JEAS

JOURNAL OF ENGINEERING
AND
APPLIED SCIENCES

Journal of Engineering and Applied Sciences 8(1) (2012), 29-38

Effects of impeller angular speed variation on particle size reduction of toasted soya bean seeds.

[1] E. C., Oriaku, [2] E.I.E. Ofodile

[1] Engineering Research, Development and Production ***(ERDP)*** *Department.*
Projects Development Institute, ***(PRODA)*** *Emene, Enugu.*
[2] Department of Mechanical Engineering; Nnamdi Azikiwe University (NAU);
Awka, Anambra State.
[1]Corresponding Author: oriaku4edy@yahoo.com

Abstract

In size reduction, mechanical forces are applied to split a solid structure into collective of pieces without changing product, the shelf life or process the materials more economically into various end products like meal, flour, feed and other split products. 2kg of toasted soya bean seeds of moisture content 9.03% (db) were milled using a designed and fabricated micro-mill at different angular speeds. The speeds ranged from 1000 to 3000 rpm and each test run lasted 3mins. The milled samples were collected and analyzed. The results showed average particle diameter obtained ranged from 0.58mm to 0.97 mm while fineness modulus ranged from 4.67 to 6.31. The angular speed of 2250rpm gave the best average particle diameter 0.58mm and lowest finest modulus of 4.67 for the intended flour production

Keywords: Size reduction, micro mill, soya bean, particle size, angular speed.

1. Introduction

Size reduction can be defined as using mechanical forces to split a solid's structure into a collection of pieces without changing the solid's aggregated state. Most dry bulk solids processes require a size reduction step to improve the final product quality or process the solid material more economically (Pallmann, 2011). Size reduction can present numerous challenges and some are industry-specific, while others depend on the material's properties (Scott *et al*., 2002). Simply reducing a material's original size isn't enough in most applications as it can be noticed that after initial size reduction, the reduced material often isn't the right size for the intended use. For instance, the particle size distribution may be too wide; either with too many fines (which can cause dusting problems during later processing) or too many coarse particles to meet the final specification. Ideally, processors want to produce a mono-disperse material, that is, a material with a narrow range of particle sizes and shapes to make the reduced material more suitable for further processing (Pallmann, 2011). The process of breaking down large particles to medium size particles and in turn milling them to micron size is achieved using mechanical equipment/machines. These machines are designed based on different principles e.g. compression, impact, attrition etc.

In compression, the materials to be reduced in size are compressed between two metallic surfaces, e.g. rollers, shafts, etc., thereby causing them to break into pieces. The operation is carried out on continuous basis to achieve high productivity. In impact, the materials to be reduced in size are given a high radial force and are compelled to hit a metallic anvil (as in cracker machines) thereby achieving the breaking of the raw material to several smaller particles. The raw material could either be compelled to hit a stationary metallic surface (anvil) or on the other hand directed to hit dynamic (rotational) metallic surface, e.g., rotational hammers. The broken particles are usually run into a receiver where they are collected for the desired purpose. In attrition principle, the materials to be broken down to smaller particles are given a rotational motion, causing them to rub against one another or against harder materials on continuous basis causing wear of the materials and eventual breakdown to the desired sizes (Coulson and Richardson, 2006).

Many methods have been used to reduce the size of materials to meet the desired end products. For the purpose of this work a micro mill was designed and fabricated for use in reducing toasted soya bean to flour which would be used in the optimization of cyclone non physical parameters. This work was aimed at determining by varying impeller speed the optimal speed that would produce the finest flour without damage to the machine.

