Effect of Airflow Rate, Moisture Content and Pressure Drop on the Airflow Resistance of Locust Bean Seed

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ABSTRACT

Resistance of a material to airflow is an important factor to consider in the design of a dryer or an aeration system. Resistance to airflow of locust bean seeds was determined in the airflow range of 0.201 to 0.275 $m^3 s^{-1} m^{-2}$ by measuring pressure drops across bed depths of 76.5 to 382.5 mm. The crop moisture content ranged between 9.50 and 37.65% (wet basis). Four bulk densities of the beans were selected at different tappings of the test column. The resistance to airflow decreased with decreasing airflow rate and bed depth, and with increasing grain moisture content.

Keywords: Airflow rate, bed depth, bulk density, locust bean seed, moisture content, pressure drop

1. INTRODUCTION

Locust bean seeds *(Parkia fillicoidea)* is a grain legume found growing in the wild savannah area of West Africa. It is fermented and consumed as a condiment which is added to soups and stews to enhance flavour and improve the nutritional value as a result of its high protein content. It is used in Ghana, Nigeria, Togo, Savanah of West and Central Africa. The fermented locust bean seeds is referred to by different local names perculiar to each locality; it is called Iru in Yoruba land, Dawadawa in Hausa land and Ogiri – Igala in Ibo land of Nigeria (Odunfa, 1985, Olajide and Ade-Omowaye, 1999). Apart from its flavouring attributes, it contributes significantly to the intake of protein, essential fatty acids and vitamin B, particularly riboflavin (Odunfa, 1985).

Efficient storage and subsequent processing of locust beans require that its high post harvest moisture content should be reduced by appropriate levels of drying. Design of efficient systems for drying and aeration of grains requires proper design of electric motor and compressor or fan selection, which can only be achieved with information on airflow resistance of the grains. The pressure drop through a bed of grain depends on the airflow rate, method of filling, the surface area and shape, configuration of voids, the variability of particle size, grain bed depth and crop moisture content (Shedd , 1953).

Shedd (1953) reported that foreign materials mixed with grain increases the resistance to airflow if the foreign material is finer than the grain. Similar results were reported for resistance to airflow of grains, seeds, other agricultural products and perforated sheets (ASAE, 1992a). Similar studies were also reported by Calderwood (1973) for milled rice, Kumar and Muir (1986) for wheat and barley, Dairo and Ajibola (1994) for sesame seed, Al-Yahya and Moghazi (1998) for barley grain and Jekayinfa (2001) for cocoa beans. The most commonly used model is the one proposed by Shedd (1953) where he presented curves relating airflow and pressure drop per unit depth of grain. Because of their simplicity and ease of handling, Shedd's curves are widely used by many designers to estimate pressure drops in grains. The curves were estimated based on the formula:

$$Q = a \, \Delta p^{b} \qquad \text{---------------------} \qquad (1)$$

Where, Q = airflow rate ($m^3 \, s^{-1} \, m^{-2}$)
Δ p = Pressure drop per unit depth (Pa/m)
and a, b = constants and are related to moisture content for some grains.

Because of the limitation of Eqn. (1) for being able to predict airflow resistance over only a narrow range of airflow rate (Q = 0.00056 to 0.203 $m^3 \, s^{-1} \, m^{-2}$), Hukill and Ives (1955) also proposed an empirical equation which accounts for the non-linear nature of resistance to airflow data. The equation is of the form;

$$\Delta p = \frac{CQ^2}{\ln[1 + dQ]} \qquad \text{---------------------} \qquad (2)$$

where,
C, d = constants for a particular grain.
Equation 2 is applicable over a wide airflow range of 0.01 to 2.0 $m^3 \, s^{-1} \, m^{-2}$.

In view of the enormous and potential use of locust beans in the food industry and other allied industries, it is important to determine the effects of some physical properties such as moisture content, bulk density, bed depth and airflow rate on the resistance to airflow through the bean seeds. The knowledge of these relationships would assist in the design of dryers and aeration systems for locust beans.

