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THE DESIGN, CONSTRUCTION AND TESTING OF AN ORANGE PELER

OLUSEGUN H.D. and AJIBOYE T. K.
Department of Mechanical Engineering
Faculty of Engineering
University of Ilorin
Ilorin, Nigeria

Abstract

The need to consume more oranges as fruit and to use its berry. seed, leaves and skin in cosmetics and pharmaceutical industry, led to the investigation of a faster peeling method by mechanical technique. The sizes of oranges in the area of Ilorin where the project was done are between 2.8 to 4.2cm radii and the design was aimed at those size of oranges. The machine peeled one orange at a time as a prelude to an orange peeler in the future which will peel many oranges in one operation. A maximum peeling force of 114.7N and a centrifugal force of 115.6N was found to be adequate for peeling with sheepsfoot shapes of moving and fixed peeling blades. The peeling force was found to be directly proportional to the mass, radius of orange, the square of the peeling speed, but inversely proportional to the sharpness of the blade4 for scraping, slashing and digging to be avoided. The peeling was 90% successful for oranges of radii 3.8 to 4.2cm radii when the machine was running at 94.2rad/s and also with oranges of radii 3.3 to 3.7cm radii when the speed was 133.3rad/s. The peeling machine was most efficient with 100% peeling when the orange sizes were between 2.8 to 3.2cm radii and operating at the speeds of 133.4 and 163.3rad/s. The fixed and moving blades were positioned at 69^0 and 21^0 to the vertical for efficient peeling. Mechanical peeling is cleaner, safer and faster than non-mechanical peeling. It enhances the use of orange juice and its bye-products in the pharmaceutical and utilities industry. It is expected that more oranges will be consumed in its various processed form when this machine is perfected and commercialized.

Keywords: Peel, Orange, Blade, Force.

Introduction

Oranges belong to the classification of fruits known as citrus. The number of valid species in the genus citrus is very widely debated today. While Tanaka (1954) claimed there are between 145 to 159 species, Swingle (1974) admitted there were 16. However, the six genera commonly acknowledged today are Fortunella, Eremocitrus, Clymenia, Poncirus, Microcitrus and Citrus. Three out of these six are of economic importance, and these are Fortunella, Poncirus and Citrus. The major commercial citrus fruits are eight species of the genus Citrus. These eight species of Citrus are the most sought after fruits, second only to apples and consequently are the most eagerly developed fruits in advanced as well as developing countries, climate permitting. These eight species of citrus are shaddock, mandarin, sour orange, sweet orange, lime, citron, lemon, and natural hybrids, Hutchison (1973).

Fortunella, Poncirus and Citrus are native to a very large area of Asia which covers the Himalayan foot hills of North-Easthern India to North Central China and the Philippines in the east, Burma, Thailand, Indonesia and New Caledonia in the south-east. Of the three, only the citrus have been grown extensively in Nigeria. The six genera constituting the group of the true citrus fruit have an unusual fruit. It is made up of a berry called the hesperidium which consist of a juicy pulp made of vesicles filling all the space in the segments of the fruit not occupied by the seed. An important feature which encourages the consumption of oranges is when it is seedless. The production of citrus fruits without seeds, occurs commonly with navel oranges, Satsuma mandarins, Tahiti limes, and "Clementine" mandarin when not cross-pollinated. The science of artificial cross-pollination known as Parthenocarpy is used not only to produce oranges without seeds but to control the production of some species. The skin which is the major interest of the study consist of a thick pulp which houses the albedo, flaredo, epidermis and oil glands. The oil glands are of a special advantage as they provide the lubricants for the cutting blades of the peeling machine. They make it possible for the peeling machine to operate for very long time without the peeling blades getting blunt, Hearn (1973)

The skin of oranges, its berry, seed and leaves are used in the pharmaceutical industry to produce drugs. They are used to produce shampoo, and scrubbing materials for gold and copper articles. They are also used to produce essential oils, salad oil,

pickles, mamalades, jams and chutneys. In the production of alcohol, oranges are used, especially when making rum. However, the greatest consumption of oranges is done when the fruits are eaten naturally and taken in the form of juice. Its nutritional value is in the supply of minerals and vitamins to the human body especially vitamin C. Therefore the more oranges are consumed the better, as lack of the minerals and vitamins can lead to very poor health. Especially with children, the consumption of oranges is vital to their mental and physical development. Oranges seriously affect the growth and development of a nation, Hearn (1973).