2. Materials and Methods

The designed micro-mill is based on the impact principle. It uses a large number of hexagonal hammers mounted radially on a disc connected to shaft. Circular motions of the dynamic components, combined with the gravitational motion of the items to be crushed (milled) and air suction of the crushed items are employed to achieve the desired result. Air flow is employed to remove the milled powder through the sieve to the cyclone. Particle size reduction is therefore achieved by continuous impact of the rotating hexagonal rods on samples. Toasted, de-husked soya bean seeds are introduced into the machine through the hopper. The seeds flow through the throat of the hopper down to the central axis of the milling chamber, where they are crushed to dust by the rotating hammer carried by the impeller of the machine. The dusts (flour) are sucked by the blower via the micron sieve mounted at the lower end of the milling chamber. The sucked dusts are blown by the air generated by the blower blades through the air exit channel to the cyclone section where they are collected. However, to be able to determine the optimal speed of the micro-mill, the micron sieve at the lower end of the milling chamber was covered with a stainless steel plate. This enabled the milled materials to remain in the chamber for collection after the timed test run.

Fig 1: Picture of the fabricated Micro-mill

Fig 2: Photograph of the mounted Set of sieves

Fig 3: Photograph of toasted dehusked soya bean sample

Fig 4: Photograph of soya bean husks

2.1. Moisture Content Determination

The moisture content of the samples was determined using the hot air oven method (AOAC, 2002). About 45- 47g for whole grains and 30g for ground samples were placed in containers of known weight and dried in an oven at 105°C to constant weight. The moisture content in percentage (%) dry basis was found by applying the following equation similar to that reported by Bup et al (2008).

$$M_c(\%db) = \left(\frac{M_i - M_f}{M_f}\right) x100\% \quad \ldots\ldots\ldots\ldots\ldots 1$$

Where M_c is the Moisture content in dry basis,

M_i is the initial mass of sample and container (g),

M_f is the final mass of sample and container (g) at constant weight.

2.2. Sieving Method

Standard sieves ISO- 3310 stainless steel on an electromagnetic sieve shaker (Model, BA 200N CISA, Cedacera Industrial) was used for analysis. The analysis was carried out similar to AASHTO T27 and T11 standards. Locally sourced “Mangu” species of soya bean from Jos, Plateau State Nigeria was used for the experiment. It was manually cleaned, toasted, de-husked and a measured quantity of 2kg was fed into the micro-mill. The ground materials were collected from the micro-mill and stored in polythene bags and tagged. They were then taken to the laboratory, weighed and the weight recorded. 400g from each sample was transferred into the first tray of a set of standard sieves which was then mounted on the shaker with its timer set at 5mins for each sample. Each of the sieves was weighed before loading and their individual weights recorded. After sieving their weights were taken again and their values recorded.

3. RESULTS

Moisture content results for whole grain soya bean;

Sample A:

Weight of Petridish = 24. 305g

Weight of sample = 45.551g

Sample B:

Weight of Petridish = 87.783g

Weight of sample = 47.165g

Sample C:

Weight of Petridish = 65.09g

Weight of sample = 47.424g

Sample A**:

Weight of Petridish = 65.361g

Weight of sample = 30.0g

Sample B**:

Weight of Petridish = 69.039g

Weight of sample = 30.0g

Sample C**:

Weight of Petridish = 72.079g

Weight of sample = 30.0g

** Denotes Ground Samples

Table 1: Data for Moisture content of Whole grain and ground toasted soya bean samples

Samples	Whole Grain Soya Bean			Ground Toasted Soya Bean		
	M_i (g)	M_f (g)	Moisture Content (%db)	M_i (g)	M_f (g)	Moisture Content (%db)
A	45.55	40.44	12.62	30	27.50	9.06
B	47.16	41.94	12.45	30	27.57	8.79
C	47.42	42.47	11.66	30	27.46	9.23
Average	46.71	41.62	12.24	30	27.51	9.03

3.1. Sieve Analysis Results

IMR = Individual Mass Retained: is the weight of the sample retained on the individual sieves.

IPR = Individual Percentage Retained: is obtained by dividing the mass retained on each sieve by the total mass of sample sieved and multiplying by 100%

CMR = Cumulative Mass Retained: is the sequential sum of the individual masses retained on the sieves.

CPR = Cumulative Percentage Retained: is the sequential sum of the individual percentages retained on the sieves.

CPP = Calculated Percentage Passing: is obtained by subtracting the CPR from 100%.

