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Design and fabrication of a potato peeling cum washing machine

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Abstract
The successful fabrication of a potato peeling and washing machine is one of the major challenges in potato processing. A potato peeling cum washing machine was designed for peeling and washing of potatoes. The machine comprises a specially designed peeling drum and a spraying unit for washing. The peeling drum with protrusions on the inside surface rotates and detaches peel from potatoes by abrasion. The water spraying unit washes the potatoes and simultaneously peel is removed from the drum through the perforation along with the flow of water. The capacity of machine is 400 kg/h with a peeling efficiency and peel losses of 97% and 0.5% respectively which is an improvement over previously fabricated designs. It is aimed at providing a base for the commercial production of a potato peeling and washing machine, using locally available raw materials at a relatively low cost. This work is intended to help solve some of the problems hindering a successful design and fabrication of a potato peeling and washing machine.

Keywords: Potato, peeling and washing, design and fabrication

Introduction

The potato ranks fourth after wheat, maize and rice in global production. It is second only to maize in terms of the number of countries that grow potato. Its importance as food is well recognized in European countries. In the developed countries a large portion of potatoes is consumed in the processed form. Potato contains about 80 % water and 20 % dry matter. A major portion of the dry matter is starch. The starch content is (about 14 %) and the sugar content is about 2 % on fresh weight basis. The crude protein content of potato is 2 % and the fat content is 0.1 %. In addition, the potato contains fiber, vitamins and glycol alkaloids in small quantities. French fries and chips arc the most popular processed products of potato. Hence, appropriate processing technology and equipment are essential to produce potato food products. It will help to reduce the losses and generate income and employment in the rural or semi-urban areas.

Potato is an important crop in India. Both area and production has increased manifolds during the past decades. India produced a record 42.34 million tonnes of potato from 1.86 million ha area during the year 2010-11. To sustain the increasing potato production, a closer look needs to be taken at the utilization of potato in our country. Almost all the potatoes produced in the country are utilized as human food. Allowing for about 10% used as seed and another about 15% lost at various stages, the per capita availability of potatoes in India is only about 15 kg/year. Various constraints in storage and marketing lead to spoilage. Processing could reduce losses due to spoilage. It has been estimated that about two to four million tons of potatoes are surplus in each of the two states of Uttar Pradesh and West Bengal. These surplus potatoes can be utilized for processing. There is an increasing demand for processed foods in urban areas. With the rising employment of women in cities, the demand for processed foods is growing further. Processing can reduce potato storage problems because processed products have longer shelf life. Above all, processing adds value to the crop leading to better returns to the growers.

Hence, removal of peel is one of the important unit operations for the further processing of potatoes in any form. The potato chip is a very popular snack food in India. For making chips, the important preparatory operations are washing and peeling. Hand peeling is traditional in India and is tedious and time consuming. Moreover, the loss of flesh is very high. However, the potato processing industry uses lye peeling.

Since, in lye peeling process, the heat ring is formed below the surface of the potato due to tissue damage and polyphenol enzyme activity, it is not recommended for making the chips (Huxsoll & Smith, 1975) [3]. For this purpose, abrasive type potato peeling and washing machine has been recommended (Campbell, 1982) [5]. Pollak and Ignall (1959) [7] also reported the comparative evaluation of various types of small, portable and electrically operated batch type abrasive peeling machine. Keeping the above facts in view, a batch type power operated abrasive potato peeling cum washing machine was developed and fabricated. The important features of the peeler are reported in this paper.

Material and Methods

Design analysis and calculations

In order to design an effective machine, the following parameters were identified as needed to be determined in order to analyze completely the component parts of the machine.

i) Determination of the weight of the peeling drum
ii) Estimation of the power required by the machine
iii) Shaft design and torque on the shaft
iv) Determination of the load on the shafts
v) Determination of the twisting moment on the shaft
vi) Determination of the shaft diameter
vii) Determination of the speed of the driven sprocket

i) Determination of the weight of the peeling drum

According to Eugene and Theodore (1996), mass of the drum m is given by,

$$m = \rho V \quad \dots (1)$$

Where ρ is the density of the material and V the volume.
But, V = (Length x width x thickness) + (2 x circumference x thickness)