The work of Singh and Reddy (2006) on the post-harvest physico-mechanical properties of orange peel (variety Nagpur Mandarin) and fruit, measured the puncture force, peek rupture force, peel cutting force, tensile strength and cutting energy. Their study recorded 79.5N and 240.7J peak cutting force and peak cutting strength of orange peel respectively. The cutting speed of blade was 1mm/s. The investigation of Singh and Reddy used orange peels that were 1.5cm (polar length) and 6cm (equatorial length) for their various tests. The blade cutter peeling speed was 1mm/s. Whereas this blade peeling speed was good for removing orange peel for test in the adoption and design of various handling, packaging, storage and transportation systems, the peeling speed of 1mm/s was too slow for fast peeling by mechanical means, if it was going to be commercially viable.

For efficient peeling of orange, the geometry or shape of blade, and blade grind were parameters which were considered with the angle of blade. The peeling blades required a belly. The belly was the curved section under the point of a blade. It increased the ability of the blade to peel. The belly should present a continuously changing angle on the orange being peeled. The more belly a blade had, the less acute its point. Basically the blade for peeling was all belly because it was required to peel only and not to pierce, dig, slash or scoop. So there is a trade off for belly instead of point (Talmadge, 1998)

The angle of blade as positioned in the peeler container was also very important for peeling. A positive angle generally provided more edge and belly for efficient peeling. This angle was greater than the tangential contact angle of orange on blade belly. The tangential contact was the angle at which orange slipped over knife without being peeled. The peeling blade did not have a point but had a thickened and full edge. This meant that the blade would not penetrate but peel the orange. Eliminating the blade point in the design of peeling meant that special arrangement was made to accommodate the convex and concave shapes of the blades (Fakrogba, 2002).

Talmadge (1998) investigated ten types of blade shapes which are the chip point, the drop point, the tanto, Amencanized tanto, chisel-ground tanto, the sheepfoot, the dagger, the spread point, the trailing point and the hook blade. For this study, the sheepfoot blade was found to be most ideal, because it had no point and the spine curved down to met the edge, thus making it possible to peel orange without slashing or digging. The edge of the sheepfoot blade did peel successfully and did not pierce, slash or scoop the orange. Seven parameters were vital in the design and construction of the orange peeling machine. They were the orange peeling force, the moving and fixed peeling blades, the shape of the blade that should peel the oranges, the blade angle of inclination to normal, the sharpness of the cutting blades, the speed of horizontal rotation, vertical displacement of orange that is being peeled (Nzom, 2003).

Presently, there are no known orange peeling machines in the market in this region, because of the complex nature and difficulty experienced in its design. If the peeling of orange can be mechanized, then not only will the industry around it be enhanced, but its consumption will greatly increase. What occurs presently is the manual system of peeling with bare hands, or with knives, or by razor blades. Peeling oranges using knife or razor blade is hazardous. Hence, a mechanized system will also prevent accidents.

The objective of this project is to make a machine which will peel one orange at a time. A future plan will be to make a machine that will peel more than one orange at a time.

Description of the Orange Peeling Machine.

The orange peeling machine, Fig 3, is 60cm in height and 18cm in diameter. The peeling compartment is on top of the single phase motor, and has a height and diameter of 20cm and 18cm respectively. The electric motor which drives the peeler rotor blades is at the bottom part of the peeled skin dispenser. The machine and motor are carried on a stand as shown on the figure. The blades attached to the fixed blade casing can be adjusted, but the ones on the cover plate are permanently riveted.

The materials used for the peeler rotor, container, cover and blades are stainless steel rod and sheet. It was necessary to use stainless steel because of the citric acid attack from the orange that was peeled. Three ranges of available induction motors with, 0.5, 1.0 and 1.5hp were used for the test.

Theoretical analysis

Orange peeler design parameters

These are;

(i) The orange peeling force
(ii) The peeling blades (moving and fixed)
(iii) The shape of the blade to peel the orange
(iv) The blades angle of inclination to the normal
(v) The sharpness of the cutting blades
(vi) The speed of horizontal rotation
(vii) The vertical displacement of orange being peeled.