Table 2: Sieve Analysis Data for Impeller Speed of 3000 rpm

Sieve sizes (mm)	**IMR (g)**	**CMR (g)**	**IPR (%)**	**CPR (%)**	**CPP (%)**
3.35	68.3	68.3	17.08	17.08	82.92
2.36	35.5	103.8	8.88	25.96	74.04
1.40	42.3	146.1	10.58	36.54	63.46
0.85	105.6	251.7	26.4	62.94	37.06
0.71	23	274.7	5.75	68.69	31.31
0.50	92.9	367.6	23.23	91.92	8.08
0.35	18.9	386.5	4.73	96.65	3.35
0.25	8.9	395.4	2.23	98.88	1.12
Pan	4.4	399.8	1.1	99.98	0.02

Source: Oriaku et al, 2011

Table 3: Sieve Analysis Data for Impeller Speed of 2250 rpm

Sieve sizes (mm)	**IMR (g)**	**CMR (g)**	**IPR (%)**	**CPR (%)**	**CPP (%)**
3.35	42.4	42.4	10.60	10.60	89.40
2.36	32.2	74.6	8.05	18.65	81.35
1.40	50.6	125.2	12.65	31.30	68.70
0.85	110.2	235.4	29.55	58.85	41.15
0.71	51.1	286.5	12.78	71.63	28.37
0.50	63.5	350.0	15.86	87.19	12.51
0.35	16.9	366.9	4.23	91.72	8.28
0.25	20.1	387.0	5.03	96.75	8.25
Pan	10.4	397.4	2.60	99.35	0.65

Source: Oriaku et al, 2011

Table 4: Sieve Analysis Data for Impeller Speed of 1875 rpm

Sieve sizes (mm)	**IMR (g)**	**CMR (g)**	**IPR (%)**	**CPR (%)**	**CPP (%)**
3.35	59.2	59.2	14.80	14.80	85.20
2.36	37.9	97.1	9.48	24.28	5.72
1.40	35.1	132.2	8.78	33.06	66.94
0.85	134.5	266.7	33.69	66.69	33.31
0.71	28.0	294.7	7.00	73.69	26.31
0.50	63.1	357.8	15.78	89.47	10.53

0.35	15.7	373.5	3.93	93.90	6.60
0.25	23.4	396.9	5.85	99.25	0.75
Pan	1.6	398.5	0.40	99.65	0.35

Source: Oriaku et al, 2011

Table 5: Sieve Analysis Data for Impeller Speed of 1500 rpm

Sieve sizes (mm)	IMR (g)	CMR (g)	IPR (%)	CPR (%)	CPP (%)
3.35	46.2	46.2	11.55	11.55	88.45
2.36	53.5	99.7	13.38	24.93	75.07
1.40	103.1	202.8	25.78	50.71	49.29
0.85	104.8	307.6	26.20	76.91	23.09
0.71	16.1	323.7	4.03	80.94	19.06
0.50	45.6	369.3	11.40	92.34	7.66
0.35	7.3	376.6	1.83	94.17	5.83
0.25	20.0	396.6	5.00	99.17	0.83
Pan	2.5	399.1	0.63	99.80	0.2

Source: Oriaku et al, 2011

Table 6: Sieve Analysis Data for Impeller Speed of 1050 rpm

Sieve sizes (mm)	IMR (g)	CMR (g)	IPR (%)	CPR (%)	CPP (%)
3.35	81.2	81.2	20.30	20.30	79.70
2.36	135.4	216.6	33.85	54.15	45.85
1.40	113.6	330.2	28.40	82.54	17.45
0.85	25.9	356.1	6.48	89.03	10.97
0.71	9.2	365.3	2.30	91.33	8.67
0.50	19.8	385.1	4.95	96.28	3.72
0.35	8.6	393.7	2.15	98.43	1.57
0.25	1.9	395.6	0.48	98.91	1.09
Pan	3.3	398.9	0.83	99.74	0.26

Source: Oriaku et al, 2011

The tables of values for sieve analysis carried out on the crushed samples, collected from the micro-mill on speed range of 1050 to 3000 rpm are shown in tables 2 - 6. Their graphical representations (using MICROSOFT EXCEL 2007) are shown in figs 5 to 9. The graphs of cumulative percentage retained (CPR) against calculated percentage passing (CPP) are shown in figure 10 to 14. The fineness modulus and average particle diameter were plotted against speed and are shown in figures 15 and 16.