2. MATERIALS AND METHODS

2.1 Sample Collection and Preparation

Locust beans used for the study were obtained from a local market in Ogbomoso ($8^o07'$ N, $4^o16'$ E) in Oyo state of Nigeria. The material was cleaned by hand picking of the rough and large materials from the beans. Samples of different moisture content levels were kept in double polythene bags and put in the freezer for two nights and were brought out 6h prior to use in order to allow samples attain room temperature.

2.2 Moisture Content Determination

The initial moisture content of the beans was determined by air-drying of 30g sample in an oven at 130°C for 6h as recommended by Young et al. (1982) and ASAE standard S 352.2 (ASAE, 1992b). The moisture contents used in this study ranged from 9.50 to 37.65% (wet basis). Samples with moisture content higher than 9.50% were obtained by adding appropriate amounts of water to rewet the samples.

2.3 The Test Apparatus

The test apparatus (Fig. 1) was made of mild steel material rolled into a cylindrical shape with a depth of 459 mm for the containment of test beans. Beginning approximately 76.5 mm above the top of the plenum chamber cap; 5 mm diameter holes were drilled through the test column wall at 76.5 mm intervals in order to measure the pressure along the column wall at different depths. Galvanised tube pressure taps, 4 mm diameter, 1 mm thick and 30 mm long were inserted into these holes and welded to the test column at about 15 mm into the test column in each case to reduce the effect of wall on the measurement of pressure drop.

The floor of the test column was made of mosquito net placed on perforated sheet and inclined at an angle of 30° firstly to prevent test materials from dropping into the plenum chamber during the cause of carrying out the experiment and secondly, to allow for free fall of the test materials via the plug and sucket when draining test materials. The test column was fixed to a plenum chamber and air was supplied by a compressor through a hose into the plenum chamber driven by a 180 W motor. The air volume flow rate was varied by means of a control valve at the air tank. The system was tested for air leaks using a soap solution for very high pressure of 10 KPa. The apparatus was primed and painted inside and outside to prevent air leakage and corrosion. An analogue manometer (model: FL 100 – 7564603, KOMISSION 326915, High Wycombe, England) capable of reading to 0.1 inch of manometer fluid was used to measure static pressures.

2.4 Procedure

The experiment was performed using the following procedure:

(i) 150 g of clean locust beans were weighed and filled into the test column by freely pouring the grain into a funnel placed about 20 mm above the column as described by Shedd (1953).

(ii) The height of the sample in the test column was measured and recorded for calculating the in situ bulk density.

(iii) Starting with the first tap above the bed floor as the reference, probe was inserted into the bean to obtain static pressures during a test run. Holes were sealed with tape at all times when not used for a static pressure probe.

(iv) The air volume flow rate was varied by means of a control valve at air tank inlet after the third step above. The manometer responded to any change in the airflow rate. Step (iii) was repeated for all the airflow rates used.

(v) To change the bulk density of the material in the test column, the column was tapped 10 times. By tapping the test column, the height of the material was reduced thus, increasing the packing. Step (ii) to (iv) were repeated for different bulk densities. The test column was then emptied and a small portion kept for moisture content determination. The procedure was followed for all the selected moisture contents.

Static pressure measurements were taken at bed depths of 76.5, 153, 229.5, 306 and 382.5 mm. The in-test column bulk density for all the experimental run was obtained from the ratio of the mass of the sample to the volume occupied in the column. The volume of column occupied by the sample was obtained by multiplying cross sectional area of column by the height of the sample in column.

