DESIGN AND DEVELOPMENT OF MECHANISM FOR SEPARATION OF ARECANUT HUSK AND KERNELS

A thesis submitted to the

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In the partial fulfillment of the requirements for the degree of

MASTER OF TECHNOLOGY
(AGRICULTURAL ENGINEERING)
in
FARM MACHINERY AND POWER

by

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CHAPTER I

INTRODUCTION

Arecanut (*Areca catechu*) is one of the important commercial crops in India. Arecanut plays an important role in Asian culture, especially in India. Arecanut belongs to family *palmae* commonly known as Supari. Arecanut is an important cash crop mostly grown in tropical pacific, Asia, parts of East Africa and Western Ghats, Eastern Ghats, East and North Eastern region of India. Arecanut is grown in soil such as laterite, red loam and alluvial soil. The climate requirement for arecanut cultivation is warm humid. Arecanut is an important component of the religious, social and cultural celebration and economic life of people in India. Arecanut is also used in ayurvedic and veterinary medicines. Arecanut is also processed into pan-masala, scented supari etc., which are getting more popular in the country. An important by product of the arecanut industry is the husk of arecanut which can be utilized for making particle boards, paper etc. (Orwa, 2009).

Global scenario of Arecanut

The total world area under arecanut cultivation in 2012 was about 7.0 lakh ha with production of 12,61,388 metric tons and productivity of 1215 kg/ha. Among the different arecanut growing countries, India ranks first in terms of both area and production. Total arecanut production of India in 2012 was 4,82,000 metric tons. India stands ranked 4th in terms of productivity. The other countries which produce arecanut in the world are Indonesia, China, Taiwan, Myanmar, Bangladesh, Srilanka, Thailand, Bhutan, and Nepal having production 187000,135000, 135000, 122000, 108000, 37700, 35000, 10500, 9188 metric tons respectively. In India, arecanut grown on 3.9 lakh ha area with production of 5.6 lakh metric tons and productivity of 1409 kg/ha (Anonymous, 2012).

Indian scenario

India is a major producer and consumer of arecanut in the world. In India different states of producing arecanut are Karnataka (46 per cent area and 46.9 per cent production), Kerala (24.3 per cent area and 23.5 per cent production), Assam (17.49 per cent area and 13.1 per cent production), Meghalaya (3.1 per cent area and 3.5 per cent production) ,Tripura (1.11 per cent area and 1.7 per cent production), Maharashtra (0.55 per cent area and 0.72 per cent production), Tamilnadu (1.26 per cent area and 2.10 per cent production), West Bengal (2.85 per cent area and 4.31 per cent production), Andaman and Nicobar Islands (1.02 per cent area and 1.2 per cent production), Mizoram (1.64 per cent area and 1.7 per cent production). It is estimated that nearly ten million people depend on arecanut industry for their livelihood in India. Because of the fact that larger part of arecanut is consumed within the country itself, the export potential of India is limited. India export small quantities of the nut in its processed form to the neighboring countries (Anonymous, 2010).

Karnataka is the largest arecanut producing state in the country producing 40 per cent of country produce. There are different varieties of arecanut grown in India like Mangala, Swarnmangala, Shrivardhan Kota, Vittal Areca hybrid-1 etc. which classify in white and red varieties. Regarding to consumption scenario in India, the country is the largest consumer of arecanut in the world. The current consumption figure has a mounted around 3, 20,000 metric tons (Anonymous, 2010).

The area under cultivation of arecanut in Maharashtra is 2300 ha with production 3600 tons and productivity of 1565 kg/ha in year 2012. Konkan region in Maharashtra is basically a narrow strip of 40 km wide and running 750 km length from north to south and it is a hilly terrain lying between Sahyadri ranges in the east and Arabian Sea in west. It receives an annual rainfall between 3000 to 4500 mm during June to October. Laterite soil is widely found in Konkan region of Maharashtra. Along the sea coast in a narrow belt, coastal saline and costal alluvial soil formed. The important crops grown in this zone are Paddy; horticultural tree crops like Coconut, Arecanut and Cashew, spices and plantation crops viz. Pepper, Ginger, Turmeric etc. (Ambavkar, 2013)

Arecanut is one of the important commercial crops of Konkan region. Arecanut production in Konkan region has now almost reached a level of self-sufficiency, but the arecanut growers are still facing the problem of dehusking of dried fruit, separation of husk and kernels, grading of arecanut in different size. Separation and grading are the important processing operation of arecanut. Separation of arecanut husk and kernels on oscillating type separator take place due to difference in densities and surface characteristics of husk and kernels. Separation in aerodynamic type separator takes place due to air velocity. Traditionally, dehusking and grading of arecanut can be done by manually. The knowledge of the morphology and size distribution of arecanut husk and kernels is essential for the accurate design of the equipment for cleaning and separation.

The university (Dr.BSKKV, Dapoli) has developed hand operated, pedal operated and power operated arecanut dehusker. In addition to this some manufacturers have developed power operated arecanut dehusker. In these mechanical dehusker after dehusking the husk and kernels are to be separated manually which is very time and laborious process. One man can handle 6 to7 kg mixtures of husk and kernels per hour.

As the separation of husk and kernels is most labour and time consuming process, which affects directly the total profit of the arecanut growers. Hence, it was necessary to develop a mechanism for separation of arecanut husk and kernels, which will be cost effective, efficient in operation and portable. Keeping above point in view it was decided to develop a small power operated mechanism for separation of arecanut husk and kernels at department of Farm Machinery and Power, College of Agricultural Engineering and Technology, Dapoli. Hence, the project entitled "Design and development of mechanism for separation of arecanut husk and kernels" was undertaken with following objectives

1. To study physical and aerodynamic properties of dried arecanut fruit, husk and kernels.
2. To design and develop mechanism for separation of husk and kernels.
3. To evaluate the performance of developed mechanism for separation of husk and kernels

CHAPTER II

REVIEW OF LITERATURE

This chapter deals with review of research work done in past by various investigators on the topic under study. The chapter has cited the review under following headings

2.1 Physical and aerodynamic properties

2.2 Design and development of separation unit

2.3 Performance evaluation of separation unit

2.1 Physical and Aerodynamic Properties

Balasubramanian (1985) studied different physical properties of dried arecanut fruit and kernel. Length and diameter of arecanut fruit were 40 and 22.9 mm, respectively, while those for kernel were 19.7 and 15 mm, respectively. The sphericity of arecanut fruit and kernel were 62.7 and 70.9 per cent, respectively. Volume, weight and true density for arecanut fruit were 10.9 cm^3, 5.06 g and 0.51 g/cc, while those for kernel were 3.46 cm^3, 3.08 g and 1.15 g/cc, respectively. The bulk density of kernel was 2.26 times the bulk density of fruit with values as 286.7 kg/m^3 and 648 kg/m^3, respectively for fruit and kernel. The values of porosity for fruit and kernel were 43.8 and 43.7 per cent, respectively. The angle of repose of arecanut fruits and kernels were 31.1 degree and 33.1 degree, respectively.

Kaleemullah and Gunasekar (2002) studied moisture dependent properties of arecanut kernels. The physical properties of arecanut kernels were determined in the moisture range from 88.91 to 10.51 per cent (d.b). The axial dimensions of kernel as major diameter, medium diameter, minor diameter, geometric mean diameter and sphericity were 2.4 (±0.3) cm, 2.39 (±0.26) cm, 1.96 (±0.24) cm, 2.24 cm and 72.3 (± 4.2) per cent, respectively at 10.51 per cent moisture (d.b.). One hundred kernel weights was 0.594 kg at moisture content 10.51 per cent (d.b). The bulk density, true density of arecanut kernel was 695.91 and 1152.48 $kg/m^{3,}$ respectively at 10.51 per cent moisture content (d.b). The angle of repose and porosity of kernel at 10.51 per cent moisture content (d.b.) were 17.69 degree and 39.62 per cent, respectively.

Aware *et al.* (2007) determined various physical properties for raw and steamed cashewnut. The average length, breadth and thickness for the raw cashewnut were 2.92, 2.21 and 1.67 cm, respectively. Similarly, sphericity, bulk density, true density were 75 per cent, 582.64 kg/m^3 and 1017.61 kg/m^3, respectively. The values of porosity and angle of repose for raw cashewnut were 42 per cent and 26.21 degrees, respectively.

Dash *et al.* (2008) conducted a study of physical properties of simarouba fruit and kernel, which are often required for the development of post-harvest equipment. The kernel had 8.51 per cent (w.b.) moisture and 61.04 per cent oil content, which is higher than the fruit and shell. The average fruit length, width, thickness and 1000 unit mass were 21.26, 13.81, 11.03 mm; and 1120.16 g, while the corresponding value for kernel were 13.78, 7.77, 6.71 mm; and 330.26 g, respectively. The sphericity and surface area of fruit were 5.8 and 63.36 per cent, respectively which were more than those of kernel. Bulk densities of fruits and kernels were 622.27 and 727.73 kg m^{-3}, the corresponding true densities were 931.96 and 1019.3 kg m^{-3}, and porosities were 33.23 and 28.61 per cent, respectively. The angle of repose of fruit and kernel were 31 and 35 degree, respectively.

Davies (2009) conducted a study of physical and mechanical properties of groundnut essential for design of equipment for harvesting, processing, transportation, cleaning, sorting, and separation and packaging. In this research some physical properties of groundnut grains were evaluated such as axial dimensions, geometric mean diameter, thousand grain mass, true and bulk densities and grain volume at moisture content 7.6 per cent dry basis. The sphericity, aspect ratio, surface area and porosity were 0.69, 56 per cent, 120.82 mm^2 and 36.4 per cent respectively. Static coefficient of friction for glass, plywood, galvanized steel and concrete structural surfaces were 0.11, 0.13, 0.14 and 0.16, respectively and angle of repose was 28.

Ayman Hafiz Amer Eissa (2009) carried out study on physical and aerodynamic properties of flaxseed. According to the study dimensions were important to design the cleaning, sizing and grading machines. The study deal with the physical, aerodynamic and solid flow properties of flaxseeds which are evaluated as a function of change in moisture content from 8.6 per cent to 23.9 per cent dry basis (d.b.), the dimensions of the length, width and thickness varied from 4.14 to 4.32 mm, 2.03 to 2.13 mm and 0.88 to 0.93 mm, respectively. As the moisture content increased from 8.6 per cent to 23.9 per cent (d.b.), the bulk density, true density and porosity were found to decrease from 46.65 to 44.89 kg/m^3; 1244 to 1176 kg/m^3 and 46.65 per cent to 44.89 per cent, whereas angle of repose and terminal velocity were found to increase from 27.6 to 35.8 and 2.46 to 3.56 m/s, respectively.

Singh *et al* (2010) carried out study on physical properties of barnyard millet grain and kernel. According to them physical properties such as the geometric mean diameter, sphericity, grain surface area, 1000 grain mass, true density (toluene displacement method), terminal velocity, dynamic angle of repose, coefficient of internal friction, coefficient of static friction at different surfaces, are important for separation. True density (proximate composition method), bulk density, interstices and rupture force of grain were found to decrease by 8.64 per cent, 20.1 per cent, 86.49 per cent and 21.17 per cent, respectively at increase of moisture content.

Erkol *et al.* (2010) studied the variations in physical properties such as the size dimensions, unit mass, sphericity, projected area, bulk density, true density, volume, porosity and terminal velocity of shelled and kernel walnuts. With increase in moisture content, the sphericity, projected area, bulk density, volume, porosity of shelled and kernel walnuts increased, whereas true density decreased. The terminal velocity increased from 14.17 m/s to 15.50 m/s and from 12.60 m/s to 14.35 m/s, for shelled and kernels walnuts respectively.

Ambavkar (2012) studied the physical properties of arecanut. For measurement of physical properties of arecanut on the basis of visual observation the arecanut were graded as a small, medium and larger size. The grades were nominated as grade A, grade B and grade C and the dimensions like length, breadth, thickness and weight were measured. It was observed that the average value of length, breadth, thickness and weight of grade A were 53.88 mm, 42.46 mm, 41.06 mm and 34.31g, respectively. For grade B the average value of length, breadth, thickness and weight observed as 46.77 mm, 38.84 mm, 38.78 mm and 26.15 g, respectively. For grade C the average value of length, breadth, thickness and weight observed as 42.49 mm, 39.60 mm, 38.04 mm and 22.33g, respectively.

Aware *et al.* (2013) studied physical properties of dried arecanut fruit and kernels. The mean major diameter, medium diameter and minor diameter of dried arecanut fruits were 48.9 mm, 30.2 mm and 29.2 mm, respectively and that of kernels were 24.2 mm, 23.2 mm and 19.4 mm, respectively. The mean percent sphericity of the fruit and kernel were 72.0 percent and 91.6 percent, respectively. The mean true density of fruit and kernel were 0.53 g/cc and 0.34 kg/m^{3,} respectively. The mean bulk density of arecanut fruit and kernel were 287.7 kg/m^3 684.5 kg/$m^{3,}$ respectively. The mean angle of repose for fruits and kernel were 24 degrees and 23 degrees, respectively.

2.2 Design and Development of Separation Unit

Perry and Chilton (1973) reported that the optimum slope of inclined vibrating screen was that which handle the greatest volume of oversize and still remove the available undersize required by the standards of the particular operation. To separate a material into coarse and stratify the load and allow fines to work their way to screen surface and pass through the opening, Increase slope in order to reduce the bed thickness.

Feller (1980) reported that, to evaluate screen performance, both partial passage and clogging of the screen should be considered. A screen rate function, defined as the sum of the passage and clogging rate factor versus relative particle size, was developed to characterize screen performance. This function was independent of screen duration and could be used as a general expression that was not limited to a particular size distribution of the material or to one screen duration.

Ismail (1986) stated that increasing the stroke length improved significantly the separation efficiency in both vertical and lateral motion at all sieve slopes, while in frontal motion, the separating efficiency decreased with the increase of stroke length at sieve slopes more than 15 degrees. In compound motions, an increase in stroke length caused a corresponding increase in separating efficiency especially in small sieves.

Ahmed (1988) mentioned that the slope of the separating sieve was a controlling factor of the effectiveness of separation. This effectiveness improves significantly as the sieve was also a controlling factor in determining the maximum possible feed rates to the winnowing machine. As the sieve slope increases, the maximum possible feed rates, provided the other factors were kept the same, was greatly reduced. It was also found that the maximum values of efficiency of separation were quite different depending on the number of oscillations per minute used.

Singh and Sahay (1994) reported that there were different motions that could take place for rigid particles placed on a moving through depending upon the frequency of oscillation.

Lars *et al.* (1998) studied that sieving separates material according to size. Objects may pass through an opening larger than their diameter while being retained by an opening of smaller diameter. Thus an oblong seed would pass through an oblong hole, while being retained by a round hole. Sieving was typically used for removal of large and small objects from the seed lot. It was also used during fruit cleaning (pre-cleaning) and for seed grading. High purity can be achieved for relatively spherical seeds and objects, whereas it was less effective for flat or winged seeds. The seed lot was sieved through a series of grids with decreasing mesh or whole size. Several types of screens were available. The choice of screen depends on seed type and quantity. Many types of mechanical seed cleaners with different and replaceable screens were available. In general, round holes were used when the items to be separated differ in width (width was the greater diameter of the cross section of the non-symmetrical seed); oblong holes were used when separation was according to thickness (i.e., the smaller diameter).

