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Design and development of a domestic dishwasher

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Abstract

A dishwasher was designed for use in the domestic setting and mini restaurants for washing dishes. It consists of tub (the washing chamber) where the washing operation takes place, the rack where the soiled dishes are placed. The dishwasher is provided with a heater for the heating of the water, water pump and two tanks (for the soapy water and rinsing water).

The machine was developed from locally sourced materials such as mild steel, angle iron and PVC water pipes. Construction and testing were carried out and the result showed that the dishes were well cleaned and it had overall acceptability based on smell, cleanliness and appearance. Seven dishes were washed and rinsed in a time of 69.29 seconds. The machine has an average capacity of cleaning 371 dishes per hour.

Keywords: Dishwasher, Detergent, Water, Pressure, Pump

Introduction

A dishwasher is a mechanical device for cleaning dishes and it can be found in restaurants and also in the kitchens of many private residents. Sharma et al (2003) defined "dish-pit" as an area where dishes are washed, particularly in food service. The dishwasher carries out the functions such as scraping, washing, rinsing and sanitizing. The types of dishwasher in use today include Immersion dishwashers, Single tank stationary rack (Door type) dishwashers, Conveyor Rack type, flight type dishwashers and Caroused type dishwasher. Dishwashing has come a long way from the days when it was wholly a hand operation using only two sinks and drain boards for soiled and clean dishes soap, lukewarm water and largely transient labour. Strong soap is used to get dishes clean. Sometimes the washing solution would be too strong and the worker would suffer skin irritation. The soil which is made up of crust meat residues, uneaten vegetable and other edible and inedible materials must be removed. Unlike manual dishwashing which relies largely on physical scrubbing to remove soiling, the mechanical dishwasher cleans by spraying hot water at $55^0C – 65^0C$ on the purpose (Arthur, 1985). First, detergent water is used for cleaning purposes, then clean water to remove the detergent residue. Some dishwashers have multiple wash and rinse periods within the complete cycle. As there is no human contact during the process, strong detergents may be used which would be too alkaline for habitual exposures to the skin. Many dishwashers also contain a heating element to achieve fast drying and sanitation of the dishes. Joel Houghton patented a wooden machine with a hand-turned wheel that splashed water on dishes, its efficiency was low, but it was the first patent in 1850 in America (Odusola and Afolabi, 2012). They also reported that for manual washing, a time of one minute was achieved for 5 plates. In some model, element can also be used to heat the hot water to the desired wash temperature. Comparing the efficiency of automatic dish washers and hand-washing of dishes is difficult because hand-washing techniques vary drastically by individual. A 2004 peer – reviewed study concluded that the best automatic dishwashers available at the time when fully loaded use best electricity, water and detergent than the average European hand – washer. The most efficient hand-washers in the study, however, were far more energy efficient than the dishwashers. In particular, higher-end dishwashers that are capable of heating water internally do not lose heat during transport to a sink. Probably the most frequent use of the mechanical dishwasher, other than for washing dishes and flatware, is for cleaning lightly soiled pots, pans and kitchen hand utensils or for rinsing after they have been hand washed. Also they can be used to wash fruit and vegetable served or cooked with their skills (Arthur, 1985).Some items can be damage if washed in a dishwasher because of the effect of the chemical and hot water. Shalia *et al* (2016) reported that automatic dishwasher uses large amount of energy, time and costly. In Nigeria today, restaurants/eateries and hotels increase on daily basis. There arise need to develop a low cost, portable and efficient dishwasher to reduce the skin irritation caused by most detergent during washing, to reduce excessive labour in our kitchen. Most mothers today now take-up paid jobs and to reduce the number of labour in mini restaurants and homes, it is expedient to develop a low cost mechanical dishwasher that will use less water and detergent. The imported ones are expensive and cumbersome.

Design Considerations

The machine was designed to have two tanks, one for the mixture of the detergent and water while the other tank contains the rising water at a temperature of 50^{o}- 65^{o}C.