Orange peeling force calculations

Referring to fig 1, the peeling process is shown where a small skin is removed at the orange radius OA (r) with an exerted pressure p. The small peeled skin is shown to have an outer pressure $p + \frac{dp}{dr}\delta r$ at an outer radius $r + \delta r$.

The peeling skin when removed will have an area δa shown. If the velocity at which the peel was removed and leaves the orange surface is u, tangential to the surface, then the outer end of removed skin will have a velocity equal to $u + \frac{du}{dr}\delta r$.

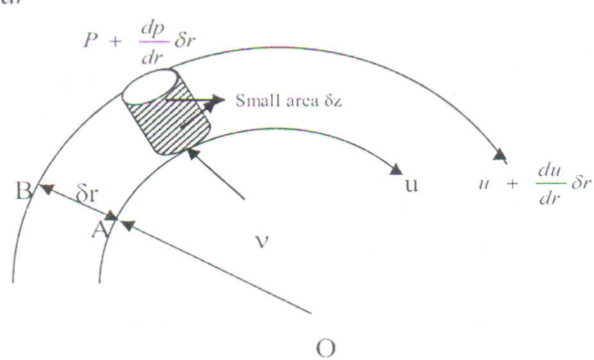

Figure 1: Showing small skin removed by sharp blade

The inward pressure force (IPF) for the elemental peeled skin is $\left(p + \frac{dp}{dr}\delta r - p\right)\delta a$

$\therefore$ Inward pressure force (IPF) = $\frac{dp}{dr}\delta r \delta a$ 1

The IPF is sustained by the centrifugal force

i.e $\frac{dp}{dr}\delta r\, \delta a = mass\ of\ peel\left(\frac{mean\, velocity}{mean\, radius}\right)^2$

$$= \rho\, \delta r\, \delta a \frac{\left(u + \frac{1}{2}\frac{du}{dr}\delta r\right)^2}{r + \frac{1}{2}\delta r} \quad \text{.............................. 2}$$

Ignoring second and higher order terms,

$$\therefore \quad \frac{dp}{dr} = \rho \frac{u^2}{r}$$

$$\frac{dp}{dr} = \rho \frac{u^2}{r} = \rho\, \Omega^2 r \quad \text{.. 3}$$

where p is peeled skin pressure, ρ is density of orange with skin, r is radius of orange, u is tangential velocity of peeled orange skin, Ω is angular velocity of peeled orange skin.

A reasonable assumption is that the peeled skin leaves the orange at the speed of the orange. Therefore, the angular velocity of the peeler rotor, ω, is equal to the angular velocity of the peeled skin, Ω.

Hence, ω for rotor blade is equal to Ω for the peeled skin.

Integrating equation (3) gives;

$p = \frac{1}{2}\rho\Omega^2 r^2 + c$, where c is a constant.

When rotor blade is at stand still, there is no peeling, i.e when p = 0, and Ω = 0, c = 0

$$p = \frac{1}{2}\rho\Omega^2 r^2 \quad \text{...................................... 4}$$

Equation (4) is the condition for maximum peeling pressure. Therefore the maximum force (N) required to peel orange is given by;

$N = p \times total\ surface\ area\ of\ orange$

$$N = \frac{1}{2}\rho\Omega^2 r^2\, 4\pi r^2$$

$$\therefore N = 2\rho\pi\Omega^2 r^4 \quad \text{.................................. 5}$$

$$N = 2\times \frac{m}{\frac{4}{3}\pi r^3} \times \pi \times \Omega^2 r^4$$

Hence, $N = 1.5\, mr\Omega^2$ 6

The peeling Blades (Moving and Fixed)

For effective peeling without piercing or slashing the sheepfoot-shape was selected based on the recommendation of Talmadge (1998). The sheepfoot shape has no point and the spine curves downward to meet the edge. The moving blades are attached to the motor shaft. The fixed blades are attached to the cylinder side and to the cover plate.

The shape of the blade to peel the orange;

The peeling blades an sheepfoot-shape but elongated as shown in figure 3 of orange peeling machine. A flat grind was used to give the thick and strong spine of blades thin and sharp peeling edges.

The Blade angels of inclination

The blade angles of inclination to the normal axis from point of attachment to the rotor, cylinder and cover plate are critical. They determined whether peeling, slashing or piercing, will take place Nzom (2003).