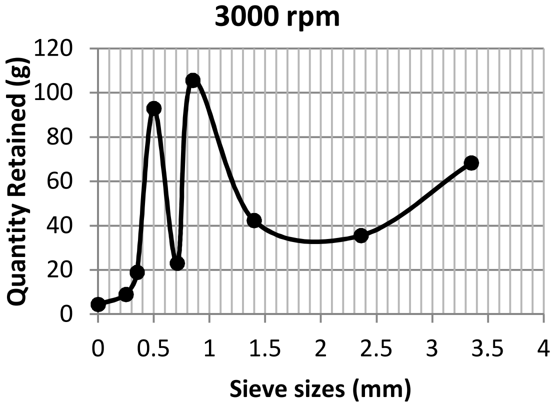

Fig 5: Graph showing particle size distribution of toasted soya bean at speed of 3000rpm

(Source: Oriaku et al, 2011)

From literature average particle size of powdered biomaterials is between 0.01mm and 1mm (Coulson and Richardson 2006). For this work samples collected on the 3.35, 2.36 and 1.4 mm sieves are classified as coarse aggregates, while those collected on the 0.85, 0.71, 0.5, 0.35, 0.25 and pan, are classified as fine aggregates. From fig 5, 36.5 % of the samples were coarse while 63.5% were fine aggregates. Similarly, fig 6 showed that 31.3% and 68.7% of coarse aggregates and fine aggregates were obtained respectively. Both graphs also showed the 0.85mm sieve retaining the largest amount of ground samples (26.54 and 29.55% for 3000rpm and 2250 rpm respectively).

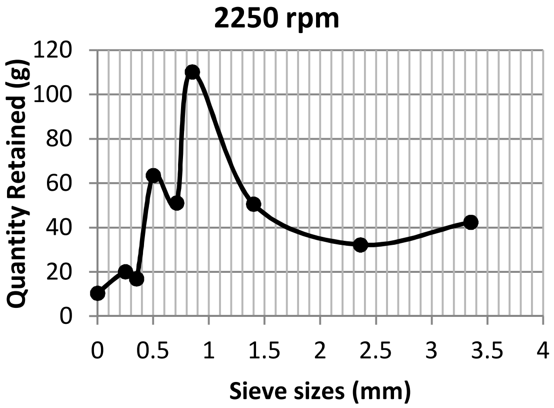

Fig 6: Graph showing particle size distribution of toasted soya bean at speed of 2250rpm

(Source: Oriaku et al, 2011)

Fig 7 shows a slight increase in coarse aggregates (33.05%) when compared to the value obtained in fig 6 (31.3%). Though 66.60% of fine aggregates were obtained, it was observed that 33.69% of this value was retained on the 0.85mm sieve. This could be an indication of uniform grinding within the specified time of milling. It was also observed that losses of 0.02, 0.65, 0.35, 0.2 and 0.26% were obtained after sieving for speeds of 3000, 2250, 1875, 1500 and 1050 rpm respectively.

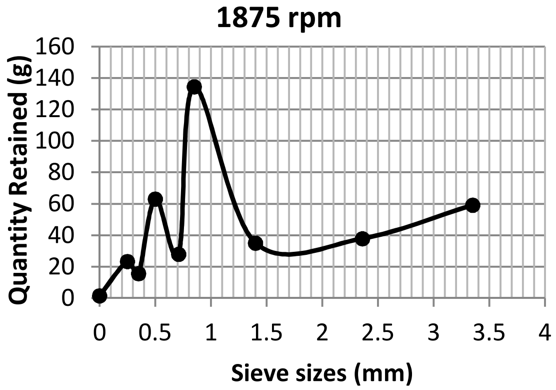

Fig 7: Graph showing particle size distribution of toasted soya bean at speed of 1875rpm

