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Aspirator Separation of Corn-fines Mixtures

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Abstract
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Keywords
Com, Separator, Aspirator, Air velocity

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Comments
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ASPIRATOR SEPARATION OF CORN-FINES MIXTURES

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ABSTRACT

A study was conducted to determine physical and chemical characteristics of corn fines removed by a Kice Mini-Aspirator. Five air velocities were used to separate mixtures of corn fines and whole kernels into heavies and liftings. As aspirator air velocity was increased, removal efficiency of every size fraction increased; starch content of liftings decreased, whereas oil content increased and protein content was unchanged.
KEYWORDS. Corn, Separator, Aspirator, Air velocity.

INTRODUCTION

The degree to which shelled corn is cleaned (separated from the fines it contains) is important since having a clean, good-looking product may increase its sale price, grade, storability and value for processing. Fines removed may include hazardous grain dust and insects. Most reports on corn fines and their removal pertain to removal by screening or sieving (Hill et al., 1982; Grama et al., 1984). Reports on aspirator separation were not found in the literature. Aspirator cleaning of corn works on this principle: a stock containing corn and fines is dropped through a fast-moving air stream, air lifts and carries away some particles (liftings) while others (heavies) fall through. Separation is dependent upon particle density and shape as well as on particle size (Kice, 1985)

PROPERTIES OF FINES FROM CORN

Hill et al. (1982) studied properties of corn from the 1976 and 1977 crops. They measured protein, oil, fiber, ash, and digestible energy values of size fractions separated by sieving. There tended to be less oil in the smaller size fractions, whereas these smaller fractions tended to have the highest protein (Table 1).

Earle et al. (1946) conducted an analysis of starch, oil, and protein content of the parts of dent corn kernels of seven midwest hybrids. Parts were identified as endosperm, germ, and pericarp. An analysis summary is shown in Table 2. The endosperm is mostly starch, whereas the germ has the highest concentrations of oil and protein.

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TABLE 1. Protein and oil of corn fines by particle size*

Property (%)	Year	Whole Corn	Sieve size (mm)† 1.8	2.4	3.2	4.0	4.8	6.4
Oil	1976	4.66	2.64	2.73	2.9	3.89	4.51	4.04
(db)	1977	4.29	2.21	2.12	2.05	2.91	4.01	3.71
Protein	1976	10.18	12.12	10.93	10.45	10.37	10.28	10.01
(db)	1977	10.21	12.42	11.00	10.43	10.39	10.42	10.12

* Hill et al., 1982.
† Size of particles in each category lies between that sieve size and the next smaller one. For example, 4.04% oil is found in particles > 4.8 mm and ≤ 6.4 mm.

TABLE 2. Analysis of starch, oil, and protein for corn parts*

	Starch (% db)	Oil (% db)	Protein (% db)
Endosperm	87.6	0.8	8.0
Germ	8.3	33.2	18.4
Pericarp	7.3	1.0	3.7
Whole kernels	73.4	4.4	9.1

* Earle et al., 1946.

OBJECTIVES

The specific objectives of this study were to:

- Determine the relationship between aspirator air velocity and removal efficiency of various corn fines size fractions.
- Determine starch, protein, and oil content of aspirator liftings from a corn-fines mixture.

EXPERIMENT

An experiment was designed to test aspirator performance on prepared samples of corn and fines.

ASPIRATOR

The aspirator used in this experiment was a Kice Model 6DT4 Mini-Aspirator having six air inlet slots, each with a cross-section of 102 mm × 10 mm (fig. 1). It employs six-pass aspiration.

CORN-FINES MIXTURE

Dry corn and fines were obtained in July 1988 from the West Central Co-op Elevator, Jordan, Iowa. This lot was divided into seven size fractions plus whole corn by means of multiple passes through a Carter-Day dockage tester equipped with round-hole sieves. Individual sizes of fines