The initial samples of oranges taken were weighed and the average mass was used to calculate the centrifugal force. Equation (3) was used to calculate the average peeling force N_a. The blade angle α was given in $\alpha = \tan^{-1}\left(\frac{C_f}{N}\right)$ which gave initial angle of 50° for the moving blade and 40° for the fixed blades, where C_f is the centrifugal force,

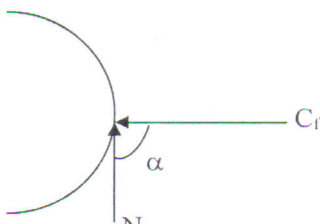

Fig.2: Orange peeling forces

N is the orange peeling force and α is the blade angle. These were the initial positions that the blades were set to the vertical, at the commencement of experiment. The blades peeled partially at these settings at the rotor speed of 94.2rad/s. However, the blades were adjusted to the angles of 15° and 75° for the moving and fixed blades respectively, at the rotor speed of 94.2rad/s for efficient peeling. At the speeds of 133.3 and 163.3rad/s, the blades angles were adjusted to 21° and 69° for the moving and fixed blades respectively, for efficient peeling.

The sharpness of the cutting blades:

Theoretical a clean peel was achieved when the sharpness of the peeling blade was inversely proportional to the contact area of the blade with the orange.

The speed of horizontal rotation:

This was the direction of the rotation of the motor. Three induction motors were used for speeds of 94.2, 133.4, and 163.3 rad/s.

The vertical displacement of the orange being peeled:

The rotor blades were designed to move the orange vertically against the fixed blades on the inner casing. The vertical displacement of the orange against the fix blades caused additional peeling to that done by the bottom rotor blades and the cover plate fixed blades.

Relationship between centrifugal force C_f, orange peeling force N and blade angle α.

From figure 2, C_f is given as;

$$C_f = N\,Cos\,\alpha \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 6$$

Substituting for N,

$$C_f = 1.5\,m\,r\,\Omega^2\,Cos\,\alpha$$

Orange Peeling Machine Operational Requirements and Material Properties.

Investigation showed that three relatively high orange peeling forces of 119.7, 93.6 and 79.9N were obtained when the machine operating speeds were 163.3 and 133.4 rad/s, Table 3, 6, and 2.The corresponding centrifugal forces were 115.6, 90.4 and 77.2N. Therefore the greatest force of 119.7N was selected for the design of the peeling blades and 115.6N for that of casing which houses the blades. The two forces of 119.7 and 115.6N are below the strength of metal iron, which is available and cheap. Hence stainless sheet was chosen for the materials of the blades, casing and cover. This was because of the acidic attack over a period of the machine life during peeling. The machine stand, brackets nuts and bolts were made from mild steel angles and bars.

The power to peel orange is directly proportional to the peeling force and the speed of peeler motor. The efficiency of peeling was however independent of high power motor output.

Procedure for fabrication and assembly.

The largest orange by our survey in Ilorin was 8.4cm diameter. The fixed blade casing of mild steel plate was constructed with a diameter of 11cm and a height of 11cm, Fig. 3. Eight stainless steel blades made to the sheepfoot shape and 6cm long by 4cm wide were fixed to the inside of the blade casing. The spacing of the blades was equi-distant at 4.3cm apart and attachment was through nuts and bolts that are adjustable from the outside. It was also possible to adjust the angle of the blade from the vertical axis by the same nuts and bolts. Four adjustable blades were attached to a mild steel rotor blade, which was connected by a bolt to the shaft of an induction motor. The spacing of the blades were at right angle. The blades attached to the cover plate are four in number and riveted. The rotor and cover blades are also sheepfoot in shape and 4cm long by 4mm wide. The motor stand was made from mild steel sheet which was beveled to have a wider base for balance. The top of the beveled stand was made circular to enable the induction motor sit firmly. Bolts were used to further secure the motor in opposition. The machine was designed to peel one orange at a time.

