



DESIGN AND FINITE ELEMENT ANALYSIS OF AN INDUSTRIAL-BASED VEGETABLE LEAF WASHING MACHINE

¹Ojo, O. T., ²Mogaji, T. S., ¹Adeyeri, M. K. ¹Ayodeji, S. P. and ³Fagbemi, T. N.

¹Department of Industrial and Production Engineering, Federal University of Technology, Akure, Ondo State, P.M.B.704, Nigeria.

²Department of Mechanical Engineering, Federal University of Technology, Akure, Ondo State, P.M.B.704, Nigeria.

³Department of Food Science and Technology, Federal University of Technology, P.M.B.704, Akure, Ondo State, Nigeria.

*Correspondence: otojo@futa.edu.ng

Ojo O. T., Mogaji T. S., Adeyeri M. K. Ayodeji, S. P. and Fagbemi T. N. (2022): Design and Finite Element Analysis of an Industrial-Based Vegetable Leaf Washing Machine. *Journal of Engineering and Engineering Technology* /16(1), 82 -94

Received 31-01-22

Accepted: 19-04-22

Abstract

The application of mechanization and process technology in washing vegetables and fruits has become a necessity in order to eliminate drudgery, reduce precious time lost to manual washing and to guarantee safety of consumers and quality of intakes especially in this Covid19 pandemic era. Hence, this work presents the design of an industrial based vegetable leaf washing machine. Some components of the machine include; Water bath, perforated screen, water pump, vegetable paddlers, rollers, shaft, bearings, air blower, electric motor, water sprinkler system, water tank, piping, and the material handling (conveyor system). Relevant design equations were used in the design analysis of the machine and finite element analysis (FEA) was carried out to ascertain the structural integrity, functionality and manufacturability of the system. With total load distribution of 9.50 kN resulting from the volume/capacity of the water bath and weight of accessories and vegetables, the behavior of the base material under various loading condition was reported. Solidworks von mises analysis carried out showed that a maximum stress distribution of $5.15 \times 10^8 \text{ N/m}^2$ was obtained which is below the yield strength of $6.20 \times 10^8 \text{ N/m}^2$ for the material selected. The maximum elongation obtained under loading condition is 14.29 mm which is very minimal for any failure to occur or reduce life cycle of the base material. Factor of safety was observed to be 1.2 hence guaranteeing a safe operation and thus optimizing production cost with a value of 1.20. Other simulation results carried out showed that the design is considered safe and fit for fabrication. The machine when fabricated can be used as a stand-alone machine and can also be integrated with a vegetable leaf powder processing plant for industrial purposes.

Keywords: Design analysis; simulation; conveyor system; mechanization; vegetable washing

Introduction

Washing which is part of human activities has become essential to human day-to-day living due to Covid19 pandemic. Thus, hygiene is central to human health and by extension, human survival (Olutomilola, 2021). Washing of farm produce is a surface treatment process and a value addition procedure meant to reduce microbial contaminants, food hazards and to guarantee human safety during consumption or as raw materials for other processing (Ambrose and Annamalai, 2013; Olutomilola *et al.*, 2019). The microbial reduction rate is affected by; the type of sanitizers used (Fatemi *et al.*, 2006), the mechanism employed for washing (Younis *et al.*, 2005), the affinity of microorganisms with the produce surfaces (Gonzalez *et al.*, 2004) and the combination of aforementioned factors (Adegbite *et al.*, 2018; Kenghe *et al.*, 2015; Ojo, 2021).

Vegetables have been described as the edible portions of a plant such as the leaves, stem, tubers and roots. Nutritionally, fruits and vegetables are parts of human diet containing essential minerals, vitamins and fibre needed for the maintenance of healthy life (Agudo, 2004).

A number of outbreaks have been traced to fresh-cut fruits and vegetables, which were caused due to unhygienic sanitary conditions. The investigations carried out to access the remote causes of these outbreaks showed that the quality of water used for washing was crucial (Gil *et al.*, 2009). Kenghe *et al.* (2015) believed that it is necessary to properly clean fruits and vegetables harvested from the field prior to weighing, grading and processing for further value addition. It was also emphasized that fruit washing can

be carried out by immersion, by spray/showers or by combination of these two processes which is generally the best solution. Washing action on fruits and vegetables are predominantly done manually, for domestic and even at commercial levels. This manual method has many drawbacks such as; hard and boring work leading to fatigue, loss of precious time and exposure to unhygienic environment (Adegbite *et al.*, 2018).

Over the years, a lot researches have been carried out to develop washing machines for leafy vegetables which are driven manually and or motorized. While some works centered on washing of root crops such as cassava, yam, plantain, cocoyam and potatoes, other were on the development of agricultural processing plants for processing agricultural produce, aimed at guaranteeing food security, improve level of hygiene, improve shelf life and to make food readily available throughout the year, thus achieving one of the agenda of sustainable development goals (SDG) of the United Nations.

Olutomilola *et al.* (2020) designed and carried out structural analysis of a particulating machine meant to work on a plantain flour process plant. Ogunlowo *et al.* (2016) evaluated the performance of an automated system developed for cleaning, peeling and washing cassava tubers. Narender *et al.* (2018) developed and carried out performance evaluation of vegetable washer for carrot crop. Ambrose and Annamalai, (2013) fabricated a root crop washer which is manually operated. Olutomilola and Omoaka, (2018) presented a theoretical design for plantain peeling machine. Kenghe *et al.* 2015 developed and tested a small-scale mechanical fruit washer. Akinnuli *et al.* (2019) worked on the design and simulation of a vegetable shredding and washing machine. Olayanju *et al.* (2019) developed a ceramic cassava peeling and washing machine. Olutomilola *et al.* (2019) presented finite element analysis of a washing and preheating machines which was designed for plantain flour process plant.