Awady *et al.* (2003) developed a separating and cleaning machine to winnow rice crop for better efficiency and reduced losses. The cleaning machine consisted of frame, grain hopper, oscillating dual-screen assembly, a centrifugal blower and electric motor. The eccentric and support linkages of screen assembly were used to oscillate and move the grain over the flat screen. During the operation, grain was loaded onto the hopper and fed into the oscillating screen through the bottom opening and regulated by the slide gate. The upper screen separated the impurities that were bigger than the grain, and the lower screen separated those that were smaller and dust.

Paliwal *et al.* (2004) designed a laboratory scale grain cleaning system. The cleaner consisted of a wooden frame which could support two screens and a similar trough of 310 x 605 mm. The sieve sizes were chosen 2.26 mm (inscribed circle) perforated double triangle for top sieve and 1.79 x 11.90 mm perforated slot for the bottom sieve. The whole assembly was mounted on a vibratory motor. The screen had a slope of 1 in 20 degrees. The rpm of the vibrator and the slope of the screens could be varied to achieve different flow rates through the cleaner. The screens could be taken out and replacement for cleaning and minor slope adjustment.

Ebaid (2005) reported that the cell shape, sieve tilt angle, sieve oscillation and air speed were the main factors that affect purity and total losses in cleaning. The purity increased by increasing air speed, sieve tilt angle and sieve oscillation. Total losses increased by increasing air speed, sieve tilt angle and oscillation.

Abd El-Tawwab *et al.* (2007) reported that the slope of the sieve was the main factor that has a great effect on separation efficiency. The separation efficiency increased significantly with increase of sieve slope at small stroke length and decreased at high stroke lengths.

Ayman Hafiz Amer Eissa (2009) conducted experiments to specify the optimum conditions of separating operation which insure the highest grade of separation efficiency with minimum losses. Pneumatic separation equipment was manufactured and tested under different combinations of the following factors viz. air stream velocity, feed rate and sample moisture content. The performance of the equipment was evaluated by using the indices as separation efficiency and percentage of seed losses. The results of the equipment performances showed that the combinations of air stream velocity, feed rate and sample moisture content affected significantly the separation efficiency and grain losses. Air stream velocity of 2–6 m/s combined with 8.5 kg/h feed rate and 8.6 per cent moisture content could be considered the most favorable combination values of these variables. They gave the highest grades of separation efficiency and the minimum grain losses.

Salwa *et al* (2010) developed a cleaning machine for separation and grading of chaff and light foreign materials. In this machine a centrifugal blower was used for air supply. The centrifugal blower had 6 straight blade impeller with circular duct. The duct was placed over the intake of the blower. The air sucked by the blower moves through the duct and entrains the light particles from seeds. The air velocity over the upper sieve was kept less than the terminal velocity of principle seeds. The sucked light particles, as duct and chaff passed through the cyclone. The centrifugal blower was operated by an electric motor of 0.75 kW. The average air velocity of the fennel seed and straw was found as 3.45 m/s and 2.3 m/s respectively.

Sun Ah Kim *et al* (2011) developed the separation machine for shatter resistant sesame after threshing. Three levels of sieve and blower speed were tested using designed sesame separation system for the shatter resistant sesame. The sieve system and blower system were developed and evaluated through the performance test in terms of separation efficiency, losses, damage, sesame and other material. Results of this work would be useful for construction and utilization of the threshing harvester. The blower speed 220 rpm was optimized for shatter resistant sesame.

Lende and chandak (2012) designed and developed the machine for tamarind cover and seed separation. They focused on design and development of machine which would separate cover and seed from tamarind. The result showed that the machine could separate 10 kg tamarind pods per hour. Power required for operating blower was 0.4 hp and power required for screen vibration was 0.04 hp. Total power required for separation was 1.2 hp.

Ismail *et al.* (2013) carried out study on design of a rice de-stoner for separating stones from rice based on their different properties. It had a sieve with opening based on the size of rice grain to separate the rice from the stones larger than it and also a second sieve which allowed sands and stones smaller than the rice only. Both sieves were vibrated, powered by a 0.5 kW DC with rotational speed of 700 rpm electric motor. The efficiency of destoner was 80 per cent and mass flow rate was 2.1 kg/s which were equivalent to 7.5 t/h capacity.

Muhammad *et al.* (2013) developed a device for cleaning threshed seeds. The cleaning system consisted of an air blast fan and a reciprocating shaker containing replaceable sieve for different crop seeds and a collecting pan. The hopper of a device was trapezoidal in shape. Fan had blade enclosed in casing. The shaker assembly consisted of sieve, grain collecting pan and the clean grain outlet. Adjustment of tilt angle was from 1 in 30 degrees. A crank mechanism with adjustable crank length and connecting rod to achieve various levels of reciprocating amplitude was employed to drive the shaker. A 2.24 kW prime mover was mounted on frame to power the fan and the crank mechanism using belt and pulley drive.

Agidi *et al.* (2013) developed a thresher for threshing, separating and cleaning millet seeds. The major components of machine included threshing, separation and cleaning units. The hopper through which the millet panicles were being fed was made of galvanized material. Separating chamber was made of mild steel with length of 0.80 m and diameter of 0.33 m. cleaning chamber was made of two sieves that undergo to and fro motion and centrifugal fan which blows air into the sieves. While the seed was moving over these sieves, the air which was being blown through them disallowing setting of trash on the sieve and anytime lighter in weight than the seed. Screens were made of mild steel material. It was concave in shape and perforated with 0.3 m length and 0.232 m diameter. The machine was operating with electric motor of 5 hp with a shaft and pulley unit which is connected by v-belt.

Tabatabaeefar *et al.* (2013) developed a device for sieving and grading of chickpea. In this machine, sieves were placed at an angle (4-8 degree) less than the angle of friction of chickpea on the surface. Sieve motion was adjusted from an eccentric with a radius of 30 mm. Sieve surface area equal to 0.88 m^2 for a capacity of 500-1500 kg/h. The opening of a sieve was 6-7 mm and 8 mm diameters were determined according to the size of the chickpea of different varieties. Centrifugal fan with straight blades was designed with an air flow rate of 1 m^3/s to supply an air velocity of up to 11 m/s with an inlet area of 0.1 m^2.

Olugboji *et al.* (2014) designed and developed rice destoning machine. Mild steel material was used for fabrication of the machine. Standard equations were used to determine the dimensions of the parts. The machine was driven by a 1 hp electric motor with 688.17 watts required power. The machine had capacity of 47.39 kg/hr and an efficiency of 82.47 per cent.

2.3 Performance Evaluation of Separation Unit

Singh *et al* (1985) carried out an experiment on separation and cleaning system of groundnut thresher. The effect of some important independent variables namely feed rate, pod moisture content, blower speed and sieve area on the performance of separation and cleaning system has been discussed. The suitable values of these variables were suggested as blower speed of 900 rpm, air velocity 9.23 m/s and sieve area 0.35 m^2.

Ahmed *et al* (1993) developed a winnowing machine. The machine was designed in such a way to change the parameters affecting the separation effectiveness such as the sieve oscillation, amplitude, sieve angle and feed rate for using a threshed wheat crop by the locally made stationary thresher. It was added that, the separation effectiveness of 97% was obtained at sieve oscillations of 500 cycle/min, sieve angle of 2 degrees. and feed rate of 30 kg/h.cm. at grain/straw ratio of 1:3.

Wang *et al.* (1994) evaluated a laboratory grain separating equipment and found the overall removal efficiency which was determined by calculating the material balance of impurities on an input output basis

$$\eta_{imp} = (IMP)_{out}/(IMP)_{in}$$

Where,

η_{imp} = overall removal efficiency, per cent.

$(IMP)_{out}$ = total mass of impurities in test sample before separation, kg

$(IMP)_{in}$ = total mass of impurities removed from test sample, kg.

Awady *et al.* (2003) showed that cleaning efficiency and total losses were positively affected by air speed, and sieve tilt angle, but purity was negatively affected by moisture content and feed rate.

Amin (2003) studied some engineering parameters affecting cleaning and separating efficiency such as type of motions (vibrating or rotary speeds), cells shape (rectangular, square and circle), position of rectangular cell (parallel or perpendicular with speed direction), sieves inclination and sieving time were considered for each machines type (vibratory and rotary machines). It was found that the efficiency increased by increasing sieving time, oscillating and rotary speed.

Tabatabaeefar *et al.* (2003) carried out study on design of a machine for removing a large amount of debris from the chickpea. Physical properties, terminal velocity which were important factor for design were determined. The arithmetic mean diameter was 6.7 to 9.7 mm with an average of 7.8 mm. The terminal velocity of a whole chickpea was 10-15 m/s with an average of 12.6 m/s. For dried leaves and stems, the averages were 3 m/s and 5.5 m/s, respectively. The cleaning, grading and overall efficiency of the machine were evaluated with 2 kg of hand cleaned peas mixed with 15 g chaff and stem and 100 g of stones and clods. The cleaning efficiency of the whole chickpea was 93 per cent and debris 91 per cent. Overall efficiency of machine was 84 per cent.

El-Sahrigi *et al* (2004) designed and constructed a separating and cleaning unit able to various types of medicinal and aromatic seeds and their associated foreign matter by making simple adjustments according to the type of seeds, its physical properties and associated impurities. They also tested the performance of a cleaning unit under the factors as frequency of the sieve unit, feed rate, air velocity and slope of the sieve unit. The maximum seed cleanliness and separation effectiveness were 99.01 and 89.75 per cent, respectively and obtained at frequency of 10.50 Hz, feed rate of 300 kg/h, slope of 13 deg. and air velocity of 3.2 m/s.

Arfia (2006) investigated the engineering parameters affecting the separation of soybean grains. The engineering parameters such as air speed, sieve tilt angle, sieve oscillation, feed rate and moisture content were also studied and determined. The obtained result showed that, the separation increased by increasing sieve oscillation, air speed and sieve tilt angle. The optimum performance was achieved at air speed of 19 m/s, sieve tilt angle of 4 degree, sieve oscillation of 2.6 Hz

(220 rpm), feed rate of 1000 kg/h and moisture content of 13 per cent . Separation efficiency at these conditions was 99.65 per cent and a total loss was 0.35 per cent.

Afify *et al.* (2007) developed a small thresher for threshing of black seed. The thresher was evaluated and tested at drum speeds of 200, 250, 300, 350 rpm, air velocity at 4.19, 5.23, 6.28, 7.32 m/s, feed rates of 600, 700, 800 and 900 kg/h and moisture content of 11.82, 13.63, 15.72 and 17.61 per cent (w.b). The result showed that minimum seed losses of 2.63 per cent, striping efficiency of 99.31 per cent, threshing efficiency of 98.74 per cent, cleaning efficiency of 95.88 per cent required energy of 2.85 kwh/t.

Simonyan and Yiljep (2008) developed a stationary grain thresher and used to study grain separation and cleaning efficiency distribution of the cleaning unit fabricated by the sieve and horizontal air steam along the sieve length. The influence of feed rate, air speed and sieve oscillation frequency on cleaning efficiency of sorghum was explored. Grain separation along the sieve can be divided into three sections increasing, peak and decreasing sections. Result showed that cleaning efficiency decreased with increasing sieve oscillations frequency and feed rate respectively. Cleaning loss increased with increasing sieve oscillation frequency, feed rate and air speed.

Fouda (2009) investigated the performance of paddy and rice separator theoretically and experimentally as a function of change in separator sieve angle, paddy moisture content and feeding ratios. The separator performance was evaluated in term of separator productivity, crank percentage, separator efficiency and energy requirement. The theoretical analysis reveals that the optimum sieve speed of 0.5 m/s (200 rpm) was recommended to prevent riding of material on a sieve surface. The experimental result showed that the separator performance was optimum under condition that sieve angle of 15 degree, paddy moisture content of 14 per cent and feeding ratio of 0.80.

Simonyan *et al* (2010) developed a rice destoning machine. The developed machine was tested in terms of the rice separation efficiency, stone separation efficiency, tray loss and impurity level after separation. The result showed an average value of rice separation efficiency, stone separation efficiency, tray loss and impurities were 74.2, 70, 25.8, 16 per cent respectively.

Simoyan and Eke (2010) studied the effect of some crop and machine parameters such as straw bulk density, feed rate, sieve oscillation and cylinder speed on the cleaning loss of a conventional stationary rasp bar sorghum thresher. Result showed that there was an increase in cleaning loss with increase in straw bulk density, cylinder speed, and sieve oscillation. The optimum combination for loss minimization was cleaning parameter with air speed 5 m/s, sieve oscillation frequency 6 oscillations per seconds and feed rate 543 kg/hr.

Werby (2010) studied some machine parameters affecting cleaning unit such as diameter of holes, air speed, sieve tilt angle, sieve oscillation with feed rate of 500 kg/hr and moisture content of 10.5 per cent of clover seed. Result showed that the machine parameters were the main factors that affect the purity and total losses in cleaning. The purity increased by increasing air speed, sieve tilt angle and sieve oscillation. Total losses increased by increasing air speed, sieve tilt angle and oscillations. The optimum performance was at air speed of 6 m/s, moisture content of 10.5 per cent, sieve oscillation of 250 rpm, sieve tilt angle of 3 degree, round shaped sieve 4 mm diameter and feed rate of 500 kg/hr. Purity at these condition was 99 per cent and total losses 1 per cent.

Salwa *et al.* (2010) developed an experimental cleaning machine. The slope of the sieve unit, air velocity, crank speed and stroke length could be adjusted easily as required. The cleaning unit was tested under the crank speed of a sieve unit, stroke length and slope of sieve unit. Seed were graded by the machine into three categories, collected at three separate outlets. The maximum cleanliness obtained for grade one, two, three were 19.15, 98.74 and 83.65 per cent respectively and obtained at crank speed of 250 rpm, amplitude 20 mm, sieve slope 8.5 degree and air velocity 2.7 m/s. The maximum effectiveness of machine was 78.8 per cent.

Ologunagba *et al.* (2010) carried out a study on palm nut and fibre separator. The basic features of the separator were feeding chute, pulverizing unit, separating unit, discharge outlets and the prime mover. The machine was tested at three different machine angle of tilt (10 degree, 20 degree and 30 degree), two different levels of moisture content termed (dry and wet) and three levels of fibre discharge openings (5, 10 and 15 mm). Test results showed that the machine gave its best work performance with dry mixture at 10 mm fibre discharge opening and 20 degree machine angle of tilt. The throughput capacity, separating efficiency and quality performance efficiency were 201.4 kg/hr, 96.3 per cent and 81.2 per cent respectively.

Taley and Bansod (2012) carried out an experiment to find the optimum machine parameter of grader machine which would give best quality of seed or grain cleaned with maximum output. This work has been undertaken with the intention to provide optimum setting of grader machine to the separator which would improve performance of grader machine, in making this setting the operator makes mistake and lots much good seeds were wasted causing loss to the farmer or industry. The process parameter include air suction of blower (opening), feed rate, speed of blower, screen size. Screen size and feed rate significant control factor.

Agidi Gbabo *et al.* (2013) developed a thresher for threshing, separating and cleaning millet seeds. The major components of machine include threshing, separation and cleaning unit. After threshing, the seeds fall through a concave grid into the cleaning unit which consists of two sieves that undergo reciprocating motion. It was showed that the machine has highest threshing and cleaning efficiencies of 63.2 per cent and 62.7 per cent respectively. The lowest threshing and cleaning effectiveness of 40.68 and 50 per cent respectively.

