MATHEMATICAL MODELLING OF PNEUMATIC CLEANING OF COWPEA (*Vigna unguiculata* (L).Walp)

BY

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DEDICATION

This project is dedicated to the memory of my mother, Late Mrs. Janet Olufunmilayo Aderinlewo for her efforts in seeing that her children achieve the best in life.

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To God be the glory, honour and praise for great things he has done. I appreciate the Lord Almighty, the Alpha and the Omega for the successful completion of this work.

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CERTIFICATION

I certify that this work was carried out by Mr. A. A. Aderinlewo in the Department of Agricultural and Environmental Engineering, University of Ibadan, Ibadan.

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LIST OF SYMBOLS

1.	a	length of grain
2.	b	width of grain
3.	c	thickness of grain
4.	ψ	sphericity
5.	R	aspect ratio
6.	A_p	projected area
7.	V_t	terminal velocity
8.	$V_{t(theor)}$	theoretical terminal velocity
9.	$V_{t\,(exp)}$	experimental terminal velocity
10.	C	drag coefficient
11.	ρ_a	density of air
12.	ρ_p	density of particle
13.	m	mass of particle
14.	g	gravitational acceleration
15.	μ	dynamic viscosity of air
16.	x	horizontal displacement of particle
17.	y	vertical displacement of particle

ABSTRACT

The presence of impurities in cowpea affects its economic value as well as industrial and domestic utilisation. This problem has persisted despite the use of various manual and mechanical cleaning methods. There exists a need to improve the efficiencies of existing cowpea cleaning devices. Literature is sparse on modelling of pneumatic separation of cowpea. This study was therefore designed to develop and validate a mathematical model for the efficient separation of impurities from cowpea in a pneumatic cleaner.

Some physical and aerodynamic properties of four cultivars of cowpea (Ife 98-12, IT90K-277-2, Ife Brown and Drum) and impurities (chaff, insect infested grains and immature grains) were determined at harvesting and at storage moisture contents range (9-22% dry basis) using standard methods. A two-dimensional mathematical model for separating cowpea and impurities in a vertical flow airstream was developed using the force and acceleration components of each particle in the horizontal and vertical directions. The resultant equations were solved numerically for displacements using a proprietary software at injection angles of 15, 30, 45 and 60^o which are greater than the coefficient of friction for cowpea on mild steel and air velocities of 4.0, 6.0, and 8.0 m/s which are also greater than the impurities' terminal velocities. The displacements were used to predict the trajectories of cowpea, impurities and their separation. The model was validated using a pneumatic cleaner and the separation efficiencies were evaluated at the angles of injection and air velocities. A paired t-test was used to compare the experimental and predicted efficiencies.

The axial dimensions, geometric mean diameter, thousand grain mass, projected area and terminal velocity of the cultivars ranged from 5.0-10.3 mm, 6.1-7.0 mm, 147.5-252.8 g, 28.0-43.6 mm^2 and 13.4-14.5 m/s respectively. The mass and terminal velocity of the impurities ranged from 8.2 x 10^{-2}-15.0 x 10^{-2} g and 1.5-3.5 m/s respectively. Vertical displacements of the cultivars below the point of injection ranged from 3.9-4.8 m. The vertical displacements of the impurities above and below points of injection varied from 3.4-72.1 m and 0.70-3.2 m respectively. The predicted separation distances between cultivars and impurities ranged from 5.0 x 10^{-2} - 897.0 x 10^{-2} m. The predicted separation efficiency ranged from 30.0-45.8%, 59.3-70.6%, 76.5-83.9% and 55.2-61.6%, 77.0-79.0%, 85.0-86.9% at 4.0, 6.0, and 8.0 m/s for injection angles of 15-30^{o} and 45-60^{o} respectively. Separation efficiencies of the machine ranged from 27.7- 44.6%, 61.4-71.9% and 76.6-80.4% for angles of 15-30^{o} at 4.0, 6.0, and 8.0 m/s respectively. For angles of 45-60^{o}, it ranged from 59.2-60.9%, 75.4-76.0% and 87.2-88.8% at 4.0, 6.0, and 8.0 m/s respectively. The model predicted significantly ($p \leq 0.05$) the separation efficiency within the experimental range.

A mathematical model for the separation of cowpea and impurities in a pneumatic cleaner was developed. It was established that separation of impurities from cowpea was best at 45^{o} angle of injection at 4.0-6.0 m/s. Therefore, it is recommended that the hopper should be inclined to the airstream at this angle.

Keywords: Cowpea, Pneumatic cleaning, Separation efficiency, Aerodynamic properties

Word count: 486

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CHAPTER ONE

INTRODUCTION

1.1 Preamble on Cowpea (*Vigna unguiculata* (L.) Walp)

Cowpea (*Vigna unguiculata* (L.) Walp) is an annual legume that is widely grown in West Africa, Southeast Asia, Latin America and the United States of America. West Africa accounts for the largest part of world cowpea production and Nigeria is the highest producer of cowpea in the world accounting for over 22% of the world production (Anonymous, 2008). The crop has many varieties which may be categorized as erect, semi erect and climbing. Seed coat can either be smooth or wrinkled depending on variety and they can have various colours which include white, cream, green, black, red and brown (Davis *et al*., 2003). The shape of the seeds vary from kidney-shaped to round depending on how tightly packed they are in the pod and variety.

Cowpea contains about 25% protein (Davis *et al.*, 2003,) making it a cheap source of protein in the diet of many Nigerians. Compared to other cereal grains, cowpea's protein is rich in the amino acids, lysine and tryptophan (Table 1.1). It is therefore valued as a nutritional supplement to cereals and a good substitute to animal protein for millions of relatively poor people in less developed countries of the tropics. Cowpea thus has the potential to be used as nutritional products to compensate for the high proportion of carbohydrate often ingested in African diets and for infant and children weaning food (Lambot, 2003). However, a major constraint to such industrial use is the poor quality of cowpea available in the market in Nigeria (Taiwo, 1998).

The poor quality of cowpea available in Nigerian market is as a result of presence of impurities in them. The impurities produced are mostly due to the traditional methods of processing employed by most farmers in the country (Ige, 1994). Processes such as harvesting, threshing, cleaning and drying are mostly done manually. Threshing is done by beating the pods with stick and cleaning is done by natural winnowing. Impurities are not totally removed from the threshed cowpea due to the limitations of natural winnowing. In addition, even with some mechanical threshers the grains produced are still mixed with impurities (Vasallo and De Leon, 2009). Impurities often found in cowpea in Nigeria include chaff, stones, broken

Table 1.1. Nutrient content of mature cowpea seed (average of eight varieties)

Nutrients	**%Composition**
Protein	24.8
Fat	1.9
Fiber	6.3
Carbohydrate	63.6
Thiamine	0.00074
Riboflavin	0.00042
Niacin	0.00281

Source: Davis *et al.* (2003)

seeds and insect infested seeds due to susceptibility of cowpea to weevils (*Callosobruchus sp*.) attack. Such impurities that were observed in Kanannado (white with black eye) variety of cowpea that were collected from different markets in Nigeria and at different periods during the 1999/2000 season are shown in Table 1.2. The defects categories are illustrated in Figure 1.1. It has been estimated that only 40% of cowpea available on the open market in Nigeria is acceptable for industrial use in relation to specifications for physical defects (Lambot, 2003).

Cowpea is also the most consumed grain legume by urban households in Nigeria (Table 1.3). The presence of impurities is also a problem to consumers of cowpea as they have to spend ample time hand picking the impurities if they want to enjoy their meal. There is therefore the need to improve on the primary processing of cowpea especially in the area of cleaning to improve the quality of cowpea available to consumers and also for industrial use.

1.2 Cleaning of Grains

Cleaning of grains is the process of removing impurities and contaminants from sound grains. This removal of contaminants from grains is usually done after threshing and is an essential aspect of grain processing. Since harvesting, post harvesting and handling methods of grains in Nigeria encourage the presence of contaminants like stones, sticks, chaffs and dust, effective cleaning is necessary before consumption (Ogunlowo and Adesuyi, 1999). Clean grain reduces problems that occur during storage and handling. It also saves storage space and increases marketability (Wang *et al*., 1994).

There are various machines and techniques for cleaning grains. They are all based on one or more differences between the physical characteristics of the contaminating particles and the grains to be cleaned. These machines include air screen cleaners, specific gravity separators, pneumatic separators and electrostatic separators. Among these techniques, using air stream for cleaning (pneumatic separation) has proved to be very effective for separating light weight contaminants from grains (Nicholls and Burrows, 1985). Vertical flow pneumatic cleaners for cowpea or winnowers have been developed which have proved effective in removing light weight impurities from cowpea (Aguirre and Garay, 1999; Adegbulugbe, 2004). In addition, pneumatic systems have many advantages which include possibility of simultaneous cleaning and sorting, flexible horizontal and vertical operation,

Table 1.2. Cowpea quality evaluation (%) overall

Constituents	**Average**	**Minimum**	**Maximum**
Protein (DM)	23.64	22.3	26.1
Moisture	8.74	6.6	13.5
Total defects	12.89	5.0	20.9
Broken	2.08	0.0	6.2
Holes	5.75	0.0	17.1
Stones	0.16	0.0	1.2
Colored	0.78	0.0	6.7
Foreign varieties	0.60	0.0	2.9
Waste	3.52	0.3	8.6

Source: Lambot (2003)

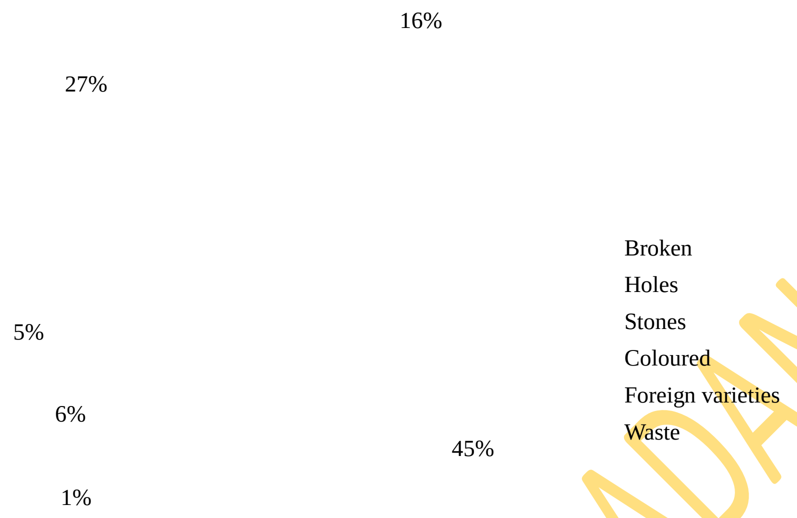


Figure 1.1 Defects category in Kanannado variety (over all mean)

Source: Lambot (2003)

Table 1.3. Urban household consumption of grain legume

Grain Legume	**Quantity consumed (kg/week)**	**Number of household**
Cowpea grains (*Vigna unguiculata*(L.) Walp.)	5	72
Shelled groundnut (*Arachis hypogaea*(L.))	8	31
Unshelled groundnut (*Arachis hypogaea*(L.))	2	16
Soybean grain (*Glycine max*. (L.) Merr.)	2	7
Soybean flour (*Glycine max*. (L.) Merr.)	1	1
Shelled *egusi*	1	50
Unshelled *egusi*	2	5
Bambara groundnut (*V. subterranean* (L.)Thou.)	3	19

Source: Kormawa *et al.* (2005)

mechanical simplicity, no change in the physical and biological properties of seeds, low energy demand, low level of noise and no air contamination (Harmond *et al.*, 1968; Tylek and Walczyk, 2004).

To maximize these advantages, there is need for investigation into optimum combination of various parameters that affect pneumatic separation such as angle of injection of cowpea-impurities mixture into the vertical air stream, air velocity, moisture content, and angle of injection of the air stream into the vertical tunnel. Some work has been done by other researchers on the effect of variation of angle of injection of the air stream into the vertical tunnel on separation of cowpea from impurities (Simolowo *et al.*, 2007). However, there is little information on the effects of other parameters such as angle of injection of cowpea-impurities mixture into the air stream, air velocity and moisture content.

1.3 Objectives

The main objective of this work is:

- To develop mathematical models for efficient separation of impurities from cowpea in a vertical flow pneumatic cleaner.

The specific objectives of this work are:

(i) To determine the physical and aerodynamic properties of four varieties of cowpea that are related to pneumatic handling and separation.

(ii) To develop mathematical models to predict the horizontal and vertical displacements of cowpea and impurities' particle and their separation in a pneumatic cleaner.

(iii) To use the displacements to predict the trajectories of cowpea and impurities particles' in a pneumatic cleaner.

(iv) To validate the models' predictions with experimental data.

1.4 Justification

The presence of impurities in locally produced cowpea in Nigeria is a problem that is greatly affecting its industrial and domestic consumption. Pneumatic cleaners are being developed as part of efforts to solve this problem. There is however need to investigate the interaction of various parameters that influence aerodynamic separation of cowpea- impurities mixture in a pneumatic cleaner. Such parameters include physical and aerodynamic properties of components of the mixture, angle of injection of cowpea-impurities mixture into the vertical air stream, air velocity, moisture content, and angle of injection of the air stream into the vertical tunnel. This will help to determine the combination of parameters that will produce optimum cleaning or separation. This investigation can be carried out by the development of mathematical models to simulate the separation process. In addition to this, modelling of the process of pneumatic cleaning of cowpea has the following advantages:

i. The models that are derived will provide a better understanding and quantification of the cleaning process and thus provide means of predicting cleaning efficiency for a wide range of cleaning condition.

ii. The models will contribute to the knowledge about the theory and mechanics of pneumatic cleaning of cowpea which will serve as veritable tools in improving the operational performance of pneumatic cleaners through design.

iii. The models will also facilitate design changes to suit different varieties of cowpea without resorting to expensive experimentation.

CHAPTER TWO

LITERATURE REVIEW

2.1 Cleaning, Separation and Grading of Grains

Cleaning of grain refers to the removal of foreign or unwanted materials from the grains. Some cleaning methods separate grains into two fractions with one fraction containing cleaned grains and the other containing inert or unwanted materials. Other methods separate grains into different fractions with different degrees of purity. Sorting refers to the separation of the cleaned grains into various quality fractions that may be defined on the basis of size, shape, density, texture and colour. Grading refers to the classification of grains based on commercial value (Henderson and Perry, 1976). Separation or cleaning of a mixture of grains and impurities is based on differences in the physical characteristics of the various components. Such physical characteristics include size, shape, density, weight, terminal velocity, electrical characteristics, colour, resilience or bounce properties and surface characteristics. Surface characteristics affects coefficient of friction and are applicable where roughness is used for cleaning operation (Henderson and Perry, 1976).

2.2 Methods and Machines used for Cleaning Agricultural Products

There are different methods and machines used for cleaning agricultural products especially grains. These methods and equipment are based on the differences in the physical and aerodynamic properties of the different components of the products to be cleaned. Some of the methods and equipment together with the physical and aerodynamic characteristics utilized for cleaning are discussed below.

2.2.1 Screens or sieves

Screens or sieves are the most widely used device for cleaning and sorting grains and other granular materials (Henderson and Perry, 1976). This method separates materials according to size. A sieve with holes or openings larger than the grains removes impurities larger than the grains by retaining the impurities and allowing grains to pass through. The one with openings smaller than the grains retains the grains while smaller impurities pass through. Sometimes, the screening unit may have two or more screens which are subjected to vibratory movement to enhance the screening operation. Screens or sieves are also used for grading grains by size (Kaul and Egbo, 1985). They are however less effective when the impurity to be removed is of the same size as the grains and also for flat and winged seeds (Schmidt, 2000).

2.2.2 Specific gravity separators

A specific gravity separator separates materials according to differences in density. It consists of an inclined mesh belt conveyor or a triangular-shaped perforated table. The material to be cleaned is placed on the conveyor or table and air is blown from below to lift the lighter particles above the surface so that they can flow down hill by gravity. The heavier particles will remain in contact with the conveyor or table and move uphill. Henderson and Perry (1976) reported that separation by gravity is based on two conditions: (1) the ability of a grain to flow down an inclined plane and (2) the lifting or floating effect produced by the upward motion of air. Gravity separators are widely used in various industries and agricultural processing plants (Feller *et al.*, 1981). They can make accurate separations under difficult conditions but they are expensive and their capacity is lower than that of other types of cleaners that are nearly similar in performance (Henderson and Perry, 1976).

2.2.3 Spiral separator

The spiral separator separates grains according to shape and ability to roll or slide. It consists of one or more sheet-metal flights wound round in a central tube to form a spiral. The grains to be cleaned are introduced at the top of the inner spiral. Round grains roll down the inclined flight while irregularly shaped particles tend to slide. The faster the grain travels down the than flight, the larger the arc of travel becomes because of centrifugal force. The round grains, having greater velocity, make a wider circle than the irregularly shaped particles and the grains can be separated from the particles by splitters as the discharge end of the flight (Harmond *et al.*, 1968).

2.2.4 Inclined draper separator (friction cleaning)

This also separates grains on the ability to roll or slide and surface structure. The grains to be cleaned are released from a hopper to the centre of an inclined draper belt traveling in an uphill direction. Round or smooth grains will roll and slide down the draper faster than the draper traveling up the incline. On the contrary, flat, rough or elongated grains will be carried to the top of the incline thereby separating it from round or smooth grains (Schmidt, 2000).

2.2.5 Magnetic separator

The magnetic separator separates on the basis of differences in seed coat characteristics (Harmond *et al.*, 1968). The grains to be cleaned will have smooth coat and the impurities to be removed from them will have a rough coat or sticky surface that can pick up and retain a fine powder when pretreated with water or a combination of water and oil. The mixture of grains and impurities to be cleaned is first mixed with a proportioned water spray and finely ground iron powder. The iron will adhere to impurities with rough seed coat such as dirt particles, chaff and cracked grains. The mixture is then passed into a region of high-intensity magnetic field which can be produced by either a permanent magnet or electromagnet. The impurities which are now coated with iron powder are attracted to the magnet thereby separating them from sound grains.

2.2.6 Centrifugal separation

Centrifugal separation is a method of separation that is based on the application of centrifugal force to a mixture or suspension of materials of closely similar densities. When a mixture of materials is subjected to centrifugal force, the usual tendency is for the heavier or denser components to move outwardly from the axis of rotation of the container and the lighter components to move inwardly toward the axis. When the denser components have more than one density, the outward movement ordinarily results in stratification, with the denser component forming the layer nearest the wall and the less dense component next to it and so on (Anonymous, 2004). The cream separator which separates the cream from skim milk is the most familiar agricultural use of this type of separation.

2.2.7 Natural winnowing

Winnowing in the wind is the process of separating chaff and other light impurities from grains by dropping or throwing it in natural air stream (Macmillan, 1999). Winnowing separates materials according to differences in density and terminal velocities. In a simple form of winnowing, the grains to be cleaned are held in a tray or flat container. They are then thrown up in the air and wind will then blow away the light impurities (Schmidt, 2000). The main disadvantages of natural winnowing however are the unpredictable direction, velocity and continuity of natural wind (Aquirre and Garay, 1999).

2.2.8 Aerodynamic or pneumatic separation

This involves the use of separating effect of moving air to remove chaff, dirt and lightweight seed from grains. In this type of separation, the aerodynamic properties of the product to be cleaned or separated are of great importance. Terminal velocity is the velocity of a body falling freely when the resistance drag force is equal to the weight of the body i.e. when velocity is constant and acceleration is thus equal to zero. A particle is lifted when air velocity is greater than its terminal velocity. It will fall gently when the air velocity is slightly lower than its terminal velocity. The moving of air for cleaning and separating can be done in two ways:

(1) by blowing air through the grain using the air coming from the discharge of a fan

(2) by drawing the air through the grain by connection to the intake fan (aspirating).

When pneumatic separation is applied to separate a product from its associated foreign materials such as straw and chaff, the terminal velocities of the particles involved defines the range of air velocity that gives good separation of the grain from foreign materials (Irtwange and Igbeka, 2003).

2.3 Physical and Mechanical Properties of Grains

Knowledge of physical and mechanical properties of crops is very important in the design of handling and processing equipment. Processes and operations such as planting, harvesting, threshing, cleaning or separating, sorting, grading, drying, conveying, packaging and storage all require knowledge of physical and mechanical properties of crops. There has been wide spread interest in the physical and mechanical properties of crops in recent years and different researchers have studied the physical and mechanical properties of different grains and seeds. The physical and mechanical properties of interest include axial dimensions, projected area, sphericity, aspect ratio, porosity, bulk density, real density, crushing strength, coefficient of static friction, mass of 1000 grains and angle of repose. Factors which affect physical and mechanical properties of crops include moisture content and variety (Irtwange, 2000).

Adegbulugbe (2004) also reported that these properties also depend on environmental factors such as climatic and soil variables.

Visvanathan *et al.* (1996) investigated the physical and mechanical properties of neem nut in the moisture content range of 7.6 to 21% w.b. The physical and mechanical properties investigated include physical dimensions, crushing strength, 1000 nut mass, porosity, bulk density and coefficient of static friction. A traveling microscope with 0.01 mm graduation was used to measure the axial dimensions and crushing strength was measured using a hardness tester. The angle of repose of the nut was determined from the diameter and height of a heap on a circular plate. The bulk density was determined by filling a circular container of known volume with a known mass of neem nuts. The bulk density was then calculated from the mass and volume. The true density was calculated from experimental values of bulk density and porosity by using the following relation.

$$\rho_p = \frac{\rho_b}{(1 - P_t)} \qquad (1)$$

Where ρ_p = particle or true density, kg/m^3

ρ_b = bulk density, kg/m^3

P_t = percentage porosity

They concluded that the crushing strength along the longitudinal axis and diametrical axis decreased linearly with moisture content. The mass of 1000 nuts and angle of repose increased linearly with increase in moisture content while the porosity, bulk density and particle density decreased linearly with increase in moisture content.

Carman (1996) carried out a study on some physical properties of lentil seeds as a function of moisture content in the range of 6.5 to 32.6% d.b. The physical properties studied include physical dimensions, bulk density, porosity and projected area. He also determined the static and dynamic coefficients of friction of lentil seeds against galvanized sheet metal, plywood and rubber surfaces. He concluded that the bulk density decreased from 1190 to 935 kg/m^3 while porosity increased from 27.4 to 32.0% as the moisture content increased from 6.5 to 32.6% d.b. The projected area, static and dynamic friction all increased with increase in moisture content but the effect was more pronounced for static coefficient of friction.

Singh and Goswani (1996) carried out a study on the physical properties of cumin seed. Physical properties such as physical dimensions, bulk density, true density, porosity, 1000 grains mass, angle of repose and coefficient of static friction on four surfaces, namely, mild steel, galvanized iron, stainless steel and aluminum in the moisture content range of 7 to 22% w.b. These properties were found to be linearly dependent on moisture content.

Surthar and Das (1996) investigated the physical characteristics of karingder seeds and kernel in the moisture content range of 5 to 40% d.b. Physical properties studied include physical dimensions, mass of 1000 seeds, bulk density, true density, angle of repose, porosity and coefficient of static friction against surfaces of three structural materials, namely, plywood, mild steel and galvanized iron. They found out that the physical properties of karingder seed and kernel were dependent on their moisture contents. For the seeds, the bulk density, coefficient of static friction and angle of repose all increased with increase in moisture content while true density and porosity decreased with increase in moisture content. For the kernel, the bulk density, real density, coefficient of static friction and angle of repose all increased with increase in moisture content while the porosity decreased with increase in moisture content.

Duarte *et al.* (2004) investigated the physical properties of soybean at a moisture content of 10.90% w.b. The properties investigated include size, shape, volume, density, porosity, sphericity and projected area. The volume was determined by displacement mass method, the density by the simple relationship between mass and volume and the sphericity was calculated from the relation:

$$S_p = \frac{(abc)^{1/3}}{a} \qquad (2)$$

Where S_p = Sphericity

a = major axial dimension

b = intermediate axial dimension

c = minor axial dimension

They obtained a projected area of 0.34 cm^2, density of 1.17 g/cm^3 equivalent diameter of 0.66 cm and sphericity of 89.68%.

Joshi *et al.* (1993) studied the physical properties of pumpkin seeds and kernels. Physical properties such as physical dimensions, bulk density, true density, porosity, coefficient of static friction and angle of repose were determined at a moisture content range of 4 to 40% d.b. They found out that these properties were all dependent on moisture content.

Desphande *et al.* (1993) carried out a study on the dependence of physical properties of soybean on moisture content in the range of 8.7 to 25.0% d.b. Physical properties such as physical dimensions, geometric mean diameter, sphericity, surface area, volume, thousand grain mass, bulk density and true density were studied. These properties were found to be linearly dependent on moisture content. They also observed that soybean grain expands more along its thickness in comparison with other two principal axes.

Olayanju (2002) studied the physical properties of beniseed in the moisture range of 5.3 to 28.3% w,b. Physical properties studied include linear dimensions, geometric size, bulk density, coefficient of static friction and thousand kernel mass. He concluded that linear dimensions, geometric size, porosity and thousand kernel mass increased with increase in moisture content. He also found out that moisture content does not have any significant effect on major diameter and sphericity.

Irtwange (2000) carried out a study on some engineering properties of African yam bean (*Sphenostylis stenocarpa*). Physical properties such as axial dimensions, equivalent diameter, individual grain weight, porosity, bulk and true densities, sphericity, angle of repose and coefficient of static friction were investigated in the moisture range of 4 to 16% w.b. These properties were all found to be dependent on moisture content.

Hauhouot-O'Hara *et al.* (2000) investigated some selected physical characteristics of cheat seed and wheat at a moisture content of 12% w.b. Physical properties investigated include dimensions, weight, sphericity and aspect ratio. They obtained the length, width and thickness of cheat to be 6.85, 1.33 and 1.24 mm respectively and 6.02, 2.79 and 2.54 mm respectively for wheat. The sphericity and aspect ratio of cheat are 32.12 and 19.26% respectively while those of wheat are 58.04 and 46.3% respectively. They indicated that separation of cheat from wheat seeds is not likely based on length but on seed width, thickness and density.

Gupta and Das (1997) studied the physical properties of sunflower seeds and kernels. Physical properties such as physical dimensions, unit mass, sphericity, bulk and true densities, porosity, coefficient of static friction and angle of repose were studied in the moisture content range of 4 to 20%. The properties were all found to be linearly depended on moisture content.

Akaaimo and Raji (2006) investigated some physical and engineering properties of *Prosopis africana* seed with a view to obtain data useful in designing handling and processing machines for the seed. Properties investigated include axial dimensions, sphericity, weight, volume, one thousand seed weight, bulk density, true density and angle of repose. They obtained one thousand seed weight as 199.80 g, bulk density and true density as 899.67 and 1397.10 kg/m^3 respectively while the volume, angle of repose, geometric mean diameter, sphericity and porosity were 0.14 cm^3, 22.3^o, 6.43, 0.65 and 35. 6%.

Al-Mahasneh and Rababah (2007) investigated the physical properties of green wheat kernels in the moisture range of 9.3 to 41.5% w.b. They found out that the axial dimensions, mass of 1000 seeds, kernel volume and static friction coefficient all increased with increase in moisture content while bulk density, true density and porosity decreased with increase in moisture content. They also reported that static friction coefficient was largest between green wheat kernels and plywood surface ranging from 0.41 to 0.62, while the largest increase in static friction coefficient with moisture content was observed for stainless steel and ranged from 0.22 to 0.64.

Perez *et al.* (2007) determined some physical and morphological properties of wild sunflower species in the moisture range of 8.9 to 10.4% w.b. They measured the length, width and thickness of the seed with a micrometer gauge and obtained average values as 4.5, 2.02 and 1.2 mm respectively. They measured the bulk and true densities with a hectoliter tester and by picnometry and obtained 350 and 399 kg/m^3 respectively. They reported that the angle of repose ranged between 28.6 and 30.2^o and the oil content between 27 and 30%.

Coskuner and Ersankarababa (2007) evaluated the physical properties of coriander seeds in the moisture range of 7.10 and 18.94% d.b. They found out that the seed length decreased linearly from 4.74 to 4.61 mm and the width, thickness, arithmetic mean diameter and geometric mean diameter increased linearly from 3.67 to 3.93 mm, 3.39 to 3.54 mm and 3.88 to 3.99 mm respectively with increase in moisture content. The sphericity, seed volume, seed surface area and coefficient of static friction increased non-linearly with increase in moisture content. They also reported that the true density increased non-linearly with moisture content from 332 to 349 kg/m^3 while bulk density decreased linearly from 234.1 to 220.2 kg/m^3.

Aviara *et al.* (2005) studied the effect of moisture content on the physical properties of sheanut (*Butyrospernum paradoxium*) in the moisture content range of

6.0 to 27.9% d.b. They reported that one thousand nut weight, volume and static coefficient of friction increased linearly with moisture content from 7.8 to 10.6 kg, 12,360 to 14,030 mm^3 and 0.300 to 0.394 respectively. They also pointed out that particle density, bulk density and angle of repose increased logarithmically with moisture content from 643 to 782 gcm^{-3}, 291.3 to 356.2 gcm^{-3} and 24.7 to 25.1^o respectively.

Polat *et al.* (2006) determined the physical properties of soybean in the moisture content range of 6.7 to 15.3% d.b. Physical properties determined include axial dimensions, geometric mean diameter, arithmetic mean diameter, sphericity, porosity, true density, bulk density, 1000 seed mass and coefficient of static friction. They reported that the axial dimensions, 1000 seed mass, sphericity, geometric mean diameter, bulk density and coefficient of static friction increased as moisture content increased while porosity and true density decreased with increase in moisture content.

Unal *et al.* (2006) evaluated the physical properties of back eyed pea as a function of moisture content. Physical properties such as axial dimensions, sphericity, thousand grain mass, surface area, projected area, bulk density, true density, porosity and static coefficient of friction were determined in the moisture content range of 10.82 to 31.76% d.b. They found out that the bulk density decreased with increase in moisture content while the other physical quantities increased with increase in moisture content.

Simonyan *et al.* (2007) determined some physical properties of Samaru Sorghum in the moisture content range of 8.89 to 16.5%. Physical properties studied include diameter, projected area, volume, mass, particle density and bulk density. They reported the mean mass, projected area, volume of sorghum as 0.044 g, 4.66 mm^2 and 0.091 cm^3 respectively. They also observed that particle density decreased with increase in moisture content.

2.3.1 Previous Work on Physical and Mechanical Properties of Cowpea

Most of the works that have been done on the physical properties of cowpea are those related to threshing, handling losses and nutrient content. Much appears not to have been done on those properties related to pneumatic cleaning and conveying.

Ige (1977) carried out a study of some parameters affecting the handling losses of five varieties of cowpea. Parameters investigated were physical dimensions and rupture strength. He concluded that physical dimensions varied among varieties and that rupture strength was highly dependent on moisture content. He further stated that there was no relationship between the size of the variety and the rupture strength.

Nwuba *et al.* (1994) studied some physical and mechanical properties of seven varieties of cowpea as related to mechanical whole crop threshing. Physical properties such as physical dimensions and sphericity were investigated at a moisture content of between 6 to 7.5% w.b. He concluded that cowpea kernel size differs significantly among different varieties thus different sieve and concave sizes are therefore necessary for threshing different varieties. He stated that cowpea grain is roughly ellipsoidal in shape with a fairy high sphericity of 78%. He pointed out that the effect of variety on mechanical properties of cowpea is not significant.

Latunde-Dada (1993) studied the iron contents and physical components of twelve cowpea varieties. He concluded that the seed coat accounted for 5.8 to 11.4% of the weight of the seeds, leached solids 5.1 to 13.6%, swelling capacity 43.9 to 94.5% and seed density ranged from 0.91 to 1.28 g/cm^3.

Obatolu *et al.* (2001) carried out an appraisal of chemical, physical and sensory characteristics of twelve cowpea varieties. They determined the proximate analysis, physical characteristics and sensory evaluation of the varieties. They concluded that the protein content ranged from 21.51 to 23.65%, fat content 1.34 to 1.84%, ash content 2.87 to 3.59%, moisture content 9.84 to 10.18%, carbohydrate 61.14 to 64.18% and tannin content 0.23 to 0.46%.

Adegbulugbe (2004) studied the effect of environmental factors and moisture content on some selected properties of three cowpea varieties in the moisture content range of 10 to 35% w.b. in six locations in South Western Nigeria. The properties investigated include axial dimensions, sphericity, porosity, bulk density, particle density and terminal velocity. He concluded that environmental factors namely climatic and soil variables strongly influenced the physical properties.

There is however need for further work on the physical and mechanical properties of cowpea that are related to pneumatic separation and conveying as well as their dependence on moisture content. Thus in this research work, these properties of four varieties of cowpea were determined in the moisture content range 8 to 18% w.b. since harvesting and most of the processing operations of cowpea are performed in this range.

2.4 Aerodynamic Properties of Grains

Air is used in handling and processing of agricultural products for transporting or separation of inert or unwanted materials from the products. Machines like pneumatic separators, pneumatic conveyors and aspirators all use the movement of air to transport or divide materials according to their aerodynamic properties particularly terminal velocities. Other aerodynamic properties of importance in pneumatic conveying are drag coefficient, Reynolds number, aerodynamic drag coefficient and aerodynamic resistance coefficient.

2.4.1 Determination of aerodynamic properties of a small particle

The terminal velocity of a small particle like agricultural grains can be determined by any of these two methods:

- **Floating test**: In this method, the aerodynamic properties of a particle is determined by measuring the air velocity (equilibrium condition) when the particle is suspended in a stream of air. The air velocity at which this takes place is taken as the terminal velocity of the particle (Csizmazia and Polyak, 2005).
- **The distance – time (drop) tests**: In this method, the terminal velocity of a particle is determined by timing the free fall of a particle that is dropped in a vertical wind tunnel. The terminal velocity is then calculated from the linear portion of the displacement – time graph of the motion (Shellard and MacMillan, 1978).

The aerodynamic drag coefficient and aerodynamic resistance coefficient can then be calculated from the terminal velocity through the relations:

$$C = \frac{2mg}{\rho_a A V_t^2} \tag{3}$$

and

$$K = \frac{mg}{V_t^2} \tag{4}$$

Where C = drag coefficient of particle, dimensionless

ρ_a = density of air, kg/m^3

A = area of particle projected to the air stream, m^2

V_t = terminal velocity, m/s^2

g = gravitational acceleration, m/s^2

m = mass of particle, kg

k = aerodynamic resistance coefficient, kg/m

Theoretically, a general expression for the terminal velocity of a particle can be obtained by setting the resistance drag force, F, equal to the weight, mg, when the particle is suspended stationary in a vertical air stream and by assuming that the air velocity, V_a, is equal to the terminal velocity of the particle, V_t, under this condition (equilibrium condition).

If $mg = F$ when $V_a = V_t$ (equilibrium condition)

and $$F = \frac{1}{2} C \rho_a A V_t^2 \quad (5)$$

then $$mg = \frac{1}{2} C \rho_a A V_t^2 \quad (6)$$

therefore $$V_t^2 = \frac{2mg}{C \rho_a A} \quad (7)$$

$$V_t = \sqrt{\frac{2mg}{C \rho_a A}} \quad (8)$$

2.4.2 Previous work on aerodynamic properties of grains

Different researchers have investigated the aerodynamic properties of different grains.

Carman (1996) investigated the terminal velocities of lentil seeds in the moisture content range of 6.5 to 32.6% d.b. using drop tests. A seed of lentil was allowed to fall from the top of a dropping tube at various heights. The duration of fall was recorded and plotted as a function of distance of fall. The terminal velocity was then calculated as the slope of the linear portion of the distance-time curve. He concluded that the terminal velocity increased linearly from 10.95 to 12.06 m/s as the moisture content increased from 6.5 to 32.6% d.b.

Singh and Goswani (1996) determined the terminal velocities of cumin seed in the moisture content range of 7 to 22% d.b. by suspension tests in a vertical air column. They concluded that the terminal velocity increased linearly from 2.6 to 4.8 m/s as the moisture content increased from 7 to 22%.

Surthar and Das (1996) investigated the terminal velocity of karingda seeds, kernel and hull in the moisture content range of 5 to 40 % d.b. by suspension tests in a vertical air column. They concluded that the terminal velocity of karingda seed and its fraction increased linearly over the moisture content range of 5 to 40% d.b., in the order of hull (2.0 to 4.1 m/s), kernel (3.5 to 4.8 m/s) and seed (4.5 to 6.5 m/s).

Khoshtaghaza and Mehdizadeh (2006) investigated the aerodynamic properties of wheat kernel and straw materials. They measured the terminal velocity of Canadian variety of wheat kernel and straw materials by suspension tests in a vertical air stream. They concluded that by increasing the mass of the kernel from 0.02 to 0.05 g and moisture content from 7 to 20% w.b., its terminal velocity increased linearly from 7.04 to 7.74 m/s and 6.8 to 8.63 m/s respectively. They also concluded that the terminal velocity and drag coefficient of wheat straw depended on node position and end node position had the highest terminal velocity and lowest resistant coefficient.

Joshi *et al.* (1993) measured the terminal velocities of pumpkin seeds and kernels in the moisture content range of 4 to 40% d.b. by suspension tests in a vertical air column. They concluded that the terminal velocity for the hull (2.29 to 3.03 m/s) was significantly lower than that for the seed (4.70 to 6.50 m/s) and the kernel (4.27 to 5.2 m/s) at all moisture contents from 4 to 40% d.b.

Rajabipour *et al.* (2004) measured the terminal velocities of different varieties of wheat and rice (paddy) at moisture contents of 8, 12, 14, 18 and 22% using a wind tunnel. They found out that the terminal velocity of wheat ranged from 6.0 to 6.9 m/s for different varieties and moisture contents while that of rice varied from 5.5 to 5.7 m/s for different varieties and moisture contents.

Irtwange and Igbeka (2003) determined the theoretical and experimental terminal velocities of two Africa yam bean accessions (TSs 137 and TSs 138) at moisture levels of 4, 8, 12 and 16% wet basis by using an aspirating column. They found out that there was no statistically significant difference in terminal velocities between accessions but there was a highly significant effect of moisture content and the method used to calculate terminal velocities.

Gorial and O’ Callaghan (1990) measured the drag coefficient of a wide range of grains and straws experimentally by finding the suspension velocities of the particles in an air stream. They reported that the range of grains found in normal sample at harvest corresponds to a range of terminal velocities rather than a single characteristics velocity. They also reported that the drag coefficients of grains, which may be correlated as a function of Reynolds number, lie within the limits of a sphere (0.44) and of a cylinder (1.0) depending on the shape of the grain. According to them, the drag coefficients of oilseed rape, soybean and millet approach that of a sphere while those of beans and maize tends towards that of a cylinder.

Duarte *et al.* (2004) studied the effect of the shape of wind tunnel on aerodynamic properties of soybean by using cylindrical tunnels of diameters 20, 30, 40, 50, 60 and 70 mm and squared tunnels of the same dimensions. They stated that the terminal velocity obtained by calculation is compatible with the one obtained from experimental data if soybean is treated as a sphere. They also reported that there is wall effect when the ratio of particle diameter to tunnel diameter is larger than 0.12 but the wall effect is smaller when the tunnel has square form.

Allen and Watts (1997) measured the terminal velocity of minica beans using a wind tunnel. They determined the terminal velocity and drag coefficient of the bean using two orientations of the bean; “flat” and “epidermis down”. They obtained 7.9 and 10.2 m/s respectively for the terminal velocity and 0.89 and 0.768 respectively for drag coefficient.

Shellard and Macmillan (1978) measured the terminal velocities of the straw and other particles which make up the head of Olympic wheat varieties by both drop tests and suspension tests in a vertical wind tunnel. They obtained a terminal velocity of 8.02 m/s for grain, 7.01 to 3.05 m/s for unthreshed and partly threshed head and 1.83 m/s for chaff.

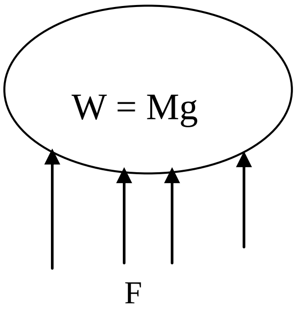
Gupta and Das (1997) measured the terminal velocity of sunflower seeds and kernels in the moisture content range of 4 to 20% d.b., by suspension tests in a vertical air stream. They found out that at any moisture content between 4 and 20% d.b., the terminal velocity of seed was higher than that of kernel and hull. In addition, the terminal velocity increased from 5.8 to 7.6 m/s, 3.5 to 5.8 m/s and 1.7 to 2.8 m/s for seed, kernel and hull respectively with increase in moisture content.

Hauhouot-O’Hara e*t al.* (2000) measured the terminal velocities of cheat seeds and wheat at a moisture content of 12% w.b. using a wind tunnel. They reported that the terminal velocities of cheat seeds ranged from 1.8 to 4.5 m/s with a mean of 3.14 m/s while the mean terminal velocities of wheat was 7.84 m/s. They concluded that aerodynamic separation of cheat seeds and wheat is theoretically possible because of the wide interval between their terminal velocities.

This research work investigated the terminal velocities of four varieties of cowpea as well as that of light weight impurities commonly found in cowpea so as to investigate their separation in a vertical flow pneumatic cleaner.

2.4.3 Aerodynamics of small particles

A particle falling freely will attain a steady velocity that depends on the physical characteristics of the particle, the fluid in which it is falling and the gravitational force (Henderson and Perry, 1976). For a particle falling freely as shown below:



the forces involved in falling are

$$M\left(\frac{dv}{dt}\right) = (V_p\rho_p - V_p\rho)g - F \tag{9}$$

$$= Mg\left(\frac{\rho_p - \rho}{\rho_p}\right) - F \tag{10}$$

F is defined as (in eqn. 5)

$$F = \frac{1}{2}Cv^2\rho A$$

By substituting for F, equation (10) now becomes

$$M\left(\frac{dv}{dt}\right) = Mg\left(\frac{\rho_p - \rho}{\rho_p}\right) - 1/2CV^2\rho A \tag{11}$$

Dividing throughout by M

$$\frac{dv}{dt} = \pm g\left(\frac{\rho_p - \rho}{\rho_p}\right) - \frac{CV^2\rho A}{2M} \tag{12}$$

Where A = projected area of particle, m^2

ρ = density of fluid, kg/m^3

ρ_p = density of particle, kg/m^3

V_p = volume of particle, m^3

C = particle aerodynamic drag coefficient, dimensionless

V = velocity of particle, m/s

F = drag force, N

M = particle mass, kg

W = particle weight, N

t = time, s

g = acceleration due to gravity, m/s^2

The projected area, A, normal to the direction of motion for ellipsoidal shape is given by (Hauhouot – O'Hara *et al.*, 2000):

$$A = \frac{\pi ab}{4} \qquad (13)$$

Where a = major axial dimension of particle, m

b = intermediate axial dimension of particle, m

The sign of the term g in equation (12) is positive for a particle starting from rest or having an initial downward velocity and it is negative for an initial upward velocity. If ρ_p is larger than ρ, the particle's motion will be downward during the steady state condition. If the fluid is denser than the particle, i.e., ρ is larger than ρ_p, the particle will rise when terminal velocity is attained (Henderson and Perry, 1976).

When the particle attains a terminal velocity V_t,

$\frac{dv}{dt,}$ = 0 and Equation (13) becomes

$$\frac{CV^2\rho A}{2M} = g\frac{(\rho_p - \rho)}{\rho_p} \qquad (14)$$

$$V^2 = \frac{2Mg(\rho_p - \rho)}{CA\rho_p\rho} \qquad (15)$$

$$V = \sqrt{\frac{2Mg(\rho_p - \rho)}{CA\rho_p\rho}} \qquad (16)$$

This gives another expression for terminal velocity.

2.4.4 Relationship between Reynolds number and drag coefficient.

Reynolds number (Re) is given by

$$\mathrm{Re} = \frac{\rho VD}{\mu} \qquad (17)$$

Where ρ = density of air, kg/m^3

V = velocity of air, m/s

D = diameter of flow, m

μ = dynamic viscosity of air, kg/m .s

Therefore, $$V = \frac{\mathrm{Re}\,\mu}{\rho D} \tag{18}$$

At equilibrium condition, V is equal to the terminal velocity of the particle. Thus,

$$V^2 = \frac{\mathrm{Re}^2\,\mu^2}{\rho^2 D^2}$$

(19)

can be equated to Equation (16)

$$\frac{2Mg(\rho_p - \rho)}{CA\rho_p\rho} = \frac{\mathrm{Re}^2\,\mu^2}{\rho^2 D^2} \tag{20}$$

$$\mathrm{Re}^2 = \frac{2Mg\rho D^2(\rho_p - \rho)}{CA\mu^2\rho_p} \tag{21}$$

Also, $$C\,\mathrm{Re}^2 = \frac{2Mg\rho D^2(\rho_p - \rho)}{A\mu^2\rho_p} \tag{22}$$

2.5 Models of grain cleaning and particle's trajectory

The models for pneumatic cleaning in a combine harvester developed by Rhumble and Lee (1970) and reported by Scrivaster *et al.* (2006) are given as:

$$\frac{d^2y}{dt^2} = g - g\left(\frac{V_y}{V_t}\right)^2 \tag{23}$$

$$\frac{d^2x}{dt^2} = g\left(\frac{V_x}{V_t}\right)^2 \tag{24}$$

Where V_x = velocity of the particle relative to the air in the horizontal direction, m/s

V_y = velocity of the particle relative to the air in the vertical direction, m/s

V_t = terminal velocity of particle, m/s

g = acceleration due to gravity, m/s^2

This model is applicable to aerodynamic or pneumatic separation of a mixture of

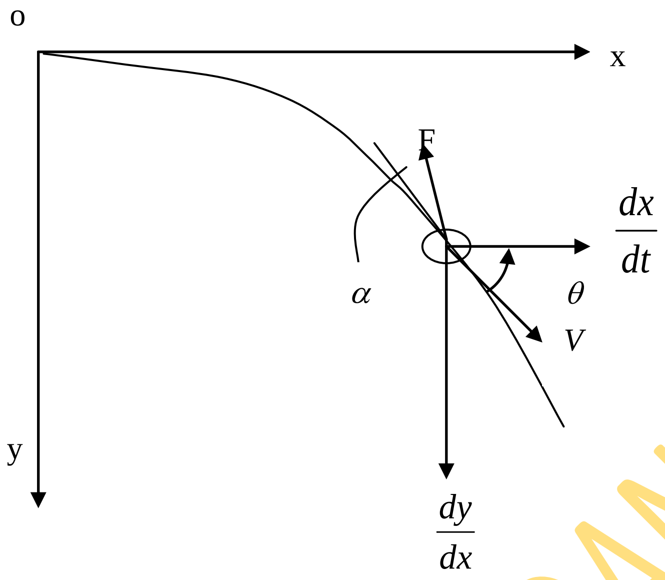


Figure 2.1. Variables in a projectile's flight

Source: Mennel and Reece, 1963

Where $\frac{dx}{dt}$ = horizontal component of particle's velocity, m/s

$\frac{dy}{dt}$ = vertical component of particle's velocity, m/s

θ = direction of particle's motion measured from the horizontal, degree

V = Particle's velocity, m/s

F = drag force (aerodynamic drag), N

α = angle between drag force and direction of motion, degrees grain, chaff and small pieces of straw when the mixture falls from the oscillating pan or an auger bed into an air blast directed at 45° towards the rear of the combine.

For a projectile moving in the x-y plane as shown in Figure 2.1, the fundamental equations of motion reported by Manuel and Reece (1963) are:

For motion with negligible air resistance,

$$\frac{dx}{dt} = u \tag{25}$$

$$\frac{dy}{dt} = gt \tag{26}$$

and the trajectory is given by

$$y = \tfrac{1}{2} g \frac{x^2}{u^2} \tag{27}$$

For motion with air resistance, the equations of motion are

$$\frac{d^2x}{dt^2} = -\frac{F}{m}\cos\theta \tag{28}$$

$$\frac{d^2y}{dt^2} = g - \frac{F}{m}\sin\theta \tag{29}$$

Where F is the aerodynamic drag defined as in Equation (5) as

$$F = \tfrac{1}{2} C\rho A V_a^{\,2} \tag{30}$$

They showed that for a spherical particle, A is given by

$$A = \frac{\pi D^2}{4} \tag{31}$$

Thus F for a spherical particle becomes

$$F = \frac{1}{8} C\rho\pi D^2 V_a^{\,2} \tag{32}$$

They further stated that for spherical particles in turbulent flow when R > 800 and C is approximately constant, Equation (31) can be expressed as

$$F = K_1 V^2 \cos\theta \qquad (33)$$

and the equations of motion as

$$\frac{d^2x}{dt^2} = -KV^2\cos\theta \qquad (34)$$

$$\frac{d^2y}{dt^2} = g - Kv^2 Sin\theta \qquad (35)$$

Where $K = \frac{K_1}{m} = C\frac{3}{4}\frac{\rho_a}{\rho_p}\frac{1}{D}$ (36)

They then transformed Equations (35) and (36) into

$$x = \frac{u^2}{g}\int_0^\theta \frac{d\theta}{\cos^2\theta\left[1+\frac{ku^2}{mg}\left\{\tan\theta\sec\theta + \log_e(\tan\theta+\sec\theta)\right\}\right]} \qquad (37)$$

$$y = \frac{u^2}{g}\int_0^\theta \frac{\tan\theta \cdot d\theta}{\cos^2\theta\left[1+\frac{ku^2}{mg}\left\{\tan\theta\sec\theta + \log_e(\tan\theta+\sec\theta)\right\}\right]} \qquad (38)$$

due to the inability to transform them into one equation relating y to x. They also stated that Equations (35) and (36) can be expressed in dimensionless form to give the very simple result

$$y = f(x, k, u, g) \qquad (39)$$

for which $\frac{gy}{u_2} = f\left(\frac{ku^2}{g}\right)..\left(\frac{gx}{u_2}\right)$ (40)

Csizmazia and Polyak (2005) reported that an airborne particle that moves relative to its surrounding air experiences gravitational, buoyant, frictional and inertial forces acting on it. They stated that for a particle transversing a vertical path y = y (t) in a gravitational field, the Newtonian mechanics gives the equation of motion:

$$m\frac{d^2y}{dt_2} = mg\frac{(\rho_s - \rho)}{\rho_s} - K\left(\frac{dy}{dt}\right)^2 \qquad (41)$$

Where m = particle mass, kg

g = gravitational acceleration, m/s^2

ρ_s = particle density, kg/m^3

ρ = air density, kg/m^3

K = aerodynamic resistance coefficient, kg/m

for grain $\rho_s >> \rho$. Therefore, when the grain attains a terminal velocity of V_t

$$\frac{d^2y}{dt^2} = 0 \text{ and } \frac{dy}{dt} = V_t$$

Equation (41) now becomes

$$mg = KV_t^2 \quad (\text{since } \frac{\rho_s - \rho}{\rho_s} \approx 1) \tag{42}$$

Therefore

$$K = \frac{mg}{V_t^2} \tag{43}$$

The resistance coefficient K is related to aerodynamic drag coefficient C (Csizmazia and Polyak, 2005) as

$$C = \frac{2K}{A\rho} \tag{44}$$

Kashayap and Panda (1965) reported that the fundamental two dimensional equations of motion of a particle in a gravitational field as

$$\Delta U_h = \frac{\rho_f CAUU_h}{2M}\Delta t \tag{45}$$

$$\Delta U_v = \left(g - \frac{\rho_f CAUU_v}{2M}\right)\Delta t \tag{46}$$

Where U = relative velocity of particle, m/s

U_h = horizontal component of particle's velocity, m/s

U_v = vertical component of particle, velocity, m/s

They used these equations to obtain the horizontal and vertical displacements which were used to plot the trajectories of wheat and impurity particles thrown into the air during winnowing.