$V = (L \times \pi D_d \times t_p) + (2 \times \pi D_d \times t_p)$

$V = \pi D_d\, t_p\, (L + 2)$

Hence equation (1) becomes

$$m = \rho \times \pi D_d\, t_p\, (L + 2) \quad \dots (2)$$

Weight of the drum is given by,
W = mg
Substituting equation (2) gives

$$W = \pi \rho D_d\, t_p\, g\, (L + 2) \quad \dots (3)$$

ii) Estimation of the power required by the machine

The force F required crushing out the potato peel by the drum of mass m having a tangential acceleration *a* is given by:

$$F = m\,a \quad \dots (4)$$

From the equation of motion:
$v = u + a\,t$
Therefore,

$$a = (v-u)/t \quad \dots (5)$$

Since the drum is turning at an average constant speed by the time the peeling begins, the initial speed u is zero. Hence equation (5) reduces to:

$$a = v/t \quad \dots (6)$$

Substituting equation (6) into (4), gives

$$F = mv/t \quad \dots (7)$$

We know that speed, v in terms of angular speed, N is given by:

$$V = r \times \omega$$
$$\omega = 2\pi N/60$$
$$v = 2\pi r N/60 \quad \dots (8)$$

Where r is the radius of the peeling drum and N is number of revolution in one minute.
Therefore, equation (7) becomes:

$$F = (m \times 2\pi r N)/60t$$

For one seconds, the force becomes:

$$F = m\, 2\pi r N/60 \quad \dots (9)$$

This is the load per second on the peeling drum as the peeling is in progress. The torque, τ due to this load is given by:

$$\tau = Fr \quad \dots (10)$$

Substituting equation (9) from (10)

$$\tau = 2\pi r^2 m N/60 \quad \dots (11)$$

The power P required to drive this torque is given by:

$$P = \tau\omega \quad \dots (12)$$

Where ω is the angular speed, which is given by:

$$\omega = 2\pi N/60$$

Therefore, equation (12) becomes:

$$P = \tau \times 2\pi N/60 \quad \dots (13)$$

Substituting equation (11) into (13), gives

$$P = m r^2\, (2\pi N/60)^2 \quad \dots (14)$$

iii) Shaft design and torque on the shaft

The shaft of the machine carries a pulley that receives power from an electric motor via a v-belt, the peeling drum and two bearings.
The minimum shaft diameter needed to avoid failure of the shaft is calculated thus:-

$$\tau_A = 60P/2\pi N_A \quad \dots (15)$$

Where P is the power delivered to the pulley by the motor, and N is the speed of the rotation of the pulley, which can be determined from the speed ratio of the shaft and the motor as thus:-

$$N_A/N_M = d/D$$
$$N_A = N_M d/D \quad \dots (16)$$

Where N_M is the motor speed, d is the motor pulley diameter, and D is the shaft pulley diameter. The torque on the other end of the shaft τ_C must be equal to that at pulley of the shaft for equilibrium of the shaft. Hence,

$$\tau_C = 60P/2\pi N_A \quad \dots (17)$$

iv) Determination of the load on the shafts
At pulley of the shaft
The belt tension ratio is given by,

$$T_1/T_2 = e^{\mu\theta} \quad \dots (18)$$

Where θ is the contact angle at the small pulley, which can be determine from the equation (30), μ is the coefficient of friction between the pulley and belt, which is read from data on catalogues, and T_1 and T_2 are the belt tensions on the tight and slack side respectively.
If $e^{\mu\theta}$ is represented as k, then equation (18) can be rewritten as,

$$T_1 = k\,T_2 \quad \dots (19)$$

The vertical load, F_A on the shaft is the bending load and is given by,

$$F_A = T_1 + T_2$$

Substituting equation (19) gives,

$$F_A = T_2\,(k + 1) \quad \dots (20)$$

The driving load F_d is given by,

$$F_d = T_1 – T_2$$

Substituting equation (19) gives,

$$F_d = kT_2 – T_2$$

Therefore,

$$F_d = T_2\,(k - 1) \quad \dots (21)$$

The driving load, in terms of the torque, is given by,

$$F_d = \tau_A/\,(D/2) \quad \dots (22)$$

Combining equation (21) and (22) gives,

$$T_2\,(k -1) = 2\tau_A/D$$

Therefore,

$$T_2 = 2\tau_A/(k-1) \quad \dots (23)$$

Substituting equation (23) into equation (20) gives the vertical load as,

$$T_2 = (2(k+1))/(k-1)$$

Since k = $e^{\mu\theta}$

$$F_A = (2\tau_A\,(e^{\mu\theta}+1))/(e^{\mu\theta}-1) \quad \dots (24)$$

At other end of the shaft,

The vertical load F_{VC} on the drum as a result of friction is the tangential load between it and the potato, and is given by,

$$F_{VC} = 2\tau_c\,/D_d \quad \dots (25)$$

The total load F_C on the drum is given by,

$$F_C = F_{VC} + W \quad \dots (26)$$

Where W is the weight of the drum, and can be determined using equation (14). Hence, substituting equations (14) and (25) into equation (26) gives,

$$F_C = 2\tau_C\,/D_d + \pi\rho D_d tg\,(L + 2) \quad \dots (27)$$

v) Determination of the twisting moment on the shaft
The twisting moment acting on the shaft may be determined from the following equation:

$$M_H = F_A \times r \quad \dots (28)$$

Where,
F_A = Vertical load on the shaft
r = Radius of the peeling drum

vi) Determination of the shaft diameter
Neglecting the effect of bending moment, the diameter of the shaft may be determined using the following torsion equation:

$$M_H/J = \tau/r_H \rightarrow d_V^3 = (16\times M_H)/\pi\times\tau \quad \dots (29)$$