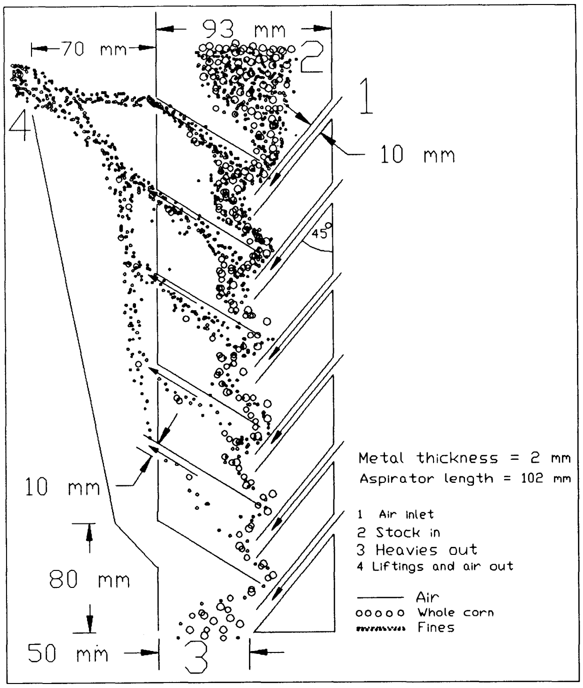

Figure 1–Cross-section of Kice Mini-Aspirator Model No. 6DT4.

were defined as shown in Table 3 (Bern and Hurburgh, 1991).

A 37-kg lot of corn and fines, with 4% Broken Corn and Foreign Material (BCFM), was prepared following the proportions of Table 3. BCFM is defined as material passing through a 4.8-mm round-hole sieve plus non-corn material remaining on the sieve (USDA, 1988). In the U.S. Department of Agriculture's BCFM definition, foreign material (FM) is material passing through a 2.4-mm sieve plus the over 4.8-mm non-corn material. Broken corn (BC) is material passing through 4.8 mm, but not 2.4 mm. The grades define all material larger than 4.8 mm as corn, but in previous work, we have defined material passing through 6.4 mm, but not 4.8 mm as large brokens (LB). (The heading of Table 4 illustrates these definitions.) This material is usually split kernels and small whole kernels. Samples tested did not contain any non-corn material larger than 4.8 mm. Because some fines were larger than BCFM, this test lot actually contained 10% fines (fines = material through a 6.4-mm sieve). Moisture content of stock was 12.6% w.b. (103° C, 72-h air-oven).

TABLE 3. Corn fines size distributions*

Size	Definition		Fines by Weight (%)
1	through 1.8 mm		5
2	through 2.4 mm	over 1.8 mm	3
3	through 3.2 mm	over 2.4 mm	7
4	through 4.0 mm	over 3.2 mm	10
5	through 4.8 mm	over 4.0 mm	15
6	through 5.6 mm	over 4.8 mm	21
7	through 6.4 mm	over 5.6 mm	39

* Bern and Hurburgh, 1991.

EXPERIMENTAL DESIGN

The experimental design is summarized in figure 2. The prepared corn and fines were divided into 16 2.27-kg samples by using a Boerner divider. One of the 16 was used as a control sample, and the remaining 15 were aspirated. Heavies and liftings were sized using a Carter-Day Dockage Tester. Individual and cumulative removal efficiencies were calculated from these data. Particle density of heavies and liftings was determined by using a Beckman model 930 air comparison pycnometer. Liftings fractions were analyzed for content of moisture, protein, starch, and oil.

AIR VELOCITY

The aspirator was modified by addition of an airflow measurement apparatus and a variable-flow fan to allow determination of air velocities. Airflow was measured after it left the aspirator dust bag by measuring air pressure drop across a perforated plate, previously calibrated by use of a Meriam model 50 MCS laminar flow meter. (See Al-Yahya, 1989 for details.) Air velocity through each aspirator slot was calculated by dividing total airflow rate by six times the cross-sectional area of an inlet slot.

Air velocities of 22, 19, 16, 13, and 8 m/s (through each aspirator inlet slot) were used. These correspond to air pressures of 398, 271, 162, 87, and 12 Pa, respectively. The highest airflow was capable of removing most fines and some whole corn kernels. The lowest airflow could remove a portion of the fine material, but no whole kernels.

A feed rate of 16 g/s and sample size of about 2270 g were used in running samples through the aspirator.

