered value of 0.8.

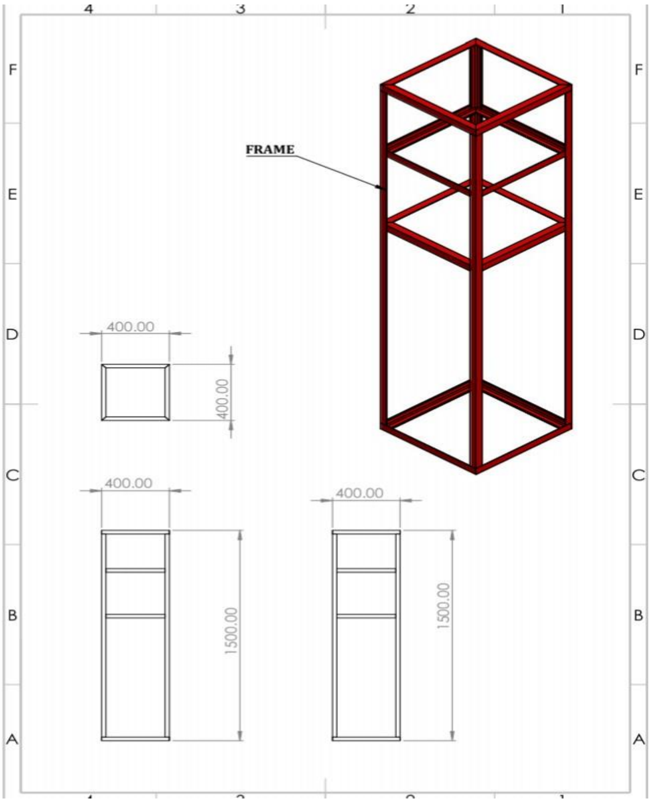

Fig. 3: CAD design of the hand washing machine components

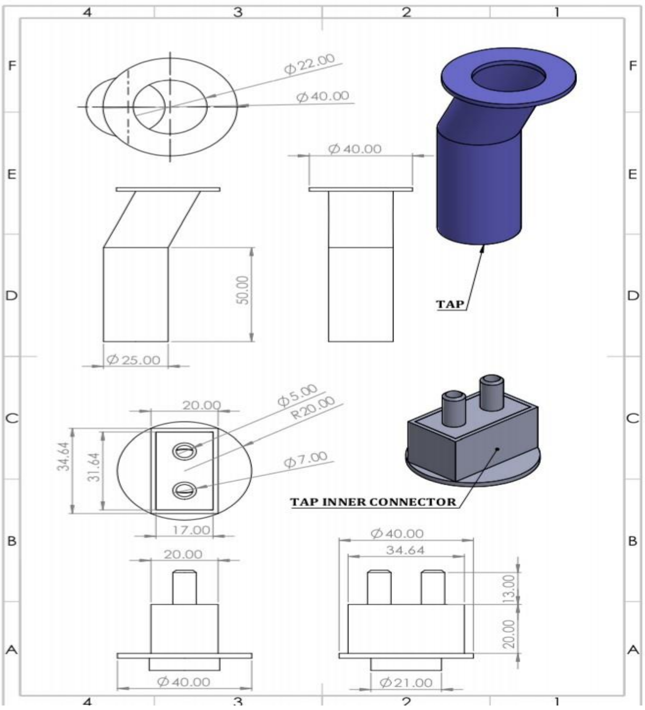

Fig. 4: CAD design of the hand washing machine Components

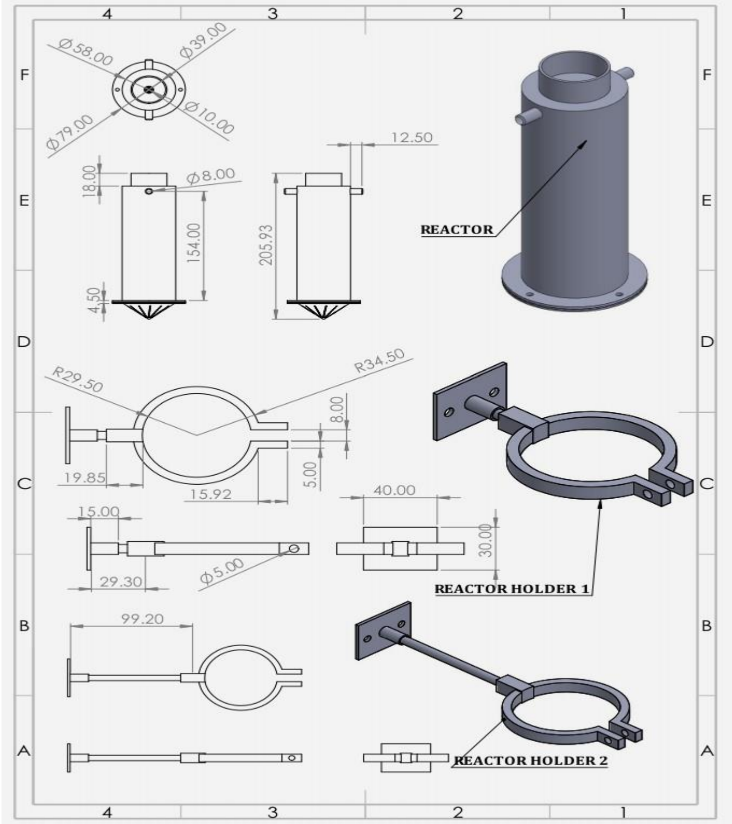

Fig. 5: CAD design of the hand washing machine Components

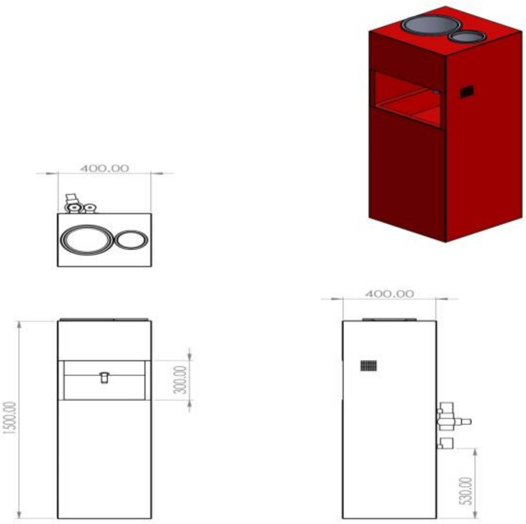

Fig. 6: Hand Washing Machine Block Diagram

Figure 8 depicted the results of used water recycling against the number of users. The results show that an appreciable volume of water was recovered. This validates the purpose of the study that water can be reused by applying the right engineering application to achieve sustainable development goals.

Figure 9 justified the cost of recycling water, as the cost reduces with an increase in the number of machine users. This trend authenticates the reliability of the system as the running cost is minimal with continuous use of the machine. This is cheaper in the long run and helps to curb the transmission of COVID-19 in the University community.

http://doi.org/10.46792/fuoyejet.v8i2.1016 http://journal.engineering.fuoye.edu.ng/

