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EFFECTS OF ANGLE OF INJECTION AND AIR VELOCITY ON DISPLACEMENT OF COWPEA AND IMPURITIES IN A VERTICAL PNUEMATIC CLEANER

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Abstract: Theoretical studies of the effects of angle of injection and air velocity on displacements of cowpea and impurities particles in a vertical pneumatic cleaner were carried out. Experimental study of the effect of angle of injection and air velocity on cleaning efficiencies of two varieties of cowpea namely IT90K-277-2 and Ife brown was also undertaken. The predicted horizontal displacements of IT90K-277-2 and Ife brown from point of injection at 0.5 s ranged from 0.14 - 0.25 m and 0.56 - 0.99 m respectively and at 1.0 s it ranged from 0.06 - 0.10 m and 0.22 - 0.40 m respectively. The predicted vertical displacements from point of injection at 0.5 s ranged from -0.98 to -1.16 m and -3.93 to -4.64 m and at 1.0 s it ranged from -1.13 to -1.20 m and -4.52 to -4.80 m respectively. The predicted horizontal displacements of the impurities from the point of injection at 0.5 s and 1.0 s for angles of injection of 15 to 60° ranged from 1.11- 19.50 m and 4.45 -78.02 m for IT90K-277-2 and 1.35 - 8.52 m and 5.40 - 34.09 m for Ife Brown respectively. The predicted vertical displacements of the impurities from the point of injection at 0.5 s and 1.0 s for angles of injection of 15 to 60° ranged from -0.77 to 18.03 m and -3.08 to 72.12 m for IT90K-277-2 and -0.57 to 6.87 m and -2.27 to 27.49 m for Ife Brown respectively. The predicted horizontal and vertical displacements of the 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. Experimental cleaning efficiency showed that cleaning efficiencies increased as the angle of injection increased which confirms the trend predicted by the displacements. It is therefore recommended that the inclination of the hopper should not be less than 45°.
Keywords: Angle of injection, air velocity, displacement, pneumatic cleaner, cleaning efficiency

1. INTRODUCTION

The separating effect of moving air has been used to remove chaff, dirt and lightweight seed from agricultural products. This process known as aerodynamic and pneumatic separation has been an effective method of removing impurities from cowpea (Aguirre and Garray, 1999: Aderinlewo and Raji, 2013). The product to be cleaned is injected into a vertical, horizontal or diagonal airflow where impurities are displaced from sound grains. In a vertical pneumatic cleaner, lightweight impurities are displaced vertically upwards from the point of injection while sound grains which are heavier are displaced vertically downwards from the point of injection.

Aerodynamic or pneumatic cleaning is affected by factors such as physical and aerodynamic properties of components of the mixture (grain and impurities mixture) such as angle of injection of the mixture into the air stream, air velocity, moisture content, and angle of injection of the air stream into the tunnel. (Gorial and O'Callaghan, 1991). There is therefore the need to investigate the interaction of these factors as they affect cowpea-impurites' separation so as to determine the combination of factors that produce optimum cleaning or separation.

The effects of these factors on separation of impurities in pneumatic systems have been investigated by different researchers. Similowo, 2007 investigated the effect of tilt angle of air blower on the cleaning efficiency of a prototype pneumatic separator for cowpea. They investigated tilt angles of 0 to 30° and concluded that maximum cleaning efficiency was obtained at 30°. Macmillan (1999) developed a computer model to analyse the particle separation that occurs when grain and chaff are winnowed by being thrown or dropped in the wind. Their 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°. Panasiewicz (1999) investigated the horizontal and vertical displacements of lupine seed injected into a diagonal airstream. They came up with equations for determining the horizontal and vertical displacements. Literature is however sparse on modelling of pneumatic separation of cowpea in a vertical flow pneumatic.

Therefore, the objective of this work was to determine the effects of angle of injection and air velocity on displacement of impurities from cowpea in a vertical pneumatic cleaner using mathematic models and experimental studies.

2. LIMITATION OF THE STUDY

The study considered separation of cowpea and impurities in vertical flow pneumatic cleaner only. Cross flow and diagonal flow cleaners were not considered.

3. METHODOLOGY

Equations for predicting the horizontal and vertical displacements of cowpea and impurities in a vertical pneumatic cleaner developed by Aderinlewo (2011) were used to predict the horizontal and vertical displacement of two varieties of cowpea (Ife Brown and IT90K-277-2) and impurities particles in a vertical pneumatic cleaner. The equations state as follows:

$$x = \frac{Ft^2}{2m}\cos\theta \qquad (1)$$

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

where x = horizontal component of particle's velocity, m/s, y = vertical component of particle's velocity, m/s, θ = direction of particle's motion measured from the horizontal, degree, m = mass of particle, kg, g = acceleration due to gravity, m/s^2, F = drag force, N, t = time of flight, s

Vertical displacement above the point of injection was taken as positive while vertical displacement below the point of injection was taken as negative.