TABLE 4. Weights (g) of heavies, liftings, and stock

Air Velocity m/s	Sieve size (mm)* 1.8	2.4	3.2	4.0	4.8	5.6	6.4	>6.4†	Total	Total Liftings
	-------FM------→ |	←------------------	---BC---	------------------	→ | ←----------	-LB-	----------→ |	←----CORN-----		
22	0	0	0	0	0	1.50	6.51	1448.00	1456.01	813.10
19	0	0	0	0	1.17	6.80	22.91	1891.70	1922.58	346.75
16	0	0	0.39	2.80	8.32	22.16	55.29	2028.00	2116.96	152.80
13	0	0.21	3.25	12.29	21.07	43.64	84.98	2039.83	2205.27	68.87
8	2.92	3.71	14.17	20.30	33.33	46.80	88.06	2043.07	2252.36	15.65
Stock	11.12	6.36	15.89	22.47	34.96	47.03	88.08	2043.41	2269.32	

* Size of particles for each entry lies between that sieve size and the next smaller one. For example, heavies from aspiration at 13 m/s was 12.29 g of material > 3.2 mm and ≤ 4.0 mm.

† All material on top of 6.4-mm sieve.

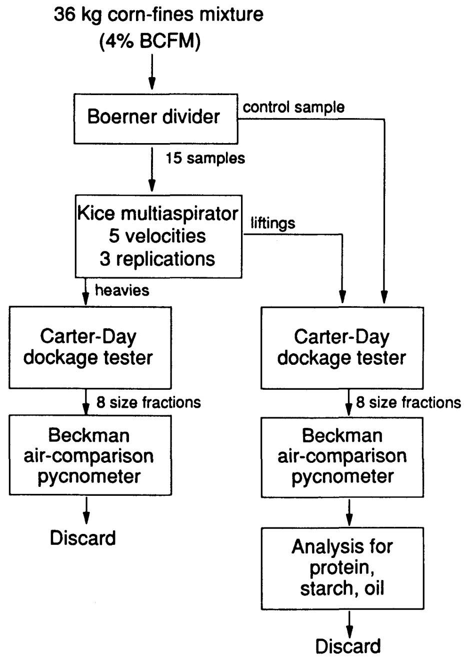

Figure 2–Experimental design.

Preliminary tests showed these values to be the most and least, respectively, that were practical for use with the aspirator being tested (Al-Yahya, 1989). Larger feed rates would result in smaller removal efficiencies. Smaller sample sizes would result in steady state operating times which were too short. Stock was metered into the aspirator with a Fritsch laboratory vibratory feeder. For each sample, heavies from the first pass and from the second pass were re-routed through the aspirator.

Removal Efficiency

Size-fraction weights for liftings and heavies were used to calculate removal efficiency of FM (foreign material: material passing through a 2.4-mm sieve), BC (broken corn: material passing through the 4.8-mm sieve but over a 2.4-mm sieve), BCFM (broken corn and foreign material: the summation of FM and BC), and LB (large broken: the material passing through a 6.4-mm sieve but over a 4.8-mm sieve).

Nutrient Content

Protein and oil analyses were done on each size fraction of liftings in the Iowa State University Grain Quality Lab using the Kjeldahl and Goldfisch methods, respectively. Starch analyses were done on these samples by San Laboratory, Cedar Rapids, IA.

Results

Table 4 shows weights of each size fraction of heavies, total heavies weighed, and total liftings weight for each air velocity. Weights of each size fraction of stock are also shown.

Individual and Cumulative Fines Removal Efficiency

Size-removal efficiencies were calculated using equation 1:

$$(RE)_i = \frac{p_{oi}W_o - p_{hi}W_h}{p_{oi}W_o} \times 100 \qquad (1)$$

where

p_{oi} = percentage of size i in stock,
p_{hi} = percentage of size i in heavies,
W_h = total weight of heavies (g),
W_o = total weight of stock (g),
$(RE)_i$ = removal efficiency (%).

Individual size-removal efficiency is useful for determining the nature of cleanings. Table 5 shows removal efficiency for each velocity level. Each table entry is the average of three replications.

Cumulative size-removal efficiency expresses the ability to remove all material less than some size. Figure 3 shows cumulative size removal efficiency versus particle size regression curves for each velocity. Each iso-velocity line predicts what will be removed from a 4% BCFM corn-fines mixture by the aspirator, when set for the indicated inlet air velocity.

