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# Aerodynamic properties of sesame (cv. N-8) as affected by moisture content of seed

M.N. MARATHE, R.V. JAYBHAYE AND P.G. MORE

The aerodynamic properties of crop grains influence the selection of the design and operational parameters of equipment. These properties are crop variety specific and moisture dependent. Measurement of terminal velocity is important to determine other aerodynamic properties. A terminal velocity measuring apparatus with vertical tapering rectangular air duct was developed which can measure velocity from 0 to 15 m/s. The sesame (*Sesamum indicum* Linn.) seeds of variety N-8 were dipped in water to obtain test samples of moisture contents 9.50, 13.46, 18.89, 24.17 and 28.99 per cent. The terminal velocity measured with the newly developed apparatus was found increased from 3.05 to 5.25 m/s with corresponding increase in moisture contents from 9.50 to 28.99 per cent (w.b.), respectively. In other aerodynamic properties, the values of drag co-efficient were found decreased from 2.9 to 0.6 and Reynolds number increased from 3939.9 to 11043.6 with corresponding increase in moisture contents from 9.50 to 28.99 per cent (w.b.), respectively. Simple linear regression equations were fitted to the obtained data to predict the aerodynamic properties of sesame seeds.

**Key Words :** Terminal velocity, Properties, Drag coefficient, Reynolds number

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## INTRODUCTION

The physical and aerodynamic properties of cereal and pulse grains and oilseeds can strongly influence their movements in agricultural machines as well as in air. Dimensions are important in the design of cleaning, sizing, grading, extracting machines. The frictional and aerodynamic properties of the seeds are important for handling equipment design, pneumatic separation and conveying (Yilmaz *et al.*, 2008), reduction of waste, etc. These properties are affected by numerous factors such as the species cultivar, size, form, superficial characteristics and moisture content of the grain (Sacilik *et al*., 2007).

Sesame seed (*Sesamum indicum* L.) are pear-shaped, ovate, small, slightly flattened and thinner at the helium. Sesame seed is a priced oilseed in the world because of the products that are derived from it. It is a rich source of oil protein, phosphorus and calcium (Anonymous, 2015). It is used as cooking oil and for medicinal purpose in Ayurveda. This unique characteristic makes it one of the major edible oils. The seed contains about 50 – 55 per cent oil; 20 – 25 per cent protein; 20 – 25 per cent carbohydrate; 5 – 6 per cent ash while the hull accounts for about 20 per cent of the seed (Akinso *et al*., 2006 and Sahay, 1998).

Harvested and threshed sesame seeds contain broken grain particles, trash material, leave particles and chaff which affect the quality and market value of the

MEMBERS OF RESEARCH FORUM
**Author for correspondence :**
**R.V. JAYBHAYE,** Department of Agricultural Engineering, College of Agriculture, LATUR (M.S.) INDIA
Email : rvjay003@gmail.com

Associate Authors' :
**M.N. MARATHE AND P.G. MORE,** Department of Process and Food Engineering, College of Agricultural Engineering and Technology, Vasantrao Naik Marathwada Krishi Vidyapeeth, PARBHANI (M.S.) INDIA
Email : marathemanohar93@gmail.com; pramodonimore@gmail.com

end product. These impurities need to be removed before selling or oil extraction. At present there is no specific machine to clean sesame seeds from threshed trash material and chaffs. Scalper screen cleaned sesame seeds can be easily cleaned by pneumatic separator. For this purpose there must be a clear difference between the compounds of the mixture at the characters on which the separation is based. The pneumatic separation of light foreign material from sesame seeds requires information on aerodynamic properties. The determination of aerodynamic properties needs measurement of terminal velocity as a function of moisture content.