Arthur (1985) reported that a ½ HP (0.375kW) pump will be required for a small dish water to pump the water to pass through the orifice for washing and rinsing while 1 HP (0.75kW) for large dish washer. For this machine a ½ HP (0.375kW) pump was used for the design.

(i) Designs For The Heat Required To Heat The Water

The Quantity of heat required can be calculated by using Pabla (2003)

$$Q = mc\Delta T \quad \ldots (1)$$

Where

Q = Quantity of heat required kJ

c = Specific Heat Capacity of water 4.2 J/kgK

m = Mass of water heated kg

ΔT = Change in temperature K

From our design, 113 liters of water is required and using conversion standard, 113liters is equated to 113kg.

Temperature (ΔT) = 55-0 = 55^{o}C

$$\Delta T = 55 + 273 = 328K$$

Substituting the values into equation (1)

Q = 113 x 4.2 x 328 = 155669J = 156kJ

(ii) Designs For The Rack

The diameters of standard dishes were measured and the average diameter was found to be 25cm per plate. The machine was design to wash seven (7) plates at a time and the space between the plates was given as 9cm apart.

The total length is (9x7) = 63cm.

(iii) Velocity of Discharge

From Douglas *et al* (2001) a pump of 0.375kW was used to pump the water from Rajput (2003)

Kinetic energy = $v^2/2g$ … (2)

Where

v = velocity of discharge m/s

G = Acceleration due to gravity kg /m^2

$0.375 = v^2/ 2 \times 10$

$V^2 = 0.375 \times 2 \times 10 = 2.74$m/s

For the orifice

Velocity of orifice = $\sqrt{2gH}$ … (3)

Where,

H = Height from the pump to the orifice (0.75m)

g = Acceleration due to gravity (m^2/s)

$V_o = \sqrt{2 \times 10 \times 0.75}$

= 3.87m/s

Taking the coefficient of discharge to be 0.97

3.87 x 0.97 = 3.75m/s

The orifice was obtained by drilling holes of 25mm along the rack. The diameter of the orifice was chosen to be small in order to obtain high pressure.

$\therefore$Area of the orifice = $\frac{\pi d^2}{4}$ … (4)

$= \frac{124 \times (0.025)^2}{4} = 4.909 \times 10^{-4}\ m^2$

(iv) Discharge

The discharge was obtained using the flow equation as stated in Khurmi and Gupta (2005)

Q = AV … (5)

Where

Q = Discharge of water m^3/s

A = Area of orifice (m)

V = velocity of discharge (m/s)

$3.87 \times 4.909 \times 10^{-4}$

$= 1.89 \times 10^{-3}\ m^3/s$.

Total Discharge = Discharge at one orifice x number of plates

$1.87 \times 10^{-3} \times 7 = 13.09 \times 10^{-3}$ m/s

Force of Water Discharged from the Orifice from Bernoulli equation as in Khurmi and Gupta (2005)

The pressure at the rack

$$\frac{P_1}{W} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{W} + \frac{V_2^2}{2g} + h_1 \quad \text{... (6)}$$

Where

P_1= Pressure of the pump kN/m^2

W_1 = Specific weight of water w = 9.81kN

V_1= Velocity of pump m/s

Z_1 = Datum (m)

P_2 = Pressure of rack kN/m^2

V_2 = Velocity at the rack m/s

h_1 = Height of Discharge (m)

W_2 = (7.64 – (1.467) = 7.489 = 7.45kJ

Pressure = force of water released from the orifice /Area of orifice … (7)

7.45 x 10^3 x area of orifice = force

7.45 x 10^3 x 4.709 x 10^{-4} =3.66N

(v) Losses in Pipe Fittings and Bends

When a flow in a pipeline is interrupted by the use of pipe fittings such as bend valve there will be pressure loss