The cleaning efficiencies at different angles of injection and air velocities of the two varieties of cowpea namely Ife Brown and IT90K-277-2 were experimentally determined using a vertical pneumatic cleaner developed at the Department of Agricultural Engineering, Federal University of Agriculture, Abeokuta. The cleaning efficiencies obtained experimentally were compared with the trends predicted by displacement equations. The physical and aerodynamic properties of the cowpea varieties and impurities are presented in Tables 1 and 2.

Table 1. Physical and aerodynamic properties of cowpea varieties

Variety	Moisture content (% w.b.)	True density kg/m^3	Bulk density kg/m^3	Porosity %	One thousand grain mass (g)	Projected area mm^2	Terminal velocity m/s
IT90K-277-2	14.1	1195	731	38.83	177.624	38.59	13.57
Ife brown	14.1	1201	731	39.15	157.993	40.97	13.92

Source: Aderinlewo and Raji (2013)

Table 2. Mass and terminal velocities of impurities

Impurity	Mass (g)	Terminal velocity (m/s)
Chaff-4 cm	0.104	1.51
Chaff-8 cm	0.147	2.23
Immature grain	0.113	3.49
Insect infested grain	0.150	2.96

Source: Aderinlewo and Raji (2013)

4. RESULTS AND DISCUSSIONS

The vertical and horizontal displacements of the cowpea varieties and the impurities predicted by the model at the time of 0.5 s and 1.0 s are shown in Tables 4 to 6. The predicted horizontal displacements of IT90K-277-2 and Ife brown from point of injection at 0.5 and 1.0 s ranged from 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 respectively for angles of injection of 15, 30, 45 and 60°. Their predicted vertical displacements from point of injection at 0.5 s and 1.0 s ranged from -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 respectively for angles of injection of 15, 30, 45 and 60°.

The predicted horizontal displacements of the impurities from the point of injection at 0.5 s and 1.0 s for angles of injection of 15 to 60° ranged from 1.11 to 19.50 m and 4.45 to 78.02 m for IT90K-277-2, 1.35 to 8.52 m and 5.40 to 34.09 m for Ife Brown respectively. The predicted vertical displacements of the impurities from the point of injection at 0.5 s and 1.0 s for angles of injection of 15 to 60° ranged from -0.77 to 18.03 m and -3.08 to 72.12 m for IT90K-277-2, -0.57 to 6.87 m and -2.27 to 27.49 m for Ife Brown 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 cowpea varieties are smaller than those of the impurities. This implied that they fell closer to the wall than the impurities.

Table 3. 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. 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 5. 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 (°)	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 6. 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 (°)	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 7. Experimental cleaning efficiencies for IT90K-277-2

Air Velocity m/s	Injection Angle (°)	Experimental Cleaning Effic.(%)
4	15	28.2
4	30	44.4
4	45	60.9
4	60	60.9
6	15	63.7
6	30	71.2
6	45	75.5
6	60	75.6
8	15	76.8
8	30	79.9
8	45	87.9
8	60	88.2

Table 8. Experimental cleaning efficiencies for Ife Brown

Air Velocity m/s	Injection Angle (°)	Experimental Cleaning Effic.(%)
4	15	27.6
4	30	44.3
4	45	60.3
4	60	60.8
6	15	62.3
6	30	71.6
6	45	75.4
6	60	75.6
8	15	76.7
8	30	80.0
8	45	87.4
8	60	87.9

The experimental cleaning efficiencies obtained at different air velocities and angles of injection are shown Tables 7 and 8. For IT90K-277-2, at air velocity of 4 m/s the cleaning efficiency increased from 28.2 to 60.9% for angle of injection of 15 to 60°. At air velocity of 6 m/s the cleaning efficiency increased from 63.7 to 75.6% and at air velocity of 8 m/s, the cleaning efficiency increased from 76.8

to 88.2%. For Ife brown, at air velocity of 4 m/s the cleaning efficiency increased from 27.6 to 60.8% for angle of injection of 15 to 60°. At air velocity of 6 m/s the cleaning efficiency increased from 62.3 to 75.6% and at air velocity of 8 m/s, the cleaning efficiency increased from 76.7 to 87.9%. The increase in cleaning efficiencies with increase in angle of injection at a particular air velocity agrees with the prediction of the displacements that the amount of impurities removed at a particular air velocity increased as the angle of injection increased.

CONCLUSION

1. The predicted horizontal and vertical displacements of the cowpea varieties decreased with increase in angle of injection.
2. 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.
3. The horizontal displacements of the cowpea varieties are smaller than those of the impurities. This implied that they fell closer to the wall than the impurities.
4. The experimental cleaning efficiencies obtained for the cowpea varieties increased as the angle of injection increased. This is in agreement with the prediction of the displacement equations.

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