Li *et al*. (2005) carried out a two-dimensional numerical study of separation process of crop seeds (soybean and mustard seeds) by screening using discrete element method (DEM) modeling technique. They demonstrated the crucial effect of particle bed dept on screening efficiency. They concluded that for a screening system involving granular materials, the critical feeding rate for the most effective screening operation can be determined by conducting the discrete element simulation.

Gorial and O'Callaghan (1991a) developed a mathematical model to simulate the paths of grains (wheat) and straw particles projected into an air stream through a belt conveyor. They obtained the displacement of a falling particle in the x and y direction as:

$$S_y = V_t^2 \ln \cosh \frac{gt}{V_t} \tag{47}$$

While for a rising particle, the displacement in the y direction was given as

$$S_y = -\frac{V^2{}_t}{g} \ln \sinh \frac{gt}{V_t} \tag{48}$$

and in the x direction as

$$S_x = V_a t + \frac{V^2{}_t}{g} \ln \left(\frac{C}{\left(C + \frac{gt}{V_t} \right)} \right) \tag{49}$$

Where S_y = displacement in y-direction

S_x = displacement in x-direction

V_t = terminal velocity

V_a = air velocity

C = integration constant

g = gravitational acceleration

Gorial and O'Callaghan (1991b) used Equations (48) and (49) to calculate the trajectories of different components of wheat-straw mixture projected by a belt conveyor into a horizontal air stream. The trajectories were used to predict the separation of the grains into different fractions and the horizontal position where each fraction was deposited. The predicted horizontal displacement of the fractions agreed reasonably with those obtained from experimental data.

Macmillan (1999) developed a computer model to analyse the particle separation that occurs when grain and chaff were winnowed by being thrown or dropped in the wind. A computer program based on numerical integration of the equations of motion was developed and used to plot the horizontal and vertical positions of each particle in a wheat-chaff mixture as a function of time. The model showed that for a given throw velocity, increasing the air velocity increases the separation for all angles of throw. It also showed that for all combination of air and throw velocity the maximum separation is achieved at an angle of throw of about 140^o.

Simonyan *et al.* (2006) used a mathematical model based on physical-aerodynamic properties of sorghum and machine characteristics to develop a predictive equation to describe the cleaning process in a stationary sorghum thresher. They used dimensional analysis to obtain a functional relationship between the cleaning efficiency and independent variables such as grain moisture content, straw moisture content, grain bulk density, straw bulk density, feed rate, sieve oscillation frequency, threshing cylinder speed, diameter of sieve hole, air velocity and particle density. The cleaning efficiency model showed a good agreement between the predicted and experimental result ($p \leq 0.05$).

Adewumi *et al.* (2006) developed a two dimensional mathematical model to predict particle trajectory when threshed cowpea materials were projected from a thresher into a horizontal air stream. The model was developed by resolving the drag and gravitational forces in the two dimensions and integrating the acceleration component twice. The resulting displacement equations were solved numerically to obtain a plot of particle trajectory which was used as a guide for selecting the dimensions of a cross flow pneumatic classifiers for the grains.

Panasiewicz (1999) developed a two dimensional model to predict the horizontal and vertical displacements of lupine seed injected into a diagonal air stream. He obtained the horizontal and vertical displacements as:

$$x = ut\cos\beta - \frac{\cos\theta}{k}\ln\left|1 + v_0 kt\right| \tag{50}$$

$$y = ut\sin\beta - \frac{\sin\theta}{k}\ln\left|1 + v_0 kt\right| \tag{51}$$

Where k= volatility coefficient

u= air velocity, m/s

θ = angle between air stream and the horizontal, degrees

v_0 = relative velocity of particles, m/s

β = angle between air velocity and gravitational force on particles, degrees

t = time (s)

This research work aims at developing models for predicting the horizontal and vertical displacements of a particle of cowpea and impurity in a vertical flow pneumatic cleaner and for predicting the cleaning efficiency of the machine.

CHAPTER THREE

METHODOLOGY

3.1 Material

3.1.1 Cowpea and light weight impurities

Four varieties of (freshly threshed) cowpea (together with chaffs) were obtained from the Institute of Agricultural Research and Training, Moor Plantation, Ibadan. The four varieties were Ife 98-12, IT90K-277-2, Ife Brown, and Drum (Plates 3.1 to 3.4.). These varieties are a fair representation of the most popular varieties in the country (two white and two brown varieties). To represent the light weight impurities that are commonly found in cowpea, the chaffs were cut into different lengths of 40 , 60 and 80 mm (4 , 6 , and 8 cm) based on preliminary investigation on chaff length distribution in cowpea available in the market. Some of the cowpea grains were also allowed to undergo insect infestations by keeping them in untreated sack bags. Furthermore, immature seeds were carefully hand picked from the threshed cowpea. The cowpea varieties and impurities are as presented in Plates 3.5 to 3.11.

3.2 Method

3.2.1 Physical properties of cowpea

The physical properties of cowpea that were determined include axial dimensions, geometric mean diameter, sphericity, aspect ratio, true density, bulk density, porosity, projected area and 1000 grain mass. These properties were determined at four moisture levels of 8, 12, 14 and 18% w.b. since harvesting and most of the processing operations of cowpea are performed in this range of moisture content.

3.2.1.1 Axial dimensions

Fifty grains from each variety of cowpea were randomly selected at each moisture content level. Each of the fifty selected grains was measured carefully along three perpendicular axes using a micrometer screw gauge reading to 0.01 mm.

The geometric mean diameter of each variety of cowpea was also determined using the following relationship (Moshenin, 1986; Desphande *et al.*, 1993; Lucas and Olayanju, 2003):

Plate 3.1. Ife 98-12

Plate 3.2. IT90K-277-2

Plate 3.3 Ife Brown

Plate 3.4. Drum

Plate 3.5. Chaff (4cm long)

Plate 3.6. Chaff (6cm long)

Plate 3.7. Chaff (8cm long)

Plate 3.8. Immature seeds

Plate 3.9. Insect infested grains (Ife Brown)

Plate 3.10. Insect infested grains (Ife 98-12)

Plate 3.11 Insect infested IT90-277-2

Geometric mean diameter, $D_g = (abc)^{1/3}$ (52)

Where a = the dimension along the longest axis (length), in mm

b = the dimension along the axis perpendicular to ‘a’ (width), in mm

c = the dimension along the longest axis perpendicular to both ‘a’ and ‘b’, in mm

3.2.1.2 Sphericity and aspect ratio

The sphericity (S_p) and aspect ratio (R_a) for 50 randomly picked grains from each variety was calculated using the following relations (Hauhouot-O’Hara *et al.*, 2000).

$$S_p = \frac{(abc)^{1/3}}{a} \tag{53}$$

$$R_a = \frac{b}{a} \tag{54}$$

3.2.1.3. True density

The true density of grain is defined as the ratio of the mass of a sample of the grain to the volume occupied by the same sample. A weighed quantity of each variety of cowpea was poured into 100 cm^3 fractionally graduated cylinder containing 50 cm^3 of distilled water. The volume of water displaced by the grains was noted. The true density was then calculated as:

$$\text{True density} = \frac{m_s}{v_w} \tag{55}$$

Where m_s = mass of sample, g

v_w = volume of water displaced, cm^3

3.2.1.4 Bulk density

The bulk density was determined by filling a container of known mass and volume to the brim with each variety of cowpea. The net mass of cowpea was obtained by subtracting the mass of the container from the mass of the container and cowpea. To achieve uniformity in bulk density, the container was tapped 10 times in the same manner in all measurement to consolidate as reported by Irtwange (2000). The bulk density was then calculated as

$$\text{Bulk density} = \frac{m_s}{v_o} \tag{56}$$

Where m_s = mass of sample, g

v_o = volume occupied, cm^3

3.2.1.5 Porosity

The porosity was calculated from the bulk and true densities by using the relationship:

$$P = 100\left(1 - \frac{\rho_b}{\rho_t}\right) \tag{57}$$

Where P = porosity, %

ρ_b = bulk density, g/cm^3

ρ_t = true density, g/cm^3

3.2.1.6 Projected area, A_p

The projected area was calculated in two ways. Firstly, since cowpea is ellipsoidal in shape (Nwuba *et al.*, 1994), the projected area was calculated using Equation (13). Secondly, because of the high sphericity index obtained for cowpea (above 70%) from the preliminary study of the sphericity of the four varieties, a spherical shape was assumed for analytical calculation and the projected area calculated as (Duarte *et al.*, 2004):

$$A_p = \frac{\pi D^2 g}{4} \tag{58}$$

3.2.1.7 Moisture content determination and adjustment

The moisture content of cowpea samples was determined by oven drying method using ASAE standards of 1998 for cowpea. About 15 g of each variety was put in the oven at a temperature of 103^o C for 72 hours. The weight of moisture in each sample was determined by subtracting the weight of the sample after drying from the weight of the sample before drying. The moisture content was then calculated from the formula:

$$\text{Moisture Content, \% w.b.} = \frac{W_m}{W_w} \times 100 \qquad (59)$$

Where W_m = weight of moisture

Ww = weight of wet material

Calculated amount of distilled water was added to bring the samples to the desired moisture content levels. The amount of water added was calculated from the relation (Visvanathan *et al.*, 1996):

$$Q = \frac{A(b-a)}{(100-a)} \qquad (60)$$

Where Q = mass of water added, g

A = initial mass of sample, g

a = initial moisture content of sample, % w.b.

b = final (desired) moisture content of sample, % w.b.

After adding the calculated amount of water, the samples were thoroughly mixed and then kept in a sealed polythene bag. The polythene bag was then kept in a refrigerator at 5^{o}C for a week to enable the moisture to equilibrate throughout the sample.

3.2.2 Aerodynamic properties of cowpea and chaffs

The terminal velocity of cowpea grain was determined experimentally by finding their suspension velocities in the vertical wind tunnel shown in Plate A3. A grain of each variety was placed on a mesh screen at the bottom of the vertical wind tunnel. Input air was adjusted until the grain began to float. The velocity at which the grain became suspended was measured. Ten replicates were taken at each moisture content level. This procedure was repeated for the chaff and the immature grains using the wind tunnel in Plate A4. The aerodynamic drag coefficient of grains was then calculated from the measured terminal velocity. For the chaff, immature and insect infested grains, the product of drag coefficient and projected area (C.A) was calculated from their terminal velocities as resistance coefficients because of their unstable behaviour in the wind tunnel in which there was no specific frontal or projected area (Shellard and Macmillan, 1978; Khostaghaza and Mehdizadeh, 2006). The terminal velocity of cowpea grains for the four varieties was calculated theoretically using Equation (8).

3.3 Cowpea Cleaning in a Vertical Flow Pneumatic Cleaner

The vertical flow pneumatic cleaner separates impurities from falling cowpea grains by altering its trajectory as it falls through the air stream (Henderson and Perry, 1976). In a typical vertical flow pneumatic cleaner (Figure 3.1), the cowpea grains to be cleaned are released from the hopper into a vertical air stream which alters the trajectory of impurities from sound grains. Examples of vertical flow pneumatic cleaners are shown in Plates A1 and A2. Thus comparing the trajectories of different particles that fall into the air stream will show how effectively impurities particles can be separated from sound grains under a given set of parameters such as angle of injection, moisture content and velocity of air steam. This will help to determine the combination of parameters that will produce optimum cleaning or separation.

3.4 Modelling of Cowpea and Impurities' Trajectories

In order to predict the trajectories of cowpea and impurities' particle in a pneumatic cleaner, the equations of their displacements must first be developed. The following assumptions were made in developing a 2-D model for the displacement of a particle of cowpea and impurity that falls from the hopper into the air stream:

i. The particles (grains) are spherical.
ii. The air flow is uniform
iii. The drag coefficient of the particles remains constant over the range of air velocities considered.
iv. The particle's motion is two dimensional (2-D)
v. Only drag and gravitational forces are responsible for the movement of particles.
vi. The effect of temperature and other environmental conditions are negligible.
vii. Pressure drop is negligible across the system.
viii. The direction of particle motion, ϴ, is equal to the angle of injection of particles.
ix. The point of injection of the particles into the air stream is the origin of the motion.
x. All the particles are adequately exposed to the air stream.

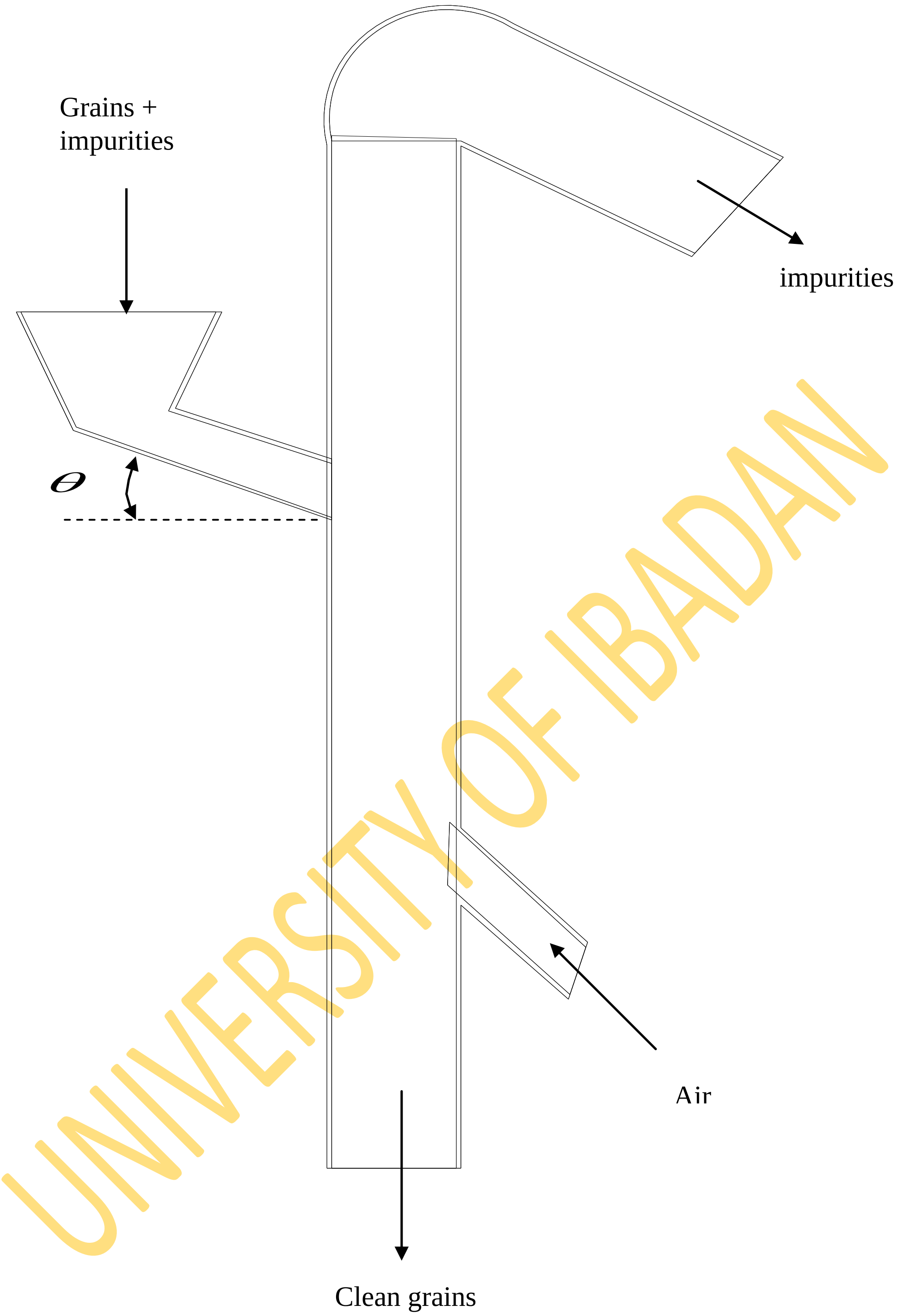


Figure 3.1. Schematic diagram of a vertical flow pneumatic cleaner

xi. The angle between drag force and direction of motion is equal to zero i.e. the drag force acts in opposite direction to the velocity of particle relative to the air.

The equations of displacement of a particle that falls from the hopper into the air stream was developed by determining the resultant of all forces acting on it (Figure 3.2) in the horizontal and vertical directions. The acceleration component of the resultant force was then integrated twice to obtain the displacement equation.

In the horizontal direction, acceleration is zero since velocity is constant. Thus resultant force is zero. Therefore

$$-F\cos\theta = m\frac{d^2x}{dt^2} \tag{61}$$

Rearranging gives

$$\frac{d^2x}{dt^2} = -\frac{F}{m}\cos\theta \tag{62}$$

In the vertical direction, the resultant force producing the acceleration is given by:

$$-mg + F\sin\theta = -m\frac{d^2y}{dt^2} \tag{63}$$

$$mg - F\sin\theta = m\frac{d^2y}{dt^2} \tag{64}$$

Rearranging and dividing through by m gives:

$$\frac{d^2y}{dt^2} = g - \frac{F}{m}\sin\theta \tag{65}$$

Equations (62) and (65) were integrated twice and simplified to obtain the displacement of the particle in the x and y directions:

$$\int d^2x = \int \frac{F}{m}\cos\theta dt^2 \tag{66}$$

$$dx = \frac{Ft}{m}\cos\theta dt + C_x \tag{67}$$

$$\frac{dx}{dt} = \frac{Ft}{m}\cos\theta + C_x \tag{68}$$

Where C_x is constant of integration.

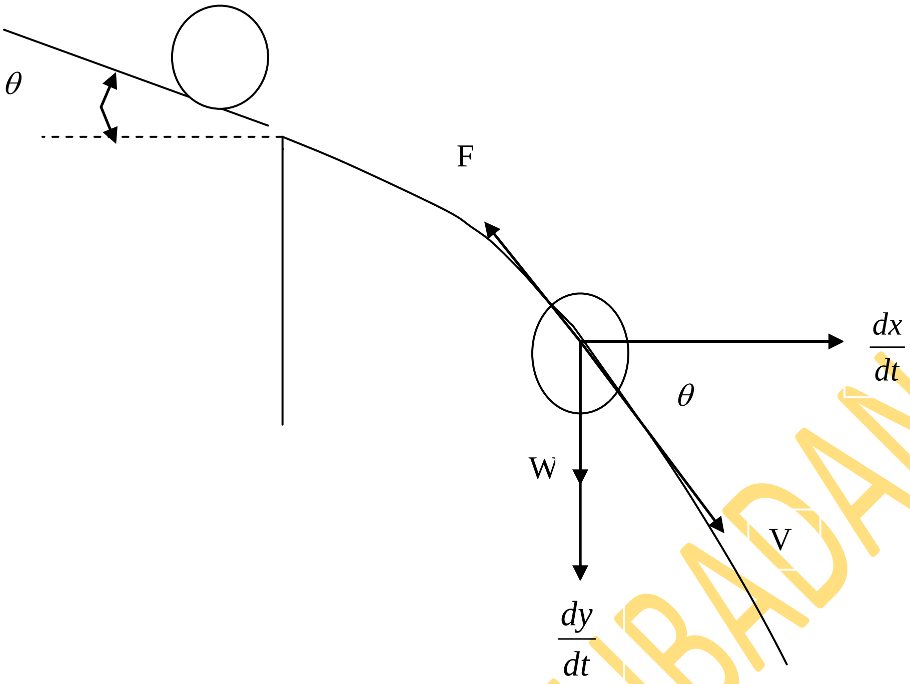


Figure 3. 2. Forces on a particle that falls from the hopper into a vertical air stream

Where $\frac{dx}{dt}$ = horizontal component of particle's velocity, m/s

$\frac{dy}{dt}$ = vertical component of particle's velocity, m/s

θ = direction of particle's motion measured from the horizontal, degree

W = weight of particle, N

V = particle's velocity, m/s

F = drag force, N

But $\frac{dx}{dt} = v_x$ (velocity in x direction) and at time t = 0, v_x = 0, thus C_x = 0

Therefore,

$$\frac{dx}{dt} = \frac{Ft}{m}\cos\theta \qquad (69)$$

$$\int dx = \frac{F}{m}\cos\theta \int t dt \qquad (70)$$

$$x = \frac{Ft^2}{2m}\cos\theta + D_x \qquad (71)$$

Where D_x is constant of integration.

x is the horizontal displacement of the particle from starting point and at time t = 0, x = 0, hence D_x = 0. Thus

$$x = \frac{Ft^2}{2m}\cos\theta \qquad (72)$$

Similarly, integrating Equation (66) gives

$$\int d^2y = \int\left(g - \frac{F}{m}\sin\theta\right)dt^2 \qquad (73)$$

$$dy = \left(gt - \frac{Ft}{m}\sin\theta\right)dt + E_y \qquad (74)$$

$$\frac{dy}{dt} = \left(gt - \frac{Ft}{m}\sin\theta\right) + E_y \qquad (75)$$

Where E_y is constant of integration.

But $\frac{dy}{dt} = v_y$ (velocity in y direction). At time t = 0, v_y = 0 and E_y

Therefore,

$$\frac{dy}{dt} = gt - \frac{Ft}{m}\sin\theta \qquad (76)$$

$$\int dy = \int\left(gt - \frac{Ft}{m}\sin\theta\right)dt \qquad (77)$$

$$y = \frac{1}{2}gt^2 - \frac{Ft^2}{2m}\sin\theta + G_y \qquad (78)$$

Where G_y is constant of integration.

y is the vertical displacement of particle from starting point and at time t = 0, $y = 0$ hence $G_y = 0$. Thus

$$y = \frac{1}{2} g t^2 - \frac{F t^2}{2m} \sin\theta \tag{79}$$

The drag force F acting on a particle is given by

$$F = \frac{1}{2} C \rho_a A V_r^{\ 2} \tag{80}$$

$$V_r = V_a + V_i \sin\theta \tag{81}$$

Where V_r = velocity of particle relative to air, m/s

Va = air velocity, m/s

V_i = injection velocity of particle, m/s

Equations (72) and (79) give the displacement of a particle that falls from the hopper into the air stream in the x and y directions. A computer package-MATHCAD was used to solve the equations for the four varieties of cowpea and different impurities namely chaff, immature grains and insect infested grains at angles of injection of 15, 30, 45 and 60^o which are greater than reported angles of friction for cowpea on plywood and mild steel (Irtwange, 2009; Chukwu and Summonu, 2010)' air velocities of 4, 6, and 8 m/s and injection velocities of 0.05 to 0.5 m/s to obtain their horizontal and vertical displacements. Plots of the vertical displacements against time and against horizontal displacements were produced for each particle. The trajectories obtained were used to predict the effect of angle of injection and air velocity on separation of impurities from cowpea.

A pneumatic cleaner was designed and constructed with a hopper of variable inclination. The design drawing of the machine is shown in Figures 3.3 and 3.4. The mixture of each variety and impurities was then injected into the pneumatic cleaner at the different angles of injection and the cleaning efficiency evaluated by using the relation (Panasiewicz, 1999):

$$n = \frac{W_1}{W_0} .100 \tag{82}$$

Where n = cleaning efficiency, %

W_0 = total mass of impurities in initial material possible to separate in pneumatic cleaner, g

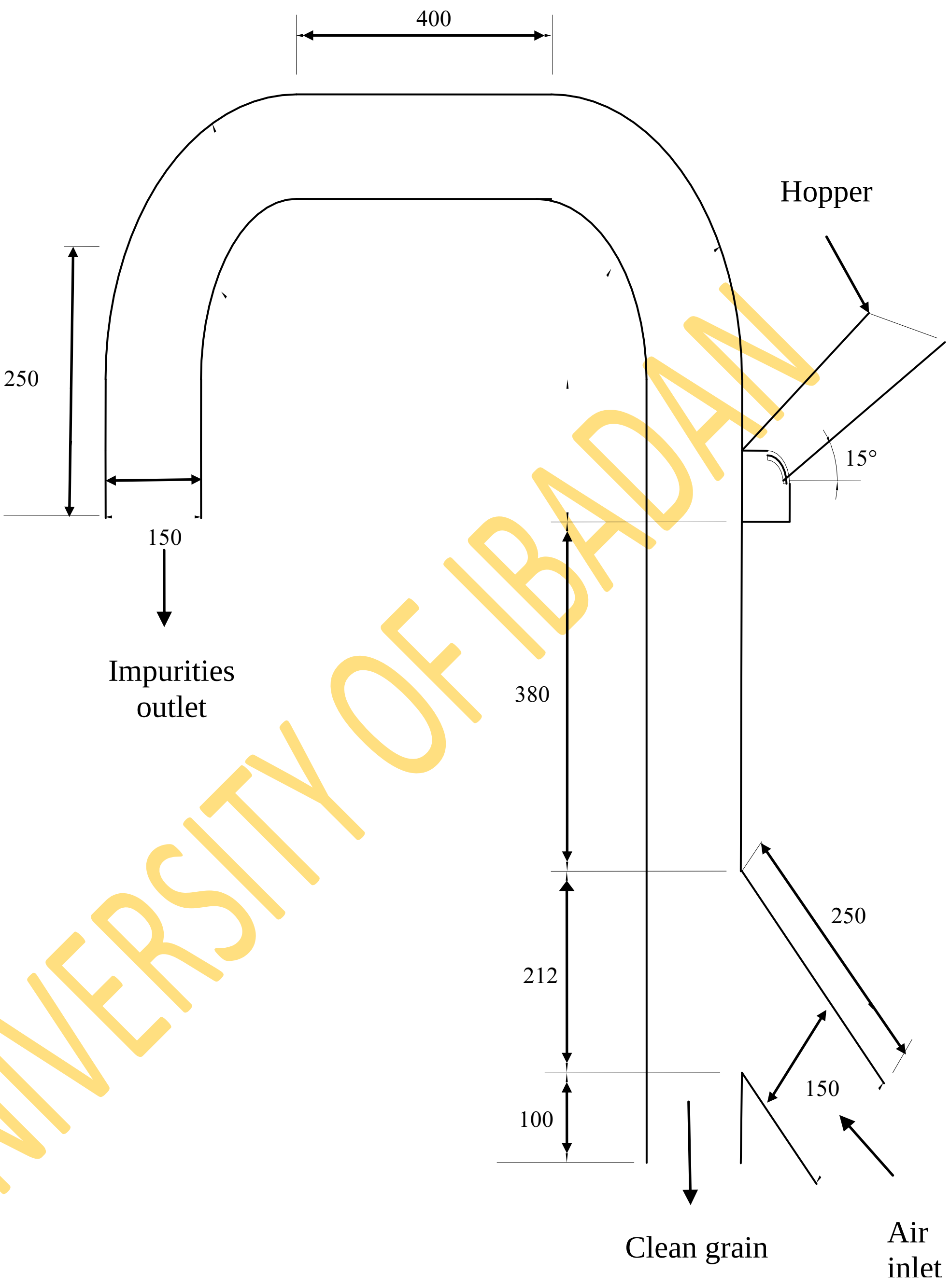


Figure 3.3. The design drawing of the pneumatic cleaner

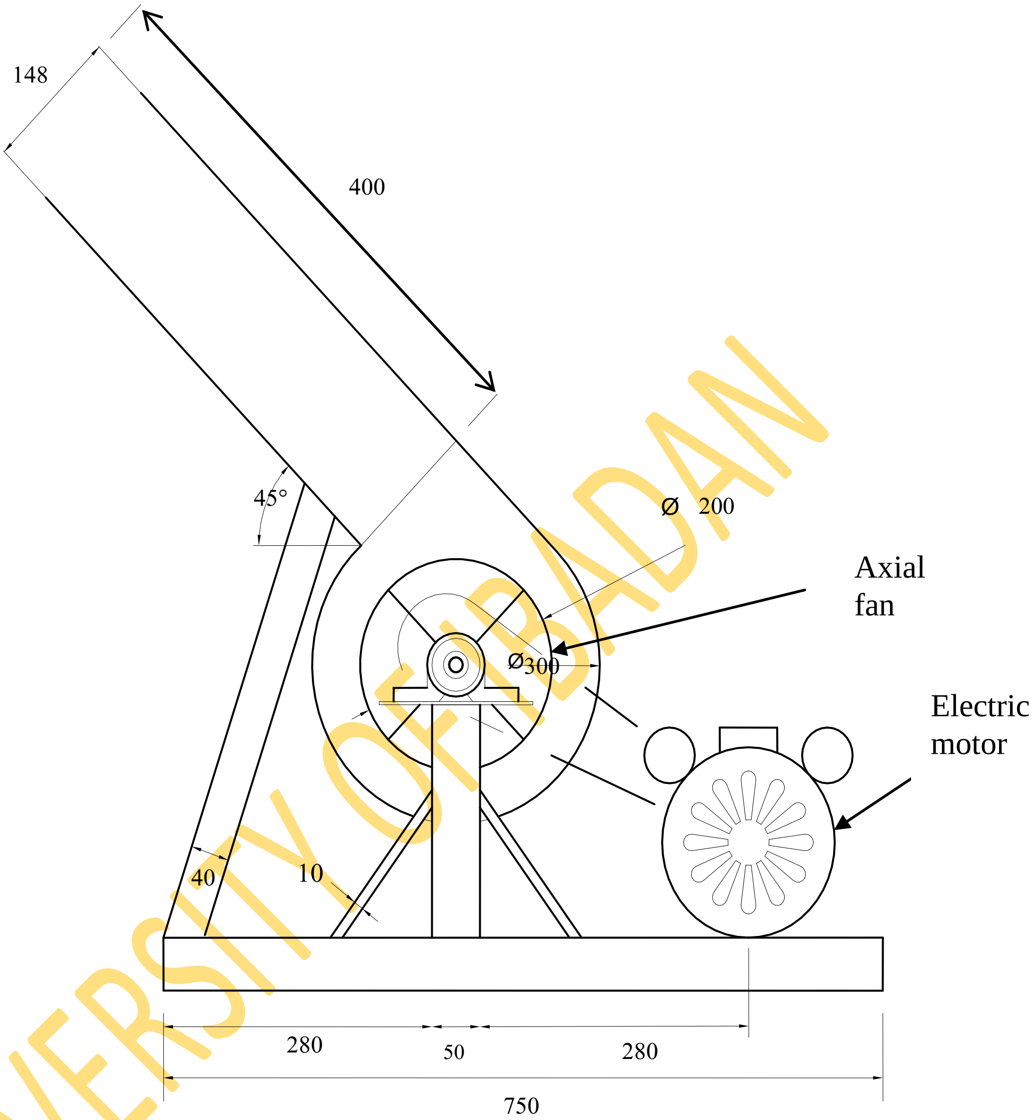


Figure 3.4. The design drawing of the blower

W_1 = mass of impurities separated from initial material in pneumatic separator, g

Three replicates were taken. The average cleaning efficiency obtained for each variety was then compared with the trajectories' prediction. A multiple regression model for predicting the cleaning efficiency was then developed.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Physical Properties of Cowpea

The results of the axial dimensions, geometric mean diameter, sphericity, aspect ratio and projected area at different moisture content levels for the four varieties of cowpea are shown in Tables 4.1 to 4.3 while detailed data are given in the Appendix (Tables A1 to A16). The analysis of variance (ANOVA) tables are shown in the in the Appendix (Tables A51 to A61).

4.1.1 Size and shape

It was observed that the axial dimensions and geometric mean diameter of the four varieties of cowpea increased as the moisture content increased from 8 to 18% w.b. (Table 4.1). For Ife 98-12, the length increased from 9.36 mm at 8% to 9.74 mm at 18% w.b. At this moisture content range the width increased from 6.34 to 6.53 mm, the thickness increased from 5.24 to 5.33 mm while the geometric mean diameter increased from 6.15 to 6.79 mm. For IT90K-277-2, the length increased from 7.70 mm at 8% to 8.49 mm at 18% w.b., the width increased from 6.08 to 6.45 mm, the thickness increased from 5.00 to 5.24 mm while the geometric mean diameter increased from 6.15 to 6.59 mm at the moisture content range respectively. For Ife Brown, the length increased from 8.01 mm at 8% w.b. to 8.49 mm at 18% w.b. At this moisture content range the width increased from 6.01 to 6.46 mm, the thickness increased from 4.42 to 4.75 mm while the geometric mean diameter increased from 5.97 to 6.38 mm. For Drum, the length increased from 9.95 mm at 8% to 10.32 mm at 18% w.b., the width increased from 7.36 to 7.63 mm, the thickness increased from 5.09 to 5.24 mm while the geometric mean diameter increased from 7.18 to 7.42 mm at the moisture content range respectively.

The increase in size and shape with increase in moisture content may be due to the fact that addition of moisture normally increases the volume and weight of any agricultural products as reported by Nalladurai *et al.* (2003). Furthermore, the length

Table 4.1. Mean of axial dimensions and geometric diameter

Variety	**Moisture Content,%**	**Length, mm**	**Width, mm**	**Thickness, mm**	**Geom. Mean Dia., mm**
Ife 98-12	8	9.36	6.34	5.24	6.15
	12	9.53	6.35	5.26	6.82
	14	9.69	6.45	5.27	6.90
	18	9.74	6.53	5.33	6.97
IT90K-277-2	8	7.70	6.08	5.00	6.15
	12	7.97	6.13	5.12	6.30
	14	8.00	6.13	5.15	6.31
	18	8.49	6.45	5.24	6.59
Ife Brown	8	8.01	6.01	4.42	5.97
	12	8.19	6.17	4.46	6.08
	14	8.28	6.29	4.58	6.20
	18	8.49	6.46	4.75	6.38
Drum	8	9.95	7.36	5.09	7.18
	12	10.26	7.50	5.20	7.36
	14	10.27	7.58	5.22	7.40
	18	10.32	7.63	5.24	7.42

to width ratio (L/W) and length to thickness ratio (L/T) for the four varieties of cowpea are also different. This indicates that the length, width and thickness are related differently for the four varieties (Table 4.2). Analysis of variance shows a highly significant difference ($p \leq 0.05$) in variety and moisture content means for length. The effect of variety and moisture content is also significant on width ($p \leq 0.05$). However, only variety significantly affected thickness at ($p \leq 0.05$). The effect of variety and moisture content is also significant on geometric mean diameter ($p \leq 0.05$). The interaction effect of variety and moisture content is not significant on the axial dimensions i.e. length, width and thickness but significant ($p \leq 0.05$) on the geometric mean diameter.

The size and shape of agricultural products are important in their electrostatic separation from unwanted materials and in the development of grading equipment from them. Also since variety has effect on the size and shape of cowpea, different sieve or screen sizes will be needed for threshing, separating and grading of the different varieties of cowpea. Furthermore, the skewdness and kurtosis analysis for the frequency distribution curve for 50 readings taken for each of the four varieties at 12% w.b. are presented in Figures 4.1 to 4.4. The curves show normal distribution for length, width, thickness, geometric mean diameter and sphericity with peaks around the means. This is an indication that the axial dimensions are relatively uniform and these are useful information in the design of separation and size reduction equipment.

4.1.2 Sphericity and aspect ratio

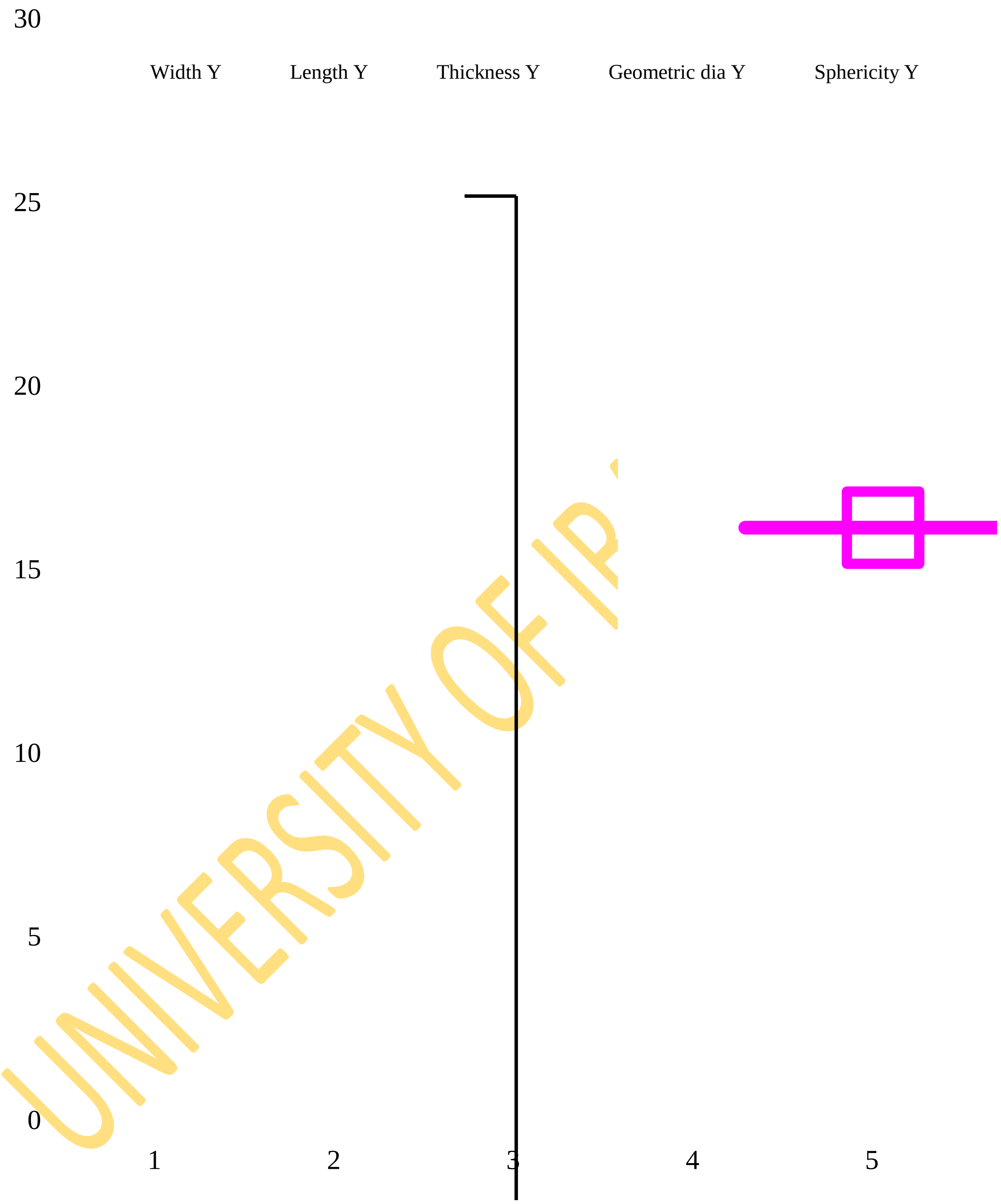
The sphericity was observed to decrease between 8 and 14% w.b. and later increased between 14 and 18% w.b. for Ife 98-12. For IT90K-277-2 it decreased between 8 and 12% w.b., increased between 12 and 14%w.b. and later decreased between 14 and 18% w.b. It decreased between 8 and 12% w.b. and increased between 12 and 18% w.b. for Ife Brown while for drum, sphericity increased between 8 and 12% and decreased between 12 and 18% w.b. (Table 4.3). Analysis of variance shows that only variety significantly affected sphericity ($p \leq 0.05$). The interaction effect of variety and moisture content was also not significant on sphericity ($p \leq 0.05$). The difference in the trend of variation of the sphericity of the four varieties with moisture content could be due to differences in the increase in length relative to the

Table 4.2. Length to width and length to thickness ratios of the cowpea varieties

Variety	Moisture content, %	L/W	L/T
Ife 98-12	8	1.48	1.79
	12	1.50	1.81
	14	1.50	1.84
	18	1.49	1.83
IT90K-277-2	8	1.27	1.54
	12	1.30	1.56
	14	1.31	1.55
	18	1.32	1.62
Ife Brown	8	1.33	1.81
	12	1.33	1.84
	14	1.31	1.81
	18	1.31	1.79
Drum	8	1.35	1.95
	12	1.37	1.97
	14	1.35	1.97
	18	1.35	1.97

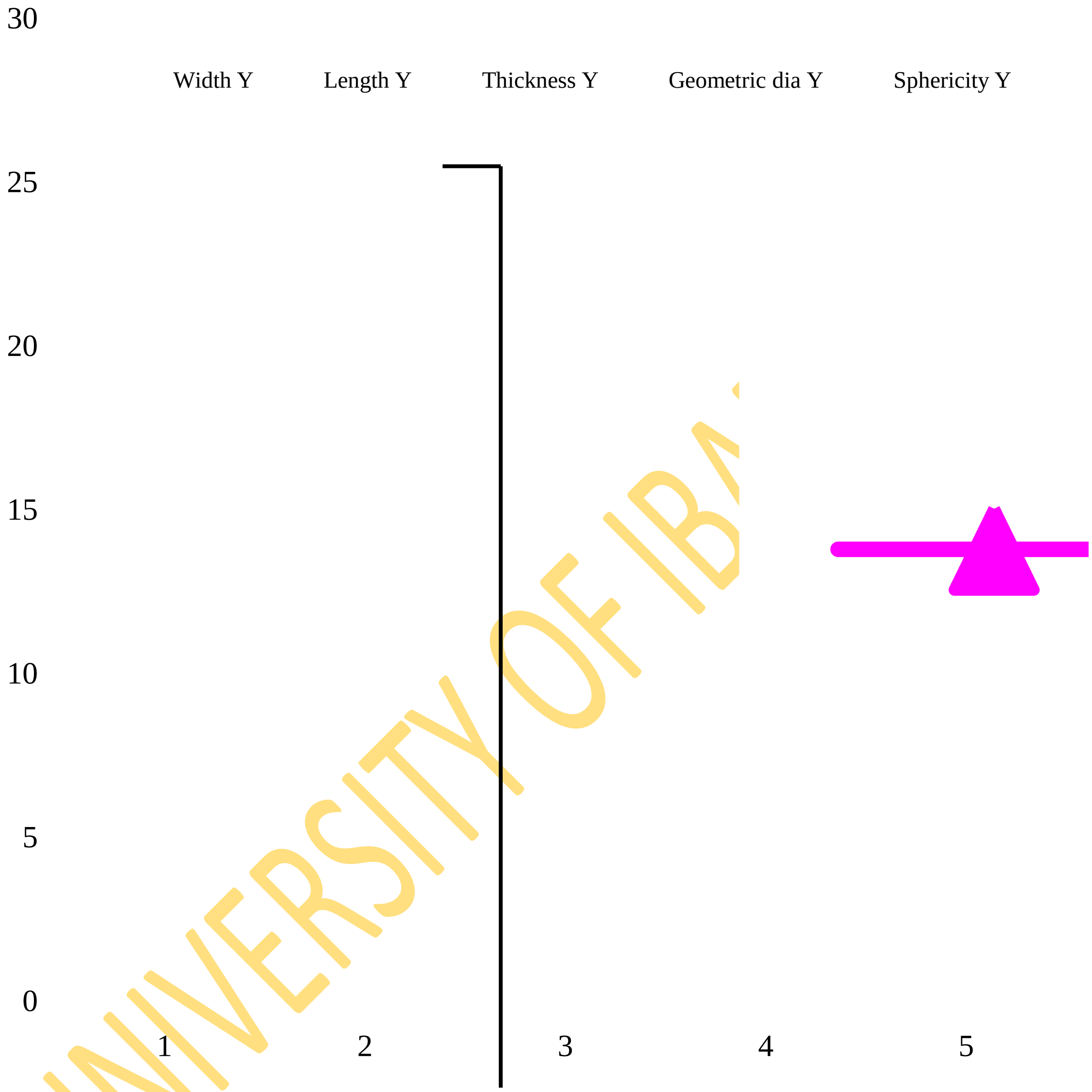
Length, mm	7.5-8.4	8.4-9.3	9.3-10.2	10.2-11.1	11.1-12.0
Width, mm	5.3-5.9	5.9-6.5	6.5-7.1	7.1-7.7	7.7-8.3
Thick., mm	4.3-4.8	4.8-5.3	5.3-5.8	5.8-6.3	6.3-6.9
Geom. Dia	5.5-6.2	6.2-6.8	6.8-7.4	7.4-8.1	8.1-8.7
Sphericty	68.7-72.1	72.1- 75.5	75.5-78.9	78.9-82.3	82.3-5.7

Figure 4.1. Frequency distribution for length, width, thickness, geometric mean diameter and sphericity for Ife 98-12 at 12% w.b.



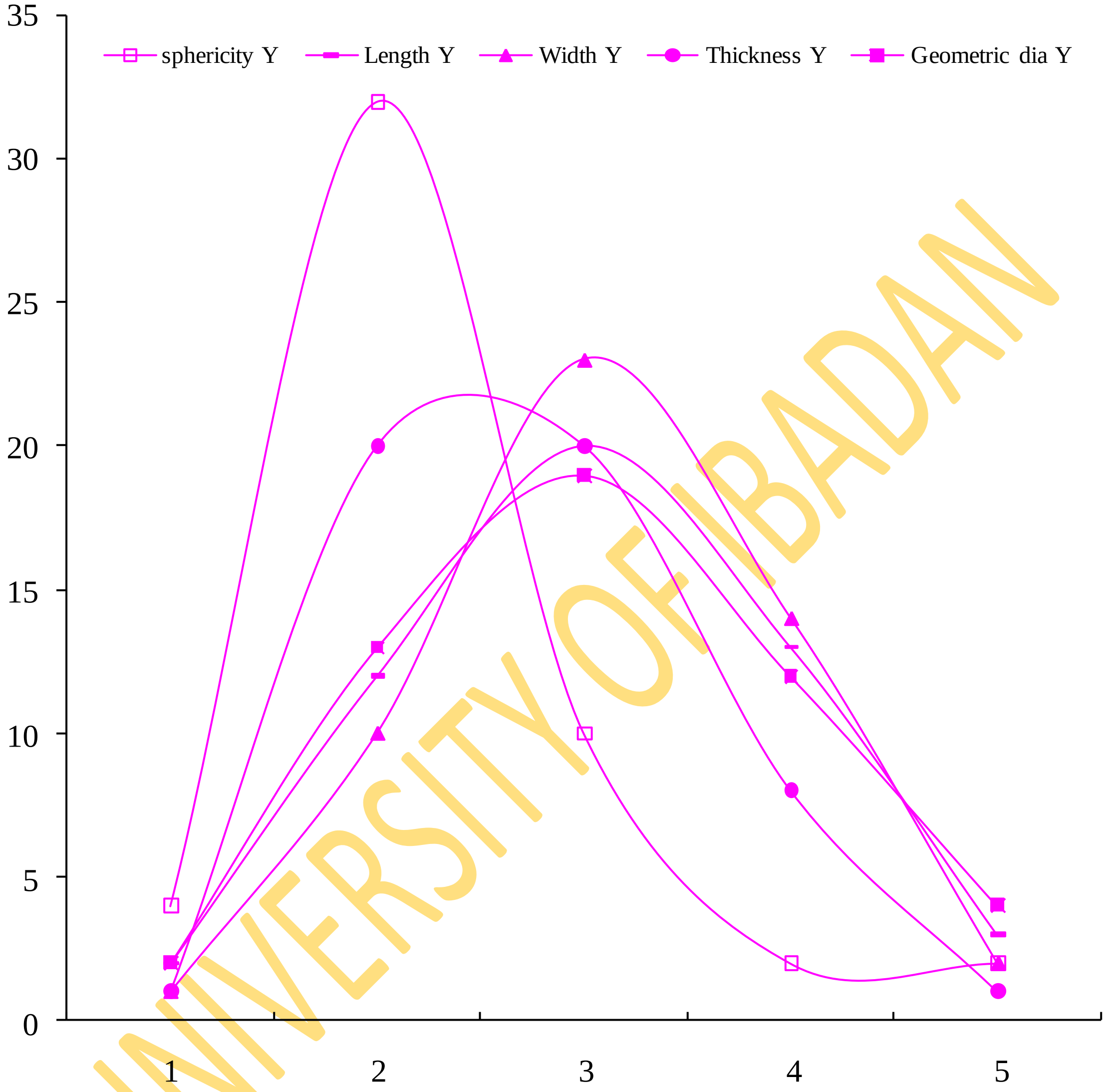
Length, mm	6.4-7.2	7.2-8.0	8.0-8.8	8.8-9.6	9.6-10.4
Width,mm	4.9-5.5	5.5-6.1	6.1-6.7	6.7-7.3	7.3-7.9
Thickness	4.1-4.6	4.6-5.1	5.1-5.6	5.6-6.1	6.1-6.7
Geometric Dia	5.3-5.7	5.7-6.2	6.2-6.7	6.7-7.2	7.2-7.6
Sphericity	46.0-58.0	58.0-70.0	70.0-82.0	82.0-94.0	94.0-106.0

Figure 4.2. Frequency distribution for length, width, thickness, geometric mean diameter and sphericity for IT90K-277-2 at 12% w.b.



Length, mm	6.7-7.4	7.4-8.1	8.1-8.8	8.8-9.5	9.5-10.2
Width, mm	4.9-5.5	5.5-6.1	6.1-6.7	6.7-7.3	7.3-7.9
Thickness, mm	3.7-4.0	4.0-4.3	4.3-4.6	4.6-4.9	4.9-5.3
Geometric Dia	5.2-5.6	5.6-6.0	6.0-6.3	6.3-6.7	6.7-7.1
Sphericity, %	66.9-70.7	70.7-74.5	74.5-78.3	78.3-82.1	82.1-85.9

Figure 4.3. Frequency distribution for length, width, thickness, geometric diameter and sphericity for Ife Brown at 12 % w.b.



Length, mm	8.1-9.2	9.2-10.3	10.3-11.4	11.4-12.4	12.5-13.6
Width, mm	6.1-6.8	6.8-7.4	7.4-8.0	8.0-8.7	8.7-9.3
Thickness	4.1-4.7	4.7-5.3	5.3-5.9	5.9-6.5	6.5-7.1
Geomet. Dia	6.3-6.8	6.8-7.3	7.3-7.8	7.8-8.3	8.3-8.9
Sphericity,%	63.4-70.2	70.2-77.0	77.0-83.80	83.8-90.6	90.6-97.4

Figure 4. 4. Frequency distribution of length, width, thickness, geometric mean diameter and sphericity for Drum at 12% w.b.

