DEVELOPMENT OF A FRUIT WASHING MACHINE

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ABSTRACT

A fruit washing machine was designed and fabricated taking into consideration the techno-economic status of the micro, small and medium scale fruit farmers who are the intended users of the machine. Considerations also included high washing capacity and efficiency and the desire to make the construction materials of stainless steel to ensure the quality of the washed product. Other consideration was a strong main frame as support to ensure structural stability of the machine. The machine was designed for ergonomic value, safety and ease of operation and maintenance by incorporating guards around the moving parts and components. Rollers were also incorporated in the design to ensure easy movement of the machine. The machine was tested using 50 samples of orange for the washing operation. During the testing, the belt conveying mechanism was such that the fruits were conveyed under high jet spray pressure in order to get rid of the attached foreign materials. The test result showed that the washing capacity was 0.0163 tonnes/h or 16.3 kg/h and washing efficiency was 62.5 %. Powered by a 1 hp single phase gear electric motor, the machine has a production cost of USD 300 while all the construction materials were available locally.

KEYWORDS: Washing, machine, fruits, oranges, washing capacity.

1. INTRODUCTION

Fruits are highly perishable FAO (1995), reported that over 23 % of most perishable fruits are lost during their journey through the agricultural food chain due to spoilage, physiological decay, water loss and mechanical damage. These occur during harvesting, transportation, processing and packaging. These losses have been estimated to be more than 50% in the tropics and sub tropics. Washing fresh produce (also known as surface treatment) can reduce the overall potential for microbial food safety hazards. This is an important step since most microbial contamination is on the surface of fruits. If pathogens are not removed, inactivated, or otherwise controlled, they can spread to surrounding produce, potentially contaminating a greater proportion of the produce. (FDA, 1998).

Fruits are prewashed to get rid of immediate surface dirt and pesticide residues before any leaves and stem still attached are removed. The removal of mites and other surface arthropods may be enhanced by the use of a mechanical surface cleaning system, such as high-pressure water sprays and/or rotating brushes (Walker, 1996). Hussain *et al* (1991) recommended that fruits must be cleaned after they are harvested to improve product appearance and edibility to remove residues of field-applied chemicals and to remove harmful microorganisms that would shorten the life of the product. According to Walker (1996), pressurized sprays ranging from 2240 to 5516 kPa were used to remove surface arthropods.

In recent research, Bai *et al* (2006) mentioned that use of high pressurized sprays causes damages to the fruit surface. Pressurized sprays at 560 kPa were more effective than those at 210 kPa in pest removal, but also damaged the fruit surface but sprays at 420 kPa were as effective and did not cause injury. Furthermore, increasing the pressure to 840 kPa did not significantly increase efficiency but reduced the fruits quality as it caused damages to the fruits.

Papadopoulou (1998) was of the opinion that the clarity of the water which was affected by the concentration of suspended particles was a measure of its quality. High pressures in the range 3000-8000 bars were suggested by Palou (2000) to be applied on some fruits in order to inactivate microorganisms and enzymes without the degradation in flavour and nutrients associated with traditional thermal processing. Unfortunately there are some problems associated with the use of this treatment on fresh-cut products, as it affects the integrity of porous ones as a consequence of the compression and expansion during pressurization and decompression of the air confined in the fruit matrix.

Rotary fruit washing machine features a simple design and sturdy construction. Fruits are fed into the hopper continuously and get washed by slow tumbling action of the rotary drum. After washing, the fruits come out through the other end (FAO, 1995). This machine is capable of washing fruits, vegetables and most suitable for washing fruits like mango, pears, apples, potatoes, carrots and other root vegetables but it cannot be used to clean fragile fruits like tomatoes.

The objectives of this study were to develop a fruit washing machine that can enhance the fruit quality and to determine the machine efficiency.

2. MATERIALS AND METHODS

2.1 Main Components of the Machine

As shown in Figure 1, the machine main frame is made of 40 mm x 40 mm angle iron with a thickness of 4 mm. it is the chaises of the machine on which other parts are built. Fruits are fed into the washing camber through the hopper. The hopper is in the form of a trapezium with upper dimension of 600 mm x 300 mm, base dimension of 500 mm x 300 mm and height of 150 mm, the hopper is twit at an angle of 5^0. The conveyor belt is made of balata material since they are water proof and can be easily made endless. This will convey the fruits to be washed to the washing chamber at a regulated speed. The washing chamber accommodates the sprinklers and the conveying belt.

