

## DEVELOPMENT OF A TERMINAL VELOCITY MEASURING DEVICE FOR GRAINS

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### Abstract

*A terminal velocity measuring device was developed using locally available materials to assist indigenous designers in determining the terminal velocity of local grains. The device consists of a frame, electric motor, elbow, regulator/control switch, fan/impeller, anemometer and observation column. The device was evaluated using three varieties of grains of Paddy Rice, Sorghum and Beans. The result showed terminal velocity values of  $6.95 \pm 0.37$ ,  $4.71 \pm 0.24$  and  $10.98 \pm 0.27\text{ms}^{-1}$  for Paddy Rice, Sorghum and Beans respectively. Efficiency of the machine was found to be 70.06%. This terminal velocity device can be used efficiently by indigenous designers to determine the terminal velocity of grains for their design work.*

**Key Words:** Terminal Velocity, grains, designers, expensive, developed

### 1 INTRODUCTION

Over the years, there has been a spectacular increase in the world demand for food grains. Forecast on future production indicates that this trend will continue. The value of locally produced agricultural grains declines substantially due to their poor quality (presence of dirt, stones, chaff etc.). This poor quality can be attributed to the fact that, majority of grain producers in the country resort to crude and local means of processing. This is because most of the machineries and equipment used in food processing in Nigeria today are imported from foreign countries like China, Netherland, Germany etc. The cost of ownership and maintenance of the equipment are too exorbitant. This makes them unaffordable to majority of intending, young entrepreneurs and domestic users. Therefore, there is need for indigenous designers to rise up to the challenge by producing local alternatives that could be affordable and effective in meeting the demands of teaming farmers and entrepreneurs [1].

In Nigeria until of recent, the demand for locally produced grains especially rice is low due to their low quality. This has been attributed to poor harvesting and post-harvest handling method which encourages the presence of contaminants such as stones, stick, chaff and leave stalk due to low quality of the processed grains [2]. These Foreign materials gets into the product during harvesting, handling and transportation which must be significantly reduced or completely removed for good market value of grains and their products. But the traditional method of winnowing employed by the peasant farmers in most parts of the country cannot effectively handle the increased grain production of the country [2]. The increasing economic importance of food materials, together with the complexity of modern technology for their production, handling, storage, processing, preservation, quality evaluation and utilization demands comprehensive information on physical and aerodynamic

properties of these materials [3]. The characteristics of these materials can strongly influence their movements in agricultural machines as well as in air. Aerodynamic properties are the most important for the description of grain movement in air. The knowledge of the aerodynamic characteristics of grains (floating velocity, terminal velocity, aerodynamic resistance coefficient) is essential for agricultural machine designers and operators [4].

Undesirable materials such as light grains, weed seeds, chaff, plant leaves and stalks can be removed using air flow. Grains, fruits and vegetables can be mechanically harvested or processed with air stream. Air can also be used for conveying of agricultural materials [5 and 6]. Proper air speed to be used in handling agricultural materials can be determined from the study of aerodynamic properties of agricultural materials. These properties are terminal velocity and drag coefficient [7]. Terminal velocity is said to be the steady air velocity value at which an object or a material is suspended in vertical air stream. In other words, it is the maximum or terminal speed which is attained in free fall before air resistance will keep it from falling faster [8]. It can be determined by using different methods. These methods are free-fall, vertical air tunnel, applied vertical air column and elutriator method [9 and 10]. For mechanization of agriculture in Nigeria to succeed, it must be based on indigenous design, development and manufacture of most of the needed machinery and equipment to ensure their suitability to the crops as well as to the farmers technical and financial capabilities [11, 12 and 13].

## 2 MATERIALS AND METHODS

### 2.1 Design Consideration

In order to choose materials for the construction of the terminal velocity measuring device, the following were considered: availability of the materials, durability, strength, versatility, ease of operation, portability, ease of maintenance, efficiency, cost and techno-economic status of the end users were all considered.

### 2.2 Design of the machine components

#### *Design of the impeller*

The impeller is the most important part of the blower because of the fact that its performance inadvertently determines the blower's performance. For the impeller design, the following parameters were considered based on the recommendations of [14]. The linear speed at the inlet is obtained using equation 1.

$$U_1 = r_1 \times \omega = \frac{2\pi N r_1}{60} \quad (1)$$

where;  $r_1$  - Radius of impeller at inlet, m,  $\omega$  - Angular velocity of the impeller, rev/sec,  $N$  - Speed of the impeller, rpm.