Muhammad et *al.* (2013) developed a device for cleaning threshed seed. The performance of the prototype was evaluated in terms of percentage cleaning efficiency and seed loss at various levels of fan speeds and feed rates. The test crops used were sorghum, soybean, and millet. The best performance was obtained at cleaning efficiencies of 95, 98, 91 per cent and percentage seed losses of 0.63, 0.81 and 0.75 per cent respectively for sorghum, soybean and millet seeds. The optimum values of feed rates were 4, 2.5 and 3.5 kg/s while fan speeds were 415, 505, and 582 rpm for the respective crops.

The above reviews covered theoretical and experimental analysis of some engineering and operational parameters affecting the performance of separator for the purpose of maximizing separator efficiency and minimizing energy requirements.

CHAPTER IV

MATERIALS AND METHODS

This chapter deals with the development of mechanism for husk and kernels separation. The performance of a separation unit depends on several factors as dimensions of the feeding hopper, opening of screen, screen vibration, air velocity at blower outlet etc. In this chapter, the methods adapted to study the physical and aerodynamic properties of arecanut fruits and kernels, design and development of vibratory and aerodynamic separation units and the methods adapted to investigate the performance of developed mechanisms are explained.

The stepwise methodology to complete the research work is given as follow

1. Physical and aerodynamic properties of arecanut fruits and kernels
2. Design and development of mechanisms for separation of husk and kernels
3. Performance evaluation of developed mechanisms
4. Data analysis and cost economics

4.1 Physical and Aerodynamic Properties of Arecanut Fruits and Kernels

Physical and aerodynamic properties were important factors for optimizing the parameters of separation unit. Hence, attempt was made to study the physical and aerodynamic properties of arecanut fruits and kernels. The physical and aerodynamic properties of arecanut fruit and kernels namely; length, width, thickness, geometric mean diameter, sphericity, surface area, bulk density, true density, angle of repose, terminal velocity were required for the design of various components of separator.

4.1.1 Determination of geometric mean diameter, surface area and sphericity

The axial and lateral dimensions of fruit and kernel were measured using digital vernier caliper in Plate 4.1. The longest dimension of arecanut is called as major diameter (a), second longest dimensions perpendicular to ‘a’ is called medium diameter (b) and third longest dimension perpendicular to both is called minor diameter (c). The dimensions were measured for 200 different samples each of fruit and kernel, which were selected randomly. The mean values of dimensions were computed. The geometric mean diameter (Dg), surface area(S) and sphericity (Φ) of the arecanut fruits and kernels were calculated using the following relationships (Aware, 2013)

$$Dg = (abc)^{1/3} \qquad (4.1)$$

$$S = \pi\, Dg^2 \qquad (4.2)$$

$$\Phi = [Dg/a] \times 100 \qquad (4.3)$$

Where,

a – Major diameter, mm.

b – Medium diameter, mm.

c – Minor diameter, mm.

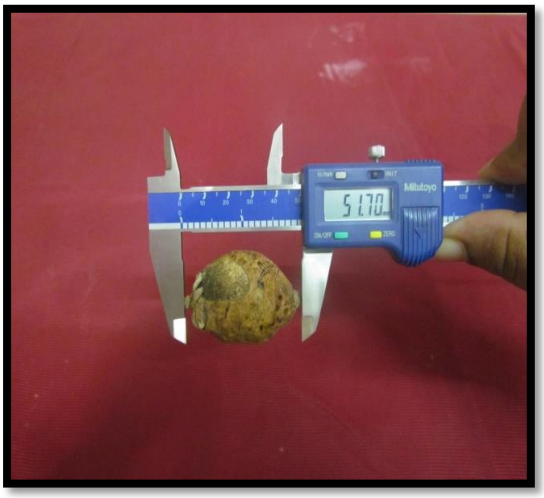

Plate 4.1. Measurement of Dimensions of Arecanut Fruit and Kernels

4.1.2 Determination of volume and true density

The bulk density of material was determined as per the standard procedure. A cylindrically shaped container of 1000 ml (1000 cm^3) volume was used for determination. The container was weighed empty to determine its mass and then it was filled with the sample and weighed once again. The bulk density was determined by dividing the mass of the material by the volume of the container (Singh and Goswami, 1996).

$$\rho_{bf} = W_f / V_v$$

(4.4)

Where,

W_f – weight of fruits, kg

V_v – volume of container, m^3

ρ_{bf} – bulk density of fruit, kg/m^3

To determine the true density of an arecanut fruit, it was weighed initially. Then a small iron weight (sinker) was taken and submerged in measuring jar filled with toluene. Toluene was used in finding true density as suggested by Mohsenin N.N. (1970). The use of sinker was necessary, as the dried fruit was not submerging in the toluene.

The volume of the sinker was recorded by measuring toluene displacement in the jar (Vs). The fruit was then tied with the sinker using a thin, strong thread and placed in the jar. The displacement of toluene due to the sinker and the fruit was noted as the combined volume of sinker and fruit (Vsf). The fruit was then untied, wiped gently and weighed (Wf). The set up for determining true density of dried arecanut is shown in Plate 4.2

The true density ((ρt) was determined by the water displacement method. Porosity (P) was determined in terms of bulk density (ρb) and true density (ρt) by using the following formula

$$P = \left[1 - \frac{\rho b}{\rho t}\right] \times 100 \qquad (4.5)$$

Plate 4.2 Set up for Determination of True Density of Arecanut Fruits and Kernel

4.1.3 Determination of angle of repose

The procedure suggested by Gupta and Das (1997) was used to determine the angle of repose of fruit as well as arecanut kernels. Container made up of acrylic sheet of size 30 cm x 30 cm x 30 cm, opened at top and bottom was used to determine angle of repose. (Plate 4.3)

It was kept in position on a horizontal surface and filled with fruits. The container was lifted gently from the horizontal surface. The height (h) and radius (r) of the base circle of the cone, formed by fruits, were measured and angle of repose (θ) was calculated as follow.

$$\theta = \tan^{-1}\left(\frac{2H}{D}\right)$$

(4.6)

Where,

θ - Angle of repose, degree

H - Height of cone, cm

D - Diameter of cone, cm

Plate 4.3 Container used to Find Angle of Repose

4.1.4 Determination of terminal velocity

Terminal velocity (V_t) of arecanut husk, kernels and broken were determined using seed blower (Plate 4.4). The material (arecanut fruit, kernels, husk and brokens) placed at the front of the blower at the net inlet side of the transparent tube. After operating the blower and increasing its speed by opening the gate slowly until the flowing air suspend the particles in the vertical active part of the transparent tube, the measured air velocity represent the terminal velocity of particles. Anemometer was used to measure the air velocity. Theoretically the terminal velocity was calculated by using following formula. (Ayman Hafiz AmerYissa, 2009)

$$V_t = \left[\frac{2Mg}{cd\rho_a A}\right]^{1/2} \qquad (4.7)$$

Where,

M - Mass of the particle kg;

g - Acceleration due to gravity, (9.81 m/s^2);

V_t - Terminal velocity m/s;

cd - Coefficient of drag;

ρ_a - Density 1.25 kg/m^3;

A - Particle area projected to air, m^2

Plate 4.4 Seed Blower for Determination of Terminal Velocity

4.1.5 Determination of moisture content

The moisture content of arecanut fruit was measured by oven dry method. The method adopted by Anthony (2011) was used for determine the moisture content. Initially the sample with the known weight 100g was kept in oven at 130 ºC for six hours. Then the sample was cooled in a dedicator and weighed using an electronic balance. The moisture content of sample was calculated by following formula.

$$M.C.(\% db) = \frac{W_2 - W_3}{W3 - W_1} \times 100$$

(4.8)

Where,

W_1 - weight of box, g

W_2 - weight of box + sample, g

W_3 - weight of box + sample after drying, g

4.2 Design and Development of Separating Mechanisms

It was decided to develop two different types of mechanisms for separation of arecanut kernels and husk, viz. vibratory separating mechanism and aerodynamic separating mechanism.

4.2.1 Design and development of vibratory separating mechanism

The vibratory separating mechanism separates the material on the basis of difference in densities of material. The vibratory separating mechanism mainly consisted of main frame, feeding hopper, screens (upper and lower), vibrating mechanism, power source and power transmission component as belt, pulley etc.

4.2.1.1 Main frame

The main frame of vibratory separating mechanism being the important part of separator on which other parts were mounted. The size and material were selected on the basis of total weight of the major components mounted on it. The main frame was fabricated with mild steel using square pipe of size 20 mm × 20 mm to supports the components. The overall dimension of frame was 900 mm x 700 mm x 1000 mm and its total weight was 25 kg.

4.2.1.2 Design of feeding hopper

The feeding hopper was made of MS sheet of 1mm thickness (16 SWG). The cross section of the hopper was trapezoidal. The shape of hopper was such that it ensures proper flow of husk and kernels mixture without blocking. The angle of inclination of the hopper with the vertical was 27˚ considering free flow of mixture of husk and kernels. The location of feeding hopper was 60 cm above the ground.

The height of hopper was selected as 285 mm and the bottom width of the hopper was 140 mm. The slope of hopper with horizontal was 62˚, which was kept more than angle of repose to unsure the proper flow.

The cross sectional area of the trapezoidal hopper was determined by equation 3.1,

$$A = 0.285\ (0.14 + 0.285 \cot 62^\circ)$$

$$A = 0.083\ m^2$$

Volume of hopper was calculated from equation 3.2,

$$V = 0.083 \times 0.5$$

$$V = 0.04154\ m^3$$

Hopper capacity was calculated from equation 3.3,

$$Q = 0.04154 \times 167.4$$

$$Q = 6.95 \text{ kg} \approx 7 \text{ kg}$$

The bulk density of mixture of husk and kernels was 167.42 kg/m^3.

4.2.1.3 Design of upper screen

For the separation of husk from the kernels, two screens were used. The upper screen was used to separate the husk and kernels falling on it. It was made up of bakelite sheet having thickness of 5 mm. It had two sections, the section just below the hopper was continuous while the remaining section was having hole of 30 mm diameter. The diameter of hole was selected by studying the physical properties of arecanut fruits and kernels. The maximum diameter of kernels was 29 mm, so the opening of upper screen was kept as holes of 30 mm diameter. The schematic view of the upper screen is shown in Fig.4.1 (a)

The distance between the openings can be determined from the equation 3.4

$$d = \frac{\sqrt{30 X 30}}{0.4(3\pi - 2 X 0.4)}$$

d = 8.70 mm ≈ 9 mm

Area of screen can be determined from the equation 3.5

$$A = 900 \text{ X } 600$$

$$A = 540000 \text{ mm}^2$$

4.2.1.4 Design of lower screen

The kernels of arecanut drops on lower screen from upper screen. The lower screen was mounted 100 mm below and parallel to the upper screen. Lower screen was designed to have the openings smaller than the size of minimum diameter of arecanut kernels which was 17 mm so as to retain all kernels and pass all brokens. Hence the diameter of opening was kept 17 mm and the distance between openings was determined from the equation 3.4. The schematic view of the lower screen is shown in Fig.4.1 (b)

$$d = \frac{\sqrt{17X17}}{0.4(3\pi - 2X0.4)}$$

d = 4.93 mm ≈ 5 mm

The broken kernels passed through the lower screen openings and collected at outlet

4.2.1.5 Determination of screen hangers dimensions

The four links were used to hang the cleaning screens on the frame. The supports were designed to carry the total weight of both the vibrating screens. Four hangers of MS flat of length 300 mm and thickness 10 mm were used for hanging the screens and fitted to frame with help of bolts. Numbers of holes were given at different space on the hanger to adjust the angle of inclination of screen.

The design load per support was determined from equation 3.7

$$F_{sl} = 60/4$$

$$F_{sl} = 15 \text{ kg}$$

$$F_{sl} = 147.15 \text{ N}$$

Bending moment due to drive mechanism was determined from equation 3.8,

$$M_b = 147.15 \text{ X } 0.15$$

$$M_b = 22 \text{ Nm}$$

Yield strength of a material was determined from equation 3.9,

$$\sigma_y = 22/1.5 \text{ X } 10^{-3}$$

$$\sigma_y = 14.66 \text{ N/m}$$

$Z = 0.03 X 0.30 / 6$

$Z = 1.5 X 10^{-3}$

Deflection of simple beam was determined from equation 3.11,

$\delta_{max} = [(147.15 X 0.15^3) / (3 X 6.75 X 10^{-5} X 170 X 10^6)]$

$\delta_{max} = 14.25 N/mm^2$

Stiffness k for each bar was determined from equation 3.13,

$k = 147.15 / 14.42$

$k = 10.20 N/mm$

For four bars total stiffness was determined from equation 3.14,

$k_T = 4 X 10.20$

$k_T = 40.80 N/mm$

4.2.1.6 Design of cam or exciter disc

Eccentric drive mechanism was used to translate rotary motion of motor to oscillating motion of screen. The mechanism was attached to lower screen. The disc of rotating cam was made up of MS plate having diameter 95 mm and 10 mm thickness. At distance of 10 mm from center of cam plate, a hole was made to insert the drive shaft of diameter 22.5 mm. Due to this offset arrangement, stroke length of 10 mm was achieved. The square pipe of 20 mm x 20 mm size and 250 mm long was used as connecting shaft between cam and screen. The screen was made vibrate by to and fro motion of connecting shaft.

The mass of cam and power required to vibrate the lower screen were calculated as follow

The volume of inner circle was calculated from equation 3.35

$V_1 = 3.14 X (1.75)^2 X 1 / 2$

$V_1 = 4.80 cm^3$

The radius of gyration was calculated from equation 3.36

$Y_1 = Y_2 = 4 X 1.75 / 3 X 3.14$

$Y_1 = Y_2 = 0.7430 cm$

The volume of outer circular disc was calculated from equation 3.37

$V_2 = 3.14 X (4.75)^2 X 1 / 2$

$V_2 = 35.42 cm^3$

The effective radius of gyration calculated from equation 3.39

$Y = 35.42 X 0.7430 – 4.80 X 0.7430 / 35.42 – 4.80$

$Y = 0.7430 cm$

The effective volume of revolution was calculated from equation 3.40

$$V = 35.42 - 4.80$$

$$V = 30.62\ cm^3$$

The mass of the cam was calculated from equation 3.41

$$M = 7.842\ X\ 30.62$$

$$M = 240.11\ g$$

By definition of centrifugal force, the minimum required speed of cam to separate mixture of 5 kg (weight of cleaning unit was 25 kg) was calculated from equation 3.43

$$\omega = \sqrt{30 X 9.81 /}\, 0.240 X 9.81 X 0.07430$$

$$\omega = 41.01\ m/s$$

Converting to revolution per minute from equation 3.44

$$N = 41.01\ X\ 60\ /\ 2\ X\ 3.14$$

$$N = 391.87\ rpm$$

Torque generated was calculated from equation 3.45

$$T = 30\ X\ 9.81\ X\ 0.007430$$

$$T = 2.186\ Nm$$

Power required was calculated from equation 3.46

$$P = 2.186\ X\ 41.01$$

$$P = 0.\ 012\ hp$$

4.2.1.7 Design of V-belt

V-belt was used to transmit the power from motor shaft to cam shaft with help of belt and pulley arrangement. Length of belt for combination 75 mm and 350 mm diameter pulley was calculated as

Let,

Diameter (d1) of driver pulley was 75 mm

Diameter (d2) of driven pulley was 350 mm

This combination of pulley was based on set speed of 305 rpm speed of cam.