The drain net allows the draining of the fruits of wash water. The water basin contains the drained water while the filter: filters the water being collected after washing in order to recycle it for the next washing operation. A centrifugal pump of known specification was be used for water pumping while the sprinklers sprayed water on the fruits at a regulated pressure. A weighing balance was employed to measure the weight of the fruits before and after washing while a stopwatch was used to record the time spent in washing operation. A Vernier caliper was used to measure the different dimensions (major, minor and lateral diameters) of the fruit to be washed.

2.2 Working Principles of the Machine

The machine was designed to operate in batches of about 50 oranges per batch which are fed into the washing chamber through the fruit hopper. The sprinklers spray water on the fruits while travelling through the conveyor belt at a controlled speed. This is to ensure that the fruits are are thoroughly cleaned to the required standard. The machine was powered by a 1-hp single phase geared electric motor of 200 rpm with a power transmission efficiency of 90 %.

The washing systems is aided by the sprinklers which spray water at high pressure spray across and along the conveying belt over the fruits to be washed. In operation, the fruits lie still on the surface of belt conveyor without relative motion between the product and the conveyor belt. In this way, there will generally be no damage to the fruits until the fruits arrive to the dryer sheet in which the washed fruits are discharged into a collector. The debris and unwanted particles are removed through the drain net or dissolved in the washing water. The water discharged into the water chamber after washing is recycled by pumping and filtering it into the washing chamber in order to maximize water use.

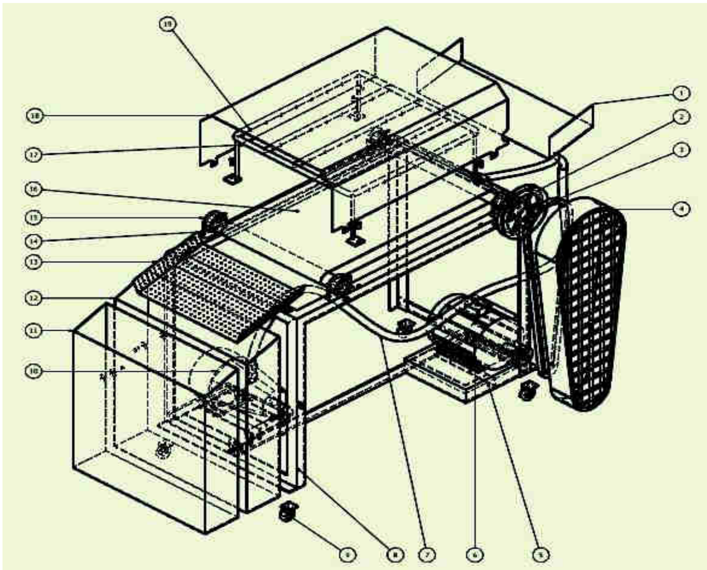

Figure 1: Exploded View of the Fruit Washing Machine: 1-Feeding Tray; 2-Pulley; 3-Belt; 4 Belt Guard; 5-Motor Seat; 6-Electric Motor; 7-Hose; 8-Frame; 9-Roller; 10-Water Pump; 11-Fruit Collector; 12-Water Tank; 13-Drain Net; 14-Shaft; 15-Bearing; 16-Conveyor Belt; 17- Pipes; 18-Washing Chamber; 19-Nozzle or Jet

2.3 Design of the Machine Components

2.3.1 Design of the Feeding Tray

The tray inclination which is considered an important design factor in feeding tray (opened hopper) design was determined using the expression given by Ashaolu, (1989). This is expressed as:

$$a = \tan^{-1} \mu \qquad \textbf{(1)}$$

where: a is angle of inclination and μ is coefficient of friction between orange and galvanized steel as proposed by Singh, (2004). Given that μ = 0.36, hence, a = 19.7^0.

2.3.2 Design of Shaft

The shaft is the main component of the machine and is acted upon by weights of material being processed, pulley, conveyor belt and the fruits. In operation, the shaft transmits the power being generated by the gear reduction motor to the conveyor belt. Therefore, in order to safeguard against bending and torsional stresses, the diameter of the shaft was determined from the equation given by Shigley and Mitchell (2001) as:

$$d^3 = \frac{16\,T}{0.27\pi\delta_0} \qquad \textbf{(2)}$$

where: d is diameter of the shaft in m, T is torque transmitted by the shaft in Nm, δ_0 is yield stress for mild steel in N/m^2 and π is a constant. Given that T = 60 Nm and δ_0 = 200 N/mm^{2,} and π = 3.142, hence, d = 17.82 mm. Therefore, a mild steel rod of diameter 25 mm and length 680 mm was used for the shaft.