While that of outlet is obtained using equation 2.

$$U_2 = r_2 \times \omega = \frac{2\pi N r_2}{60} \quad (2)$$

where;  $U_2$  - Vane velocity at outlet, m/s,  $\omega$  - Angular velocity of the impeller, rev/sec,  $N$  - Speed of the impeller, rpm,  $r_2$  - Radius of impeller at outlet, m.

The expected flow rate is obtained using equation 3.

$$Q = 2\pi r_1 b_1 v_1 \quad (3)$$

where;  $V_1$ - Absolute velocity of jet, m/s, which is given as  $V_1 = v_{f1} = U_1 \tan \theta$   $r_1$  - Radius of impeller at inlet, m,  $b_1$  - Vane width at inlet, m,  $v_1$  - Velocity of impeller, m/s.

### 2.3 Design of Impeller Fan Blade Profile

Blade Profile is made by tangent arc method as recommended by [15]. The blade profile was determined from the following relation:

$$R_b = \frac{r_2^2 - r_1^2}{2[r_1 \cos \beta_1 - r_2 \cos \beta_2]} \quad (4)$$

Where:  $R_b$  = Blade profile radius, mm,  $r_1$  and  $r_2$  = internal and outer radius, mm,  $\beta_1$  and  $\beta_2$  = blade angles, degree, From the relationship above,  $\beta_2 = 0$   $r_1 = 0.01063$  and  $r_2 = 0.055$ ,  $R_b = 0.0512\text{m} = 51.22\text{mm}$ .

### 2.4 Shaft Power Required to Run the Fan

According to [15], the ideal shaft power required to run the fan can be calculated using equation 5.

$$S_p = \frac{(\Delta p + dp_{suc} + dp_{imp} + dp_{vc}) + Q + Q_L}{\eta_{total}} + \text{power loss due to disk friction} \quad (5)$$

Where:  $S_p$  = Shaft Power, kw,  $\Delta p$  = Pressure Head, Pa,  $dp_{suc}$  = Pressure loss in suction, Pa,  $dp_{imp}$  = Pressure loss in impeller, Pa,  $dp_{vc}$  = Pressure loss in impeller housing, Pa,  $Q$  = Air flow discharge,  $\text{ms}^{-3}$ ,  $Q_L$  = Pressure loss in suction, Pa.

### 2.5 Description of the Machine

The orthographic, isometric and exploded views of the terminal velocity measuring device is shown in Figures 1, 2 and 3 respectively. The terminal velocity measuring device as shown in figure 2 consists of frame 5 made from 25mm by 25mm by 2mm thick mild steel angle iron which provides support to all other components of the machine, electric motor casing 9 constructed from 2 mm thickness mild steel sheet which houses the electric motor, elbow 4 constructed from 2mm thick mild steel sheet material is an L-shaped structure which connects the fan casing to the observation chamber, it transfers the air volumes from the fan 8 to the observation chamber 2, regulator/control switch 6 is used to control the speed of the fan, fan/impeller casing 10 constructed from 2mm thick mid steel sheet material houses the fan and the impeller, anemometer holder 1 constructed from 2.5 mm X 2.5 mm angle iron houses the impeller, anemometer not visible which is used to measure the speed of the air, impeller 8 which is housed by an impeller casing constructed from 1.5mm thickness mild steel sheet that is connected to a 1hp electric motor 7 having an angular speed of 1,200rpm which runs it, the impeller sucks in air and delivers it to the elbow, an observation column 2 constructed from 2mm thick clear transparent glass panes joined together in a rectangular prism form using adhesive materials, the observation chamber 2 is used to study the motion of the seeds in the stream of air coming in from the blower fan 8 and perforated wire mesh 3 which holds the seed grains at the base of the observation column, it prevent the seed grains from falling into the device.

### 2.6 Mode of Operation of the Terminal Velocity Device

The major aim of the laboratory grain terminal velocity device is to determine the terminal velocity of seed grains which is of utmost importance in the design and construction

of processing equipment's. The device uses an electric motor which rotates the fan attached to it in the impeller casing. With the movement of the impeller, air of unmeasured velocity is transferred through the elbow to the observation column. The rate of air flow from the blower is controlled by control switch connected to the blower and the movement of the air rushing into the observation column is guided with the use of a straightener. The seed whose terminal velocity is to be determined is placed in the observation section of the device. Air velocity is then increased gradually until the particle becomes suspended. At a point above the suspension point a digital anemometer is attach to measure the speed of the air. The anemometer measures to resolution of 0.1 m/s.

