Design and characterization of automatic hand washing and drying machine

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Abstract. The unhealthy pattern of washing and drying of hands in various restaurants and places of food selling has prompted the need for this project. We have taken the standard mechanical Hand washing and drying machine and made it a technological engineering wonder of touch-less Hand washing And Drying. The machine comprises a housing having a top portion and a bottom portion. The top portion is quasi-rectangular shaped structure comprising a fluid injection system for injecting water and liquid soap to users' hands. The bottom portion comprises a box shaped structure wherein by the side is the heating chamber for drying the hands. The machine further comprises a wash basin coupled in the interior of said box shaped structure with circular opening under where the used water or liquid soap pass through, an electronic eye for detecting the insertion of hands in said wash basin and a control unit for timing the activation of said water injection. Also in the heating chamber comprising an air injection system for injecting air through said heating chamber, a thermostat to control the temperature and a sensor that activate the drying process whenever the hands cast dark shadow across it. This research work has successfully presented a functional and highly efficient low cost sensor controlled hand washing and drying machine which is usable in different places within our geographical environment.

Keywords: Touchless hand washing, hand drying, Fluid injection system, Electronic eye, Air injection system, control unit.

1 INTRODUCTION

Importance of hand washing cannot be over-emphasized, especially in developing nations where eating with hands is a common practice. In some developing cultures, there is always the reluctance of hand washing before meals; and in some, hand washing has become a culturally accepted norm. Eating with the hands was going on for generations before anyone thought of washing their hands first. So along the way, through technology and hygiene practices, people become educated in the improvement of hand washing.

Hand washing is the single most important way of preventing the spread of infections, according to the US Centre for Disease Control and Prevention. Unwashed or poorly washed hands are very common way of spreading many diseases such as: cold, flu, ear infections, strep throat, diarrhea and other intestinal problems. Germs and viruses causing these diseases are passed on by such routine things as handling food, touching door knobs, shaking hands and putting mouths on a telephone receiver. And in our daily activities we practice one of these either in the offices, at home, in the market places, in the classroom and so on. Good hand washing practices have also been known to reduce the incidence of other diseases, notably pneumonia, trachoma, scabies, skin and eye infections and diarrhea-related diseases like cholera and dysentery, according to World Health Organization (WHO). The promotion of hand washing with soap is also a key strategy for controlling the spread of Avian Influenza (bird flu). After the incidence of SARS-Severe Acute Respiratory Syndrome in 2003, more and more people on their daily lives gave more attention to health habits; the daily number of hand-washing increased than before. This prompted us to contribute with this project as a way to increasing the practice of hand washing in our society so as to remain healthy.

This machine is specially designed for use in the offices, public restroom and as well for the general domestic washing and drying of the hands at home. It supplies both soapy and clean water in a sequential order during the washing and rinsing cycle and then supplies a warm air current to dry up the completely washed hand thereof. It is handy and easy to use. More importantly, it can avoid the contagious diseases; for example, when it was a manual type hand washing machine, to turn on/off the tap, you must need the help of your hands. In this case, your hands or fingers would be infected with any virus left by any possible previous user if he or she is infected with a disease. With the automatic type, you will not only use the water at ease, but also avoid any possible contact with any contagious disease.

Also some cases were considered whereby people would inevitably, more or less, waste some water as we might have seen people washing their hands at any public places or at home. It is not necessarily because people tend to waste some water at their own will, for example, when it is a traditional mechanical type, people would wash their hands under the pressed water with the switch on, as the switch is positioned at this state, the water keeps being pressed down at the same amount no matter when the person really needs the water to wash or not. This causes low efficiency of water usage. Another possibility is that people who are in a hurry may often unconsciously forget about turning the tap off, if they really forget about it, the water would keep flowing or dripping until it gets turned off by the next user. As for the automatic type, it turns on and off automatically as it senses any object with energy or heat. In this case, the unnecessary waste of water can be avoided. Therefore with all these benefits, the automatic hand washing machine are becoming increasingly popular among schools, families, dining halls, companies or any other public places.

1.1 The Hand Dryer

The unhealthy pattern of drying hands after washing in various restaurants and places of food selling has also prompted the need for this project. It was observed that good number of Nigerian citizens like enjoying traditional delicacies without the use of cutleries. They wash and dry their hands with a hand towel respectively. This indeed is completely unhygienic as these hand towels are sometimes not changed as at when due. Automatic hand dryers have many benefits when it comes to staying healthy, cutting cost and reducing waste.