Ayodeji, (2016) worked on conceptual design of a process plant for plantain flour production from green plantain pulp. The process plant consists of washing, slicing, drying, milling and sieving machines. The design and analysis of machines that make up the plant and its performance evaluation were carried out using solidworks software and relevant appropriate design equations. Ojo, (2021) in his PhD thesis developed a process plant for the production of vegetable leaf powder. The process plant which was automated is made up of washing, pre- drying, drying, milling and packaging machines and has production capacity of 300 g per 8 hours of work.

Since thorough cleaning is regarded as crucial operation in the production and distribution of fresh produce, it is therefore necessary to advance methods used in washing vegetables in order to guarantee their consumption and human safety. Hence, this work focuses on the design and simulation of a vegetable washing machine which can function as a stand-alone machine or be integrated to vegetable leaf powder process plant for industrial use.

Materials and Method

Design Consideration

In order to have a design with optimal performance, factors considered at the design phase of this machine are; capacity of the machine, material resistance to corrosion, method of recirculation of water, direction and speed of rotation of paddler shafts, pressure of blower, ease of fabrication, operation and maintenance, the use of stainless steel (a food grade material) for major part of the machine and plastic mesh as conveyor belt, the effective tension in the conveyor belt needed to raise loads and the angle of inclination of the water sprinklers.

Description/Principle of Operation of the Machine

The designed washing machine when fabricated has ability to wash leafy vegetables, either for immediate consumption or for further processing into powder through processes such as pre-drying, drying, pulverizing and packaging in a vegetable leaf process plant.

The machine consists of; machine frame, water storage tank, loading point, water bath, perforated screen, vegetable paddlers and rollers with flexible rubber brush, air blower (to create agitation of leaves), water pump, pipe connections, pressurized water sprinklers that will introduce jets of water, pulleys, electric motor, rubber belt conveyor system, base water reservoir and water collection trough. There is a provision for automatic recirculation of water before it is finally released out of the washing machine. The mode of operation of this machine is such that vegetable leaves are sorted out manually (to prevent processing unhealthy leaves) and are fed in into the washing chamber.

The controlled combination of pressurized water through the air blower which sets up much needed agitation in the water bath to shake off dirty particles on vegetables, and together with the action of two paddlers which rotate in anti-clockwise direction, thus results into washing of vegetables while debris that would have gone into the production line goes through a mesh and settles at the base of the water bath before they are flushed out periodically as sediments through the main waste valve. There is also a rinsing action from the water sprinkler system which introduces jets of water to the washed leaves before draining.

The Washing Machine Design Drawings

The detailed conceptual drawing of the proposed automated washing machine was done using Solidworks computer aided design CAD application software (version, 2019) because of the provision for features such as; 3D solid modelling and simulation, large and complex assembly design, automatic drawing view creation and update, advanced surface design and flattening, direct model editing and CAD import/export to mention but a few.

The isometric view of vegetable washing machine is presented in Figure 1 while the orthographic view of the design showing the front, side and plan views of the machine is shown in Figure 2 a, b and c respectively. The machine part list is indicated in Table 1.

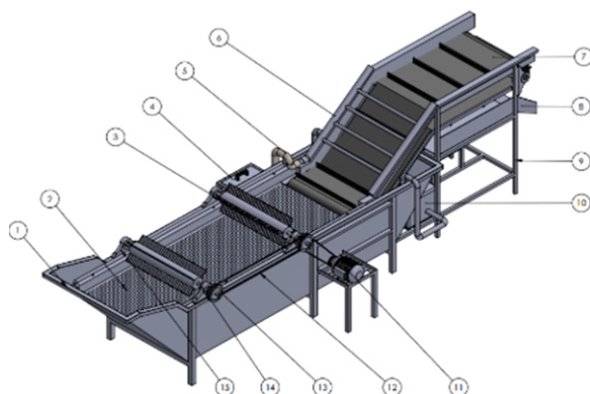


Figure 1: Isometric view of the washing machine

Table 1: Machine Part List

Part No	Part Name	Quantity
1	Loading point	1
2	Screen	1
3	Roller paddle	2
4	Base water reservoir	1
5	Water supply pipe	1
6	Water sprinkler system	1
7	Mesh conveyor belt	1
8	Trough	1
9	Machine frame	1
10	Air blower chamber	1
11	Electric motor	1
12	V-belt	2
13	Pulley	2
14	Water bath	1
15	Bearing	4

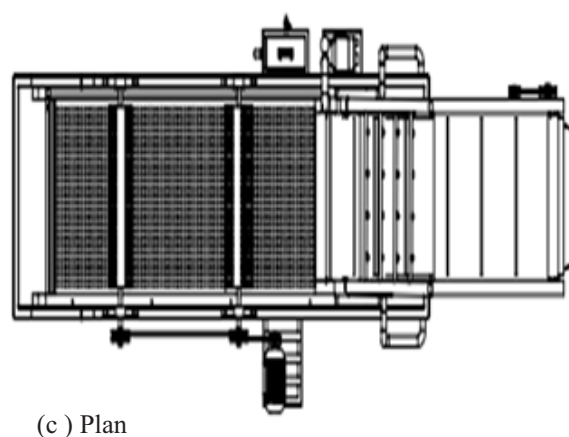
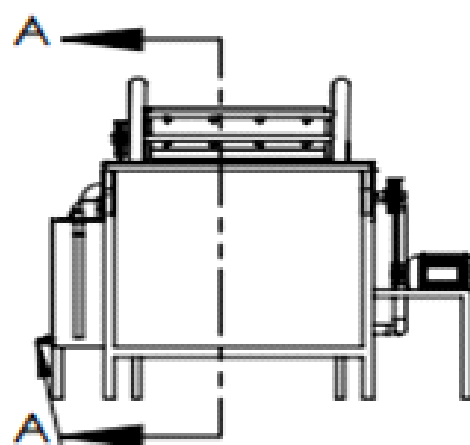
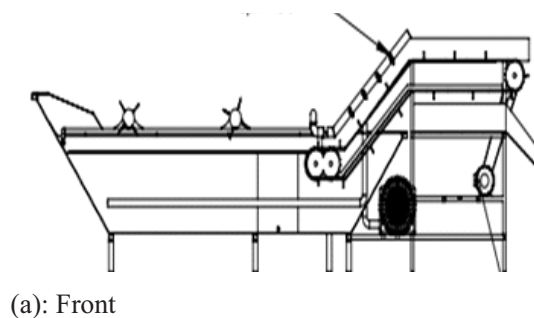


