

Experimental Analysis of Particle Size Distribution using Electromagnetic Sieve

Ujam, A.J., and Enebe, K. O

a. Department of Mechanical and production Engineering Enugu State University of Science and Technology, Enugu, Nigeria

b. Scientific Equipment Development Institute, Enugu, Enugu State, Nigeria.

Abstract: - This work is aimed at grading the particle sizes of powders and granular distribution of particle sizes of a local agricultural product, **GARRI**. To be able to do this, an electromagnetic sieving machine which transforms electromagnetic energy to mechanical energy was designed and constructed. The Choice of **Electromagnetic Sieving Machine** was to increase the amplitude of oscillation and thereby reducing the time of sieving. With the aid of the machine, sieving was carried out three times at different voltage settings. The tests conducted show that with increase in voltage, the amplitude of oscillation also increased, thereby reducing the sieving time. Optimal output (from 1kg of Garri) was obtained in 120 seconds at a voltage setting of 255 volts which generated 5mm amplitude. The different particle sizes were evaluated by the use of an electronic microscope. The efficiency of the machine was evaluated to be 98%.

Key words: - Particle size, Vibration, Sieve, Energy, magnetic flux

I. INTRODUCTION

The **particle-size distribution (PSD)** of a powder, or granular material, or particles dispersed in fluid, is a list of values or a mathematical function that defines the relative amount, typically by mass, of particles present according to size.[1] PSD is also known as **grain size distribution**. [2]

The PSD of a material can be important in understanding its physical and chemical properties. It affects the strength and load-bearing properties of rocks and soils. It affects the reactivity of solids participating in chemical reactions, and needs to be tightly controlled in many industrial products such as the manufacture of printer toner and cosmetics.

The way PSD is usually defined is by the method by which it is determined. The most easily understood method of determination is **sieve analysis**, where powder is separated on sieves of different sizes. Thus, the PSD is defined in terms of discrete size ranges: e.g. "% of sample between 45 μm and 53 μm ", when sieves of these sizes are used. The PSD is usually determined over a list of size ranges that covers nearly all the sizes present in the sample. Some methods of determination allow much narrower size ranges to be defined than can be obtained by use of sieves, and are applicable to particle sizes outside the range available in sieves. However, the idea of the notional "sieve", that "retains" particles above a certain size, and "passes" particles below that size, is universally used in presenting PSD data of all kinds.

One of the most important types of analytical work associated with producing resources and wares with desired properties, is particle size, shape, and distribution analysis. [3]

Sieving, microscopy, computerized image analysis, laser diffraction, sedimentation, and centrifugation, are some of the particle size analysis methods by which a samples particle characterization may be established.

The method one employs, has to do with the nature of the sample, ie...liquid or solid, the size range of the particles to be analyzed, the relevance of the results to the finished product properties, and cost. For some applications, like certain pharmaceuticals, particle shape characteristics may also have a bearing on the outcome of the finished good.

The use of sieves with different sized mesh is one of the oldest, most reliable, and most commonly used methods for providing an analysis of particle size distribution.

Although sieve shakers have limitations based on the assumption that all particles are spherical, they work well for a wide variety of applications, and because it is relatively inexpensive, is generally the first method employed by companies when a particle size distribution analysis program is initiated. [3]

A sieve analysis consists of using a single or set of screens (typically woven wire mesh), decreasing in opening size, to separate or classify a sample. Several mechanisms are used to disperse the sample and transport it through the screens (i.e. vibration, air entrainment or flowing liquid). While considered relatively low resolution, sieving's practical application lends itself well to quality control specifications. ASTM E-11 establishes acceptance criteria for the woven wire mesh opening tolerances of standard sieve sizes. For optimal quality control, PTL verifies its in-house sieves with an external vendor for compliance with the ASTM E-11. [4]

While sieving may appear rudimentary compared to more modern instrumental particle characterization techniques, it still requires several important considerations to obtain the best repeatable and precise results. Several factors must be considered when developing a robust sieving method or performing a routine quality analysis. Sample size, sieving duration, controlled agitation parameters and end point determination are all critical method variables which need to be addressed.

The vibrating sieve shaker applies the principle of electromagnetic induction. When the particles are characterized, the products are useful as a raw material or consumption purposes. Many dependent variables are considered in this work and the effectiveness of each of them contributes to the overall efficiency. Such dependent variables are the amplitude of vibration, voltage variation which is a function of magnetic flux density, the mass of product collected and the resident time for the sieving. The effectiveness of the designed sieve will help in particle separation in local industries, especially cassava (garri) processing industries.