Table 4.3 Mean of sphericity, aspect ratio, thousand grain mass and projected area

Variety	Moisture Content, %	Sphericity, %	Aspect ratio	Thous. grain Mass, g	Proj. area mm^2
Ife 98-12	8	72.73	0.68	191.600	36.38
	12	71.57	0.67	198.936	36.75
	14	71.24	0.67	203.975	37.50
	18	71.55	0.67	213.963	38.41
IT90K-277-2	8	80.29	0.79	166.040	29.89
	12	77.64	0.77	173.794	31.27
	14	79.28	0.77	177.624	31.38
	18	77.76	0.76	186.499	34.21
Ife Brown	8	74.67	0.75	147.547	28.02
	12	74.40	0.76	155.089	29.34
	14	75.01	0.76	157.993	30.24
	18	75.27	0.75	166.373	32.10
Drum	8	72.51	0.74	225.473	40.64
	12	72.78	0.74	235.910	42.69
	14	72.30	0.74	240.634	43.14
	18	72.33	0.74	252.801	43.56

width and thickness for the four varieties (Table 4.2).

The aspect ratio was observed to be constant for the four varieties within the moisture content range with an average of 67% for Ife 98-12, 77% for IT90K-277-2, 76% for Ife Brown and 74% for Drum. The high value of the sphericity and aspect ratio of the four varieties of cowpea is indicative of their ability to roll. This information is useful in the design of hoppers, separation and conveying equipment for cowpea. The high value of the sphericity also indicates that cowpea can be treated as a sphere for analytical calculation (Dutta, *et al*., 1988). Analysis of variance shows that only the effect of variety was significant on aspect ratio ($p \leq 0.05$). The effect of moisture content and the interaction effect of variety and moisture content were not significant ($p \leq 0.05$) on aspect ratio.

4.1.3 Thousand grain mass and projected area

The thousand grain mass of the four varieties of cowpea increased as the moisture content increased from 8 to 18% w.b. The thousand grain mass of Ife 98-12 increased from 191.600 g at 8% w.b to 213.963 g at 18% w.b. It increased from 166.040 g at 8% to 186.499 g at 18% w.b. for IT90K-277-2. The thousand grain mass of Ife Brown increased from 147.547 g at 8% w.b. to 166.373 g at 18% w.b. That of Drum increased from 225.473 g at 8% to 252.801 g at 18% w.b. The one thousand grain mass is a useful index in measuring the relative amount of dockage or foreign materials in a given lot of material, and the amount of shriveled or immature kernels (Simonyan *et al*., 2007). It is also useful in selecting storage and handling containers. Analysis of variance showed that the effect of variety and moisture content is significant ($p \leq 0.05$) on thousand grain mass. The interaction effect of variety and moisture content is however not significant ($p \leq 0.05$) on thousand grain mass.

The projected area of the four cowpea varieties also increased as the moisture content increased from 8 to 18% w.b. When cowpea was treated as a sphere, the projected area of Ife 98-12 increased from 36.38 mm^2 at 8% w.b. to 38.41 mm^2 at 18% w.b. It increased from 29.89 mm^2 at 8% w.b. to 34.21 mm^2 at 18% w.b. for IT90K-277-2. The projected area of Ife Brown increased from 28.02 mm^2 at 8% w.b.

to 32.10 mm^2 at 18% w.b. That of Drum increased from 40.64 mm^2 at 8% w.b. to 43.56 mm^2 at 18% w.b. Similarly, with cowpea's shape treated as ellipsoidal, the projected area of Ife 98-12 increased from 46.84 mm^2 at 8% w.b. to 50.28 mm^2 at 18% w.b. It increased from 36.90 mm^2 at 8% w.b. to 43.08 mm^2 at 18% w.b. for IT90K-277-2. The projected area of Ife Brown increased from 37.89 mm^2 at 8% to 42.90 mm^2 at 18% w.b. That of Drum increased from 57.58 mm^2 at 8%w.b. to 61.92 mm^2 at 18% w.b. (Appendix Tables A1 to A16). However, because of the high sphericity obtained for the four varieties of cowpea, they are better treated as sphere for analytical calculation (Duarte *et al*., 2004).

The increase in projected area with increase in moisture content is expected since axial dimensions also increased with increase in moisture content. The projected area of a seed is indicative of its pattern of behavior in a flowing fluid such as air as well as the ease of separating extraneous materials from the seeds during cleaning by pneumatic means (Heidarbegi *et al*., 2008). Analysis of variance shows that the effect of variety and moisture content is significant on projected area ($p \leq 0.05$). The interaction effect of variety and moisture content is however not significant ($p \leq 0.05$) on projected area.

4.1.4 Individual grain mass and mass/projected area

The individual grain mass obtained for each of the four varieties of cowpea is presented in Table 4.4. It also increased with increase in moisture content. It increased from 0.193 g at 8% w.b. to 0.210 g at 18% w.b. for Ife 98-12. It increased from 0.163 g at 8% w.b. to 0.186 g at 18% w.b. for IT90K-277-2. For Ife Brown, it increased from 0.146 g at 8% w.b. to 0.169 g at 18% w.b. For Drum, it increased from 0.223 g at 8% w.b. to 0.247 g at 18% w.b. The individual grain mass is in close agreement with the thousand grain mass obtained for the four cowpea varieties. The individual grain mass is essential in calculating particle's acceleration and displacement. The mass/projected area ratio of the four varieties of cowpea also increased with increase in moisture content. It increased from 5.1 x 10^{-3} g/mm^2 at 8% w.b. to 5.56 x 10^{-3} g/mm^2 at 18% w.b. It increased from 4.80 x 10^{-3} g/mm^2 at 8% w.b. to 5.16 x 10^{-3} g/mm^2 for IT90K-277-2. It increased from 5.04 x 10^{-3} g/mm^2 at 8% w.b. to 5.37 x 10^{-3} g/mm^2 at 18% w.b. It also increased from 5.40 x 10^{-3} g/mm^2 at 8% w.b. to 5.64 x 10^{-3}

Table 4.4 Individual grain mass and mass/projected area ratio

Variety	Moisture content, %	Individual grain mass, g	Proj. Area, mm^2	Mass/proj. area (X 10^{-3}) g/mm^2
Ife 98-12	8	0.193	37.82	5.10
	12	0.195	36.37	5.36
	14	0.198	37.05	5.34
	18	0.210	37.74	5.56
IT90K-277-2	8	0.163	33.96	4.80
	12	0.168	34.47	4.87
	14	0.177	35.42	5.00
	18	0.186	36.05	5.16
Ife Brown	8	0.146	28.98	5.04
	12	0.156	30.14	5.18
	14	0.158	30.22	5.23
	18	0.169	31.50	5.37
Drum	8	0.223	41.32	5.40
	12	0.235	42.59	5.52
	14	0.239	43.52	5.49
	18	0.247	43.76	5.64

g/mm^2 at 18% for Drum. The mass/projected area is an important property of a particle in pneumatic separation because to separate two particles they must have different values of M/A (mass/projected area) ratios (Kashayap and Pandya, 1965).

4.1.5 Bulk and True Densities

The bulk and true densities of the four varieties of cowpea at different moisture contents are summarized in Table 4.5 while detailed data are given in the Appendix (Tables A17 to A32). The bulk density decreased with increase in moisture content for the four varieties of cowpea. For Ife 98-12, the bulk density decreased from 0.694 g/cm^3 at 8% w.b. to 0.672 g/cm^3 at 18% w.b. That of IT90K-277-2 decreased from 0.778 g/cm^3 at 8% w.b to 0.725 g/cm^3 at 18% w.b. The bulk density of Ife Brown, decreased from 0.756 g/cm^3 at 8% w.b. to 0.725 g/cm^3 at 18% while that of drum decreased from 0.709 g/cm^3 at 8% w.b. to 0.678 g/cm^3 at 18% w.b. The decrease in bulk density with increase in moisture content may be due to the fact that with an increase in the moisture content of a particle, its volume increases thus the same weight of the material occupies more volume of the container thus decreasing its bulk density (Irtwange, 2000).

The true density decreased with increase in moisture content. For Ife 98-12, the true density decreased from 1.253 g/cm^3 at 8% w.b to 1.127 g/cm^3 at 18% w.b., for IT90K-277-2, it decreased from 1.247 g/cm^3 at 8% to 1.193 g/cm^3 at 18% w.b., for Ife Brown it decreased from 1.216 g/cm^3 at 8% w.b to 1.999 g/cm^3 at 18% w.b. and for Drum, it decreased from 1.230 g/cm^3 at 8% w.b. to 1.135 g/cm^3 at 18% w.b. The decrease in true density with increase in moisture content could be that the increase in the volume of the grains as they absorb moisture is greater than the corresponding weight gained. Analysis of variance shows that the effects of variety and moisture content were significant ($p \leq 0.05$) on both bulk density and true density. Also, the interaction effect of variety and moisture content was also significant ($p \leq 0.05$) on bulk and true density. The decrease in bulk density and true density of the cowpea varieties with increase in moisture content is similar to observations made by other investigators such as Visvanathan *et al.*, (1996) for neem nut, Lucas and Olayanju

Table 4.5 Mean of bulk density, true density and porosity

Variety	Moist. Cont.,%	Bulk density, $^{kg}/_{m^3}$	True density, $^{kg}/_{m^3}$	Porosity, %
Ife 98-12	8	0.694	1.253	44.61
	12	0.678	1.159	41.52
	14	0.676	1.136	40.49
	18	0.672	1.127	40.35
IT90K-277-2	8	0.778	1.247	37.61
	12	0.758	1.200	36.83
	14	0.731	1.195	38.83
	18	0.725	1.193	39.23
Ife Brown	8	0.756	1.216	37.83
	12	0.738	1.214	39.21
	14	0.731	1.201	39.13
	18	0.725	1.199	39.53
Drum	8	0.709	1.230	42.39
	12	0.696	1.204	42.19
	14	0.689	1.151	40.14
	18	0.678	1.135	40.26

(2003) for beniseed and Irtwange (2000) for African yam bean. The bulk and true densities are essential in knowing the weight of crop per unit volume and are useful in the design of silos, storage bins, and design of specific gravity separators (Nalladurai *et al*., 2003). They are also useful in the design of pneumatic conveyors (Scrivastava *et al*., 2006).

4.1.6 Porosity

The porosity of the four varieties of cowpea at different moisture content is presented in Table 4.5 while detailed data are given in the Appendix (Tables A1 to A16). The analysis of variance is shown in the Appendix (Table A58). The results show that the porosity of Ife 98-12 and Drum decreased with increase in moisture content. The porosity of Ife 98-12 decreased from 44.61% at 8% w.b. to 40.35% at 18% while that of Drum decreased from 42.39% at 8% to 40.26% at 18% w.b. The porosity of IT90K-277-2 decreased from 37.61% at 8% w.b. to 36.83% at 12% and later increased to 39.23% at 18% w.b. while that of Ife Brown increased from 37.61% at 8% w.b. to 39.53% at 18% w.b. The reason for the decrease and increase in porosity with increase in moisture content could be that as the particles absorb moisture, their weight and volume increased leading to decreases in their bulk and true densities. However, there are differences in the decrease of bulk density relative to true density for the four varieties. Analysis of variance shows that the effects of both variety and moisture content are significant ($p \leq 0.05$) on porosity. The knowledge of porosity or percentage of void of grains is useful for the following:

1. Air flow studies: the knowledge of porosity in grain bulk is essential in the aeration process during their processing and storage. The static pressure or resistance to air flow of grains depends on the porosity of the bulk material (Irtwange, 2000). Its knowledge is thus useful in pneumatic handling of grains.

2. Heatflow studies: the knowledge of porosity is useful in determining thermal diffusivity in drying and other heat transfer problems (Nalladurai, 2003).

4.2 Aerodynamic Properties

The results of the terminal velocities and drag coefficients of the four varieties of cowpea are presented in Table 4.6. Detailed data are given in the Appendix (Tables A33 to A48). The summary of the aerodynamic properties of other cowpea particles are shown in Table 4.7. Detailed data are given in the Appendix (Tables A49 to A50). The analysis of variance is shown in the Appendix (Table A63). The terminal velocities of the four varieties of cowpea increased with increase in moisture content. The terminal velocity of Ife 98-12 increased from 13.80 m/s at 8% w.b. to 14.30 m/s at 18% w.b. That of IT90K-277-2 increased from 13.35 m/s at 8% w.b to 13.83 m/s at 18% w.b. The terminal velocity of Ife Brown increased from 13.72 m/s at 8% w.b. to 14.04 m/s at 18% w.b. while that of Drum increased from 14.15 m/s at 8% w.b. to 14.47 m/s at 18% w.b. The increase in terminal velocity with increase in moisture content for the four varieties is almost linear (Figure 4.7). However the drag coefficient appeared to be constant for the four varieties of cowpea within the moisture content range with an average of 0.45. The increase in terminal velocity with increase in moisture content of each variety can be attributed to the increase in mass of individual grain per unit frontal area across the air path. The terminal velocities of the impurities ranged from 1.51 to 3.49 m/s at moisture contents of 7.80 to 11.80% w.b. The wide difference between the terminal velocities of cowpea varieties and the impurities shows that their aerodynamic separation is possible. Analysis of variance shows that the effects of variety and moisture content were significant ($p \leq 0.05$) on terminal velocity. The interaction of variety and moisture content however was not significant ($p \leq 0.05$) on terminal velocity. Other investigators have observed similar trends for different grains. Irtwange (2000) and Olayanju (2002) observed an increase in terminal velocity with increase in moisture content for African yam bean and beniseed respectively.

4.3 Vertical and horizontal displacements of cowpea and impurities

The vertical and horizontal displacements of the cowpea varieties and the impurities predicted by the model at 0.5 s and 1.0 s are shown in Tables 4.8 to 4.15. Details of the predicted horizontal and vertical displacements of the four varieties and

Table 4.6 Mean of aerodynamic properties of four cowpea varieties

Variety	Moisture content, %	Terminal velocity, m/s	Drag coefficient
Ife 98-12	8	13.80	0.45
	12	14.05	0.46
	14	14.06	0.45
	18	14.30	0.45
IT90K-277-2	8	13.35	0.45
	12	13.47	0.45
	14	13.57	0.45
	18	13.83	0.45
Ife Brown	8	13.72	0.45
	12	13.88	0.45
	14	13.92	0.45
	18	14.04	0.45
Drum	8	14.15	0.45
	12	14.30	0.45
	14	14.26	0.45
	18	14.47	0.45

Table 4.7 Aerodynamic properties of other cowpea particles (impurities)

S/N	Particle	Average Mass (g)	Moisture Content %	Terminal Velocity, m/s
1.	Chaff 4cm long(a)	0.104	7.80	1.51
2.	Chaff 4cm long(b)	0.117	10.23	1.77
3.	Chaff 6cm long(a)	0.136	7.80	1.96
4.	Chaff 6cm long(b)	0.144	10.23	2.09
5.	Chaff 8cm long(a)	0.147	7.80	2.23
6.	Chaff 8cm long(a)	0.151	10.23	2.32
7.	Insect infested Ife98-12	0.150	11.60	2.96
8.	Insect infested IT90-277-	0.130	11.60	5.11
9.	Insect infested Ife Brown	0.082	11.60	2.81
10.	Immature seed	0.113	11.80	3.49

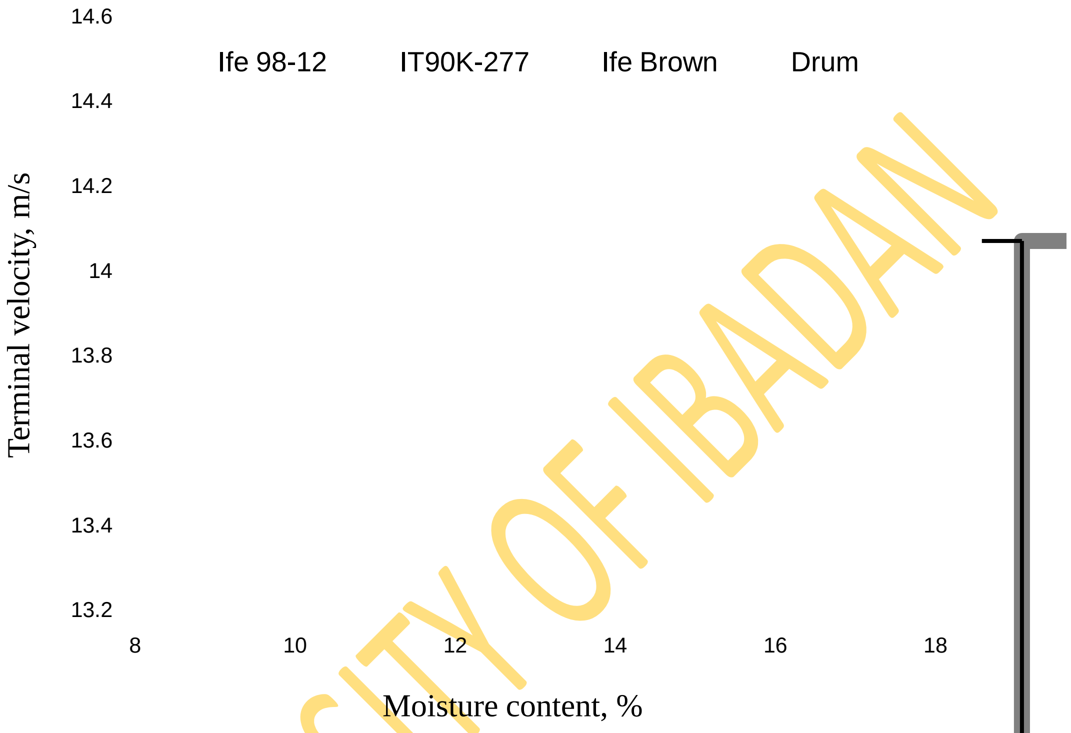


Figure 4.5. Effect of moisture content on terminal velocities of cowpea varieties

Table 4.8 Horizontal and vertical displacements of Ife 98-12 and impurities at injection velocity of 0.20m/s and air velocity of 4m/s at 0.5s

	Horizontal displacement (m)				Vertical displacement (m)			
Angle of Injection (^{o})	15	30	45	60	15	30	45	60
Ife 98-12	0.10	0.09	0.08	0.05	-1.20	-1.17	-1.15	-1.13
Insect Infested	2.22	2.04	1.70	1.22	-0.63	-0.05	0.47	0.88
Chaff-4cm	8.52	7.82	6.52	4.68	1.06	3.29	5.29	6.87
Chaff-8cm	3.90	3.58	2.99	2.14	-0.18	0.84	1.75	2.48

Table 4.9 Horizontal and vertical displacements of Ife 98-12 and impurities at injection velocity of 0.2 m/s and air velocity of 4m/s at 1.0s

	Horizontal displacement (m)				Vertical displacement (m)			
Angle of Injection (^{o})	15	30	45	60	15	30	45	60
Ife 98-12	0.40	0.37	0.31	0.22	-4.80	-4.69	-4.60	-4.53
Insect Infested	8.88	8.16	6.80	4.88	-2.53	-0.19	1.90	3.54
Chaff-4cm	34.09	31.31	26.07	18.70	4.23	13.17	21.17	27.49
Chaff-8cm	15.61	14.32	11.91	8.55	-0.72	3.36	7.00	9.91

Table 4.10 Horizontal and vertical displacements of IT90K-277-2 and impurities at injection velocity of 0.5 m/s and air velocity of 6m/s at 0.5s

	Horizontal displacement (m)				Vertical displacement (m)			
Angle of Injection (°)	15	30	45	60	15	30	45	60
IT90K-277-2	0.25	0.23	0.19	0.14	-1.16	-1.09	-1.03	-0.98
Insect Infested	2.46	1.59	1.34	1.11	-0.77	-0.31	0.11	0.70
Chaff-4cm	19.50	18.22	15.30	11.11	3.99	9.29	14.07	18.03
Chaff-8cm	8.95	8.10	7.04	5.06	-1.17	3.45	5.81	7.54

Table 4.11 Horizontal and vertical displacements of IT90K-277-2 and impurities at injection velocity of 0.5 m/s and air velocity of 6m/s at 1.0s

	Horizontal displacement (m)				Vertical displacement (m)			
Angle of Injection (°)	15	30	45	60	15	30	45	60
IT90K-277-2	0.99	0.92	0.77	0.56	-4.64	-4.37	-4.13	-3.93
Insect Infested	6.83	6.35	5.35	4.45	-3.08	-1.24	0.44	2.80
Chaff-4cm	78.02	9.29	61.19	44.47	16.00	37.16	56.29	72.12
Chaff-8cm	35.81	32.40	28.14	20.24	-4.69	13.80	23.24	30.15

Table 4.12 Horizontal and vertical displacements of Ife Brown and impurities at injection velocity of 0.2 m/s and air velocity of 4 m/s at 0.5 s

	Horizontal displacement (m)				Vertical displacement (m)			
Angle of Injection (^{o})	15	30	45	60	15	30	45	60
Ife brown	0.10	0.09	0.08	0.06	-1.20	-1.17	-1.15	-1.13
Insect Infested	2.46	2.28	1.89	1.35	-0.57	0.09	0.66	1.11
Chaff-4cm	8.52	7.83	6.52	4.68	1.06	3.29	5.29	6.87
Chaff-8cm	3.90	3.58	2.14	2.48	-0.18	0.84	2.48	2.48

Table 4.13 Horizontal and vertical displacements of Ife brown and impurities at injection velocity of 0.2 m/s and air velocity of 4 m/s at 1.0 s

	Horizontal displacement (m)				Vertical displacement (m)			
Angle of Injection (^{o})	15	30	45	60	15	30	45	60
Ife brown	0.40	0.37	0.31	0.22	-4.80	-4.69	-4.60	-4.52
Insect Infested	9.84	9.14	7.55	5.40	-2.27	0.37	2.64	4.45
Chaff-4cm	34.09	31.31	26.08	18.70	4.22	13.17	21.17	27.49
Chaff-8cm	15.61	14.32	8.55	8.55	-0.72	3.36	9.91	9.91

Table 4.14 Horizontal and vertical displacements of Drum and impurities at injection velocity of 0.2 m/s and air velocity of 4 m/s at 0.5 s

	Horizontal displacement (m)				Vertical displacement (m)			
Angle of Injection (^{o})	15	30	45	60	15	30	45	60
Drum	0.10	0.09	0.07	0.05	-1.20	-1.18	-1.15	-1.14
Insect Infested	1.6	1.47	1.22	0.88	-0.80	-0.55	-0.05	0.30
Chaff-4cm	8.52	7.83	6.52	6.73	1.06	3.29	5.29	6.89
Chaff-8cm	3.90	3.58	2.98	2.14	-0.18	0.84	1.75	2.48

Table 4.15 Horizontal and vertical displacements of Drum and impurities at injection velocity of 0.2 m/s and air velocity of 4 m/s at 1.0 s

	Horizontal displacement (m)				Vertical displacement (m)			
Angle of Injection (^{o})	15	30	45	60	15	30	45	60
Drum	0.38	0.35	0.29	0.21	-4.80	-4.70	-4.61	-4.54
Insect Infested	6.42	5.87	4.89	3.52	-3.19	-1.52	-0.02	1.19
Chaff-4cm	34.09	31.31	26.07	18.70	4.23	13.17	21.17	27.49
Chaff-8cm	15.61	14.32	11.91	8.55	-0.72	3.36	7.00	9.91

impurities between 0.1 and 1.0 s are shown in appendix Tables A64 to A87. The predicted horizontal displacements of Ife 98-12, IT90K-277-2, Ife brown and Drum from point of injection at 0.5 and 1.0 s ranged from 0.05 to 0.10 m and 0.22 to 0.40 m, 0.14 to 0.25 m and 0.56 to 0.99 m, 0.06 to 0.10 m and 0.22 to 0.40 m, 0.05 to 0.10m and 0.21 to 0.38m respectively for angles of injection of 15, 30, 45 and 60^o. Their predicted vertical displacements from point of injection at 0.5 s and 1.0 s ranged from -1.13 to -1.20 m and -4.53 to -4.80 m, -0.98 to -1.16 m and -3.93 to -4.64 m, -1.13 to -1.20 m and -4.52 to -4.80 m, -1.14 to -1.20 m and -4.54 to -4.80 m respectively for angles of injection of 15, 30, 45 and 60^o.

The predicted horizontal displacements of the impurities from the point of injection at 0.5 s and 1.0 s at angles of injection of 15 to 60^o ranged from 1.22 to 8.52 mm and 4.88 to 34.09 mm for Ife 98-12, 1.11 to 19.50 mm and 4.45 to 78.02 mm for IT90K-277-2, 1.35 to 8.52 mm and 5.40 to 34.09 mm for Ife Brown, 0.88 to 8.52 mm and 3.52 to 34.09 mm for Drum respectively. The predicted vertical displacements of the impurities from the point of injection at 0.5 s and 1.0 s at angles of injection of 15 to 60^o ranged from -0.63 to 6.87 mm and -2.53 to 27.49 mm for Ife 98-12, -0.77 to 18.03 mm and -3.08 to 72.12 mm for IT90K-277-2, -0.57 to 6.87 mm and -2.27 to 27.49 mm for Ife Brown and -0.80 to 6.89 mm and -3.19 to 27.49 mm for Drum respectively.

It was observed that the predicted horizontal and vertical displacements of the four varieties decreased with increase in angle of injection. For the impurities, as the angle of injection increased, the predicted horizontal displacements decreased but the predicted vertical displacements increased. This showed that impurities are farther displaced from the grains as the angle of injection increased. The decrease in the predicted horizontal and vertical displacements of the four varieties could be due to the fact that as the angle of injection increased the resistance drag force acting on the grains also increased. Thus resistance to the motion of the grains as they fall through the air stream increased as the angle of injection increased. This led to reduction in horizontal and vertical displacements. For the impurities, the increase in the resistance drag force led to increase in their vertical motion since their vertical motion is caused by the drag force. This led to increase in their vertical displacements. Furthermore, the horizontal displacements of the four varieties are smaller than those of the impurities.

This implied that they fell closer to the wall than the impurities. Thus the horizontal displacements of the varieties can be used as a guide for selecting diameter or length of the machine if a circular or square section is to be used.

4.4 Prediction of Impurities' separation from Trajectories of Cowpea and Impurities Particles

The plots of vertical displacement against time and vertical displacement against horizontal displacement (at 0.5 s) for the four varieties of cowpea and impurities injected into the pneumatic cleaner at angles of injection of 15, 30, 45 and 60^o with airflow velocities of 4, 6 and 8 m/s are shown in Figures 4.6 to 4.15. The remaining plots are shown in the Appendix (Figures A1 to A40). These plots predict the effect of angle of injection and air velocity on separation of impurities from cowpea. The trajectories of the mixture of Ife 98-12, chaff and insect infested grain injected at 15^o with air velocity of 4 m/s (Figures 4.6 and 4.13) predict that only chaff-4 cm was lifted or blown away while the other heavier particles of sound grain, insect infested grain and chaff-8 cm fell through the air stream. This amounts to 33% separation. With an angle of injection of 30^o, chaff-8cm was also lifted or blown away along with chaff-4cm while sound grain and insect infested grain fell through the air stream. With an angle of injection of 45^o, all the impurities namely chaff-4cm, chaff-8cm and insect infested grain were lifted or blown away while only the sound grain to fall through the air stream. The case was the same when the angle of injection was increased to 60^o with the impurities being lifted farther away from the sound grain.

The trajectories of the mixture of IT90K-277-2, chaff and insect infested grains predicted that with an air flow of 6 m/s and angle of injection of 15^o (Figs. A1-A8), both chaff-4 cm and chaff-8 cm were lifted while sound grain and insect infested grain fell through the air stream. The case was the same when the angle of injection was increased to 30 and 45^o respectively. With an increase in angle of injection to 60^o, chaff-4 cm, chaff-8 cm and insect infested grain were all lifted and only sound grain fell through the air stream.

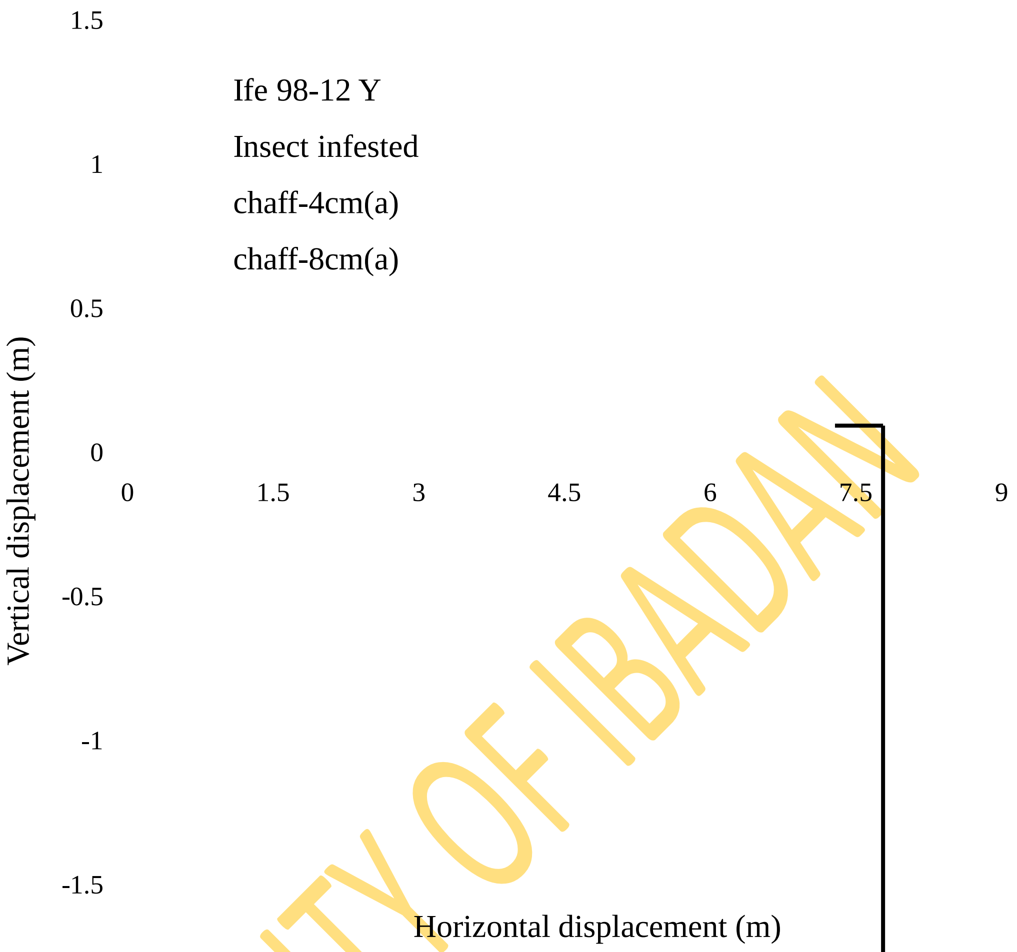


Figure 4.6. Ife 98-12-impurities mixture injected at 15° . Injection velocity = 0.20 m/s. Air velocity = 4 m/s.

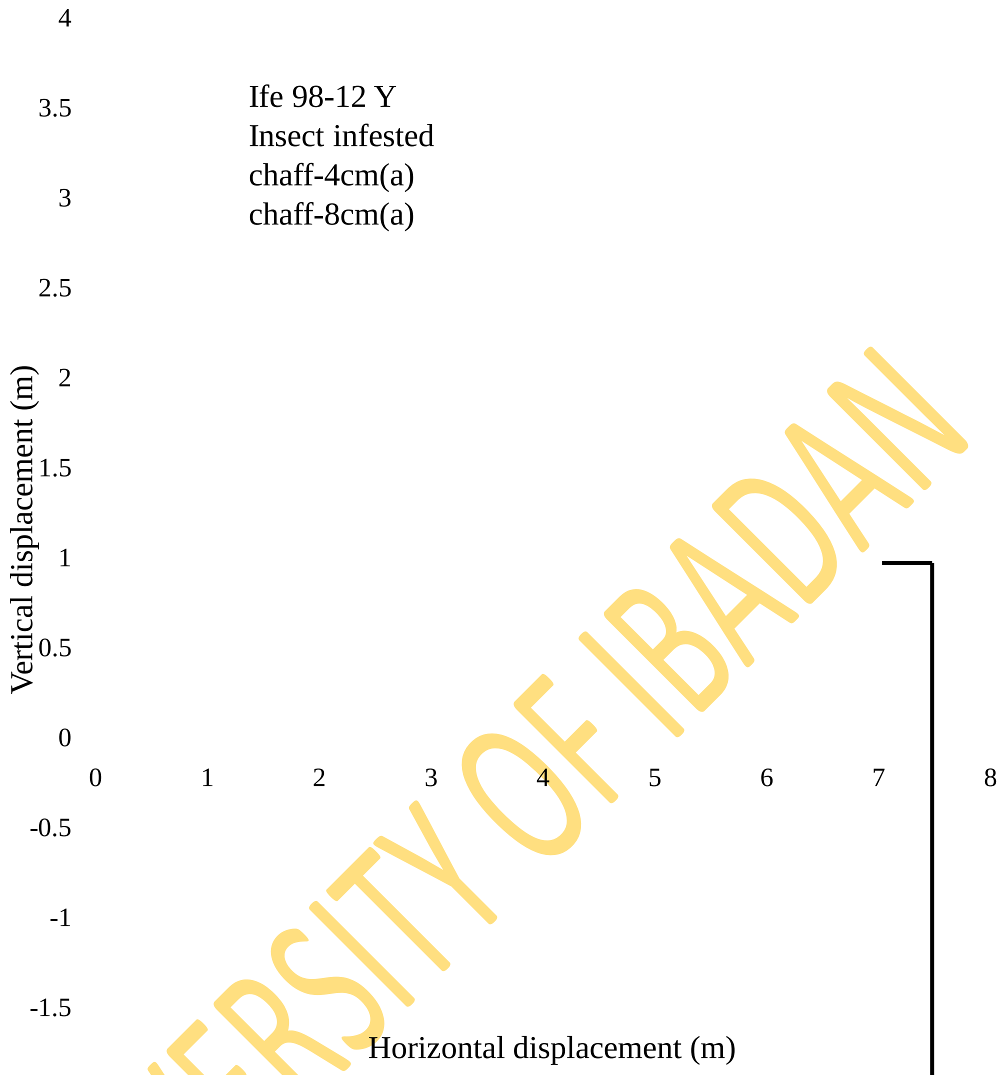


Figure 4.7. Ife 98-12-impurities mixture injected at 30° . Injection velocity = 0.20 m/s. Air velocity = 4 m/s.

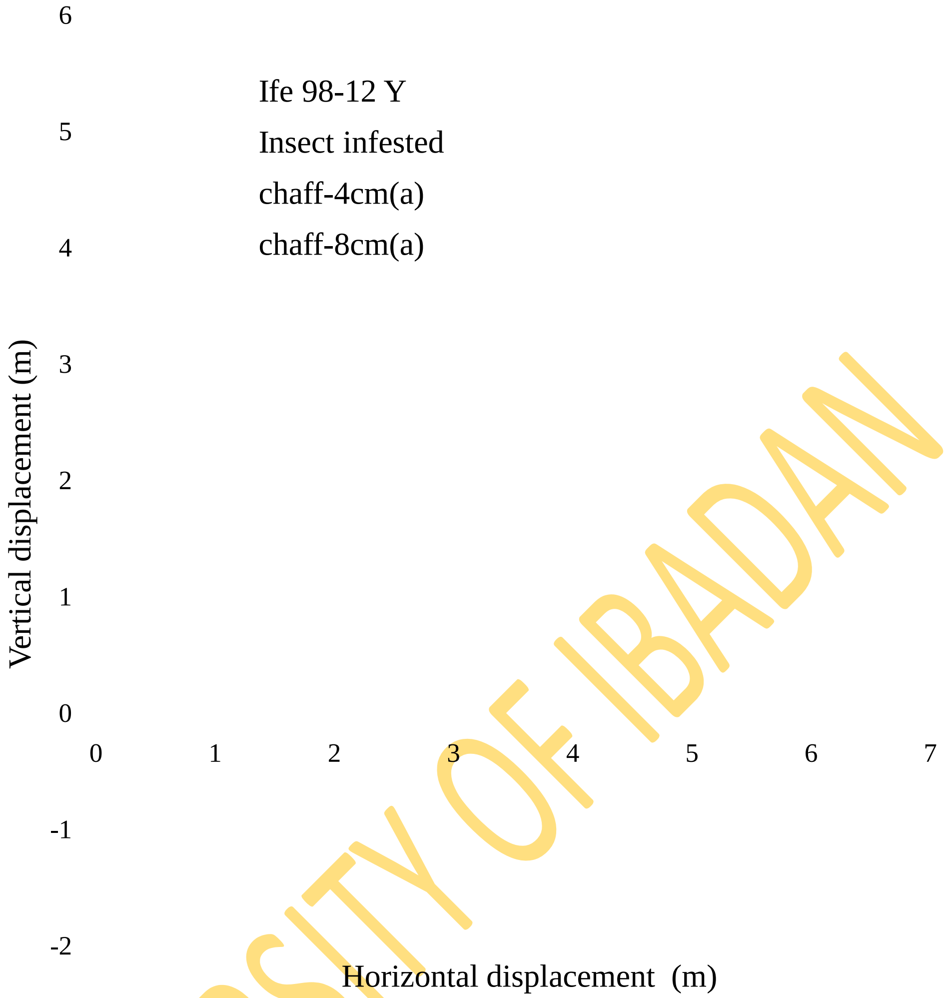


Figure 4.8. Ife 98-12-impurities mixture injected at 45°. Injection vel. = 0.20 m/s. Air vel. = 4 m/s.

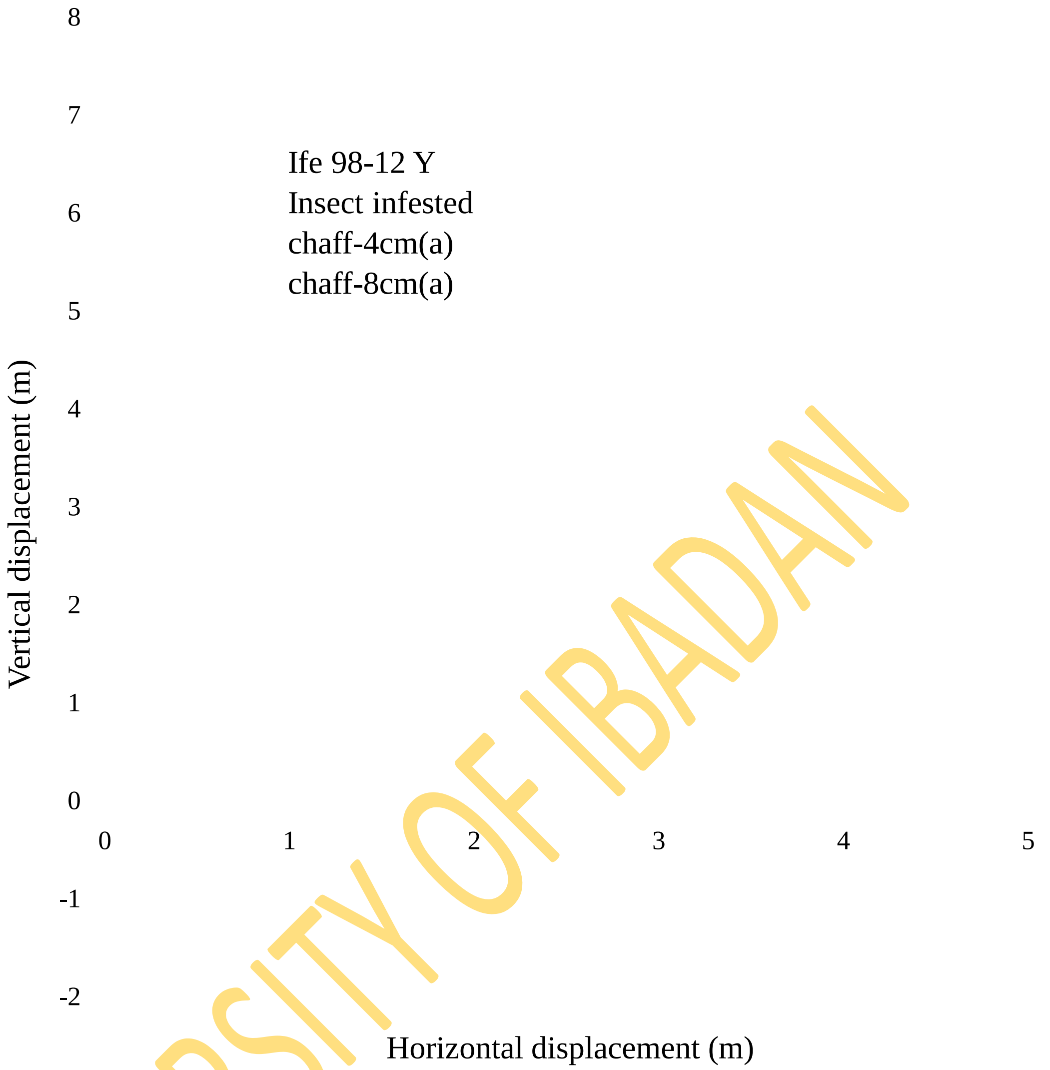


Figure 4.9. Ife 98-12-impurities mixture injected at 60° . Injection vel. (m).
Air vel. = 4 m/s.

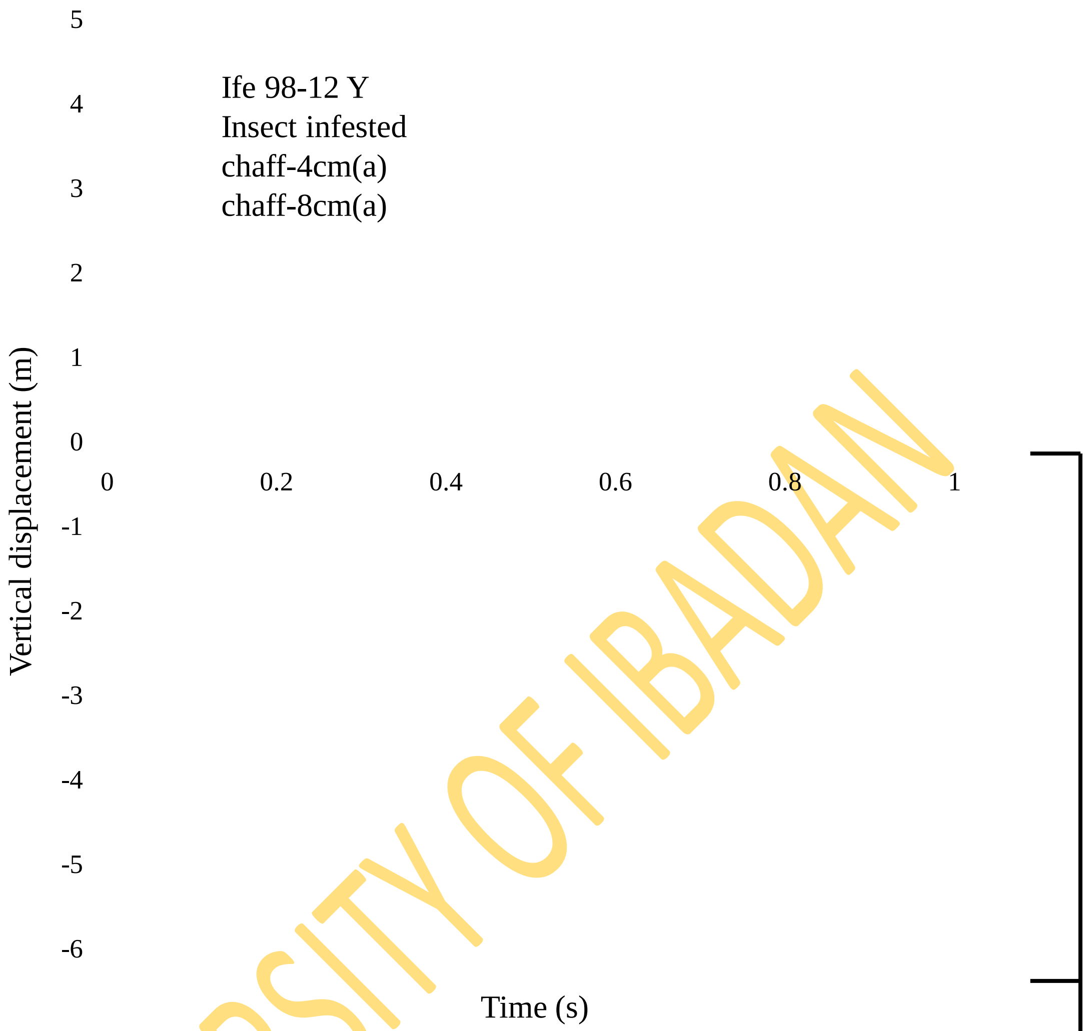


Figure 4.10. Ife 98-12-impurities mixture injected at 15° . Injection velocity = 0.20 m/s. Air vel. 4 m/s.

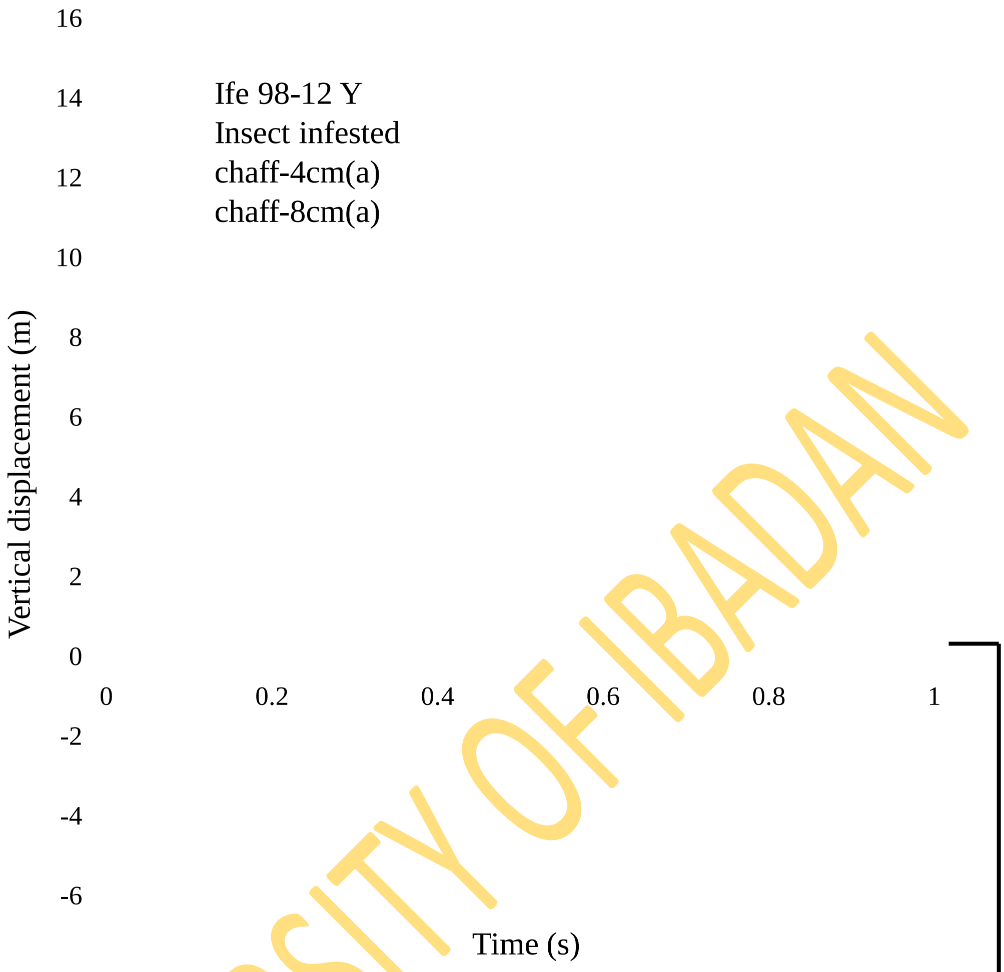


Figure 4.11. Ife 98-12-impurities mixture injected at 30° Injection vel. = 0.20 m/s. Air vel. = 4 m/s.

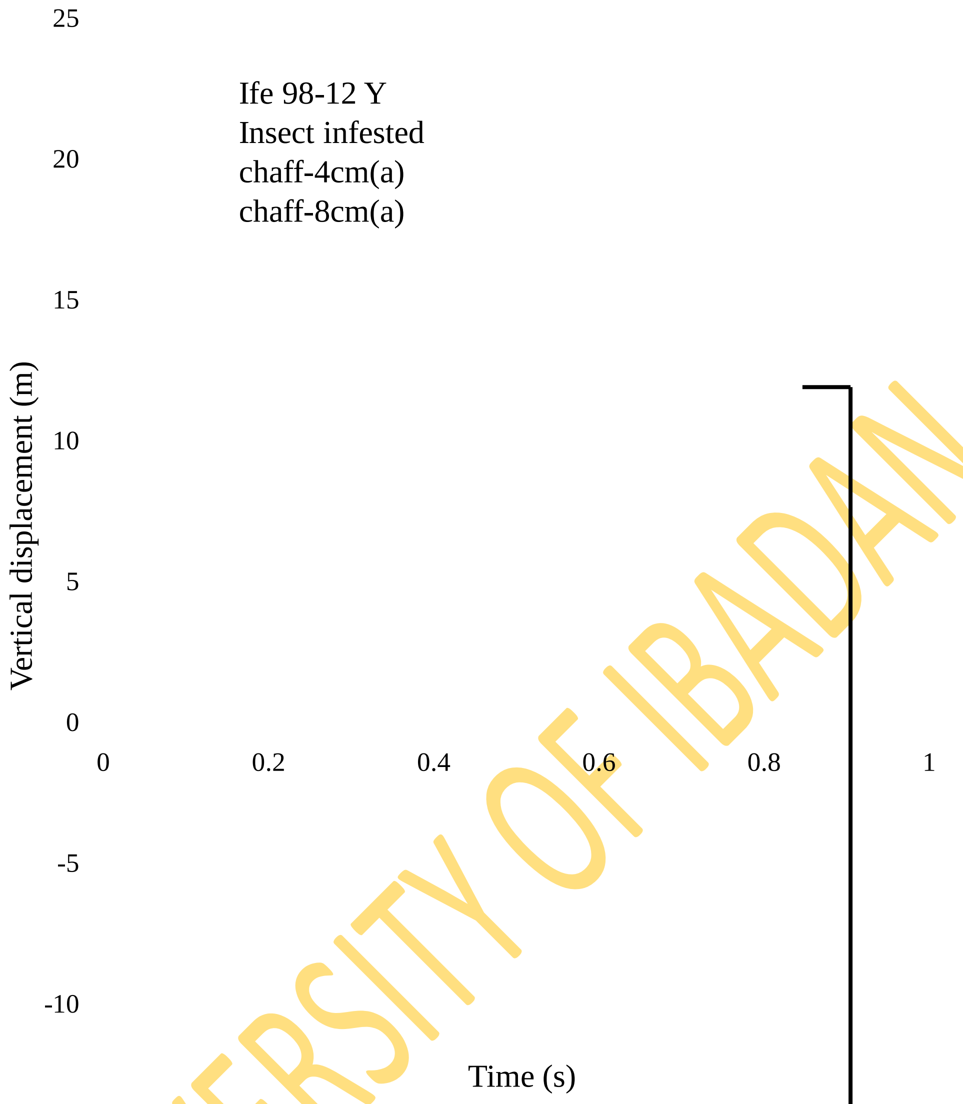


Figure 4.12. Ife 98-12-impurities mixture injected at 45^o . Injection velocity = 0.20 m/s.Air vel. = 4 m/s.