For example, an air velocity of 13 m/s will remove about 90% of the material smaller than 3 mm, about 57% of the material smaller than 5 mm, and about 8% of the

TABLE 5. Size removal efficiency (%)

Air Velocity m/s	Sieve size (mm)*							
	1.8	2.4	3.2	4.0	4.8	5.6	6.4	> 6.4†
	----------FM---------→ | ←		----------BC----------		→ | ←-----LB-----		→ | ←-----CORN-----	
22	100.0	100.0	100.0	100.0	100.0	96.8	92.6	29.2
19	100.0	100.0	100.0	100.0	96.6	85.5	74.0	7.4
16	100.0	100.0	97.6	87.6	76.2	52.8	37.2	0.8
13	100.0	96.6	79.6	45.3	39.7	7.1	3.5	0.2
8	73.8	41.6	10.8	9.7	4.6	0.4	0.0	0.0

* Size of particles for each category lies between that sieve size and the next smaller one. For example, liftings from aspiration at 13 m/s contained 45.3% of the material which passed through the 4.0-mm sieve but remained on top of the 3.2-mm sieve.

† All material on top of 6.4-mm sieve.

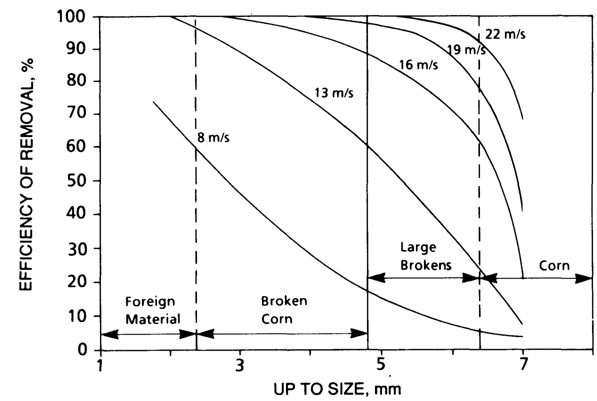

Figure 3–Cumulative size removal efficiency (%) as a function of corn fines sizes at five different air velocity levels.

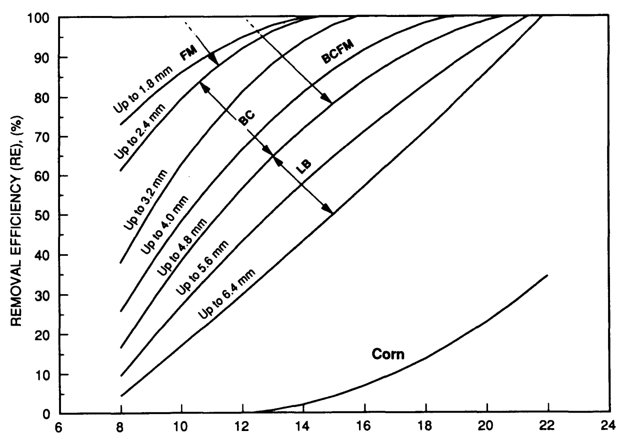

Figure 4–Cumulative size-removal efficiency (%) and air velocity for eight sieve sizes.

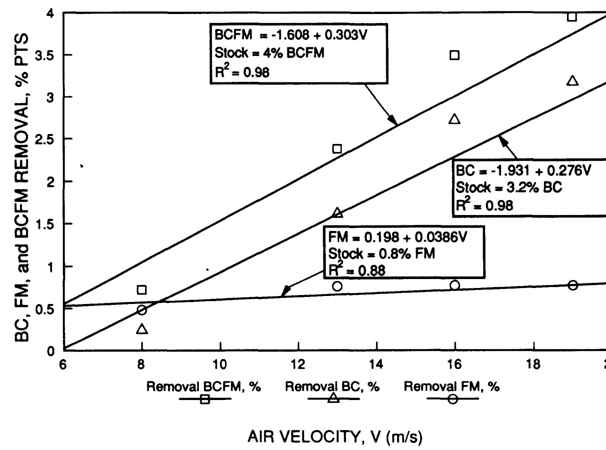

Figure 5–Broken corn (BC), foreign material (FM), and broken corn and foreign material (BCFM) removed as a function of air velocity (stock = 3.2% BC + 0.8% FM).