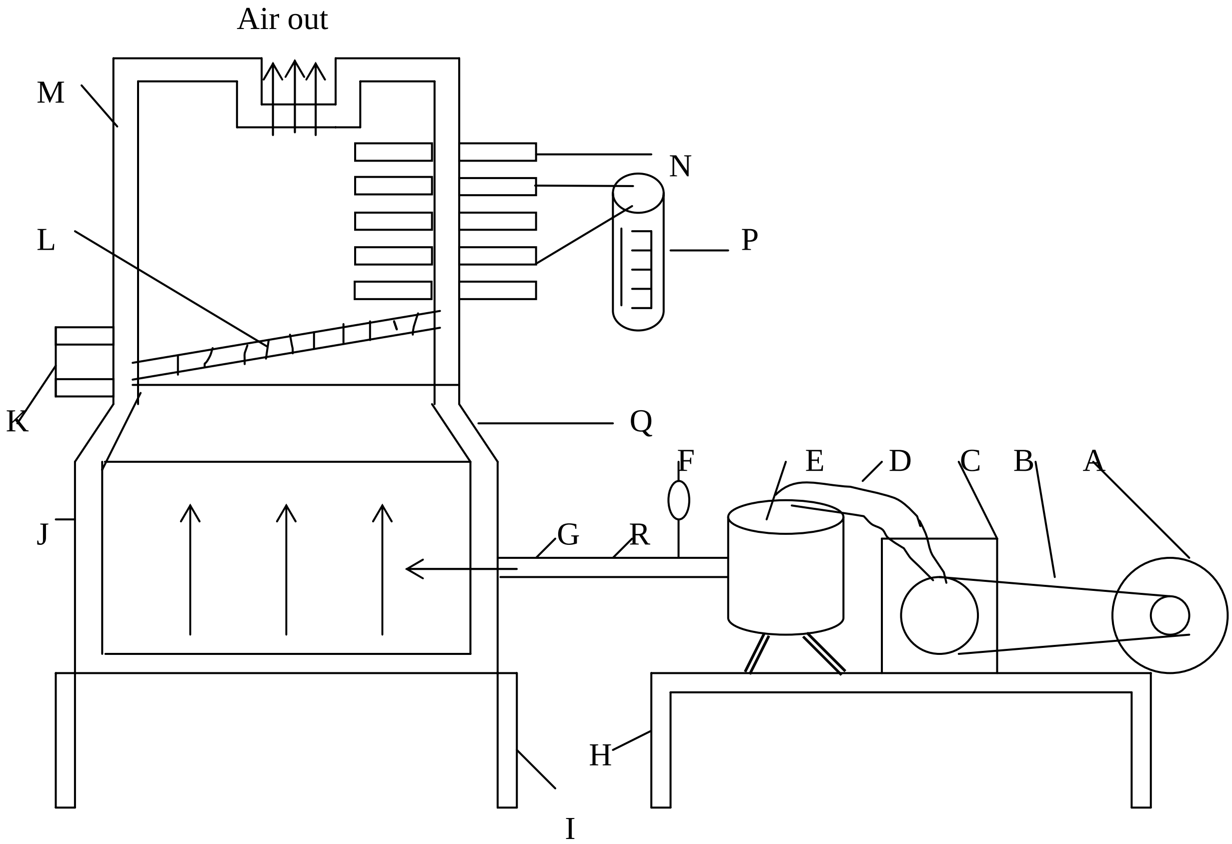

Figure 1: Airflow Test Apparatus

A = Motor (0.18kW)	I = Chamber Stand
B = Driving belt	J = Plenum Chamber
C = Compressor	K = Plug and socket
D = Connecting hose	L = Perforated sheet
E = Air tank	M = Test column
F = Control valve	N = Pressure tap
G = Pressure inlet	P = Manometer
H = Motor stand	Q = Plenum chamber cap
	R = Compressor – inlet hose

3. RESULTS AND DISCUSSION

Table 1 shows the bulk densities of the seeds at 4 moisture content levels and zero percent fine material. Each value as presented represents an average of three readings obtained from the experiment. BD_1, BD_2, BD_3, and BD_4, are the bulk density values at free filling, after 10 tapings, after 20 tapings and 30 tapings of the test column, respectively.

From the test data, an increase in bulk density was observed as the moisture content increased. Siebenmorgen and Jindal (1987), Mohsenin (1986) and Dairo and Ajibola (1994) made similar observations on rough rice and bulk sesame seed. This might probably be as a result of changes in surface characteristics of the materials at high moisture content. The material becomes rough and sticky as moisture content increases leading to reduced void spaces and thus, more packed mass of material (Dairo and Ajibola, 1994., Jekayinfa, 2001).