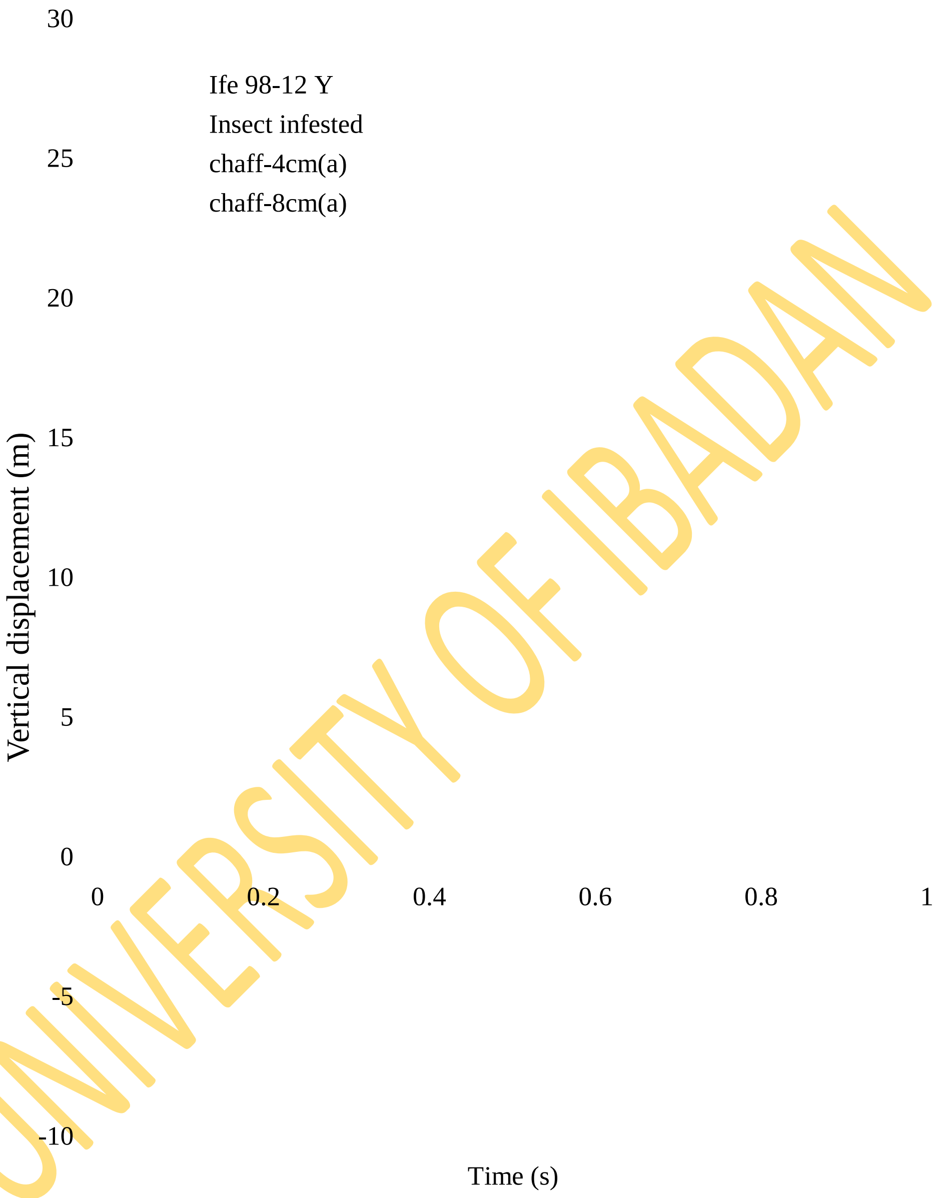


Figure 4.13. Ife 98-12-impurities mixture injected at 60° . Injection vel. = 0.20 m/s. Air velocity = 4 m/s.

The trajectories of the mixture of Ife Brown and impurities (Figures A9 to A16) predicted that at an angle of injection of 15^o and air velocity of 4 m/s, only chaff-4cm was lifted. This amounts to 33% separation. At angle of injection of 30^o, all the impurities namely chaff-4 cm, chaff-8 cm and insect infested grains were lifted and only the sound grain fell through the air stream. This amounts to 100% separation. The lifting of the impurities increased and they were separated farther away from sound grain when the angle of injection was increased to 45 and 60^o.

The trajectories of the mixture of Drum and impurities (Figures A17 to A24) showed that at an angle of injection of 15^o and air flow of 4 m/s, only chaff 4-cm was lifted. This amounts to 33% separation. With an increase in the angle of injection to 30^o, chaff-4 cm and chaff-8 cm were lifted. With an increase in the angle of injection to 45^o, all the impurities namely chaff-4 cm, chaff-8 cm and immature grain were all lifted. The case was the same at angle of injection of 60^o with the impurities being separated further away from sound grain.

When air velocity of 8 m/s was used for the mixture of impurities and the four varieties of cowpea (Figures A25 to A40), the trajectories predicted that all the impurities were all lifted or separated from sound grains at all angles of injection. However, it is cheaper to operate at lower air velocity because it translates to lower power consumption and lower fan capacity.

It can be observed from the predictions of the trajectories that the separation of impurities from cowpea at a particular air velocity improved as the angle of injection increased. Optimum lifting or separation of all impurities from sound grains occurred from angle of injection of 45^o upwards. This is similar to observation made by Ogunlowo and Oladapo (1999) that the efficiency of separation of foreign materials from grains in a cross-flow cleaner was high when the directional air stream was set at angles between 30^o and 60^o to the horizontal. Macmillan (1999) also reported that when grain and chaff are winnowed by being thrown through or dropped in the wind, maximum separation is obtained when the mixture is thrown against the wind at an angle of about 140^o to the horizontal. This is a useful guide in the inclination of the hopper.

4.5 Predicted Separation Distance of Cowpea and Impurities Particles across the Point of Injection

The predicted distance of separation of the impurities from sound grains across the point of injection by the trajectories at angles where they are clearly separated from sound grains at time interval of 0.1 to 1.0 s for the four varieties are shown in Tables 4.16 to 4.19. The distance ranged from 0.07 to 6.50 m at 45^o and 0.08 to 8.07 m at 60^o for Ife 98-12. It ranged from 0.05 to 4.58 m at 45^o and 0.07 to 6.73 m at 60^o for IT90K-277-2. The distance ranged from 0.06 to 4.58 m at 30^o, 0.07 to 7.24 m at 45^o and 0.09 to 6.73 m at 60^o for Ife Brown. It also ranged from 0.05 to 3.72 m at 45^o and 0.06 to 4.65 m at 60^o for Drum. The separation distances of impurities and the four varieties showed that at time interval of 0.2 to 0.3 s, impurities have been sufficiently separated from sound grains. Hence separation distance at any of these time intervals can be used as a guide in locating points of grain collection and discharge for the impurities. This will prevent the machine from being unnecessarily too tall since these two points determine the height of the machine.

4.6 Model Verification

The model's prediction of increased vertical displacement of impurities with increase in angle of injection together with the prediction of the trajectories that separation of impurities from sound grains increased with increase in angle of injection and air velocities implied that the cleaning efficiency of a pneumatic cleaner increases with increase in angle of injection and air velocity. To verify this, the cleaning efficiency of the constructed pneumatic cleaner (Plate 4.1) was evaluated experimentally when the mixture of impurities and each of the four varieties was injected into it at the different angles of injection of 15, 30, 45 and 60^o and air velocities of 4, 6 and 8 m/s. Figures 4.14 to 4.17 show the surface plots of cleaning efficiency of the four cultivars at the different angles of injection and air velocities.. Detail cleaning efficiency at each angle of injection and air velocity are shown in the Appendix (Tables A80 to A83). The result showed that the cleaning efficiency increased as the angle of injection and air velocity increased. The cleaning efficiency increased from 27.7 to 61.1%, 63.2 to 75.9% and 76.7 to 87.2% as the angle of

Table 4.16. Separation distance between Ife 98-12 and impurities across point of injection

Variety	Time (s)	Separation distance at 45°	Separation distance at 60°
Ife 98-12	0.1	0.07	0.08
	0.2	0.26	0.32
	0.3	0.58	0.73
	0.4	1.04	1.29
	0.5	1.62	2.02
	0.6	2.34	2.90
	0.7	3.18	3.95
	0.8	4.16	5.16
	0.9	5.26	6.53
	1.0	6.50	8.07

Table 4.17. Separation distance between IT90K-277-2 and impurities across the point of injection

Variety	Time (s)	Separation distance at 45°	Separation distance at 60°
IT90K-277-2	0.1	0.05	0.07
	0.2	0.18	0.27
	0.3	0.41	0.61
	0.4	0.73	1.08
	0.5	1.14	1.68
	0.6	1.65	2.42
	0.7	2.24	3.30
	0.8	2.93	4.31
	0.9	3.71	5.46
	1.0	4.58	6.73

Table 4.18. Separation distance of Ife Brown and impurities across the point of injection

Variety	Time	Separation distance		
		30^o	45^o	60^o
Ife Brown	0.1	0.06	0.07	0.09
	0.2	0.20	0.29	0.36
	0.3	0.51	0.65	0.81
	0.4	0.81	1.16	1.43
	0.5	1.27	1.81	2.24
	0.6	1.82	2.61	3.23
	0.7	2.48	3.55	4.39
	0.8	3.23	4.63	5.74
	0.9	4.10	5.86	7.26
	1.0	4.58	7.24	8.97

Table 4.19. Separation distance of Drum and impurities across the point of injection

Variety	Time (s)	Separation distance at 45^o	Separation distance at 60^o
Drum	0.1	0.05	0.06
	0.2	0.18	0.22
	0.3	0.41	0.52
	0.4	0.73	0.92
	0.5	1.15	1.43
	0.6	1.65	2.06
	0.7	2.25	2.81
	0.8	2.94	3.67
	0.9	3.72	4.65
	1.0	4.58	5.74

injection increased from 15 to 60° at 4, 6, and 8 m/s for Ife 98-12. It increased from 28.8 to 60.9%, 63.7 to 75.6% and 76.8 to 88.2% as the angle of injection increased from 15 to 60° at 4, 6, and 8m/s for IT90K-277-2. It increased from 27.6 to 60.8%, 62.3 to 75.6% and 76.7 to 87.9% as the angle of injection increased from 15 to 60° at 4, 6, and 8 m/s for Ife Brown. It also increased from 27.7 to 59.6%, 61.4 to 75.5% and 76.6 to 87.2 % as the angle of injection increased from 15 to 60° at 4, 6, and 8 m/s for Drum. This agrees reasonably with the prediction of the model.

The surface plots show that as the angle of injection and air velocity increased cleaning efficiency increased up till air velocity of 8 m/s. At 8 m/s, increase in angle of injection does not appreciably affect cleaning efficiency. This agrees with the prediction of the trajectories. The reason why 100% separation was not experienced experimentally was because some impurities particles were trapped between falling sound grains and as a result they do not have opportunity to interact adequately with the air current and be lifted.

4.7. Model for Predicting Cleaning Efficiency

In order to obtain an empirical model for predicting cleaning efficiency from air velocity and angle of injection, a multiple regression equation was developed by using Design Expert 8. The model is given by

$$\text{Cleaning Efficiency} = -88.418 * 1.974X_1 + 30.469X_2 - 0.124X1X_2 - 0.0106X_1^2 - 1.427X_2^2$$

Where X_1 = air velocity in m/s
X_2 = angle of injection in degrees

The experimental and predicted cleaning efficiencies of the four cultivars are shown in Tables 4.20 to 4.23. A plot of the predicted and actual cleaning efficiency as shown in Figure 4.18 shows unifom distribution with a coefficient of correlation of 0.98 indicating that the model predicietd well the cleaning efficiency.

Plate 4.1. The designed and constructed pneumatic cleaner

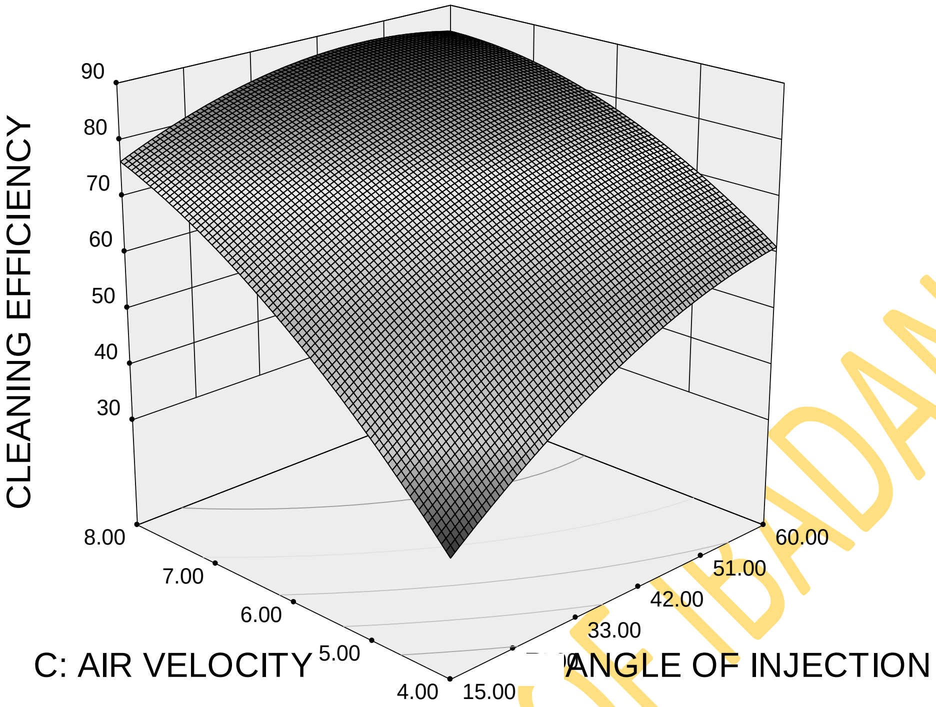


Figure 4.14. Response surface plot for cleaning efficiency of Ife 98-12

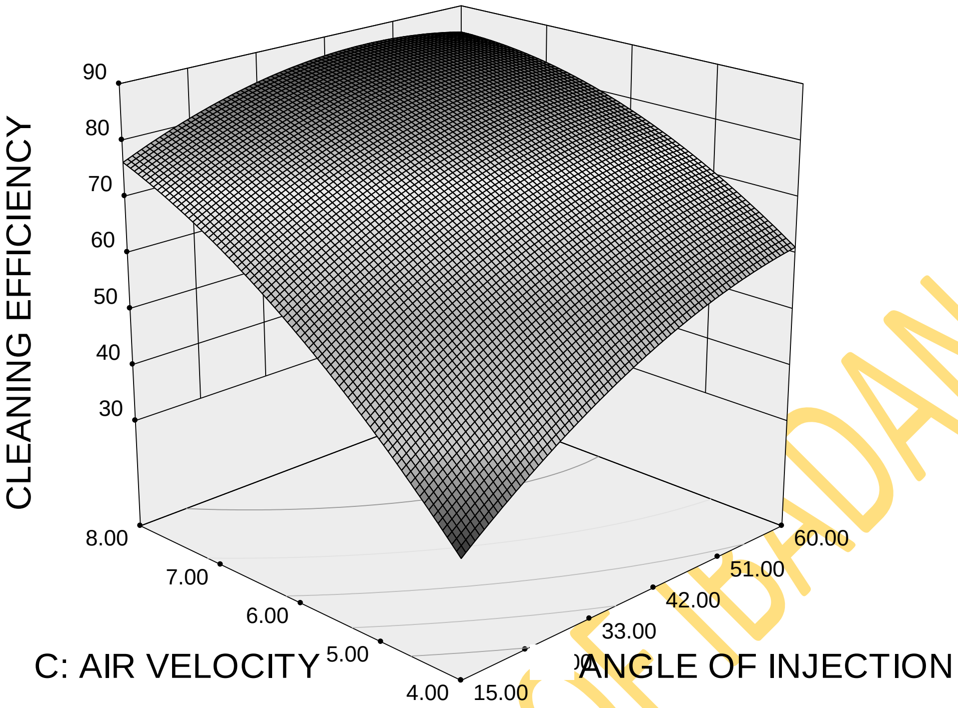


Figure 4.15. Response surface plot for cleaning efficiency of IT90K-277-2

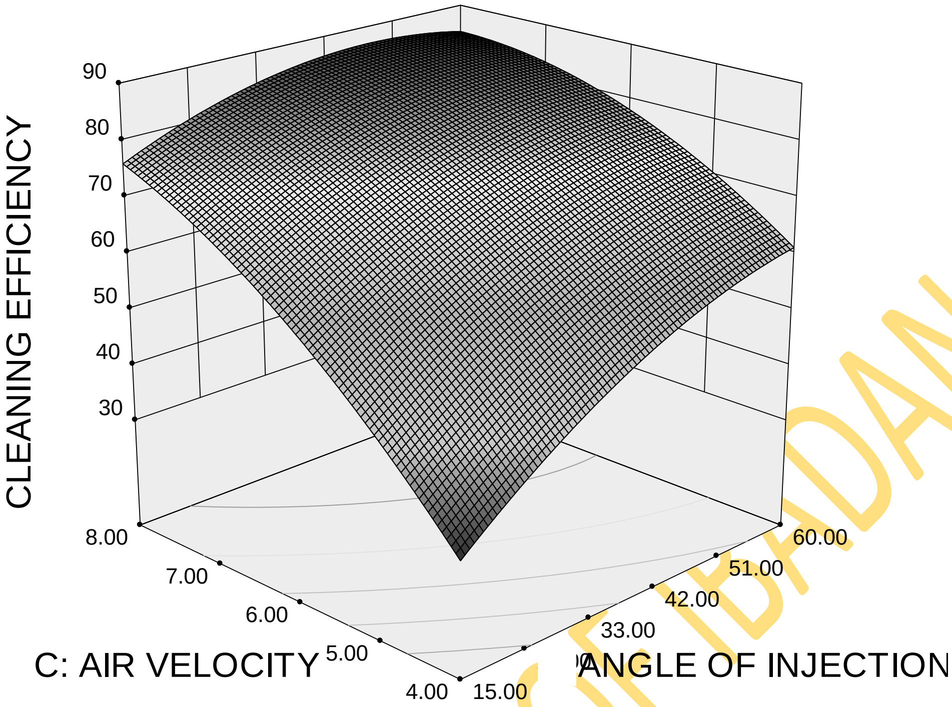


Figure 4.16. Response surface plot cleaning efficiency of Ife Brown

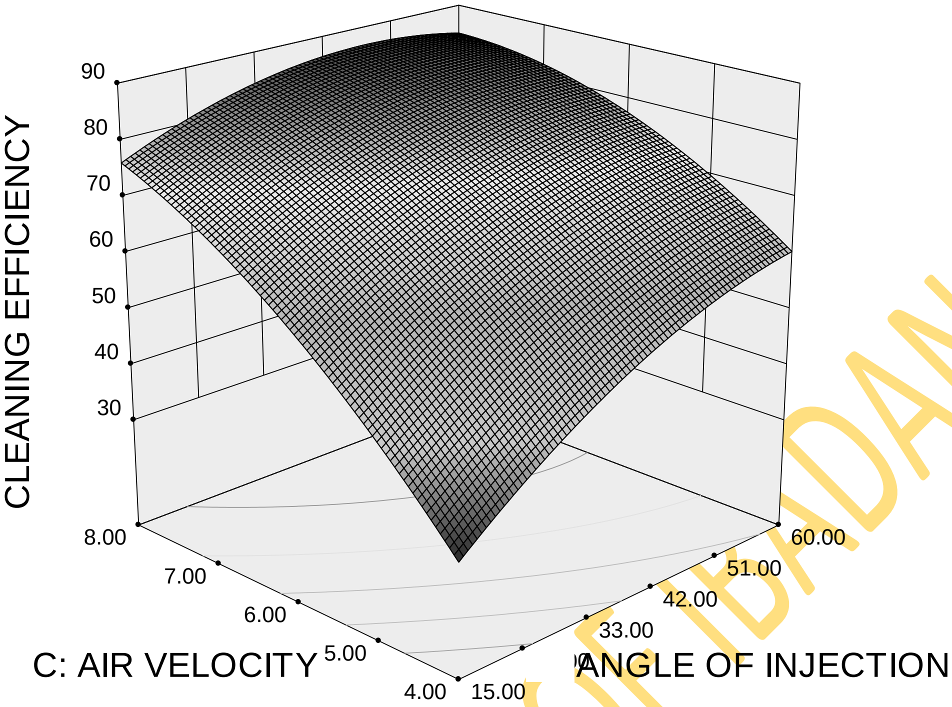


Figure 4.17. Response surface plot for cleaning efficiency of Drum

The predicted cleaning efficiencies were compared with experimental values using the paired t-test at 95% confidence level. The result of the ANOVA shown in Table 4.24 showed t value of 0.017 with a $P(t \leq 0.05)$ of 0.987 indicating that there is no significant difference between the two paired value. This shows that the model predicted well the experimental values.

Table 4.20. Predicted and experimental cleaning efficiencies for Ife 98-12

Ife 98-12	Air Velocity m/s	Injection Angle (^{o})	Experimental Cleaning Effic.(%)	Predicted Cleaning Effic. (%)
	4	15	27.7	30.7
	4	30	44.1	45.7
	4	45	60.6	56.0
	4	60	61.1	61.5
	6	15	63.2	59.3
	6	30	71.9	70.6
	6	45	76.0	77.2
	6	60	75.9	79.0
	8	15	76.7	76.1
	8	30	80.9	84.1
	8	45	87.5	87.0
	8	60	87.2	85.0

Table 4.21. Predicted and experimental cleaning efficiencies for IT90K-277-2

IT90K-277-2	Air Velocity m/s	Injection Angle (^{o})	Experimental Cleaning Effic.(%)	Predicted Cleaning Effic. (%)
	4	15	28.2	30.8
	4	30	44.4	45.8
	4	45	60.9	56.1
	4	60	60.9	61.6
	6	15	63.7	59.4
	6	30	71.2	70.6
	6	45	75.5	77.2
	6	60	75.6	79.0
	8	15	76.8	76.5
	8	30	79.9	84.1
	8	45	87.9	86.9
	8	60	88.2	85.0

Table 4.22. Predicted and experimental cleaning efficiencies for Ife Brown

Ife Brown	Air Velocity m/s	Injection Angle (°)	Experimental Cleaning Effic.(%)	Predicted Cleaning Effic. (%)
	4	15	27.6	30.2
	4	30	44.3	45.4
	4	45	60.3	55.8
	4	60	60.8	61.4
	6	15	62.3	59.3
	6	30	71.6	70.3
	6	45	75.4	77.0
	6	60	75.6	78.9
	8	15	76.7	76.3
	8	30	80.0	83.9
	8	45	87.4	86.7
	8	60	87.9	84.7

Table 4.23. Predicted and experimental cleaning efficiencies for Drum

Drum	Air Velocity m/s	Injection Angle (°)	Experimental Cleaning Effic.(%)	Predicted Cleaning Effic. (%)
	4	15	27.7	30.0
	4	30	44.6	45.0
	4	45	59.2	55.2
	4	60	59.6	60.7
	6	15	61.4	58.9
	6	30	71.6	70.3
	6	45	75.5	76.7
	6	60	75.5	78.4
	8	15	76.6	76.3
	8	30	80.4	83.9
	8	45	87.5	86.7
	8	60	87.2	84.7

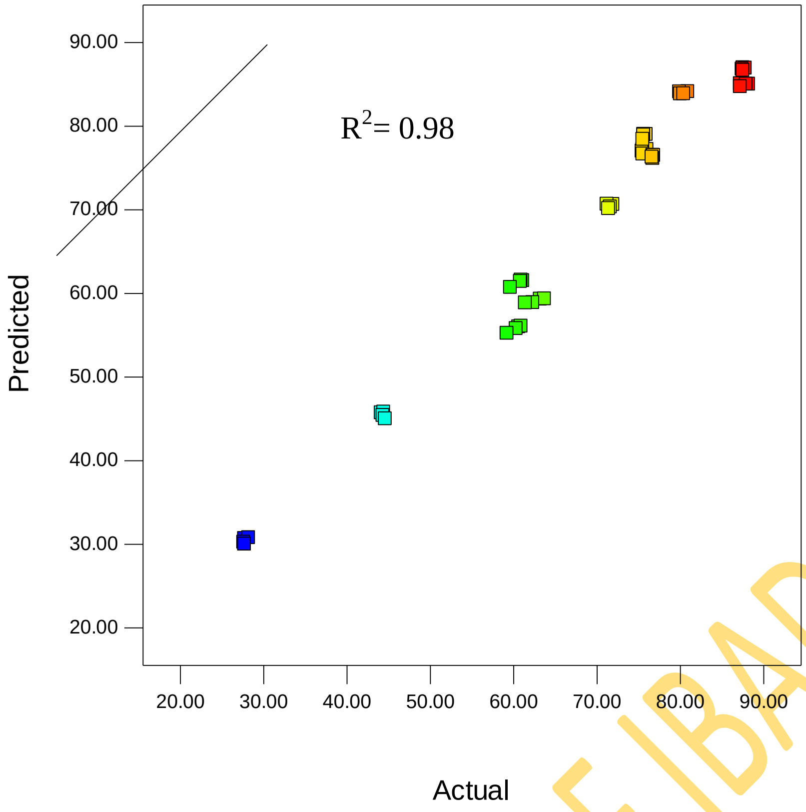


Figure 4.18. Correlation between actual and predicted efficiencies for the four varieties

Table 4.24. ANOVA summary of the paired t-test

Parameter	Value
Mean	0.0063
Standard Deviation	2.57
Standard Error (Mean)	0.37
t-value	0.017
Df	47
Significant (2-tailed)	0.987

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

From the results obtained from this research, the following conclusions may be drawn.

i. Important physical and aerodynamic properties of cowpea that are useful for the design of cleaning, sorting, grading and pneumatic conveying machine for cowpea have been determined.

ii. Moisture content has significant effect on most of the physical and aerodynamic properties in the moisture content range of 8 to 18% w.b. The axial dimensions, geometric mean diameter, projected area, thousand grain mass and terminal velocity increased with increase in moisture content. The bulk and true densities decreased with increase in moisture content. The terminal velocities also increased with increase in moisture content in this moisture content range.

iii. Mathematical models for predicting the cleaning efficiency and the displacements of cowpea and impurities particles in a vertical flow pneumatic cleaner were established.

iv. The predicted horizontal and vertical displacements of the four cowpea varieties decreased with increase in angle of injection. For the impurities, as the angle of injection increased, the horizontal displacements decreased but the vertical displacements increased. This showed that impurities are farther displaced from the grains as the angle of injection increased.

v. The trajectories of different cowpea and impurities particles plotted with the displacements predicted that the quantity of impurities removed from cowpea by a pneumatic cleaner increased as the angle of injection and air velocity increased. Optimum separation occurs when the particles are injected at an angle of injection not less than 45^o.

vi. The predicted cleaning efficiencies as the angle of injection increased from 15 to 60^o increased from 30.7 to 61.5%, 59.3 to 79.0% and 76.1 to 85.0% for Ife 98-12, 30.8 to 61.6%, 59.4 to 79.0% and 76.5 to 85.0% for IT90K-277-2, 30.2 to 61.4%, 59.3 to 78.9% and 76.3 to 84.7% for Ife Brown, 30.0 to 60.7%, 58.9 to 78.4% and 76.3 to 84.7% for Drum respectively at 4, 6, and 8 m/s.

vii. The cleaning efficiencies obtained experimentally at angles of injection of 15 to 60^{o} increased from 27.7 to 61.1%, 63.2 to 75.9% and 76.7 to 87.2% for Ife 98-12, 28.8 to 60.9%, 63.7 to 75.6% and 76.8 to 88.2% for IT90K-277-2, 27.6 to 60.8%, 62.3 to 75.6% and 76.7 to 87.9% for Ife Brown, 27.7-59.6%, 61.4 to 75.5% and 76.6 to 87.2 % for Drum respectively at 4, 6, and 8 m/s. The paired t-test ($p \leq 0.05$) showed that the model predicted significantly the separation efficiency within the experimental range.

The following recommendations are therefore made

i. Utilisation of the data obtained in designing pneumatic cleaners and conveyors for cowpea.

ii. Based on the finding of this work the cleaning efficiency for cowpea is highest at angle of injection of 45^{o} upwards, the hopper of pneumatic cleaners for cowpea should be inclined at this angle.

iii. Further work should be done in using the models to study the horizontal and vertical displacements of cereals like rice, millet and sorghum and their impurities. Their trajectories in the pneumatic cleaner should be investigated so as to examine the possibility of having a multipurpose grain cleaner that can perform optimally with cowpea and cereals.

iv. The effect of shape of machine on cleaning efficiency should be investigated.

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APPENDICES

Table A1. Some physical properties of Ife 98-12 at 8% w.b.

S/N	**a (mm)**	**b (mm)**	**c (mm)**	**D_m (mm)**	**Ψ %**	**R=b/a**	**$A_p = \frac{\pi ab}{4}$ (mm^2)**	**$A_p = \pi D_m^2/4$ (mm^2)**
1.	10.64	6.74	5.41	7.29	68.54	0.63	56.32	41.78
2.	9.60	6.08	5.03	6.65	69.23	0.63	45.84	34.69
3.	10.84	7.73	5.91	7.79	71.83	0.68	62.75	47.62
4.	10.80	7.16	5.35	7.45	68.99	0.66	60.73	43.61
5.	9.17	6.27	5.00	6.60	71.97	0.68	45.16	34.21
6.	9.63	6.57	6.00	7.24	75.19	0.68	49.69	41.18
7.	9.13	5.92	5.17	6.54	71.61	0.72	37.45	28.85
8.	8.15	5.85	4.67	6.06	74.37	0.65	42.45	33.57
9.	9.42	6.65	5.44	6.99	74.15	0.71	49.20	38.32
10.	8.42	5.67	4.61	6.04	71.71	0.68	62.09	47.24
11.	10.80	7.32	5.90	7.76	71.81	0.68	62.09	47.24
12.	8.58	5.70	4.25	5.92	69.04	0.66	38.41	27.56
13.	8.80	5.91	4.35	6.09	69.24	0.67	40.85	29.16
14.	11.00	7.45	6.25	8.00	72.74	0.68	64.36	50.28
15.	9.43	6.03	4.91	6.54	69.31	0.64	44.66	33.55
16.	10.17	6.86	5.82	7.41	72.81	0.68	54.79	43.07
17.	10.45	7.00	5.65	7.45	71.28	0.67	57.45	43.58
18.	10.45	6.52	5.93	7.39	70.74	0.62	53.51	42.93
19.	8.56	5.95	5.42	6.51	76.07	0.70	40.00	33.30
20.	9.34	6.45	5.32	6.84	73.27	0.69	47.32	36.78
21.	9.77	6.11	5.38	6.85	70.09	0.63	46.88	36.83
22.	9.51	6.65	5.38	6.98	73.41	0.70	49.67	38.28
23.	8.90	6.07	5.05	6.49	72.87	0.68	42.43	33.04
24.	8.60	5.55	5.05	6.22	72.37	0.65	37.49	30.42
25.	10.25	6.85	5.53	7.30	71.17	0.67	55.15	41.80
26.	9.62	6.94	5.93	7.35	76.33	0.72	52.44	42.35
27.	9.65	6.64	5.65	7.13	73.86	0.69	50.33	39.90
28.	9.80	6.35	5.35	6.94	70.72	0.75	48.88	37.73
29.	8.95	6.32	5.60	6.82	76.16	0.71	44.43	36.50
30.	9.50	6.35	5.62	6.98	73.40	0.67	47.38	38.19
31.	7.56	6.26	5.05	6.21	82.09	0.83	37.17	30.25
32.	9.01	6.07	4.80	6.41	71.07	0.67	42.95	32.20
33.	9.12	6.30	4.93	6.57	72.01	0.69	45.13	33.88
34.	10.60	6.22	5.10	6.57	72.01	0.59	51.78	37.98
35.	9.04	5.92	5.00	6.44	71.28	0.66	42.03	32.61
36.	9.80	6.55	5.10	6.90	70.33	0.67	50.41	37.31
37.	7.85	5.57	4.25	5.71	72.69	0.71	34.34	25.58
38.	9.15	6.30	5.23	6.71	73.28	0.69	45.27	35.31
39.	8.37	5.66	4.30	5.88	70.30	0.68	37.21	27.19
40.	8.46	5.66	4.50	5.60	70.86	0.67	37.61	28.23
41.	7.85	5.40	4.76	5.87	74.72	0.69	33.29	27.02

42.	8.73	6.90	5.55	6.94	79.50	0.79	47.31	37.83
43.	9.25	6.75	5.57	7.03	76.21	0.73	49.04	38.84
44.	10.00	6.50	5.66	7.17	71.65	0.65	51.05	40.33
45.	9.00	5.75	4.80	7.06	78.48	0.64	40.64	39.18
46.	8.47	5.51	5.05	6.18	72.93	0.65	36.65	29.97
47.	9.12	6.65	5.00	6.72	73.67	0.73	47.63	35.45
48.	9.90	6.80	5.95	7.37	74.46	0.69	52.87	42.68
49.	8.89	6.02	4.46	6.20	69.78	0.68	42.03	30.22
50.	9.78	6.77	5.88	7.30	74.66	0.69	52.00	41.88
$\sum x$	467.88	316.86	261.87	307.58	3636.36	33.93	2342.03	1818.83
$\bar{x}$	9.36	6.34	5.24	6.15	72.73	0.68	46.84	36.38
STD	0.84	0.52	0.49	0.55	0.03	0.04	7.62	5.91

Table A2. Some physical properties of Ife 98-12 at 12%

S/N	**a (mm)**	**b (mm)**	**c (mm)**	**D_m (mm)**	**Ψ %**	**R=b/a**	**$A_p = \frac{\pi ab}{4}$ (mm^2)**	**$A_p = \pi D_m^2/4$ (mm^2)**
1.	10.65	6.75	6.00	7.56	70.94	0.63	56.46	44.84
2.	10.96	6.74	5.70	7.50	68.39	0.62	58.02	44.12
3.	10.84	7.37	5.91	7.79	71.83	0.65	43.83	31.50
4.	10.80	7.16	5.35	7.45	68.99	0.71	55.88	43.68
5.	9.32	5.74	5.07	6.47	69.45	0.62	42.02	32.91
6.	9.91	6.40	5.25	6.93	69.94	0.65	49.82	37.73
7.	9.13	5.92	5.17	6.54	71.61	0.64	41.09	34.07
8.	9.94	6.60	5.38	7.07	71.10	0.66	51.53	39.23
9.	9.65	6.90	5.25	7.04	73.00	0.72	52.30	38.97
10.	10.45	6.80	5.60	7.36	70.39	0.65	55.81	42.49
11.	10.34	6.93	6.30	7.67	74.19	0.67	56.28	46.22
12.	8.78	5.97	4.90	6.36	72.40	0.68	41.17	31.74
13.	9.73	6.03	5.10	6.69	68.74	0.62	46.08	35.14
14.	9.36	6.70	5.53	6.95	74.23	0.72	49.25	37.92
15.	10.08	6.30	5.20	6.91	68.57	0.63	49.88	37.52
16.	9.81	6.31	5.93	7.16	72.99	0.64	48.62	40.27
17.	10.15	6.00	5.88	7.10	69.96	0.59	47.83	39.61
18.	9.40	6.45	5.05	6.74	71.70	0.69	47.62	35.68
19.	8.45	6.54	6.53	7.12	84.25	0.77	43.40	39.81
20.	10.80	7.00	5.60	7.51	69.53	0.65	59.38	44.28
21.	10.00	6.71	5.25	7.06	70.63	0.67	52.70	39.18
22.	9.65	6.27	4.91	6.67	69.15	0.65	47.52	34.97
23.	10.00	6.62	5.50	7.14	71.41	0.66	51.99	40.05
24.	10.15	6.50	5.77	7.25	71.40	0.64	51.82	41.25
25.	9.15	6.05	4.57	6.32	69.12	0.66	43.48	31.42
26.	9.50	6.70	5.85	7.19	75.73	0.71	49.99	40.65
27.	10.08	6.34	5.50	7.06	70.01	0.63	50.19	39.12
28.	10.34	7.05	6.66	7.86	76.01	0.68	57.25	48.52
29.	9.87	6.50	5.10	6.89	69.82	0.71	44.43	36.50
30.	9.33	6.90	5.71	7.16	76.78	0.74	50.56	40.30

31.	8.76	5.45	3.82	5.67	64.74	0.62	37.50	25.26
32.	9.18	5.95	4.70	6.36	69.23	0.65	42.90	31.72
33.	7.75	5.50	4.90	5.93	76.56	0.71	33.48	27.65
34.	8.42	5.80	4.55	6.06	71.93	0.69	38.36	28.81
35.	9.30	5.67	4.75	6.30	67.78	0.61	41.42	31.21
36.	9.62	6.32	5.34	6.87	71.44	0.66	47.75	37.10
37.	8.37	5.84	4.94	6.23	74.40	0.70	38.39	30.46
38.	9.98	6.35	5.38	6.99	70.00	0.64	49.77	38.33
39.	7.89	5.25	4.76	5.82	73.77	0.67	32.53	26.61
40.	8.67	6.15	5.05	6.46	74.48	0.71	41.88	32.75
41.	8.92	6.30	4.40	6.28	70.36	0.71	44.14	30.94
42.	10.00	7.21	6.37	7.72	77.15	0.72	56.63	46.75
43.	8.94	6.35	4.40	6.30	70.45	0.71	44.59	31.15
44.	8.13	5.24	4.00	5.54	68.19	0.65	33.46	24.14
45.	10.20	6.90	5.22	7.16	70.22	0.68	55.28	40.29
46.	9.58	6.30	5.05	6.73	70.25	0.66	47.40	35.57
47.	9.25	6.65	5.61	7.01	75.83	0.72	48.31	38.64
48.	10.15	7.40	5.75	7.56	74.47	0.73	58.99	44.87
49.	10.13	6.69	5.23	7.08	69.86	0.66	53.23	39.34
50.	8.71	5.25	4.00	5.68	65.17	0.60	35.91	25.31
$\sum x$	476.48	317.31	262.97	340.85	3578.54	33.37	2383.97	1837.37
$\bar{x}$	9.53	6.35	5.26	6.82	71.57	0.67	47.68	36.75
STD	0.74	0.53	0.63	0.57	0.03	0.04	6.99	5.98

Table A3. Some physical properties of Ife 98-12 at 14% w.b.

S/N	**a (mm)**	**b (mm)**	**c (mm)**	**D_m (mm)**	**Ψ %**	**R=b/a**	**$A_p = \frac{\pi ab}{4}$ (mm^2)**	**$A_p = \pi D_m^2/4$ (mm^2)**
1.	9.79	6.65	5.90	7.27	74.25	0.68	51.13	41.50
2.	9.80	6.25	4.75	6.63	67.61	0.64	48.11	34.48
3.	11.05	7.86	5.60	7.86	71.17	0.71	68.21	48.58
4.	9.55	6.75	5.05	6.88	72.03	0..71	50.63	37.17
5.	8.55	7.00	6.05	7.13	83.36	0.82	47.01	39.90
6.	8.70	5.75	4.62	6.14	70.54	0.66	39.29	29.58
7.	10.55	6.61	6.20	7.56	71.67	0.63	54.77	44.91
8.	10.55	7.08	5.74	7.54	71.47	0.67	58.67	44.66
9.	8.96	6.60	5.33	6.81	75.95	0.74	46.45	36.38
10.	9.75	7.08	5.74	7.54	73.81	0.67	58.67	44.66
11.	9.10	6.15	5.10	6.58	72.35	0.68	43.96	34.05
12.	9.05	5.11	4.73	6.03	66.58	0.57	36.32	28.51
13.	9.55	6.15	4.63	6.48	67.84	0.64	46.13	32.97
14.	9.35	5.46	5.05	6.36	68.03	0.58	40.02	31.78
15.	10.60	6.40	5.22	7.07	66.74	0.60	53.28	39.31
16.	9.10	6.53	5.60	6.93	76.15	0.72	46.67	37.71
17.	10.35	6.92	5.85	7.48	72.30	0.67	56.25	43.98
18.	10.00	7..10	6.00	7.52	75.24	0.71	55.76	44.47
19.	9.45	5.85	4.86	6.45	68.28	0.62	43.42	32.70

20.	8.88	6.50	4.20	6.24	70.22	0.73	45.33	30.54
21.	10.05	5.55	5.35	6.68	66.49	0.55	43.81	35.07
22.	10.50	6.81	6.01	7.55	71.87	0.65	56.16	44.73
23.	10.45	6.90	5.76	7.46	71.40	0.66	56.63	43.72
24.	10.50	6.50	5.85	7.36	70.13	0.62	53.60	42.59
25.	9.71	6.15	5.00	6.68	68.83	0.63	46.90	35.09
26.	9.84	6.60	5.55	7.12	72.32	0.67	51.01	39.78
27.	10.45	6.71	5.52	7.29	69.74	0.64	55.07	41.71
28.	8.30	5.70	4.45	5.95	71.67	0.69	37.16	27.80
29.	8.85	6.85	6.65	7.39	83.47	0.77	47.61	42.86
30.	8.50	6.60	5.02	6.57	77.35	0.78	44.06	33.95
31.	8.65	6.70	5.42	6.80	78.59	0.78	45.52	36.29
32.	10.20	6.60	5.34	7.11	69.71	0.65	52.87	37.71
33.	10.10	6.85	5.50	7.25	71.75	0.68	54.34	41.24
34.	9.90	6.65	4.55	6.69	67.59	0.67	51.71	35.16
35.	9.10	6.15	4.75	6.43	70.66	0.68	43.96	32.47
36.	10.00	6.86	5.70	7.31	73.13	0.69	53.88	42.00
37.	8.60	5.80	4.46	6.06	70.46	0.67	39.18	28.84
38.	9.90	6.92	5.35	7.16	72.29	0.70	53.81	40.22
39.	9.86	6.75	5.40	7.11	72.11	0.69	52.27	39.70
40.	9.45	5.55	4.61	6.23	65.92	0.59	41.19	30.48
41.	10.30	6.55	5.41	7.15	69.38	0.64	52.99	40.11
42.	9.00	5.65	4.35	6.05	67.20	0.63	39.94	28.73
43.	9.70	6.30	4.95	6.71	69.20	0.65	48.00	35.39
44.	9.20	6.05	4.80	6.44	70.00	0.66	43.72	32.58
45.	9.15	6.35	4.50	6.39	69.88	0.69	45.63	32.11
46.	11.17	7.45	6.33	8.08	72.30	0.67	65.36	51.23
47.	10.61	5.95	5.63	7.08	66.76	0.56	49.58	39.41
48.	9.80	6.30	5.22	6.86	69.96	0.64	48.49	36.92
49.	9.15	5.90	4.32	6.16	67.27	0.65	42.40	29.76
50.	10.85	6.76	5.66	7.46	68.75	0.62	57.61	43.71
$\sum x$	484.52	322.25	263.29	344.72	3561.77	33.34	2460.05	1875.17
$\bar{x}$	9.69	6.45	5.27	6.89	71.24	0.67	49.20	37.50
STD	0.72	0.54	0.58	0.52	0.04	0.06	6.81	5.66

Table A4. Some Physical properties of Ife 98-12 at 18%

S/N	**a (mm)**	**b (mm)**	**c (mm)**	**D_m (mm)**	**Ψ %**	**R=b/a**	**$A_p = \frac{\pi ab}{4}$ (mm^2)**	**$A_p = \pi D_m^2/4$ (mm^2)**
1.	11.05	7.30	6.47	8.05	72.86	0.66	63.35	50.91
2.	9.95	6.25	5.29	6.90	69.38	0.63	48.84	37.43
3.	9.57	6.43	5.18	6.83	71.38	0.67	48.33	36.65
4.	10.78	7.18	6.00	7.74	71.84	0.67	60.79	47.10
5.	10.45	6.40	5.36	7.10	67.98	0.61	52.53	39.63
6.	10.05	7.47	6.41	7.84	77.97	0.74	63.61	52.51
7.	10.90	7.43	6.75	8.18	75.01	0.68	63.61	52.51
8.	9.48	6.40	4.30	6.39	67.40	0.68	47.65	32.07

9.	9.94	6.31	5.73	7.11	71.53	0.64	49.26	39.70
10.	10.79	7.26	5.72	7.65	70.92	0.67	61.52	45.99
11.	9.88	6.96	5.17	7.08	71.70	0.70	54.01	39.42
12.	9.90	6.22	5.10	6.80	68.66	0.63	48.36	36.29
13.	10.11	7.44	6.54	7.89	78.08	0.74	59.08	48.94
14.	10.53	7.89	5.82	7.85	74.54	0.75	65.25	48.39
15.	10.90	7.00	5.59	7.53	69.06	0.64	59.93	44.50
16.	8.70	5.80	4.86	6.26	71.95	0.67	39.63	30.77
17.	10.70	6.65	5.83	7.46	69.70	0.62	55.89	43.69
18.	9.98	7.30	5.53	7.39	74.01	0.73	57.22	42.84
19.	9.57	7.03	6.45	7.58	79.11	0.74	52.84	45.02
20.	10.30	7.10	5.45	7.36	71.45	0.69	57.44	42.54
21.	10.55	7.03	6.25	7.74	73.36	0.67	58.25	47.04
22.	9.34	6.00	4.80	6.46	69.11	0.64	44.01	32.73
23.	10.63	6.57	5.95	7.46	70.20	0.62	54.85	43.74
24.	9.04	6.38	5.97	7.01	77.53	0.71	45.30	38.58
25.	10.52	7.42	5.07	7.34	69.79	0.71	61.31	42.34
26.	9.86	6.97	5.46	7.21	73.15	0.71	54.01	40.86
27.	10.25	7.45	5.71	7.58	73.99	0.73	59.96	45.18
28.	10.00	6.12	5.60	7.00	69.98	0.61	48.07	38.46
29.	9.20	6.00	5.40	6.68	72.61	0.65	43.35	35.05
30.	9.72	6.02	5.46	6.84	70.33	0.62	45.96	36.71
31.	9.38	6.05	4.82	6.49	69.20	0.62	45.96	36.71
32.	9.55	6.20	4.65	6.51	68.12	0.65	44.57	33.10
33.	9.70	6.58	5.38	7.00	72.19	0.65	46.50	33.24
34.	9.68	6.13	5.32	6.81	70.34	0.68	50.13	38.51
35.	8.41	5.81	4.85	6.19	73.58	0.63	46.60	36.41
36.	8.50	5.50	4.25	5.84	68.65	0.65	36.72	26.74
37.	10.00	6.75	4.83	6.88	68.83	0.68	53.01	37.20
38.	9.05	6.25	5.20	6.65	73.48	0.68	44.42	34.74
39.	9.00	5.70	4.30	6.04	67.14	0.63	40.29	28.67
40.	9.62	6.30	5.16	6.79	70.56	0.66	47.60	36.19
41.	7.77	5.65	4.90	5.99	77.11	0.73	34.48	28.20
42.	8.35	6.40	4.75	6.33	75.83	0.77	41.97	31.49
43.	8.08	5.15	3.75	5.38	66.63	0.64	32.68	22.76
44.	10.75	6.85	5.40	7.35	68.41	0.64	57.84	42.47
45.	10.05	6.80	5.25	7.11	70.71	0.68	53.67	39.66
46.	9.52	6.05	4.50	6.38	66.97	0.64	45.24	31.93
47.	10.40	6.18	5.20	6.94	66.73	0.59	50.48	37.82
48.	7.25	5.90	4.69	5.85	80.75	0.81	33.60	26.92
49.	9.60	6.45	4.75	6.65	69.27	0.67	48.63	34.74
50.	9.91	6.15	5.15	6.80	68.58	0.62	47.87	36.27
$\sum x$	487.21	326.63	266.32	348.28	3577.66	33.58	2514.25	1920.40
$\bar{x}$	9.74	6.53	5.33	6.97	71.55	0.67	50.28	34.41
STD	0.84	0.62	0.64	0.62	0.03	0.05	8.25	6.78

Table A5. Some physical properties of IT90K-277-2 at 8% w.b.