Peeler test and performance indication

Three types of oranges classified primarily by their sizes were peeled during the test. Three induction motors were used to obtain 3 speeds. In the first test, ten oranges with size range of 3.6 to 4.2 radii were peeled in the machine. The first orange measure 3.8cm and weighed 75g. It was placed in the fixed casing and covered. The induction motor was started and was allowed to run for 30 seconds at the speed of 94.2rad/s. The peeled orange was removed and observed. Nine other oranges in the same range were weighed and peeled at the speed of 94.2rad/s. Results were entered in Table 1. Calculations of peeling force and centrifugal force were carried out and entered in the Table. The test was repeated with an induction motor of 133.4rad/s and for 163.3 rad/s and results entered on Table 2 and 3.

The experiment was done for two other sizes of oranges, the ones that were of the range 3.3 – 3.7cm and 2.8 – 3.2cm radii. The results were entered on Table 4, 5, 6, 7, 8 and 9.

Evaluation Test Procedure

The test revealed that five situations occurred. The machine either peeled or scrapped or slashed or dug or slipped the orange. The condition when slipping took place was with recorded machine forces of 17.8 to 25.5 N. Scrapping was recorded with a peeling force of between 25.5 to 36 N. The successful peeling of the orange took place with a recorded peeling force of 36 to 63.2N. Slashing of the oranges occurred when the peeling force was between 63.3 – 83N, and digging of the peeling blades recorded the force of between 83 to 119.7N. The test and evaluation was done with the blade adjusted to 21 ^{o} for the moving blades and 69^{o} for the fixed blades. All angles of blade were measured from the vertical.

Results and discussion

When the peeling speed of the machine was 94.2rad/s and the orange type of radii between 3.8 to 4.2cm, Table 1, nine of the oranges were successfully peeled of the ten average tested. When the type of orange of size between 3.3 and 3.7cm radii were tested, scraping was observed at the same machine speed of 94.2rad/s. All the ten samples entered on Table 4 were scraped. A smaller type of orange of size 2.8 to 3.2cm radii were also scraped by the machine see Table 7. It was observed that testing at a speed of 94.2rad/s was successful when the size of orange was 3.8 to 4 .2cm radii. For sizes of oranges below that radius, scrapping occurred, when tested at 94.2rad/s.

The condition of slashing was noticed when oranges of size 3.8 to 4.2 cm radii were tested at the speed of 133.4 rad/s. As seen on Table 2, the peeling forces of 66.2 to 83 was unique to this group. The ten samples tested in this group were all slashed. However, when the sample type of 3.3 to 3.7 cm radii were tested, nine were successfully peeled, Table 5. A 100% peeling was achieved when tests were done for size of orange 2.8 to 3.2 radii at a machine speed of 133.4rad/s, Table 8.

When tests were carried out on orange size of 3.8 to 4.2 radii at the machine speed of 163.3rad/s, the peeling blades dug into the orange which was entered on Table 3. The difference between digging and slashing was that the orange vesicles, filled with the juicy pulp (flesh of orange) was ploughed by the peeling blades in the case of digging, whereas the vesicles were cut in slashing. Testing oranges of reduced size, 3.3 to 3.7cm radii had only a 30% success rate, entered on Table 6. However, a 100% success was again recorded when the orange size was 2.8 to 3.2cm radii and the machine speed was 163.3rad/s, entered on Table 9.

For the tests, the blade sharpness was maintained by the oil from the oil glands of the orange skin. It acted as a natural lubricant which extended the life of the peeling blades.

Conclusion

The orange peeling machine was designed to peel one orange at a time. The peeling force was found to be directly proportional to the mass, radius of orange and to the square of the peeling speed and inversely proportional to the sharpness of the blade. Peeling was found to be 90% successful when the speed of machine was 94.2rad/s and the radii of oranges between 3.8 to 4.2cm. The peeling was also 90% successful at the speed of 133.4rad/s for oranges of radii between 3.3 to 3.7cm. A 100% peeling were recorded for oranges tested at 133.4rad/s and 163.3rad/s when radii of oranges were between 2.8 to 3.2cm. The peeling machine was found to be most efficient for sizes of orange of between 2.8 to 3.2cm radii at the machine speeds of 133.4 and 163.3rad/s.