Akinso *et al.* (2008) determined aerodynamic properties of two varieties of sesame seeds (Yandev 55 and E8). Authors observed the terminal velocities of Yandev-55 as 2.9, 3.6, 4.7 and 5.4 m/s while the terminal velocities of E8 as 3.4, 4.12, 5.1 and 6.3 m/s at a moisture content level of 8.0, 10.3, 15.9 and 21.2 % (w.b.), respectively. Fawal *et al.* (2009) designed an apparatus in Egypt consisted a transparent tapered tube used as a cyclone which was fixed at the outlet side of the blower for measurement of terminal velocity.

In the present study with the objective of designing pneumatic separator for removing light material from sesame, an apparatus was developed in 2016 for measurement of terminal velocity of sesame seed of variety N-8 and other aerodynamic properties were determined.

## METHODOLOGY

### Theoretical consideration :

Air was supplied by a centrifugal, straight blade blower with a duct. Air duct was fitted to the outlet of blower and front end was tangentially connected to the wind tunnel. The capacity of the blower for maintaining the required air flow rate was determined based on the total pressure drop in the system and the maximum air flow rate required.

### Design of impeller (impeller eye and inlet duct size):

Assuming duct velocity at suction $V_{duct}$ = 16 m/s (Roy, 1996), the diameter of suction duct was designed by considering Q = Outlet factor as:

$$\mathbf{D_{duct}} = \sqrt{\frac{\mathbf{4Q}}{\Pi \mathbf{V_{duct}}}} = \sqrt{\frac{\mathbf{4 \times 0.5}}{\Pi \times \mathbf{16}}} = \mathbf{0.199\,m} \qquad (1)$$

The standard suction flange sizes are – 1, 1.25, 1.5, 2, 2.5, 3, 4, 5, 6, 8, 10, 12, 14, 16,18 inch, Hence, diameter of suction flange before duct $D_{suction}$ = 8 inch = 203 mm was selected.

Taking impeller eye velocity $V_{eye}$ slightly higher than suction velocity = 18 m/s.

Suction velocity head at impeller inlet eye,

$$\mathbf{H} = \frac{\mathbf{V_{eye}^2}}{\mathbf{2g}} = \frac{\mathbf{18^2}}{\mathbf{2 \times 9.81}} = \mathbf{16.51\,m^2} \qquad (2)$$

Impeller inlet area,

$$\mathbf{A_1} = \frac{\mathbf{1.03 \times Q}}{\mathbf{V_1}} = \frac{\mathbf{1.03 \times 0.5009}}{\mathbf{18.99}} = \mathbf{0.0272\,m^2} \qquad (3)$$

### Blower horse power:

HP = 0.00436 x Pressure differential x cfr x rpm (excluding frictional hp) (4)

= 0.00436 × 3.5 × 0.004 × 16000 = 0.97664 ≈ 1 hp

### Airflow straighter tubes:

The air flow direction required in fluidization chamber or tunnel is vertical. Therefore, an arrangement was necessary in between wind tunnel and air blower to convert the turbulent flow of air into vertical flow. In order to kill turbulence of air, airflow straightner tubes of 1.2 cm diameter 5 cm length were fitted at the end of vertical air flow pipes. The dimensions of the inlet section and air flow straighter tubes were selected on trial and error basis such that there would be minimum pressure drop and can eliminate swirl motion of air (Jayebhaye, 2012).

### Design of wind tunnel:

The wind tunnel was selected as downward tapering section; this section was selected because diffusiveness of turbulence far exceeds molecular diffusion and has a more intimate connection with the mean flow (Lin, 1959 and Turns, 2000). The rectangular air chamber was made from MS angle at sides and acrylic material on four sides (Gamal, 2013) so that the fluidization chamber of grains can be observed (Fawal *et al.*, 2009).