Figure 2: Orthographic views showing the (a) front, (b) side and (c) plan views of the design drawing

Machine Components Design Calculations

The design calculations of some of the machine components are presented in Equations 1 to 24:

The tank water pressure was determined from Equation 1

$$P_w = \rho gh \quad (1)$$

where;

P_w is the water pressure (kN/m^2),

ρ is the density of water which equals 1000 kg/m^3 ,

g is the acceleration due to gravity $= 9.81 \text{ m/s}^2$,

h is the head which is 8 metres.

Water flow capacity from the overhead tank was derived from Equation 2

$$Q = A_p V_f \quad (2)$$

where;

A_p is the area of pipe (m^2), V_f is the velocity of fluid (m/s),

Q is the flow capacity (m^3/s).

The hydraulic power of the pump was determined using Equation 3:

$$P_h = Q \rho gh \quad (3)$$

where; P_h is the hydraulic pump power (kW)

Dimension of Belt, Speed and Belt Capacity

The determination of the diameter of driver and driven pulley lies on the type and dimension of conveyor belting used. Undue stress must not be imposed by the pulley on the belt (Daniyan, *et al* 2014). The conveyor belt length is taken to be the length as measured from the pulley centre parallel to belt line. Thus, belt length is a function of both the diameter of pulley and centre distance (Fenner, 2009).

The belt speed was determined using Equation 4:

$$V_b = \frac{\pi ND}{60} \quad (4)$$

where V_b is the belt speed (m/s),

N is the speed of rotation of drive pulley (rpm),

D is the roller diameter (m)

Conveyor belt capacity was determined using Equation 5.

$$BC = 3.6 A \rho_m V_b \quad (5)$$

where BC is the belt capacity (kg/s), A is the conveyor belt area (m), ρ_m is the material density (kg/m^3)

In calculating the mass of material, Equation 6 was used as posited by (Piotr, 2009).

$$M_m = \frac{BC}{3.6 V_b} \quad (6)$$

where M_m is the mass of material (kg/m),

Effective tension of conveyor belt

The four components of tension peculiar with belt conveyor systems. They are; Tension to move an empty belt, Tension to move the load horizontally, Tension to raise or lower the load against height and the tension to overcome the resistance of accessories. The aforementioned tension was calculated from equations 7, 8, and 9 respectively and the summation gave the effective tension in belt as given by Equation 10.

$$T_x = 9.8 G F_x L_C \quad (7)$$

where;

T_x is the the tension to move the empty belt in newton, G is the mass of moving part (kg/m), F_x is the coefficient of friction for empty belt, L_c is the corrected length factor in metres,

$$T_y = 9.8M_m F_y L_y \quad (8)$$

where;

T_y is the tension to move the load horizontally in Newton, F_y is the friction coefficient for loaded belt, L_y is the belt length along the conveying route in metres.

$$T_z = 9.8M_m H \quad (9)$$

where;

T_z is the tension to raise or lower the load in Newton, H is the change in elevation along conveyor length in metres.

$T_u = 0$ (No accessories are present)

Effective tension T_e in the belt was thus determined from Equation 10

$$T_e = T_x + T_y + T_z + T_u \quad (10)$$

The power absorbed (P) by the conveyor belt was determined using Equation 11 while the Horsepower (P_p) required for conveyor belt drive was determined using Equation 12.

$$P = T_e V_b \quad (11)$$

$$\text{And, } P_p = \frac{T_e V_b}{33000} \quad (12)$$

According to (Piotr, 2009), the conveyor belt breaking strength was obtained from Equation 13 as follows:

$$B_s = \frac{C_r \times P_p}{C_v \times V_b} \quad (13)$$

where;

B_s is the belt breaking strength, C_r is the friction factor, P_p is the horse power required C_v is the breaking strength lost factor

Roller Diameter

The roller enhances and facilitates easy rotation of belt. In choosing correct roller diameter, belt width must be considered (Rulmeca, 2003). The relationship between roller diameter, belt speed and the number of revolutions per minutes of the pulley is presented in Equation 14.

$$D = \frac{V \times 1000 \times 60}{\pi N} \quad (14)$$

(parameters as defined in equation 4).

Shaft Design

A shaft being a rotating machine element is used for power transmission from one machine part to another. The power delivered to the shaft is sequel to tangential force and the resultant torque set up within the shaft which permits the power to be transferred to various machine members connected to the shaft. Materials used for shaft should have the high strength, good machinability, low notch sensitivity and excellent heat treatment properties (Khurmi and Gupta, 2005).

The speed of shaft, maximum tension, tension in the tight and slack side of the belt, power transmitted by V-belt, torque transmitted by belt drive, power developed by shaft and shaft diameter were determined according to (Khurmi and Gupta, 2005), using Equations 15 to 23 respectively.

$$N_1 D_1 = N_2 D_2 \quad (15)$$

where; N_1 is the speed of drive pulley (rpm), N_2 is the speed of the driven pulley (rpm), D_1 is the diameter of drive pulley (m), D_2 is the diameter of driven pulley (m)

Maximum tension required by the belt to function effectively was obtained using Equation 16:

$$T_{max} = \sigma A \quad (16)$$

where;

σ is the allowable stress (Nmm⁻²), A is the cross section area of belt (m²),

$$T_1 = T_{max} - T_c \quad (17)$$

where;

T_{max} is the maximum tension of the belt in Newton, T_1 is the tension in the tight side of the belt in Newton, T_c is the centrifugal tension in Newton

$$2.3 \log \left[\frac{T_1}{T_2} \right] = \mu \cdot \theta \cdot \operatorname{cosec} \beta \quad (18)$$

where;

θ is the angle of contact on the motor pulley, μ is the coefficient of friction between belt and pulley β is the groove angle of the pulley, T_2 is the tension in the slack side of the belt,

$$P = (T_1 - T_2) V \quad (19)$$

$$L = \pi(R + r) + 2C + \frac{(R+r)^2}{C} \quad (20)$$

where;

α is the coefficient of increase of the belt length per unit force, R is the radius of the shaft pulley (m), r

is the radius of the motor pulley (m), c is the centre distance between the two pulleys

$$T = (T_1 - T_2)R \quad (21)$$

$$P = \frac{2\pi NT}{60} \quad (22)$$

where N = speed of shaft.