(Source: Oriaku et al, 2011)

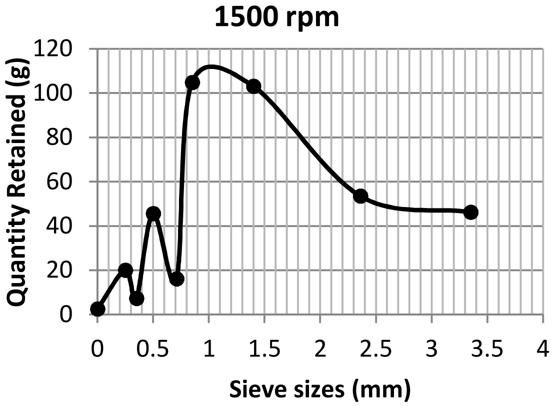

Fig 8: Graph showing particle size distribution of toasted soya bean at speed of 1500rpm

(Source: Oriaku et al, 2011)

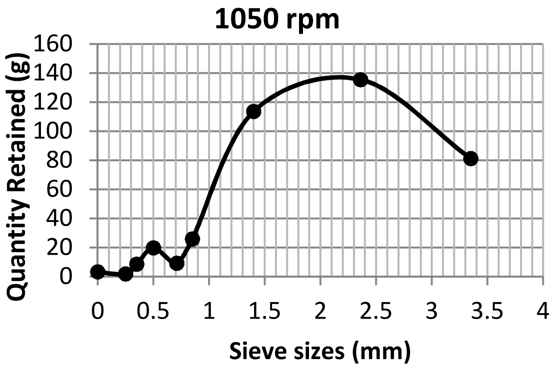

Fig 9: Graph showing particle size distribution of toasted soya bean at speed of 1050rpm

(Source: Oriaku et al, 2011)

For speed of 1500rpm, 50.7% of aggregates were observed to be coarse and 49.1% were fine aggregates. This shows that there was a decrease in size reduction as impeller angular speed reduced within the specified time of grinding. This was clearly shown in the values obtained for 1050rpm speed. Coarse aggregates were found to be 82.55% of the total samples used while fine aggregates were 17.19%. The results obtained for these two speeds (1500 and 1050 rpm) imply that for the purpose of this work, both are inadequate.

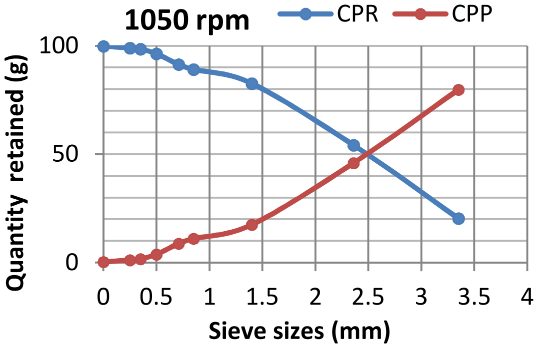

Fig 10: Graph showing CPR and CPP at impeller speed of 1050 rpm.

(Source: Oriaku et al, 2011)

The above graph shows plots of CPR and CPP intersecting at sieve size of 2.5mm with the point of intersection corresponding to 50% of ground sample. This shows considerable large amount of coarse aggregates which is in line with findings in fig 9. A similar situation is observed in fig 11, though the point of intercession of both plots was at sieve size 1.4mm.

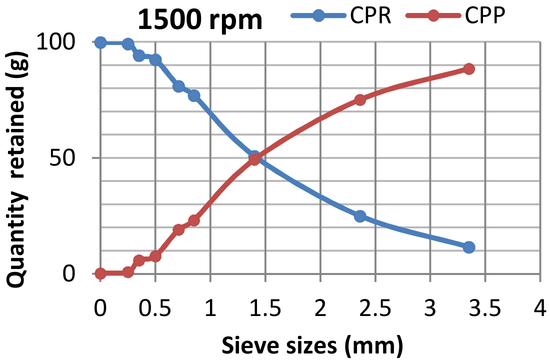

Fig 11: Graph showing CPR and CPP at impeller speed of 1050 rpm.