S/N	a (mm)	b (mm)	c (mm)	D_m (mm)	Ψ %	R=b/a	$A_p = \frac{\pi ab}{4}$ (mm^2)	$A_p = \pi D_m^2/4$ (mm^2)
1.	8.33	6.33	5.52	6.63	79.56	0.76	41.41	34.50
2.	8.07	6.35	5.54	6.57	81.44	0.79	40.25	33.93
3.	7.00	5.91	4.73	5.81	82.94	0.84	32.49	26.47
4.	8.90	6.32	5.37	6.71	75.39	0.71	44.18	35.36
5.	9.13	6.80	5.52	7.00	76.65	0.75	48.76	38.46
6.	7.58	6.17	5.40	6.32	83.39	0.81	36.73	31.38
7.	8.13	6.26	5.07	6.37	78.31	0.77	39.97	31.83
8.	8.09	5.70	4.53	5.93	73.34	0.71	36.22	27.65
9.	7.02	5.62	4.66	5.69	81.00	0.80	30.99	25.39
10.	7.92	6.30	5.36	6.44	81.35	0.80	39.19	32.60
11.	6.60	5.44	4.60	5.49	83.13	0.82	28.20	23.64
12.	9.19	6.97	5.25	6.95	75.67	0.76	50.31	37.98
13.	8.00	5.80	4.85	6.08	76.03	0.73	36.44	29.06
14.	8.27	5.95	5.46	6.45	78.02	0.72	38.65	32.70
15.	7.67	6.12	4.87	6.11	79.72	0.80	36.87	29.36
16.	9.17	6.72	5.62	7.02	76.58	0.73	48.40	38.73
17.	7.55	6.35	4.85	6.15	81.45	0.84	37.65	29.70
18.	8.80	6.18	4.92	6.44	73.23	0.70	42.71	32.61
19.	7.93	6.12	5.05	6.26	78.92	0.77	38.12	30.76
20.	8.40	6.70	5.60	6.81	81.02	0.80	44.20	36.37
21.	8.31	6.10	5.25	6.43	77.40	0.73	39.81	32.50
22.	6.60	5.70	4.95	5.71	86.52	0.86	29.55	25.61
23.	7.16	6.17	4.76	5.95	83.05	0.86	34.70	27.77
24.	7.33	5.65	4.17	5.57	76.00	0.77	32.53	24.37
25.	7.85	6.10	4.50	6.00	76.37	0.78	37.61	28.23
26.	8.03	6.22	5.51	6.50	81.0	0.78	39.23	33.23
27.	6.88	5.85	4.55	5.69	82.54	0.85	31.61	25.33
28.	7.90	6.85	5.18	6.54	82.84	0.87	42.50	33.64
29.	8.43	6.46	4.98	6.47	76.78	0.77	42.77	32.91
30.	6.83	5.55	4.47	5.53	81.02	0.81	29.77	24.05
31.	8.05	5.78	4.60	5.98	74.31	0.72	36.54	28.10
32.	7.53	6.31	5.21	6.28	83.39	0.84	37.32	30.97
33.	8.45	5.75	3.57	5.58	66.00	0.68	38.16	24.43
34.	7.15	5.61	4.65	5.71	79.91	0.79	31.50	25.64
35.	6.05	5.30	4.85	5.38	88.89	0.88	25.18	22.71
36.	8.05	6.15	5.35	6.42	79.78	0.76	38.88	32.39
37.	7.93	6.15	5.36	6.39	80.63	0.78	38.30	32.11
38.	7.39	5.75	4.15	5.61	75.88	0.78	33.37	24.70
39.	5.84	5.20	4.30	5.07	86.87	0.89	23.85	20.22
40.	7.42	6.11	5.35	6.24	84.05	0.82	35.61	30.55
41.	7.37	6.27	5.45	6.32	85.69	0.85	36.29	31.32
42.	6.26	6.14	5.05	5.79	92.49	0.98	30.19	26.33
43.	8.16	6.55	5.95	6.83	83.65	0.80	41.98	36.59
44.	7.95	6.75	4.83	6.38	80.20	0.85	42.15	31.93
45.	6.67	5.45	4.50	5.47	81.99	0.82	28.55	23.49

46.	6.21	5.36	4.66	5.37	86.52	0.86	26.14	22.67
47.	8.05	6.15	5.37	6.43	79.88	0.76	38.88	32.47
48.	8.07	6.27	5.35	6.47	80.16	0.78	39.74	32.87
49.	8.14	5.88	5.23	6.30	77.42	0.72	37.59	31.20
50.	6.90	6.10	5.00	5.95	86.21	0.88	33.06	27.79
$\sum x$	384.73	303.79	249.87	307.58	4014.58	39.72	1845.11	1494.59
$\bar{x}$	7.69	6.08	5.00	6.15	80.29	0.79	36.90	29.89
STD	0.80	0.41	0.46	0.47	0.05	0.06	5.86	4.52

Table A6. Some physical properties of IT90K-277-2 at 12% w.b.

S/N	**a (mm)**	**b (mm)**	**c (mm)**	**D_m (mm)**	**Ψ %**	**R=b/a**	**$A_p = \frac{\pi ab}{4}$ (mm^2)**	**$A_p = \pi D_m^2/4$ (mm^2)**
1.	7.54	5.78	4.86	5.96	79.06	0.77	34.23	27.91
2.	7.84	6.00	4.95	6.15	78.47	0.77	36.95	29.73
3.	8.91	6.81	5.52	6.94	77.94	0.76	47.66	37.88
4.	8.91	6.60	5.46	6.85	76.85	0.74	46.19	36.83
5.	9.62	5.46	5.31	6.53	67.92	0.57	41.25	33.53
6.	6.34	5.80	5.02	5.69	89.81	0.92	28.88	25.46
7.	9.17	6.47	5.43	6.86	74.76	0.71	46.60	36.91
8.	6.75	5.10	4.92	5.53	81.97	0.76	27.04	24.04
9.	8.95	6.50	5.32	6.76	75.58	0.73	45.69	35.94
10.	7.93	6.81	5.15	6.53	82.31	0.86	42.41	33.46
11.	8.63	6.03	4.87	6.33	73.33	0.70	40.87	31.45
12.	7.45	6.02	5.20	6.16	82.62	0.81	35.22	29.76
13.	8.83	6.03	4.73	6.32	71.52	0.68	41.82	31.32
14.	6.95	5.81	4.37	5.61	80.70	0.84	31.71	24.71
15.	8.10	6.54	5.54	6.65	82.04	0.81	41.61	34.68
16.	9.17	6.72	5.62	7.02	76.58	0.80	38.94	31.82
17.	8.10	6.16	4.86	6.24	76.99	0.76	39.19	30.54
18.	8.45	6.55	5.42	6.69	79.22	0.78	43.47	35.20
19.	8.52	6.86	6.13	7.10	83.36	0.81	45.90	39.62
20.	8.97	6.46	5.82	6.96	77.60	0.72	45.51	38.05
21.	8.00	6.34	5.04	6.35	79.33	0.79	39.84	31.63
22.	8.41	6.00	5.37	6.47	76.94	0.71	39.63	32.89
23.	8.61	6.33	5.06	6.51	75.60	0.74	42.81	33.28
24.	8.73	6.12	5.60	6.69	76.61	0.70	41.96	35.13
25.	8.34	5.93	5.00	6.28	75.26	0.71	38.84	30.94
26.	7.45	6.45	5.05	6.24	83.72	0.87	38.84	30.56
27.	7.81	6.10	5.12	6.25	80.00	0.78	37.42	30.66
28.	8.25	6.15	5.42	6.50	78.82	0.75	39.85	33.21
29.	8.11	6.22	5.02	6.33	78.01	0.77	39.62	31.44
30.	7.85	6.38	4.80	6.22	79.21	0.81	39.34	30.37
31.	8.07	6.05	4.85	6.19	76.66	0.75	38.35	30.06
32.	6.65	5.69	4.92	5.71	85.86	0.86	29.72	25.61
33.	7.40	5.08	4.39	5.49	74.12	0.69	29.53	23.63
34.	8.37	5.95	5.46	6.48	77.4	0.71	39.11	32.97
35.	6.80	5.25	4.33	5.37	78.92	0.77	28.04	22.62

36.	7.84	6.17	4.96	6.21	79.26	0.79	37.99	30.33
37.	7.32	6.28	5.70	6.40	87.42	0.86	36.10	32.16
38.	8.06	6.78	5.95	6.88	85.32	0.84	42.92	37.14
39.	7.07	5.02	4.77	5.53	78.25	0.71	27.88	24.04
40.	7.20	6.00	4.75	5.90	81.92	0.83	33.93	27.32
41.	7.80	6.35	4.55	6.09	78.02	0.81	38.90	29.09
42.	7.65	6.00	5.00	6.13	8.03	0.78	36.05	29.44
43.	8.10	6.22	5.18	6.39	78.90	0.77	39.57	32.07
44.	7.10	5.65	4.07	5.47	76.98	0.80	31.51	23.46
45.	7.76	5.85	5.01	6.10	78.66	0.75	35.65	29.26
46.	7.91	6.85	5.75	6.78	85.70	0.87	42.57	36.10
47.	8.10	6.10	5.02	6.28	77.57	0.75	38.81	31.01
48.	8.55	7.25	5.43	6.96	81.36	0.85	48.69	38.00
49.	8.62	6.40	5.76	6.82	79.16	0.74	43.33	36.57
50.	6.86	5.37	4.56	5.52	80.43	0.78	28.93	23.91
$\sum x$	398.62	306.42	255.97	314.72	3882.07	38.60	1927.83	1563.71
$\bar{x}$	7.97	6.13	5.12	6.29	77.64	0.77	38.56	31.27
STD	0.72	0.47	0.43	0.45	0.04	0.06	5.55	4.41

Table A7. Some physical properties of IT90K-277-2 at 14% w.b.

S/N	**a (mm)**	**b (mm)**	**c (mm)**	**D_m (mm)**	**Ψ %**	**R=b/a**	**$A_p = \frac{\pi ab}{4}$ (mm^2)**	**$A_p = \pi D_m^2/4$ (mm^2)**
1.	8.61	5.94	5.06	6.37	74.01	0.69	40.17	31.90
2.	8.14	6.22	5.35	6.47	79.49	0.76	39.77	32.88
3.	9.05	6.55	5.73	6.98	77.10	0.72	46.56	38.23
4.	8.05	6.20	5.30	6.42	79.74	0.77	39.20	32.36
5.	8.24	6.26	5.90	6.73	81.63	0.76	40.51	35.54
6.	8.69	6.29	5.34	6.63	76.33	0.72	42.93	34.56
7.	8.90	6.16	5.50	6.71	75.35	0.69	43.06	35.32
8.	8.70	6.37	5.43	6.70	77.03	0.73	43.53	35.27
9.	6.83	5.69	4.54	5.61	82.12	0.83	30.52	24.71
10.	6.18	5.28	4.24	5.17	83.69	0.85	25.63	21.01
11.	8.32	6.20	5.15	6.43	77.27	0.75	40.51	32.46
12.	8.89	6.91	5.00	6.75	75.90	0.78	48.25	35.75
13.	9.13	6.56	5.85	7.05	77.22	0.72	47.04	39.03
14.	9.02	6.28	5.21	6.66	73.81	0.70	44.49	34.82
15.	8.00	6.21	5.50	6.49	81.11	0.78	39.02	33.07
16.	8.25	6.17	5.10	6.38	77.32	0.75	39.98	31.96
17.	9.95	6.51	5.30	7.00	70.37	0.65	50.87	38.51
18.	8.40	6.05	5.32	6.47	76.98	0.72	39.91	33.82
19.	8.30	6.08	5.60	6.56	79.06	0.73	39.63	33.82
20.	6.76	5.84	5.00	5.82	86.13	0.86	31.01	26.63
21.	8.26	6.25	4.42	6.11	73.98	0.76	40.55	29.33
22.	8.47	6.25	5.45	6.61	78.01	0.74	41.58	34.29
23.	7.13	5.25	4.85	5.66	79.42	0.74	29.40	25.18
24.	6.60	5.70	4.88	5.68	86.11	0.86	29.55	25.37

25.	8.83	6.84	5.45	6.91	78.19	0.78	47.44	37.44
26.	6.88	5.87	5.12	5.91	85.95	0.85	31.72	27.46
27.	7.17	6.42	5.08	6.16	85.93	0.89	36.15	29.81
28.	6.54	5.65	4.72	5.59	85.43	0.86	29.02	24.52
29.	8.00	6.10	5.40	6.41	80.14	0.76	38.33	32.28
30.	9.40	6.50	5.29	6.86	73.01	0.69	47.99	36.99
31.	9.08	6.77	5.65	7.03	77.41	0.75	48.28	38.81
32.	8.10	6.46	5.32	6.53	80.61	0.80	41.10	33.48
33.	8.75	6.50	5.07	6.61	75.50	0.74	44.67	28.91
34.	8.66	6.53	5.45	6.75	78.00	0.75	44.41	35.84
35.	8.45	6.05	5.45	6.53	77.29	0.72	40.15	33.50
36.	7.60	6.52	5.32	6.41	84.37	0.86	38.93	32.29
37.	7.30	5.55	4.81	5.80	79.42	0.76	31.82	26.40
38.	7.28	5.65	4.61	5.75	78.92	0.78	32.31	25.92
39.	7.08	5.60	4.90	5.79	81.80	0.79	31.14	26.35
40.	8.55	6.22	5.44	6.61	77.35	0.73	41.77	34.36
41.	7.45	5.46	4.02	5.47	73.40	0.73	31.95	23.49
42.	9.31	6.95	5.43	7.06	75.79	0.75	50.82	39.11
43.	8.20	6.20	5.45	6.52	79.50	0.76	39.93	33.38
44.	6.84	5.57	4.50	5.56	81.22	0.81	29.92	24.24
45.	7.10	5.45	5.21	5.86	82.59	0.77	30.39	27.00
46.	7.60	6.00	4.76	6.01	79.08	0.79	35.81	28.37
47.	7.45	6.40	4.50	5.99	80.36	0.86	37.45	28.15
48.	6.78	5.35	5.30	5.77	85.12	0.79	28.49	26.16
49.	7.80	6.75	5.16	6.48	83.03	0.87	41.35	32.95
50.	6.75	5.86	4.86	5.77	85.50	0.87	31.07	26.16
$\sum x$	399.82	306.44	257.29	315.59	3964.09	38.57	1929.41	1569.16
$\bar{x}$	8.00	6.13	5.15	6.31	79.28	0.77	38.59	31.38
STD	0.89	0.43	0.41	0.48	0.04	0.06	6.63	4.77

Table A8. Some physical properties of IT90K-277-2 at 18% w.b.

S/N	**a (mm)**	**b (mm)**	**c (mm)**	**D_m (mm)**	**Ψ %**	**R=b/a**	**$A_p = \frac{\pi ab}{4}$ (mm^2)**	**$A_p = \pi D_m^2/4$ (mm^2)**
1.	8.75	6.80	5.95	7.07	80.85	0.78	46.73	39.31
2.	8.40	6.45	5.50	6.68	79.52	0.77	42.55	35.04
3.	9.65	6.70	5.40	7.04	72.96	0.69	50.78	38.94
4.	8.90	6.60	5.61	6.91	77.61	0.74	46.13	37.47
5.	9.27	6.95	5.83	7.22	77.83	0.75	50.60	40.89
6.	8.35	6.50	5.55	6.70	80.28	0.78	42.63	35.29
7.	8.20	6.55	5.55	6.68	81.46	0.80	42.18	35.05
8.	8.33	6.71	5.65	6.81	81.75	0.81	43.90	36.42
9.	9.50	6.40	5.61	6.99	73.55	0.67	47.75	38.34
10.	8.60	6.85	5.72	6.96	80.92	0.80	46.27	38.03
11.	8.60	6.76	5.20	6.71	78.04	0.79	45.66	35.38
12.	8.50	6.35	5.47	6.66	78.34	0.75	42.39	34.82
13.	8.25	6.70	5.70	6.80	82.48	0.81	43.41	36.37

14.	9.16	6.40	6.10	7.10	77.49	0.70	46.04	39.57
15.	7.40	5.41	4.70	5.73	77.44	0.73	31.44	25.79
16.	8.50	6.15	5.26	6.50	76.50	0.72	41.06	33.21
17.	9.32	7.16	4.61	6.75	72.43	0.77	52.41	35.79
18.	8.55	7.22	5.46	6.96	81.40	0.84	48.48	38.04
19.	8.52	5.72	3.85	5.72	67.19	0.67	38.28	25.74
20.	8.62	6.66	6.05	7.03	81.55	0.77	45.09	38.81
21.	8.05	7.00	4.90	6.51	80.89	0.87	44.26	33.30
22.	8.82	6.70	5.10	6.70	76.02	0.76	46.41	35.31
23.	7.92	5.80	4.15	5.76	72.67	0.73	36.08	26.02
24.	8.65	6.45	5.17	6.61	76.38	0.75	43.82	34.29
25.	9.20	6.66	5.00	6.74	73.28	0.72	48.12	35.69
26.	8.25	6.50	5.15	6.51	78.94	0.79	42.12	33.31
27.	8.40	6.45	4.60	6.29	74.92	0.77	42.55	31.10
28.	8.10	6.65	5.55	6.69	82.54	0.82	42.31	35.12
29.	6.90	5.45	4.35	5.47	79.26	0.79	29.54	23.49
30.	8.41	5.91	5.45	6.47	76.94	0.70	39.04	32.88
31.	8.25	6.30	4.85	6.32	76.57	0.76	40.82	31.34
32.	6.70	5.90	5.18	5.89	87.97	0.88	31.05	27.29
33.	8.35	6.70	5.75	6.85	82.06	0.80	43.94	36.87
34.	8.40	6.50	5.36	6.64	79.04	0.77	42.88	34.62
35.	8.25	6.40	5.25	6.52	79.03	0.78	41.47	33.39
36.	9.15	6.66	5.70	7.03	76.82	0.73	47.86	38.81
37.	8.40	6.45	5.25	6.58	78.29	0.77	42.55	33.97
38.	8.70	6.80	5.65	6.93	79.77	0.78	46.46	37.76
39.	7.85	6.50	4.91	6.30	80.31	0.83	40.08	31.21
40.	8.21	6.10	5.42	6.47	78.86	0.74	39.33	32.93
41.	8.65	6.26	5.62	6.73	77.76	0.72	42.53	35.53
42.	8.70	6.45	5.40	6.72	77.20	0.74	44.07	35.43
43.	9.25	6.15	4.85	6.51	70.38	0.67	44.68	33.29
44.	8.90	6.26	4.90	6.49	72.89	0.70	43.76	33.05
45.	9.36	7.02	5.47	7.11	75.96	0.75	51.61	39.70
46.	7.82	5.87	4.00	5.68	72.68	0.75	36.05	25.37
47.	9.01	6.43	4.75	6.50	72.19	0.71	45.50	33.23
48.	8.05	6.45	5.25	6.48	80.55	0.80	40.78	33.02
49.	8.30	5.87	4.70	6.12	73.71	0.71	38.27	29.40
50.	8.00	6.72	5.71	6.75	84.32	0.84	42.22	35.74
$\sum x$	424.37	322.40	262.16	329.40	3887.79	38.08	2153.94	1710.75
$\bar{x}$	8.49	6.45	5.24	6.59	77.76	0.76	43.08	34.21
STD	0.59	0.40	0.51	0.41	0.04	0.05	4.80	4.06

Table A9. Some physical properties of Ife Brown at 8%

S/N	a (mm)	b (mm)	c (mm)	D_m (mm)	Ψ %	R=b/a	$A_p = \frac{\pi ab}{4}$ (mm^2)	$A_p = \pi D_m^2/4$ (mm^2)
1.	8.26	6.25	4.38	6.09	73.76	0.76	40.55	29.15
2.	8.02	6.15	4.22	5.93	73.89	0.77	38.74	27.59
3.	7.89	5.96	4.07	5.76	73.04	0.76	36.93	26.08
4.	8.50	6.29	4.77	6.34	74.07	0.74	41.99	31.59
5.	8.30	5.70	4.05	5.77	69.45	0.69	37.16	26.10
6.	7.77	5.72	4.00	5.62	72.37	0.74	34.91	24.83
7.	8.55	6.20	4.45	6.18	72.27	0.73	41.63	29.99
8.	7.67	6.15	4.37	5.91	77.01	0.80	37.05	27.41
9.	8.21	6.10	4.40	6.04	73.57	0.74	39.33	28.65
10.	7.91	6.20	4.62	6.10	77.07	0.78	38.52	29.19
11.	8.81	6.50	4.87	6.53	74.16	0.74	44.98	33.53
12.	8.87	6.52	4.75	6.50	73.29	0.74	45.42	33.19
13.	8.70	6.50	4.85	6.50	74.68	0.75	44.41	33.15
14.	8.33	5.65	4.30	5.87	70.48	0.68	36.96	27.07
15.	8.12	6.70	5.01	6.48	79.85	0.83	42.73	33.02
16.	8.35	6.10	4.60	6.16	73.83	0.73	40.00	29.85
17.	7.03	5.85	4.45	5.68	80.76	0.83	32.30	25.32
18.	8.30	6.40	4.60	6.25	75.32	0.77	41.72	30.70
19.	9.24	5.96	4.18	6.13	66.33	0.65	43.25	29.50
20.	7.17	5.58	4.19	5.51	76.90	0.78	31.42	23.88
21.	8.20	6.35	4.60	6.21	75.74	0.77	40.90	30.29
22.	7.46	5.87	4.48	5.81	77.89	0.79	34.39	26.52
23.	7.50	5.75	3.80	5.47	72.96	0.77	33.87	23.52
24.	7.74	5.42	4.38	5.69	73.45	0.70	32.95	25.38
25.	8.35	6.05	4.45	6.08	72.82	0.73	39.68	29.04
26.	7.68	5.10	3.76	5.28	68.76	0.66	30.76	21.90
27.	7.45	5.69	4.42	5.72	76.81	0.76	33.29	25.72
28.	7.00	5.46	3.90	5.30	75.74	0.78	30.02	22.08
29.	7.15	5.26	4.34	5.47	76.43	0.74	29.54	23.46
30.	7.85	6.25	4.91	6.22	79.26	0.80	38.53	30.41
31.	8.10	6.27	4.62	6.17	76.15	0.77	39.89	29.88
32.	7.74	6.00	4.21	5.80	74.99	0.78	36.47	26.46
33.	7.30	6.10	4.47	5.84	79.98	0.84	34.97	26.78
34.	8.05	5.75	4.07	5.73	71.21	0.71	36.35	25.81
35.	8.20	6.16	4.35	6.03	73.59	0.75	39.67	28.60
36.	7.66	5.55	4.95	5.95	77.65	0.73	33.39	27.79
37.	8.25	5.70	4.22	5.83	70.70	0.69	36.93	26.72
38.	8.10	6.50	4.70	6.28	77.51	0.80	41.35	30.96
39.	6.31	5.90	4.66	5.58	88.39	0.94	29.24	24.43
40.	8.10	6.16	4.56	6.10	75.37	0.76	39.19	29.27
41.	8.12	6.20	4.35	6.03	74.23	0.76	39.54	28.54
42.	7.73	5.90	4.36	5.84	75.51	0.76	35.82	26.76
43.	8.60	5.86	4.05	5.88	68.42	0.68	39.51	27.20
44.	7.66	6.15	4.30	5.87	76.67	0.80	37.00	27.09

45.	8.26	5.74	4.30	5.89	71.25	0.70	37.24	27.21
46.	8.15	6.32	4.43	6.11	74.98	0.78	40.45	29.33
47.	8.61	6.26	4.66	6.31	73.28	0.73	42.33	31.27
48.	7.70	6.05	4.75	6.05	78.55	0.79	36.59	28.73
49.	9.08	6.45	4.73	6.52	71.79	0.71	46.00	33.38
50.	8.19	6.02	4.05	5.84	71.37	0.74	38.72	26.83
$\sum x$	400.29	300.71	220.96	298.27	3733.55	37.67	1894.60	1401.09
$\bar{x}$	8.01	6.01	4.42	5.97	74.67	0.75	37.89	28.02
STD	0.56	0.35	0.30	0.31	0.04	0.05	4.17	2.89

Table A10. Some physical properties of Ife Brown at 12% w.b.

S/N	**a (mm)**	**b (mm)**	**c (mm)**	**D_m (mm)**	**Ψ %**	**R=b/a**	**$A_p = \frac{\pi ab}{4}$ (mm^2)**	**$A_p = \pi D_m^2/4$ (mm^2)**
1.	7.94	6.61	4.65	6.25	78.71	0.83	41.22	30.67
2.	7.94	6.02	4.10	5.81	73.16	0.76	37.54	26.50
3.	8.36	6.03	4.18	5.95	71.18	0.72	39.59	27.81
4.	7.64	6.22	4.71	6.07	79.47	0.81	37.32	28.95
5.	7.41	6.30	4.21	5.81	78.46	0.85	36.67	26.55
6.	8.45	6.36	4.81	6.37	75.39	0.75	42.21	31.87
7.	8.81	6.32	4.44	6.28	71.24	0.72	43.73	30.94
8.	8.14	6.33	4.60	6.19	76.03	0.78	40.47	30.08
9.	8.42	6.22	4.45	6.15	73.09	0.74	41.13	29.74
10.	8.23	6.52	4.83	6.38	77.47	0.79	42.14	31.93
11.	8.47	6.57	4.72	6.40	75.61	0.78	43.71	32.21
12.	8.30	5.67	4.31	5.88	70.79	0.67	36.96	27.11
13.	8.17	6.25	4.70	6.21	76.06	0.77	40.10	30.33
14.	7.70	5.65	4.80	5.93	77.05	0.73	34.17	27.65
15.	9.11	6.30	4.56	6.37	69.90	0.69	45.08	31.85
16.	7.00	5.28	4.23	5.39	76.96	0.75	28.86	22.79
17.	8.42	6.35	4.72	6.32	75.05	0.75	41.99	31.37
18.	8.11	6.02	4.09	5.84	72.07	0.74	38.35	26.83
19.	7.78	6.08	4.40	5.93	76.17	0.78	37.15	27.58
20.	8.13	6.55	4.59	6.25	76.91	0.81	41.82	41.82
21.	8.44	6.29	4.35	6.14	72.69	0.75	41.70	29.56
22.	8.75	5.84	4.46	6.11	69.80	0.67	40.13	29.30
23.	8.20	6.36	4.50	6.17	75.22	0.78	40.96	29.88
24.	7.80	6.93	4.78	6.37	81.66	0.89	42.45	31.86
25.	8.44	6.93	4.58	6.45	76.38	0.81	45.94	32.64
26.	8.69	6.45	4.30	6.22	71.61	0.74	44.02	30.42
27.	7.34	6.12	4.92	6.05	82.37	0.83	35.28	28.71
28.	8.34	6.98	4.67	6.50	77.12	0.83	46.21	33.20
29.	8.44	6.17	4.35	6.10	72.22	0.73	40.90	29.19
30.	7.52	6.23	4.31	5.87	78.01	0.83	36.80	27.03
31.	6.73	5.27	4.19	5.30	78.70	0.78	27.86	22.04
32.	8.17	6.09	4.50	6.07	74.32	0.75	39.08	28.96

33.	9.00	6.98	4.65	6.64	73.72	0.78	49.34	34.58
34.	8.03	6.16	4.36	6.0	74.68	0.77	38.85	28.28
35.	7.19	5.68	4.02	5.48	76.16	0.79	32.08	23.55
36.	9.31	6.02	4.36	6.25	67.15	0.65	44.02	30.70
37.	7.69	6.44	4.32	5.98	77.77	0.84	38.90	28.10
38.	8.45	5.52	4.41	5.93	69.86	0.65	36.63	27.62
39.	9.43	6.47	4.92	6.70	71.00	0.69	47.92	35.21
40.	7.69	6.15	4.18	5.82	75.75	0.80	37.14	26.65
41.	9.03	6.80	4.85	6.68	73.95	0.75	48.23	35.03
42.	8.38	5.92	4.15	5.90	70.46	0.71	38.96	27.38
43.	8.16	5.30	4.30	5.71	69.95	0.65	33.97	25.59
44.	7.30	5.10	3.70	5.16	70.75	0.70	29.24	20.95
45.	7.78	5.83	4.20	5.75	73.96	0.75	35.62	26.00
46.	8.11	6.00	4.50	6.03	74.32	0.74	38.22	28.53
47.	8.40	6.10	4.37	6.07	72.29	0.73	40.24	28.96
48.	8.82	6.94	4.30	6.41	72.66	0.79	48.08	32.26
49.	8.40	6.06	4.97	6.32	75.29	0.72	39.98	31.43
50.	8.72	5.80	4.35	6.04	69.23	0.67	39.72	28.62
$\sum x$	409.37	308.58	222.92	303.99	3716.82	37.68	1988.68	1466.76
$\bar{x}$	8.19	6.17	4.46	6.08	74.40	0.76	39.77	29.34
STD	0.57	0.45	0.27	0.33	0.03	0.06	4.77	3.56

Table A11. Some physical properties of Ife Brown at 14% w.b.

S/N	a (mm)	b (mm)	c (mm)	D_m (mm)	Ψ %	R=b/a	$A_p = \frac{\pi ab}{4}$ (mm^2)	$A_p = \pi D_m^2/4$ (mm^2)
1.	8.50	6.28	3.95	5.95	70.02	0.74	41.93	27.82
2.	9.08	6.55	4.85	6.61	72.77	0.72	46.71	34.29
3.	8.02	6.30	5.21	6.41	79.91	0.79	39.68	32.26
4.	8.52	7.00	4.98	6.67	78.31	0.82	46.84	34.96
5.	9.00	6.23	5.00	6.54	72.72	0.69	44.04	33.64
6.	8.30	6.60	4.40	6.22	74.98	0.80	43.02	30.42
7.	9.30	6.45	4.65	6.53	70.26	0.69	47.11	33.53
8.	7.75	6.65	4.60	6.16	79.46	0.85	39.87	29.78
9.	7.77	6.32	4.37	6.08	78.21	0.81	38.57	29.00
10.	8.36	5.81	4.36	5.96	71.31	0.70	38.15	27.96
11.	8.40	6.55	4.41	6.24	74.25	0.78	43.21	30.55
12.	8.05	6.29	4.69	6.19	76.93	0.78	39.77	30.12
13.	8.79	5.94	4.55	6.19	71.48	0.68	41.01	30.13
14.	8.63	5.93	4.51	6.13	73.90	0.69	40.19	29.55
15.	8.62	5.68	4.03	5.82	67.54	0.66	38.45	26.62
16.	8.12	6.48	4.92	6.37	78.49	0.71	41.33	31.90
17.	7.40	6.15	4.32	5.81	78.58	0.83	35.74	26.56
18.	8.02	6.60	4.66	6.27	78.20	0.82	41.57	30.89
19.	7.90	6.16	4.46	6.01	76.07	0.78	38.22	28.37
20.	9.01	6.20	4.67	6.39	70.92	0.69	48.74	34.40
21.	7.97	5.50	5.00	6.03	75.65	0.69	34.43	28.55

22.	7.80	6.25	4.55	6.05	77.61	0.80	38.29	28.78
23.	9.12	6.32	4.50	6.38	69.93	0.69	45.27	31.94
24.	7.75	6.12	4.20	5.84	75.36	0.79	37.25	26.79
25.	9.00	6.30	4.26	6.23	69.20	0.70	44.53	30.46
26.	8.57	6.45	4.62	6.34	74.03	0.75	43.41	31.61
27.	8.86	6.00	4.32	6.12	69.12	0.68	41.75	29.45
28.	7.75	6.60	4..77	6.25	80.63	0.85	40.17	30.68
29.	9.01	6.65	4.75	6.58	73.01	0.66	47.06	33.98
30.	8.30	6.62	4.92	6.47	77.90	0.80	43.15	32.84
31.	8.25	6.32	4.62	6.24	75.58	0.77	40.95	30.54
32.	8.17	5.85	4.03	5.78	70.69	0.72	37.54	26.19
33.	7.53	6.18	4.39	5.89	78.21	0.82	36.55	27.25
34.	8.90	6.05	4.45	6.21	69.79	0.68	42.29	30.30
35.	7.76	6.76	4.20	6.04	83.57	0.87	41.20	28.65
36.	7.60	6.54	4.75	6.18	81.32	0.86	39.04	30.00
37.	7.20	6.38	4.55	5.93	77.46	0.80	36.08	27.66
38.	7.65	6.06	4.48	5.92	77.41	0.79	36.41	27.54
39.	8.30	6.00	4.36	6.01	72.41	0.72	39.11	28.37
40.	8.45	6.25	4.65	6.26	74.11	0.74	41.48	30.78
41.	8.33	6.66	4.62	6.35	76.26	0.80	43.57	31.69
42.	8.58	5.74	4.54	6.07	70.74	0.60	38.68	28.93
43.	8.04	6.00	4.63	6.07	70.60	.69	37.89	28.91
44.	8.52	6.64	4.88	6.51	76.43	0.78	44.43	33.30
45.	7.77	5.39	4.48	5.72	73.68	0.82	32.89	25.74
46.	8.33	6.45	4.95	6.43	77.20	0.77	42.20	32.48
47.	8.45	7.00	5.27	6.78	80.24	0.83	46.46	36.11
48.	7.74	6.41	4.64	6.13	79.18	0.83	38.97	29.50
49.	8.40	6.40	4.65	6.30	74.99	0.76	42.22	31.17
50.	8.25	6..35	4.31	6.09	73.81	0.77	41.15	29.12
$\sum x$	413.89	314.31	228.96	309.78	3750.43	37.86	2048.56	1512.06
$\bar{x}$	8.28	6.29	4.58	6.20	75.01	0.76	40.97	30.24
STD	0.72	0.54	0.58	0.52	0.04	0.06	3.53	2.46

Table A12. Some physical properties of Ife Brown at 18% w.b.

S/N	a (mm)	b (mm)	c (mm)	D_m (mm)	Ψ %	R=b/a	$A_p = \frac{\pi ab}{4}$ (mm^2)	$A_p = \pi D_m^2/4$ (mm^2)
1.	8.50	6.50	5.43	6.69	78.76	0.77	43.39	35.20
2.	7.98	6.16	4.50	6.05	75.79	0.77	38.61	28.73
3.	9.38	6.13	4.69	6.46	68.88	0.65	32.78	32.78
4.	9.11	7.02	5.34	6.99	76.72	0.77	50.23	38.37
5.	8.33	6.79	4.55	6.36	76.36	0.82	44.42	31.78
6.	10.01	7.20	5.15	7.19	71.79	0.72	56.61	40.56
7.	8.51	6.04	4.79	6.27	73.65	0.71	40.32	30.85
8.	8.87	6.85	4.95	6.70	75.54	0.77	47.72	35.26
9.	9.00	7.39	5.45	7.13	79.22	0.82	52.24	39.93

10.	9.46	6.64	5.08	6.83	72.23	0.70	49.33	36.68
11.	8.65	6.61	5.31	6.72	77.70	0.76	44.91	35.48
12.	8.14	6.27	5.15	6.41	78.69	0.77	40.09	32.23
13.	9.43	6.24	4.66	6.50	68.89	0.66	46.22	33.15
14.	8.12	6.75	5.43	6.68	82.22	0.83	43.05	25.01
15.	8.36	6.71	5.40	6.72	80.33	0.80	44.06	35.43
16.	8.67	6.42	4.53	6.32	72.87	0.74	43.72	31.35
17.	8.73	7.38	4.73	6.73	77.08	0.85	50.60	35.57
18.	9.34	7.28	4.73	6.85	73.36	0.78	53.40	36.87
19.	8.25	6.65	4.57	6.31	76.43	0.81	43.09	31.23
20.	7.95	7.35	4.90	6.59	82.91	0.92	45.89	34.12
21.	8.37	7.27	5.34	6.87	82.14	0.87	47.79	37.12
22.	8.30	6.90	5.40	6.76	81.48	0.83	44.98	35.92
23.	8.85	6.80	4.77	6.60	74.54	0.77	47.27	34.18
24.	9.04	6.15	5.40	6.70	74.07	0.68	43.62	35.21
25.	9.28	5.96	4.31	6.20	66.82	0.64	43.43	30.20
26.	8.33	6.92	5.29	6.73	80.80	0.83	45.27	35.58
27.	8.57	6.11	5.32	6.53	76.21	0.71	41.13	33.50
28.	9.30	6.75	4.72	6.67	71.67	0.73	49.30	34.91
29.	8.50	6.12	4.83	6.31	74.24	0.72	40.86	31.27
30.	8.18	6.14	4.90	6.27	76.61	0.75	39.45	30.84
31.	7.60	6.04	4.55	5.93	78.07	0.80	36.04	27.65
32.	8.95	6.45	4.85	6.54	73.09	0.72	45.34	33.61
33.	8.00	6.42	4.55	6.16	76.99	0.80	40.34	29.80
34.	8.50	6.12	5.32	6.52	76.67	0.72	40.86	33.35
35.	8.97	6.17	4.90	6.47	72.16	0.69	43.47	32.91
36.	8.38	6.20	3.96	5.90	70.45	0.74	40.81	27.37
37.	8.23	6.71	4.52	6.30	76.50	0.82	43.37	31.14
38.	9.46	5.55	4.14	6.01	63.56	0.59	41.24	28.39
39.	7.05	5.65	3.53	5.20	73.76	0.80	31.28	21.24
40.	8.40	6.05	4.50	6.12	72.80	0.72	39.91	29.37
41.	8.29	6.76	4.51	6.32	76.27	0.82	44.01	31.40
42.	8.64	6.45	4.95	6.51	75.34	0.75	43.77	33.28
43.	7.80	6.10	4.98	6.19	79.33	0.78	37.37	30.07
44.	8.48	6.74	4.58	6.40	75.44	0.80	44.89	32.14
45.	7.20	5.55	4.16	5.50	76.36	0.77	31.39	23.74
46.	8.29	6.36	4.10	6.00	72.40	0.77	41.41	28.29
47.	7.35	5.25	3.65	5.20	70.79	0.71	30.31	21.26
48.	7.83	6.52	4.20	5.99	76.44	0.83	40.10	28.14
49.	7.15	5.65	4.00	5.45	76.18	0.79	31.73	23.30
50.	8.37	6.62	4.08	6.09	72.78	0.79	43.52	29.15
$\sum x$	425.45	322.86	237.65	318.91	3763.38	38.15	2144.97	1604.87
$\bar{x}$	8.49	6.46	4.75	6.38	75.27	0.76	42.90	32.10
STD	0.63	0.50	0.49	0.44	0.04	0.06	5.57	4.24

Table A13. Some physical properties of Drum at 8% w.b.

S/N	a (mm)	b (mm)	c (mm)	D_m (mm)	Ψ %	R=b/a	$A_p = \frac{\pi ab}{4}$ (mm^2)	$A_p = \pi D_m^2/4$ (mm^2)
1.	10.00	7.91	5.37	7.52	75.17	0.79	62.13	44.38
2.	9.58	7.31	5.00	7.05	73.57	0.76	55.00	39.02
3.	11.91	7.40	4.60	7.40	62.14	0.62	69.22	43.02
4.	10.45	8.00	5.34	7.64	73.14	0.77	65.66	45.88
5.	9.36	7.77	6.05	7.61	81.26	0.83	57.12	45.44
6.	9.85	7.55	5.22	7.29	74.06	0.77	58.41	41.80
7.	9.90	6.98	5.00	7.02	70.88	0.71	54.27	38..67
8.	10.53	6.80	4.31	6.76	64.18	0.65	56.24	35.87
9.	11.43	7.67	5.65	7.91	69.22	0.67	68.85	49.17
10.	9.16	7.76	6.16	7.59	82.90	0.85	55.83	45.29
11.	9.83	6.70	4.40	6.62	67.32	0.68	51.73	34.39
12.	10.26	8.21	5.30	7.75	72.48	0.77	68.93	47.15
13.	9.95	6.75	4.27	6.59	66.28	0.68	52.75	34.16
14.	9.46	6.80	4.20	6.46	68.34	0.72	50.52	32.82
15.	8.72	7.50	5.90	7.28	83.49	0.86	51.37	41.63
16.	9.45	7.55	5.07	7.13	75.40	0.80	56.04	39.87
17.	9.13	7.17	5.32	7.04	77.06	0.79	51.41	38.88
18.	12.18	7.67	4.72	7.61	62.49	0.63	73.37	45.45
19.	10.37	8.00	5.62	7.75	74.77	0.77	65.16	47.22
20.	8.30	7.32	5.16	6.76	81.85	0.88	47.72	36.25
21.	10.23	7.08	5.50	7.36	71.93	0.69	56.89	42.52
22.	9.38	7.19	5.51	7.19	76.65	0.77	52.97	40.60
23.	11.90	7.65	5.45	7.92	66.53	0.64	71.50	49.22
24.	9.28	6.85	4.90	6.78	73.05	0.74	49.93	36.09
25.	10.55	7.65	4.85	7.32	69.34	0.73	63.39	42.03
26.	10.80	7.21	5.11	7.36	68.10	0.67	61.16	42.49
27.	9.61	7.67	5.77	7.52	78.25	0.80	57.89	44.42
28.	9.28	8.15	6.07	7.70	83.43	0.88	59.08	46.57
29.	11.05	7.60	4.65	7.31	66.15	0.69	65.96	41.96
30.	9.42	7.17	4.36	6.65	70.63	0.76	53.05	34.76
31.	9.10	7.66	5.78	7.39	81.16	0.84	54.75	42.84
32.	10.17	7.37	4.07	6.73	66.19	0.73	58.87	35.59
33.	10.66	7.25	4.81	7.19	67.45	0.68	60.70	40.61
34.	9.22	7.10	4.81	6.80	73.79	0.77	51.41	36.35
35.	9.25	6.64	5.06	6.78	73.18	0.72	48.29	36.06
36.	9.71	7.21	4.62	6.86	70.69	0.74	54.99	37.01
37.	8.87	6.65	5.05	6.68	75.29	0.75	46.33	35.03
38.	8.81	6.74	4.59	6.48	73.59	0.77	46.64	33.02
39.	9.62	6.75	4.89	6.82	70.92	0.70	51.00	36.55
40.	9.37	7.02	4.55	6.69	71.39	0.75	51.66	35.14
41.	9.27	7.21	4.48	6.69	72.17	0.78	52.49	35.15
42.	9.61	7.51	5.56	7.38	76.75	0.78	56.68	42.73
43.	11.11	7.55	5.61	7.79	70.01	0.68	65.88	47.52
44.	9.55	7.71	5.29	7.30	76.47	0.81	57.83	41.89
45.	10.37	7.62	5.00	7.34	70.76	0.74	62.06	42.29

46.	9.65	7.53	5.61	7.41	76.84	0.78	57.07	43.18
47.	9.47	7.03	4.48	6.68	70.55	0.74	52.29	35.06
48.	10.92	7.38	5.05	7.41	67.86	0.68	63.30	43.13
49.	10.54	7.40	5.11	7.36	69.82	0.70	61.26	42.54
50.	10.50	7.50	5.18	7.42	70.63	0.71	61.85	43.20
$\sum x$	497.48	367.87	254.43	359.10	3625.57	37.18	2878.85	2031.88
$\bar{x}$	9.95	7.36	5.09	7.18	72.51	0.74	57.58	40.64
STD	0.86	0.40	0.52	0.41	0.05	0.06	6.68	4.56

Table A14. Some physical properties of Drum at 12 %

S/N	**a (mm)**	**b (mm)**	**c (mm)**	**D_m (mm)**	**Ψ %**	**R=b/a**	**$A_p = \frac{\pi ab}{4}$ (mm^2)**	**$A_p = \pi D_m^2/4$ (mm^2)**
1.	11.00	7.66	4.70	7.34	66.76	0.70	66.18	42.36
2.	9.35	7.06	4.92	6.87	73.52	0.76	51.85	37.11
3.	10.50	7.72	5.28	7.54	71.77	0.74	63.66	44.61
4.	12.53	7.75	5.30	8.02	63.86	0.62	76.27	50.49
5.	11.05	7.05	5.00	7.30	66.09	0.64	61.18	41.89
6.	9.25	6.62	4.76	6.63	71.68	0.72	48.09	34.53
7.	10.01	7.65	5.17	7.34	73.35	0.76	60.14	42.35
8.	11.03	7.86	5.20	7.67	69.52	0.71	68.09	46.18
9.	9.88	7.76	5.64	7.56	76.64	0.79	60.22	4.91
10.	8.88	6.20	4.70	6.37	71.76	0.70	43.24	31.89
11.	9.71	7.75	5.17	7.30	75.18	0.80	59.10	41.86
12.	9.25	7.50	5.55	7.28	78.65	0.81	54.49	41.57
13.	10.15	7.30	4.85	7.57	74.56	0.72	58.19	44.98
14.	10.91	7.65	5.15	7.55	69.17	0.70	65.55	44.73
15.	10.13	7.35	5.16	7.27	71.76	0.73	58.48	41.51
16.	11.10	8.20	4.90	7.55	70.45	0.77	69.04	44.80
17.	10.72	8.20	4.90	7.55	70.45	0.77	69.04	44.80
18.	10.90	8.61	5.66	8.10	74.30	0.79	73.71	51.51
19.	11.35	8.25	6.10	8.30	73.10	0.73	73.54	54.07
20.	10.45	7.50	5.75	7.67	73.37	0.72	61.56	46.17
21.	9.30	7.40	5.05	7.03	75.60	0.80	54.05	38.82
22.	9.90	7.60	5.65	7.52	75.95	0.77	59.10	44.40
23.	12.15	7.85	5.90	8.26	67.95	0.65	74.91	53.53
24.	10.31	7.70	5.56	7.61	73.85	0.75	62.35	45.53
25.	12.15	8.10	4.65	7.70	63.43	0.67	77.30	46.64
26.	10.28	7.60	5.15	7.38	71.81	0.74	61.36	42.81
27.	9.40	7.50	4.51	6.83	72.61	0.80	55.37	36.59
28.	11.32	8.10	5.45	7.94	70.10	0.72	72.02	49.46
29.	10.61	7.35	5.37	7.48	70.51	0.69	61.25	43.96
30.	11.00	7.15	5.38	7.51	68.25	0.65	61.77	44.27
31.	8.24	7.00	5.45	6.80	82.52	0.85	45.30	36.31
32.	8.82	7.80	5.50	7.23	82.00	0.88	54.03	41.09
33.	10.51	7.15	5.90	7.63	72.55	0.68	59.12	45.67
34.	9.55	7.32	4.68	6.89	72.15	0.77	54.90	37.29

35.	8.85	6.60	4.52	6.42	72.49	0.75	45.88	32.32
36.	9.75	7.15	5.00	7.04	89.70	0.73	54.75	38.90
37.	9.81	6.90	4.95	6.95	70.80	0.70	53.16	37.89
38.	10.32	7.50	4.20	6.88	87.34	0.73	60.79	37.13
39.	10.85	8.20	4.90	7.58	69.88	0.76	69.88	45.16
40.	9.42	7.05	4.80	6.83	72.52	0.75	52.16	36.65
41.	11.00	7.70	5.15	7.58	68.95	0.70	66.52	45.17
42.	9.40	7.00	4.78	6.80	72.35	0.75	51.68	36.32
43.	9.20	6.62	6.45	7.32	79.61	0.72	47.83	42.13
44.	9.78	6.85	4.70	6.80	69.56	0.70	52.62	36.35
45.	10.60	7.95	5.25	7.62	71.88	0.75	66.19	45.60
46.	11.30	7.85	4.90	7.58	67.04	0.70	69.67	45.07
47.	11.05	8.45	5.72	8.11	73.42	0.77	73.34	51.70
48.	8.50	7.40	4.95	6.78	79.74	0.87	49.40	36.04
49.	10.65	7.50	5.20	7.46	70.06	0.70	62.73	43.72
50.	10.75	7.35	5.05	7.36	68.48	0.68	62.06	42.57
$\sum x$	512.92	375.05	260.08	367.94	3639.04	36.74	3033.10	2134.42
$\bar{x}$	10.26	7.50	5.20	7.36	72.78	0.74	60.66	42.69
STD	0.95	0.50	0.45	0.45	0.05	0.05	8.63	5.21

Table A15. Some physical properties of Drum at 14 % w. b.

S/N	**a (mm)**	**b (mm)**	**c (mm)**	**D_m (mm)**	**Ψ %**	**R=b/a**	**$A_p = \frac{\pi ab}{4}$ (mm^2)**	**$A_p = \pi D_m^2/4$ (mm^2)**
1.	9.55	7.56	4.95	7.10	74.31	0.79	56.70	39.55
2.	10.10	7.85	5.65	7.65	75.76	0.78	62.27	45.98
3.	11.05	7.90	5.05	7.61	68.88	0.72	68.56	45.49
4.	10.90	7.70	5.05	7.51	68.91	0.71	65.92	44.32
5.	9.85	7.60	4.60	7.01	71.16	0.77	58.80	38.59
6.	10.00	7.70	5.35	7.44	74.41	0.77	60.48	43.48
7.	10.22	7.95	4.86	7.34	71.79	0.78	63.81	42.27
8.	9.55	7.27	5.25	7.14	74.80	0.76	54.53	40.08
9.	10.55	7.60	5.47	7.60	72.02	0.72	62.97	45.34
10.	9.70	6.30	5.55	7.65	78.82	0.86	63.23	45.91
11.	10.00	8.00	5.70	7.70	76.97	0.80	62.83	46.53
12.	9.70	7.60	5.70	7.49	77.22	0.78	57.90	44.06
13.	11.05	7.50	5.60	7.74	70.07	0.68	65.09	47.08
14.	10.27	7.50	4.87	72.12	70.22	0.73	60.50	40.85
15.	13.00	8.20	6.00	8.62	66.28	0.63	83.72	58.30
16.	10.75	7.60	4.65	7.24	67.37	0.71	64.17	41.20
17.	11.05	7.65	5.63	7.81	70.66	0.69	66.39	47.88
18.	10.00	7.35	4.65	6.99	69.92	0.74	57.73	38.39
19.	12.60	7.72	4.95	7.84	62.21	0.61	76.40	48.25
20.	9.75	7.45	4.25	6.76	69.32	0.76	57.05	35.88
21.	8.80	7.25	4.75	6.72	76.33	0.82	50.11	35.44
22.	10.95	7.80	4.75	7.40	67.61	0.71	67.08	43.04
23.	8.82	7.25	5.55	7.08	80.27	0.82	51.95	39.35

24.	11.45	7.55	5.55	7.83	68.37	0.66	67.90	48.14
25.	9.71	7.36	4.85	7.02	72.34	0.76	56.13	38.75
26.	8.85	7.20	4.76	6.72	75.92	0.81	5.05	35.46
27.	10.00	7.86	5.75	6.76	76.74	0.79	61.73	46.25
28.	10.65	8.05	5.10	7.59	76.74	0.76	67.33	45.24
29.	10.60	8.10	5.35	7.72	72.79	0.76	67.43	46.76
30.	10.65	7.51	5.36	7.54	70.80	0.71	62.82	44.65
31.	9.66	7.00	5.25	7.08	73.30	0.73	53.11	39.38
32.	9.32	7.36	5.15	7.07	75.85	0.79	53.88	39.25
33.	12.20	7.65	5.05	7.88	64.61	0.63	73.30	48.80
34.	11.10	7.95	7.40	8.68	78.16	0.72	69.31	59.12
35.	11.10	7.70	5.35	7.70	67.58	0.69	67.13	46.62
36.	10.51	7.11	4.62	7.02	66.75	0.68	58.69	38.65
37.	11.25	7.70	4.55	7.33	65.17	0.68	68.04	42.22
38.	10.37	7.76	5.15	7.46	71.90	0.75	63.20	43.66
39.	9.65	7.50	5.10	7.17	74.33	0.78	56.84	40.41
40.	8.75	6.70	4.50	6.41	73.30	0.77	46.04	32.31
41.	10.45	7.65	5.31	7.52	71.85	0.73	62.79	44.36
42.	9.60	7.52	5.40	7.31	76.10	0.78	56.70	41.91
43.	10.25	7.90	5.40	7.59	74.05	0.77	63.60	45.25
44.	9.35	7.35	5.30	7.14	76.38	0.79	63.98	40.06
45.	10.62	7.30	5.00	7.29	68.66	0.69	60.89	41.75
46.	8.85	6.67	4.95	6.73	72.80	0.72	48.46	35.62
47.	9.25	6.67	4.95	6.73	72.80	0.72	48.46	35.62
48.	10.80	8.00	5.17	7.64	70.78	0.74	67.86	45.89
49.	9.80	7.20	5.60	7.34	74.88	0.74	55.42	42.29
50.	10.60	8.40	6.10	8.16	76.97	0.79	69.93	52.28
$\sum x$	513.60	379.15	260.80	369.91	3615.23	37.10	3067.99	2157.12
$\bar{x}$	10.27	7.58	5.22	7.40	72.30	0.74	61.36	43.14
STD	0.93	0.38	0.51	0.45	0.04	0.05	7.53	5.31

Table A16. Some physical properties of Drum at 18% w.b.