The center distance C between two adjacent pulleys was calculated from equation 3.48

$$C = 75 + 350\ /\ 2 + 75$$

$$C = 287.5\ mm$$

Length of belt was calculated from equation 3.47

$$L = 2 \text{ X } 287.5 + 3.14/2 \text{ X } (75 + 350) + (350-75)^2/ (4 \text{ X } 287.5)$$

$$L = 1307 \text{ mm}$$

Similarly, the belt length for achieving 356 and 413 rpm speed of cam were calculated as 1162 mm and 1036 mm, respectively.

4.2.1.8 Design of shaft

Shaft was an important part in power transmission. Power from motor to other part must be transmitted with the help of the shaft. The shaft of cast iron or MS was used to transmit the power from motor shaft to cam shaft to drive cleaning unit. The diameter of shaft was determined considering it was subjected to twisting and bending using equation 3.50 Equivalent twisting moment was calculated as

$$M_t = \{(1.5 \text{ X } 7 \text{ X}10^3)^2 + (1.0 \text{ X}110 \text{ X } 10^3)^2\}^{1/2}$$

$$M_t = 110.9 \text{ X } 10^3 \text{ Nmm}$$

Equivalent bending moment was calculated from equation 3.51

$$M_b = ½(1.5 \text{ X } 7 \text{ X}10^3 + 110.9 \text{ X } 10^3)$$

$$M_b = 60.70 \text{ X } 10^3 \text{ Nmm}$$

Diameter of shaft was calculated by using equation 3.49

$$d^3 = [(32/3.14 \text{ X } 56 \text{ X } 10^6) \text{ X}110.9 \text{ X}10^3]$$

$$d = 22.3 \text{ mm}$$

As detailed above, the dimension of various components of vibratory separating mechanism viz cam, V- belt, shaft etc were calculated. The arrangement of cam and roller follower are shown at Plate 4.5

4.2.1.9 Power required for driving the vibratory separating mechanism

Total weight of the cleaning unit was 25 kg and the weight of mixture of husk and kernels was 30 kg. So, the total weight was 55 kg. The length of stroke was 10 mm.

Torque required to drive the cleaning unit was calculated from equation 9.4

$$T = 55 \text{ X } 9.81 \text{ X } 20/2 \text{ X } 1000$$

$$T = 5.4 \text{ Nm}$$

Thus, power required was calculated from equation 9.4

$$P = 2 \text{ X } 3.14 \text{ X } 400 \text{ X } 5.4 /60$$

$$P = 226.08 \text{ watts}$$

$$P = 0.3 \text{ hp}$$

Considering the 10 per cent power loss due to friction, the total power required to drive the developed vibratory separator was computed as 0.33 hp. Therefore a 0.50 hp electric motor was selected for the operation of this machine. The overall dimensions of developed vibratory separator are shown in Fig.4.2. The final prototype of developed vibratory separator is shown in Plate 4.6

4.2.2. Design and Development of Aerodynamic Separating Mechanism

The aerodynamic separating mechanism separates the mixture of arecanut husk and kernels on the basis of air velocity. The aerodynamic separating mechanism consisted of main frame, feeding hopper, blower and power source

4.2.2.1 Main frame

The main frame of aerodynamic separating mechanism was fabricated with mild steel using angle of size 20 mm × 20 mm x 3 mm, to supports to all the components. The overall dimension of frame was 530 mm x 150 mm x 525 mm.

4.2.2.2 Feeding hopper

The feeding hopper of aerodynamic separating mechanism was made of MS sheet of 1mm thickness (16 SWG). The cross section of the hopper was trapezoidal. The height of hopper was 220 mm and the bottom width of the hopper was 90 mm. The cross sectional area of the trapezoidal hopper was determined by equation 3.1,

$$A = 0.220\ (0.9 + 0.220 \cot 60^\circ)$$

Considering height (h) as 220 mm and bottom width 90 mm

$$A = 0.225 \text{ m}^2$$

The slope of hopper with horizontal was 60˚, which was kept more than angle of repose to unsure the proper flow.

Volume of hopper was calculated from equation 3.2,

$$V= 0.225 \times 0.15$$

$$V = 0.03389 \text{ m}^3$$

Hopper capacity was calculated from equation 3.3,

$$Q = 0.03389 \times 167.4$$

$$Q = 5.6 \text{ kg}$$

The bulk density of mixture of husk and kernels was 167.4 kg/m^3.

4.2.2.3 Design of blower

The air flow was a fundamental requirement for cleaning and separation of impurities. Blower was used to deliver specified amount of air volume to perform the operation. There are different parts of blower like impeller, blades, and casing. In this machine blower was used to remove the impurities or husk material from arecanut kernels.

The air velocity for design of blower was decided by calculating the terminal velocity of husk and kernels. The minimum terminal velocity of kernel was 16.3 m/s and the maximum terminal velocity of husk was 11.4 m/s. It was necessary to remove all husk material but to retain all kernels and the maximum broken. Initially considering the main criteria to remove all husks, the blower outlet air velocity was taken as 16 m/s.

Let blower outlet of square cross section having size 0.15 X 0.15 m. The discharge of air required for blowing the impurities from the area of 0.15 X 0.15 m^2 and velocity of 16 m/s was calculated as below

$$Q = 0.0225 \text{ X } 16$$

$$Q = 0.360 \ m^3/s$$

4.2.2.3.1 Design of impeller

Impeller was a most important part of blower. Impeller was driven by blower shaft; create the air flow by revolving the air centrifugally away from the impeller blade tips.

4.2.2.3.1.1 Impeller outside diameter

Impeller outside diameter was calculated by using the equation 3.15

$$d_2 = [0.360/1440/60 \text{ X } 0.6]^{1/3}$$

$$d_2 = 29.60$$

$$d_2 = 296 \text{ mm} = 300 \text{ mm}$$

4.2.2.3.1.2 Outlet air velocity

Outlet air velocity U_2 calculated from equation 3.16

$$U_2 = 3.14 \text{ X } 0.2960 \text{ X } 1440/60$$

U_2 = 22.3 m/s

4.2.2.3.1.3 Calculation for other velocity components

Radial component of air velocity at impeller inlet is V_{m2} calculate from equation 3.17

Vm_2 = 0.2 X 22.30

Vm_2 = 4.56 m/s

Velocity of air at the blower outlet was calculated from equation 3.18

V_2 = 1.7 X 22.30

V_2 = 37.91 m/s

Radial component of the velocity at impeller inlet Vm_1

$Vm_1 = Vm_2$ = 4.56 m/s

Velocity of air at blower inlet V_o by equation 3.19

V_o = 2 X 4.56

V_o = 9.12 m/s

4.2.2.3.1.4 Impeller eye diameter

Impeller eye diameter d_1 calculated from equation 3.23

$d_1 = [4 X 0.360 / 3.14 X 9.12]^{1/2}$

d_1 = 0.22423 = 225 mm

4.2.2.3.1.5 Inlet blade angle

Inlet blade angle β_1 is calculated from equation 3.24

$\tan\beta_1$ = 4.56 X 60 / 3.14 X 0.225 X 1440

$\beta_1 = 13.60^0$

4.2.2.3.1.6 Number of blades

Number of blade mounted on impeller was calculated from equation 3.25

Z_n = 6.5 sin 13.60 (300 + 250 / 300 – 250)

Z_n = 16.76 = 16

4.2.2.3.1.7 Width of blade

Width of blade calculated from equation 3.27

b_1 = 0.360 / 3.14 X 0.225 X 4.56

b_1 = 100 mm

4.2.2.3.1.8 Width of impeller

Width of impeller was calculated from equation 3.29

W = 100 + 2 + 4 X 2 + 2 X 0.5

W = 107 mm

The impeller of blower was designed and developed as per design calculations. The schematic view of impeller is shown in Fig. 4.4.

4.2.2.3.2 Design of casing

Cut off angle of casing curvature was determined following standard procedure

4.2.2.3.2.1 Determination of cut off angle

Assumption:

Maximum discharge 0.50 m^3/sec

Maximum velocity 25 m/s

Angle of air leaving the impeller with vertical near casing wall, $\alpha = 13.60^0$

Radial clearance 30 mm

Known parameter

Radius of impeller $r_3 = 0.300 / 2 = 0.15$ m =150 mm.

Radius of base circle, r_4 = radius of impeller + Radial clearance

$$r_4 = 150 + 30 = 180 \text{ mm}$$

Cut off or tongue angle = $1 / \tan\alpha \ln [r_4/r_3]$

$$= 1 / \tan 13.60 \ln [180 / 150]$$

$$= 22.67^0$$

4.2.2.3.2.2 Determination of curvature of casing contour (Constant mean velocity method)

Using constant mean velocity method

$$A_\theta = \theta - \theta_T / 360 \text{ X c/s area of casing at cut off}$$

Where A_θ= c/s area at angle θ^0

If cut off is at 360^0 we have, A_{360} i.e c/s area of casing at cut off is Q/V = 0.360/20 = 0.018 m^2. But cut off is at angle of 22.67^0.

C/s area at cut off (modified c/s) = 360 -22.67 /360 X 0.0188

$$= 0.0168 \text{ m}^2$$

Considering area of casing is rectangular we have

$A_o = b (r-r_4)$

b = width of casing

= 1.24 X 0.12

= 0. 1488 m

At cut off

$r – r_4 = 0$

$r = r_4 = 180$ mm

$A_{60} = 60 – \theta / 360$ X c/s area at cut off (modified c/s area)

$A_{60} = 60 – 21 / 360 \text{ X } 0.0188$

$A_{60} = 1.82 \text{ X } 10^{-3} \text{ m}^2$

But we have,

$A_\theta = b (r – r_4)$

$A_{60} = 0.1488 (r - 180)$

$1.82 \text{ X } 10^{-3} = 0.1488r – 0.026784$

$r_{60} = 0.19236$ m = 192 mm

The radius of curvature of casing at different angles can be found from the above equation as

r_{60} =0.1923 m = 192 mm

r_{90} =0.204 m = 204 mm

r_{120} =0.214 m = 214 mm

r_{150} =0.225 m = 225 mm

r_{180} =0.235 m = 235 mm

r_{210} = 0.246 m = 246 mm

r_{240} = 0.256 m = 240 mm

r_{270} = 0.267 m = 267 mm

r_{300} = 0.277 m = 277 mm

r_{330} = 0.288 m = 288 mm

r_{360} = 0.299 m = 299 mm

The schematic view of casing is shown in Fig.4.5. The overall dimensions of developed aerodynamic separator are shown in Fig.4.6. The final prototype of Aerodynamic separator is shown in Plate 4.7

4.2.2.4 Power required for driving the aerodynamic separating mechanism

The important part of aerodynamic separator was blower. The weight of impeller plates were 1.75 kg and that of blades was 1.25 kg. Total weight of impeller was 3 kg. Diameter of impeller was 300 mm. So, the torque required to drive the blower was calculated from equation 3.53

T = 3 X 9.81 X 300/2 X 1000

T = 4.414 Nm

Hence, power required was calculated from equation 3.52

$$P = 2 \times 3.14 \times 800 \times 4.414 / 60$$

$$P = 369.58 \text{ watts}$$

$$P = 0.50 \text{ hp}$$

Considering the 10 per cent power loss due to friction, the total power required to drive the developed separator was computed as 0.55 hp. Therefore a 0.75 hp electric motor was selected for the operation of this machine.

4.3 Construction and Working of Vibratory Separating Mechanism

The fabrication of vibratory separating mechanism was done as per design calculation in the workshop of Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, College of Agricultural Engineering and Technology, Dapoli. The main frame having dimension 900 mm x 700 mm x 1000 mm was fabricated using a square pipe of size 20 mm x 20 mm. The motor of 0.50 hp was mounted on the frame by using nuts and bolts. The trapezoidal shaped feeding hopper of height 285 mm was fabricated by using MS sheet of 1mm thickness (16 SWG). The dimensions of hopper at top were 500×350 mm and at bottom were 500×140 mm. The cleaning unit consisting of two screens (upper and lower) were mounted on frame by using four hangers of MS flat having length 300 mm and thickness 10 mm. It was made to vibrate by eccentric drive mechanism. The mechanism consisted of cam disc having diameter 95 mm. Stroke length of 10 mm was achieved by fitting a shaft at 10 mm distance offset from the center of cam. A shaft of 25 mm diameter was fitted on the main frame by using two pedestal bearings of size P 204 (25 mm ID) with the help of nuts and bolts. The follower having length 250 mm was attached to the lower screen of cleaning unit.

The rotary motion of electric motor (0.5 hp, single phase, 1425 rpm.) was converted into oscillatory motion by using cam and follower. The motion from motor shaft was transmitted to cam by belt and pulley. The cam rotated and converted the rotary motion into vibratory motion providing stroke of 10 mm through the follower which was connected to lower screen of cleaning unit. The mixture of husk and kernels was feed in hopper. The mixture from hopper slide on upper screen. The husk and unhusked fruit separated from upper screen and the kernels and brokens dropped through the openings of 30 mm diameter on lower screen due to screen vibration. The kernels separated from lower screen and broken dropped through the lower screen opening of 17 mm diameter. The husk, kernels and brokens were collected at the respective outlets.

4.4 Construction and Working of Aerodynamic Separating Mechanism

The development of aerodynamic separating mechanism was done as per design calculation in the workshop of Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, College of Agricultural Engineering and Technology, Dapoli. The main frame of dimension 530 mm x 150 mm x 525 mm was fabricated using a MS angle of size 20 mm × 20 mm x 3 mm. The motor of 0.75 hp was mounted on the frame by using nuts and bolts. The trapezoidal shaped feeding hopper of height 220 mm, upper width 200 mm and bottom width of 90 mm was fabricated using MS sheet of 1mm thickness (16 SWG). The centrifugal type of blower having impeller and casing was fabricated. The impeller having outside diameter 300 mm, 16 forward curved blades and 107 mm width was fabricated. The casing was fabricated by using MS sheet of 1mm thickness (16 SWG) as per design calculation. The blower was mounted on main frame using two pedestal bearings of size P204, nuts and bolts. The belt and pulley were used for power transmission.

In the working of aerodynamic separating mechanism, the motor transmits the rotary motion from motor shaft rotating at 1425 rpm. The power from motor shaft was transmitted to impeller mounted shaft with the help of belt and pulley. The impeller rotates and air velocity was generated. The mixture of husk and kernels was feed in hopper. The mixture drop from hopper opening and due to the difference of density the kernels drop and pass through the kernels outlet and the husk was blow by using air velocity generated from blower in husk outlet. The husk, kernels and broken collected at the respective outlets.

4.5 Performance and Evaluation of Developed Separator

Performance of developed separators were evaluated by taking different test. Tests were conducted to cover the full combination of the considered variables under different levels.