Table 1.Bulk density of locust bean seeds at each moisture content and zero percent fine material used in the study

Moisture content % wet	Bulk density, kg/ m^3				
	Replication	BD_1	BD_2	BD_3	BD_4
9.5	1	149.98	151.31	152.60	153.97
	2	149.80	150.98	152.56	153.89
	3	149.63	151.27	152.61	153.94
16.0	1	150.31	153.31	154.64	155.97
	2	150.21	153.45	154.65	155.87
	3	150.45	154.35	154.95	156.25
20.5	1	150.85	153.65	155.25	156.85
	2	150.65	153.70	155.05	156.25
	3	150.95	154.10	156.15	156.95
37.7	1	152.15	153.95	156.15	159.95
	2	152.35	154.05	156.25	160.15
	3	152.85	154.65	156.75	161.25

BD_1 – Bulk density achieved at free filling
BD_2 – Bulk density after 10 tappings
BD_3 – Bulk density after 20 tappings
BD_4 – Bulk density after 30 tappings

The resistance to airflow per unit grain depth, was converted to pressure drop per unit depth as presented in Table 2, excluding the data obtained at BD_1 because these were used in plotting the graph presented in Fig. 2. It can be observed from Table 2 that pressure drop generally decreased with increase in moisture content at all levels of airflow, bulk density and bed depth used. Table 2 also revealed that pressure drop increased as airflow rate, since the pressure required to force air through a bed of grain is dissipated continuously due to friction and turbulence. Similar observations were made by Jayas et al. (1987) for wheat and barley, Gunasekaran and Jackson (1988) for rice, Dairo and Ajibola (1994) for sesame seed and Jekayinfa (2001) for cocoa beans.

Table 2 Observed pressure drop per unit depth (Pa/m) across a test column of locust bean seed as affected by moisture content

Moisture content, % wet basis	Airflow rate $m^3s^{-1}m^{-2}$	Pressure drop per unit depth (Pa/m)		
		BD_2	BD_3	BD_4
9.5	0.201	586	728	822
	0.226	659	806	889
	0.250	719	876	948
	0.275	784	982	1002
16.0	0.201	525	511	412
	0.226	598	525	479
	0.250	631	603	543
	0.275	729	669	610
20.5	0.201	466	394	308
	0.226	538	466	406
	0.250	608	543	484
	0.275	663	603	543
37.7	0.201	371	349	372
	0.226	440	408	431
	0.250	500	501	517
	0.275	586	561	577