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Notations

Symbol	*Meaning*	*Units*
r	radius	m
p	pressure	N/m ^{2}
u	velocity	m/s
a	area	m ^{2}
ρ	density	kg/m ^{3}
Ω	angular velocity	rad/s
ω	angular velocity	rad/s
c	constant	
m	mass	kg
α	blade angle	^{o} (degree)
N	peeling force	N
IPF	inward pressure force	N
C_f	centrifugal force	N

Table 1: Specification of the calculated forces to peel orange of 3.8 – 4.2 radii at rotor speed 94.2 rad/s

S/No	Radius of Orange fruit (cm)	Mass of Orange fruit (gm)	Rotor speed rad/s	Rotor speed square rad/s	Peeling force (N)	Maximum centrifugal force (N)
	R	m	Ω	Ω	N	C_f
1	3.8	75	94.2	8873.6	37.9	36.6
2	4.1	68	94.2	8873.6	37.1	35.8
3	3.9	67	94.2	8873.6	34.8	33.6
4	4.2	74	94.2	8873.6	41.4	40.0
5	4.0	73	94.2	8873.6	38.9	37.6
6	4.1	66	94.2	8873.6	36.0	34.8
7	3.8	71	94.2	8873.6	35.9	34.7
8	4.2	65	94.2	8873.6	36.3	35.1
9	3.9	72	94.2	8873.6	37.4	36.1
10	4.0	69	94.2	8873.6	36.7	35.5

Average radius of orange r_o = 4.0
Average mass of orange m_o = 70gm
Average Peeling force N_o = 37.2 N
Source: Experiment

Table 2: Specification of the calculated forces to peel orange of 3.8 – 4.2 radii at rotor speed 133.4 rad/s

S/No	Radius of Orange fruit (cm)	Mass of Orange fruit (gm)	Rotor speed rad/s	Rotor speed square rad/s	Peeling force (N)	Maximum centrifugal force (N)
	R	m	Ω	Ω	N	C_f
1	4.0	69	133.4	17796.6	73.7	71.2
2	3.9	71	133.4	17796.6	73.9	71.4
3	3.8	65	133.4	17796.6	65.9	63.7
4	4.1	72	133.4	17796.6	78.8	76.1
5	3.9	66	133.4	17796.6	68.7	66.4
6	4.1	73	133.4	17796.6	79.9	77.2
7	3.7	67	133.4	17796.6	66.2	63.9
8	4.2	74	133.4	17796.6	83.0	80.2
9	4.0	68	133.4	17796.6	72.6	70.1
10	3.9	75	133.4	17796.6	78.1	75.4

Average radius of orange r_o = 4.0
Average mass of orange m_o = 70gm
Average Peeling force N_o = 74.1 N
Source: Experiment

Table 3: Specification of the calculated forces to peel orange of 3.8 – 4.2 radii at rotor speed 163.3 rad/s

S/No	Radius of Orange fruit (cm)	Mass of Orange fruit (gm)	Rotor speed rad/s	Rotor speed square rad/s	Peeling force (N)	Maximum centrifugal force (N)
	R	M	Ω	Ω	N	C_f
1	3.9	74	163.3	26666.9	115.4	111.5
2	4.2	67	163.3	26666.9	112.6	108.8
3	4.1	73	163.3	26666.9	119.7	115.6
4	3.8	66	163.3	26666.9	100.3	96.9
5	4.0	72	163.3	26666.9	115.2	111.3
6	3.9	65	163.3	26666.9	101.4	98.0
7	4.1	71	163.3	26666.9	116.4	112.4
8	3.8	64	163.3	26666.9	97.3	94.0
9	3.9	70	163.3	26666.9	109.2	105.5
10	4.0	68	163.3	26666.9	108.8	105.1

Average radius of orange r_o = 4.0
Average mass of orange m_o = 69gm
Average Peeling force N_o = 109.6 N
Source: Experiment

Table 4: Specification of the calculated forces to peel orange of 3.3 – 3.7 radii at rotor speed 94.2 rad/s

S/No	Radius of Orange fruit (cm)	Mass of Orange fruit (gm)	Rotor speed rad/s	Rotor speed square rad/s	Peeling force (N)	Maximum centrifugal force (N)
	R	M	Ω	Ω	N	C_f
1	3.5	59	94.2	8873.6	27.5	26.6
2	3.6	65	94.2	8873.6	31.1	30.0
3	3.3	58	94.2	8873.6	25.5	24.6
4	3.4	64	94.2	8873.6	29.0	28.0
5	3.7	56	94.2	8873.6	27.6	26.7
6	3.5	63	94.2	8873.6	29.3	28.3
7	3.6	55	94.2	8873.6	26.4	25.5
8	3.7	62	94.2	8873.6	30.5	29.5
9	3.3	57	94.2	8873.6	25.0	24.2
10	3.4	61	94.2	8873.6	27.6	26.7