The test sieve shakers electromagnetic design offers many equipment – feature benefit compared with manual motor driven units. The electromagnetic shaker combines sharp, vertical motion with rotary motion at 3,600 vibrations per minutes for optimum performance. This high speed straight to line vibratory actions minimizes particle detention, provide faster particle separation with improved accuracy and assure uniform particle size distribution. Electromagnetic drives also assure outstanding durability with virtually no maintenance or part replacement. There are no motor for overheat or burn out, no belt, gears, pulley or other moving components to wear and lubrication is not required. Operation is simple. The operator places the nested sieve on the top sieve and pushes the handle down to lock the sieve in position. The unit preset timer is actuated to test the material sample. The time control devices guarantees uniformly – timed sample analysis. A rheostat control can be set to a fixed voltage value to assure a consistence analysis of the design and operation noise level conform with standard. Test sieve shakers are compact, light weight. Each sieve shakers hold about six - eight – inch diameter standard screen full height testing sieves and a bottom pan, or twelve half height sieves and bottom pan Units operates at 230 volts, 50Hz single phase ac.

1.2 Mathematical models

Probability distributions

- The **log-normal distribution** is often used to approximate the particle size distribution of aerosols, aquatic particles and pulverized material.
- The **Weibull distribution** or Rosin Rammler distribution is a useful distribution for representing particle size distributions generated by grinding, milling and crushing operations.
- The **log-hyperbolic distribution** was proposed by Bagnold and Barndorff-Nielsen[5] to model the particle-size distribution of naturally occurring sediments. This model suffers from having non-unique solutions for a range of probability coefficients.
- The **skew log-Laplace model** was proposed by Fieller, Gilbertson and Olbricht [6] as a simpler alternative to the log-hyperbolic distribution.

Rosin-Rammler distribution

The Weibull distribution, now named for Waloddi Weibull was first identified by Fréchet (1927) and first applied by Rosin & Rammler (1933) to describe particle size distributions. It is still widely used in mineral processing to describe particle size distributions in comminution processes.

$$f(x; P_{80}, m) = \begin{cases} 1 - e^{\ln(0.2) \left(\frac{x}{P_{80}}\right)^m} & x \geq 0, \\ 0 & x < 0, \end{cases}$$

where

x : Particle size

P_{80} : 80th percentile of the particle size distribution

m : Parameter describing the spread of the distribution
 The inverse distribution is given by:

$$f(F; P_{80}, m) = \begin{cases} P_{80}^m \sqrt{\frac{\ln(1-F)}{\ln(0.2)}} & F > 0, \\ 0 & F \leq 0, \end{cases}$$

where

F : Mass fraction

Parameter estimation

The parameters of the Rosin-Rammler distribution can be determined by refactoring the distribution function to the form[7]

$$\ln(-\ln(1-F)) = m \ln(x) + \ln\left(\frac{-\ln(0.2)}{(P_{80})^m}\right)$$

Hence the slope of the line in a plot of $\ln(-\ln(1-F))$ versus $\ln(x)$

yields the parameter m and P_{80} is determined by substitution into

$$P_{80} = \left(\frac{-\ln(0.2)}{e^{\text{intercept}}}\right)^{\frac{1}{m}}$$

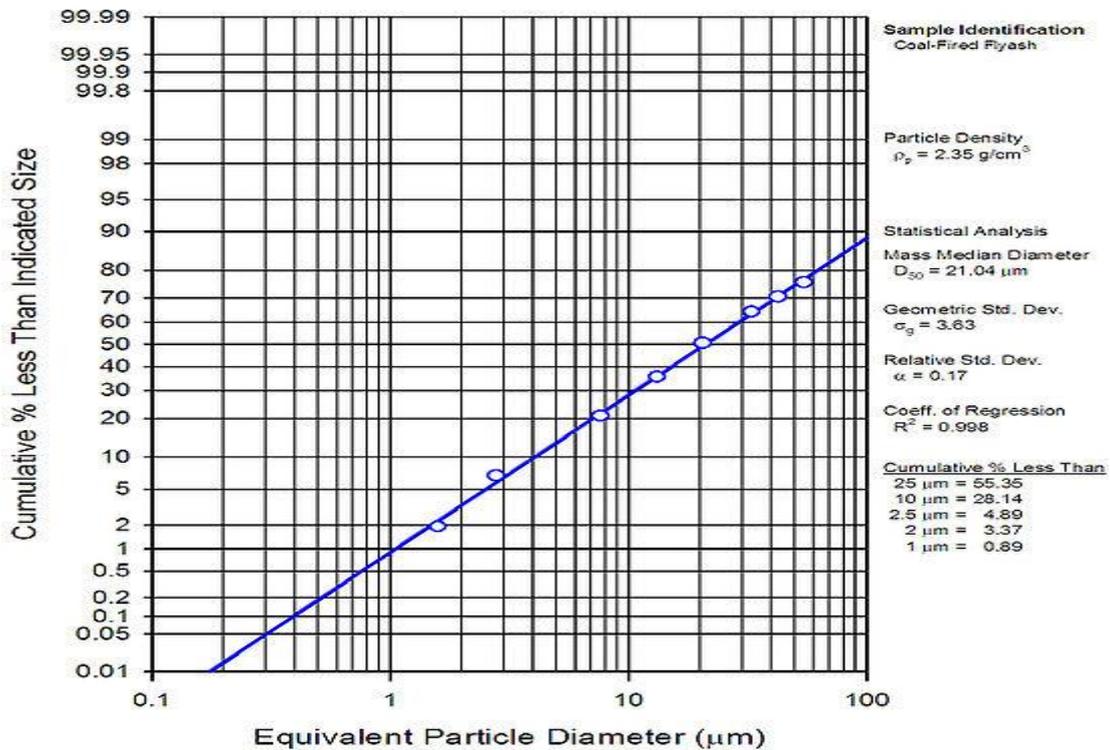


Fig.1 Log-Normal Distribution results graph-Cumulative percent less than indicated size as a function of particle size. [8]