The instrument was designed and used to measure the terminal velocity for suspension (Ozdemir and Akinci, 2004) of sesame seeds at different moisture content levels. The seed samples were placed on bottom screen in vertical tapering rectangular air column and air was passed from blower till the grains remain suspended. The terminal velocity was measured using digital anemometer Model No. Divine Xt GM 8908 version A 0 Envid Corporation, Surat (India). When a seed is suspended into air stream, equilibrium is achieved between its weight and drag force as follows (Mohsenin, 1986):

$$Cd = \frac{2\,Mg}{A\rho_a V_t^2} \quad (5)$$

Also Reynolds number was calculated according to eq. 6 (Hexing, 1989) as:

$$N_{Re} = \frac{\rho_a V_t \sqrt{A}}{\mu} \quad (6)$$

where, M = Mass of seeds, g; g = Acceleration due to gravity (9.8 m/s$^2$); A = Projection area, mm$^2$; $\rho_a$=Density of air (1.28 kg/m$^3$); $V_t$ = Terminal velocity, m/s; $\mu$ = Dynamic viscosity of the air ($1.8\times10^{-6}$).

**Preparation of test seed samples :**

In order to determine terminal velocity and different aerodynamic properties the samples of Sesame seeds (cv. N-8) collected from Sesame Research Center, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani. The seeds manually cleaned to get rid of foreign matters, broken and immature seeds. The initial moisture content of the seeds was determined and the different moisture content levels were obtained by adding water in the bulk of seeds and measuring the moisture contents after every hour. From these samples, five test seed samples of desired moisture content levels were selected for further replications (Nalbandi *et al.*, 2010). All the aerodynamic properties of seeds were obtained for five moisture contents in the range of 9.50 – 28.99 per cent (w.b.) which is usual range during harvesting, storage and processing operations of sesame seed. The tests were carried out with three replications for each moisture content level.

**Hot air oven :**

The moisture content of seed samples was determined by standard oven drying method (AOAC, 2005) using electrical hot air oven (Electronics and Electrical Engg. Co., Kolkata). Weighed test samples (5 g) were kept in electric hot air oven at a temperature of 100±2 °C for 18 hours and the change in weight was noted.

**Statistical analysis:**

Statistical analysis was done with Microsoft Excel-2007. Mean, standard deviations and co-efficients of determination ($R^2$) were calculated for each parameter. Regression models were developed to fit to the experimental data for establishing the relationship between each parameter and moisture content (SAS, 2001). F test analysis of variance was used for significance testing (Montgomery, 2004). Validation of the developed models was done by measuring the aerodynamic properties (5 replications) at seed moisture content of 12.5 per cent (w.b.) to compare the experimental and predicted values of aerodynamic properties at selected moisture content.

## OBSERVATIONS AND ASSESSMENT

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads :

**Terminal velocity measuring apparatus :**

The apparatus shown in Fig. 1 was used to measure the terminal velocity for suspension of safflower seeds at different moisture content levels. The apparatus sketched in Fig. 1 and 2 was designed and fabricated in the National Fabricators Workshop, Parbhani (India). The airflow was produced by an electric centrifugal blower of 1 hp and 16000 rpm model ID-GBL1200 of make Ideal India Ltd., Mumbai (India), fixed on the frame, which discharge air blast into a transparent tapering wind tunnel of height 70 cm. The tapering air column of tunnel has 8×7 cm square cross section at bottom and 20×15 cm square cross section at top. A mesh screen of small