Loss of head due to bend in the pipe is calculated by

$$h_{Fittings} = K^{\left(\frac{V^2}{2g}\right)} \quad \text{…(8)}$$

Where

$h_{Fittings}$ = Head losses in the pipe(m)

K = Coefficient of bend = (0.9)

g = Acceleration due to gravity (m^2/g)

For an elbow joint of 90^o

$$h = \frac{0.9\,(3.75^2)}{2 \times 10} = \frac{0.9x3.75^2}{2 \times 10} = 0.63\text{m}$$

(iv) Loss Due To Gate Valve

K for gate valve = 0.25

Substituting k into equation (7)

$$h = \frac{0.25\,(3.75^2)}{2 \times 10} = \frac{0.25\,x3.75^2}{2 \times 10} = 0.18\text{m}$$

(v) Loss Due To Tee Junction

K for Tee Junction = 1.8

$$h = \frac{1.8\,(3.75^2)}{2 \times 10} = \frac{1.8x3.75^2}{2 \times 10} = 1.27\text{m}$$

(vi) Major Loss Due To Friction

The loss of head or energy in pipes due to friction is calculated from Darcy Weisbach Formula (Douglas et al, 2001).

$$h_f = \frac{4\,f\,LV^2}{2Dg} \quad \text{... (9)}$$

Where h_f = Loss of head due to friction

F = coefficient of friction
L = length of the pipe (m)
V = mean velocity (m/s)
D = diameter of pipe (m)

$$F = \frac{0.0791}{(Re)^{\frac{1}{4}}} \quad \ldots (10)$$

Where
Re = Reynold number varying from 4000 to 10^6

$$F = \frac{0.0791}{(4000)^{\frac{1}{4}}} = 9.94 \times 10^{-3}$$

Substituting (9) into equation (8)

$$h_f = \frac{4 \times 9.94 \times 10^{-3} \times 0.75 \times 3.75^2}{2 \times 10 \times 0.03} = 0.6989 = 0.699\text{m}$$

(vii) Momentum And Fluid Flow

From Newton's second law states that the rate of change of momentum of a body is proportional to the force applied and takes place in the direction of the force Momentum = Mass x Velocity …(11)

113 x 3.75 = 423.75kgm/s

Figure 1 shows the developed dishwasher. Figure 2 shows the various parts of the dishwasher while Figure 3 shows the views of the dishwasher.