II. MATERIALS AND METHODS

2.1 Sample Collection:

Cassava tubers are harvested wet, peeled and ground in the grinding machine. It is partially dried using the screw jack. The product “garri” is then fried in the frying pan and ready for consumption. But sometimes, it becomes difficult for consumption or other useful purposes due to sizes of the grain. The designed sieves however, solved a problem of difficulty posed by large sizes of the particles. The grading process using the electromagnetic sieve provides better particle sizes of the product that are exportable to other countries of the world.

2.2 – Equipment/Material used for Experiment

1. One Kilogram (1000g) of fried “garri” sample
2. A stop watch
3. A locally fabricated electromagnetic sieving machine.
4. Sieves
5. Voltage regulator (digital meter)
6. Springs

2.3: Experimental Procedures

1 kg (1000g) sample of “garri” was weighed using the weighing balance. The designed electromagnetic sieve was connected to the electric mains and voltage was adjusted with the regulator to read 235 volts. The sieve agitated as the voltage is varied and a stop watch is set to measure the time for a complete sieving. Different aggregate of “garri” particle sizes were collected on each sieve and weighed. The procedure was repeated with the voltage varied at 245, 255 and 265 volts. The corresponding time (seconds) for each experiment was noted. The particles sizes were also recorded and evaluated using the electronic microscope.

III. RESULTS

The result shows that the designed sieve is capable of grading the product “garri” at different aggregates. The mass of “garri” on each sieve was noted at different voltage variation in a particular time intervals. The results are tabulated below.

Table 1 Voltage Varied at 235 Volts: Time for sieving – 230 seconds

Mesh Nos	Weight of Mesh (Kg)	Weight of Mesh + Weight of Garri(Kg)	Weight of Garri(Kg)-Product	Particle Size (μ)
1	0.380	0.440	0.120	>18μm
2	0.480	0.770	0.290	18μm
3	0.480	0.720	0.240	24μm
4	0.680	1.020	0.340	30μm

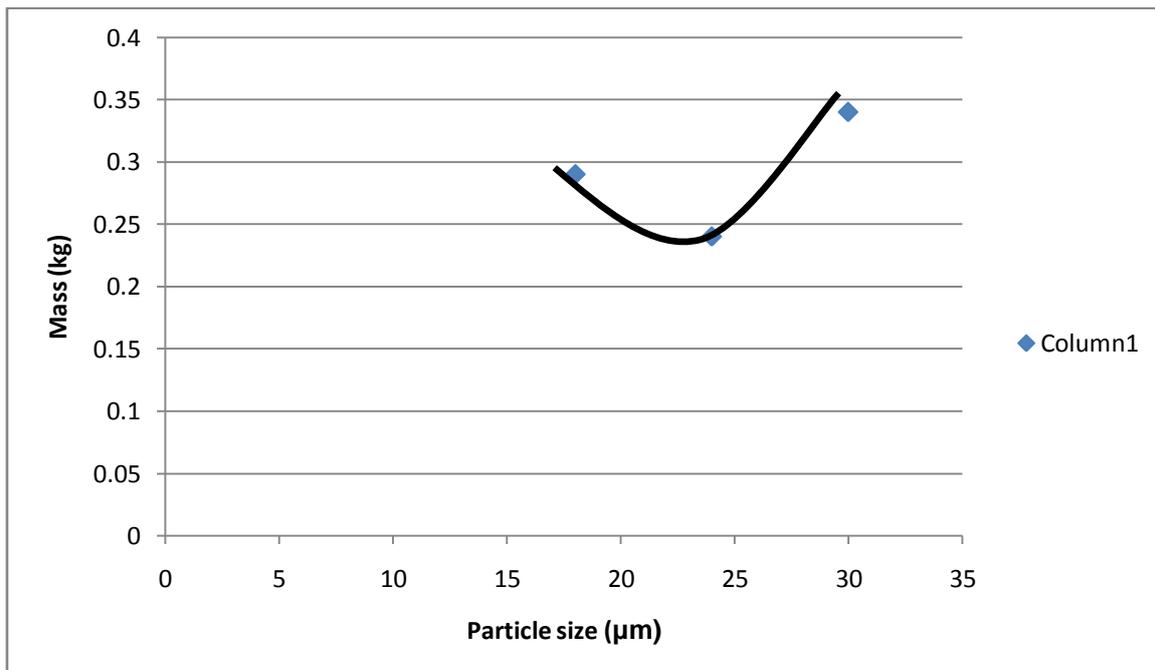


Fig 2: Graph of mass Vs Particle size for 235volts

.Table 2 Voltage varied at 245Volts. Time of sieving – 180seconds

Mesh Nos	Weight of Mesh (Kg)	Weight of Mesh + Weight of Garri(Kg)	Weight of Garri(Kg)-Product Y	Particle Size (μ)
1	0.380	0.420	0.040	>18μm
2	0.480	0.780	0.300	18μm
3	0.480	0.640	0.260	24μm
4	0.680	1.060	0.380	30μm