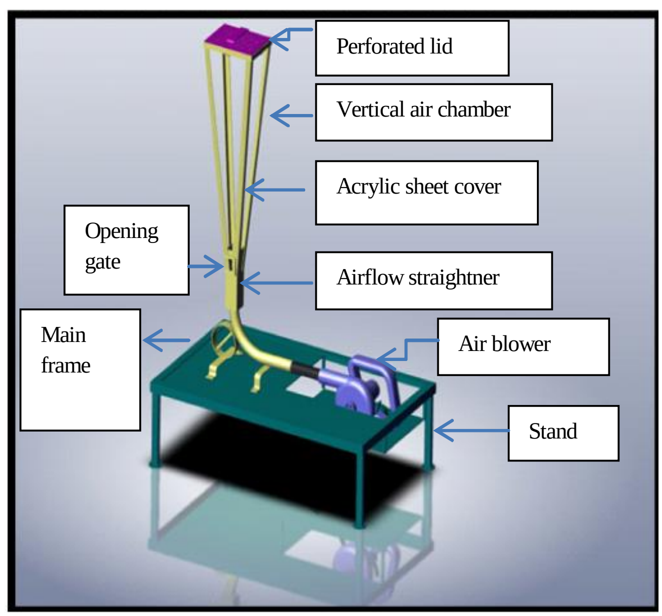


**Fig. 1 : Terminal velocity measuring instrument**

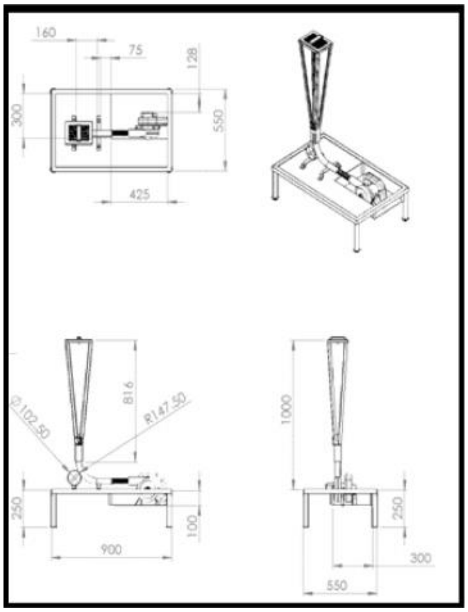


**Fig. 2 : Design dimensions of instrument (dimensions in mm)**

opening was fitted at the bottom of the transparent air column for holding the grain samples (about 25 g) and another detachable screen was fitted at the top for retaining light seeds during experiments. For regulating the air flow rate a control knob was provided on the blower.

The test trials did show that a maximum air velocity upto 15 m/s could be achieved for soybean samples.

## Aerodynamic properties of sesame :

*Terminal velocity:*

Experimental values obtained for terminal velocity of sesame varied between 3.05 and 5.25 m/s (Table 1). It was observed that terminal velocity increased linearly with the increase in moisture contents.

The experimental values are given as: mean values ± SD

The increase in terminal velocity with particle size may be attributed to the increase in mass of an individual seed per unit frontal area presented to the air stream. It follows that larger particles of similar shape need higher terminal velocities than smaller ones. The variations observed in terminal velocity of sesame with increase in the moisture content are shown in Fig. 3.

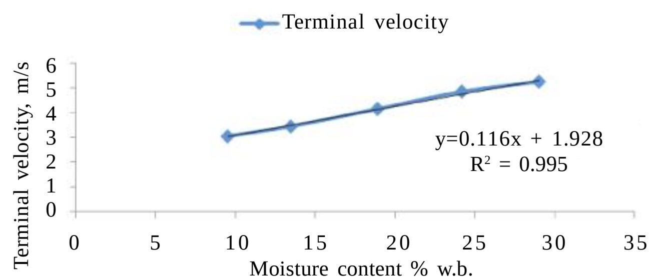


**Fig. 3 : Effect of moisture content on terminal velocity of sesame**

Similar results were obtained by Akinso *et al.* (2006) on sesame, Gowda *et al.* (1990) on linseed, Ozarslan (2002) on cotton seed, Joshi *et al.* (1993) for pumpkin seeds and Carman (1996) for lentil seeds. The increase in terminal velocity was found to increase with increasing moisture contents, inferring that low moisture content is appropriate for designing pneumatic equipment to reduce energy input (Baryeh, 2002). The functional relationship between terminal velocity and moisture contents of the sesame seeds could be represented by the eq. 7.

$$V_t = 0.1169M + 1.9382 \; (R^2 = 0.99) \qquad (7)$$

The statistical analysis showed that the moisture content had significant effect on the terminal velocity of sesame seeds (Table 2).