S/N	**a (mm)**	**b (mm)**	**c (mm)**	**D_m (mm)**	**Ψ %**	**R=b/a**	**$A_p = \frac{\pi ab}{4}$ (mm^2)**	**$A_p = \pi D_m^2/4$ (mm^2)**
1.	11.45	7.40	4.98	7.50	65.51	0.65	66.55	44.19
2.	10.20	8.30	6.50	8.19	80.34	0.81	66.49	52.74
3.	10.50	7.85	5.47	7.67	73.03	0.75	64.74	46.18
4.	10.00	7.80	5.85	7.70	76.99	0.78	61.26	46.55
5.	10.55	8.10	4.90	7.48	70.91	0.77	67.12	43.96
6.	10.55	8.10	4.90	7.48	70.91	0.77	67.12	43.96
7.	10.16	8.15	5.52	7.70	75.82	0.80	65.03	46.60
8.	11.10	7.90	5.55	7.87	70.86	0.71	68.87	48.59
9.	11.35	8.02	5.7	8.04	70.80	0.71	71.49	50.71
10.	12.10	7.52	5.40	7.89	65.21	0.62	71.46	48.91
11.	10.83	8.17	5.50	7.87	72.63	0.75	69.49	48.59
12.	11.47	8.25	5.50	7.60	66.30	0.72	74.32	45.42

13.	9.63	8.11	5.70	7.64	79.29	0.84	61.34	45.79
14.	9.75	7.02	4.95	6.97	71.50	0.72	53.76	38.17
15.	11.35	7.80	5.55	7.89	69.52	0.69	69.53	48.90
16.	8.57	7.75	5.60	7.19	83.92	0.90	52.16	40.62
17.	10.15	8.16	5.20	7.55	74.40	0.80	65.05	44.79
18.	8.85	7.35	5.50	7.10	80.21	0.83	51.09	39.58
19.	10.37	8.60	6.20	8.21	79.15	0.83	70.04	52.91
20.	10.35	7.72	5.25	7.49	72.33	0.75	62.76	44.01
21.	8.90	7.50	5.25	7.05	79.22	0.84	52.43	39.04
22.	10.38	6.90	5.50	7.33	70.62	0.67	56.25	42.20
23.	10.25	8.10	5.55	7.73	75.35	0.79	65.21	46.86
24.	9.46	7.40	5.72	7.37	77.91	0.78	54.98	42.67
25.	10.60	6.65	5.05	7.09	66.86	0.63	55.36	39.45
26.	10.45	7.65	5.80	7.74	74.07	0.73	62.79	47.05
27.	10.26	7.74	4.65	7.17	69.93	0.75	62.37	40.43
28.	9.62	7.40	4.90	7.04	73.17	0.77	55.91	38.92
29.	10.76	8.10	6.45	8.25	76.70	0.75	68.45	53.50
30.	11.92	8.10	4.70	7.68	64.47	0.68	75.83	46.38
31.	11.77	8.30	4.92	7.83	66.55	0.71	76.73	48.19
32.	9.60	7.81	5.50	7.44	77.53	0.81	58.89	43.51
33.	11.23	7.03	5.00	7.34	65.32	0.63	62.01	42.26
34.	10.30	7.45	5.45	7.48	72.60	0.72	60.27	43.92
35.	9.55	7.50	4.51	6.86	71.85	0.79	56.25	36.98
36.	10.35	7.25	5.05	7.24	69.92	0.70	58.93	41.13
37.	9.81	7.32	4.85	7.04	71.72	0.75	56.40	38.88
38.	10.90	7.10	5.55	7.55	69.22	0.65	60.78	44.71
39.	10.15	7.16	5.00	7.14	70.30	0.71	57.08	39.99
40.	9.50	7.08	4.20	6.56	69.07	0.75	52.83	33.81
41.	8.62	7.25	4.90	6.74	78.19	0.84	49.08	35.68
42.	11.22	6.80	4.98	7.24	64.50	0.61	59.92	41.20
43.	9.73	7.30	4.95	7.06	72.54	0.75	55.79	39.13
44.	9.52	7.58	4.32	6.78	71.22	0.80	56.68	36.11
45.	10.48	7.77	4.00	6.88	65.65	0.74	63.96	37.18
46.	8.87	6.84	5.10	6.76	76.25	0.77	47.65	35.93
47.	9.90	7.50	5.35	7.35	74.25	0.76	58.32	42.44
48.	10.42	7.20	4.33	6.87	65.97	0.69	58.92	45.29
49.	9.80	8.05	5.55	7.59	77.48	0.82	61.96	45.29
50.	10.80	7.60	4.95	7.41	68.58	0.70	64.47	43.08
$\sum x$	515.80	381.60	262.00	371.12	3616.04	37.19	3095.99	2178.20
$\bar{x}$	10.32	7.63	5.24	7.42	72.33	0.74	61.92	43.56
STD	0.86	0.46	0.52	0.42	0.05	0.07	7.21	4.77

Table A17. Density, Porosity and Thousand Grain Mass of Ife 98-12 at 8% w.b.

S/N	Bulk Density g/cm^3	True Density g/cm^3	Porosity %	Thousand Grain Mass (g)
1.	0.698	1.254	44.34	189.160
2.	0.693	1.252	44.65	194.040
3.	0.691	1.253	44.85	191.600
$\bar{x}$	0.694	1.253	44.61	191.600
STD	0.004	0.001	0.26	2.440

Table A18. Density, Porosity and Thousand Grain Mass of Ife 98-12 at 12% w.b.

S/N	Bulk Density g/cm^3	True Density g/cm^3	Porosity %	Thousand Grain Mass (g)
1.	0.678	1.159	41.50	197.758
2.	0.680	1.160	41.38	200.100
3.	0.676	1.159	41.67	198.950
$\bar{x}$	0.678	1.159	41.52	198.936
STD	0.002	0.001	0.15	1.171

Table A19. Density, porosity and thousand grain mass of Ife 98-12 at 14% w.b.

S/N	Bulk Density g/cm^3	True Density g/cm^3	Porosity %	Thousand Grain Mass(g)
1.	0.676	1.138	40.60	202.754
2.	0.674	1.136	40.67	205.194
3.	0.678	1.134	40.21	203.976
$\bar{x}$	0.676	1.136	40.49	203.975
STD	0.002	0.002	0.25	1.220

Table A20. Density, porosity and thousand grain mass of Ife 98-12 at 18% w.b.

S/N	Bulk Density g/cm^3	True Density g/cm^3	Porosity %	Thousand Grain Mass (g)
1.	0.672	1.127	40.37	215.204
2.	0.674	1.126	40.14	212.720
3.	0.670	1.127	40.55	213.964
$\bar{x}$	0.672	1.127	40.35	213.963
STD	0.002	0.001	0.21	1.242

Table A21. Density, porosity and thousand grain mass of IT90K-277-2 at 8% w. b.

S/N	Bulk Density g/cm^3	True Density g/cm^3	Porosity %	Thousand Grain Mass (g)
1.	0.780	1.247	37.45	166.460
2.	0.776	1.246	37.72	165.620
3.	0.778	1.248	37.66	166.050
$\bar{x}$	0.778	1.247	37.61	166.040
STD	0.002	0.001	0.14	0.420

Table A22. Density, porosity and thousand grain mass of IT90K-277-2 at 12% w.b.

S/N	Bulk Density g/cm^3	True Density g/cm^3	Porosity %	Thousand Grain Mass (g)
1.	0.756	1.200	37.00	174.000
2.	0.760	1.198	36.56	173.587
3.	0.758	1.202	36.94	173.795
$\bar{x}$	0.758	1.200	36.83	173.794
STD	0.002	0.002	0.24	0.207

Table A23. Density, porosity and thousand grain mass of IT90K-277-2 at 14% w.b.

S/N	Bulk Density g/cm^3	True Density g/cm^3	Porosity %	Thousand Grain Mass (g)
1.	0.734	1.195	38.58	177.204
2.	0.729	1.196	39.05	178.043
3.	0.730	1.194	38.86	177.626
$\bar{x}$	0.731	1.195	38.83	177.624
STD	0.002	0.001	0.24	0.420

Table A24. Density, porosity and thousand grain mass of IT90K-277-2 at 18% w.b.

S/N	Bulk Density g/cm^3	True Density g/cm^3	Porosity %	Thousand Grain Mass (g)
1.	0.726	1.192	39.09	186.289
2.	0.724	1.193	39.31	186.709
3.	0.725	1.194	39.28	186.500
$\bar{x}$	0.725	1.193	39.23	186.499
STD	0.001	0.001	0.12	0.210

Table A25. Density, porosity and thousand grain mass of Ife Brown at 8% w.b.

S/N	Bulk Density g/cm^3	True Density g/cm^3	Porosity %	Thousand Grain Mass (g)
1.	0.756	1.218	37.93	145.860
2.	0.754	1.214	37.89	149.220
3.	0.758	1.216	37.66	147.560
$\bar{x}$	0.756	1.216	37.83	147.547
STD	0.002	0.002	0.15	1.680

Table A26. Density, porosity and thousand grain mass of Ife Brown at 12% w.b.

S/N	Bulk Density g/cm^3	True Density g/cm^3	Porosity %	Thousand Grain Mass (g)
1.	0.738	1.214	39.21	154.246
2.	0.739	1.213	39.08	155.926
3.	0.737	1.214	39.29	155.095
$\bar{x}$	0.738	1.214	39.19	155.089
STD	0.001	0.001	0.11	0.840

Table A27. Density, porosity and thousand grain mass of Ife Brown at 14% w.b.

S/N	**Bulk Density g/cm^3**	**True Density g/cm^3**	**Porosity %**	**Thousand Grain Mass (g)**
1.	0.727	1.201	39.30	157.833
2.	0.733	1.200	38.92	158.153
3.	0.731	1.203	39.24	157.994
$\bar{x}$	0.731	1.201	39.15	157.993
STD	0.003	0.002	0.20	0.160

Table A28. Density, Porosity and Thousand Grain Mass of Ife Brown at 18% w.b

S/N	**Bulk Density g/cm^3**	**True Density g/cm^3**	**Porosity %**	**Thousand Grain Mass (g)**
1.	0.726	1.199	39.45	167.213
2.	0.725	1.198	39.48	165.533
3.	0.724	1.200	39.67	166.374
$\bar{x}$	0.725	1.199	39.15	166.373
STD	0.001	0.001	0.12	0.840

Table A29. Density, porosity and thousand grain mass of Drum at 8% w.b.

S/N	**Bulk Density g/cm^3**	**True Density g/cm^3**	**Porosity %**	**Thousand Grain Mass (g)**
1.	0.708	1.230	42.44	227.7000
2.	0.710	1.232	42.37	225.240
3.	0.708	1.228	42.35	223.480
$\bar{x}$	0.709	1.230	42.39	225.473
STD	0.001	0.002	0.05	2.120

Table A30. Density, porosity and thousand grain mass of Drum at 12% w.b.

S/N	**Bulk Density g/cm^3**	**True Density g/cm^3**	**Porosity %**	**Thousand Grain Mass (g)**
1.	0.696	1.204	42.19	234.750
2.	0.697	1.203	42.06	235.980
3.	0.695	1.205	42.32	237.000
$\bar{x}$	0.696	1.204	42.19	235.910
STD	0.001	0.001	0.13	1.127

Table A31. Density, porosity and thousand grain mass of Drum at 14% w.b.

S/N	**Bulk Density g/cm^3**	**True Density g/cm^3**	**Porosity %**	**Thousand Grain Mass (g)**
1.	0.689	1.151	40.14	241.201
2.	0.691	1.150	39.91	238.100
3.	0.687	1.152	40.36	242.600
$\bar{x}$	0.689	1.151	40.14	240.637
STD	0.002	0.001	0.23	2.303

Table A32. Density, porosity and thousand grain mass of Drum at 18% w.b.

S/N	Bulk Density g/cm^3	True Density g/cm^3	Porosity %	Thousand Grain Mass (g)
1.	0.678	1.135	40.26	254.686
2.	0.677	1.134	40.30	252.916
3.	0.679	1.136	40.23	250.800
$\bar{x}$	0.678	1.135	40.26	252.801
STD	0.001	0.001	0.04	1.946

Table A33. Aerodynamic Properties of Ife 98-12 at 8% w.b.

S/N	Mass, g	Area, mm^2	Drag. Coef	$V_{t(theor)}$, m/s	$V_{t(exp)}$, m/s
1.	0.20	41.78	0.45	13.46	13.30
2.	0.18	33.30	0.45	14.30	14.20
3.	0.20	43.61	0.45	13.18	13.00
4.	0.19	41.18	0.45	13.22	13.10
5.	0.18	29.16	0.50	15.29	14.40
6.	0.18	30.42	0.44	14.97	14.30
7.	0.19	36.83	0.45	13.97	13.80
8.	0.22	43.65	0.45	18.82	13.70
9.	0.20	38.32	0.44	14.06	14.00
10.	0.19	33.98	0.46	14.55	14.20
$\bar{x}$	0.19	37.82	0.45	14.08	13.80
STD	0.01	5.19	0.02	0.67	0.49

Table A34. Aerodynamics properties of Ife 98-12 at 12 % w.b.

S/N	Mass, g	Area, mm^2	Drag. Coef	$V_{t(theor)}$ .m/s	$V_{t(exp)}$, m/s
1.	0.19	37.73	0.45	13.81	13.60
2.	0.20	40.05	0.45	13.75	13.60
3.	0.21	38.97	0.45	14.29	14.10
4.	0.19	35.14	0.45	14.31	14.20
5.	0.22	42.49	0.45	14.00	13.90
6.	0.20	39.12	0.45	13.91	13.80
7.	0.19	36.50	0.45	14.73	14.40
8.	0.18	31.42	0.46	14.73	14.40
9.	0.19	33.52	0.46	14.65	14.40
10.	0.18	29.19	0.48	15.28	14.60
$\bar{x}$	0.20	36.37	0.46	14.28	14.05
STD	0.01	3.91	0.01	0.46	0.33

Table A35. Aerodynamic Properties of Ife 98-12 at 14% w.b.

S/N	Mass, g	Area, mm^2	Drag. Coef	$V_{t(theor)}$, m/s	$V_{t(exp)}$, m/s
1.	0.21	43.50	0.45	13.52	13.40
2.	0.20	39.91	0.45	13.78	13.60
3.	0.19	31.78	0.47	15.05	14.80
4.	0.21	33.85	0.45	15.33	15.10
5.	0.21	35.34	0.45	15.00	14.90
6.	0.20	32.00	0.45	15.39	15.20
7.	0.20	36.71	0.45	14.36	14.20
8.	0.19	33.60	0.45	14.63	14.50
9.	0.20	40.10	0.45	13.74	13.60
10.	0.19	30.10	0.47	15.46	15.00
$\bar{x}$	0.20	37.05	0.45	14.28	14.06
STD	0.01	4.26	0.01	0.62	0.53

Table A36. Aerodynamic Properties of Ife 98-12 at 18% w.b.

S/N	Mass, g	Area, mm^2	Drag. Coef	$V_{t(theor)}$, m/s	$V_{t(exp)}$, m/s
1.	0.21	37.43	0.46	14.58	14.30
2.	0.21	44.00	0.46	13.44	13.20
3.	0.22	37.25	0.45	15.33	15.10
4.	0.21	33.85	0.45	15.33	15.10
5.	0.21	35.34	0.45	15.00	14.90
6.	0.20	32.00	0.45	15.39	15.20
7.	0.20	36.71	0.45	14.36	14.20
8.	0.21	40.00	0.45	14.10	14.00
9.	0.21	42.65	0.46	13.66	13.40
10.	0.20	38.20	0.45	14.08	13.90
$\bar{x}$	0.21	37.74	0.45	14.49	14.30
STD	0.01	3.58	0.005	0.64	0.66

Table A37. Aerodynamic Properties of IT90K-277-2 at 8% w.b.

S/N	Mass, g	Area, mm^2	Drag. Coef	$V_{t(theor)}$, m/s	$V_{t(exp)}$, m/s
1.	0.17	37.47	0.45	13.12	13.00
2.	0.17	36.42	0.45	13.30	13.10
3.	0.17	37.79	0.45	13.05	12.90
4.	0.16	33.21	0.45	13.51	13.35
5.	0.16	33.30	0.45	13.49	13.35
6.	0.17	35.31	0.45	13.50	13.36
7.	0.16	34.82	0.45	13.19	13.00
8.	0.16	32.93	0.45	13.57	13.40
9.	0.15	27.29	0.45	14.43	14.20
10.	0.16	31.10	0.45	13.96	13.80
$\bar{x}$	0.16	33.96	0.45	13.51	13.35
STD	0.01	3.01		0.40	0.38

Table A38. Aerodynamic Properties of IT90K-277-2 at 12% w.b.

S/N	**Mass, g**	**Area, mm^2**	**Drag. Coef**	**V$_{t(theor)}$, m/s**	**V$_{t(exp)}$, m/s**
1.	0.17	35.36	0.45	13.49	13.30
2.	0.17	36.50	0.45	13.28	13.15
3.	0.16	27.30	0.45	14.90	14.80
4.	0.17	37.44	0.45	13.11	13.00
5.	0.17	37.80	0.45	13.05	12.90
6.	0.17	35.32	0.45	13.50	13.30
7.	0.17	34.56	0.45	13.65	13.50
8.	0.17	32.90	0.45	13.99	13.80
9.	0.16	31.12	0.45	13.95	13.80
10.	0.17	31.12	0.45	13.95	13.80
$\bar{x}$	0.17	34.47	0.45	13.62	13.47
STD	0.004	3.07		0.52	0.53

Table A39. Aerodynamic Properties of IT90K-277-2 at 14% w.b.

S/N	**Mass, g**	**Area, mm^2**	**Drag. Coef**	**V$_{t(theor)}$, m/s**	**V$_{t(exp)}$, m/s**
1.	0.18	35.71	0.45	13.82	13.60
2.	0.18	38.23	0.45	13.35	13.20
3.	0.17	37.44	0.45	13.11	13.00
4.	0.18	35.35	0.46	13.89	13.60
5.	0.18	35.56	0.46	13.84	13.60
6.	0.18	33.82	0.45	14.20	14.00
7.	0.17	33.96	0.45	14.19	14.00
8.	0.17	32.46	0.45	14.08	13.90
9.	0.18	36.99	0.45	13.58	13.40
10.	0.18	36.70	0.46	13.62	13.40
$\bar{x}$	0.18	35.42	0.45	13.77	13.57
STD	0.01	1.99	0.01	0.34	0.32

Table A40. Aerodynamic Properties of IT90K-277-2 at 18% w.b.

S/N	**Mass, g**	**Area, mm^2**	**Drag. Coef**	**V$_{t(theor)}$, m/s**	**V$_{t(exp)}$, m/s**
1.	0.18	38.94	0.45	13.23	13.10
2.	0.19	38.03	0.45	13.76	13.60
3.	0.19	35.79	0.45	14.18	14.00
4.	0.19	35.31	0.45	14.28	14.10
5.	0.18	33.21	0.45	14.33	14.20
6.	0.18	37.50	0.45	13.48	13.30
7.	0.19	35.38	0.45	14.26	14.10
8.	0.19	36.42	0.45	14.06	13.90
9.	0.18	33.00	0.45	14.37	14.20
10.	0.19	36.87	0.45	13.97	13.80
$\bar{x}$	0.19	36.05	0.45	13.99	13.83
STD	0.01	1.83		0.37	0.36

Table A41. Aerodynamic Properties of Ife Brown at 8% w.b.

S/N	**Mass, g**	**Area, mm^2**	**Drag. Coef**	**$V_{t(theor)}$, m/s**	**$V_{t(exp)}$, m/s**
1.	0.14	26.08	0.45	14.26	14.10
2.	0.13	23.32	0.45	14.53	14.40
3.	0.15	33.19	0.45	13.08	12.90
4.	0.15	33.15	0.45	13.09	12.90
5.	0.15	33.53	0.46	13.02	12.90
6.	0.14	23.46	0.45	15.03	14.90
7.	0.15	27.07	0.45	14.49	14.30
8.	0.15	31.59	0.45	13.41	13.30
9.	0.15	28.60	0.45	14.09	13.90
10.	0.15	29.85	0.44	13.80	13.60
$\bar{x}$	0.15	28.98	0.45	13.88	13.72
STD	0.01	3.72	0.004	0.67	0.68

Table A42. Aerodynamic Properties of Ife Brown at 12% w.b.

S/N	**Mass, g**	**Area, mm^2**	**Drag. Coef**	**$V_{t(theor)}$, m/s**	**$V_{t(exp)}$, m/s**
1.	0.16	26.50	0.45	15.12	14.90
2.	0.16	32.21	0.45	13.72	13.60
3.	0.15	30.27	0.45	13.70	13.50
4.	0.15	27.12	0.45	14.47	14.30
5.	0.16	31.93	0.45	13.50	13.30
6.	0.15	31.93	0.45	13.34	13.20
7.	0.16	33.60	0.45	13.43	13.30
8.	0.16	26.83	0.45	15.03	14.90
9.	0.16	28.96	0.44	14.47	14.40
10.	0.15	30.70	0.45	13.60	13.40
$\bar{x}$	0.16	30.14	0.45	14.04	13.88
STD		2.53	0.003	0.64	0.64

Table A43. Aerodynamic Properties of Ife Brown at 14% w.b.

S/N	**Mass, g**	**Area, mm^2**	**Drag. Coef**	**$V_{t(theor)}$, m/s**	**$V_{t(exp)}$, m/s**
1.	0.16	34.29	0.45	13.29	13.10
2.	0.16	30.42	0.45	14.11	13.90
3.	0.16	27.96	0.45	14.72	14.60
4.	0.16	31.90	0.46	13.78	13.50
5.	0.15	26.56	0.45	14.62	14.50
6.	0.15	28.78	0.45	14.05	13.90
7.	0.16	30.54	0.45	14.09	13.90
8.	0.16	29.45	0.46	14.34	14.10
9	0.16	28.75	0.45	14.52	14.40
10.	0.16	33.54	0.45	13.44	13.30
$\bar{x}$	0.16	30.22	0.45	14.10	13.92
STD	0.004	2.32	0.004	0.46	0.48

Table A44. Aerodynamic Properties of Ife Brown at 18% w.b.

S/N	Mass, g	Area, mm^2	Drag. Coef	$V_{t(theor)}$, m/s	$V_{t(exp)}$, m/s
1.	0.17	34.45	0.46	13.67	13.40
2.	0.17	31.78	0.45	14.23	14.00
3.	0.17	30.20	0.45	14.52	14.40
4.	0.16	28.73	0.45	14.52	14.40
5.	0.16	30.20	0.46	14.17	13.90
6.	0.17	32.23	0.45	14.13	13.90
7.	0.17	32.50	0.45	14.07	13.90
8.	0.18	33.57	0.46	14.25	14.00
9.	0.17	31.23	0.46	14.36	14.10
10.	0.17	30.14	0.45	14.61	14.40
$\bar{x}$	0.17	31.50	0.45	14.26	14.04
STD	0.01	1.66	0.005	0.27	0.29

Table A45. Aerodynamic Properties of Drum at 8% w.b.

S/N	**Mass, g**	**Area, mm^2**	**Drag. Coef**	**$V_{t(theor)}$, m/s**	**$V_{t(exp)}$, m/s**
1.	0.20	35.87	0.45	14.53	14.40
2.	0.23	44.38	0.45	14.01	13.90
3.	0.23	39.02	0.45	14.94	14.80
4.	0.23	38.67	0.45	15.00	14.80
5.	0.22	37.16	0.45	14.97	14.80
6.	0.23	47.22	0.45	13.58	13.40
7.	0.23	42.29	0.46	14.35	14.10
8.	0.23	45.89	0.45	13.78	13.60
9.	0.20	40.15	0.45	13.74	13.60
10.	0.23	42.52	0.45	14.31	14.10
$\bar{x}$	0.22	41.32	0.45	14.32	14.15
STD	0.01	3.58	0.003	0.51	0.51

Table A46. Aerodynamics Properties of Drum at 12% w.b.

S/N	**Mass, g**	**Area, mm^2**	**Drag. Coef**	**$V_{t(theor)}$, m/s**	**$V_{t(exp)}$, m/s**
1.	0.23	42.36	0.46	14.34	14.10
2.	0.24	46.17	0.45	14.03	13.90
3.	0.24	41.51	0.45	14.80	14.60
4.	0.23	38.89	0.46	14.96	14.70
5.	0.23	37.50	0.45	15.24	15.00
6.	0.24	47.81	0.45	13.78	13.60
7.	0.24	44.80	0.46	14.24	14.00
8.	0.24	45.96	0.45	14.06	13.90
9.	0.23	36.65	0.45	15.42	15.30
10.	0.23	44.27	0.45	14.03	13.90
$\bar{x}$	0.24	42.59	0.45	14.49	14.30
STD	0.01	3.68	0.005	0.54	0.53

Table A47. Aerodynamic Properties of Drum at 14% w.b.

S/N	Mass, g	Area, mm^2	Drag. Coef	$V_{t(theor)}$, m/s	$V_{t(exp)}$, m/s
1.	0.24	45.49	0.45	14.13	14.00
2.	0.24	44.32	0.45	14.32	14.10
3.	0.24	43.48	0.46	14.46	14.20
4.	0.24	47.88	0.45	13.78	13.60
5.	0.24	39.75	0.45	15.12	15.00
6.	0.23	39.38	0.45	14.87	14.70
7.	0.24	44.20	0.45	14.85	14.70
8.	0.24	44.06	0.45	14.36	14.20
9.	0.24	43.04	0.45	14.53	14.40
10.	0.24	46.62	0.46	13.96	13.70
$\bar{x}$	0.24	43.52	0.45	14.44	14.26
STD	0.003	2.65	0.004	0.40	0.42

Table A48. Aerodynamic Properties of Drum at 18% w.b.

S/N	Mass, g	Area, mm^2	Drag. Coef	$V_{t(theor)}$, m/s	$V_{t(exp)}$, m/s
1.	0.25	48.59	0.46	13.96	13.70
2.	0.24	38.17	0.45	15.43	15.30
3.	0.25	42.20	0.45	14.98	14.80
4.	0.25	44.01	0.45	14.67	14.50
5.	0.25	45.79	0.45	14.38	14.20
6.	0.24	40.62	0.45	14.96	14.80
7.	0.24	39.45	0.45	15.17	15.00
8.	0.25	45.44	0.45	14.43	14.20
9.	0.25	45.29	0.45	14.46	14.30
10.	0.25	48.08	0.45	14.03	13.90
$\bar{x}$	0.25	43.76	0.45	14.65	14.47
STD	0.005	3.36	0.003	0.46	0.48

Table A49. Aerodynamic Properties of Chaff

	Length : 4cm				**Length: 6cm**				**Length: 8cm**			
S/N	**(a) M.C. 7.8%**		**(b) M.C. 10.23%**		**(a) M.C. 7.8%**		**(b) M.C. 10.23%**		**(a) M.C. 7.8%**		**(b) M.C. 10.23%**	
	Mass (g)	T.Vel (m/s)	Mass (g)	T.Vel (m/s)	Mass (g)	T.Vel (m/s)	Mass (g)	T.Vel (m/s)	Mass (g)	T.Vel (m/s)	Mass (g)	T.Vel (m/s)
1.	0.096	1.3	0.129	2.0	0.141	2.0	0.171	2.5	0.115	1.8	0.167	2.4
2.	0.122	1.9	0.109	1.5	0.126	1.8	0.128	1.8	0.119	2.2	0.174	2.5
3.	0.089	1.2	0.119	1.8	0.148	2.2	0.149	2.1	0.154	2.3	0.130	2.3
4.	0.107	1.8	0.109	1.8	0.161	2.4	0.170	2.4	0.153	2.3	0.156	2.4
5.	0.108	1.5	0.111	1.5	0.162	2.5	0.168	2.3	0.172	2.5	0.117	1.9
6.	0.087	1.2	0.121	1.9	0.122	1.6	0.130	2.0	0.115	1.8	0.175	2.5
7.	0.099	1.4	0.128	2.0	0.103	1.5	0.150	2.2	0.157	2.4	0.155	2.4
8.	0.108	1.6	0.115	1.8	0.124	1.8	0.125	2.0	0.127	2.0	0.122	2.2
9.	0.120	1.8	0.120	2.0	0.142	2.0	0.140	2.0	0.171	2.5	0.128	1.9
10.	0.104	1.4	0.106	1.4	0.131	1.8	0.108	1.6	0.183	2.5	0.190	2.7
$\bar{x}$	0.104	1.51	0.117	1.77	0.136	1.96	0.144	2.09	0.147	2.23	0.151	2.32

Table A50. Aerodynamic Properties of Other cowpea particles

S/N	Insect damaged Ife 98-12		Insect damaged IT90K-277-2		Insect damaged Ife Brown		Immature grains	
	Mass g	**Term. Vel., m/s**	**Mass g**	**Term. Vel., m/s**	**Mass g**	**Term. Vel., m/s**	**Mass g**	**Term. Vel., m/s**
1.	0.152	2.96	0.130	5.0	0.150	2.90	0.108	3.5
2.	0.150	2.85	0.128	4.0	0.101	3.00	0.112	3.8
3.	0.148	3.10	0.132	6.5	0.062	2.80	0.108	3.4
4.	0.146	2.80	0.130	4.5	0.054	2.74	0.116	3.6
5.	0.154	3.06	0.128	5.0	0.083	2.76	0.112	3.4
6.	0.152	2.95	0.131	4.4	0.078	2.74	0.113	3.7
7.	0.146	2.86	0.124	4.7	0.056	2.60	0.098	2.5
8.	0.152	2.95	0.128	5.2	0.090	2.84	0.116	3.3
9.	0.154	3.12	0.134	5.8	0.070	2.86	0.128	3.9
10.	0.148	2.92	0.130	6.0	0.071	2.86	0.118	3.8
$\bar{x}$	0.150	2.96	0.130	5.11	0.082	2.81	0.113	3.49
STD		0.11		0.78	0.03	0.11	0.01	0.40

4.3 Summary of Analysis of Variance for the Physical Properties

The summary of analysis for the physical properties at four moisture content levels showing sources of variation, degrees of freedom (DF), sum of squares (SS), mean square (MS), and F-values are presented in the Tables below.

Table A51. Analysis of variance for length (mm)

Source of Variation	Degree of Freedom	SS	MS	F_{cal}	F_{tab}	
					5%	**1%**
Variety	3	655.466	218.489	374.77**	2.60	3.78
Moist. Cont	3	26.313	8.771	15.04*	2.60	3.78
Interaction	9	4.830	0.537	0.92^{NS}	1.88	2.41
Error	784	457.058	0.583			
Total	799	1143.667				

**highly significant difference, *significant difference, NS-non significant different

Table A52. Width (mm)

Source of Variation	Degree of Freedom	SS	MS	F_{cal}	F_{tab}	
					5%	**1%**
Variety	3	235.230	78.410	368.122**	2.60	3.78
Moist. Cont	3	11.088	3.696	17.352*	2.60	3.78
Interaction	9	1.941	0.216	1.014^{NS}	1.88	2.41
Error	784	167.16	0.213			
Total	799	415.419				

Table A53. Thickness (mm)

Source of Variation	**Degree of Freedom**	**SS**	**MS**	**F_{cal}**	**F_{tab}**	
					5%	**1%**
Variety	3	64.09	21.36	19.24*	2.60	3.78
Moist. Cont	3	4.39	1.46	1.32^{NS}	2.60	3.78
Interaction	9	1.78	0.20	4.75*	1.88	2.41
Error	784	869.75	1.11			
Total	799	940.01				

Table A54. Geometric mean diameter (mm)

Source of Variation	**Degree of Freedom**	**SS**	**MS**	**F_{cal}**	**F_{tab}**	
					5%	**1%**
Variety	3	164.50	54.83	274.15**	2.60	3.78
Moist. Cont	3	23.97	7.99	39.95*	2.60	3.78
Interaction	9	8.58	0.95	4.75*	1.88	2.41
Error	784	158.24	0.20			
Total	799	355.29				

Table A55. Aspect ratio

Source of Variation	**Degree of Freedom**	**SS**	**MS**	**F_{cal}**	**F_{tab}**	
					5%	**1%**
Variety	3	1.21	0.40	104.17**	2.60	3.78
Moist. Cont	3	0.014	4.67 x 10^{-3}	1.22^{NS}	2.60	3.78
Interaction	9	0.026	2.89 x 10^{-3}	0.75^{NS}	1.88	2.41
Error	784	3.01	3.84 x 10^{-3}			
Total	799	4.26				

Table A56. Bulk density, $^{kg}/_{m^3}$

Source of Variation	**Degree of Freedom**	**SS**	**MS**	**F_{cal}**	**F_{tab}**	
					5%	**1%**
Variety	3	39687.56	13229.19	3614.53**	2.92	4.51
Moist. Cont	3	7992.56	2664.19	727.92**	2.92	4.51
Interaction	9	360.69	40.08	10.95*	2.21	3.07
Error	32	116.67	3.66			
Total	47	49207.48				

Table A57. True density, kg/m^3

Source of Variation	Degree of Freedom	SS	MS	F_{cal}	F_{tab}	
					5%	**1%**
Variety	3	14437.50	4812.50	2816.90**	2.92	4.51
Moist. Cont	3	38977.17	12992.39	7604.84**	2.92	4.52
Interaction	9	15531.66	1725.74	1010.13**	2.21	3.07
Error	32	54.67	1.708			
Total	47	69001.00				

Table A58. Porosity, %

Source of Variation	Degree of Freedom	SS	MS	F_{cal}	F_{tab}	
					5%	**1%**
Variety	3	111.09	37.03	198.82**	2.92	4.51
Moist. Cont	3	6.24	2.08	11.17*	2.92	4.51
Interaction	9	57.71	6.41	34.42*	2.21	3.07
Error	32	5.96	0.186			
Total	47	181.60				

Table A59. Thousand grain mass, g

Source of Variation	Degree of Freedom	SS	MS	F_{cal}	F_{tab}	
					5%	**1%**
Variety	3	19542.39	6514.13	280.42**	2.60	3.78
Moist. Cont	3	1148.47	382.82	16.48*	2.60	3.78
Interaction	9	158.27	17.59	0.76^{NS}	1.88	2.41
Error	784	18,212.43	23.23			
Total	799	39061.56				

Table A60. Projected area $\frac{\pi ab}{4}$, (mm^2)

Source of Variation	Degree of Freedom	SS	MS	F_{cal}	F_{tab}	
					5%	**1%**
Variety	3	56911.47	18970.49	456.78**	2.60	3.78
Moist. Cont	3	2320.28	773.43	18.66*	2.60	3.78
Interaction	9	312.16	34.68	0.84^{NS}	1.88	2.41
Error	784	32490.83	41.44			
Total	799	92034.74				

Table A61. Projected area $\frac{\pi D_m^{\ 2}}{4}$, (mm^2)

Source of Variation	**Degree of Freedom**	**SS**	**MS**	**F$_{cal}$**	**F$_{tab}$**	
					5%	**1%**
Variety	3	19542.39	6514.13	280.42**	2.60	3.78
Moist. Cont	3	1148.47	382.82	16.48*	2.60	3.78
Interaction	9	158.27	17.59	0.76^{NS}	1.88	2.41
Error	784	18,212.43	23.23			
Total	799	39061.56				

Table A62. Sphericity, %

Source of Variation	**Degree of Freedom**	**SS**	**MS**	**F$_{cal}$**	**F$_{tab}$**	
					5%	**1%**
Variety	3	5927.66	1975.89	87.90*	2.60	3.78
Moist. Cont	3	106.74	35.58	1.58^{NS}	2.60	3.78
Interaction	9	361.01	40.11	1.78^{NS}	1.88	2.41
Error	784	17622.63	22.48			
Total	799	24018.04				

Table A63. Terminal velocity, m/s

Source of Variation	**Degree of Freedom**	**SS**	**MS**	**F$_{cal}$**	**F$_{tab}$**	
					5%	**1%**
Variety	3	11.64	3.88	14.37*	3.78	3.78
Moist. Cont	3	3.33	1.11	4.11*	3.78	3.78
Interaction	9	0.25	0.028	0.104^{NS}	2.41	2.41
Error	144	38.39	0.27			
Total	159	53.61				

Table A64. Predicted horizontal and vertical displacements of Ife 98-12 at angle of injection of 15°, air velocity =4m/s, injection velocity = 0.20m/s

	Ife 98-12		**Insect infested**		**chaff-4cm(a)**		**chaff-8cm(a)**	
Time	X	Y	X	Y	X	Y	X	Y
0	0	0	0	0	0	0	0	0
0.1	0.004	-0.048	0.089	-0.025	0.341	0.042	0.156	-0.007
0.2	0.016	-0.192	0.355	-0.101	1.363	0.169	0.624	-0.029
0.3	0.036	-0.432	0.799	-0.227	3.068	0.381	1.405	-0.065
0.4	0.064	-0.768	1.420	-0.404	5.454	0.677	2.497	-0.116
0.5	0.100	-1.199	2.219	-0.632	8.522	1.057	3.902	-0.181
0.6	0.144	-1.727	3.195	-0.910	12.271	1.522	5.618	-0.260
0.7	0.197	-2.351	4.349	-1.238	16.702	2.072	7.647	-0.354
0.8	0.257	-3.070	5.680	-1.617	21.815	2.706	9.988	-0.463
0.9	0.325	-3.886	7.188	-2.047	27.610	3.425	12.641	-0.586
1.0	0.401	-4.797	8.875	-2.527	34.086	4.228	15.606	-0.723

Table A65. Predicted horizontal and vertical displacements of Ife 98-12 at angle of injection of 30°, air velocity =4m/s, injection velocity = 0.20m/s

	Ife 98-12		**Insect infested**		**chaff-4cm(a)**		**chaff-8cm(a)**	
Time	X	Y	X	Y	X	Y	X	Y
0	0	0	0	0	0	0	0	0
0.1	0.004	-0.046	0.082	-0.002	0.313	0.132	0.143	0.034
0.2	0.015	-0.188	0.326	-0.008	1.252	0.527	0.573	0.134
0.3	0.033	-0.422	0.734	-0.018	2.818	1.185	1.288	0.302
0.4	0.059	-0.751	1.305	-0.031	5.010	2.108	2.291	0.538
0.5	0.092	-1.173	2.040	-0.049	7.828	3.293	3.579	0.840
0.6	0.133	-1.690	2.937	-0.070	11.272	4.742	5.154	1.210
0.7	0.181	-2.299	3.998	-0.095	15.342	6.454	7.015	1.647
0.8	0.236	-3.003	5.222	-0.124	20.039	8.430	9.162	2.151
0.9	0.299	-3.801	6.608	-0.158	25.361	10.669	11.596	2.722
1.0	0.369	-4.692	8.159	-0.195	31.310	13.172	14.316	3.360

Table A66. Predicted horizontal and vertical displacements of Ife 98-12 at angle of injection of 45^o, air velocity =4m/s, injection velocity = 0.20m/s

	Ife 98-12		**Insect infested**		**chaff-4cm(a)**		**chaff-8cm(a)**	
Time	X	Y	X	Y	X	Y	X	Y
0	0	0	0	0	0	0	0	0
0.1	0.003	-0.046	0.068	0.019	0.260	0.212	0.119	0.070
0.2	0.012	-0.184	0.272	0.076	1.043	0.847	0.476	0.280
0.3	0.028	-0.414	0.612	0.171	2.347	1.905	1.072	0.630
0.4	0.049	-0.736	1.088	0.304	4.172	3.387	1.905	1.120
0.5	0.077	-1.150	1.701	0.474	6.519	5.292	2.976	1.750
0.6	0.110	-1.655	2.449	0.683	9.387	7.621	4.286	2.520
0.7	0.150	-2.253	3.333	0.930	12.777	10.373	5.834	3.430
0.8	0.196	-2.943	4.354	1.214	16.688	13.548	7.619	4.480
0.9	0.248	-3.725	5.51	1.537	21.120	17.147	9.643	5.670
1.0	0.306	-4.599	6.803	1.898	26.074	21.169	11.905	7.000

Table A67. Predicted horizontal and vertical displacements of Ife 98-12 at angle of injection of 60^o, air velocity =4m/s, injection velocity = 0.20m/s

	Ife 98-12		**Insect infested**		**chaff-4cm(a)**		**chaff-8cm(a)**	
Time	X	Y	X	Y	X	Y	X	Y
0	0	0	0	0	0	0	0	0
0.1	0.002	-0.045	0.049	0.035	0.187	0.275	0.085	0.099
0.2	0.009	-0.181	0.195	0.142	0.748	1.099	0.342	0.396
0.3	0.020	-0.407	0.439	0.319	1.683	2.474	0.770	0.892
0.4	0.035	-0.724	0.748	0.567	2.992	4.398	1.369	1.586
0.5	0.055	-1.131	1.219	0.885	4.675	6.872	2.139	2.478
0.6	0.079	-1.629	1.756	1.275	6.733	9.896	3.080	3.568
0.7	0.107	-2.217	2.393	1.735	9.164	13.469	4.192	4.857
0.8	0.140	-2.896	3.121	2.267	11.969	17.592	5.475	6.343
0.9	0.177	-3.665	3.952	2.869	15.148	22.265	6.929	8.028
1.0	0.219	-4.525	4.877	3.542	18.702	27.488	8.554	9.912

Table A68. Predicted horizontal and vertical displacements of IT90K-277-2 at injection angle of 15^{o}, air velocity =6m/s, injection velocity = 0.5m/s

	IT90K-277=2		**Insect infested**		**chaff-4cm(a)**		**chaff-8cm(a)**	
Time	X	Y	X	Y	X	Y	X	Y
0	0	0	0	0	0	0	0	0
0.1	0.010	-0.046	0.068	-0.031	0.780	0.160	0.358	0.047
0.2	0.039	-0.186	0.273	-0.123	3.121	0.640	1.432	0.188
0.3	0.089	-0.418	0.614	-0.277	7.022	1.440	3.223	0.422
0.4	0.158	-0.743	1.092	-0.492	12.483	2.560	5.729	0.750
0.5	0.247	-1.160	1.706	-0.769	19.504	3.999	8.953	1.173
0.6	0.355	-1.671	2.457	-1.108	28.086	5.759	12.892	1.689
0.7	0.483	-2.274	3.344	-1.507	38.228	7.839	17.548	2.298
0.8	0.631	-2.970	4.368	-1.969	49.931	10.239	22.919	3.002
0.9	0.799	-3.759	5.528	-2.492	63.194	12.959	29.007	3.799
1.0	0.986	-4.641	6.825	-3.076	78.017	15.999	35.812	4.691

Table A69. Predicted horizontal and vertical displacements of IT90K-277-2 at injection angle of 30^{o}, air velocity =6m/s, injection velocity = 0.5m/s

	IT90K-277-2		**Insect infested**		**chaff-4cm(a)**		**chaff-8cm(a)**	
Time	X	Y	X	Y	X	Y	X	Y
0	0	0	0	0	0	0	0	0
0.1	0.009	-0.044	0.063	-0.012	0.729	0.372	0.324	0.138
0.2	0.0368	-0.175	0.254	-0.049	2.915	1.486	1.296	0.552
0.3	0.0828	-0.394	0.571	-0.112	6.558	3.345	2.916	1.242
0.4	0.147	-0.699	1.016	-0.198	11.658	5.946	5.184	2.208
0.5	0.230	-1.093	1.587	-0.310	18.216	9.291	8.101	3.451
0.6	0.331	-1.575	2.286	-0.446	26.231	13.378	11.665	4.969
0.7	0.451	-2.143	3.111	-0.607	35.703	18.210	15.877	6.763
0.8	0.589	-2.799	4.064	-0.793	46.632	23.784	20.737	8.834
0.9	0.745	-3.543	5.143	-1.004	59.019	30.101	26.246	11.180
1.0	0.920	-4.374	6.35	-1.239	72.863	37.162	32.402	13.802

Table A70. Predicted horizontal and vertical displacements of IT90K-277-2 at injection angle of 45^o, air velocity =6m/s, injection velocity = 0.5m/s

	IT90K-277-2		**Insect infested**		**chaff-4cm(a)**		**chaff-8cm(a)**	
Time	X	Y	X	Y	X	Y	X	Y
0	0	0	0	0	0	0	0	0
0.1	0.008	-0.041	0.051	0.004	0.612	0.563	0.281	0.232
0.2	0.031	-0.165	0.210	0.018	2.448	2.251	1.126	0.929
0.3	0.070	-0.372	0.482	0.040	5.507	5.066	2.533	2.091
0.4	0.124	-0.661	0.863	0.071	9.791	9.006	4.502	3.718
0.5	0.194	-1.033	1.340	0.112	15.298	14.072	7.0352	5.809
0.6	0.279	-1.487	1.932	0.161	22.029	20.263	10.130	8.365
0.7	0.379	-2.024	2.621	0.219	29.984	27.581	13.794	11.385
0.8	0.496	-2.644	3.423	0.285	39.163	36.023	18.013	14.870
0.9	0.628	-3.346	4.330	0.361	49.566	45.592	22.790	18.820
1.0	0.774	-4.131	5.354	0.446	61.191	56.287	28.144	23.235

Table A71. Predicted horizontal and vertical displacements of IT90K-277-2 at injection angle of 60^o, air velocity =6m/s, injection velocity = 0.5m/s

	IT90K-277-2		**Insect infested**		**chaff-4cm(a)**		**chaff-8cm(a)**	
Time	X	Y	X	Y	X	Y	X	Y
0	0	0	0	0	0	0	0	0
0.1	0.006	-0.039	0.045	0.028	0.445	0.721	0.202	0.301
0.2	0.023	-0.157	0.178	0.112	1.779	2.884	0.810	1.206
0.3	0.051	-0.354	0.401	0.252	4.002	6.491	1.821	2.713
0.4	0.090	-0.629	0.712	0.449	7.115	11.539	3.238	4.824
0.5	0.141	-0.983	1.113	0.701	11.118	18.030	5.060	7.537
0.6	0.202	-1.415	1.602	1.009	16.010	25.963	7.286	10.853
0.7	0.275	-1.926	2.181	1.374	21.791	35.339	9.917	14.773
0.8	0.360	-2.516	2.849	1.795	28.462	46.158	12.952	19.295
0.9	0.456	-3.184	3.605	2.271	36.022	58.418	16.393	24.420
1.0	0.563	-3.931	4.451	2.804	44.471	72.121	20.238	30.148

Table A72. Predicted horizontal and vertical displacements of Ife brown at angle of injection of 15°, air velocity =4m/s, injection velocity = 0.20m/s

	Ife Brown		**Insect infested**		**chaff-4cm(a)**		**chaff-8cm(a)**	
Time	X	Y	X	Y	X	Y	X	Y
0	0	0	0	0	0	0	0	0
0.1	0.004	-0.048	0.098	-0.023	0.341	0.042	0.156	-0.007
0.2	0.016	-0.192	0.394	-0.091	1.363	0.169	0.624	-0.029
0.3	0.037	-0.432	0.886	-0.204	3.068	0.381	1.405	-0.065
0.4	0.065	-0.767	1.574	-0.363	5.454	0.677	2.497	-0.116
0.5	0.101	-1.199	2.460	-0.567	8.522	1.057	3.901	-0.181
0.6	0.146	-1.727	3.541	-0.817	12.271	1.522	5.618	-0.260
0.7	0.199	-2.35	4.820	-1.112	16.702	2.072	7.647	-0.354
0.8	0.260	-3.07	6.296	-1.452	21.815	2.706	9.988	-0.463
0.9	0.329	-3.885	7.968	-1.838	27.610	3.425	12.642	-0.586
1.0	0.406	-4.796	9.837	-2.269	34.086	4.228	15.610	-0.723

Table A73. Predicted horizontal and vertical displacements of Ife brown at angle of injection of 30°, air velocity =4m/s, injection velocity = 0.20m/s

	Ife Brown		**Insect infested**		**chaff-4cm(a)**		**chaff-8cm(a)**	
Time	X	Y	X	Y	X	Y	X	Y
0	0	0	0	0	0	0	0	0
0.1	0.004	-0.047	0.091	0.004	0.313	0.132	0.143	0.034
0.2	0.015	-0.188	0.366	0.015	1.252	0.527	0.573	0.134
0.3	0.033	-0.422	0.823	0.033	2.818	1.185	1.288	0.302
0.4	0.060	-0.75	1.462	0.059	5.010	2.108	2.291	0.537
0.5	0.093	-1.173	2.285	0.093	7.828	3.293	3.579	0.840
0.6	0.134	-1.688	3.289	0.134	11.272	4.742	5.154	1.209
0.7	0.182	-2.298	4.478	0.182	15.342	6.454	7.015	1.647
0.8	0.238	-3.002	5.849	0.237	20.038	8.430	9.162	2.150
0.9	0.301	-3.799	7.402	0.301	25.361	10.669	11.596	2.721
1.0	0.372	-4.69	9.138	0.371	31.310	13.171	14.316	3.360

Table A74. Predicted horizontal and vertical displacements of Ife brown at angle of injection of 45^{o}, air velocity =4m/s, injection velocity = 0.20m/s

	Ife Brown		**Insect infested**		**chaff-4cm(a)**		**chaff-8cm(a)**	
Time	X	Y	X	Y	X	Y	X	Y
0	0	0	0	0	0	0	0	0
0.1	0.003	-0.046	0.076	0.026	0.261	0.212	0.086	0.099
0.2	0.012	-0.184	0.302	0.106	1.043	0.847	0.342	0.396
0.3	0.028	-0.414	0.679	0.238	2.347	1.905	0.770	0.892
0.4	0.050	-0.735	1.208	0.423	4.172	3.387	1.368	1.586
0.5	0.078	-1.149	1.887	0.661	6.519	5.292	2.139	2.478
0.6	0.112	-1.654	2.717	0.952	9.387	7.621	3.080	3.568
0.7	0.152	-2.251	3.699	1.295	12.776	10.373	4.192	4.857
0.8	0.199	-2.94	4.831	1.692	16.688	13.549	5.475	6.343
0.9	0.251	-3.722	6.114	2.141	21.120	17.147	6.929	8.028
1.0	0.310	-4.595	7.548	2.643	26.0746	21.169	8.554	9.912

Table A75. Predicted horizontal and vertical displacements of Ife brown at angle of injection of 60^{o}, air velocity =4m/s, injection velocity = 0.20m/s

	Ife Brown		**Insect infested**		**chaff-4cm(a)**		**chaff-8cm(a)**	
Time	X	Y	X	Y	X	Y	X	Y
0	0	0	0	0	0	0	0	0
0.1	0.002	-0.045	0.054	0.044	0.187	0.275	0.085	0.099
0.2	0.009	-0.181	0.216	0.178	0.748	1.010	0.342	0.396
0.3	0.020	-0.407	0.486	0.400	1.683	2.474	0.770	0.892
0.4	0.036	-0.723	0.864	0.711	2.992	4.398	1.369	1.586
0.5	0.056	-1.130	1.350	1.111	4.675	6.872	2.139	2.478
0.6	0.080	-1.627	1.944	1.601	6.733	9.896	3.080	3.568
0.7	0.109	-2.214	2.645	2.179	9.164	13.469	4.192	4.857
0.8	0.143	-2.892	3.455	2.845	11.969	17.592	5.475	6.343
0.9	0.180	-3.660	4.373	3.601	15.149	22.265	6.929	8.028
1.0	0.223	-4.519	5.399	4.446	18.702	27.488	8.554	9.912

Table A76. Predicted horizontal and vertical displacements of Drum at angle of injection of 15°, air velocity =4m/s, injection velocity = 0.20m/s

	Drum		Immature seeds		chaff-4cm(a)		chaff-8cm(a)	
Time	X	Y	X	Y	X	Y	X	Y
0	0	0	0	0	0	0	0	0
0.1	0.004	-0.048	0.062	-0.032	0.341	0.042	0.156	-0.007
0.2	0.015	-0.192	0.263	-0.127	1.363	0.169	0.624	-0.029
0.3	0.034	-0.432	0.581	-0.287	3.068	0.381	1.405	-0.065
0.4	0.061	-0.769	1.034	-0.510	5.454	0.676	2.497	-0.116
0.5	0.095	-1.201	1.620	-0.796	8.522	1.057	3.901	-0.181
0.6	0.137	-1.729	2.313	-1.147	12.271	1.522	5.618	-0.260
0.7	0.186	-2.355	3.142	-1.561	16.702	2.072	7.647	-0.355
0.8	0.243	-3.074	4.111	-2.039	21.815	2.706	9.988	-0.463
0.9	0.308	-3.891	5.241	-2.580	27.610	3.425	12.640	-0.586
1.0	0.380	-4.803	6.420	-3.186	34.086	4.228	15.612	-0.723

Table A77. Predicted horizontal and vertical displacements of Drum at angle of injection of 30°, air velocity =4m/s, injection velocity = 0.20m/s

	Drum		Immature seed		chaff-4cm(a)		chaff-8cm(a)	
Time	X	Y	X	Y	X	Y	X	Y
0	0	0	0	0	0	0	0	0
0.1	0.004	-0.047	0.059	-0.015	0.313	0.132	0.143	0.034
0.2	0.014	-0.188	0.235	-0.061	1.252	0.527	0.573	0.134
0.3	0.032	-0.423	0.528	-0.137	2.818	1.185	1.288	0.302
0.4	0.056	-0.752	0.939	-0.243	5.010	2.108	2.291	0.538
0.5	0.088	-1.175	1.467	-0.379	7.828	3.293	3.579	0.840
0.6	0.126	-1.693	2.113	-0.546	11.272	4.742	5.154	1.210
0.7	0.172	-2.304	2.875	-0.743	15.342	6.454	7.015	1.647
0.8	0.224	-3.010	3.756	-0.971	20.039	8.430	9.162	2.151
0.9	0.284	-3.810	4.753	-1.229	25.361	10.669	11.596	2.722
1.0	0.350	-4.703	5.868	-1.517	31.310	13.172	14.316	3.360

Table A78. Predicted horizontal and vertical displacements of Drum at angle of injection of 45°, air velocity =4m/s, injection velocity = 0.20m/s

	Drum		**Immature seed**		**chaff-4cm(a)**		**chaff-8cm(a)**	
Time	X	Y	X	Y	X	Y	X	Y
0	0	0	0	0	0	0	0	0
0.1	0.003	-0.046	0.049	-0.001	0.261	0.212	0.119	0.070
0.2	0.012	-0.185	0.195	-0.001	1.043	0.847	0.476	0.280
0.3	0.026	-0.415	0.440	-0.002	2.347	1.905	1.072	0.630
0.4	0.046	-0.738	0.782	-0.003	4.172	3.387	1.905	1.120
0.5	0.073	-1.154	1.221	-0.004	6.519	5.292	2.976	1.750
0.6	0.105	-1.661	1.759	-0.007	9.387	7.621	4.286	2.520
0.7	0.142	-2.261	2.394	-0.009	12.777	10.373	5.834	3.430
0.8	0.186	-2.953	3.127	-0.013	16.688	13.549	7.619	4.480
0.9	0.235	-3.738	3.957	-0.016	21.120	17.147	9.643	5.670
1.0	0.290	-4.615	4.885	-0.020	26.075	21.170	11.905	7.000

Table A79. Predicted horizontal and vertical displacements of Drum at angle of injection of 60°, air velocity =4m/s, injection velocity = 0.20m/s

	Drum		**Immature seed**		**chaff-4cm(a)**		**chaff-8cm(a)**	
Time	X	Y	X	Y	X	Y	X	Y
0	0	0	0	0	0	0	0	0
0.1	0.002	-0.045	0.035	0.012	0.187	0.275	0.086	0.099
0.2	0.008	-0.182	0.141	0.048	0.748	1.100	0.342	0.396
0.3	0.019	-0.409	0.317	0.107	1.683	2.474	0.770	0.892
0.4	0.033	-0.727	0.563	0.191	2.992	4.398	1.369	1.586
0.5	0.052	-1.136	0.880	0.298	4.675	6.872	2.139	2.478
0.6	0.075	-1.636	1.268	0.430	6.733	9.896	3.080	3.568
0.7	0.102	-2.226	1.725	0.585	9.164	13.469	4.192	4.857
0.8	0.133	-2.908	2.253	0.764	11.969	17.621	5.475	6.340
0.9	0.169	-3.680	2.852	0.967	15.149	22.265	6.929	8.028
1.0	0.209	-4.543	3.521	1.193	18.702	27.488	8.555	9.912

Table A80. Predicted horizontal and vertical displacements of Ife 98-12 at angle of injection of 15°, air velocity = 8 m/s, injection velocity = 0.2 m/s.