4.5.1 Performance and evaluation of vibratory separator

The details about independent and dependent parameters for evaluation of vibratory separation are as fallows

Independent parameters	Levels	Description
Feed rate	4	18, 24, 30, 36 kg/h
Cam speed	3	305, 356, 413 rpm

Dependent parameters

Separation efficiency

Separation loss

Separation effectiveness

Replications 3

The performance of developed vibratory separator was carried out at three different speeds (305, 356 and 413 rpm) and four different feed rates (18, 24, 30 and 36 kg/h). The mixture of husk and kernels was feed into the machine with the help of feeding hopper. Electric motor of 0.5 hp power was used to operate this mechanism. Three different cam speeds viz. 305, 356 and 413 rpm were achieved by proper combination of pulleys. As the rated speed of electric motor was 1425 rpm; 75 mm and 350 mm diameter pulleys were used to get speed 305 rpm, while 75 mm and 300 mm diameter pulleys were used to get cam speed of 356 rpm. Similarly 87.5 mm and 300 mm diameter pulleys were used to achieve 413 rpm cam speed. The feeding mixture contains about proportion 60 per cent kernels, 30 per cent husk and 10 per cent broken. The aim was to determine the performance of the cleaning unit and also to get the best combinations among the variables that lead to maximum cleanliness in all outputs with minimum overlap and minimum losses. Each test was carried out for 10 minutes. Each combination of feed rate and crank speed were replicated three times and the representative value taken as the mean of the three readings resulting in total 36 observations (4 feed rate X 3 cam speed) for each dependent parameter. The outputs from kernels, husk and broken outlet were collected. Similarly the kernels and brokens coming in kernels outlet were separated and weighted individually. Similarly, the husk and kernels with brokens from husk outlet was separated and weighted individually. The kernels with brokens and husk from kernels outlet separated. The output from kernel outlet, husk outlet and broken outlet were collected and weighed using an electronic balance having capacity 6 kg and least count 0.01 gm. The angle of screen inclination was kept 10^0 and the stroke length was kept 10 mm in all experiments. Using the equations given in chapter III various dependent parameters such as separation efficiency, separation loss and separation effectiveness were calculated. Experimental set up of vibratory separator is shown in Plate 4.9

4.5.2 Performance and evaluation of aerodynamic separator

The details about independent and dependent parameters for evaluation of aerodynamic separation are as fallows

Independent parameters	Levels	Description
Feed rate	4	18, 24, 30, 36 kg/h
Air velocity	5	8.5, 9.5, 10.5, 11.5, 12.5 m/s

Dependent parameters

Separation efficiency

Separation loss

Separation effectiveness

Replications 3

The performance of developed aerodynamic separator was conducted at five different air velocities (8.5, 9.5, 10.5, 11.5, 12.5 m/s) and four different feed rates (18, 24, 30, 36 kg/hr).The mixture of husk and kernels were feed into the machine with the help of feeding hopper. The velocities were varied by varying the speed of impeller. It was done by controlling the input current by variable resister dimmer. The feeding mixture contains about proportion 60 per cent kernels, 30 per cent husk and 10 per cent brokens. Each test was carried out for 10 minutes. Each combination of feed rate and air velocity were replicated three times and the representative value taken as the mean of the three readings resulting in total 60 observations (4 feed rate X 5 air velocity) for each dependent parameter. The contaminant in kernels outlet and in husk outlets was separated. Similarly the kernels and brokens coming in kernels outlet was separated. Similarly, the husk and kernels with brokens from husk outlet was separated and weighted individually. An electric weighing balance of 6 kg capacity and 0.01gm were used to weighing the sample Using the equations given in chapter III various dependent parameters such as separation efficiency, separation loss and separation effectiveness were calculated. Experimental set up of aerodynamic separator shown in Plate 4.10

4.6 Data Analysis

The data analysis of experiment was carried out by using General Liner Model (GLM) procedure of Statistical Analysis System (SAS, 1989). The method of regression analysis as described by Gomez and Gomez (1984) was used to describe the relationship. The regression coefficient and coefficient of determination were computed. The optimum values of independent parameter were calculated and setting the derivative of each regression equations to zero.

4.7 Instruments used During Research Work

During the research work various instruments were used to determine various parameters. The performance of separator was evaluated by measuring capacity, various efficiencies and losses. The list of these instruments is given below in the table 4.1

Table 4.1 Measuring instruments used in recent work.

Sr. No.	Parameter	Instrument	Least count	Range
1	Size (L ,W ,T)	Digital Vernier caliper	0.01 mm	
2	Terminal velocity	Anemometer		
3	Bulk density	MS sheet container 30X30X30 cm^3	-	-
4	Time	Stop watch	0.5 seconds	0-30 min
5	Speed	Digital Tachometer	1 rpm	0-9999 rpm
6	Moisture content	Hot air oven	0.1^0C	0 -150^0C
7	Weight of arecanut mixture (husk and kernels)	Digital balance	0.05 g	0- 6 kg
8	Weight of husk and broken	Digital balance	0.01 g	0-1 kg

4.8 Cost Economics of Separator

In this session, the fixed cost, variable cost and operating cost for the separator is given. The Operating cost is addition of fixed cost and variable cost.

4.8.1 Fixed cost

1. Cost of machine.
2. Depreciation (Rs/h).

= (C – S) / (L X H)

3. Interest (Rs/h).

= ((C + S) / 2) X I / H

4. Insurance and taxes (Rs/h) = 2% of initial cost.
5. Housing (Rs/h) = 1.5 % of initial cost.

Total fixed cost = 2+3+4+5

4.8.2 Variable Cost

1. Electricity cost (Rs/h)

= Electricity consumed (kWh) X Electricity charge (Rs. /kWh)

2. Operators cost (Rs/h)

= Wage of operator/ Working hours

3. Repair and maintenance = 10% of initial cost.

Total variable cost = 1+2+3

4.8.3 Operating cost

= Fixed cost + Variable cost

Where,

C = Initial cost of machine, Rs.

H = Annual use of machine, hr.

I = Interest rate, %

L = Total life of machine, yr.

S = Salvage value, Rs.

CHAPTER V

RESULTS AND DISCUSSION

In this chapter, the physical and aerodynamic properties of arecanut fruits and kernels related to the development of husk and kernel separation unit are studied. The influence of selected variables on separation efficiency, separation loss, separation effectiveness and design concepts of components are discussed and explained. It also includes the performance evaluation of developed mechanisms for separation of husk and kernels. The results of the different test obtained and their discussion are presented in this chapter under following headings,

5.1 Physical and aerodynamic properties of arecanut fruit and kernels

5.2 Detailed specifications of developed mechanisms

5.3 Performance and evaluation of developed mechanisms

5.4 Effect of machine parameter on performance of separating mechanisms

5.1 Physical and Aerodynamic Properties of Arecanut Fruit and Kernels

Arecanut fruits and kernels properties were important for optimizing the parameters of the husk and kernels separating mechanism. The physical properties of fruits and kernels have been found useful for designing separator components viz. hopper, vibrating screen and blower. The physical and aerodynamic properties of fruits and kernels namely; length, width, thickness, weight, surface area, bulk density, true density, angle of repose, terminal velocity and moisture content were measured using standard procedure given in chapter IV.

5.1.1 Geometric mean diameter, surface area and sphericity

The geometrical parameters namely dimension of the principal axes (a is major diameter, b is the medium diameter and c is the minor diameter) of randomly selected 200 arecanut fruit and kernels were measured using digital vernier caliper having a least count of 0.01 mm. Geometric mean diameter, surface area and sphericity were calculated. Based on the geometrical parameters of the kernels, the opening of screen in vibratory separator was designed for separation of husk and kernels. The physical properties of arecanut fruits and kernels are presented in the Table 5.1 and 5. 2 respectively.

The major, medium and minor diameters of arecanut fruit were in the range of 32.94 to 62.18 mm, 26.48 to 55.33 mm and 23.24 to 49.47 mm with mean values as 48.18 mm, 38.35 mm and 32.13 mm, respectively. Similarly, the major, medium and minor diameters of arecanut kernel were in the ranges as 17.96 to 33.95 mm, 15.14 to 31.5 mm and 14.92 to 31.46 mm with mean values as 22.69 mm, 19.79 mm and 19.21 mm, respectively. The ranges for geometric mean diameter for arecanut fruit and kernel were 28.64 to 45.30 mm and 15.82 to 31.18 mm respectively. The average geometric mean for fruit and kernel were 37.51 and 19.08 mm, respectively. The sphericity of the fruit varied between 67.86 and 93.88 per cent with a mean value of 78.25 per cent. The sphericity of kernel varied between 88.11 and 91.84 per cent with a mean value of 87.31 per cent. The ranges for surface area for arecanut fruit and kernel were 2575.47 to 6463.03 mm^2 and 786.32 to 3052.74 mm^2, respectively. The average surface area for fruit and kernel were 4446.72 and 1238.18 mm^2, respectively. The detailed values of randomly selected 200 samples were also given in Appendix A. Aware (2013) reported that the major, medium and minor diameters of arecanut fruit for mean values were 48.9 mm, 30.2 mm and 29.2 mm, respectively. Similarly, the major, medium and minor diameters of arecanut kernel for mean values were 24.2 mm, 23.2 mm and 19.4 mm, respectively. The average geometric mean for fruit and kernel were 34.9 and 22.1 mm, respectively. The sphericity of kernel varied between 82.4 and 98.0 per cent with a mean value of 91.6 per cent.

Table 5.1 Physical Properties of Fruits

Sr.No.	Parameter	Range	Mean
1	Major diameter, mm Medium diameter, mm Minor diameter, mm	32.94 - 62.18 26.48 – 55.33 23.24 – 49.47	48.18 38.35 32.13
2	Geometric mean diameter, mm	28.64 - 45.30	37.51
3	Surface area, mm^2	2575.4 - 6443.0	4446.72
4	Sphericity, per cent	67.86 – 93.88	78.25
5	Weight, g	6.25- 15.48	10.86
6	Bulk density, kg/m^3	259.4 – 275.8	270.4
7	True density, g/cc	0.3 -0.6	0.5
8	Porosity, per cent	-	46
9	Angle of repose, degree	30.5 – 39.3	35.6

Table 5.2 Physical Properties of Kernels

Sr.No.	Parameter	Range	Mean
1	Major diameter, mm Medium diameter, mm Minor diameter, mm	17.96 – 33.95 15.14 – 31.50 14.92 - 31.46	22.69 19.79 19.21
2	Geometric mean diameter, mm	15.82 – 31.18	19.08
3	Surface area, mm^2	786.3 – 3052.7	1238.18
4	Sphericity, per cent	88.11 – 91.84	87.31
5	Weight, g	3.46 -10.61	6.75
6	Bulk density, kg/m^3	733.6 – 739.6	735.31
7	True density, g/cc	0.9 – 1.6	1.1
8	Porosity, per cent	-	66
9	Angle of repose, degree	30.4 -35.3	32.2

5.1.2 Bulk density, true density and porosity

Separation of arecanut husk and kernels was due to difference in density of arecanut husk and kernels. The bulk density was determined by using equation 4.4 and true density was calculated by water displacement method. The values of bulk density, true density and porosity of arecanut fruit and kernels are given in Table 5.1 and Table 5.2, respectively. The bulk density of fruit varied from 259.4 to 275.8 kg/m^3 and the bulk density of kernels varied from 733.6 to 739.6 kg/m^3. The average value of bulk density for fruits and kernels were 270.45 and 735.31 kg/m^3, respectively. True density of arecanut fruits varied from 0.3 to 0.6 g/cc and for kernels true density varied from 0.9 to 1.6 g/cc. The mean value for true density of fruit and kernels were found 0.5 and 1.1 g/cc, respectively. Porosity for arecanut fruits was 46 per cent and for kernels it was 66 per cent. The detailed values of bulk densities and true densities of randomly selected 200 samples are also given in Appendix B. According to Aware (2013) the average bulk density of fruits was 287.7 kg/m^3. The average bulk density of kernel was 684.5 kg/m^3. The bulk density of kernel was approximately 2.4 times the bulk density of fruit. According to Balasubramanian (1985), the bulk density of kernel was 2.26 times the bulk density of fruit with values as 286.7 kg/m^3 and 648 kg/m^3. Kaleemullah and Gunasekar (2002) reported the bulk density of arecanut kernel was 695.91 kg/m^3 at 10.51 per cent moisture content on dry basis.

5.1.3 Angle of repose

Angle of repose was an important property for design of a hopper for feeding the mixture of husk and kernels. The angle of repose was calculated for fruits and kernels by using equation 4.6 and presented in Table 5.1 and 5.2, respectively. The angle of repose for fruits was ranged from 30.5 to 39.3 degrees with a mean value of 35.6 degrees. The angle of repose for kernel was varied from 30.4 to 35.3 degrees with mean value of 32.2 degrees. According to Aware (2013) the angle of repose for fruits and kernels were 24.4 degree and 23.3 degree, respectively. Angle of repose was 31.1 deg for fruit and 33.1 deg for kernel as reported by Balasubramanian (1985). The variation was due to change in shape and size of arecanut kernel which is evident by variation in geometric mean and sphericity. The detailed values of angle of repose are also given in Appendix C.

5.1.4 Moisture content

Moisture content of arecanut was calculated by using the oven dry method for arecanut fruits. The moisture content was calculated from equation 4.8. The average value of moisture content of arecanut fruits is 11.19 per cent (wb). The detailed values of moisture content are given in Appendix D.

5.1.5 Terminal velocity of arecanut husk, kernels and broken

Terminal velocity of arecanut husk, kernels and broken were important to decide the blower outlet air velocity for removing the husk material. Terminal velocity is the velocity at which particle remain in suspended state in air. The terminal velocity of husk, kernels and broken was determined by using the seed blower. The maximum, minimum and average value of terminal velocity for arecanut husk, kernels and broken is presented in Table 5.3. The detailed value of terminal velocity for husk, kernels and broken is given in Appendix E

Table 5.3 Terminal Velocity of Husk, Kernels, and Broken

Particulars	Proportion in mixture of husk, kernels and brokens (per cent)	Terminal velocity m/s		
		Minimum	Maximum	Mean

Husk	30	03.6	11.4	07.35
Kernels	60	16.3	26.2	20.65
Brokens	10			
Proportion in 10 per cent brokens				
Less than 0.5 g	4	5.8	8.6	6.99
0.5 – 1.5 g	10	7.3	9.3	8.18
1.5 – 2.5 g	12	8.7	14.1	11.66
2.5 – 3.5 g	20	11.9	16.0	14.21
More than 3.5 g	54	10.02	16.6	14.22

Generally the proportion of husk, kernals and broken in the mixture of arecanut husk and kernels was about 30, 60, and 10 per cent, respectively. The different sizes of brokens were classified into five categories on weight basis such as broken of weight < 0.5 g, 0.5- 1.5 g, 1.5- 2.5 g, 2.5 – 3.5 g and > 3.5 g; which are in proportion of 4, 10, 12, 20, and 54 per cent, respectively. The average value of terminal velocity for husk and kernels were 7.35 m/s and 20.65 m/s, respectively. The average value of terminal velocity for the broken of weight < 0.5 g, 0.5 – 1.5 g, 1.5 – 2.5 g, 2.5 -3.5 g and > 3.5 g were 6.99, 8.18, 11.66, 14.21 and 14.22 m/s, respectively.

5.2 Detailed Specification of Developed Mechanisms for Separation of Husk and Kernels

The two separating mechanism viz. vibratory separating mechanism and aerodynamic separating mechanism were designed and developed for separation of husk and kernels. The details of the components, their specifications and the material required are presented in the Table 5.4 and Table 5.5, respectively.

Table 5.4 Detailed Specification of Developed Vibratory Mechanism for Separation of Husk and Kernels.