The shaft diameter was determined from torsion equation as presented in Equation 24

$$\frac{T_m}{J} = \frac{\tau}{r} \quad (23)$$

where;

T_m is the twisting moment or torque for pulley (Nm), J is polar moment of area of the shaft about the axis of rotation (mm^4), r

r is the distance from the neutral axis to the outermost fibre (mm)

r is the shaft radius (mm)

Results and Discussion

The design calculations of the machine components were done through the application of appropriate design equations. The summary of these design factors and design results arising from the design equations are presented in Table 2.

Also, Finite element analysis and the simulation of machine parts was carried out to ascertain the structural integrity and functionality of the system using Solidworks software. The results of the simulation of some of the machine parts are given in Figures 3 to 13 respectively.

Table 2: Summary of machine design factors and designed values

S/N	Design factor	Designed Values
1	Tank water pressure, P_w	52.9 (kN/m^2)
2	Flow capacity, Q	0.0032 (m^3/s)
3	Hydraulic power, P_h	171.3 (W)
4	Conveyor belt speed, V_b	3 (m/s)
5	Conveyor belt capacity, BC	14.9 (kg/s)
6	Mass of material, M_m	4.97 (kg/m)
7	Tension to move the empty belt, T_x	117.8 (N)
8	Tension to move the load horizontally, T_y	28.8 (N)
9	Tension to raise or lower the load, T_z	7.32 (N)
10	Effective tension in the belt, T_e	154 (N)
11	Power absorbed by the belt, P	462 (W)
12	Horsepower (hp) required for conveyor belt drive, P_p	2.8 (Hp)
13	Conveyor belt breaking strength, B_s	20
14	Roller diameter, D	143 (mm)
15	Shaft speed, N_1	1144 (rpm)
16	Maximum Tension in belt, T_{max}	525 (N)
17	Tension in the Tight Side of the Belt, T_1	521.9 (N)
18	Tension in the Slack Side of the Belt, T_2	16.2 (N)
19	Power transmitted by V-belt, P_v	1.5 (kW)
20	Length of Belt, L	1588 (mm)
21	Torque transmitted by belt drive, T	36.3 (Nm)
22	Power developed by shaft, P_s	1.52 (kW)
23	Shaft diameter from Torsion Equation, d	32 (mm)

Simulation Result of the Water Bath

Model name: Base tank sim cONT
Study name: Static 16 Default<As Machined>-j
Plot type: Static nodal stress SRes1
Deformation scale: 1

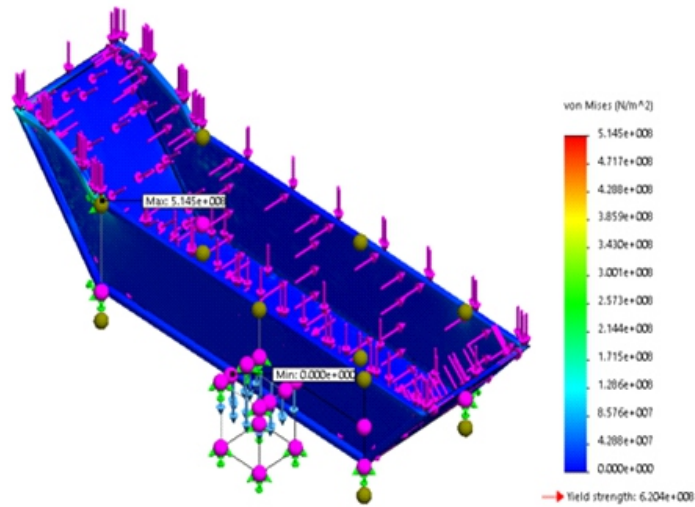


Figure 3: Water bath showing stress

Model name: Base tank sim cONT
Study name: Static 16 Default<As Machined>-j
Plot type: Static strain Strain1
Deformation scale: 1

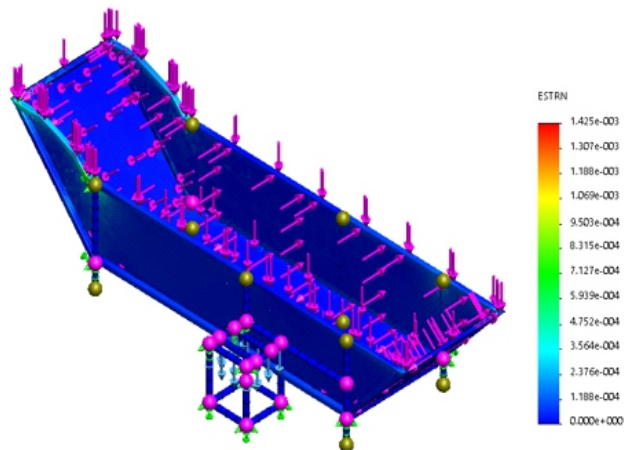


Figure 4: Water bath showing strain

Model name: Base tank sim cONT
Study name: Static 16 Default<As Machined>-j
Plot type: Static displacement Displacement1
Deformation scale: 1