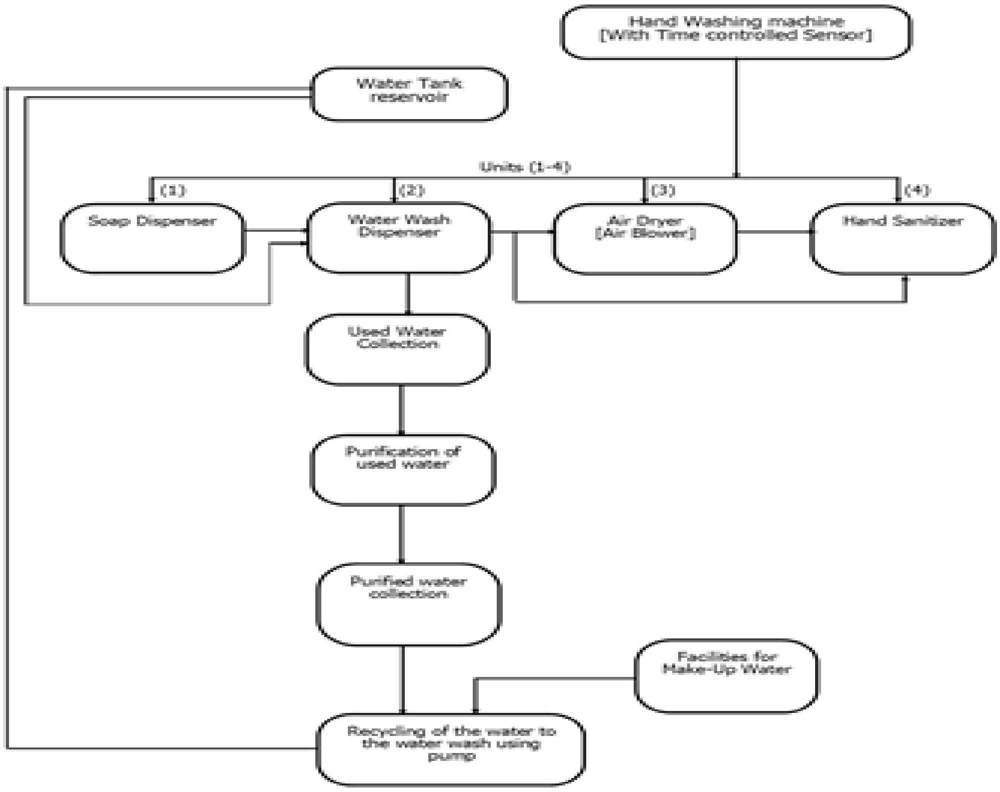

Fig. 7: Architecture of automated washing machine

Table 2. Different levels of used hand washing purification of water

Sample	5g of $CaCO_3$ and 5g of $MgSO_4$	10g of $CaCO_3$ and 5g of $MgSO_4$	5g of $CaCO_3$ and 10g of $MgSO_4$	15g of $CaCO_3$ and 5g of $MgSO_4$	5g of $CaCO_3$ and 15g of $MgSO_4$	10g of $CaCO_3$ and 15g of $MgSO_4$	15g of $CaCO_3$ and 10g of $MgSO_4$
A	80%	73%	75%	68%	68%	74%	74%
B	83%	72%	74%	67%	69%	73%	73%
C	82%	73%	74%	67%	68%	73%	73%

Table 3. Performed Evaluation of the hand washing machine System

Week	No of person	Tt	Qs (g)	Vt (kg)	Vu (kg)	Vr (kg)	$\%V_r$	Cost (₦)
1	10	3.50	20	13	5.0	4.0	80	2,000
2	15	5.25	30	13	7.5	6.0	80	1,800
3	18	6.30	36	13	9.0	7.2	80	1,500
4	22	7.70	44	13	11.0	8.8	80	1,200
5	25	8.75	50	13	12.5	10.0	80	1,000

Tt is Total time of dispense in minutes; Q_s is quantity of liquid soap dispensed in grams; V_t is volume of water in the tank in kilograms ; V_u is volume of used water for washing in kilograms ; V_r is the Volume of recycled water in kilograms ; % V_r is the percentage of recycled water