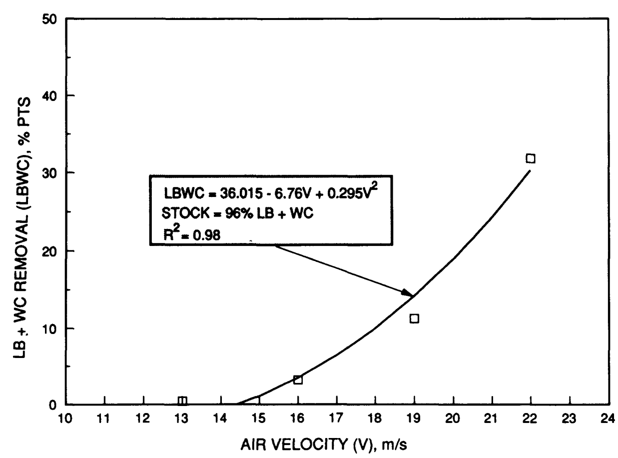

Figure 6–Large broken corn (LB) and whole corn (WC) removed as a function of air velocity (stock = 96% LB +WC).

material smaller than 7 mm. An air velocity of 13 m/s will remove about 97% of the FM, about 61% of the BC + FM, and about 25% of the LB + BC + FM.

Air Velocity and Aspirator Cumulative Removal Efficiency Relationships

Removal-efficiency relationships are shown as a function of air velocity in figure 4. Table 6 lists the quadratic regression equations for each of the eight sieve sizes in figure 4. Figure 4 indicates that a velocity greater than 14 m/s will remove all FM, a velocity greater than 21 m/s will remove all BC + FM, and a velocity greater than 22 m/s will remove all LB + BC + FM. Whole corn in liftings at these three velocities, as percentages of total whole corn, are about 2%, 28%, and 33%, and as percentages of stock are about 1.8, 25, and 30%, respectively.

TABLE 6. Equations of cumulative size-removal-efficiency percent at five different air velocity levels*

Size (mm)	b_o	b_1	b_2	R^2
1.8	-18.82	15.52	-0.504	0.98
2.4	-67.58	21.67	-0.697	0.98
3.2	-120.19	25.74	-0.746	1.00
4.0	-102.24	19.90	-0.486	1.00
4.8	-100.87	177.81	-0.391	0.99
5.6	-74.29	11.87	-0.174	0.97
6.4	-40.59	5.17	0.058	0.97
7.1	32.0	-6.05	0.28	0.98

* $RE = b_o + b_1(v) + b_2(v)^2$.

Figures 5 and 6 show removal efficiency-air velocity relationships for BC, FM, and LB + whole corn. Removal efficiencies are in percentage point units for these quantities. The figures indicate what air velocities are needed to achieve removal of various percentage points of material. For example, figure 5 predicts that a velocity of about 12 m/s is needed to remove 2 percentage points of BCFM. Figure 6 predicts that LB and whole corn cannot be removed by that airflow.

Removal Efficiency and Chemical Properties Relationships

Results for each particle size from wet-chemistry analyses for protein, oil, and starch percentages are presented in Table 7. Protein and oil percentages in the stock were less than what Hill et al. (1982) found in 1976- and 1977-crop corn (Table 1).

Weighted averages of oil, protein, and starch percentages in the liftings were calculated for each velocity

TABLE 7. Wet chemistry analyses for oil, protein, and starch, for each corn-fines size

Property (%)	Stock	Fines Size (mm) 1.8	2.4	3.2	4.0	4.8	5.6	6.4	7.1
Oil*	3.53	2.25	2.32	2.11	2.29	3.59	3.99	3.75	3.54
Protein*	9.79	10.47	9.86	8.94	8.47	9.02	9.39	9.96	9.82
Starch*	70.55	64.28	66.36	73.58	75.88	72.85	71.43	70.54	70.48

* Dry basis.

by using analysis results for each size fraction (Table 7) and test results from size analysis of liftings. These are shown in figures 7, 8, and 9.

Figure 7 indicates that oil in liftings increased with air velocity, and was considerably less than oil in the stock except at the greatest air velocities levels. This suggests that particles removed at slower velocities were mainly low-oil pericarp and endosperm (Table 2). Germ particles constitute more of the liftings at greater velocities.