2.3.3 Design of Drive Mechanism

In determining the diameter of the driven pulley, the expression given by (Gupta, 2006) was used in conjunction with relevant information in standard tables.

$$N_1D_1 = N_2D_2 \qquad (3)$$

where N_1 and N_2 are the speed of the driven pulley and speed of the driving pulley respectively in rpm and D_1 and D_2 are the diameter of the driven pulley and diameter of the driving pulley respectively in mm.

According to Kempe's Engineers Yearbook and Gates Rubbert Company Manual, the minimum pitch diameter for A – type V-belting transmitting power at a speed of 1500 rpm is 2.2 in (or 55.9 mm). For this reason, a driving pulley diameter of 60 mm was chosen to be used. The calculated value of driven pulley using Equation (3) is 4500 mm (4.5 m). However, due to this large calculated driven pulley, a gear reduction box will be attached to the conveyor shaft in order to give the required speed of the conveyor 20 rpm.

Angle of Wrap

The angle of wrap was determined using the expression given by (Gupta, 2006) which was stated in the expression below as:

$$\theta_S = \pi - 2Sin^{-1}\left(\frac{D-d}{3C}\right) \qquad (4)$$

where: θ_S is angle of wrap in radian, D is diameter of bigger pulley, d is diameter of smaller pulley and C is Centre to centre distance between both pulleys. Substituting the values of D, d and C into Equation (4) gives the angle of wrap as 2.92 radians.

2.3.4 Design of the Conveyor Belt

The conveyor belt will reduce the fruit's velocity, minimize the chance for damage. Fruit-to-fruit contact is preferred over fruit-to-metal therefore the conveyor belt is made of balata belt. The dumping sequence and fruit flow control are critical for uniform throughput and an efficient operation. The groove angle was determined using the expression given by Gupta (2006) shown in Equation (5) below as:

$$\beta = \sin^{-1}\left[\frac{(R-r)}{C}\right] \qquad (5)$$

where: β is groove angle, R is radius of driven pulley, r is radius of driving pulley and C is distance between the centres of the two pulleys. Given that R = 12.5 mm, r = 12.5 mm and C =

Angle of Contact:

Flat belt drives consist of a strong elastic cone surrounded by an elastomer. Drives of this type have a lot of advantages over gear drives or V-Belt drives. According to Shigley and Mitchell (2001), the contact angle is found to be

$$\theta_d = \pi - 2\sin^{-1}\left(\frac{D-d}{2C}\right) \qquad (6)$$

Since D = d = 12.5 mm, hence, $Q_d = \pi$ radians or 180^0.

Belt Design

The length of the belt was be determined using the equation below (Gupta, 2006):

$$L = \pi (r_1 + r_2) + 2C + \frac{(r_1+r_2)^2}{C} \quad (7)$$

where: L is total length of the belt in mm, r_1 and r_2 are radii of the driven pulley and driving pulley respectively in mm, C is distance between the centres of the two pulleys in mm. Substituting the values of the parameters in the equation gives L as 1478.539 mm.

2.3.5 Power Requirements and capacity of the conveyor

The power required to drive the conveyor was determined using equation (8)

$$P = (T_1 - T_2)V \quad (8)$$

where: T_1 and T_2 are Tensions on the tight and slack sides of the belt respectively in N. With T_1 = 368.92 N and T_2 = 349.53 N; hence, P = 28.51 W.

The capacity of the conveyor was determined by the equation given by Miller *et al* (2010) as:

$$C = \frac{W \times S \times 6}{10 \times A} \quad (9)$$

where: C, W, S and A is the capacity (tonnes/hr.), width of conveyor in meters (m), linear speed (m/min) and area of the conveyor (m^2) respectively. Substituting W = 0.45 m, S = 0.13 m/min and A = 0.75 m^2; hence, C = 0.052 tonnes/hr.

2.4 Construction of the Machine

The machine components were fabricated based on the design specifications and were assembled together as shown by its isometric view in Figure 2. The materials of construction, their specifications and construction procedures are as shown in Table 1.