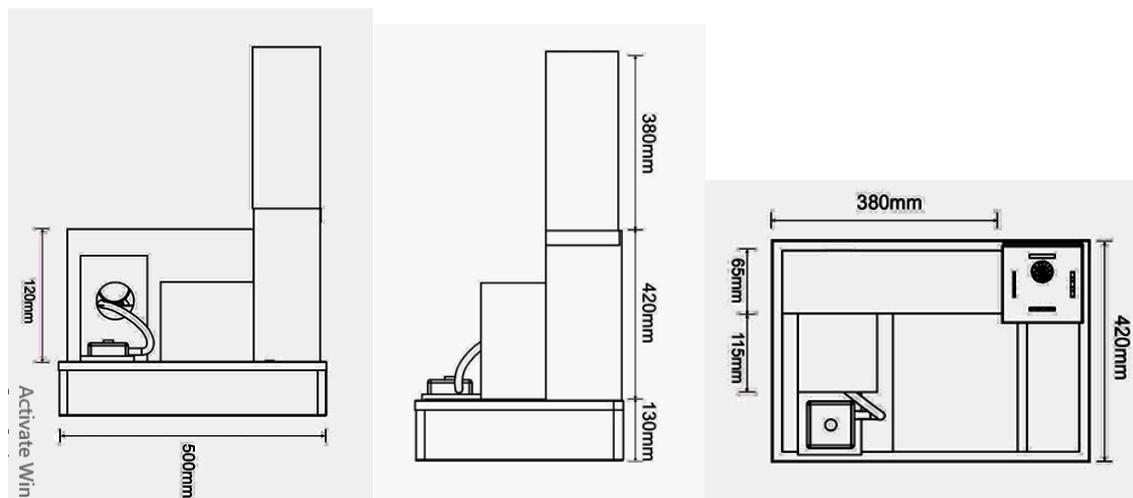


Figure 1. Orthographic view of the terminal velocity measuring device

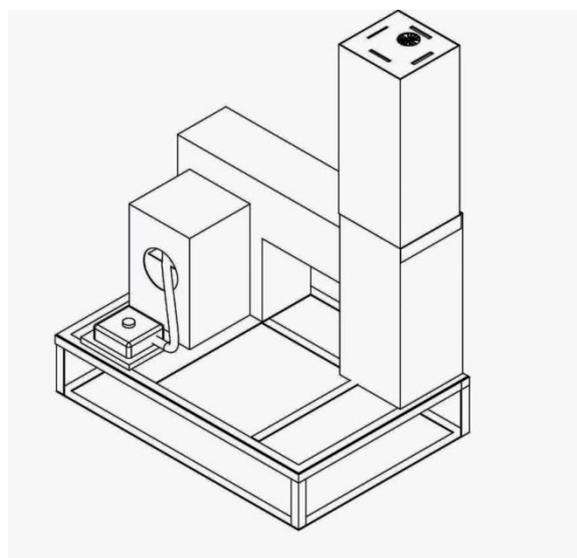


Figure 3.3 Isometric Projection of the Terminal Velocity Device

Figure 2. Isometric View of the terminal velocity measuring device

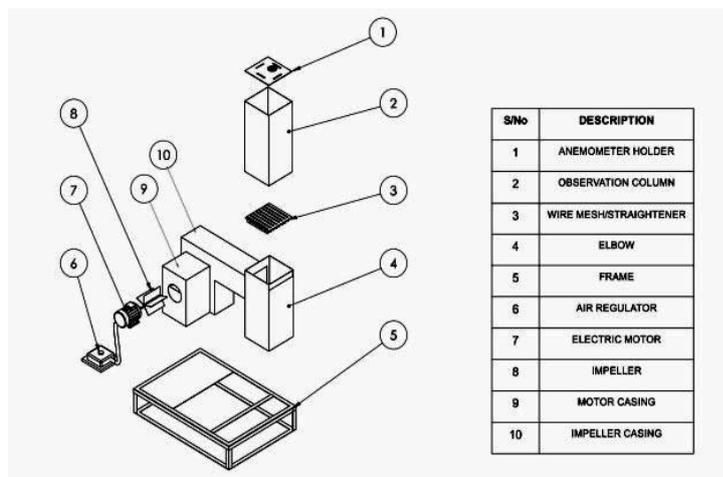


Figure 3. Exploded View of the terminal velocity measuring device

### 2.7 Performance Evaluation of the Terminal Velocity

The performance evaluation of the constructed laboratory terminal velocity device was carried out based on the recommendations of Vibhakar (2012) where the following equations 6, 7 and 8 were used to obtain the efficiency of a blower consisting of an electric motor and an impeller.