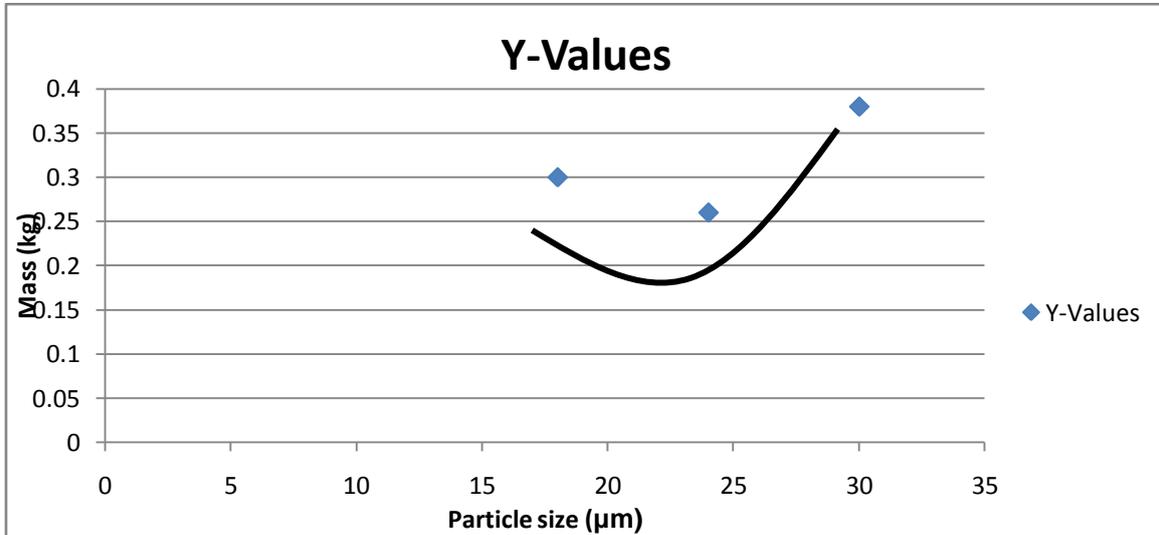


Fig 3: Graph of mass Vs Particle size for 245 volts

Table 3. Voltage varied at 255Volts. Time of sieving – 120 seconds

Mesh Nos	Weight of Mesh (Kg)	Weight of Mesh + Weight of Garri(Kg)	Weight of Garri(Kg)-Product Y	Particle Size (μ)
1	0.380	0.390	0.010	>18μm
2	0.480	0.780	0.300	18μm
3	0.480	0.760	0.280	24μm
4	0.680	1.080	0.400	30μm

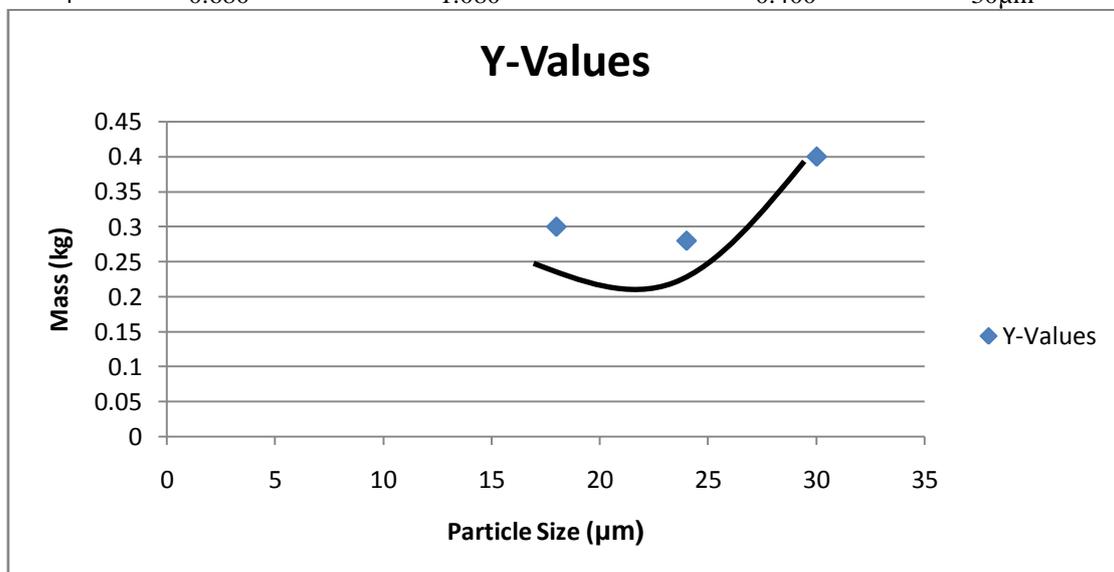


Fig 4 Graph of mass Vs Particle size for 255 volts

Table 4: Variation of voltage with time.