Average radius of orange r_o = 3.5
Average mass of orange m_o = 60gm
Average Peeling force N_o = 28 N
Source: Experiment

Table 5: Specification of the calculated forces to peel orange of 3.3 – 3.7 radii at rotor speed 133.4 rad/s

S/No	Radius of Orange fruit (cm)	Mass of Orange fruit (gm)	Rotor speed rad/s	Rotor speed square rad/s	Peeling force (N)	Maximum centrifugal force (N)
	R	M	Ω	Ω	N	C_f
1	3.6	60	133.4	17796.6	57.7	55.7
2	3.3	57	133.4	17796.6	50.2	48.5
3	3.5	61	133.4	17796.6	57.0	55.1
4	3.3	56	133.4	17796.6	49.3	47.6
5	3.6	63	133.4	17796.6	60.6	58.5
6	3.4	56	133.4	17796.6	50.8	49.1
7	3.7	64	133.4	17796.6	63.2	61.1
8	3.4	58	133.4	17796.6	52.7	50.8
9	3.5	66	133.4	17796.6	61.7	59.6
10	3.6	59	133.4	17796.6	56.7	54.8

Average radius of orange r_o = 3.5
Average mass of orange m_o = 60gm
Average Peeling force N_o = 56 N
Source: Experiment

Table 6: Specification of the calculated forces to peel orange of 3.3 – 3.7 radii at rotor speed 163.3 rad/s

S/No	Radius of Orange fruit (cm)	Mass of Orange fruit (gm)	Rotor speed rad/s	Rotor speed square rad/s	Peeling force (N)	Maximum centrifugal force (N)
	R	M	Ω	Ω	N	C_f
1	3.4	61	163.3	26666.9	83.0	80.2
2	3.3	56	163.3	26666.9	73.9	71.4
3	3.7	60	163.3	26666.9	88.8	85.8
4	3.6	55	163.3	26666.9	79.2	76.5
5	3.5	62	163.3	26666.9	86.8	83.8
6	3.7	57	163.3	26666.9	84.4	81.5
7	3.4	63	163.3	26666.9	85.7	82.8
8	3.3	57	163.3	26666.9	75.2	72.6
9	3.6	65	163.3	26666.9	93.6	90.4
10	3.6	58	163.3	26666.9	83.5	80.7

Average radius of orange r_o = 3.5
Average mass of orange m_o = 59.4gm
Average Peeling force N_o = 83.4 N
Source: Experiment

Table 7: Specification of the calculated forces to peel orange of 2.8 – 3.2 radii at rotor speed 94.2 rad/s

S/No	Radius of Orange fruit (cm)	Mass of Orange fruit (gm)	Rotor speed rad/s	Rotor speed square rad/s	Peeling force (N)	Maximum centrifugal force (N)
	R	M	Ω	Ω	N	C_f
1	3.0	45	94.2	8873.6	18.0	17.4
2	2.8	55	94.2	8873.6	20.5	19.8
3	3.2	49	94.2	8873.6	20.9	20.2
4	2.9	54	94.2	8873.6	20.8	20.1
5	3.0	47	94.2	8873.6	18.8	18.2
6	3.1	53	94.2	8873.6	21.9	21.2
7	2.8	48	94.2	8873.6	17.9	17.3
8	3.2	52	94.2	8873.6	22.1	21.3
9	2.9	46	94.2	8873.6	17.8	17.2
10	3.1	51	94.2	8873.6	21.0	20.3

Average radius of orange r_o = 3.0
Average mass of orange m_o = 50.4gm
Average Peeling force N_o = 19 N
Source: Experiment

Table 8: Specification of the calculated forces to peel orange of 2.8 – 3.2 radii at rotor speed 133.4 rad/s