1.2 Benefits of this design

a. **Hygiene:** Washing hands thoroughly is effective in preventing the spread of germs, yet drying hands is just as important. It might be tempting to simply dry your hands off on your pants while exiting the restroom, but that means your hands may remain damp for several minutes. What many people do not know is that bacteria is more likely to spread through damp hands rather than dry hands, so making sure your hands are completely dry before leaving the restroom helps prevent illness even further. In busy restrooms paper towel dispensers can run out quickly, leaving people with no other choice than to skip hand drying. Automatic hand dryers require very little maintenance, and with the development of no-touch technology, there is no need to touch any bacteria-laden surfaces in the process.

b. **Cost**: Due to the constant maintenance and refills that come along with paper towel dispensers, automatic hand dryers are cost-effective solutions. Not only must paper towels be refilled, but there are also costs associated with the production and clean-up of paper towels. For example additional trash bags and cleaning products are needed to dispose of the paper towels and reduce the spread of germs through towels left on counter tops. Electric hand dryers last several years and require little maintenance, decreasing the total cost for maintaining the restroom.

c. **Waste:** automatic hand dryers also have more environmental benefits than paper towels. While some paper towels may be made of recycled materials, used paper towels cannot be recycled leading to an increase in waste and a continued destruction of trees for paper production. Switching to the use of automatic hand dryers in public restrooms can be helpful to reduce waste as well as energy, as the cost and energy used to produce paper towels outweigh that of hand dryers.

1.2 Objectives of the Design

The following are the objectives:

1. To enhance the level of hygiene wherever applicable.
2. To increase the level of awareness of people as regards to the proper washing and drying of hands in accordance with the policy of the National Orientation Agency in Nigeria.
3. To solve a considerable fraction of the problems associated with washing and drying of hands, so as to reduce the risk of disease transfer, between individuals.
4. To expose the fact that the proper washing and drying of hands after holding objects, using the toilet and even transfer/exchanging money between individuals, will geometrically reduce the rate and/or presence of ill health in the area in question.

2 REVIEW OF RELATED LITERATURES

2.1 Background of the Invention

In 1847 Hungarian-born physician Ignaz Semmelweis made striking observations which lead to the practice of hand washing in medical clinics. While working at an obstetrics clinic in Vienna, Dr. Semmelweis was disturbed by the fact that fatal child bed (or "puerperal") fever occurred significantly more frequently in women who were assisted by medical students, compared with those who were assisted by midwives. Through meticulous examination of clinical practices, he discovered that medical students who assisted in childbirth often did so after performing autopsies on patients who had died from sepsis (of bacterial origin). After instituting a strict policy of hand-washing with a chlorinated antiseptic solution, mortality rates dropped by 10- 20 fold within 3 months, demonstrating that transfer of disease could be significantly reduced by this simple hygienic practice.

2.2 The Mukombe or Tippy Tap

The Mukombe was designed by Dr. Jim Watt of the Salvation Army in Chiweshes, Zimbabwe. Mukombe is the fruit of an indigenous plant (type of guard or calabash), but many vessels can also be used in the same way like the Tippy Tap, promoted by UNICEF and Water Aid in Uganda.

The Tippy Tap is a simple water dispenser which enables people to wash their hands without wasting water. The Tippy Tap primary consists of a 3 to 5 liters of jerry can that is filled with water and suspended from a wooden frame. A string attached to the neck of the jerry can is tied to a piece of wood at ground level. Soap is suspended from the frame beside the jerry can, and pressing with the foot on the wood tips the jerry can, releasing a stream of water through a small hole. As only the soap is touched with the hands the device is very hygienic. A gravel bed is used to soak away the water and prevent mosquitoes. When the container is empty the cap is unscrewed and the container is removed from the stick. The container is then filled again at a water pump and reassembled.

In the southern highlands region of Tanzania, the NGO Shipo installs sample of Tippy Tap, after which families make copies. Most of the Tippy Taps are installed near latrines of schools.

2.3 Invention of Automatic Hand Washing Machine

Automatic hand washing machines were first developed in the 1950, but were not produced for commercial use till the late 1980s when they first appeared (to the general public) at airport lavatories. Story has it that the first airport to adopt the new technology is O'Hare Airport. It is called by other names such as electronic, sensor, hands-free, touch-less or even infrared hand washing machines. Automatic hand washing machines have become a central theme in the American experience. They are now found in places, far removed from airports and other institutions, places like restaurants, hotels, casinos, malls, sports arenas as well as residential properties.