Voltage (Volts)	Time (Seconds)
235	230
245	180
255	120
265	90

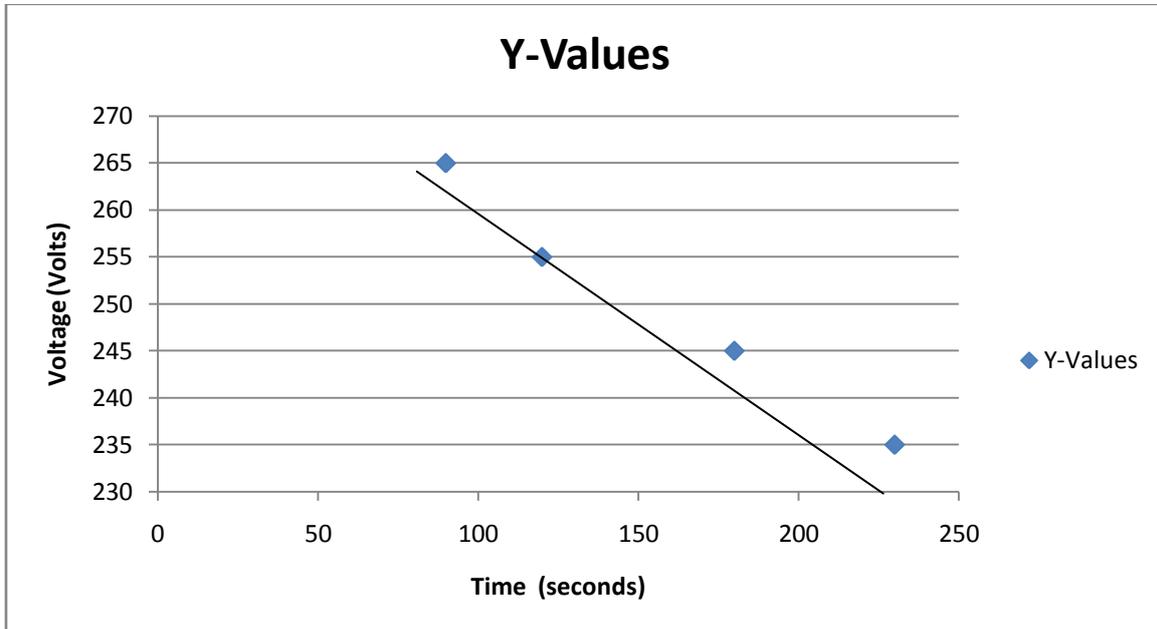


Fig 5: Graph of Voltage Vs time.

Table 5 Variation of average mass collected with time

Voltage (Volts)	Average mass(Kg)	Time (Seconds)
235	0.290	230
245	0.313	180
255	0.326	120