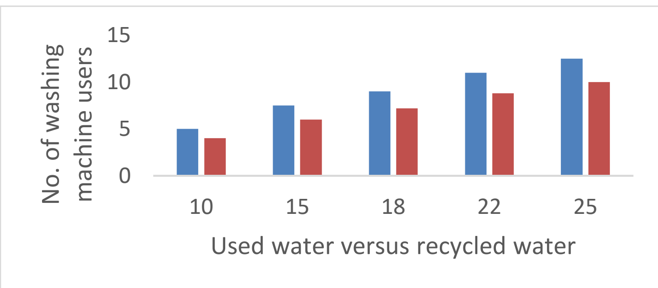

Fig. 8: Used H_2O for hand washing versus recycled water

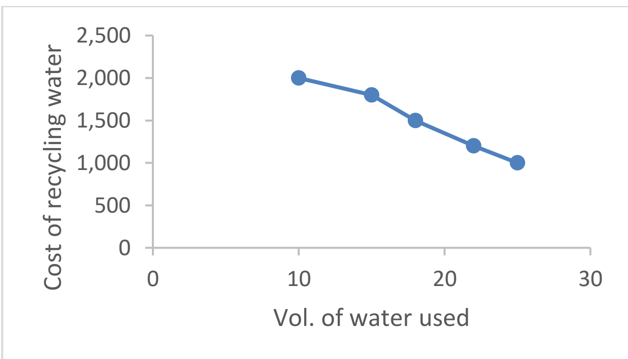

Fig. 9: Vol. of water used versus the recycling cost

http://doi.org/10.46792/fuoyejet.v8i2.1016 http://journal.engineering.fuoye.edu.ng/

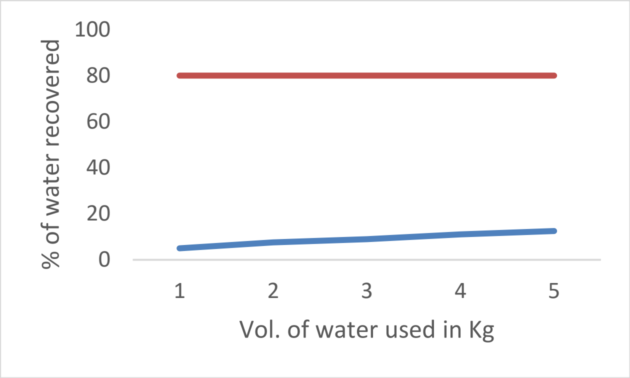

Fig. 10: Vol. of water used and % of purified water recovered

Figure 10 has helped to substantiate that the constant 80% water recovery rate is achievable if the dosing of the two chemicals used in this study is maintained. This is a great achievement compared to the previous study.

4 Conclusion

The automated hand washing machine has been successfully developed to compensate for the shortcomings of the conventional hand washing machine. The machine is user-friendly, free of hazards, time-saving and meets the world health organization (WHO) campaign requirements against COVID-19. The statistical data recorded during the machine performance evaluation show the automated handwashing machine is innovative, sustainable and economical to use. It was deduced from the experimental test that, the more the machine usage, the higher the amount of recycled water from waste collection through sequential slow takers and purification into the recycling tank. The link between the recycled tank and the overhead tank using the pump revealed that the cost of refilling the tank of its maintenance is considerably low. However, the cost of hygiene cannot be compared with saving a life. This innovative hand washing machine is eco-friendly and it will help to reduce the environmental pollution associated with conventional hand washing machines while helping to promote a cleaner environment and protect the ecosystem from natural depletion in line with the sustainable development goal. This machine can be used in offices, farms, hospitals, schools, hotels, markets etc. It is therefore recommended to the government, religious groups, none profitable organizations and relevant agencies for the promotion of quality health and social life.

References

Bello, Kazeem Aderemi, Oyelaran, Olatunde Ajani, Bolaji, Bukola Olalekan, Awogbemi, Omojola, Adeodu, Adefemi Omowole, & Busari, Abayomi. (2021). *Evaluation of engineering students' output during covid-19 pandemic lockdown.* Paper presented at the 2021 World Engineering Education Forum/Global Engineering Deans Council (WEEF/GEDC).

Filali, Hanen, Barsan, Narcis, Souguir, Dalila, Nedeff, Valentin, Tomozei, Claudia, & Hachicha, Mohamed. (2022). Greywater as an alternative solution for sustainable management of water resources—A review. *Sustainability, 14*(2), 665.

Flaaen, Aaron, Hortaçsu, Ali, & Tintelnot, Felix. (2020). The production relocation and price effects of US trade policy: the case of washing machines. *American Economic Review, 110*(7), 2103-2127.