Where:
J = $(\pi\times d_H^4)/32$ = Polar moment of inertia of the shaft about the axis of rotation
T_H = Permissible Torsion shear stress
$r_H = d_H/2$ = Distance from neutral axis to the outer most fiber
Where: d_H = Diameter of the shaft

vii) Determination of the speed of the driven sprocket
The speed of the driven (big) sprocket may be determined from the following equation:

$$N_S/N_B = D_B/D_S \quad \dots (30)$$
$$N_B = (N_S\times D_S)/D_B$$

Where:
N_S = Speed of driver (small) sprocket
N_B = Speed of big sprocket
D_S = Diameter of small sprocket
D_B = Diameter of big sprocket

Material Selection
Material selection is of utmost importance to ensure that the components to be fabricated have the desired performance requirements. Since different components of the potato peeling machine would be subjected to varying forms and the degree of stresses strains, torque and frictional effect, the material with the appropriate engineering properties were chosen.

Material Selection Criteria
The materials to be used for fabrication were selected after a careful study of the desired physical, mechanical, chemical and even aesthetic characteristics of a number of proposed materials. For this design, due economical considerations and

availability of raw materials, high and medium carbon steel was mostly used for body parts and chuck materials while cast iron was chosen for the pulley, Khurmi and Gupta (2004) [8].

Machine Frame

The machine frame supports the other parts of the potato peeler machine, as well as providing balance. It is subjected to the direct weight or load of other members of the machine (hence compressive forces) and also to torque and vibration from the peeling drum and motor. The desired material should be of high rigidity, hardness, adequate toughness and posses' good machining characteristics. For this purpose, angular high carbon steel rods were chosen.

Peeling Drum

The peeling drum was made of medium high carbon steel sheet. The drum is to be punched or punctured from one side leaving the spiky. It rotates (powered by an electric motor) hence generate torque. Though hardness of the drum is desired because of the intended penetration and abrasion of the potato, the ductility of the drum material should be adequate to retain a rigid shape (cylindrical) when in use.

Body

The body covers the moving part of the machine. In addition to aesthetics, it also provides support and balance for the chuck and handle. Medium carbon steel was used because of its machinability, hardness and rigidity.

Pulley

The pulley, attached to the shaft through the peeling drum, should rigid, hard and machine able. Cast iron was chosen for this purpose as the pulley would be subjected to tension forces from the belt as well as torque and speed variations from the motor.

Lifting Bottle Jack

Corrosion resistance high strength iron material was used for bottle jack to lift the machine for the experiment during the operation.

Fabrication

The manufacturing process used in the fabrication of the potato peeling machine is such that the total cost of fabrication is reduce and also one that can make use of the available materials. The manufacturing process involved in this work includes, joining of metal parts by welding, cutting using hacksaw and hand cutting machine. Each component of the machine is fabricated separately before they are joined or welded together as the case may be.

Peeling Drum and Machine Assembly

This consists of the peeling drum, the shaft, the driven pulley and bearings. The main components of the machine are (1) abrasive roller (2) power transmission system (3) Water spray system (4) water lifting pump. The bearings and the pulleys as a result of the fact that they are readily available in the market and the relative high cost of fabricating a new one, they are purchased from the market. The peeling drum with protrusions on the inside surface rotates and detaches peel from potatoes by abrasion. The spikes on the drum were made by punching holes on the metal sheet from one side of the metal sheet so that the roughness produced on the other side of the metal sheet. The holes were punched much closed to each other so as to produce the roughness of the spikes enough to peel the potato. This sheet is then folded into a cylindrical shape and then welded along the edges where the sheet is joined using electric arc welding. The machine works on the principal of abrasive peeling. The water spraying unit washes the potatoes and simultaneously peel is removed from the drum through the perforation along with the flow of water. Peeled Potato can be transferred to the collecting container by opening shutter of outlet chute.

Potato peeling machine consists of abrasive roller with 355.6 mm diameter and a steel drum having 487.7 mm dia. and 956.2 mm long each. The roller is surrounded with steel drum and both rotate in opposite direction. The machine is fabricated in a rectangular shape to provide the strength and firmness to the machine. The prototype is 660.4 mm wide, 1143 mm long, 1192.8 mm high and fabricated with mild steel angle iron 40mm x 40mm x 5 mm. The body was covered by using G.I. steel 0.95 mm thick and painted with enamel paint to avoid rusting. It receives torque from 1 HP electric motor with speed of 1440 rpm. The drive system consists of belt and pulley arrangement with maximum machine speeds (SP) of 432 rpm. Moreover, reduction in speed was achieved by larger size pulley.