Known for their assistive qualities, automatic hand washing machines are making their presence felt at living establishments and places where the elderly and or handicapped individuals call homes. They are water saving devices and other benefits as earlier motioned are found in inhibiting the spread of germs which are known to thrive on faucets handles.

2.4 Later Developments

In the U.S PAT. No 55 22, 411, issued to Johnson, entitled "HAND WASHING AND DRYING EQUIPMENT UNIT" discloses a portable hand washing and drying unit including a housing having an opening for receiving the hands of the user (the opening of the housing is closed via a door when not in use), the hand washing and cleaning liquid reservoir and electrically powered fan for providing a flow of air to dry the hands. The user manually operates a valve to dispense the cleaning liquid and manually operates a switch to turning on the fan for drying the hands.

U.S. PAT No.4, 606, 085, issued to Davies entitled "HAND WASHING DEVICE" discloses an electro mechanical device that is provided with time element which are initiated by the flow of water. The hand washing device has a wash cycle and a rinse cycle and an emollient timer triggered after the rinse cycle to dispense of the emollient.

Another apparatus with US PAT No.4, 398, 310 issued to Liengard entitled, "WASH STAND DEVICE" discloses a hand washing device which is triggered by light barrier. The hand washing device comprises a control system for regulating moistening, washing, rinsing and drying stages of the washing process.

Macfartane et al, discloses a machine with US PAT No. 4, 145, 769 entitled "AUTOMATIC HANDWASHING AND DRYING APPARATUS" which includes a first manually operable control device for causing operation of a solenoid operated valve to deliver hand washing water directly into a bowl for a preselected period of time. A second manually operable control device is provided for causing operation of a force air drying structure to provide hand drying air to the bowl.

While each of the above hand washing and drying devices function as desired none of them are touch-less or hand free washing machine. This design operates via an infrared sensor; when the users placed his/her hands in the washing chamber without pressing any button as previous designs have one or more buttons to press, may touch the cleaning fluid (soap) dispensing device or the drying device; therefore the efforts to minimize the spread of bacteria and other diseases with the use of automated water dispensing is futile.

3 DESIGN

All the above described machines offered a guide to our own design. Our present design solves the aforementioned problems in a straightforward and simple manner. What is provided is touch-less hand washing and drying machine. The machine comprises a housing having a top portion and a bottom portion. The top portion is quasi-rectangular shaped structure comprising a fluid injection system for injecting water and fluid soap to the user's hands. The bottom portion comprises a box shaped structure where in by the side is the heating chamber for drying the hands.

The machine further comprises a wash basin coupled in the interior of said box shaped structure with circular opening under where the used water or liquid soap pass through, an electronic eye for detecting the insertion of hands in said wash basin and a control unit for timing the activation of said water injection system and said liquid soap injection in response to the detecting of said electronic eye to carry out a hand washing process. Also in the heating chamber comprising an air injection system for injecting air through said heating chamber, a thermostat to control the temperature and a sensor that activate the drying process whenever the hands cast dark shadows across it.

There are also three different reservoirs, clean water reservoir, liquid soap reservoir and a waste water reservoir. The clean water and liquid soap reservoir contain two different pumps. The first pump delivers soapy water through the discharge nozzle mounted above the washing sink after which the second pump delivers clean water through the same nozzle during washing and rinsing respectively.

Fig. 1: The automatic hand washing and drying machine with the detached centrifugal chabmer beside it

3.1 Components Survey

The Connection Pipes

The piping system are being used to channel the soapy and system from the reservoirs to the discharge nozzle for washing hand, also another connecting pipe is used to channel the dirty water to the collecting reservoir.

The Blower/Fan

This is the centrifugal type. It produces air current employing the use of rotating impeller. It also has a stationery casing to guide the flow of air to and from the impeller.

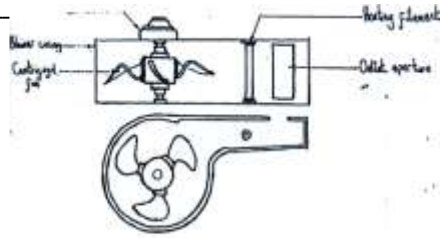

Fig 2: A sketch of the centrifugal chamber

The Heater

The heater consists of a heating filament.