Protein values of liftings were near those of the stock, except at the lowest velocity (fig. 8). Starch values in low-velocity liftings were considerably higher than in the stock

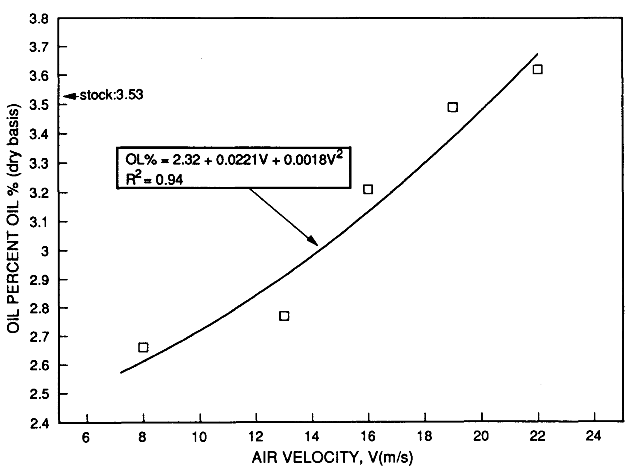

Figure 7–Oil content of liftings (%, dry basis) as a function of air velocity.

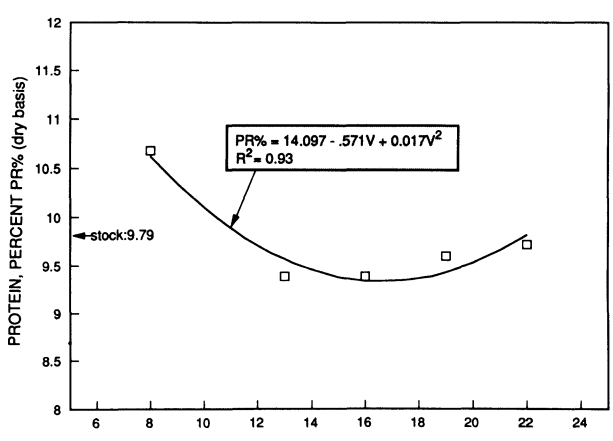

Figure 8–Protein content of liftings as a function of air velocity.

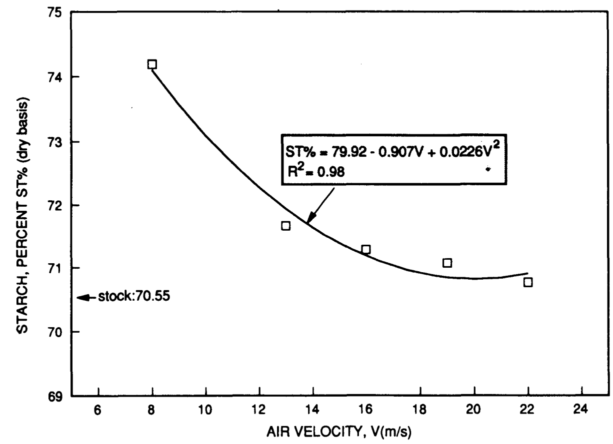

Figure 9–Starch content of liftings as a function of air velocity.

TABLE 8. Particle density for aspirator heavies and liftings

Air velocity (m/s)	Particle density of heavies (kg/m^3)	Particle density of liftings (kg/m^3)
8	1313	1402
13	1310	1375
16	1309	1374
19	1303	1329
22	1291	1320

stock = 1314 kg/m^3

and decreased with increasing velocity (fig. 9). This again suggests that slow-velocity liftings contain greater proportions of endosperm.

PARTICLE DENSITY

Table 8 shows particle density results. Particle density of heavies was in every case lower than that of liftings. Densities of both heavies and liftings tended to be smaller at greater air velocities. Yang et al. (1990) observed a similar relationship. These results may be due to the effects of particle shape and size on drag forces caused by an airstream. Though more dense, particles with a large surface area and/or a small size are more readily lifted.

CONCLUSIONS

1. Removal efficiency for all sizes of corn fines, and for whole corn, increased as aspirator air velocity increased. Air velocities can be selected to remove all FM, BC + FM, or LB + BC + FM, but an increasing weight of whole corn will be removed along with each of these fractions. About 98% of FM, 67% of the BC + FM, and 39% of the LB + BC + FM can be removed, without appreciable removal of whole corn, with an air velocity of about 13 m/s.
2. Corn fines removed by using greater air velocity contained a smaller percentage of starch, whereas slower air velocities resulted in greater starch content. Corn fines removed by using greater air velocities contained more oil content whereas slower

air velocities resulted in less oil content. Corn fines removed at all air velocities exhibited similar amounts of protein.

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