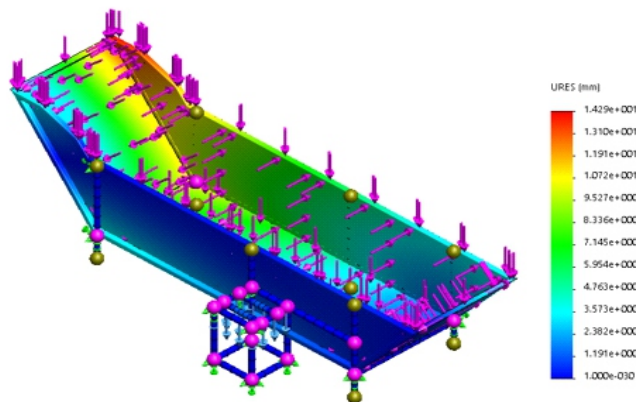


Figure 5: Water bath showing displacement

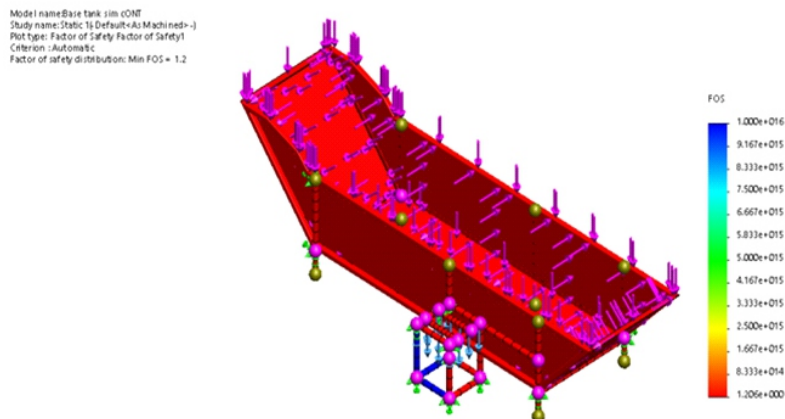


Figure 6: Factor of Safety for water bath

Finite element analysis (FEA) was ran on the water bath of the washing machine with Stainless steel AISI 304 selected. Load distribution resulting from the volume/capacity of the water bath and weight of vegetables it can contain was applied to different part members of the base material and their behavior under various loading condition is reported as observed from the simulation software used for this study. Solidworks von mises analysis carried out showed stress distribution on the base materials with the biggest magnitude of forces that can be obtained while in operation which in turn can cause deformation with total load of 9.5 kN. It was observed that a maximum stress distribution of $5.145 \times 10^8 \text{ N/m}^2$ was obtained which is below the yield strength of $6.20422 \times 10^8 \text{ N/m}^2$ of the material. This result gives a plus to the frame buildup of the part showing where highest stress is

concentrated and also where lowest stress is concentrated. However, the stress gotten is allowable stress and the material is suitable for usage under designed loading condition. Furthermore, displacement analysis was also checked to know the extent of elongation of the material under loading. The maximum elongation that can obtained under loading condition is 14.2902 mm which is very minimal for any failure to occur or reduce life cycle of the base material.

Factor of safety was observed to be 1.2. Technically, factor of safety is ability of a system's structural capacity to be viable beyond its expected or actual loads (Rutheravan, 2016); and with the result obtained in this work, this base part will perform as expected under the designed condition without failure also optimizing production cost with a value of 1.2.