The Heating Chamber

The heating chamber is the compartment that houses the heater in this chamber; there is a mixture of the heat generated by the heating filament and the air current generated by the centrifugal fan, thus producing warm air current for effective drying of the washed hands.

The Pump

The pumps are two in number, one for soapy water and the other is used for pumping clean water. The pumps are 12 bolts direct current electric type each. The choice of direct current type was made because it is les noisy in operation. The pumps deliver certain quantity of water from the reservoir to the washing sink at will.

The Reservoirs

There are three reservoirs. Each reservoir holds an average of five liters of soapy water, clean water and dirty water. The reservoirs are made of plastic materials. The dirty water reservoir has a discharge port through which dirty water is discharged when it gets full.

The Sink

The sink generally have two taps (faucets) that supply soapy and clean water and may include a spray feature to be used for faster rinsing. The sink includes a drain with a strainer.

3.2 Parameter Calculations

Heat Requirements

Given that the human body temperature is 37°C required drying temperature is 40°C normal room temperature is 35°C.

Dimension of the heater casing is (200x200)mm heat gained or lost through the walls of the heating chamber is given by the relation.

$$\phi = \frac{A \times \Delta T \times K}{\Delta X}$$ Where;

ϕ = heat (watts) ΔT = temperature difference (°C) A = external surface area (M^2)

K = thermal conductivity of the insulating materials (0.07 watts/meter °C)

ΔX = insulation thickness (m)

Substitutes

$$\phi = \frac{\left(200 \times 10^{-3} \times 200 \times 10^{-3}\right) \times (0.07) \times (40 - 35)}{25 \times 10^{-3}} = 5.6kW$$

Power Requirements of the Centrifugal Fan Motor

The power of the motor of the centrifugal fan was obtained considering the power required for the pressure drop from the inlet of the centrifugal fan casing across the heating chamber.
Given that;

Density of air = ρ_A = 1.72kg/m^3
Operating temperature T_2 = 40°C = 40 + 273k = 313K
Specific heat capacity of air at constant pressure (C_p) = 1.005J/kg°K

Knowing that,

The speed of the fan N_f = 300rpm
Diameter of the fan D_f = 120mm
The velocity of air stream is given by: $V_f = (18852 \text{ x}10^{-3})$m/s = 18.85m/s
Coefficient of entry (Ce) = 0.97m/s
Area of heating chamber = (0.2x0.2)m^2 = 0.04m^2 using the relation

$$W = F_A.\phi.C_p \quad \text{. . . . (i)}$$

But $\phi = A_1.V_f C_e$ . . . .(ii)

Where A_1 = area of the inlet section

$$A_1 = \frac{\pi d^2}{4} \quad \text{. . . .(iii)}$$

Substituting in equation (iii)

$$A_1 = \frac{3.142(0.12)^2}{4} = 0.189m^2$$

Then $\phi = \left(0.189m^2 \times 19.85 \times 0.97\right)m/s = 3.45m^3/s$

Substituting in equation (i)

$W = 1.172 \times 3.45 \times 313 \times 1.005 = 1272.9$ W

Time for Drying

The power required drying/producing the warm air that will dry the hand is the combination of the power of the heater and the power of the fan.
Illustration

$P_R = P_H\ X + P_F$

Where P_R = power required, P_H = power of heater, P_F = power of fan
P_R = 5600W + 1271.9W = 6871.9W
And

$P_R = P_A \times Qx\ cp \times \Delta T$

$$P_R = \frac{P_A \times V \times cp \times \Delta T}{T}$$

Where,
P_A = 1. 172 ΔT = 40 - 37 = 3^0 C Volume (V) = 165x10^3 litres = 165m^3
Cp = 1.005 kJ/kg/°k
Now the time (t) required for drying is given by

$$t = \frac{P_A \times Vx\ cp \times \Delta T}{P_R} = \frac{1.172 \times 165 \times 1.005 \times 3}{6.872} = 44.\ 84\text{sec}$$

Time required for drying is, say, 45 seconds.