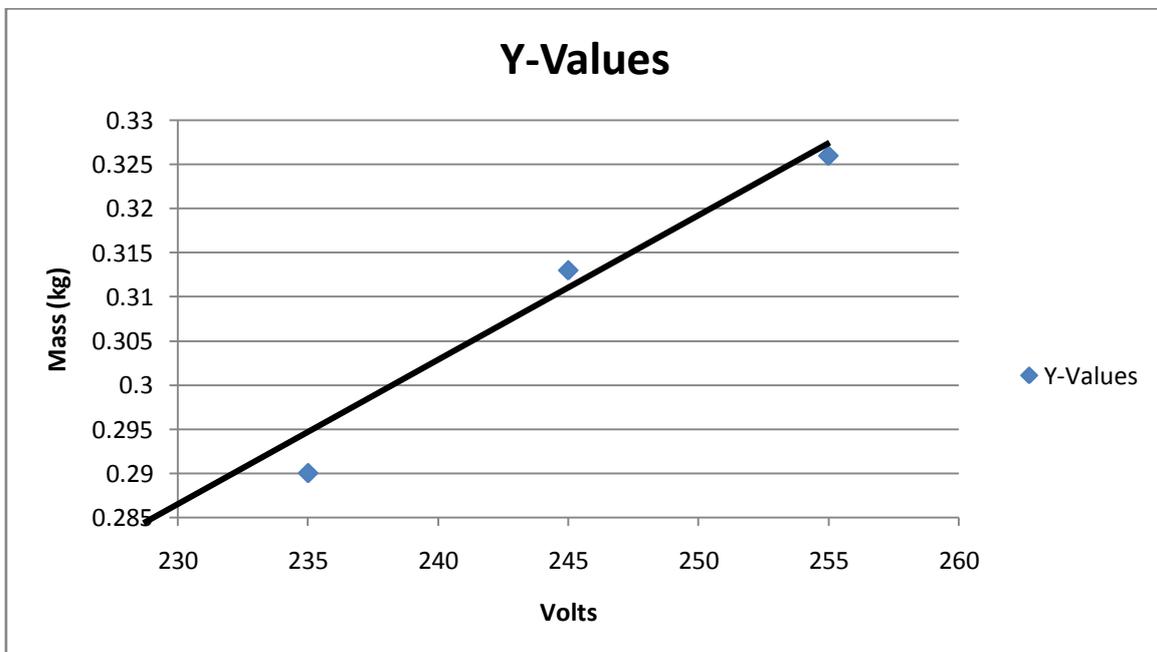


Fig 6 Graph of average mass Vs voltage

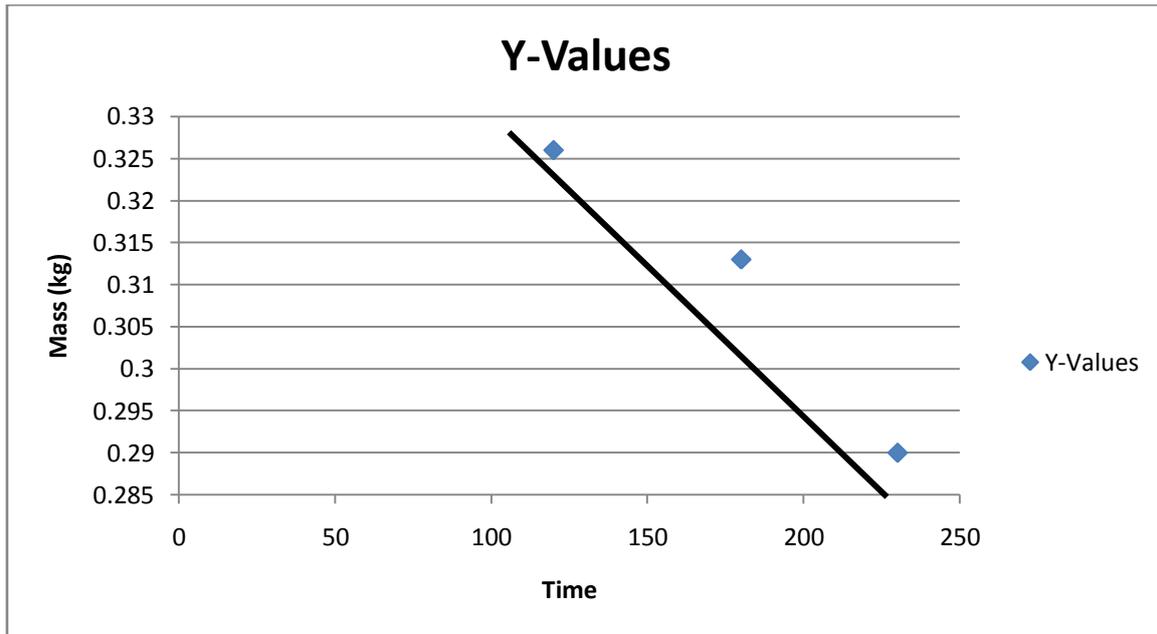


Fig 7: Graph of average mass Vs time at 255 volts.

IV. DISCUSSIONS

The designed electromagnetic sieve was operated with a combined action of electricity and magnetism. The shaking principle was also achieved with the help of spring (amplitude) displacement due to the increased magnetic flux existing between the air gap.

Fig. 2 indicates that there is an increase in mass collected at the sieves as the particle size decreases except in the second set of sieve when the voltage was varied at 235Volts. The decrease in mass at the second sieve can be attributed to the uneven distribution of the agitation.

Fig.3 indicates that there is an increase in mass collected at the sieves as the particle size decreases except in the second set of sieve as the voltage was varied at 245Volts. The decrease in mass at the second sieve may also be attributed to poor agitation at the middle sieve. There was also an increase in mass collected at the bottom due to the direct flux.

Fig.4 indicates that there is an increase in mass collected at the sieves as the particle size decreases except in the second set of sieve as usual. Here the voltage is varied at 255Volts and highest separation was achieved. This is known as the peak voltage. The decrease in mass at the second sieve may also be attributed to poor agitation.

Fig.5 indicates that as the voltage increases, the time of sieving decreases proportionally. This is as a result of increase in amplitude.

Fig.6 shows that mass collected from the sieves increases as the voltage increases. The result shows that the designed sieve is capable of grading the product “garri” into different aggregates. The mass of “garri” on each sieve is noted at different voltage variation in a particular time intervals. It was observed that with increase in voltage sieving time was reduced.

V. CONCLUSION

Many natural and manufactured materials occur in a diverse form, which means that they consist of differently shaped and sized particles. The particle size distribution is responsible for important physical and chemical properties such as: Mechanical bulk behavior, Surface reaction, Taste, Miscibility, Filtration properties, Conductivity.