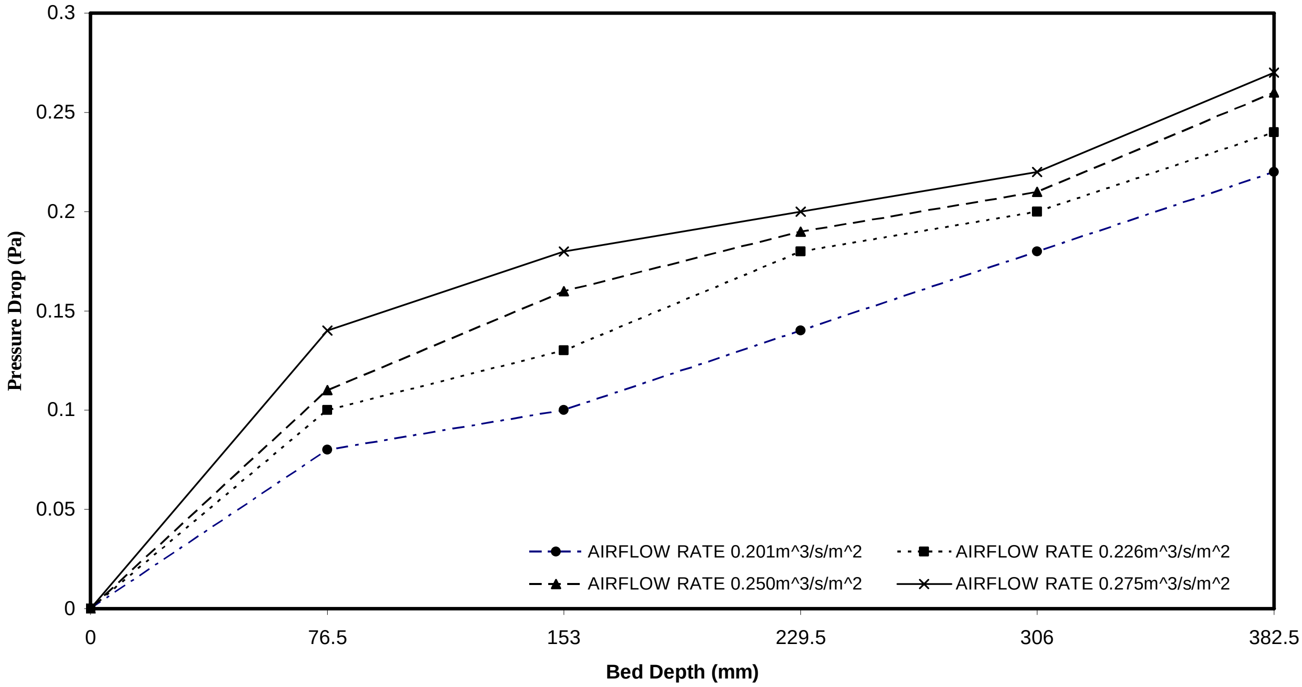

Fig. 2. Effect of bed depth on static pressure drop of locust bean seeds at 9.5% moisture content (wet basis) at various airflow rates for bulk density at free filling (BD_1)

As expected, there was an increase in airflow resistance as bed depth increased from 76.5 mm to 382.5 mm for all combinations of moisture content and airflow rate. In general, there was an increasing linear relationship between bed depth and airflow resistance. Figure 2 illustrates a typical effect of bed depth on pressure drop for bulk density at free filling (BD_1) at various airflow rates and 9.5% moisture content level. This is similar to the observations of Shedd (1953), Jayas et al. (1987), Gunasekaran and Jackson (1988) and, Dairo and Ajibola (1994). From the test results, it was observed that the resistance to airflow generally increased with decreased moisture content at all airflow rates used. This result is attributable to the changes in the surface characteristics resulting from changes in moisture content. At low moisture level, the locust beans cotyledons are hard and smooth thereby causing an increase in frictional losses (high resistance to airflow). This corroborates the results obtained in the studies on bluestem grass seed (Farmer et al., 1981) and cocoa beans (Jekayinfa, 2001).

There was an increase in pressure drop per height as the bulk density increased from the initial bulk density at free filling (BD_1) to the bulk density obtained after 30 tapings of the test column (BD_4) at every moisture content and airflow rate treatment combination. It can, therefore, be concluded that pressure drop in bulk locust bean seed increased more rapidly with increasing air velocities than with decreasing bed depths. This observation agrees with the report of Shedd (1953).

A linear regression analysis was used to relate the pressure drop to the airflow rate using Shedd's equation, at various levels of factors used. Shedd's relationship in Eqn. (1) on logarithmic transformation is:

$$\text{Log}Q = \log a + b\log \Delta P \qquad \text{------------} \qquad (3)$$

The parameter estimates at different combinations of moisture content and bulk density are presented in Table 3. The coefficient of determination (R^2) was greater than 0.97 in most cases tested indicating good fits of the model.

Table 3.Parameter estimates at different combinations of moisture content and bulk density at zero percent fine material

Bulk density kg/m^3	Moisture content, % wet basis	a	b	R^2
150.73	9.5	2.02×10^{-4}	1.08	0.999
	16.0	4.45×10^{-4}	0.98	0.973
	20.5	9.36×10^{-4}	0.87	0.995
	37.7	3.27×10^{-3}	0.70	0.998
154.80	9.5	1.94×10^{-4}	1.05	0.993
	16.0	3.41×10^{-4}	1.03	0.975
	20.5	2.67×10^{-3}	0.72	0.996
	37.7	4.95×10^{-3}	0.63	0.991
156.77	9.5	5.14×10^{-6}	1.58	0.999
	16.0	1.63×10^{-3}	0.80	0.999
	20.5	9.01×10^{-3}	0.54	0.980
	37.7	3.35×10^{-3}	0.69	0.993

4. CONCLUSIONS

The following conclusions are drawn from this investigation into resistance to airflow characteristics of locust bean seeds.

(1) the resistance to airflow increased with increasing airflow rate, bed depth and with decreasing moisture content
(2) the bulk density of locust bean seeds increased as the moisture content of the seeds increased; and
(3) the Shedd's model adequately described the resistance to airflow of locust bean seeds. The coefficient of determination (R^2) was greater than 0.98 for all the test conditions considered, indicating good fits of the model.

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