(Source: Oriaku et al, 2011)

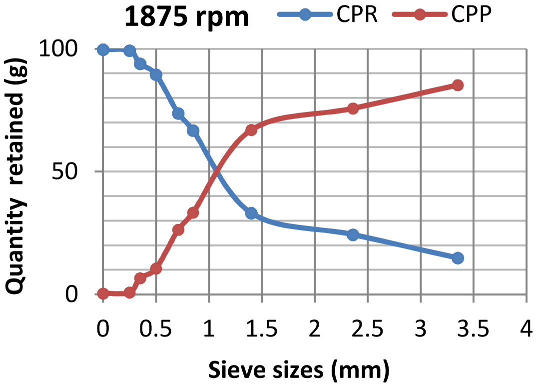

Fig 12: Graph showing CPR and CPP at impeller speed of 1875 rpm.

(Source: Oriaku et al, 2011)

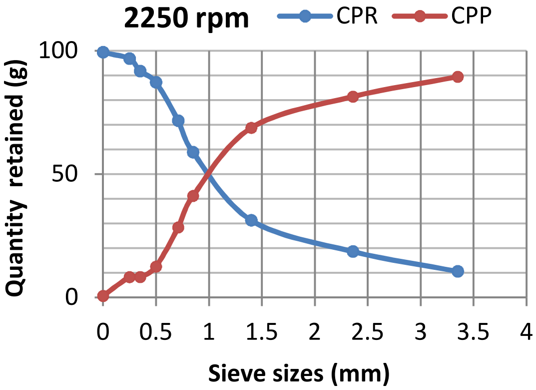

Fig 13: Graph showing CPR and CPP at impeller speed of 2250 rpm.

(Source: Oriaku et al, 2011)

Sieve analysis of samples for angular speed of 1875rpm and 3000rpm (figs 12 and 14) gave point of intercession for both plots at a point slightly above 1mm. This corresponds to findings in figs 5, 6 and 7 which may be an indication of uniform grinding. However, analysis of samples for angular speed of 2250rpm gave the lowest value of intercept (1mm); showing finer aggregates were obtained within the specified grinding time. This gives the desired particle size for the purpose of this experiment.

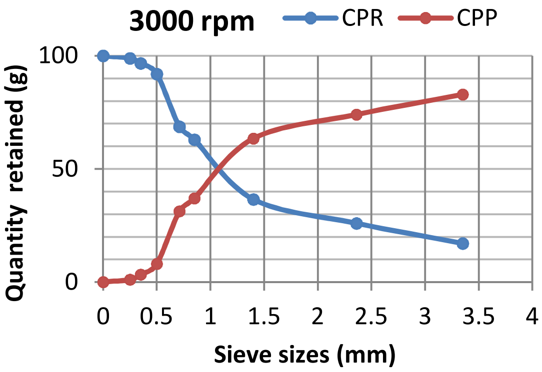

Fig 14: Graph showing CPR and CPP at impeller speed of 3000 rpm.

(Source: Oriaku et al, 2011)

Table 7: Results showing Fineness Modulus and Average Particle Diameter

Speed	fineness modulus	Average particle diameter (mm)
3000	4.99	0.64
2250	4.67	0.58
1875	4.94	0.63
1500	5.31	0.71
1050	6.31	0.97

(Source: Oriaku et al, 2011)

Fineness modulus indicates the uniformity of grind in resultant product. It is determined by adding the weight fractions retained above each sieve and dividing the sum by 100. For this work, the plot of fineness modulus against speeds showed that a quadratic relationship exists between them and the mathematical model expressing this is given in equation 3. The minima which had a value of 4.65 and corresponds to speed of 2400rpm showed the best uniformity of grind of the micro-mill was obtained at this speed. The average particle diameter is defined by the following equation

$D = 0.135\,(1.366)^{FM}$ 2

(Sahay and Singy, 1994)

Where; D = Average Particle Diameter
FM = fineness modulus.