Simulation Result of Washing Chamber Top Mesh

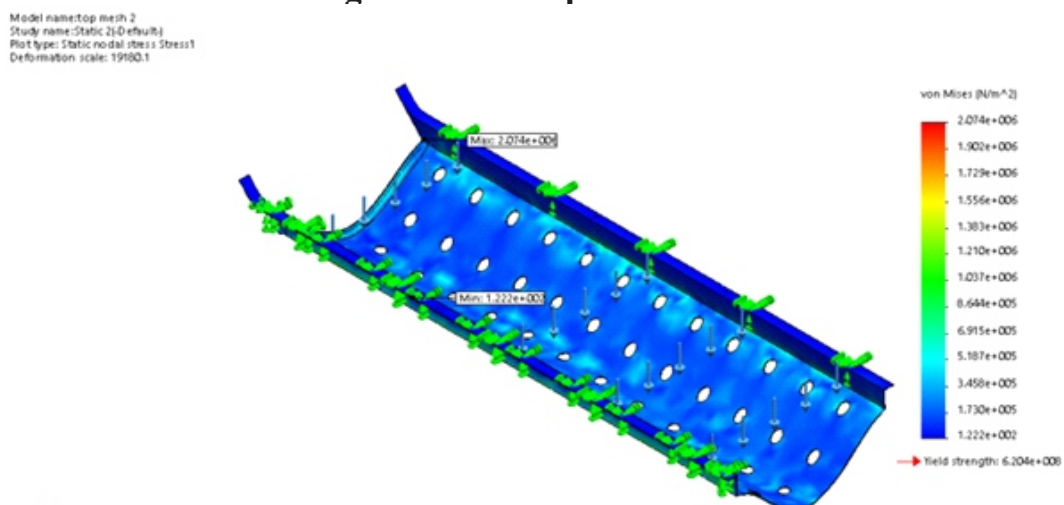


Figure 7: Washing chamber top mesh showing stress

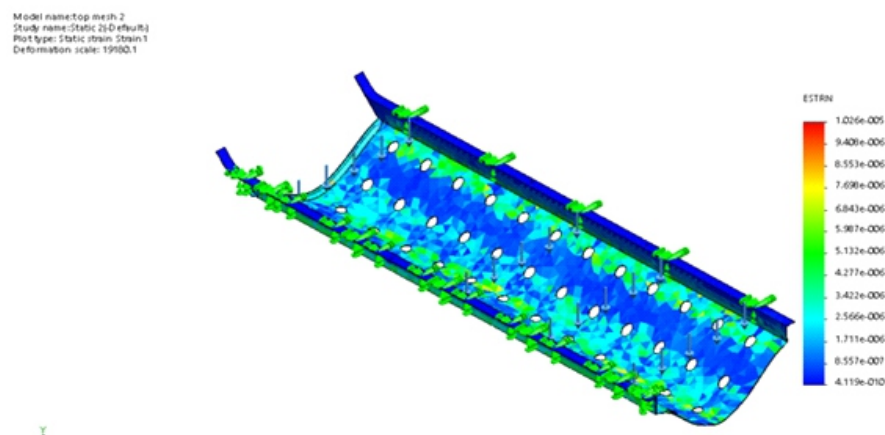


Figure 8: Washing chamber top mesh showing strain

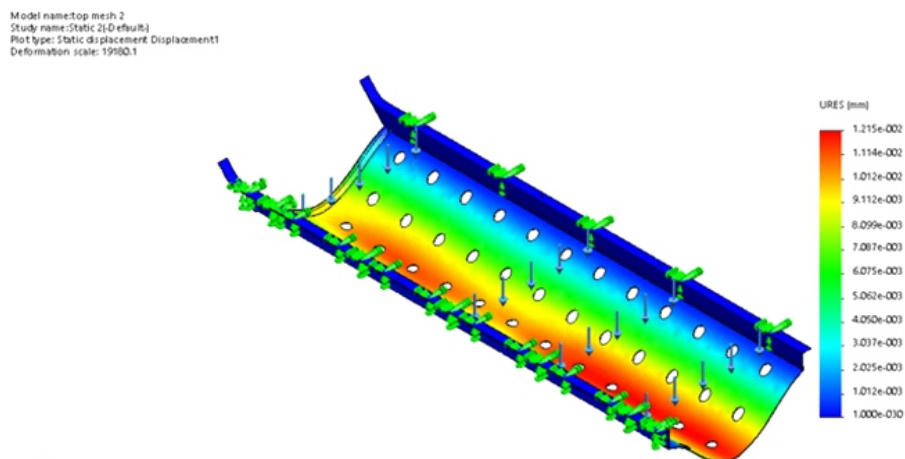


Figure 9: Washing chamber top mesh showing displacement

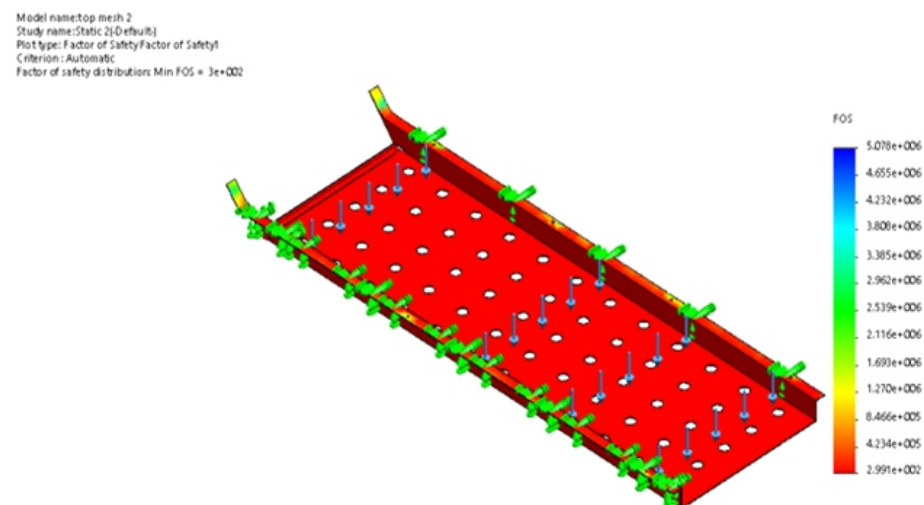


Figure 10: Washing chamber top mesh Factor of Safety

Figures 7-10 present the result of FEA conducted on the top mesh of the washing shamber loading condition when subjected to designed load. Behaviors in term of stress, displacement and Factor of safety (FOS) is as shown in the maximum stress obtained on the part member as $2.07436 \times 10^6 \text{ N/m}^2$ while the yield strength

is $6.20422 \times 10^8 \text{ N/m}^2$ when subjected to required force thus justifying that the materials will perform considerable well. Stress due Displacement was also checked and it can be seen that a 0.0121492 mm was obtained which is negligible, thus it falls within clearance displacement for the chosen material.

Simulation of the Paddler's Shaft

Model name: Nroller
Study name: Static 1 (Default)
Plot type: Static nodal stress Stress 1
Deformation scale: 1

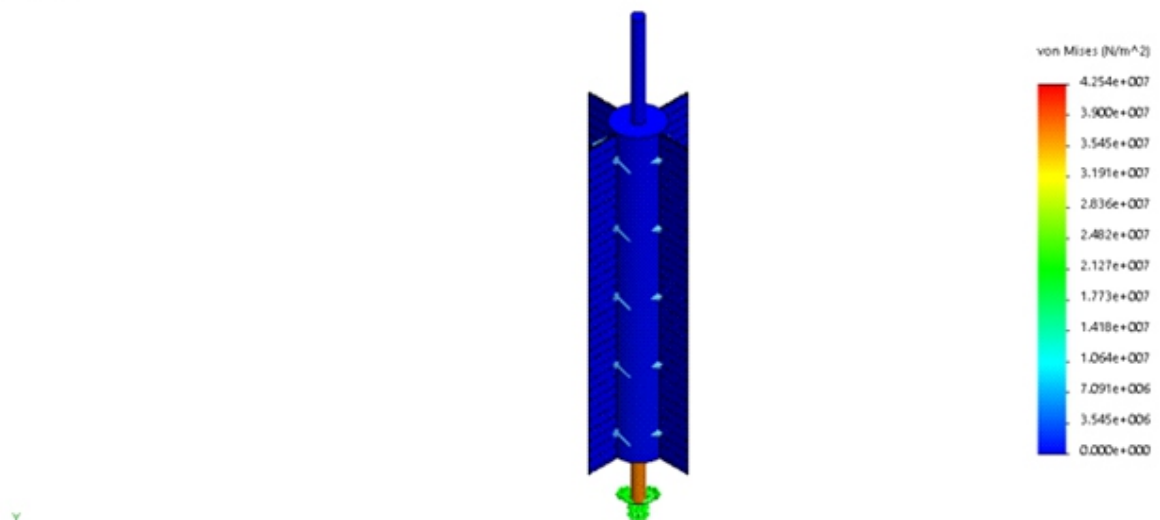


Figure 11: Static stress result of paddler shaft

Model name: Nroller
Study name: Static 1 (Default)
Plot type: Static strain Strain 1
Deformation scale: 1