Sr. No.	Components	Specification	Material

1	Main frame	Main frame Overall length – 900 mm, Overall width – 700 mm, Overall height – 1000 mm	MS square pipe 20 X 20 mm
2	Hopper	Trapezoidal shape cross section, height of hopper 285 mm, upper side 500×350 mm, bottom side 500×140 mm, angle of inclination of 62˚ with the horizontal.	16 SWG MS sheet
3	Screens	Upper screen size - 900 X 600 mm, Opening of screen - 30 mm, Distance between the openings - 9 mm. Lower screen size - 900 X 600 mm, Opening of screen - 17 mm, Distance between the two openings- 5 mm. Hanger dimensions 4 MS flat of length 300 mm and thickness of 10 mm	Bakelite sheet of 5 mm thickness MS flat
4	Eccentric drive mechanism	Cam - Diameter of rotating disc – 95 mm Follower - Length of connecting rod – 250 mm Stroke length – 10 mm	MS plate of thickness 100 mm MS flat 20 X 5 mm
5	Power transmission	V-Belt, B section Pulleys of diameter size 5, 7.5, 8.75, 30, 35 mm were used for various speeds Shaft– Length of shaft 400 mm Diameter of shaft 22.5 mm	Rubber Cast iron Round bar 30 mm -
6	Power source	0.50 hp electric motor, single phase, speed 1425 rpm	

Table 5.5 Detail Specification of Developed Aerodynamic Mechanism for Separation of Husk and Kernels.

Sr. No.	Components	Specification	Material

1	Main frame	Main frame Overall length – 650 mm Overall width – 200 mm Overall height – 525 mm	MS angle 20 X 20 X 4 mm
2	Hopper	Trapezoidal shape cross section, height of hopper 220 mm, upper side 200 X 150 mm, bottom side 90 X 150 mm, angle of inclination 60^0 with the horizontal.	16 SWG MS sheet
3	Blower	Type – Centrifugal blower Impeller outside diameter -300 mm Impeller inside diameter – 225 mm Length of blade - 107 mm No of blades – 16 Size – Length – 485 mm Width – 140 mm Height – 550 mm	16 SWG MS sheet, 12 SWG MS sheet
4	Power transmission	V-Belt, B section Pulleys of diameter size 6.25 and 8.75 mm Shaft– Length of shaft 150 mm Diameter of shaft 25 mm	Rubber Cast iron Round bar 30 mm
5	Power source	0.75 hp electric motor, single phase, speed 1425 rpm.	-

5.3 Performance Evaluation of Developed Vibratory Mechanism

Performance of vibratory mechanism was evaluated at four different feed rates (18, 24, 30, 36 kg/h) and three different speeds of cam (305, 356, 413 rpm). The machine parameters like stroke length, screen slope and openings of screen were kept constant for each experiment. Each experiment was replicated thrice and each experiment conducted for 10 min. The dependent parameters were separation efficiency, separation loss and separation effectiveness.

The mixture of arecanut husk, kernels and broken was taken in proportion of about 60 per cent kernels, 30 percent husk and 10 per cent broken. The mixture of arecanut husk and kernels feed in hopper according to feed rates 3 kg, 4 kg, 5 kg, and 6 kg mixture were feed in 10 minutes in order to maintained feed rates of 18, 24, 30 and 36 kg/h, respectively. The speed of cam rotation was adjusted with help of different pulley combinations. Power was transmitted with the help of V-belt. Time required for separation was measured using stopwatch. The materials at husk, kernels and broken outlet were collected and weighted by using digital balance. The readings at all outlets were noted and separation efficiency, separation loss and separation effectiveness were calculated.

The details of masses of arecanut kernels, husk and brokens at different outlets are given in Table 5.6. The details of masses of kernels, husk and broken at different outlet are given at appendix F (Table F1)

Table 5.6 Masses of Arecanut Husk, Kernels and Brokens at Different Outlets at three Different Crank Speed and at Four Different Feed Rates

Sr. No	Speed rpm	Feed rate kg/h	Mass of kernels in kernels outlet (g)	Mass of husk in kernels outlet (g)	Mass of kernels in husk outlet (g)	Mass of brokens (g)
1	305	18	1717	58	103	280
		24	2289	92	124	388
		30	2873	119	155	486
		36	3461	167	160	582
2	356	18	1737	58	78	287
		24	2280	89	131	388
		30	2868	113	143	488
		36	2295	87	117	585
3	413	18	1684	54	127	289
		24	2280	89	131	384
		30	2851	109	163	487
		36	3433	140	179	590

Using the values of masses of husk, kernel and broken at different inlet and outlets, separation efficiency, separation loss and separation effectiveness were calculated and given in Table 5.7.

Table 5.7 Effect of Cam Speed and Feed Rate on Separation Efficiency, Separation Loss and Separation Effectiveness at Three Different Speed and Four Different Feed Rates

Sr.No.	Speed (rpm)	Feed Rate (kg/h.)	Separation efficiency (per cent)	Separation loss (per cent)	Separation effectiveness (per cent)
1	305	18	92.9	5.4	84.79
		24	92.3	5.2	85.37
		30	92.0	5.2	85.39
		36	90.7	4.4	87.29
2	356	18	93.6	5.7	83.91
		24	92.6	5.5	84.58
		30	92.4	4.8	86.47
		36	91.8	4.6	86.79
3	413	18	94.0	7.1	80.36
		24	93.5	5.9	83.50
		30	92.8	5.4	84.66
		36	92.2	5.0	85.90
	Average	18	93.5	6.1	83.02
		24	92.8	5.5	84.48
		30	92.4	5.1	85.51
		36	91.6	4.7	86.66

The effect of feed rates on separation efficiency at three different cam speeds has been presented in Fig 5.1. It was observed from Table 5.7 and Fig 5.1 that the separation efficiency was decreased as feed rate increased from 18 kg/h to 36 kg/h for all cam speeds. Separation efficiency was decreased from 92.9 to 90.7 per cent, 93.6 to 91.8 per cent and 94.0 to 92.2 per cent at cam speeds 305, 356 and 413 rpm, respectively. The maximum separation efficiency 94 per cent was obtained at speed 413 rpm and feed rate 18 kg/h. The average separation efficiency at each feed rate and at different cam speeds were calculated as given in Table 5.7 and graphically represented in Fig.5.1. The average separation efficiency for different cam speeds viz. 305, 356 and 413 rpm were 93.5, 92.8, 92.4 and 91.6 per cent, respectively. Hence, the average separation efficiency found to decrease from 93.5 to 91.6 per cent as cam speed increased from 305 to 413 rpm for different feed rates.

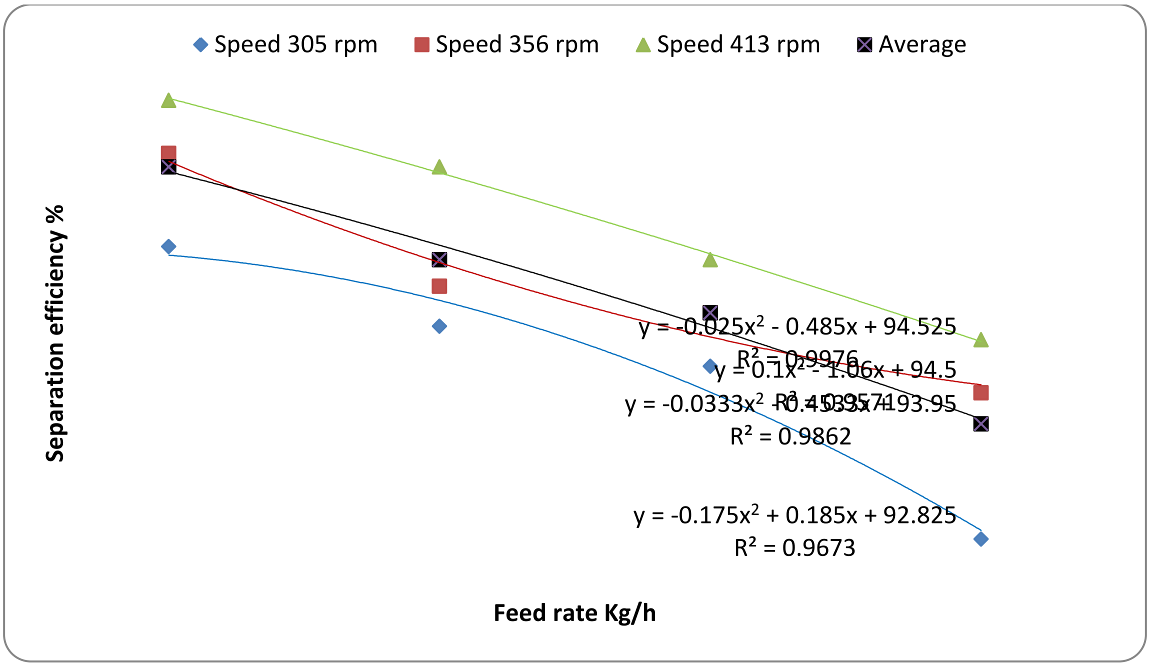

Fig 5.1 Effect of Feed Rate on Separation Efficiency at Three Different Cam Speeds

The effect of feed rates on separation loss at three different cam speeds has been presented in Fig 5.2. It was observed from Table 5.7 and Fig 5.2 that the separation loss was decreased as feed rate increased from 18 kg/h to 36 kg/h for all cam speeds. Separation loss was decreased from 5.4 to 4.4 per cent, 5.7 to 4.6 per cent and 7.1 to 5.0 per cent at cam speed 305, 356 and 413 rpm, respectively. The minimum separation loss 4.4 per cent was obtained at speed 305 rpm and feed rate 18 kg/h. The average separation loss at each feed rate and at different cam speeds were calculated as given in Table 5.7 and graphically represented in Fig.5.2. The average separation loss for different cam speed viz. 305, 356 and 413 rpm were 6.1, 5.5, 5.1 and 4.7, per cent respectively. Hence, the average separation loss was found to decrease from 6.1 to 4.7 per cent as cam speed increased from 305 to 413 rpm for different feed rates.

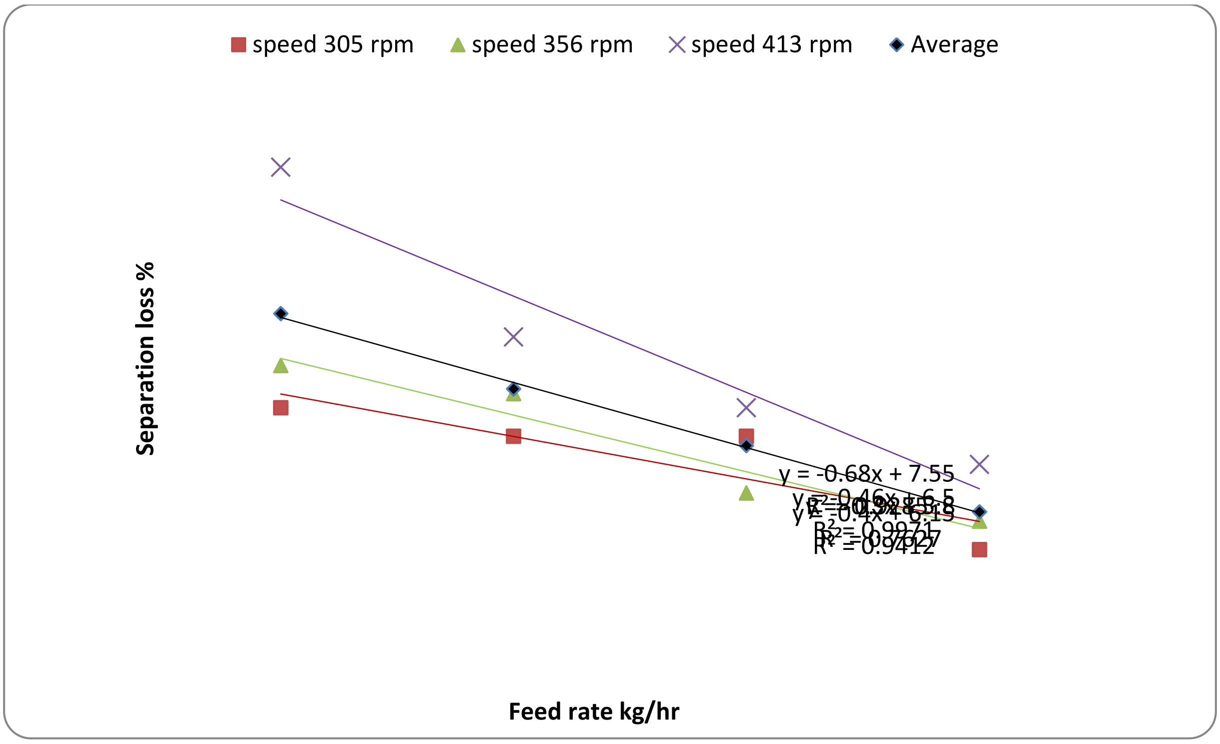

Fig 5.2 Effect of Feed Rates on Separation Loss at Three Different Cam Speeds

The effect of feed rates on separation effectiveness at three different cam speeds has been presented in Fig 5.3. It was observed from Table 5.7 and Fig 5.3 that the separation effectiveness was increased as feed rate increased from 18 kg/h to 36 kg/h for all cam speeds. Separation effectiveness was increased from 84.79 to 87.29 per cent, 83.91 to 86.79 per cent and 80.36 to 85.90 per cent at cam speed 305, 356 and 413 rpm, respectively. The maximum separation effectiveness 87.29 per cent was obtained at speed 305 rpm and feed rate 36 kg /h. The average separation effectiveness at each feed rate and at different cam speeds were calculated as given in Table 5.7 and graphically represented in Fig.5.3. The average separation effectiveness for different cam speed viz. 305, 356 and 413 rpm were 83.02, 84.48, 85.51 and 86.66 per cent, respectively. Hence, the average separation effectiveness found to increase from 83.02 to 86.66 per cent as cam speed increased from 305 to 413 rpm for different feed rates.