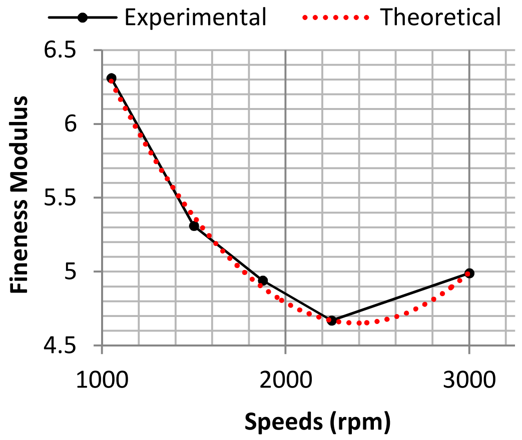

Fig15: Graph showing fineness modulus at the various impeller speeds.
(Source: Oriaku et al, 2011)

$Y = 9.86 - 0.0044\,x + 9.13 \times 10^{-7} x^2$ ……. 3

Where Y = fineness modulus and x = selected speed

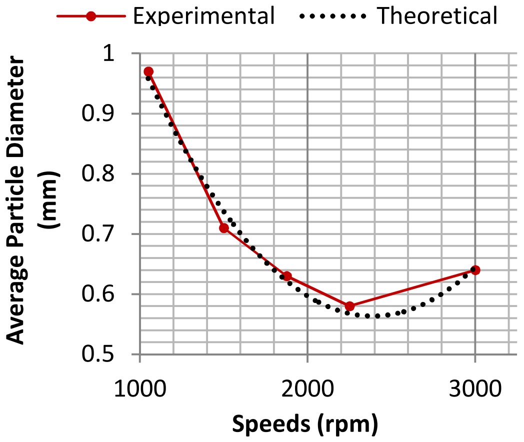

Fig16: Graph showing Average Particle Diameter at the various impeller speeds.
(Source: Oriaku et al, 2011)

$Y = 1.82 - 0.001x + 2.20 \times 10^{-7} x^2$ …… *4*

Y is average particle diameter (mm); x is speed (rpm)

Similarly the relationship between average particle diameter and selected speeds was quadratic with its best fit mathematical model shown in equation 4. The smallest particle diameter (0.56mm) was also obtained at speed of 2400 rpm.

3.2. Crushing efficiency

The ratio of the surface energy created by crushing to the energy absorbed by the solid is referred to as Crushing efficiency Σ_c.

3.3. Energy requirements

The energy absorbed by a unit mass of the material is given by the equation

$$E_a = \frac{e\,(A_p - A_f)}{\Sigma_c} \qquad \ldots\ldots\ldots\ldots\ldots\; 5$$

Where

e = surface energy per unit area

A_p = area per unit mass of product

A_f = area per unit feed.

(Sahay and Singy, 1994)

The input energy (E) requirement for size reducing machine is greater than energy absorbed by the solid (E_a). Some part of input energy is used to overcome friction in moving parts and bearings of machines; the rest is used for crushing. The ratio of the energy absorbed to the input energy is known as the mechanical efficiency Σ_m.

$$\text{Then } E = \frac{E_a}{\Sigma_m} = \frac{e\,(A_p - A_f)}{\Sigma_c\,\Sigma_m} \qquad \ldots\ldots\ldots\ldots\; 6$$

The power required by the machine can also be calculated by the equation.

$$P = E \times f = \frac{fe\,(A_p - A_f)}{\Sigma_c\,\Sigma_m} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\; 7$$

Where f = feed rate in tons per hour.

When a feed is reduced to symmetrical particles of smaller sizes, the energy requirements must be related to some function of the size of the feed and ground product. Based on this, both the particles are symmetrical, and a common dimension is used to calculate energy requirement. Therefore, the necessary energy required for size reduction is

$$E = C \int \frac{d_x}{x^n} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\; 8$$

Where: (**d_x**) refers to the size of the crushed product and (x) refers to the size of the feed.