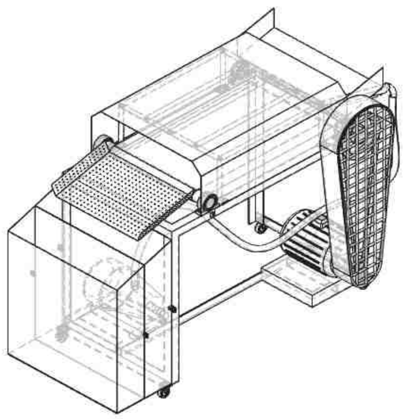

Figure 2: Isometric View of the Fruit Washing Machine

Table 1: Materials of Construction, their Specifications and Construction Procedures

S/N	Component Parts	Materials	Procedure	Quantity
1	Frame	Galvanized steel, 40 × 40 mm angle iron	600 mm × 4, 770 mm × 4 and 1060 mm × 3 was cut to form the breadth, height and length respectively of the frame. They were welded together to form a rigid frame.	3 standard length
2	Feeding Tray	1 mm galvanized steel.	The metal sheet was bent at 3 sides and screwed to the wall of the washing chamber inside	200 x 600 mm
3	Washing chamber	1.5 mm galvanized steel	The sheet was belt at 250 × 600 × 800 mm to form the height, breath and the length of the chamber.	$^1/_2$ of standard dimension
4	Pulley	Mild steel, single groove (Ø 300mm)	A pulley of 300 mm diameter was selected.	1
5	Engine Base	Galvanized steel, 40 ×40 mm angle iron	The angle iron was cut into 300mm in 5 places and welded together to form the base of the prime mover of the machine.	
6	Shaft	Mild steel	The mild steel was machined to Ø20 mm and 500 mm long. Two pairs of pillow bearing was used to support the shaft.	2

3. PERFORMANCE EVALUATAION OF THE MACHINE

3.1 The Machine

After fabrication of the component parts, the machine was assembled as shown in Figure 3. Testing was carried out in this project work to determine the suitable washing rate, washing efficiency and volume of water required to wash fruits. The gear electric motor was connected by belt mechanism to the pulley of the shaft of the conveyor belt and the water pump was connected to the sprinkler system. The machine was set into operation and, after the smooth running was maintained, fruits were introduced into the washing chamber through the feeding trays. The washing operation continued.

3.2 Washing Efficiency of the Machine

Washing efficiency of the machine was calculated by the expression given by Scott *et al* (1981) and shown in Equation (10) as:

$$WE = \frac{100\,SR}{SA}\ \% \qquad (10)$$

where: WE is washing efficiency in %, SR is mass of foreign materials removed by washing (mass of sample before washing - mass of sample after washing) in g/ kg and SA is mass of foreign material attached in g/kg. SA was estimated by hand washing 30 samples of fruits to full cleaning and weighing the foreign materials attached with one kg of fruits. From the test, SR and SA were found to be 100 and 160 respectively in g/kg resulting in WE being 62.5 %.

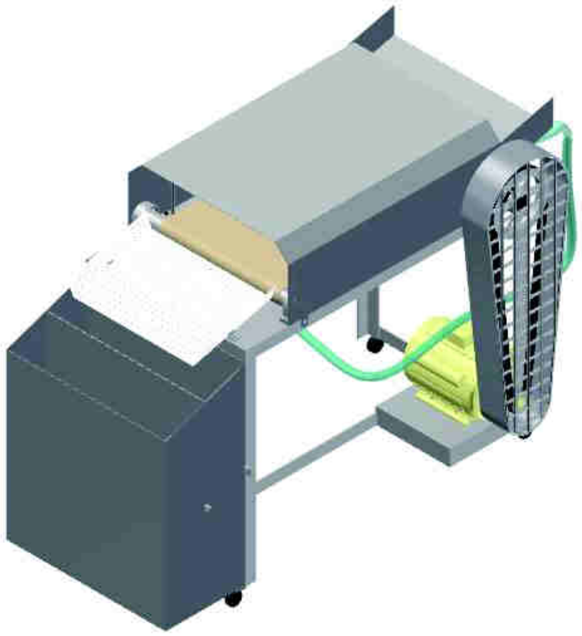

Figure 3: Pictorial View of the Fruit Washing Machine

3.3 Productivity of the Machine

The washing productivity of the machine was determined using the expression given by the equation given below as:

$$C = \frac{M \times 60}{T_w} \qquad (11)$$

where: C is washing capacity of the machine in tonnes/h, M is mass of the washed fruit in tonnes and T_W is washing time in min. From the test, M and T_W were found to be 0.00244 tonnes and 9 min respectively resulting in C being 0.0163 tonnes/h or 16.3 kg/h.

4. CONCLUSION

The study examined the effect of pressurized sprays and conveyor belts on fruits. Washing as a unit operation in fruit processing is of high necessity and very important in any fruit process industries. From the test carried out on the machine the following salient points can be concluded that the water pressure was able to remove the foreign materials attached to fruits and also reduce the heat built up in the fruits by cooling. The steady slow speed of the geared electric motor enhances the thorough washing of the fruits. The use of water proof belt for the conveyor belt is strongly recommended as this will not absorb moisture as well as reducing the load on the conveyor belt.

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