## Drag co-efficient:

Experimental values obtained for drag co-efficient of sesame are given in Table 1. It was observed that terminal velocity decreased linearly with the increase in moisture contents.

The values of drag co-efficient of N-8 were found decreased from 2.9 to 0.6 with corresponding increase in moisture content from 9.50 to 28.99 % (w.b.),

**Table 1 : Effect of moisture content on aerodynamic properties of sesame (cv. N-8)**

| Moisture content, % (w.b.) | Terminal velocity, $V_t$, m/s | Drag co-efficient, $D_g$ | Reynolds number, $N_{Re}$ |
|---|---|---|---|
| 9.50 | 3.05±0.01 | 2.9±0.01 | 3939.9±4.90 |
| 13.46 | 3.45±0.21 | 2.4±0.09 | 4979.1±2.78 |
| 18.89 | 4.15±0.19 | 1.8±0.06 | 7417.6±3.98 |
| 24.17 | 4.85±0.17 | 1.1±0.08 | 9795.0±3.86 |
| 28.99 | 5.25±0.18 | 0.6±0.03 | 11043±4.21 |

respectively. The terminal velocity increased with increase in moisture contents of the sesame seeds. The same apply to Reynolds number. But reverse was the case for the drag co-efficient as increase in moisture content lead to decrease in drag co-efficient (Akinso *et al.*, 2008). The variations observed in drag co-efficient of sesame with increase in the moisture content are shown in Fig. 4.

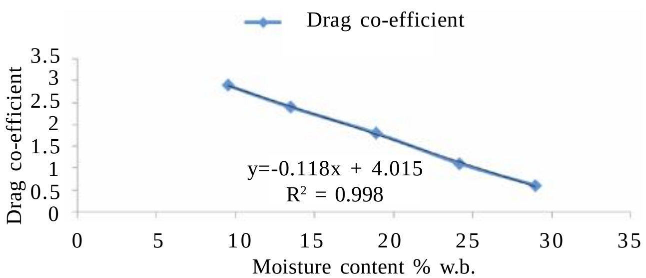


**Fig. 4 : Effect of moisture content on drag co-efficient of sesame**

These results were similar to those of sesame (Akinso *et al*., 2008), cotton seeds (Ozarslan, 2002), sesame (Yilmaz *et al.*, 2008) and faba bean (Dilmac *et al.*, 2016). The correlation between drag co-efficient and moisture contents of the sesame seeds could be represented by the eq. 8. There was significant effect of moisture content on the drag co-efficient and it was reducing effect (Table 2).

$$Dg = -0.1187\ M + 4.0158\ (R^2 = 0.99) \qquad (8)$$

## Reynolds number:

Experimental values obtained for Reynolds number of sesame are given in Table 1. It was observed that Reynolds number increased linearly with the increase in moisture contents.

The values of Reynolds number of N-8 were found increased from 3939.9 to 11043.6 with corresponding increase in moisture content from 9.50 to 28.99 % (w.b.), respectively. Addition of moisture to the investigated seed increased its weight, thus more force required to lift the material. This could necessitate the observed increase in terminal velocity with increase in moisture content. Thus, Reynolds number is directly proportional to terminal velocity and size while these parameters are inversely proportional to drag co-efficient. As is shown, both terminal velocity and size of sesame seed increase with increase in moisture contents. Therefore, behaviour of Reynolds number of studied variety of sesame to treatments is rational. The graphical relationship is shown in Fig. 5.

Similar trends were reported for sesame seed (Akinso *et al.*, 2006), lentil seeds (Carman, 1996). The linear regression obtained Reynolds number of sesame and experimental moisture contents are shown in eq. 9

$$N_{Re} = 384.09\ M + 136.4\ (R^2 = 0.9912) \qquad (9)$$

The Reynolds number varied significantly with changes in moisture content of seeds and it also significantly varied amongst replications (Table 2).