3.4. Rittingers Crushing Law

A crushing law proposed by Rittinger states that the work required in crushing is proportional to the new surface created. Rittinger assumed that size reduction is essentially a shearing procedure. Therefore, energy requirement is proportional to the square of the common linear dimension and thus the value of "n" becomes 2. The energy requirement is given by the equation below

$$E = c\left(\frac{1}{X_p} - \frac{1}{X_f}\right) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\; 9$$

Where X_p = length of product

X_f = length of feed

C = Rittingers constant

To calculate the efficiency of the micro mill, power requirement for crushing is determined using Rittingers law.

Average diameter of soya bean = 7mm

Average Particle size of milled soyabean = (0.64 + 0.58 + 0.632 +0.71 + 0.97)/5

= 3.532 / 5 = 0.706mm

Rittingers constant = 15.278 (adopted from similar material crushing)

Feed rate = 120kg/hr = 120/ 1000 = 0.12 tons/hr

$$\text{Therefore, } \frac{P}{0.12} = 15.278\left(\frac{1}{0.706} - \frac{1}{7}\right)$$

$$P = 0.12\,(15.278 \times (1.42 - 0.143)$$

$$P = 0.12 \times 15.278 \times 1.277 = 2.341\text{Kw}$$

The total power developed by the machine obtained from load analysis of the machine is 14Kw.

Crushing efficiency is then calculated as

$$\eta_c = \frac{\textit{Total power developed} - \textit{power utilised in crushing}}{\textit{Total power developed}} \times 100\%$$

$$\eta_c = \frac{14 - 2.341}{14} \times 100\% = 83.28\%$$

4. Conclusion

From the above results it can be concluded that though size reduction was achieved for all the speeds selected, particle analysis showed variation in aggregates collected. Impeller angular speeds of 1875, 2250 and 3000 rpm gave high values of fine aggregates while 1500 and 1050rpm speeds gave high values of coarse aggregates. The fineness modulus values of 4.99, 4.64 and 4.94 for the higher speeds show uniformity of grind and their average particle diameters of 0.65, 0.58 and 0.63 respectively were within range for powdered biomaterials. The angular speed of 2250rpm had the best values of fineness modulus and average particle diameter (4.64 and 0.58) making it the optimum for the designed machine and experiment at 83.28% crushing efficiency.

References

AASHTO T27/T11. Sieve Analysis Of Fine And Coarse Aggregates: WAQTC (accessed October, 2011)

AOAC, 2002. *Official Methods of Analysis,* 17th Ed. Association of Official Analytical Chemists, Gaithersburg, Maryland, USA.

Bup N.D, C´esar K, Dzudie.T, Kuitche A, Abi C.F, and Tchi´egang C., 2008. *Variation of the Physical Properties of Sheanut (VitellariaParadoxa Gaertn.) Kernels during Convective Drying.* International Journal of Food Engineering. Volume 4, Issue 7, 2008 Article 7

Coulson J.M, J.F. Richardson, J.R. Backhurst, and J.H. Harker, 2006. *Chemical Engineering Unit Operations:* Volume Two fifth Edition (Particle Technology and Separation Processes) Elsevier. Linacre House, Jordan House Oxford.

Esref Isik, 2007. *Some engineering properties of Soybean grains.* American Journal of food technology 2 (3): 115-125, ISSN 1557-4571

Kibar, H. and T. Öztürk, 2008. *Physical and mechanical properties of soybean:* Int. Agrophysics, 2008, 22, 239-244

Oriaku E. C, C.N. Edeh, J., Nwannewuihe, H.U and Onwukwe M. C., 2011. *Official Work Document*, Projects Development Institute (PRODA). Enugu, Nigeria

Pallmann, H., 2011. *What you should know before selecting size reduction machines.* Pallman Industries inc. CSC Publishing, Powder and Bulk Engineering. Atlantic Way, NJ: United States.

Sahay, K.M and Singy, K.K, 1994. *Unit operations of agricultural processing:* First edition.

Scott W, T. Kendrick, J. Tomaka, and J. Cain, 2002. *Size reduction solutions for hard-to-reduce materials.* Powder and Bulk Engineering. The Fitzpatrick Co. 832 Industrial Drive Elmhurst, IL. www.fitzpatrick.be