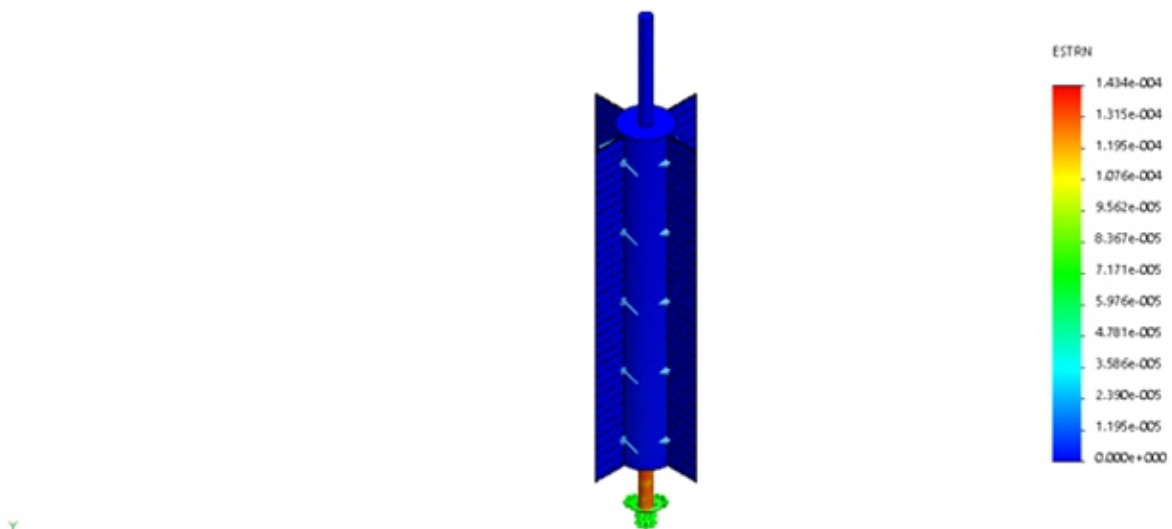


Figure 12: Paddler's shaft showing strain

Model name: Nroller
Study name: Static 1 (Default)
Plot type: Static displacement Displacement1
Deformation scale: 1

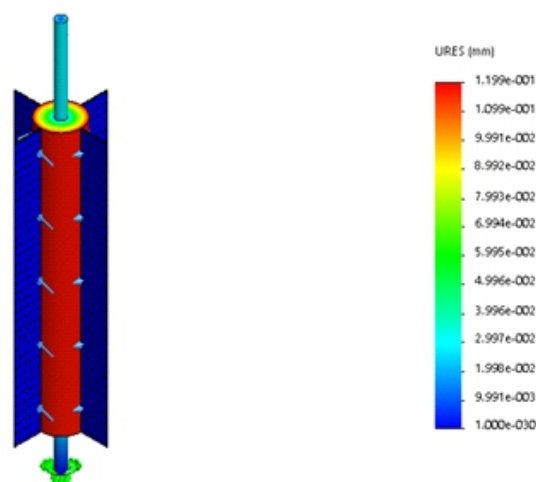


Figure 13: Paddler's shaft showing displacement

The vegetable paddlers are important part of the washing machine. The paddlers through its anti-clockwise rotation turn vegetables into the water bath, enabling washing of vegetable leaves inside the washing tub. FEA was also carried out on the paddler's shaft. Being a part subjected to constant rotational effect, torque has to be checked to see the behavior under loading. Von mises analysis was ran on the base part and a torque of 65 Nm (from the design analysis) was applied to the rotating shaft. As shown in Figure 11, stress distribution of 4.25439×10^7 N/m² was observed from simulation result as the maximum obtainable stress while under loading. This allowable stress is far below the yield stress of the material which is 6.20422×10^8 N/m², thus making the material suitable for usage.

Displacement also checks how much the material will be subjected to extension under design loading and a maximum value of 0.119893 mm was obtained as shown in Figure 13. This value is minimal thus implying that the base part is suitable under design condition and it will satisfactorily serve its intended purpose.

Conclusion

This work presents the design of a vegetable leaf washing machine. FAE analysis of the washing chamber of the designed machine revealed that a maximum stress distribution of 5.145×10^8 N/m² was obtained which is below the yield strength of 6.20422×10^8 N/m² of the selected material. Behaviors in term of stress, displacement and Factor of Safety

(FOS) of the washing chamber mesh showed 2.07436×10^6 N/m² as the maximum stress obtained on the part member while the yield strength is 6.20422×10^8 N/m² when subjected to required a combine load of 9.5 kN, thus justifying that the materials will perform considerable well. Stress distribution of 4.25439×10^7 N/m² was observed from simulation result of the designed vegetable paddlers as the maximum obtainable stress while under loading. This allowable stress is far below the yield stress of the material which is 6.20422×10^8 N/m², thus making the material suitable for usage. The results from the design calculations and simulation of machine components revealed the necessary information needed to successfully fabricate the washing machine. When this machine is fabricated, it would have a highly effective washing action, low water consumption, require low maintenance. This washing machine can stand alone when fabricated and can also be integrated with vegetable leaf powder processing plant for the production of vegetable powder. This machine is expected to serve as a model which can be adopted by manufacturers of food processing equipment. The designed machine when developed can as well be used to wash different varieties of vegetables for many applications, thereby minimizing the challenges inherent in the traditional methods of vegetable washing.