## Validation of regression models :

In order to verify and determine the predictability of the developed regression models, experiments were conducted at selected moisture content of 12.5% (w.b.). The observed experimental values (mean of 5 replications) of aerodynamic properties and values predicted by the model are presented in Table 3. The experimental values

**Table 2 : Analysis of variance for aerodynamic properties of sesame seeds**

| Property | Source of variation | Count | df | Sum of square | Mean sum of square | F-cal | F-tab (at 4x2 df) | Significance |
|---|---|---|---|---|---|---|---|---|
| Terminal | Repl | 3 | 2 | 0.00012 | 0.00006 | 0.00158 | 19.2 | NS |
| velocity, $V_t$ | $V_t$ | 5 | 4 | 10.25810 | 2.56452 | 67.75201 | 19.2 | Significant |
| | Error | - | 8 | 0.30281 | 0.03785 | | | |
| | Total | 15 | 14 | 10.56104 | | | | |
| Drag coeff., $C_d$ | Repl | 3 | 2 | 0.03157333 | 0.01578667 | 12.26943 | 19.2 | NS |
| | $C_d$ | 5 | 4 | 10.45170 | 2.61292 | 2030.772 | 19.2 | Significant |
| | Error | - | 8 | 0.010293 | 0.00128 | | | |
| | Total | 15 | 14 | 10.49357 | | | | |
| Reynolds | Repl | 3 | 2 | 153.45737 | 76.72868 | 86.94764 | 19.2 | Significant |
| Number, | $N_{Re}$ | 5 | 4 | 110515698 | 27628924.4 | 31308626 | 19.2 | Significant |
| $N_{Re}$ | Error | - | 8 | 7.05976 | 0.88247 | | | |
| | Total | 15 | 14 | 110515858 | | | | |

NS=Non-significant

**Table 3 : Comparison of experimental and predicted values of aerodynamic properties**

| Response | Predicted value | Experimental value (mean±SD) | Mean difference | Variation (%) | CV (%) |
|---|---|---|---|---|---|
| Terminal velocity | 3.389 | 3.408±0.075 | -0.018 | 0.04 | 2.22 |
| Drag co-efficient | 2.532 | 2.474±0.036 | 0.058 | -2.34 | 1.47 |
| Reynolds number | 4937.525 | 4901.5±7.629 | 35.785 | -0.73 | 0.16 |

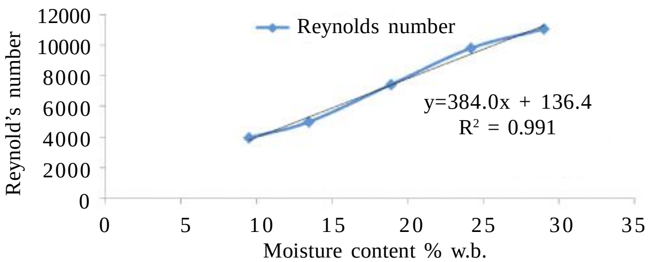


**Fig. 5 : Effect of moisture content on Reynolds number of sesame**

were compared with the predicted values by sample T-test. The Null hypothesis was tested and there was no significant difference between the actual and predicted values of properties as indicated by lower values (below 10 %) of co-efficient of variation (CV) which measures the unexplained or residual variability in the data as percentage of the mean of the response variable. This indicated the suitability of the corresponding models to predict the values of aerodynamic properties at given seed moisture content.

## Conclusion :

The designed apparatus for measurement of the terminal velocity was suitable for measuring terminal velocity of grains upto 15 m/s. The terminal velocity and Reynolds number increased with increase in moisture content but drag co-efficient was inversely proportional to the moisture content and terminal velocity. A pneumatic separator can be designed with provision for effective separation of undesired light material with average terminal velocity below 4 m/s from sesame seed after pre-cleaning.

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