The Efficiency of the Blower

$$n = \frac{Power\ output}{Power\ input}$$

P_{in} = IV = 220V x 37A = 814W
P_{out} = 6872W

$$n = \frac{6982}{8140} \times \frac{100}{1} = 84\%$$

Efficiency of the Pumps

Power output of the pump, P_{out} = ρgQH = l000 x 9.81 x 0.591 x 1= 5800W
Where, ρ = 1000kg/m^3, g = 9.81m/s^2, Q =0.591m^3/s , H = 1m

$$Efficiency, \quad n = \frac{Power\ output}{Power\ input} = \frac{5800 \times 100}{8140 \times 1} = 71\%$$

3.3 The Pipe System Geometry

Loss Due To Sudden Enlargement in the Pipe

Pipe diameter (d_1) = 10mm, Pipe diameter due to enlargement (d_2) say 20mm
Assuming hydraulic gradient rises by 10mm
Applying Bernoulli's equation to small and large pipe sections,

We get $\frac{P_1}{W} + \frac{V_1^2}{2g} + 2 = \frac{P_2}{w} + \frac{V_2^2}{2g} + Z_2 + h_e$ (i.e. head loss due to sudden enlargement) … (iv)

But, $h_e = \frac{(V - V_2)^2}{2g}$ … (v)

From continuity equation we have, $A_1V_1 = A_2V_2$

$$V_1 = A_2V_2 = 4 \times D_2{}^2 \times V_2 = \left(\frac{D_2 \times V_2}{D_1}\right)$$

$$Or\ V_1 = \left(\frac{20^2}{10}\right) \times V_2 = 4V_2$$

Substituting this value of V_1 in eqn (v) we have

$$h_e = \frac{(4V_2 - V_2)^2}{2g} = \frac{9V_2{}^2}{2g}$$

Now substituting the values of h_e and V_1 in eqn (iv) we have

$$\frac{P_1}{w} + \frac{(4V_2)}{2g} + z_1 = \frac{P_2}{w} + \frac{V_2{}^2}{2g} + Z_2 + \frac{9V_2{}^2}{2g}$$

$$\frac{16V_2{}^2}{2g} - \frac{V_2{}^2}{2g} - \frac{9V_2{}^2}{2g} = \left(\frac{P^2 + 2_2}{w}\right) - \left(\frac{P_1 + 2_1}{w}\right) = 0.01m$$

The term, $\dfrac{p+Z}{w}$ describes the hydraulic gradient

$$\frac{6V_2^{\,2}}{2g} = 0.01$$

$$V_2 = \frac{(0.01\times 2\times 9.81)^{1/2}}{6} = 0.181m/s$$

Therefore, $h_e = \dfrac{9v_2^{\,2}}{2g} = \dfrac{9\times(0.181)^2}{2\times 9.81}\ \dfrac{0.295}{19.62}$ = 0.015m

Rate of Flow ϕ

We know that $\phi = A_2 V_2 = \dfrac{\pi}{4}\times 0.02^2\times 0.181$ = $0.00005m^3/s$

Power Loss Due to Sudden Enlargement, P_{Loss}

$$P_{lost} = \frac{W\phi ge}{100}$$

Where w = pg = 981 x 1 $1000N/m^2$ ϕ = 0.000057m3/s h_e = 0.015m

$P_{lost} = \dfrac{(9.81\times 1000)\times 0.000057\times 0.015}{1000}$ = 0.008W

The Power Delivered To the Water by the Pump

$$h_f = \frac{flv^2}{D\times 2g}$$

Where h_f = head loss due to friction F = 0.03 (Darcy – Weisbach friction)
L = 50m (length of the pipe) D = 10mm = 0.01m (Pipe diameter)

$$h_f = \frac{0.03\times 50\times 0.181}{0.01\times 2\times 9.81} = \frac{0.2715}{0.1962} = 1.38m$$

$P = w\phi h_f = 9.81\times 0.000057\times 1.38 = 7.7\times 10^{-4}W$ = 0.77

3.4 Electrical Connection

The electrical circuit is designed in such a way that when alternating current from the power source (220 volts) mains is applied to the circuit by putting on the wall switch, the heater is on and is regulated/ maintained at 40°C by a thermostat connected to step down the voltage from 220V to 12V and then a rectifier is connected to change the current form. The fan and two pumps (soapy water and clean water pump) are connected in parallel to each other with an indicator light (light emitting diodes) connected in parallel to the fan, first pump and second pump respectively.

Conclusion

This research work has successfully presented a functional and highly efficient low cost sensor-controlled hand washing and drying machine which is usable in different places within our geographical environment and settings such as hotels, homes, hospitals, executive offices, restaurants, schools etc. as way of adopting a good hand washing and drying process or procedure hence improving hygienic condition of individuals; and this eliminates the transfer of facal pathogens from one person to another.

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