a) Hydraulic efficiency.

$$\eta_{hy} = \frac{\Delta p}{\Delta p + dp_{suc} + dp_{imp} + dp_{vc}} \tag{6}$$

Where:  $\eta_{hy}$  = hydraulic efficiency, %,  $\Delta p$  = Pressure Head, Pa,  $dp_{suc}$  = Pressure loss in suction, Pa,  $dp_{imp}$  = Pressure loss in impeller, Pa,  $dp_{vc}$  = Pressure loss in impeller housing, Pa.

b) Volumetric efficiency

$$\eta_{vol} = \frac{Q}{Q + Q_L} \tag{7}$$

Where:  $Q$  = Air flow discharge,  $ms^{-3}$ ,  $Q_L$  = Pressure loss in suction, Pa.

c) Total Efficiency

$$\eta_{total} = \eta_{hy} \times \eta_{vol} \tag{8}$$

Where:  $\eta_{hy}$  = hydraulic efficiency, %,  $\eta_{vol}$  = Volumetric efficiency, %,  $\eta_{total}$  = Total efficiency, %.

## 3 RESULTS AND DISCUSSION

The machine was used to determine the terminal velocity of Paddy Rice, Sorghum and Beans, the result is presented in Table 1. The terminal velocity for paddy rice ranged between 5.88 to 6.34  $ms^{-1}$  with the mean value as  $6.05 \pm 0.37$ . While that of sorghum and beans ranged between 4.30 to 5.02  $ms^{-1}$  and 10.58 to 11.31  $ms^{-1}$  with mean values of  $4.71 \pm 0.24$  and  $10.98 \pm 0.27$  respectively. In comparison to theoretical and previously reported terminal velocity values obtained through other methods, [16] reported to have obtained terminal velocity values of 11.4  $ms^{-1}$  and 11.80  $ms^{-1}$  for the two varieties of local Turkish beans he tested, [17] found the terminal velocity of paddy to be between 5.5 to 5.7  $ms^{-1}$  while [18] reported the terminal velocity of rice to be between 4.25 to 5.01  $ms^{-1}$ . [19] Also reported a terminal velocity of 4.5  $ms^{-1}$  for tender sorghum. The terminal velocity values

obtained in this work were slightly different to those reported by other researchers. The reason for this could be due to the difference in types, varieties or moisture content of the grains used.

Table 1. Result of terminal velocity values obtained using the constructed device.

Seed Type	Minimum Value of terminal velocity (ms <sup>-1</sup> )	Maximum Value of terminal Velocity (ms <sup>-1</sup> )	Mean Value of terminal velocity (ms <sup>-1</sup> )	Standard Deviation (ms <sup>-1</sup> )
Paddy Rice	5.88	6.34	6.05	0.37
Sorghum	4.30	5.02	4.71	0.24
Beans	10.58	11.31	10.98	0.27

The performance of the device was obtained using equations 6 through 8 and the results obtained are presented on Table 2. An efficiency of 70% was obtained for the device which is satisfactory

Table 2. Performance Evaluation Result of terminal velocity measuring device

Parameter	Symbol	Value (%)
Hydraulic efficiency	$\eta_{hy}$	78.65
Volumetric efficiency	$\eta_{vol}$	89.09
Total Efficiency	$\eta_{total} = \eta_{hy} \times \eta_{vol}$	70.06

#### 4 CONCLUSION

A terminal velocity measuring device was designed, constructed and tested. The device was used to determine the terminal velocities of Paddy Rice, Sorghum and Beans, whose average values were found to be  $6.95 \pm 0.37$ ,  $4.71 \pm 0.24$  and  $10.98 \pm 0.27$  respectively, these values are close to those obtained using other methods and devices. The total efficiency of the machine was 70.06%. It was however recommended that machine be redesign for other grains with higher physical dimension. It was observed during testing that this machine had difficulties in giving stable terminal velocity values for beans due to its high physical dimensional properties.

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