Gondo, Reniko, & Kolawole, Oluwatoyin D. (2022). Household water access and COVID-19 in Karoi town, Zimbabwe. *Scientific African, 16*, e01145.

Hamdi, Saipul. (2022). Covid-19, social stigma and changing religious practice in Tablighi Jamaat Communities in Lombok, Indonesia. *International Journal of Disaster Risk Reduction, 76*, 102996.

Jama-Rodzeńska, Anna, Białowiec, Andrzej, Koziel, Jacek A, & Sowiński, Józef. (2021). Waste to phosphorus: A transdisciplinary solution to P recovery from wastewater based on the TRIZ approach. *Journal of Environmental Management, 287*, 112235.

Koondhar, Mohsin Ali, Channa, Irfan Ali, Bukhari, Syed Abid Ali Shah, Soomro, Abdul Hameed, Channa, Abdul Sami, & Koondhar, Noshad Ali. (2022). Experimental-based automatic control of washing machine using a programmable logic controller. *Journal of Applied and Emerging Sciences, 12*(1).

Mai, Nguyen Thi Tuyet, & Cuong, Mai The. (2022). Vietnam in the combat against COVID-19: Responses of the government and cooperation among stakeholders *Community, Economy and COVID-19: Lessons from Multi-Country Analyses of a Global Pandemic* (pp. 611-632): Springer.

Navaratnam, Satheeskumar, Nguyen, Kate, Selvaranjan, Kajanan, Zhang, Guomin, Mendis, Priyan, & Aye, Lu. (2022). Designing post-COVID-19 buildings: Approaches for achieving healthy buildings. *Buildings, 12*(1), 74.

Obaideen, Khaled, Shehata, Nabila, Sayed, Enas Taha, Abdelkareem, Mohammad Ali, Mahmoud, Mohamed S, & Olabi, AG. (2022). The role of wastewater treatment in achieving sustainable development goals (SDGs) and sustainability guidelines. *Energy Nexus, 7*, 100112.

Satria, Habib, Nasution, Mahliza, Mungkin, Moranain, Anisa, Yuan, & Hardinata, Aristo. (2022). Design and Demonstration of the Use of Automatic Hand Washing Sink Technology in Covid-19 Pandemic Conditions. *International Journal of Education, Information Technology, and Others, 5*(2), 127-132.

Sibiri, Hagan, Zankawah, Sanusi Mumuni, & Prah, David. (2020). Coronavirus diseases 2019 (COVID-19) response: Highlights of Ghana's scientific and technological innovativeness and breakthroughs. *Ethics, Medicine and Public Health, 14*, 100537.

Smith, Stephanie R, Hagger, Martin S, Keech, Jacob J, Moyers, Susette A, & Hamilton, Kyra. (2022). Improving hand hygiene behaviour using a novel theory-based intervention during the COVID-19 pandemic. *Annals of Behavioral Medicine, 56*(11), 1157-1173.

Tarpani, Raphael Ricardo Zepon, & Azapagic, Adisa. (2023). Life cycle sustainability assessment of advanced treatment techniques for urban wastewater reuse and sewage sludge resource recovery. *Science of the Total Environment, 869*, 161771.

Valsamatzi-Panagiotou, Aikaterini, & Penchovsky, Robert. (2022). Environmental factors influencing the transmission of the coronavirus 2019: a review. *Environmental Chemistry Letters, 20*(3), 1603-1610.

Vignesh, T, Selvakumar, D, Prasath, C, Manikandan, N, & Viswanath, R Sri. (2019). *Design and fabrication of home automation.* Paper presented at the IOP Conference Series: Materials Science and Engineering.

Zhang, Xiaoyuan, & Liu, Yu. (2022). A Circular Economy is game-changing municipal wastewater treatment technology towards energy and carbon neutrality. *Chemical Engineering Journal, 429*, 132114.

http://doi.org/10.46792/fuoyejet.v8i2.1016 http://journal.engineering.fuoye.edu.ng/