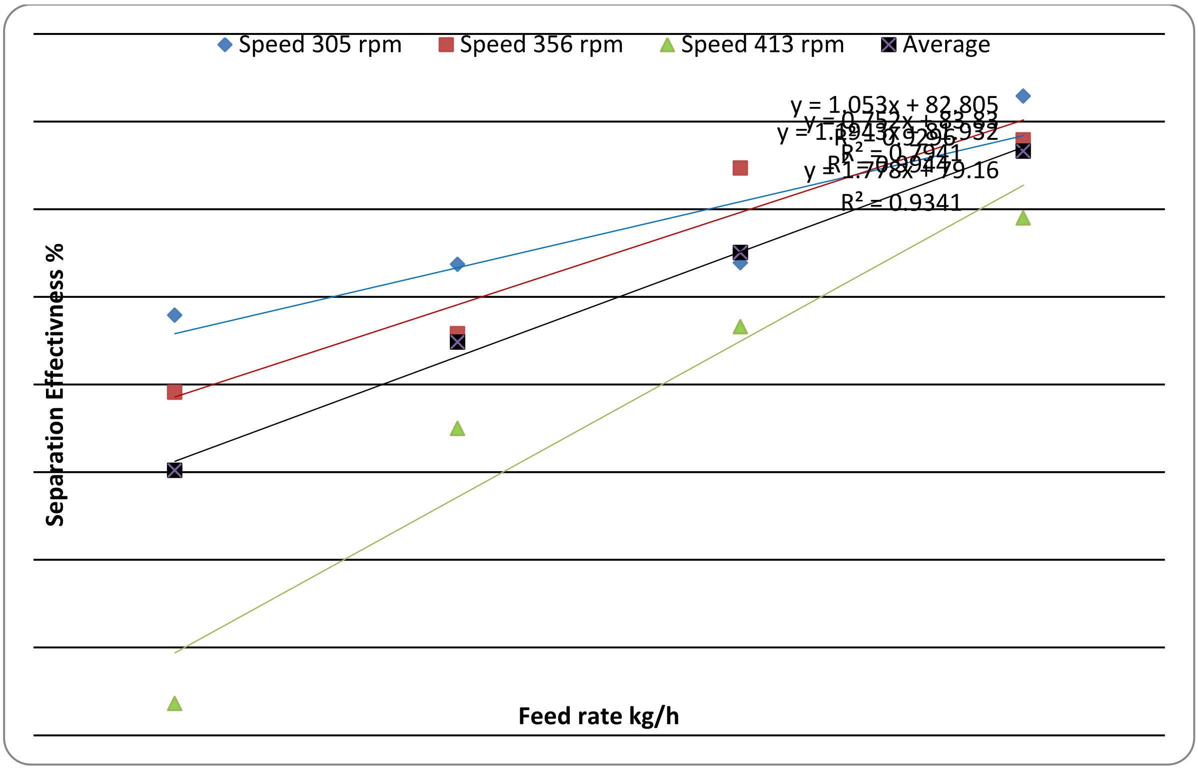

Fig 5.3 Effect of Four Different Feed Rates on Separation Effectiveness at Three Different Cam Speeds

The regression coefficients and coefficients of determination R^2 for different dependent parameter have been computed by least square method for the curves showing the variation in separation efficiency, separation loss and separation effectiveness with feed rates are given in Table 5.8. It was observed that the computed R^2 values for three regression lines ranged from minimum 0.98 at separation loss and maximum 99.75 at separation effectiveness. The optimum feed rate for each dependent parameter (separation efficiency, separation loss, and separation effectiveness) has been calculated by setting the first derivative of each regression equation of feed rate on dependent parameters to zero and solving for most efficient feed rate. The result indicated that the optimum feed rate at maximum separation efficiency and minimum separation loss and maximum separation effectiveness were 27.18, 22.64 kg/h and 28.45 kg/h, respectively. Hence, the optimum feed rate considering the parameters viz. separation efficiency, separation loss and separation effectiveness was 26.09 kg/h.

Table 5.8 Regression Coefficient and Coefficient of Determination of Feed Rate on Separation Efficiency, Separation Loss and Separation Effectiveness for Vibratory Separator.

Sr No	Dependent parameters	a	B	R^2	Optimum feed rate (kg/h)	For optimum value of feed rate	For average value of feed rate
1	Separation efficiency	- 0.13302	7.233093	0.9971	27.18	98.32	98.2
2	Separation loss	- 0.0108	0.48913	0.9849	22.64	5.53	5.41
3	Separation effectiveness	- 0.11105	6.32079	0.9975	28.45	89.93	89.0

The regression coefficients and coefficients of determination R^2 for different dependent parameter have been computed by least square method for the curves showing the variation in separation efficiency and separation effectiveness with cam speed are given in Table 5.9 showing the variation in separation efficiency and separation effectiveness.

Table 5.9 Regression Coefficient and Coefficient of Determination of Cam Speed on Separation Efficiency and Separation Effectiveness for Vibratory Separator.

Sr No	Dependent parameters	a	b	R^2	Optimum speed (rpm)	For optimum value of feed rate	For average value of feed rate
1	Separation efficiency	- 0.000693	0.5178	0.9998	373.59	95.75	96.59
2	Separation effectiveness	- 0.00072	0.498602	0.9975	346.25	88.71	86.18

It was observed that the computed R^2 values for two regression lines ranged from minimum 0.99 at separation efficiency and maximum 0.99 at separation effectiveness. The optimum cam speed for each dependent parameter (separation efficiency and separation effectiveness) has been calculated by setting the first derivative of each regression equation of cam speed on dependent parameters to zero and solving for most efficient cam speed. The result indicated that the optimum crank speed for maximum separation efficiency was 373.59 rpm and the optimum cam speed for maximum separation effectiveness was 346.25 rpm. Hence the optimum cam speed considering the both parameter viz separation efficiency and separation effectiveness was 360 rpm.

5.4. Performance Evaluation of Developed Aerodynamic Mechanism.

Performance of aerodynamic mechanism was evaluated at four different feed rates (18, 24, 30 and 36 kg/h) and five different air velocities (8.5, 9.5, 10.5, 11.5 and 12.5 m/s). Each experiment was conducted for 10 min. and replicated thrice. The blower outlet air velocity was set with the help of dimmer by increasing or decreasing the speed of motor. The air velocity was measured with help of anemometer and speed of blower shaft was measured by using the digital tachometer.

The mixture of arecanut husk, kernels and broken was taken in proportion of 60 per cent kernels, 30 percent husk and 10 percent broken as mentioned before. The broken was categorized into five groups to calculate the actual broken loss at different air velocities. The different sizes of brokens were classified into five categories on weight basis as having weight < 0.5 g, 0.5- 1.5 g, 1.5- 2.5 g, 2.5 – 3.5 g and > 3.5 g. The proportions of brokens according to its weight were 4, 10, 12, 20 and 54 per cent, respectively. The mixture was feed in hopper as per the feed rates. For different feed rates, viz. 18, 24, 30 and 36 kg/h; 3 kg, 4 kg, 5 kg, and 6 kg mixture was feed in 10 minutes. Power was transmitted with the help of V-belt. Time required for separation was measured using stopwatch. The material at husk and kernels outlet were collected and weighted by using digital balance.

The masses of arecanut kernels, husk and brokens at different outlets are noted. The details are given in Appendix F. The values of masses at each individual velocity and feed rate were averaged and tabulated at Table 5.10.

Table 5.10 Masses of Arecanut Husk, Kernels and Brokens at Different Outlets at Five Different Air Velocity and at Four Different Feed Rates

Sr.No	Velocity (m/s)	Feed rate (kg / h.)	Mass of kernels in kernel outlet (g)	Mass of husk in kernel outlet (g)	Mass of kernel in husk outlet (g)	Mass of broken from all outlet (g)
1	8.5	18	1797	174	08	296
		24	2395	264	08	397
		30	2988	484	16	496
		36	3595	705	14	591
2	9.5	18	1794	147	10	296
		24	2389	173	18	393
		30	2982	226	25	493
		36	3591	302	25	584
3	10.5	18	1792	65	14	294
		24	2386	126	19	395
		30	2968	205	36	495
		36	3586	283	28	586
4	11.5	18	1797	29	27	276
		24	2390	75	23	388
		30	2976	88	33	491
		36	3586	283	28	586
5	12.5	18	1797	8	35	265
		24	2387	68	34	378
		30	2984	82	35	483
		36	3584	107	36	580

Using the values of masses of kernels, husk and brokens at different outlets and masses of these parameters at inlet as per Table F1 of Appendix F. Separation efficiency, separation loss and separation effectiveness were calculated for each combination of velocity and feed rate for three replications. These values were averaged and tabulated in Table 5.11.

Table 5.11 Effect of Air Velocity and Feed Rate on Separation Efficiency, Separation Loss and Separation Effectiveness at Five Different Air Velocities and Four Different Feed Rates

Sr.No.	Velocity (m/s)	Feed rate (kg / h.)	Separation efficiency (per cent)	Separation loss (per cent)	Separation Effectiveness (per cent)
1	8.5	18	80.6	0.3	98.64
		24	78.0	0.3	98.97
		30	67.7	0.5	98.26
		36	60.8	0.4	98.68
2	9.5	18	83.7	0.6	98.33
		24	85.6	0.7	97.76
		30	85.0	0.8	97.51
		36	83.2	0.7	97.91
3	10.5	18	92.7	0.8	97.74
		24	89.5	0.8	97.67
		30	86.3	1.2	96.44
		36	84.3	0.8	97.67
4	11.5	18	96.8	1.6	95.71
		24	93.7	0.9	97.22
		30	94.1	1.1	96.82
		36	92.4	1.0	97.17
5	12.5	18	99.1	2.0	94.49
		24	94.3	1.4	95.91
		30	94.6	1.2	96.63
		36	94.0	1.0	97.11
	Average	18	90.58	1.06	96.98
		24	88.22	0.82	97.50
		30	85.54	0.96	97.13
		36	82.94	0.78	97.70

The effect of feed rates on separation efficiency at five different air velocities has been presented graphically in Fig 5.4. It was observed from Table 5.11 and Fig. 5, at air velocity 8.5 m/s, separation efficiency varied from 80.6 to 60.8 per cent for different feed rate viz. 18, 24, 30 and 36 kg/h. Similarly at air velocity 9.5 m/s, the separation efficiency varied from 83.7 to 83.2 per cent and at air velocity 10.5 m/s, the separation efficiency varied from 92.7 to 84.3 per cent. Similarly, at air velocity 11.5 and 12.5 m/s the separation efficiency varied from 96.8 to 92.4 per cent and 99.1 to 94 per cent, respectively as feed rate increased from 18 to 36 kg/h. The maximum separation efficiency was 99.1 per cent obtained at air velocity 12.5 m/s and feed rate 18 kg/hr. The average separation efficiencies at each feed rate and at different air velocities were also calculated as given in Table 5.11. The relationship between feed rate and separation efficiency at different air velocities has been presented graphically in Fig. 5.4. The average separation efficiency for different air velocities viz. 8.5, 9.5, 10.5, 11.5 and 12.5 m/s were 90.58, 88.22, 85.54 and 82.94 per cent, respectively. Hence, the average separation efficiency found to decrease from 90.58 to 82.94 per cent as air velocity increased from 8.5 m/s to 12.5 m/s for different feed rates.

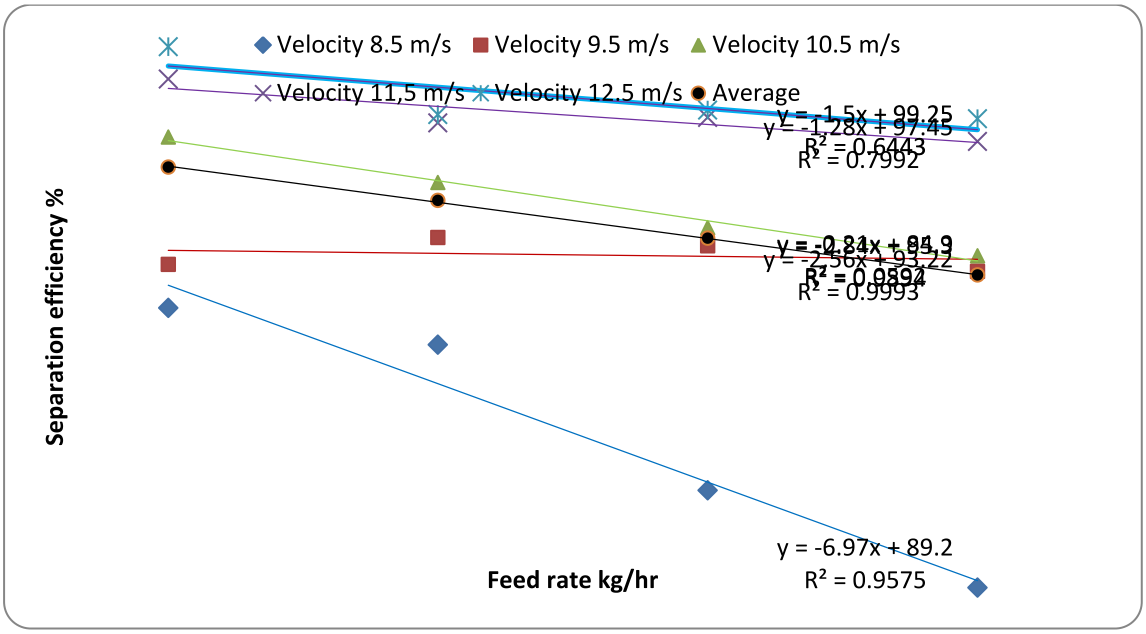

Fig 5.4 Effect of Feed Rate on Separation Efficiency at Five Different Air Velocities

The effect of feed rates on separation loss at five different air velocities has been presented graphically in Fig 5.5. It was observed from Table 5.11 and Fig 5.5 at air velocity 8.5 m/s, the separation loss varied in the range of 0.5 to 0.3 per cent for different feed rate viz 18, 24, 30, 36 kg/h. Similarly at air velocity 9.5 m/s, the separation loss varied from 0.6 to 0.7 per cent and at air velocity 10.5 m/s, the separation loss 0.8 per cent. Similarly, at air velocity 11.5 and 12.5 m/s the separation loss varied from 1.6 to 1 per cent and 2 to 1 per cent as feed rate increased from 18 to 36 kg/h. The minimum separation loss 0.3 per cent obtained at air velocity 8.5 m/s and feed rate 18 kg/h. The average separation loss at each feed rate and at different air velocities were calculated as given in Table 5.11. The relationship between feed rate and separation efficiency at different air velocities has been presented graphically in Fig. 5.5. The average separation loss for different air velocities viz. 8.5, 9.5, 10.5, 11.5 and 12.5 m/s were 1.06, 0.82, 0.96 and 0.78 per cent respectively. Hence, the average separation loss found to decrease from 1.06 to 0.78 per cent as velocity increased from 8.5 m/s to 12.5 m/s for different feed rates.