	Ife 98-12		Insect infested		chaff-4cm		chaff-8cm(a)	
Time	**X**	**Y**	**X**	**Y**	**X**	**Y**	**X**	**Y**
0	0	0	0	0	0	0	0	0
0.1	0.024	-0.043	0.350	0.045	1.347	0.312	0.614	0.116
0.2	0.095	-0.171	1.401	0.179	5.387	1.247	2.458	0.462
0.3	0.214	-0.384	3.154	0.404	12.121	2.806	5.529	1.040
0.4	0.381	-0.683	5.608	0.718	21.548	4.989	9.830	1.849
0.5	0.596	-1.067	8.762	1.122	33.668	7.795	15.359	2.889
0.6	0.858	-1.536	12.617	1.615	48.482	11.225	22.118	4.160
0.7	1.168	-2.091	17.174	2.198	65.989	15.278	30.105	5.663
0.8	1.525	-2.730	22.431	2.871	86.190	19.955	39.320	7.397
0.9	1.930	-3.456	28.389	3.634	109.085	25.256	49.765	9.361
1.0	2.383	-4.267	35.049	4.486	134.672	31.180	61.438	11.557

Table A81. Predicted horizontal and vertical displacements of Ife 98-12 at angle of injection of 30°, air velocity = 8 m/s, injection velocity = 0.2 m/s.

	Ife 98-12		Insect damaged		chaff-4cm		chaff-8cm(a)	
Time	**X**	**Y**	**X**	**Y**	**X**	**Y**	**X**	**Y**
0	0	0	0	0	0	0	0	0
0.1	0.014	-0.041	0.317	0.134	1.224	0.658	0.558	0.273
0.2	0.057	-0.163	1.268	0.536	4.896	2.631	2.234	1.094
0.3	0.129	-0.367	2.854	1.206	11.017	5.919	5.026	2.461
0.4	0.230	-0.652	5.074	2.145	19.586	10.523	8.936	4.374
0.5	0.358	-1.019	7.928	3.351	30.602	16.442	13.962	6.835
0.6	0.516	-1.468	11.416	4.825	44.067	23.677	20.106	9.842
0.7	0.703	-1.998	15.539	6.568	59.981	32.226	27.366	13.397
0.8	0.918	-2.609	20.296	8.579	78.342	42.092	35.744	17.498
0.9	1.161	-3.302	25.687	10.857	99.152	53.272	45.238	22.145
1.0	1.434	-4.077	31.712	13.403	122.409	65.768	55.850	27.340

Table A82. Predicted horizontal and vertical displacements of Ife 98-12 at angle of injection of 45^o, air velocity = 8 m/s, injection velocity = 0.2 m/s.

	Ife 98-12		**Insect damaged**		**chaff-4cm**		**chaff-8cm(a)**	
Time	X	Y	X	Y	X	Y	X	Y
0	0	0	0	0	0	0	0	0
0.1	0.012	-0.037	0.261	0.212	1.006	0.957	0.457	0.408
0.2	0.047	-0.149	1.045	0.849	4.025	3.829	1.828	1.632
0.3	0.107	-0.335	2.351	1.910	9.056	8.615	4.113	3.671
0.4	0.189	-0.595	4.180	3.396	16.100	15.315	7.312	6.527
0.5	0.296	-0.930	6.532	5.306	25.157	23.930	11.424	10.198
0.6	0.426	-1.340	9.406	7.640	36.226	34.460	16.451	14.685
0.7	0.580	-1.823	12.803	10.399	49.307	46.904	22.392	19.988
0.8	0.758	-2.381	16.722	13.583	64.401	61.261	29.246	26.107
0.9	0.959	-3.014	21.164	17.191	81.508	77.535	37.015	33.042
1.0	1.184	-3.721	26.128	21.223	100.627	95.721	45.697	40.792

Table A83. Predicted horizontal and vertical displacements of Ife 98-12 at angle of injection of 60^o, air velocity = 8 m/s, injection velocity = 0.2 m/s.

	Ife 98-12		**Insect damaged**		**chaff-4cm**		**chaff-8cm(a)**	
Time	**X**	**Y**	**X**	**Y**	**X**	**Y**	**X**	**Y**
0	0	0	0	0	0	0	0	0
0.1	0.008	-0.034	0.186	0.274	0.719	1.1959	0.328	0.519
0.2	0.034	-0.138	0.745	1.095	2.875	4.783	1.313	2.077
0.3	0.076	-0.310	1.678	2.465	6.469	10.763	2.954	4.675
0.4	0.135	-0.551	2.983	4.381	11.500	19.134	5.251	8.311
0.5	0.211	-0.861	4.660	6.846	17.969	29.897	8.206	12.987
0.6	0.304	-1.240	6.711	9.858	25.875	43.051	11.816	18.700
0.7	0.413	-1.687	9.134	13.418	35.219	58.597	16.083	25.454
0.8	0.540	-2.204	11.931	17.526	46.000	76.535	21.007	33.246
0.9	0.683	-2.790	15.100	22.181	58.219	96.865	26.587	42.077
1.0	0.843	-3.444	18.641	27.384	71.875	119.586	32.823	51.946

Table A84. Predicted horizontal and vertical displacements of IT90K-277-2 at angle of injection of 15°, air velocity = 8 m/s, injection velocity = 0.5 m/s.

	IT90K-277-2		**Insect damaged**		**chaff-4cm**		**chaff-8cm(a)**	
Time	X	Y	X	Y	X	Y	X	Y
0	0	0	0	0	0	0	0	0
0.1	0.018	-0.044	0.325	0.038	1.375	0.319	0.624	0.118
0.2	0.073	-0.177	1.299	0.152	5.498	1.277	2.497	0.473
0.3	0.164	-0.397	2.923	0.342	12.371	2.873	5.618	1.064
0.4	0.293	-0.706	5.196	0.608	21.993	5.108	9.988	1.891
0.5	0.458	-1.104	8.119	0.949	34.365	7.982	15.606	2.956
0.6	0.659	-1.589	11.691	1.367	49.485	11.494	22.473	4.256
0.7	0.897	-2.163	15.913	1.861	67.355	15.644	30.588	5.792
0.8	1.172	-2.825	20.785	2.430	87.974	20.433	39.951	7.566
0.9	1.483	-3.576	26.306	3.076	111.342	25.861	50.563	9.575
1.0	1.831	-4.414	32.476	3.80	137.459	31.927	62.424	11.821

Table A85. Predicted horizontal and vertical displacements of IT90K-277-2 at angle of injection of 30°, air velocity = 8 m/s, injection velocity = 0.5 m/s.

	IT90K-277-2		**Insect infested**		**chaff-4cm**		**chaff-8cm(a)**	
Time	X	Y	X	Y	X	Y	X	Y
0	0	0	0	0	0	0	0	0
0.1	0.017	-0.039	0.332	0.142	1.270	0.684	0.580	0.286
0.2	0.068	-0.157	1.326	0.569	5.080	2.736	2.321	1.144
0.3	0.152	-0.354	2.984	1.281	11.429	6.157	5.222	2.574
0.4	0.271	-0.629	5.304	2.278	20.318	10.946	9.284	4.576
0.5	0.423	-0.982	8.288	3.559	31.747	17.103	14.507	7.150
0.6	0.609	-1.414	11.935	5.125	45.716	24.628	20.891	10.295
0.7	0.828	-1.925	16.245	6.976	62.225	33.522	28.435	14.013
0.8	1.082	-2.514	21.218	9.111	81.273	43.784	37.138	18.303
0.9	1.370	-3.182	26.854	11.531	102.861	55.414	47.004	23.165
1.0	1.690	-3.929	33.153	14.236	126.990	68.412	58.029	28.598

Table A86. Predicted horizontal and vertical displacements of IT90K-277-2 at angle of injection of 45^o, air velocity = 8 m/s, injection velocity = 0.5 m/s.

	IT90K-277-2		**Insect infested**		**chaff-4cm**		**chaff-8cm(a)**	
Time	X	Y	X	Y	X	Y	X	Y
0	0	0	0	0	0	0	0	0
0.1	0.014	-0.035	0.275	0.226	1.054	1.005	0.486	0.437
0.2	0.057	-0.140	1.102	0.905	4.215	4.019	1.943	1.747
0.3	0.127	-0.314	2.479	2.037	9.485	9.043	4.373	3.931
0.4	0.226	-0.559	4.406	3.621	16.862	16.076	7.773	6.989
0.5	0.354	-0.873	6.885	5.659	26.347	25.120	12.146	10.920
0.6	0.509	-1.256	9.915	8.149	37.939	36.173	17.490	15.724
0.7	0.693	-1.710	13.495	11.091	51.639	49.236	23.806	21.402
0.8	0.905	-2.234	17.626	14.487	67.447	64.308	31.093	27.954
0.9	1.146	-2.828	22.308	18.334	85.363	81.390	39.353	35.380
1.0	1.414	-3.491	27.540	22.635	105.386	100.481	48.584	43.679

Table A87. Predicted horizontal and vertical displacements of IT90K-277-2 at angle of injection of 60^o, air velocity = 8 m/s, injection velocity = 0.5 m/s.

	IT90K-277-2		**Insect infested**		**chaff-4cm**		**chaff-8cm**	
Time	X	Y	X	Y	X	Y	X	Y
0	0	0	0	0	0	0	0	0
0.1	0.010	-0.031	0.486	0.437	0.764	1.275	0.349	0.555
0.2	0.041	-0.126	1.943	1.747	3.058	5.0999	1.395	2.219
0.3	0.092	-0.283	4.372	3.931	6.880	11.475	3.138	4.993
0.4	0.163	-0.503	7.773	6.989	12.230	20.400	5.578	8.877
0.5	0.254	-0.786	12.146	10.920	19.111	31.874	8.716	13.870
0.6	0.366	-1.131	17.490	15.724	27.519	45.899	12.551	19.973
0.7	0.499	-1.540	23.806	21.402	37.457	62.474	17.083	27.186
0.8	0.651	-2.011	31.093	27.954	48.923	81.598	22.313	35.508
0.9	0.824	-2.545	39.353	35.380	61.918	103.273	28.240	44.940
1.0	1.018	-3.142	48.584	43.680	76.442	127.497	34.864	55.481

Table A88. Average cleaning efficiency of the pneumatic cleaner at different angles Injection and different air velocities for Ife 98-12

Variety	Angle of Injection (^{o})	Air Velocity, m/s	Average Cleaning Efficiency, %
Ife 98-12	15	4	27.7
	30	4	44.1
	45	4	60.6
	60	4	61.1
	15	6	63.2
	30	6	71.9
	45	6	76.0
	60	6	75.9
	15	8	76.7
	30	8	80.9
	45	8	87.5
	60	8	87.2

Table A89. Average cleaning efficiency of the pneumatic cleaner at different angles Injection and different air velocities for IT90K-277-2

Variety	Angle of Injection (^{o})	Air Velocity, m/s	Average Cleaning Efficiency, %
IT90K-277-2	15	4	28.2
	30	4	44.4
	45	4	60.9
	60	4	60.9
	15	6	63.7
	30	6	71.2
	45	6	75.5
	60	6	75.6
	15	8	76.8
	30	8	79.9
	45	8	87.8
	60	8	88.2

Table A90. Average cleaning efficiency of the pneumatic cleaner at different angles Injection and different air velocities for Ife Brown

Variety	Angle of Injection (^{o})	Air Velocity, m/s	Average Cleaning Efficiency, %
Ife Brown	15	4	27.6
	30	4	44.3
	45	4	60.3
	60	4	60.8
	15	6	62.3
	30	6	71.6
	45	6	75.4
	60	6	75.6
	15	8	76.7
	30	8	80.0
	45	8	87.4
	60	8	87.9

Table A91. Average cleaning efficiency of the pneumatic cleaner at different angles Injection and different air velocities for Drum

Variety	Angle of Injection (^{o})	Air Velocity, m/s	Average Cleaning Efficiency, %
Drum	15	4	27.7
	30	4	44.6
	45	4	59.2
	60	4	59.6
	15	6	61.4
	30	6	71.4
	45	6	75.5
	60	6	75.5
	15	8	76.6
	30	8	80.4
	45	8	87.5
	60	8	87.2

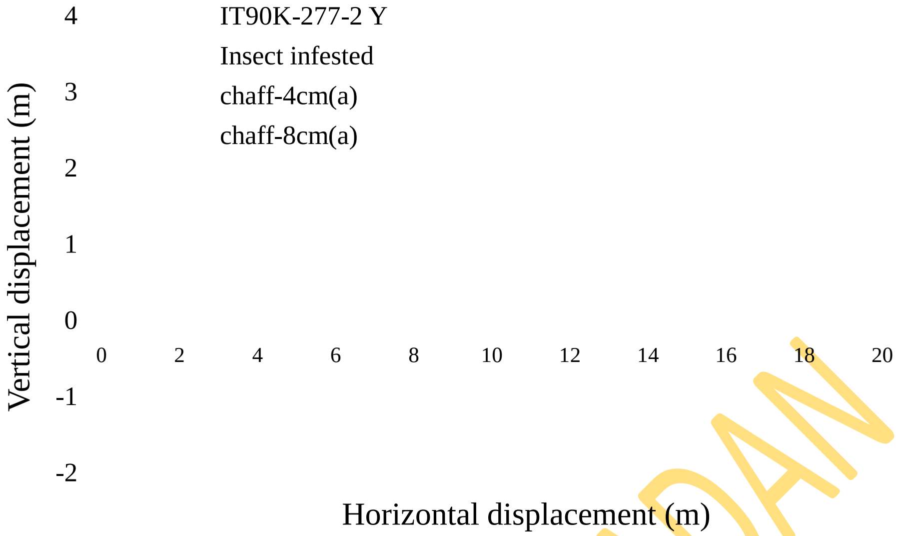

Figure A1. IT90K-277-2-impurities mixture injected at 15° . Injection velocity = 0.5m/s. Air velocity = 6m/s.

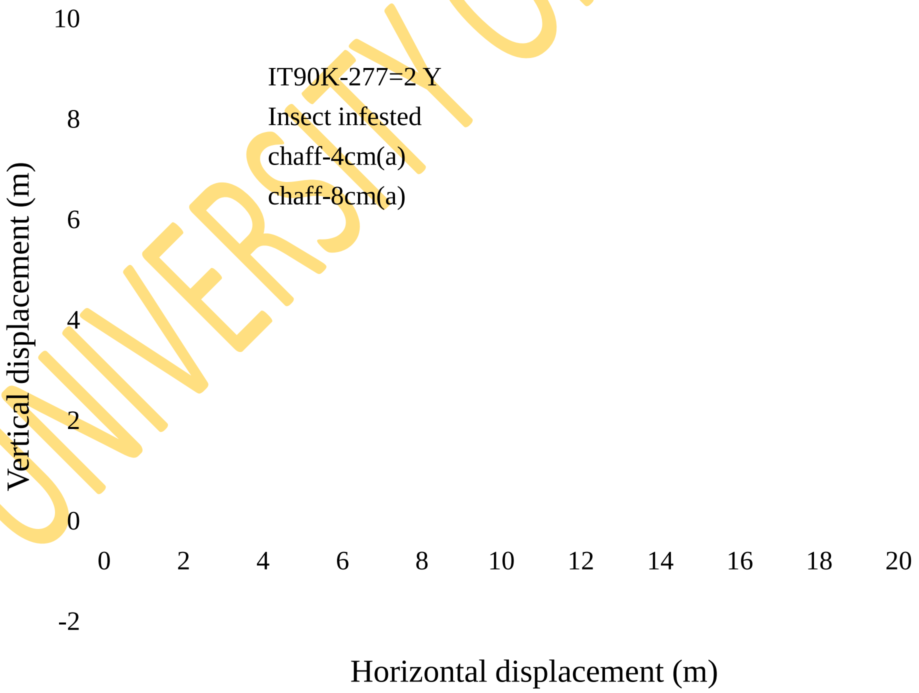

Figure A2. IT90K-277-2-impurities mixture injected at 30° . Injection vel. = 0.50m/s. Air vel. = 6m/s.

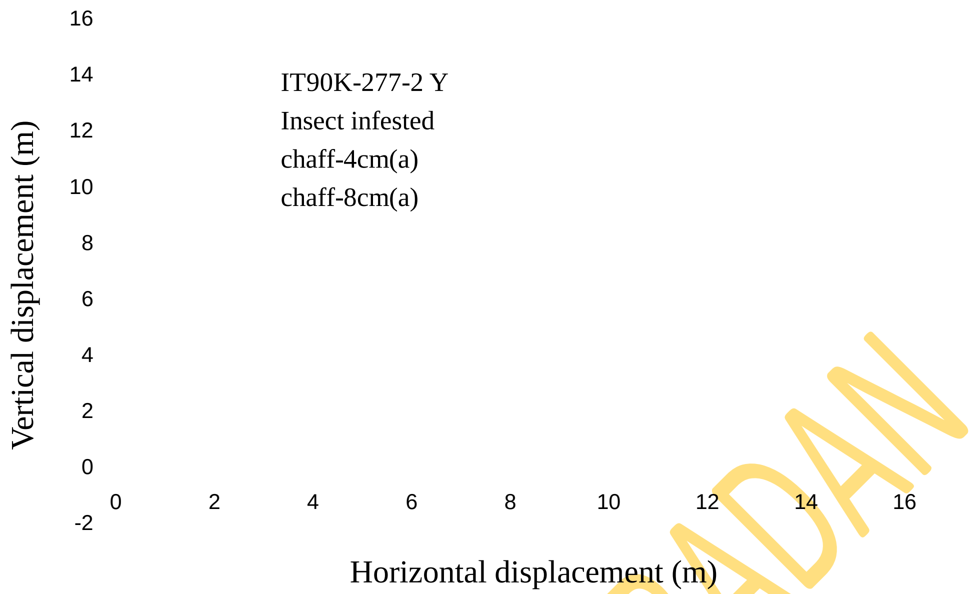

Fig.A3. IT90K-277-2-impurities mixture injected at 45º . Injection vel.=0.5m/s. Air vel. =6m/s.

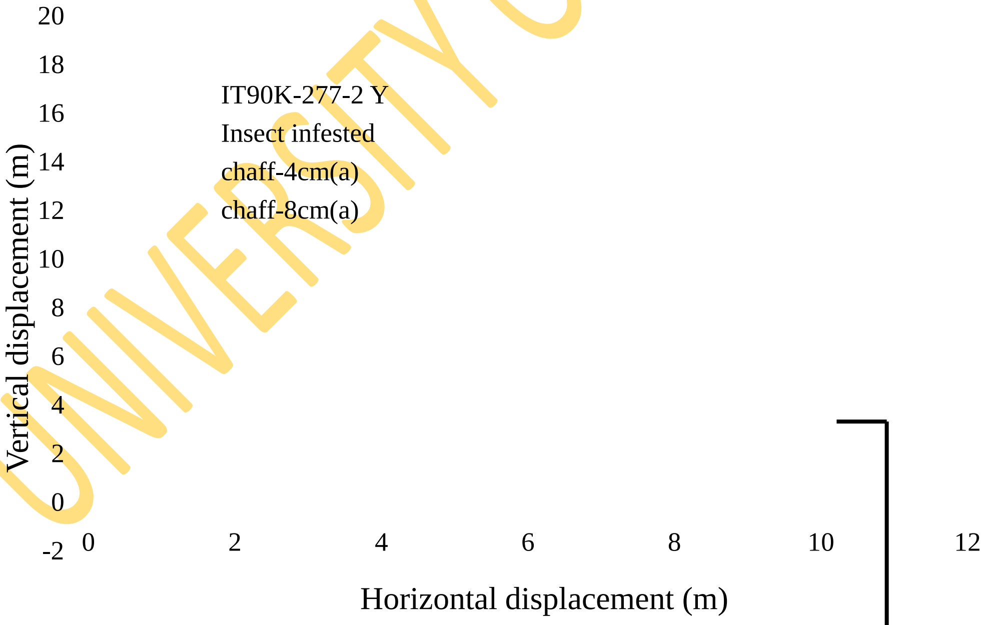

Figure A4. IT90K-277-2-impurities mixture injected at 60º. Injection vel. = 0.5m/s. Air vel. = 6m/s.

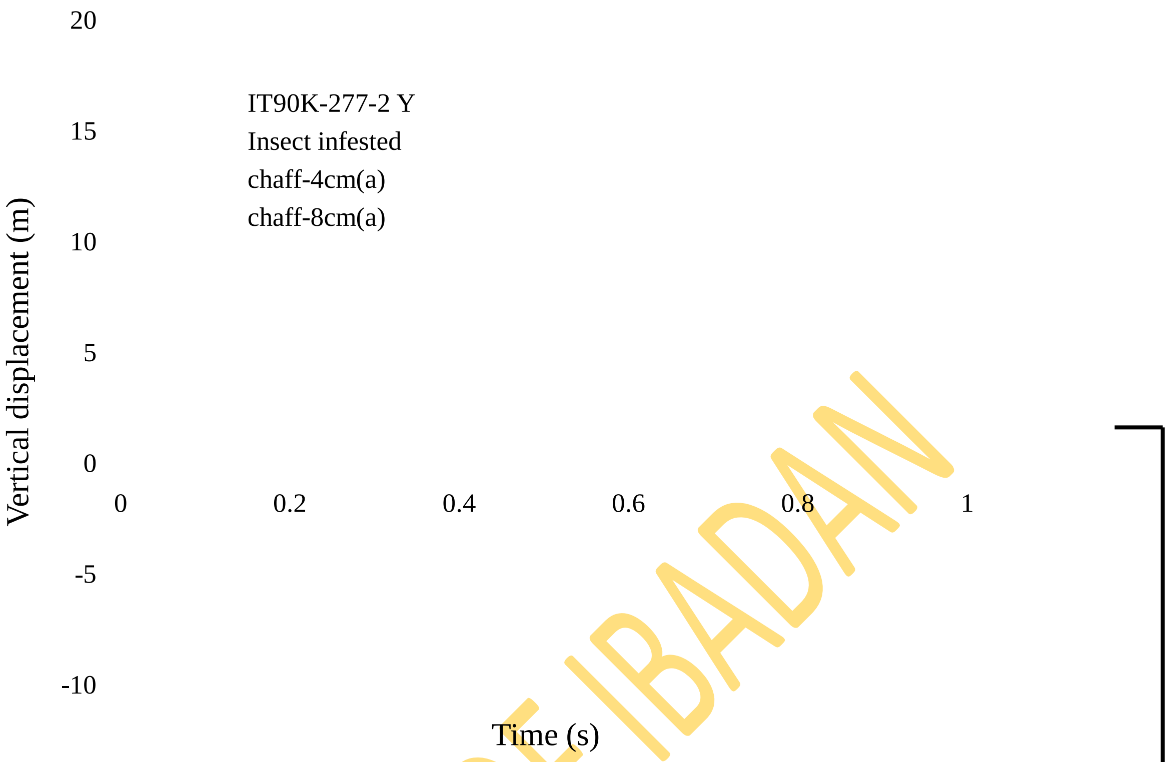

Figure A5. IT90K-277-2-impurties mixtures injected at 15° . Injection vel. = 0.5m/s. Air vel. = 6m/s.

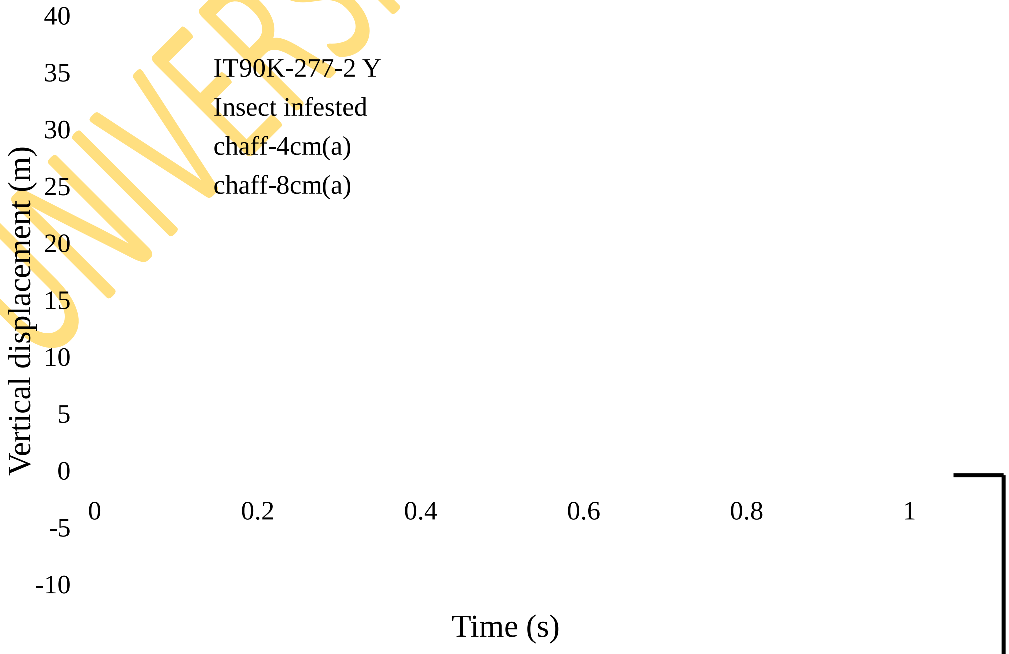

Figure A6. IT90K-277-2-impurities mixture injected at 30° . Injection vel. = 0.5m/s. Air vel. = 6m/s.

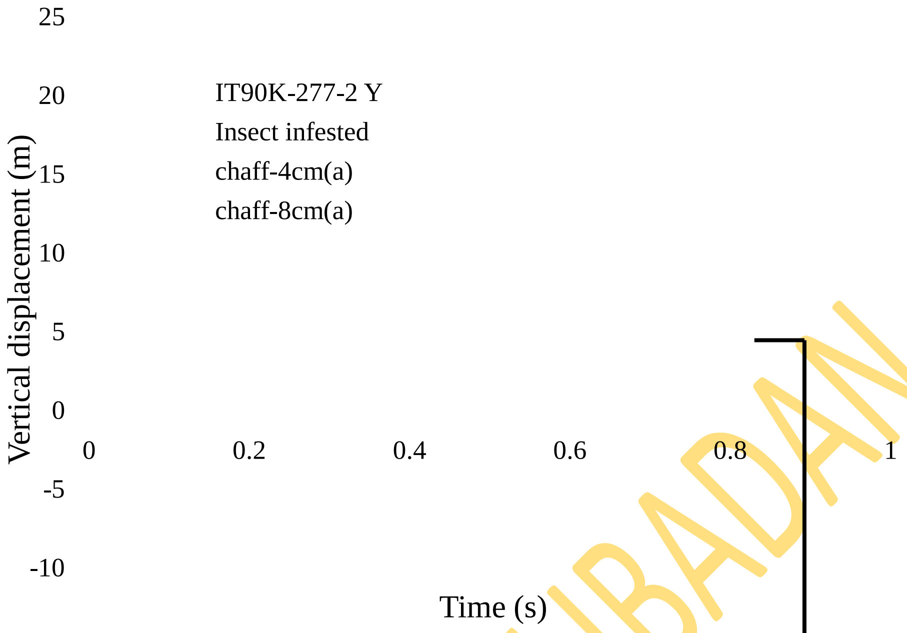

Figure A7. IT90K-277-2-impurities mixture injected at 45° . Injection vel. = 0.5m/s.Air vel. = 6m/s

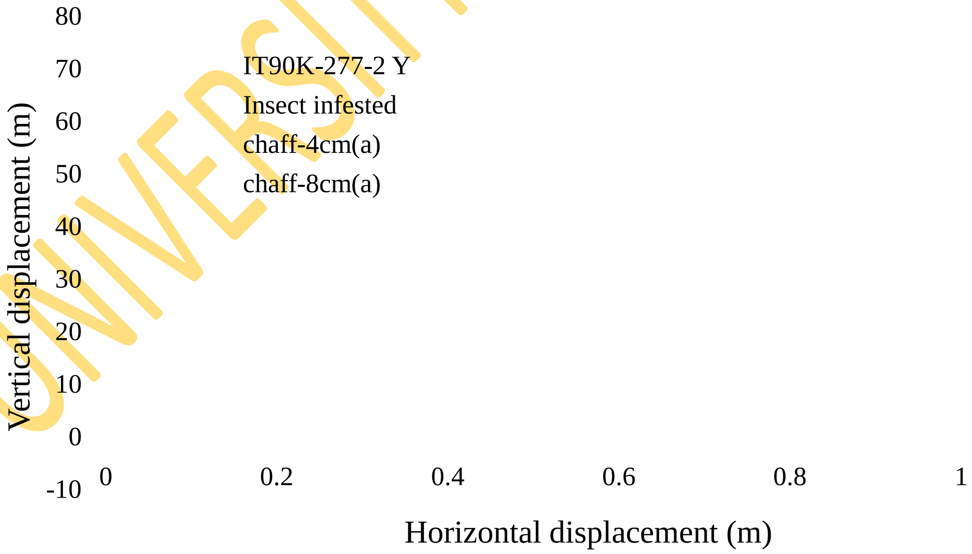

Figure A8. IT90K-277-2- impurities mixture injected at 60° . Injection vel. = 0.5m/s. Air velocity = 6m/s.

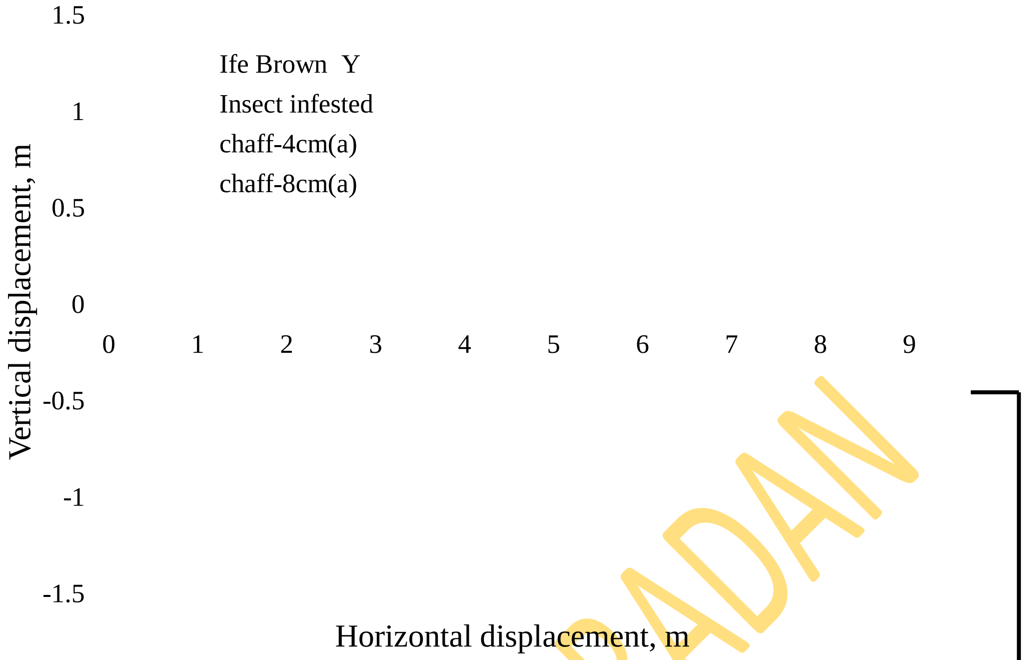

Figure A9. Ife Brown-impurities mixture injected at 15° . Injection vel. = 0.2m/s. Air vel. = 4m/s.

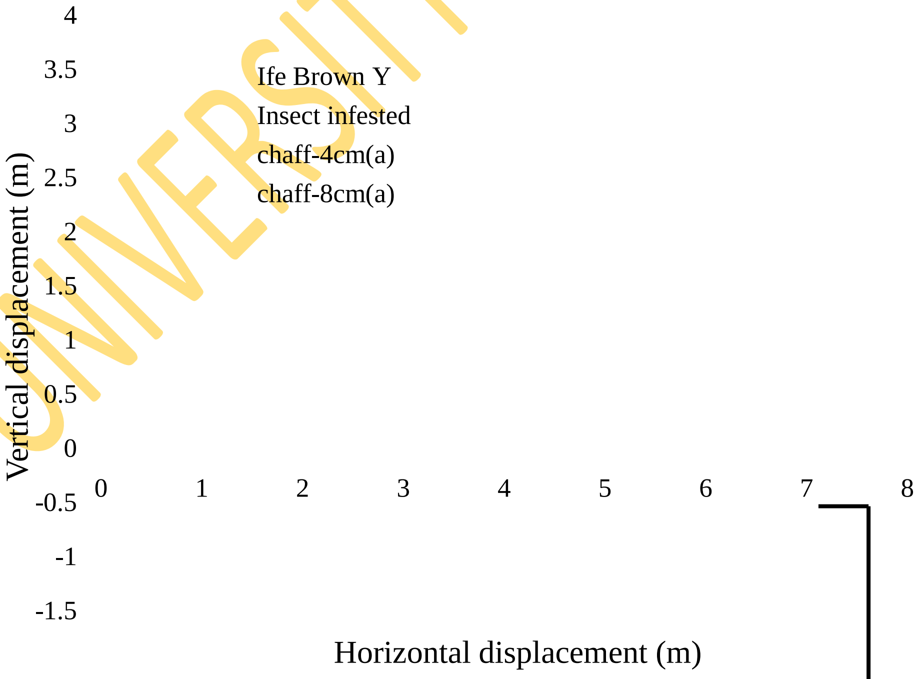

Figure A10. Ife Brown-impurities mixture injected at 30° . Injection vel. = 0.2m/s. Air vel. = 4m/s.

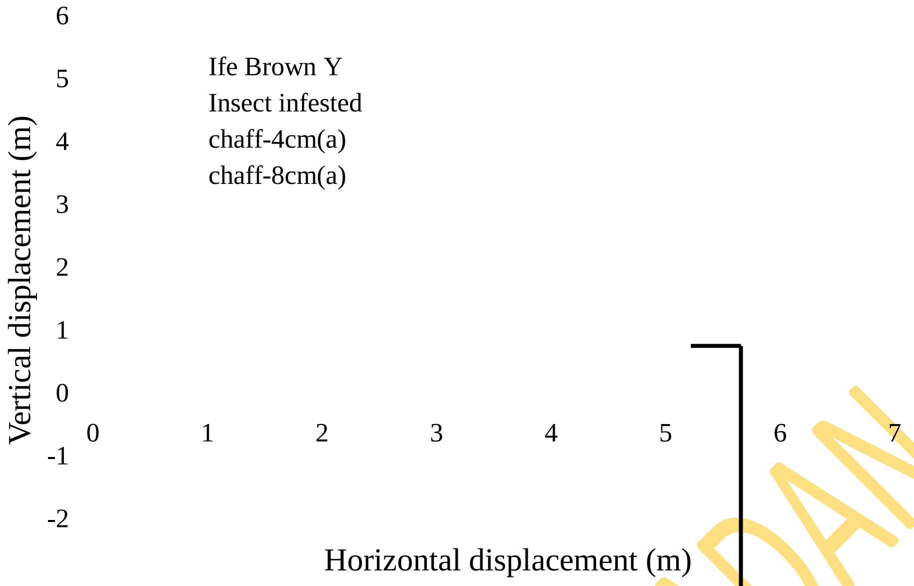

Figure A11. Ife Brown-impurities mixture injected at 45^o . Injection vel. = 0.2m/s. Air vel. = 4m/s.

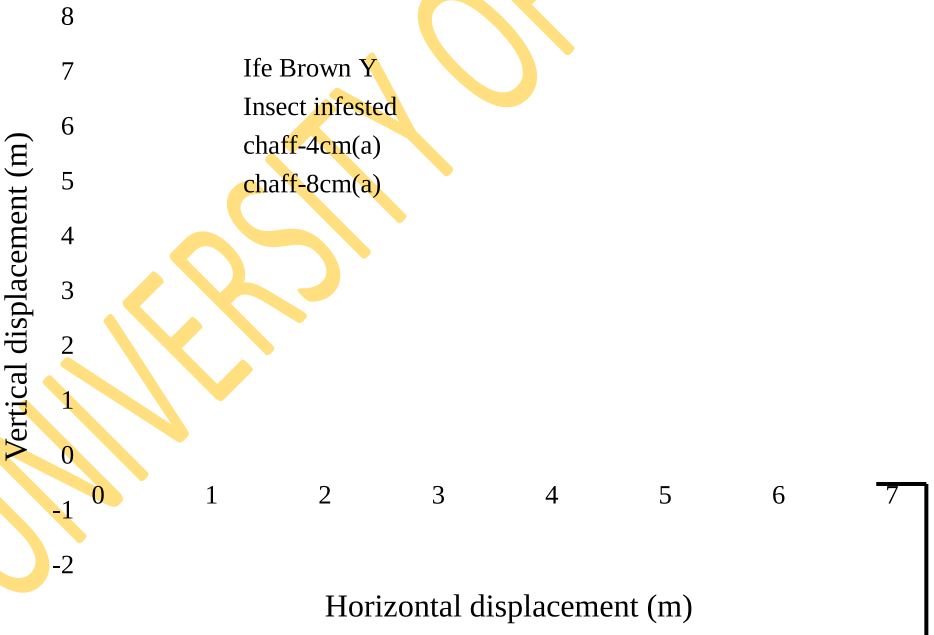

Figure A12. Ife Brown impurities mixture injected at 60^o . Injection vel. = 0.2m/s. Air vel. = 4m/s.

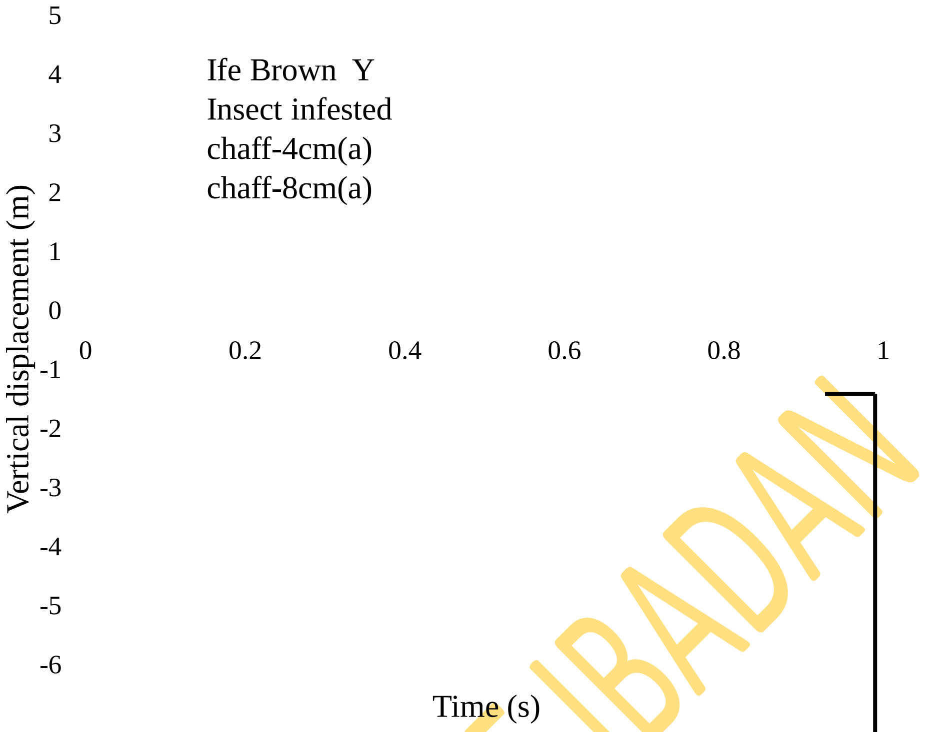

Figure A13. Ife Brown impurities mixture injected at 15° . Injection vel. = 0.2m/s. Air velocity = 4m/s.

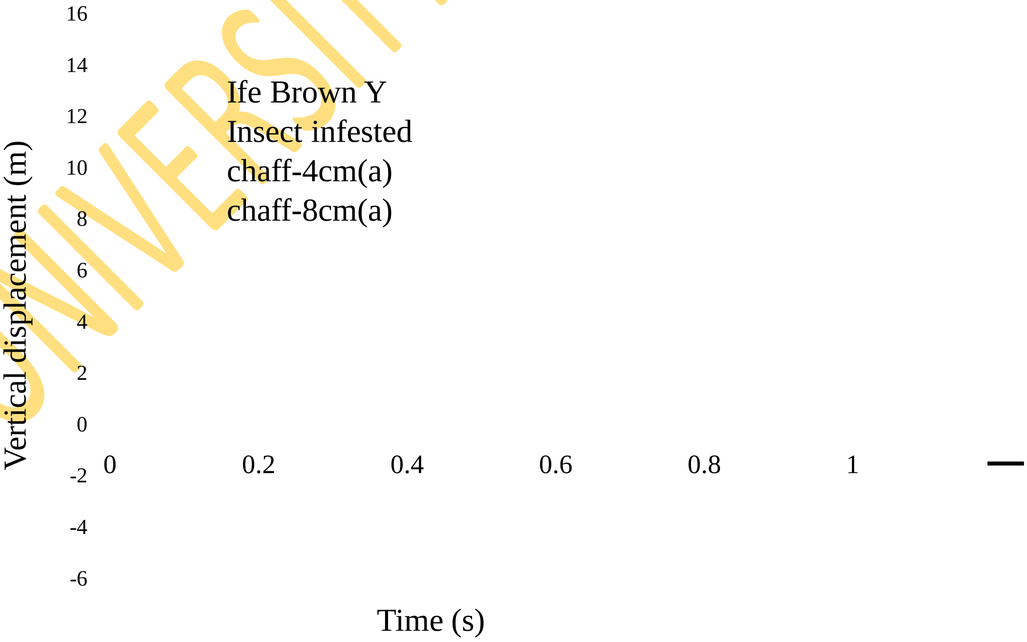

Figure A14. Ife Brown-impurities mixture injected at 30° . Injection vel. = 0.2m/s. Air vel. = 4m/s.

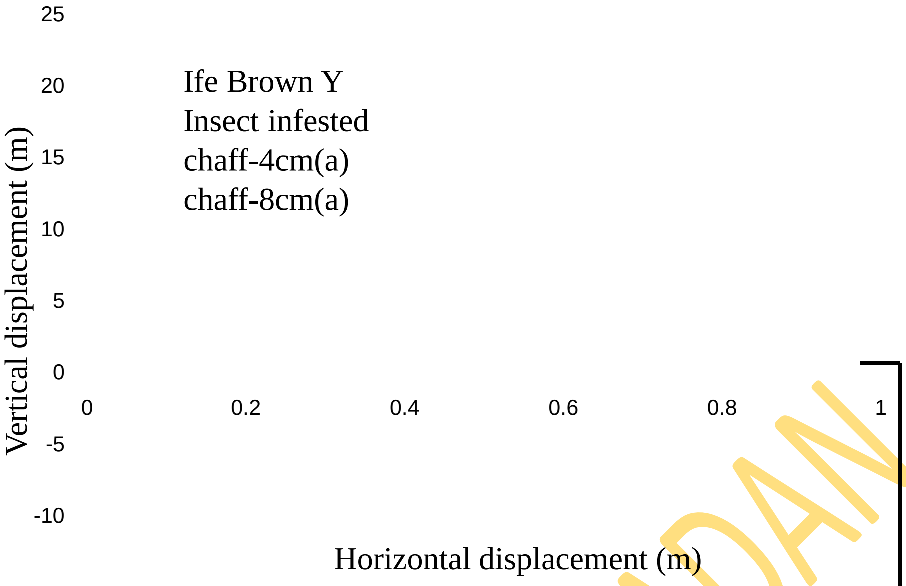

Figure A15. Ife Brown-impurities mixture injected at 45^o . Injection vel. = 0.2m/s. Air vel. = 4m/s.