Results and Discussion

The machine having completed, in terms of the design and fabrication, was tested to verify if the efficiency of peeling is satisfactory. In fact, all the design concepts and calculated results were religiously followed and arrived at with little or no variations. Finally, the peeling machine was tested with potato. Figure 1 shows the complete view of the potato peeling and washing machine. The following is the procedure for testing:

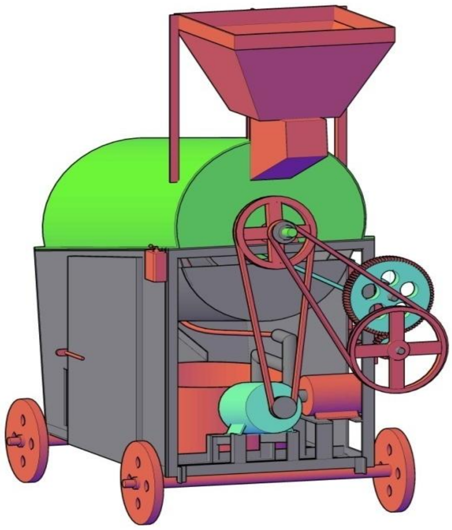

Fig 1: Potato Peeling cum Washing Machine

The Kufri-Jyoti variety of potatoes (*Solanum tuberosum* L.) about 4 months old were used for the experiment. The length, breadth and thickness of potatoes were measured using a Vernier calliper. The following formulae were used to calculate the equivalent diameter D_{eq} and sphericity Φ the potatoes (Mohsenin, 1970):

$$D_{eq} = (LBT)^{1/3}$$

Where ***L*** is the length, B is the breadth and ***T*** is the thickness, and

$$\Phi = D_{eq}/L$$

For determination of the peel content, five samples of 200 g each were weighed separately and recorded.

The potato samples were boiled in water for 0.5 h to loosen the peels. After cooling the boiled potatoes at room temperature (30-32°C) for about 0.5 h, the peels were separated from the flesh manually. The peels and potatoes were then dried in an air oven at 80°C for about 6 h. The peel percentage was then calculated by using following formulae:

Peel content (% db) = (Dried wt of peel/ Dried wt of potato sample) x 100

The machine was set for the experiment. A sample of five potatoes was weighed individually and marked for identification. For marking, the potatoes were punched with a pin and different colour dyes were poured on each sample. These marked potatoes were then mixed with the experimental batch load in the drum. For experimental purposes, a known quantity (5, 10, 15 and 20 kg) of potatoes was fed into the drum. The inlet pipe of the water spraying unit was connected to a water tap. The drum was then rotated at speeds of 30 and 40 rpm.

The speed was varied by changing the pulley of the drum shaft. The marked samples were taken out for analysis after 4, 6, 8 and 10 min. The samples were gently wiped with blotting paper to remove the surface moisture and weighed immediately. The peel content of these potatoes was determined with the help of the above mentioned formula. The water drained was collected and weighed to determine the quantity of water required to perform the operation. Each experiment was carried out in triplicate and average values are reported.

Peeling efficiency (%) = (Fraction of peel on raw material – fraction of remaining peel on peeled potato)/ Fraction of peel on raw material

The percentage peel losses were determined by using the following formula (Willard, 1971) [9]:

Peel losses (%) = (Weight of raw potatoes-Weight of peeled potatoes)/ Weight of raw potatoes x 100

Conclusion

The machine is very efficient with very less water consumption i.e. 6Kg/ liter. The capacity of the machine was found to be 400 kg/hr with peeling efficiency of 97% with negligible peel loss i.e. 0.5 %. The machine cost around Rs. 50,000/- along with an electric motor. The performance test result are encouraging in terms of lower energy and water consumption and negligible breakage rate with good peeling quality and is suitable for small scale processing of potato chips and other products.

At the end of an intensive research, construction and testing, a satisfactory potato peeling cum washing machine with efficiency of 97 % and less peel losses was fabricated using the available raw materials and techniques. This work designed and developed a machine for peeling and washing of potatoes. The machine is fabricated using readily available materials and it is applicable for local production of peeled potatoes for potato processing. The machine is easy to use, safe to operate, easy to repair and easy to maintain. The technology is affordable and less expensive when compared to Imported peeling machines. It has low operating cost. This clearly shows that it is more advantageous to peel potatoes using this machine than other imported ones. Hence, the machine will be welcomed by industries given its performance, affordability and simplicity.

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