References

- Adegbite, S. A., Adeyemi, S. K., Komolafe, A. O., Salami, M. O., Nwaeche, C. F. and Ogunbiyi, A. (2018). Design and Development of Fruit Washer. *Journal of Scientific Research & Reports, Science domain International*. 21(6):1-11.
- Agudo, A. (2004). Measuring Intake of Fruits and Vegetables. Background Paper for the Joint Food and Agricultural Organization of the United Nations/WHO Workshop on Fruit and Vegetables for Health; 1-3 September, (2004), Kobe, Japan.
- Akinnuli B. O., Ojo O. O., Caleb O.O. and Okeyedun K. A. (2019). Design and Simulation of a Vegetable Shredding and Washing Machine. *International Journal of Excellence Innovation and Development*, 2(3): 33-41.
- Ambrose, D. C. P. and Annamalai, S. J. K. (2013). Development of a Manually Operated Root Crop Washer. *African Journal of Agricultural Research*, 8(24): 3097-3101.
- Ayodeji, S. P. (2016). Conceptual Design of a Process Plant for the Production of Plantain Flour. *Cogent Engineering*. 3:1-16.
- Daniyan, I. A., Adeodu, A. O. and Dada, O. M. (2014). Design of a Material Handling Equipment: Belt Conveyor System for Crushed Limestone using 3 Roll Idlers. *Journal of Advancement in Engineering and Technology*. 1(3):1-7
- Fatemi, P., Laborde, L. F., Patton, J., Sappers, G. M., Annous, B. and Knabel, S. J. (2006). Influence of Punctures, Cuts, and Surface Morphologies of Golden Delicious Apples on Penetration and Growth of *Escherichia Coli* O157: H7. *Journal of Food Prot.* 69:267-275.
- Fenner Dunlop (2009). Conveyor Handbook. Conveyor Belting Australia. pp. 1-10. <https://nadau.tistory.com/attachment/cfile25.uf@1126EB384FFCE8722A285D.pdf>
- Gil, M. I., Selma, M. V., López-Gálvez, F., Allende, A. (2009). Fresh-Cut Product Sanitation and Wash Water Disinfection: Problems and Solutions. *Int Journal of Food Microbiol*, 134: 37-45.
- Gonzalez R. J., Luo, Y., Ruiz-Cruz, S. and McEvoy, J. L. (2004). Efficacy of Sanitizers to Inactivate *Escherichia Coli* O157:H7 On Fresh-Cut Carrot Shreds Under Simulated Process Water Conditions. *Journal of Food Prot.* 67: 2375-2380.
- Kenghe, R. N., Magar, A. P., and Kenghe, K. R. (2015). Design, Development and Testing of Small-Scale Mechanical Fruit Washer. *International Journal of Trend in Research and Development* 2(4):168-171.
- Khurmi R. S. and Gupta, J. K. (2005). A Textbook on Machine Design. Fourteenth Edition; Eurasia Publishing House (PVT.) Ltd. p 470-580.
- Little, C., War, L., Gillespie, I., Mitchell, R. (2003). Microbiological Study of Ready-to-Eat Salad Vegetables from Retail Establishments Uncovers A National Outbreak of Salmonellosis. *Journal of Food Prot* 66: 403-409.
- Narender, S., Mukesh, Vijaya Rani, Anil Kumar, Kanishk Verma, and Nitin Karwasra (2018). Performance Evaluation of Vegetable Washer for Carrot Crop. *International Journal of Current Microbiology and Applied Science*. 7(1):454-458.
- Ogunlowo, S., Olaleye, S. A. and Fasunla, M. S. (2016): Performance Evaluation of the Automated System for Cleaning, Peeling and Washing Cassava Tubers. *International Journal of Advances in Agricultural and Environmental Engineering*, 3(2): 327-332.
- Ojo, O. T. (2021). Development of a Process Plant for the Production of Vegetable Leaf Powder. A PhD Thesis of Mechanical Engineering Department, Federal University of Technology, Akure. Unpublished. pp 1-266.
- Olayanju, A. T., Isaac, M. O., Okonkwo, C. E., Alake, A. S. and Friday, M. G. (2019): Development of a Ceramic Cassava Peeling-and-Washing Machine. Mindanao. *Journal of Science and Technology*, 17: 84-97.
- Olutomilola, E. O. and Omoaka, A. (2018). Theoretical Design of a Plantain Peeling Machine. *FUTA Journal of Engineering and Engineering Technology*, 12(2): 229-237.

- Olutomilola, E. O., Ayodeji, S. P., and Adeyeri, M. K. (2019). Finite Element Analysis of a Washing and Preheating Unit Designed for Plantain Flour Processing Plant. *International Journal of Engineering Technologies*. 5(4):1-11
- Olutomilola E.O., Ayodeji S.P., and Adeyeri M. K. (2020). Design and Structural Analysis of a Particulating Machine for Plantain Flour Process Plant. *ARPN Journal of Engineering and Applied Sciences*, 15(17): 1816-1824.
- Piotr K. (2010). Belt conveyors for bulk materials. CEMA Belt Book. 5th Ed.
- Rulmeca (2003). Rollers and Components for Bulk Handling, RULLI RULMECA. 4th Edition.
- Rutheravan, M. (2016). Summary of Safety Criteria in Design. Technical Report. Pp 1-4. Available from: <https://www.researchgate.net/publication/303517627>. Accessed on:29/10/2021.
- Younis, S. M., Omran, M. S., Sharobeem, Y. F. and Thabet, R. N. (2005). Development of Washing Machine for Horticultural Fruits. *MISR Journal of Agricultural Engineering*. 22: 532-553.