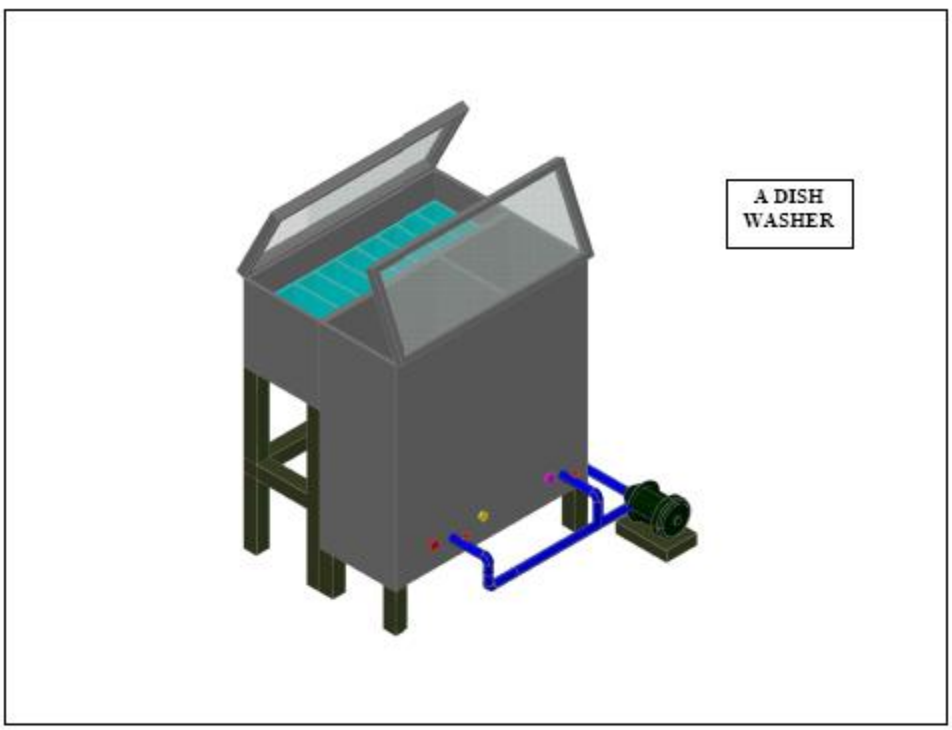
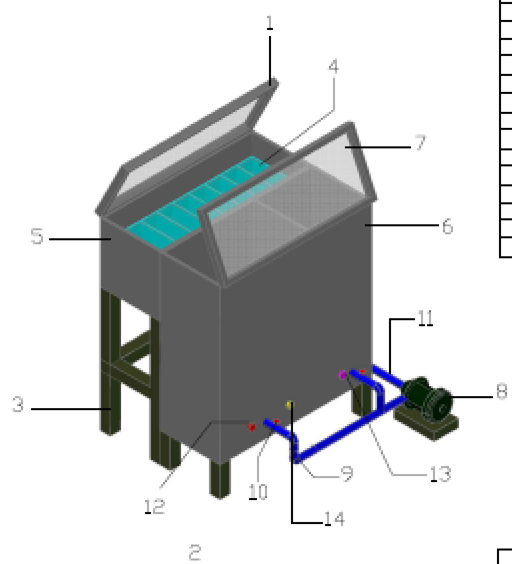


Figure 1: The dishwasher



S/N	PART NAME	QTY	MATERIAL
1	DOOR FRAME	2	MILD STEEL
2	CONTROL CIRCUIT	1	BOARD
3	FRAME		MILD STEEL
4	RACK	1	MILD STEEL
5	TUB	1	MILD STEEL
6	TANK	1	MILD STEEL
7	GLASS	2	PLAIN
8	FEED PUMP	1	
9	ELBOW	3	PLASTIC
10	CONTROL VALVE	2	PLASTIC
11	PVC PIPE		PLASTIC
12	INDICATOR	1	NEON BULB
13	SWITCH	1	PLASTIC
14	THERMISTOR	1	NEON BULB