S/No	Radius of Orange fruit (cm)	Mass of Orange fruit (gm)	Rotor speed rad/s	Rotor speed square rad/s	Peeling force (N)	Maximum centrifugal force (N)
	R	M	Ω	Ω	N	C_f
1	3.1	50	133.4	17796.6	41.4	40.0
2	2.7	51	133.4	17796.6	36.8	35.5
3	3.2	76	133.4	17796.6	39.3	38.0
4	3.0	48	133.4	17796.6	38.4	37.1
5	2.9	52	133.4	17796.6	40.3	38.9
6	3.0	47	133.4	17796.6	37.6	36.3
7	2.7	54	133.4	17796.6	38.9	37.6
8	3.1	48	133.4	17796.6	39.7	38.4
9	3.0	54	133.4	17796.6	43.3	41.8
10	3.2	46	133.4	17796.6	39.3	38.0

Average radius of orange r_o = 3.0
Average mass of orange m_o = 49.5gm
Average Peeling force N_o = 39.5 N
Source: Experiment

Table 9: Specification of the calculated forces to peel orange of 2.8 – 3.2 radii at rotor speed 163.3 rad/s

S/No	Radius of Orange fruit (cm)	Mass of Orange fruit (gm)	Rotor speed rad/s	Rotor speed square rad/s	Peeling force (N)	Maximum centrifugal force (N)
	R	M	Ω	Ω	N	C_f
1	3.2	44	163.3	26666.6	56.3	54.4
2	3.0	54	163.3	26666.6	64.8	62.6
3	3.0	50	163.3	26666.6	60.0	58.0
4	2.8	53	163.3	26666.6	59.4	57.4
5	3.0	49	163.3	26666.6	58.8	56.8
6	2.9	52	163.3	26666.6	60.3	58.2
7	3.1	48	163.3	26666.6	59.5	57.5
8	3.2	51	163.3	26666.6	65.3	63.1
9	2.8	47	163.3	26666.6	52.6	50.8
10	3.1	50	163.3	26666.6	62.0	59.9

Average radius of orange r_o = 3.0
Average mass of orange m_o = 49.8gm
Average Peeling force N_o = 60 N
Source: Experiment

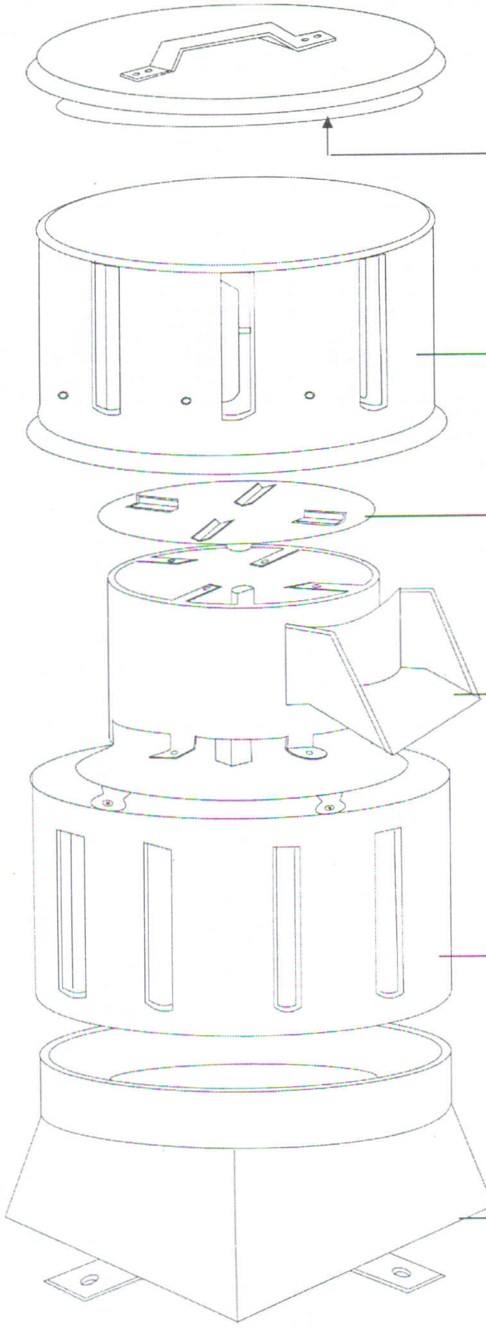

Fig.3: The Orange Peeling Machine