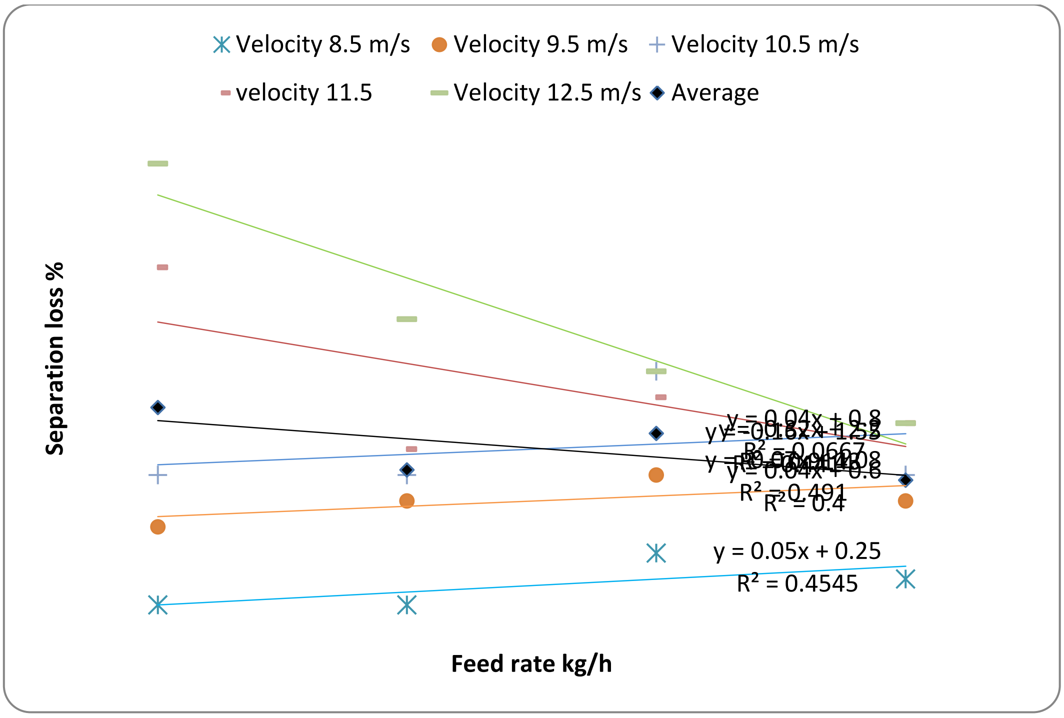

Fig 5.5 Effect of Feed Rate on Separation Loss at Five Different Air Velocities

The effect of feed rates on separation effectiveness at five different air velocities has been presented graphically in Fig 5.6. It was observed from Table 5.11 and Fig 5.6 at air velocity 8.5 m/s, separation effectiveness varied from 98.64 to 98.68 per cent for different feed rate viz. 18, 24, 30 and 36 kg/h. Similarly at air velocity 9.5 m/s, the separation efficiency varied from 98.33 to 97.91 per cent and at air velocity 10.5 m/s, the separation efficiency varied from 97.74 to 97.67 per cent. Similarly, at air velocity 11.5 and 12.5 m/s the separation efficiency varied from 95.71 to 97.17 per cent and 94.49 to 97.11 per cent as feed rate increased from 18 to 36 kg/h. The maximum separation effectiveness 98.97 per cent obtained at air velocity 8.5 m/s and feed rate 24 kg/h. The average separation effectiveness at each feed rate and at different air velocities were calculated as given in Table 5.11 and graphically represented in Fig.5.6. The average separation effectiveness for different air velocities viz. 8.5, 9.5, 10.5, 11.5 and 12.5 m/s were 96.98, 97.50, 97.13 and 97.70 per cent respectively. Hence, the average separation effectiveness found to increase from 96.98 to 97.70 per cent as air velocity increased from 8.5 m/s to 12.5 m/s for different feed rates.

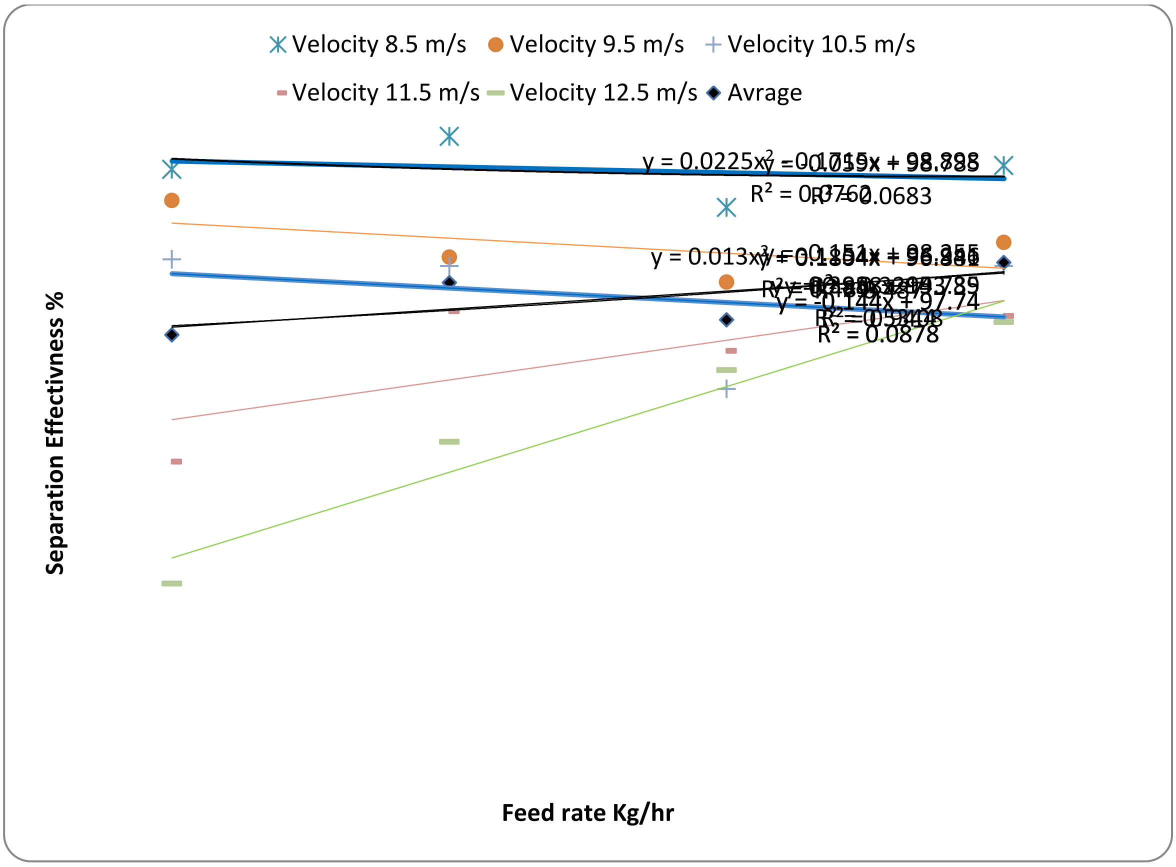

Fig 5.6 Effect of Feed Rate on Separation Effectiveness at Five Different Air Velocities

The regression coefficients and coefficients of determination R^2 for different dependent parameter have been computed by least square method for the curves showing the variation in separation efficiency, separation loss and separation effectiveness with feed rate are given in Table 5.12.

Table 5.12 Regression Coefficient and Coefficient of Determination of Feed Rate on Separation Efficiency, Separation Loss and Separation Effectiveness For Aerodynamic Separator.

Sr No	Dependent parameters	a	b	R^2	Optimum feed rate (kg/h)
1	Separation efficiency	- 0.1373	7.142092	0.9860	26.00
2	Separation loss	- 0.00163	0.080614	0.81	24.72
3	Separation effectiveness	- 0.13483	7.460604	0.9972	27.66

It was observed that the value of R^2 considering separation efficiency, separation loss and separation effectiveness were 0.98, 0.81 and 0.99 respectively. The optimum feed rate for each dependent parameter (separation efficiency, separation loss, and separation effectiveness) has been calculated by setting the first derivative of each regression equation of feed rate on dependent parameters to zero and solving for most efficient feed rate. The result indicated that the optimum feed rate for maximum separation efficiency was 26 kg/h and the optimum feed rate for maximum separation effectiveness was 27.66 kg/h. Hence, optimum feed rate considering the both parameters viz separation efficiency and separation effectiveness was 26.12 kg/h.

The regression coefficients and coefficients of determination R^2 for different dependent parameter have been computed by least square method for the curves showing the variation in separation efficiency and separation effectiveness with air velocity are given in the Table 5.13 showing the variation in separation efficiency and separation effectiveness.

Table 5.13 Regression Coefficient and Coefficient of Determination of Air Velocity on Separation Efficiency and Separation Effectiveness for Aerodynamic Separator.

Sr No	Dependent parameters	a	b	R^2	Air velocity (m/s)
1	Separation efficiency	- 0.90914	19.1090	0.9998	10.50
2	Separation effectiveness	- 0.95004	19.4243	0.9996	10.22

It was observed that the value of R^2 considering separation efficiency and separation effectiveness were 0.9998 and 0.9996 respectively. The optimum air velocity for each dependent parameter (separation efficiency and separation effectiveness) has been calculated by setting the first derivative of each regression equation of air velocity on dependent parameters to zero and solving for most efficient air velocity. The result indicated that the optimum air velocity for maximum separation efficiency was 10.50 m/s and the optimum air velocity for maximum separation effectiveness was 10.22 m/s. Hence, optimum air velocity considering the both parameters viz separation efficiency and separation effectiveness was 10.36 m/s.

5.5 Cost Estimation of Developed Mechanism

The cost required for manufacturing of mechanisms which includes material cost and fabrication cost. The costs were calculated and details are given in Appendix G. The material cost for vibratory mechanism was Rs 9,043/- and fabrication cost was Rs 2,000/- Hence total cost of vibratory separator was Rs 11043/-. The operating cost including fixed and variable cost was Rs 27.22/h which were 1.941 and 25.28 Rs/ h respectively for vibratory separator. Similarly, for aerodynamic separating mechanism the total cost of mechanism was Rs 9872/- including Rs 7872/- as material cost and Rs 2,000/- fabrication cost. The total operating cost including fixed and variable cost was Rs 28.99/h for aerodynamic separator.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Arecanut (*Areca catechu*) is one of the important crops in India. Arecanut plays an important role in Asian culture, especially in India. Arecanut is grown in soils such as laterite, red loam and alluvial soils under warm humid climate. The total world area under arecanut cultivation in 2012 was about 7.0 lakh ha with production of 12,61,388 metric tons with productivity of 1215 kg/ha. India ranks first in terms of both area and production of arecanut. Total arecanut production of India in 2012 was 482000 metric tons. The area under cultivation of arecanut in Maharashtra was 2300 ha with production 3600 tons and productivity of 1565 kg/ha. Arecanut production in Konkan region has now almost reached a level of self sufficiency, but the arecanut growers are still facing the problem of dehusking of dried fruit, separation of husk and kernels, grading of arecanut in different size. The university (Dr.BSKKV, Dapoli) has developed hand operated, pedal operated and power operated arecanut dehusker. In addition to this some manufacturer has also developed power operated arecanut dehusker. In those mechanical dehuskers after dehusking the husk and kernels were separated manually which was very time and labour consuming process. It affected dehusking capacity and hence the profit of the arecanut growers. There was a need to develop a mechanism for separation of arecanut husk and kernels. Hence the study on design and development of mechanism for separation of arecanut husk and kernels was undertaken.

The physical and aerodynamic properties of arecanut fruit and kernels namely; major diameter, medium diameter, minor diameter, geometric mean diameters, sphericity, surface area, bulk density, true density, angle of repose, terminal velocity were determined for the design of separators components. The average value of major, medium, minor, geometric mean diameter, surface area, sphericity, bulk density, true density and angle of repose for fruits were found 48.18 mm, 38.39 mm, 32.24 mm, 37.51 mm, 4446.74 mm^2, and 78.25 per cent, 270.4 kg/m^3, 0.5 g/cc and 35.71 degree, respectively and for kernels it were found 22.31 mm, 19.61 mm, 19.21 mm, 19.81 mm, 1238.18 mm^2 and 87.31 per cent, 735.31 kg/m^3, 1.1 g/cc and 32.2 degree, respectively. Based on physical and aerodynamic properties the vibratory and aerodynamic type of separating mechanism has been design, developed and evaluated.

The vibratory separating mechanism mainly consisted of main frame, feeding hopper, screens, vibrating mechanism and power source. The main frame was fabricated with mild steel using square pipe of size 20 mm × 20 mm to supports to all the components. The overall dimension of frame was 900 mm x 700 mm x 1000 mm. The hopper was made of trapezoidal for proper flow of mixture of husk and kernels. Two screens were used for separating husk and kernels. Upper screen separated husk at initial stage and kernels dropped on lower screen. Screen was made up of bakelite sheet having thickness of 5 mm. The diameter of hole was selected by studying the physical properties of arecanut fruits and kernels. The vibration for cleaning unit was given by using eccentric drive mechanism. The stroke of reciprocation was 10 mm. The total power required to drive the developed vibratory separator was computed as 0.3 hp.

The aerodynamic separating mechanism mainly consisted of main frame, feeding hopper, blower and power source. The main frame was fabricated with MS angle of size 20 mm × 20 mm x 3 mm. The overall dimension of frame was 530 mm x 200 mm x 525 mm. The hopper was made of trapezoidal for proper flow of mixture of husk and kernels. The centrifugal blower was designed outlet air velocity 16 m/s. The total power required to drive the developed aerodynamic separator was computed as 0.5 hp.

The performance of developed vibratory separator was carried out at three different speeds (305, 356 and 413 rpm) and four different feed rates (18, 24, 30 and 36 kg/h). The separation efficiency was decreased as feed rate increased from 18 kg/h to 36 kg/h for all cam speeds. The maximum separation efficiency, 94 per cent was obtained at cam speed 413 rpm with feed rate 18 kg/h. The separation loss was decreased as feed rate increased from 18 kg/h to 36 kg/h for all cam speeds. The minimum separation loss was found as 4.4 at cam speed 305 with feed rate 18 kg/h. The average separation loss was decreased from 6.1 to 4.7 per cent as cam speed increased from 18 kg/h to 36 kg/h for different feed rates. With increase in feed rate form 18 kg/h to 36 kg/h for all cam speeds, the separation effectiveness was increased. The maximum separation effectiveness as 87.29 per cent was obtained at cam speed 305 rpm with feed rate 36 kg/h. The optimum value of feed rate for maximum separation efficiency, minimum separation loss and maximum separation effectiveness was 26.09 kg/h. Similarly, the optimum cam speed form maximum separation efficiency and maximum separation effectiveness was 360 rpm.

The developed aerodynamic separator was evaluated at five different air velocities (8.5, 9.5, 10.5, 11.5 and 12.5 m/s) and four different feed rates (18, 24, 30 and 36 kg/h). The maximum separation efficiency was 99.1 per cent at blower outlet velocity 12.5 m/s with feed rate 18 kg/h. The average separation efficiency was found to decrease from 90.58 to 82.94 per cent as air velocity increased from 8.5 m/s to 12.5 m/s for different feed rates. The minimum separation loss was 0.3 per cent at blower outlet velocity 8.5 m/s with feed rate 18 kg/h. The average separation loss was found to decrease from 1.06 to 0.78 per cent as air velocity increased from 8.5 m/s to 12.5 m/s for different feed rates. The maximum separation effectiveness 98.97 per cent was obtained at air velocity 8.5 m/s and feed rate 24 kg/h. The optimum feed rate for maximum separation efficiency and maximum separation effectiveness were 26 kg/h and 27.66 kg/h, respectively. Hence, optimum feed rate was considered as 26.83 kg/h, considering both as separation efficiency and separation effectiveness. Similarly, optimum air velocity was 10.22 m/s considering both separation efficiency and separation effectiveness.

The total cost of a vibratory separator was Rs 11,043/- and the operating cost was Rs 27.22/h whereas the total cost of an aerodynamic separator was Rs 9,872/- and the operating cost was Rs 28.99 /h.

Conclusions

1. In case of vibratory separator, the separation efficiency and separation loss were decreased as feed rate increased from 18 kg/h to 36 kg/h for all cam speeds viz. 305, 356 and 413 rpm. Whereas, separation effectiveness was decreased as feed rate increased for different cam speeds.
2. The optimum value of feed rate and cam speed in case of vibratory separator for combined effect of maximum separation efficiency, minimum separation loss and maximum separation effectiveness were 26.09 kg/h and 360 rpm, respectively.
3. In case of aerodynamic separator, optimum feed rate and air velocity were 26.83 kg/h, and 10.22 m/s, respectively; considering both parameters as separation efficiency and separation effectiveness.
4. The total cost of a vibratory separator was Rs 11,043/- and that an aerodynamic separator was Rs 9,872/-.

Thus the developed separating mechanisms were found effective for separation of husk from kernels. The performance evaluation of developed vibratory and aerodynamic separator was satisfactory.