If the particle distribution changes during the manufacturing process then the quality of the finished product will also change. Only a continuous monitoring of the particle size distribution can guarantee a constant product quality.

The designed “Throw action” type utilizes the electromagnetic induction at varied voltages. The vertical oscillation is used to determine the amplitude of the vibration and hence maximum sample collected per sieve. The sieve is capable of handling up to one kilogramme (1000g) of garri sample at a batch. The three grades of particle sizes collected (30 μ m, 24 μ m and 18 μ m) are exportable to other countries of the world if labeled accordingly.

The result show that increased voltage gives a maximum collection of finest particle at a smallest resident time. The amplitude of the vibration and mass of the sieved samples, also increases as the voltage increases. But as the voltage increase arbitrarily, the mass of the finest particle decreases because the electromagnetic energy are not all converted to electromechanical energy. Therefore, several losses are encountered. The particle sizes collected at the different sieves was evaluated using an electronic microscope.

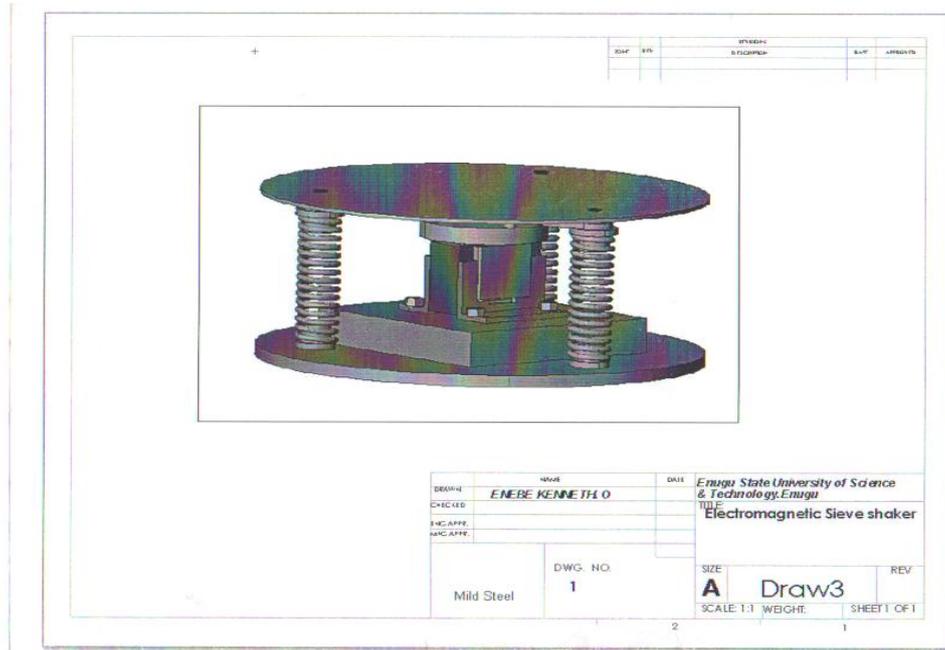


Fig. 8 Constructed electromagnetic sieve shaker

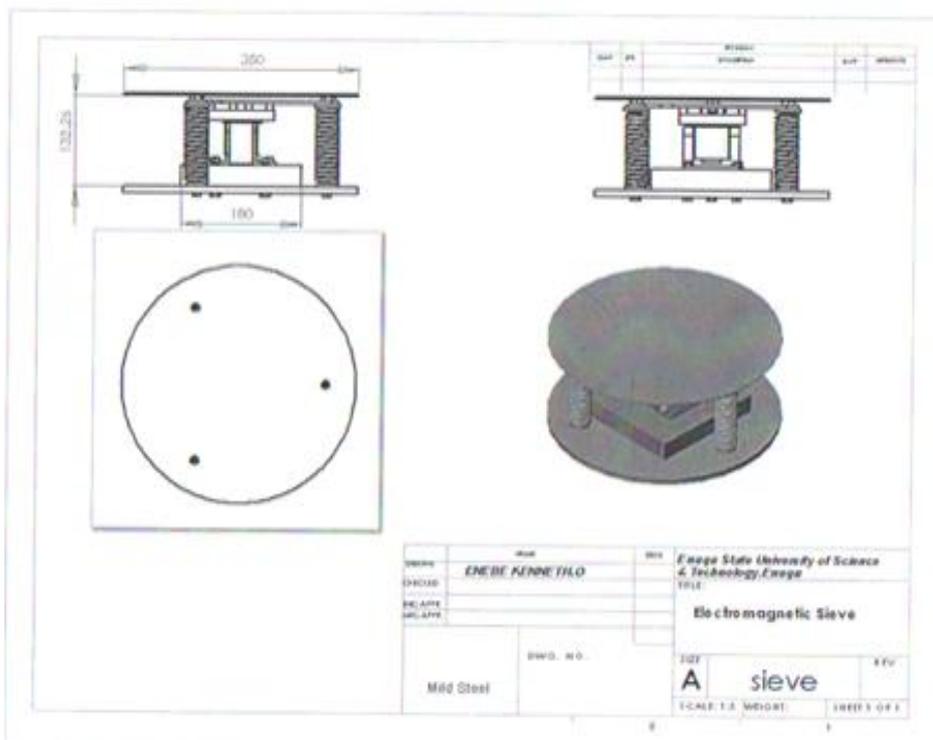


Fig.9 Views of the electromagnetic sieve shaker

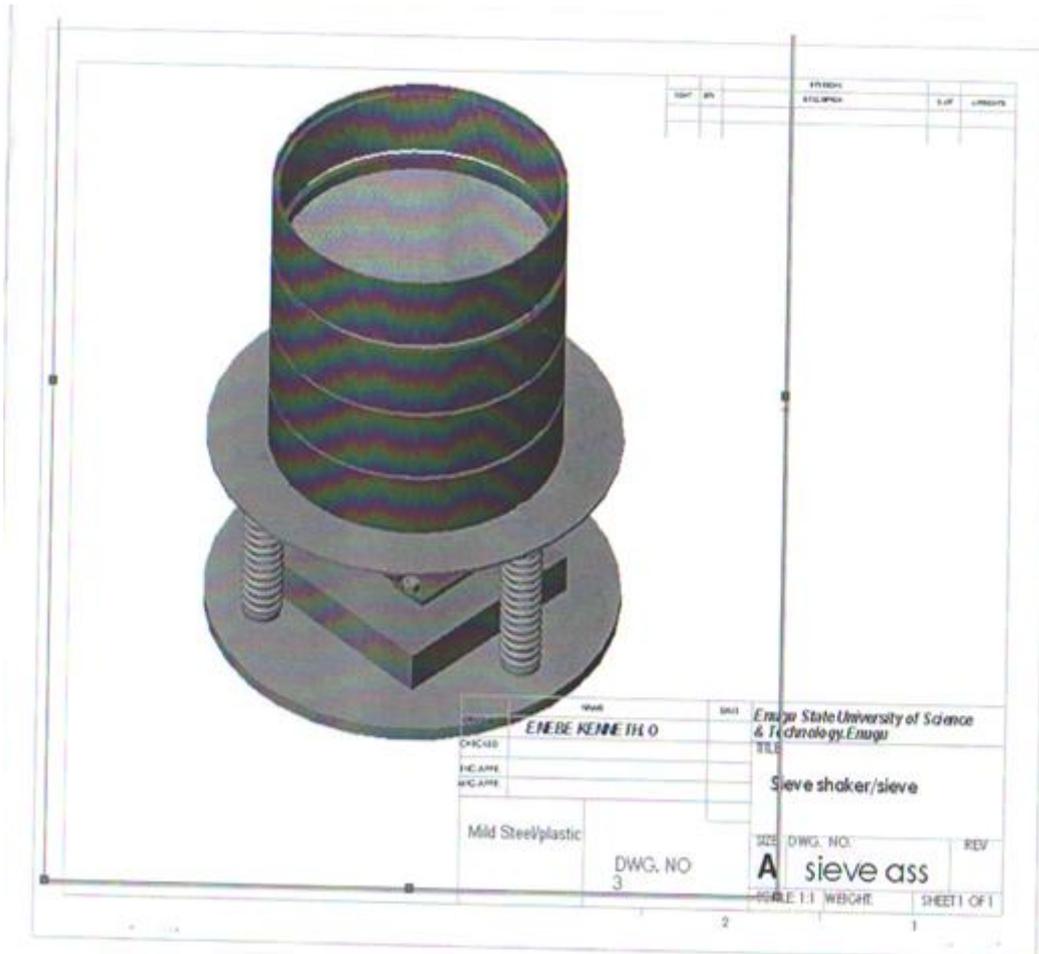


Fig.10. Assembled Sieve and Shaker

REFERENCES

- [1] Jillavenkatesa, A; Dakpunas, S. J and Lin-Sien Lum (2001), "Particle Size Characterization", NIST Special Publication, 960-1.
- [2] Sivakugan, N. (2000), "Soil Classification", James Cook University Geoengineering Lecture Handout www.coffeelabequipment.com (2013), "Particle Size Analysis"
- [3] www.advantechmfg.com (1995), "Principles and Procedures-manual with tables 2",
- [4] ASTM E11-04
- [5] Bagnold, R. A and Barndoff-Nelson, O. (1980) "The Pattern of natural distribution", Sedimentology 27 (2); 199:207
- [6] Fieller, N. R; Gilbertson, D. D and Olbricht, W. (1984), "A new method of environmental analysis of particle size distribution data from shoreline sediments", Nature 311 (5987): 648-651.
- [7] Wills, B. A and Napier-Munn. (2006), "Mineral Processing Technology: an introduction to the practical aspects of ore treatment and mineral recovery", Elsevier, Great Britain, 7th Ed.
- [8] www.wikipedia.org/wiki/user:Rhoades500. (2009), "Particle size distribution.