A DISH WASHER

Figure 2: Parts list of the Dishwasher

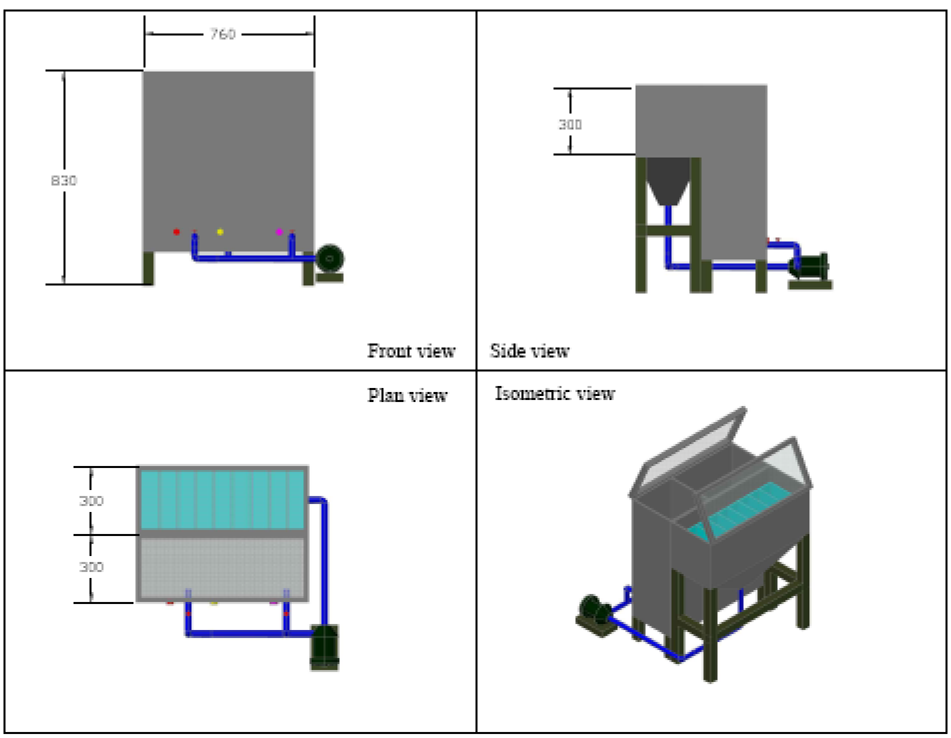


Figure 3: The views of the dishwasher

Working operation

The machine consist of pumping machine valves to control the flow of water, rack for holding plates, two tanks one for soapy water and the other for rinsing water. A tub of 75cm long, 30cm wide and 50cm deep was constructed to carry out the washing operation. The two tanks were filled with water one for washing which was mixed with detergent whiles the other tank for the rinsing of dishes. The heater was switched on from the power source and the water was allowed to attain a temperature of 55^oC. This was observed with a temperature indicator. Dirty dishes (seven in number) were loaded in the rack and detergent was added to the heated water in appropriate proportion. The soapy water tank valve was opened and the spray was achieved with the aid of the pumping machine at a high pressure on the surfaces of the dirty dishes. The valve of the soapy water was closed after some minutes and that of the rinsing water was opened and allowed to spray the dish for some minutes to achieve rinsing of the plates. After some minutes the pumping machine was switched off and the dishes were transferred to another rack for the water to be drained. The machine was tested in respect of time taken to carry out the operation. The result obtained from the test carried out at the end of the operation. The operation was performed seven times and the average machine capacity was also determined.

Results and discussion

Table 1 shows the results obtained when the dish washer was operated.

The average time taken for the complete operation was calculated to be 69.29seconds and the average machine capacity was 371 dishes per hour. It was observed that in cases where the soil got stuck to the dishes the soil could not be removed in one cycle of operation. It was also observed that the washing has to be done the second time before the soil could totally be removed. The dishes should be washed immediately after eating so as to be able to perform the operation once. The dishes could also be pre-soaked before washing.

Table 1: **Result of Test Performed on the Dishwasher.**

TEST	Time Taken For Washing (Sec)	Time Taken For Rinsing (Sec)	Total Time taken (Sec)
1st	30	45	75
2nd	40	40	80
3rd	25	45	70
4th	35	45	50
5th	30	40	70
6th	28	45	73
7th	32	35	67

Sensory Evaluation

A seven member panelists from Agricultural Engineering department was selected based on experience and familiarity with dishes for sensory evaluation. The evaluation was conducted under white light produced by fluorescent light in a spacious workshop room. After the washing operation was performed, the cleaned dishes were given to them for smell, feel and visual evaluation.

Smell: The dishes had long lasting fresh odour which cleared away lingering cooking smells

Feel: The dishes were felt by the finger and the panelists were of the opinion that there was no grease on the plates and the plates were not slippery to the fingers.

Visual: The soil which was made up of meat residues and other edible and inedible material was removed. Therefore, the dishes were sparkly clean.

The panelists were of the opinion that the dishes were well cleaned. Based on cleanliness and appearance, it had overall acceptability.

Conclusion

In the design and construction of the dishwasher, a step by step process was taken to produce a machine which can effectively achieve the aim it was built for. The machine was tested and it was able to clean 7 dishes per operation. The average time for the washing and rinsing operation was 69.29 seconds. The dish washer has a capacity of 371dishes/hr.

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