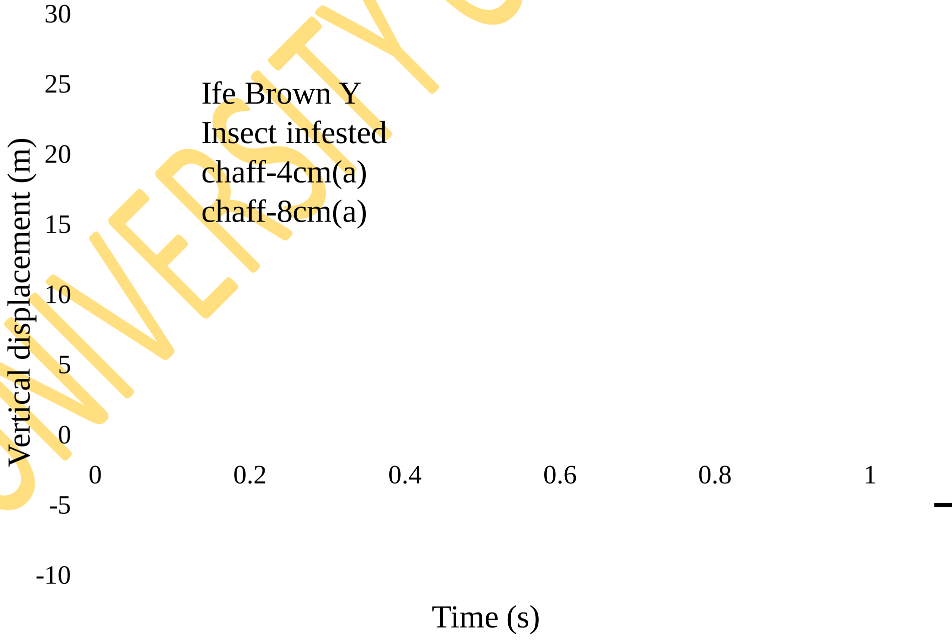

Figure A16. Ife Brown impurities mixture injected at 60^o . Injection vel. = 0.2m/s. Air velocity = 4m/s.

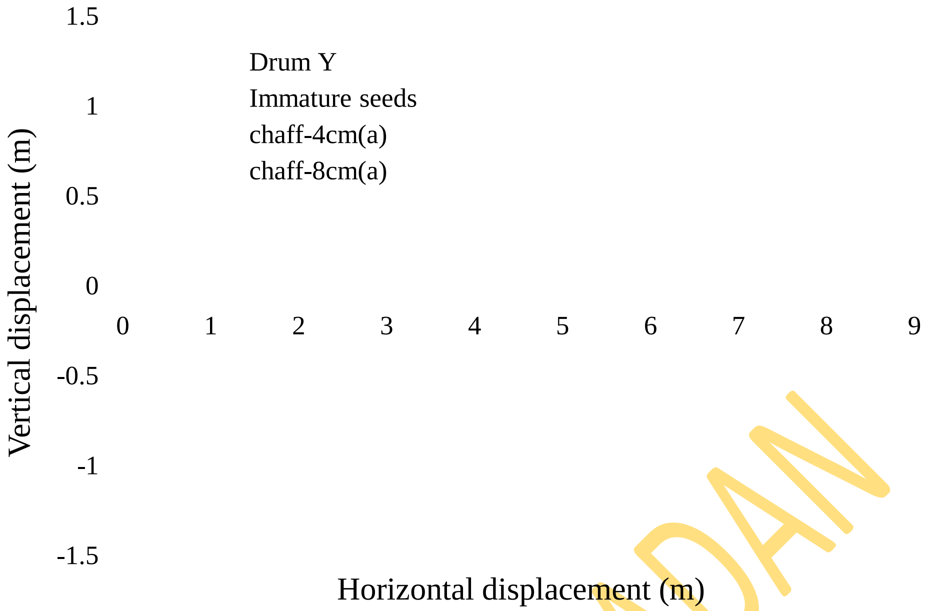

Figure A17. Drum inpurities mixture injected at 15° . Injection vel. = 0.2m/s. Air vel. = 4m/s

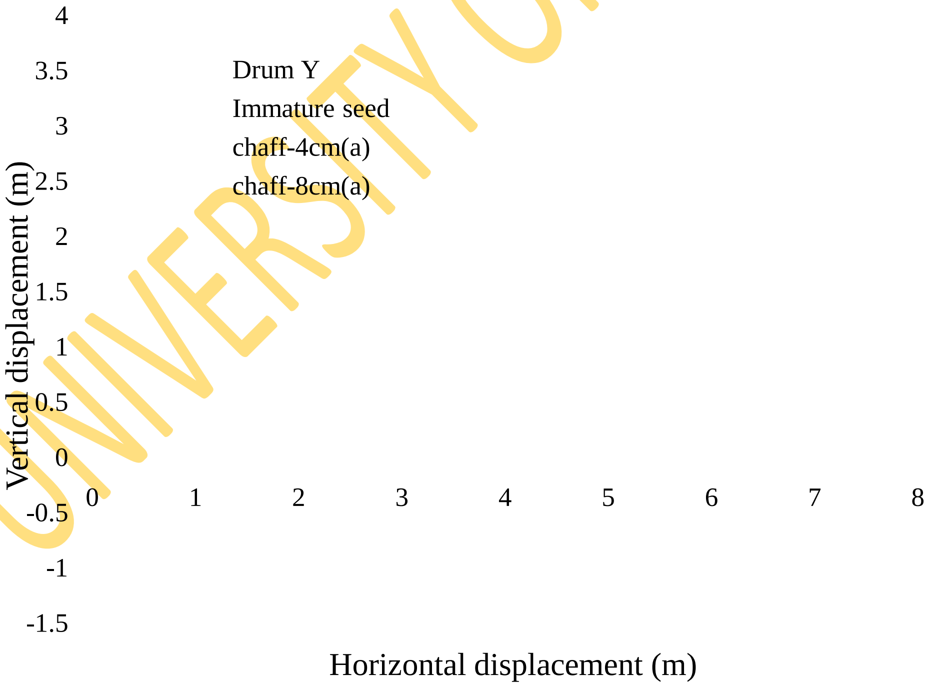

Figure A18. Drum-impurities mixture injected at 30° . Injection vel. = 0.2m/s. Air velocity = 4m/s

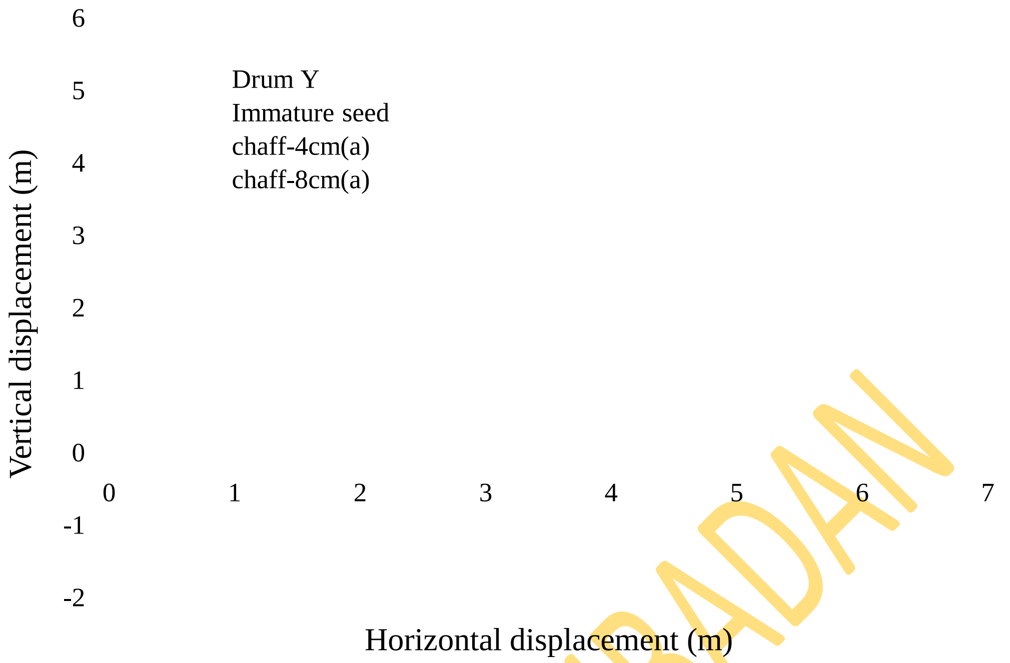

Figure A19. Drum-impurities mixture injeated at 45° .Injection vel. = 0.2m/s. Air vel. = 4m/s.

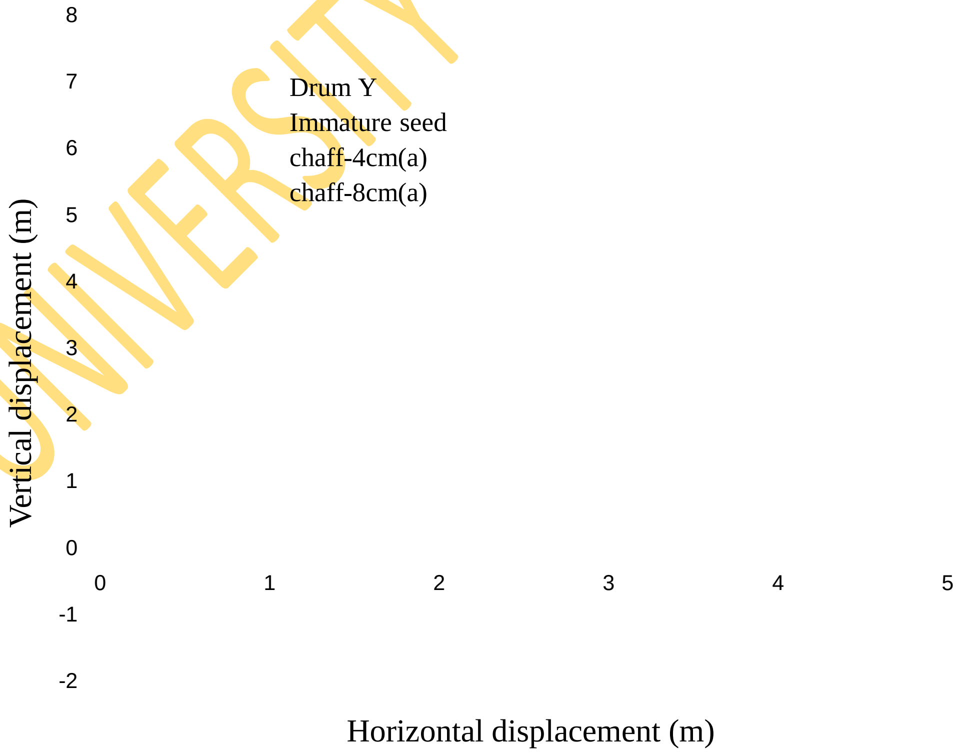

Figure A20. Drum-impurities mixture injected at 60° . Injection vel. = 0.2m/s. Air vel. = 4m/s.

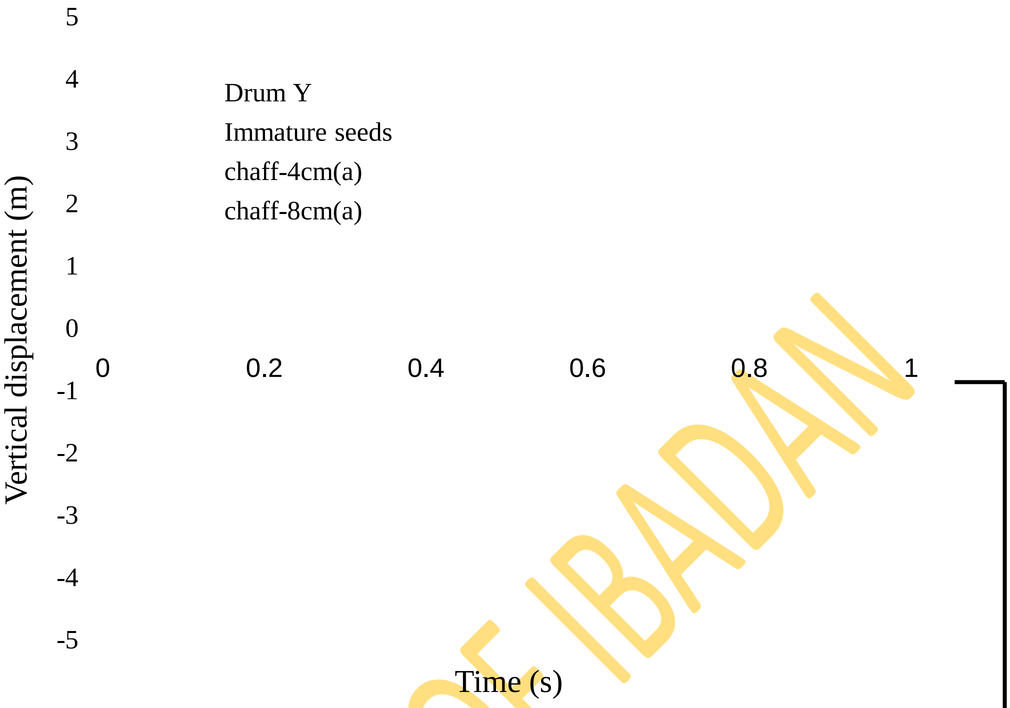

Figure A21. Drum-impurities mixture injected at 15^o. Injection vel. = 0.2m/s. Air vel. = 4m/s.

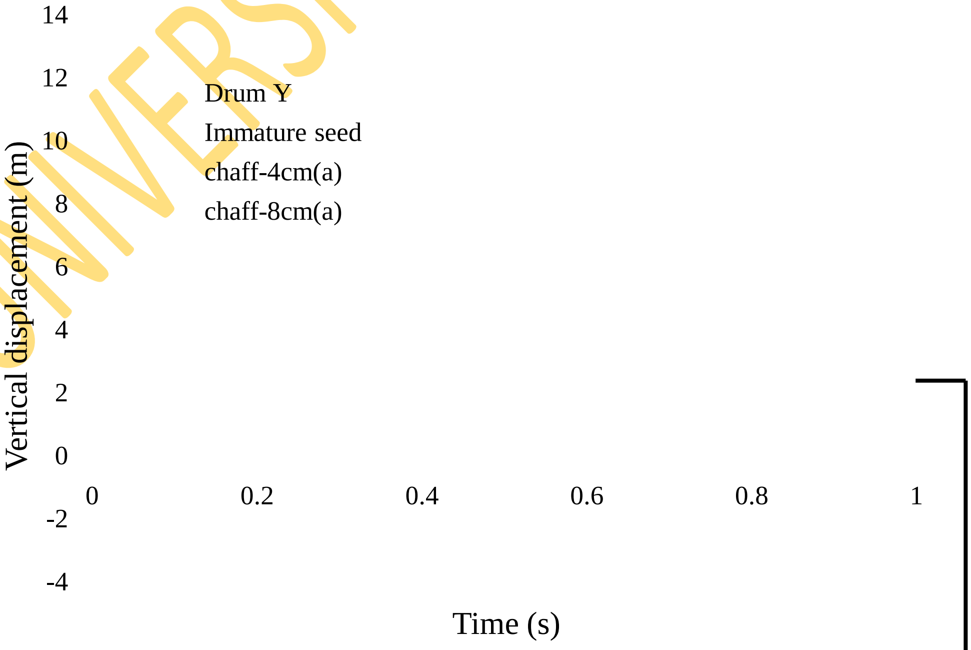

Figure A22. Drum impurities mixture injected at 30^o . Injection velocity = 0.2m/s. Air vel. = 4m/s.

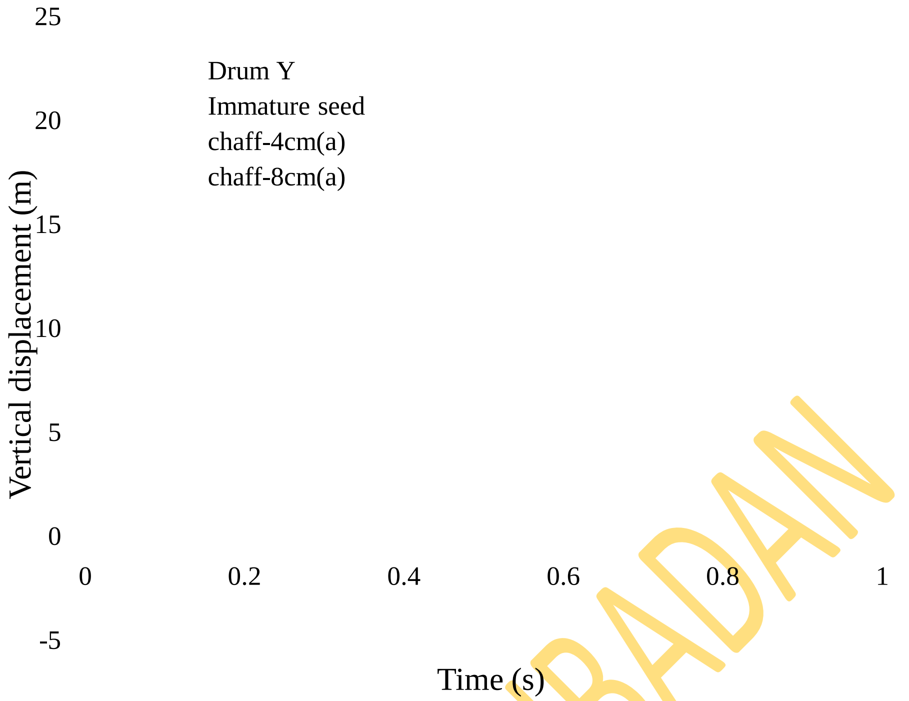

Fig.A23. Drum-impurities mixture injected at 45° . Injection vel.=0.2m/s. Air vel.=4m/s

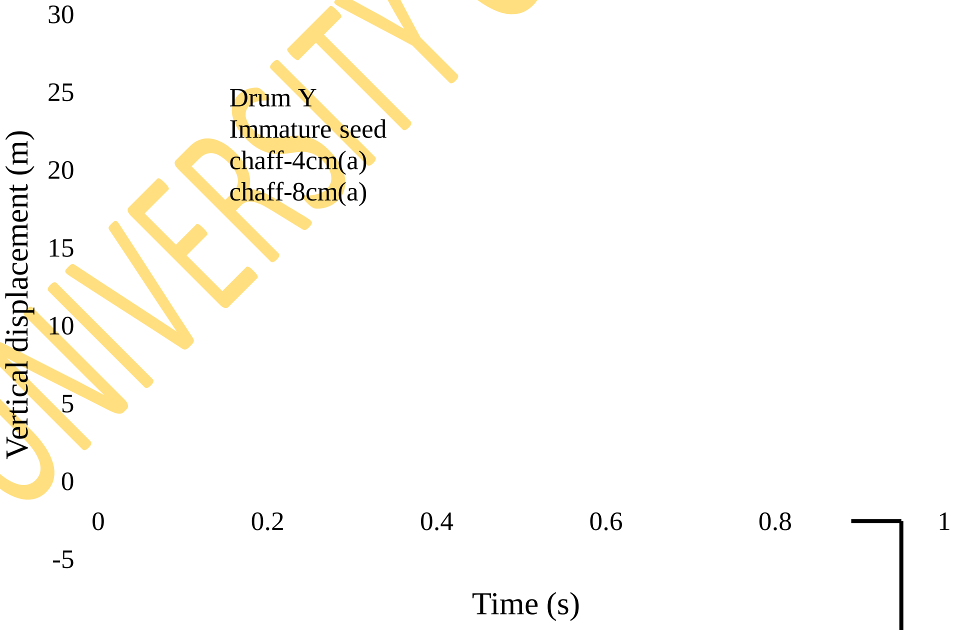

Figure A24. Drum-impurities mixture injected at 60° .Injecteion vel. = 0.2 m/s. Air vel. = 4m/s.

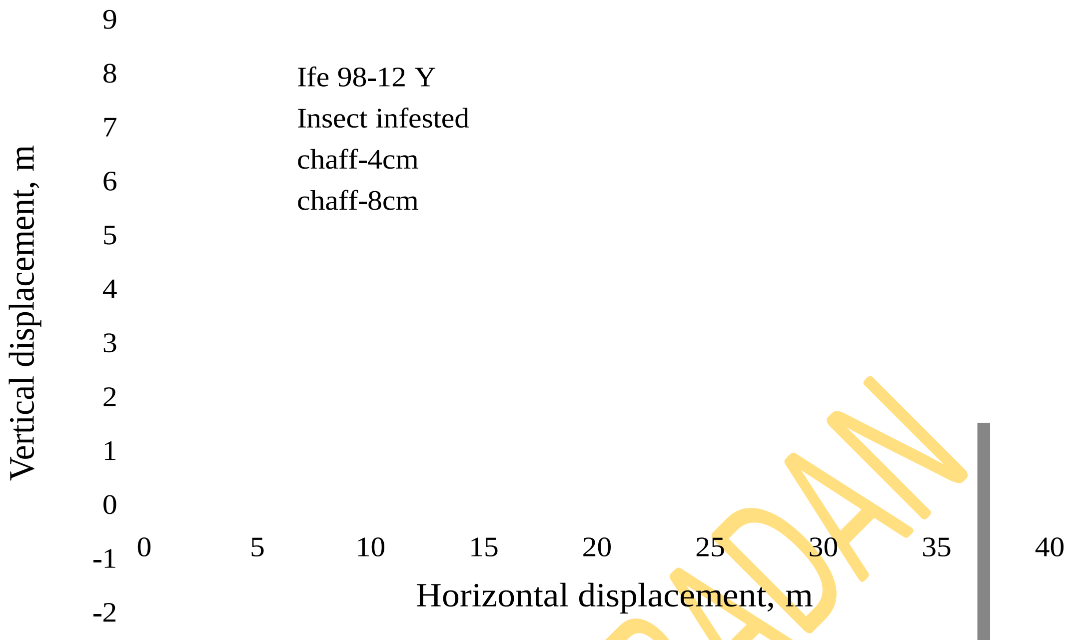

Figure A25. Ife 98-12-impurities mixture injected at 15°. Injection

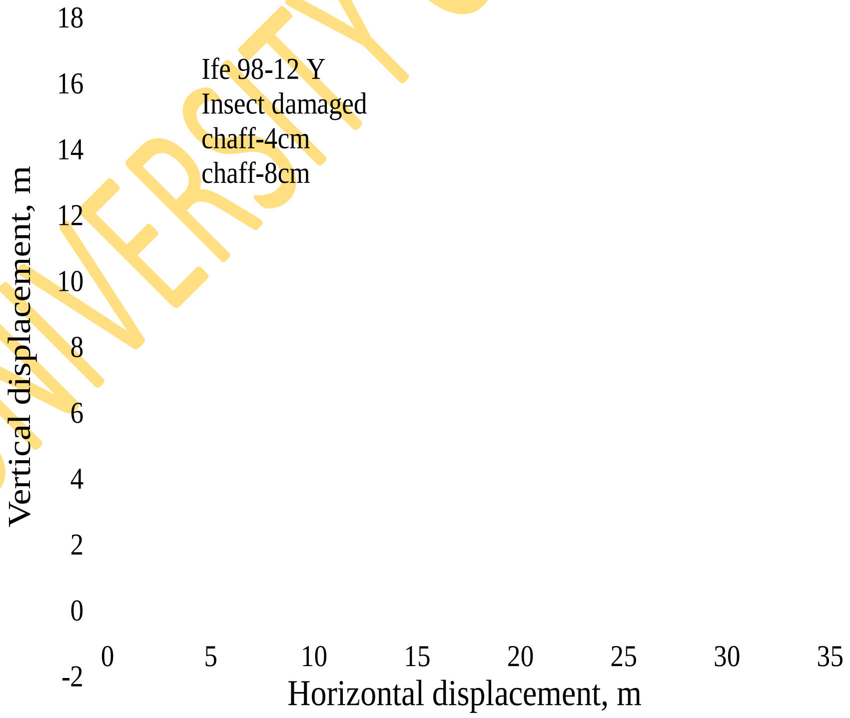

Figure A26. Ife 98-12-impurities mixture injected at 30°.
Injection vel. = 0.2m/s. Air velocity = 8m/s

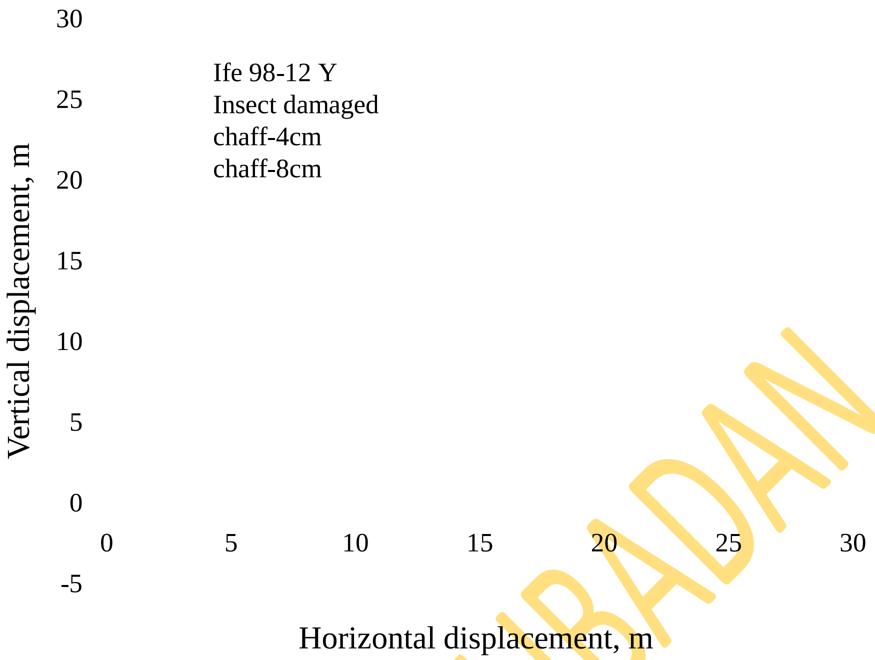

Figure A27. Ife 98-12-impurities mixture injected at 45°.
Injection vel. = 0.2m/s. Air vel. = 8m/s

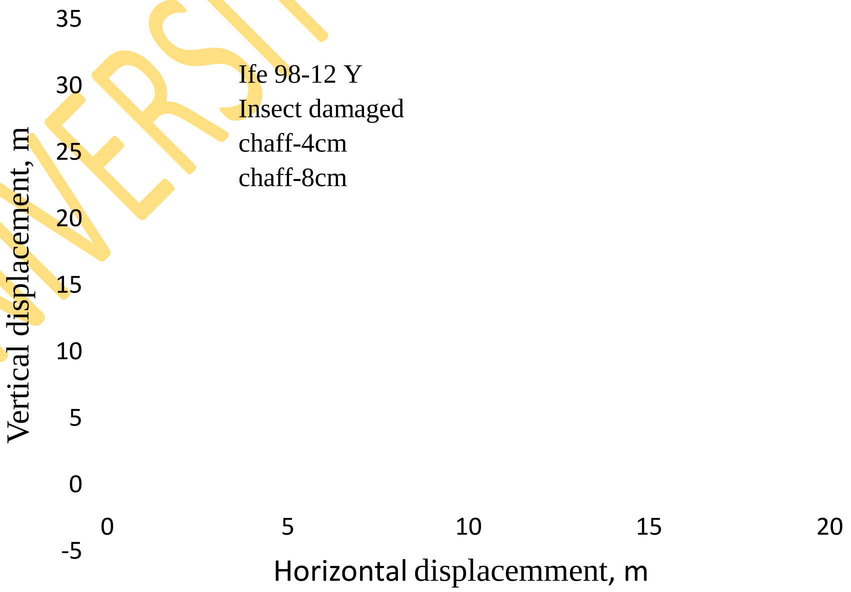

Figure A28. Ife 98-12-impurities mixture injected at 60°
.Injection vel. = 0.2m/s. Air vel. = 8m/s

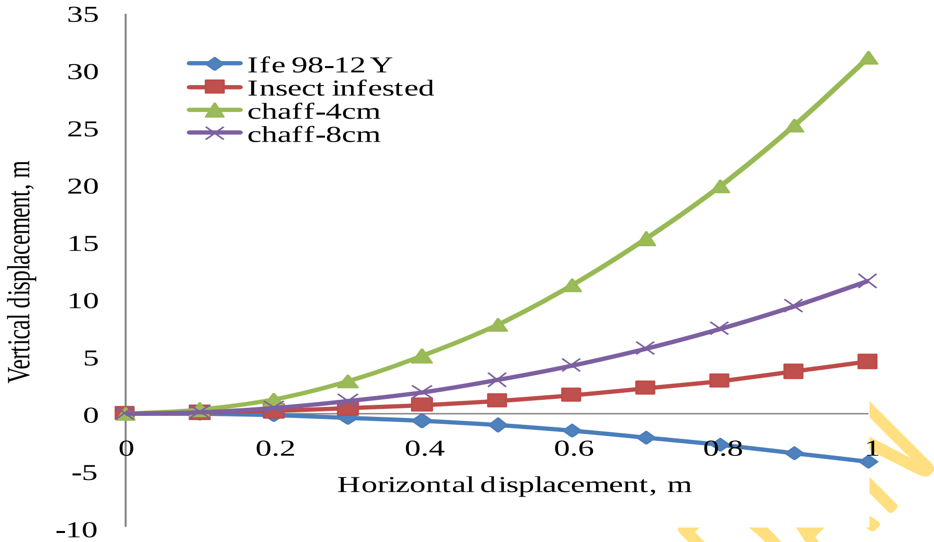

Figure A29. Ife 98-12-impurities mixture injected at 15°.
Injection vel. = 0.2m/s. Air vel. = 8m/s

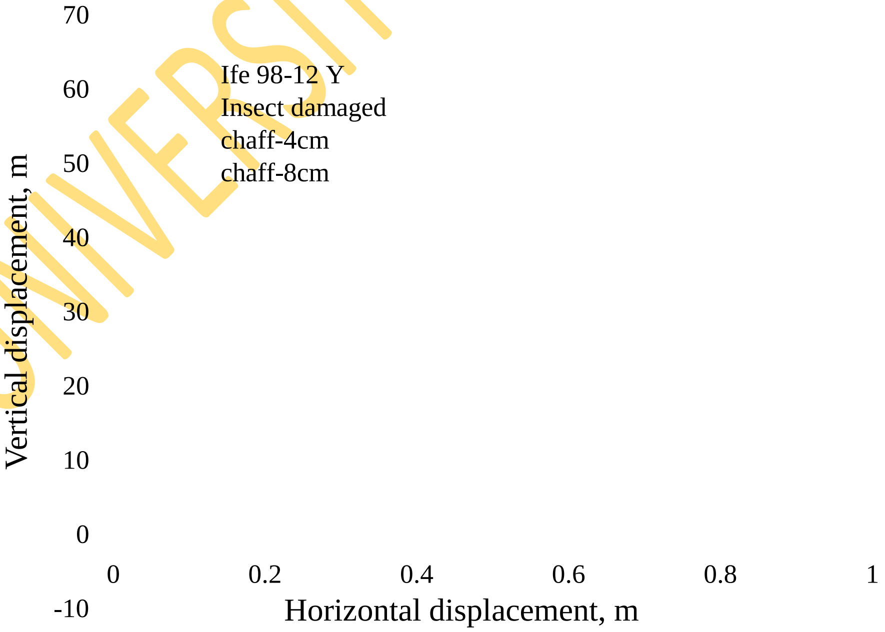

Figure A30. Ife 98-12-impurities mixture injected at 30°.
Injection vel. = 0.5 m/s. Air vel. = 8m/s

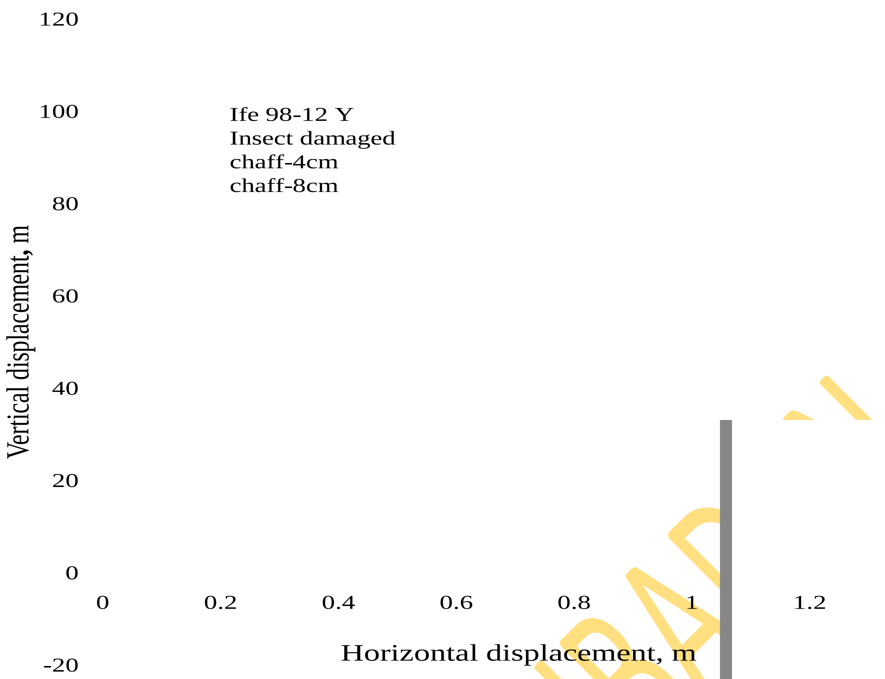

Figure A31. Ife 98-12-impurities mixture injected at 45°. Injection vel .= 0.2m/s. Air vel. = 8m/s

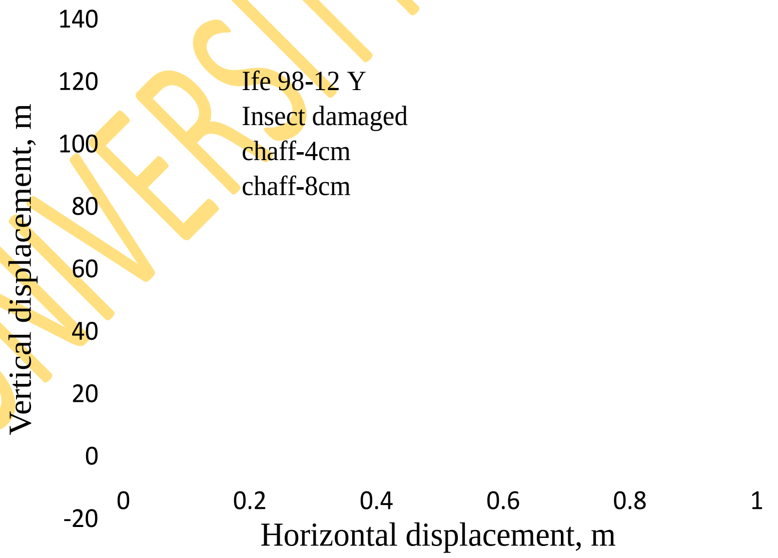

Figure A32. Ife 98-12-impurities mixture injected at 60°. Injection vel. = 0.2 m/s. Air vel. = 8m/s

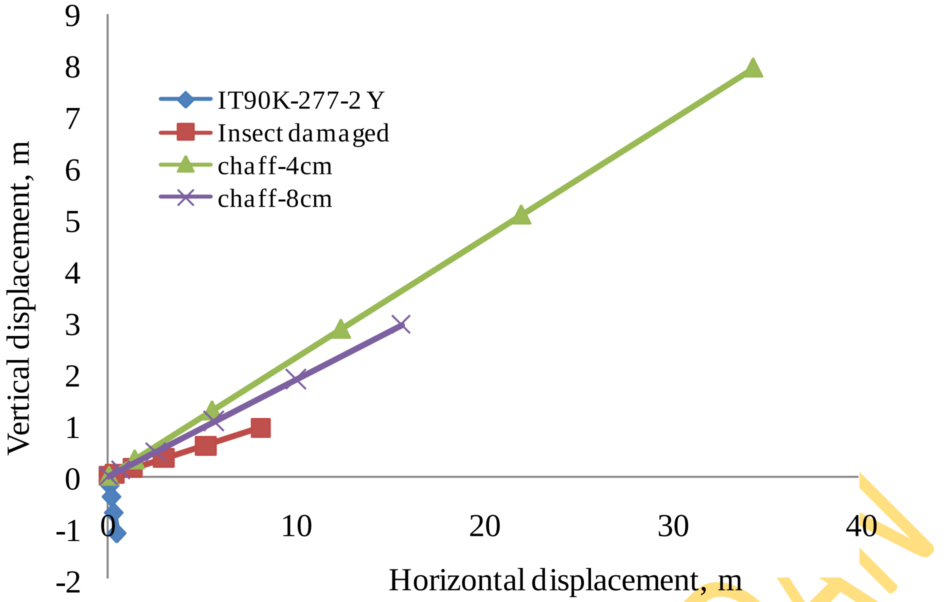

Figure A33. IT90K-277-2 -impurity mixture injected at 15° .
Injection Vel.= 0.5m/s. Air vel. = 8m/s

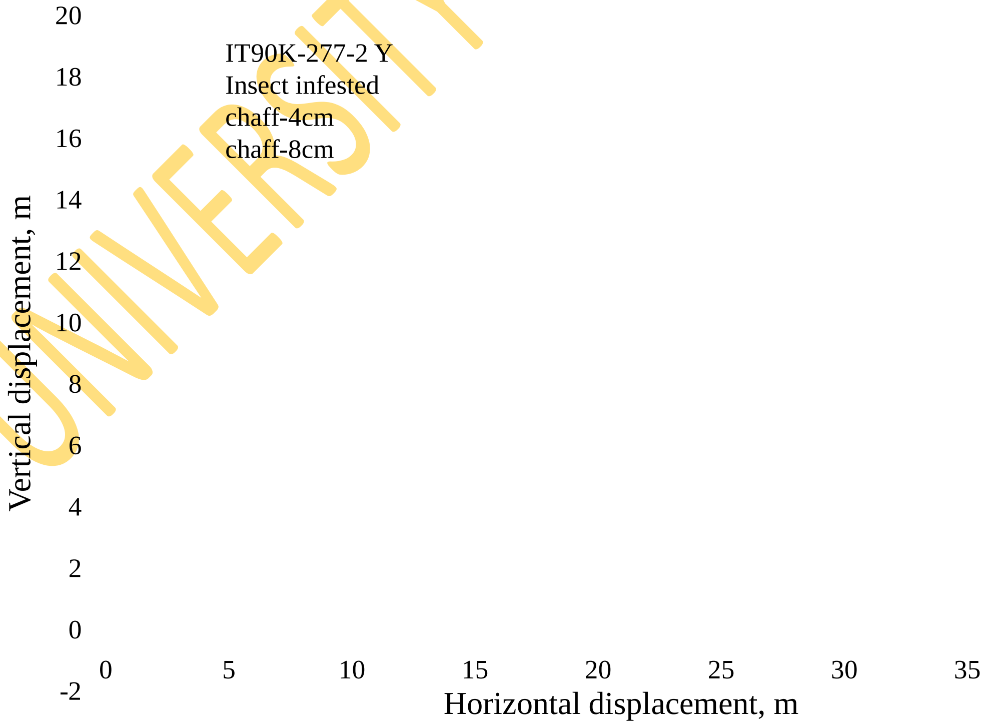

Figure A34. IT90K-277-2-impurities mixture injected at 30°.
Injection vel. = 0.5m/s. Air vel. = 8m/s.

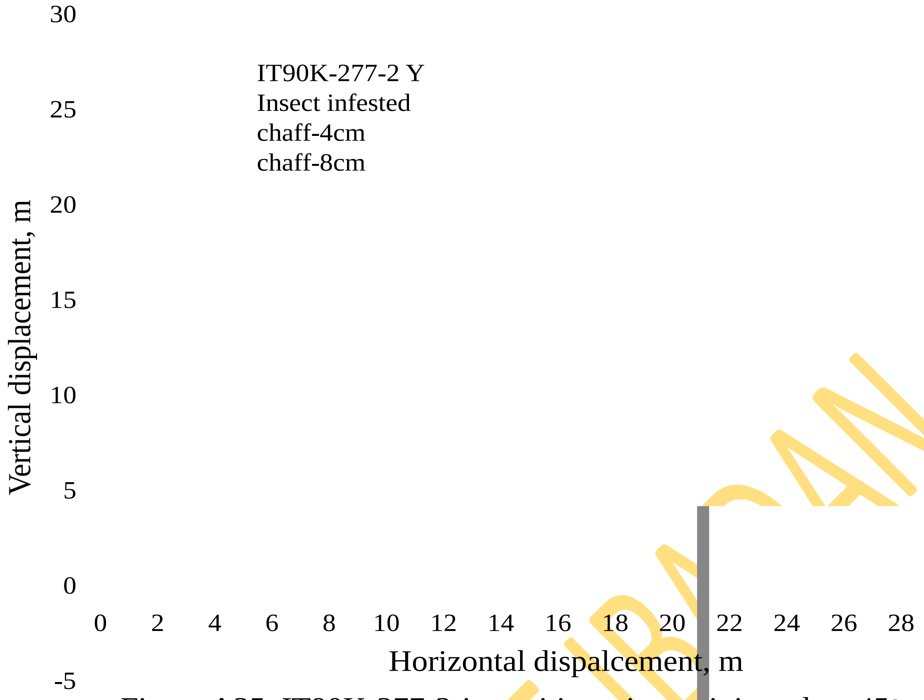

Figure A35. IT90K-277-2-impurities mixture injected at 45°.
Injection vel. = 0.5m/s. Air vel. = 8m/s

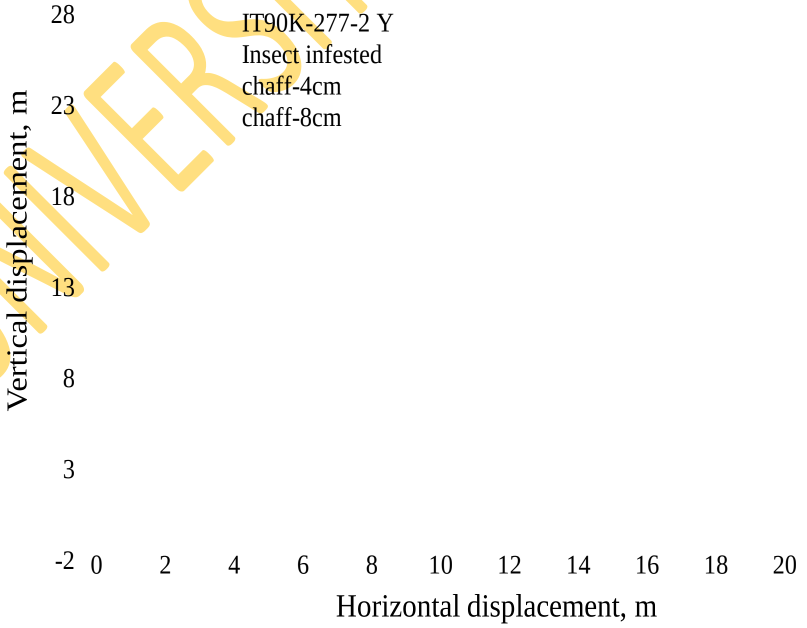

Figure A36. IT90K-277-2-impurities mixture injected at 60°.
Injection vel. = 0.5 m/s, Air vel.= 8m/s

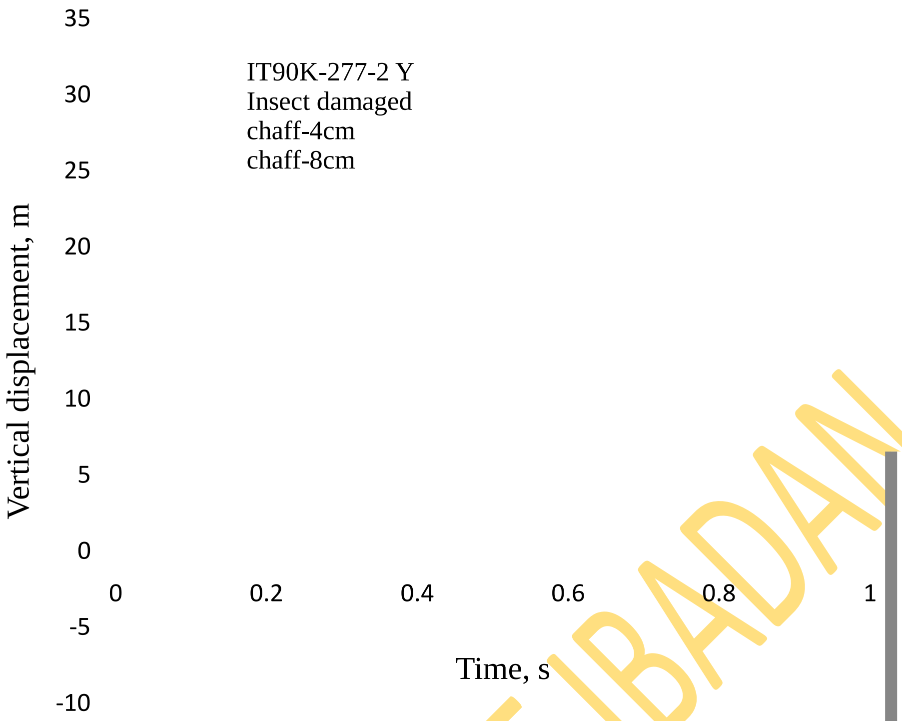

Figure A37.IT90K-277-2 -Impurities mixture injected at 15^o. Injection velocity = 0.5m/s. Air vel.= 8m/s

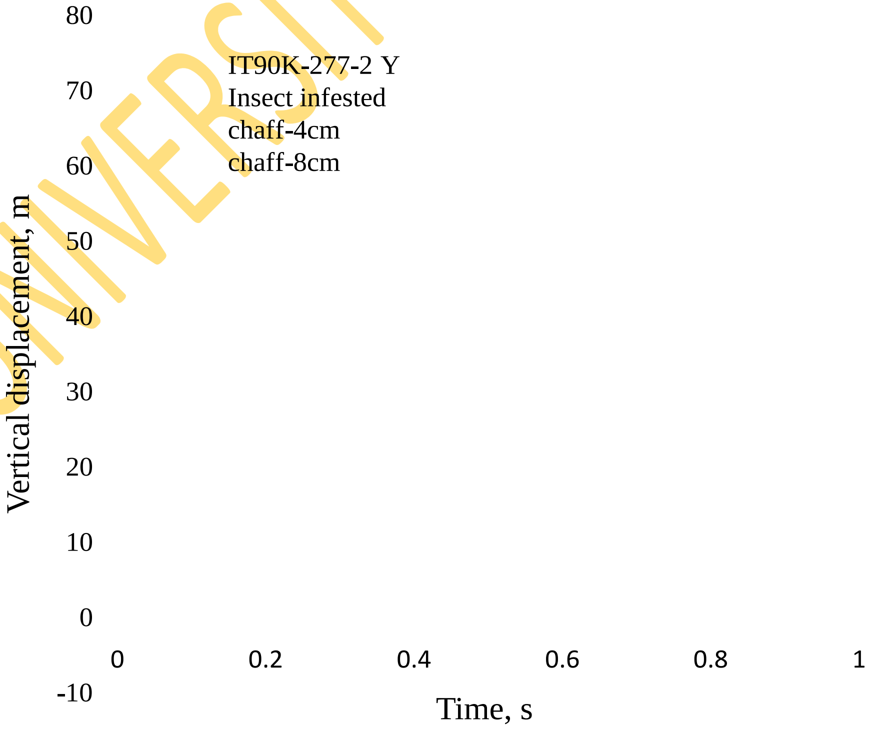

Figure A38. IT90K-277-2-impurity mixture injected at 30^o. Injection vel. = 0.5m/s. Air vel. = 8m/s.

Figure A39. IT90K-277-2-impurities mixture injected at 45°. Air velocity = 8m/s. Injection velocity = 0.5m/s

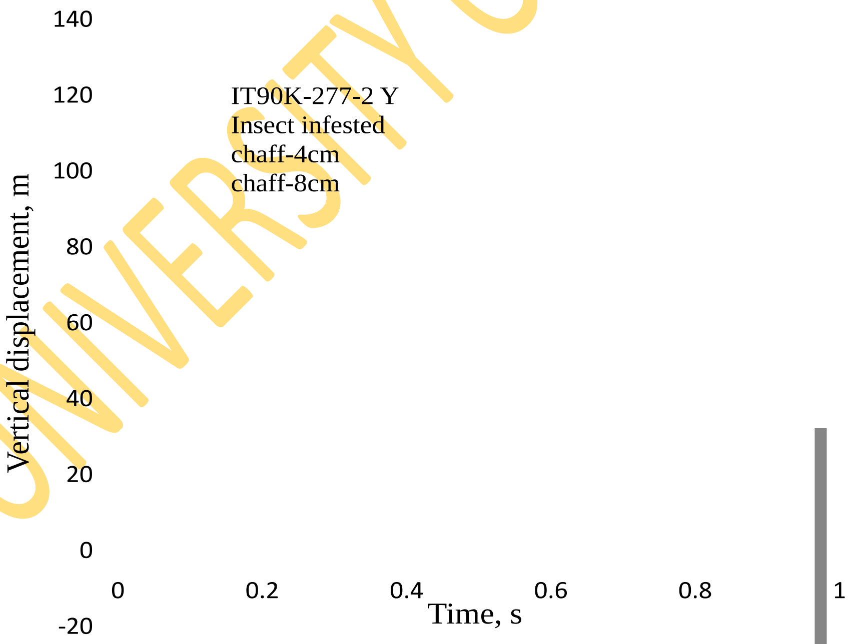

Figure A40. IT90K-277-2-impurities mixture injected at 60°. Injection vel.= 0.5m/s. Air vel. = 8m/s

CALCULATION OF C X A (Drag Coefficient x Area) FOR COWPEA PARTICLES

From equation (8) $$V_t = \sqrt{\frac{2mg}{C\rho_a A}}$$

$$CA = \frac{2mg}{\rho_a v_t^2}$$

Where $\rho_a = 1.1774$ kg/m^3 (At 300.15 K or 27^{0}C)

$g = 9.81$m/s

S/N	Particle	Mass, g	Terminal Velocity v_t,m/s	C.A, m^2
1.	Insect infested Ife 98-12	0.150	2.96	2.86 x 10^{-4}
2.	Insect infested IT90K-277-2	0.130	5.11	8.26 x 10^{-5}
3.	Insect infested Ife Brown	0.082	2.81	1.72 x 10^{-4}
4.	Immature grains	0.113	3.49	1.55 x 10^{-4}
5.	Chaff-4cm(a)	0.104	1.51	7.60 x 10^{-4}
6.	Chaf-6cm(a)	0.136	1.96	5.90 x 10^{-4}
7.	Chaff-8cm (a)	0.147	2.23	4.91 x 10^{-4}
8.	Chaff-4cm(b)	0.117	1.77	6.17 x 10^{-4}
9.	Chaff-6cm(b)	0.144	2.09	5.49 x 10^{-4}
10.	Chaff-8cm(b)	0.151	2.32	4.69 x 10^{-4}

Plate A1. A pneumatic cleaner at the department of Agricultural and Environmental Engineering, University of Ibadan

Plate A2. A pneumatic separator for cowpea at college of Agriculture I. A. R. &T, Ibadan

Source: Adegbulugbe (2004)

Plate A3. A vertical wind tunnel used for measuring the terminal velocity of particles of 7m/s and above

Plate A4. A vertical wind tunnel for measuring lower values of terminal velocities