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PNEUMATIC CONVEYING OF GRAINS

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ABSTRACT

Rough rice (long and medium grain), long grain brown rice, wheat, and soybeans were conveyed through a pressure type pneumatic conveyor. Four different air to solid ratios and five air velocities were evaluated to determine the effects on grain damage and the power requirements in such conveying. The effect of conveying on rice quality was measured in terms of fissured and broken grains; for wheat, in terms of brokens and for soybeans, in terms of splits. The operating variables resulting in the least grain damage and conveying power were identified.

KEYWORDS: Pneumatic, Air Velocity, Air to Solid Ratio, Power, Conveying, Rice, Wheat, Soybeans

INTRODUCTION

Pneumatic conveying is a popular method of handling dry bulk materials. It may be defined as the transporting of such materials through a pipeline by either a positive or a negative pressure air stream. Experience is essential in the design of a pneumatic conveying systems as engineering formulas alone do not assure an efficient system. Pneumatic conveyors are commonly used to load or unload grains from ships. Many grain processing plants also use these systems. The system developed and used here is for use in a processing plant where very large capacities are not needed.

The value of the grain decreases for most end uses if it is damaged or broken. There can be many reasons for the damage of grains conveyed through a pneumatic conveyor. Some of these reasons are: the turbulent interchange in the flow pattern, impact of grains with each other and with the pipe wall, impact at elbows where there is a change in direction, and crushing at the airlock feeder. Foster (1973) reported that the impact damage to the grains primarily depends upon the air velocity. Magee et al. (1984) reported that with 20 m/s (4000 fpm) conveying velocity, damage to corn was similar to that for bucket elevators and drag conveyors, and it increased with an increase in the velocity. Feed rate had little effect on grain damage. Chung et al. (1973) reported moisture content, system length, conveying air velocity, and kernel size and shape as factors that affect corn damage in pneumatic conveying systems. Moreira et al. (1981) and Keller et al. (1972) reported that impact damage is highly dependent on kernel velocity.

The power requirements and pressure drop in the system are important aspects of pneumatic conveying in addition to the grain damage. Chatley (1940) presented a procedure for calculating the power requirements for vertical and horizontal suction conveying and reported that horizontal conveying required more power than vertical conveying. Jennings (1940) reported exactly the opposite results based on practical observations. Crane and Carleton (1957) developed an equation for pressure drop at steady state conditions along straight sections of pipe at any angle of inclination. Wolfe et al. (1970) developed an equation for pressure drop in horizontal conveying pipes. Segler (1951) varied grain flow rates and pipe diameters in a pressure-type pneumatic system and reported the minimum air velocities and resistance to flow. Susai and Gustafson (1982) reported on power requirements and kernel velocities in a pneumatic system and found that the power required to accelerate corn depended on the change in kernel velocity.

Most of the research reported in the literature has been conducted with shelled corn. Data on other grains are limited. This study was conducted to determine the effects of pneumatic conveying on damage to long and medium grain rough rice, long grain brown rice, wheat and soybeans. The objectives were:

1. To determine the damage to rough rice, brown rice, wheat and soybeans when transported in a pneumatic conveyor.
2. To determine the optimum conveying velocity and air to solid (A/S) ratio for minimum grain damage.
3. To determine the power requirements at various operating conditions for each type of grain.

MATERIALS AND METHODS

System Description

The pneumatic conveying system was set up as shown in Figure 1. A BRUNenmatic[1] pneumatic conveying system made by Bruning Enterprises, Shelbyville, IN., was used. It consisted of:

a. A positive displacement blower (Schwitzer* model 4504), powered by a 15 kw (20 hp), 3 phase electric motor.
b. A silencer placed downstream from the air pump.
c. A rotary airlock feeder powered by a 0.375 kw (0.5 hp), 3 phase electric motor, placed downstream from the silencer.

The grains were fed into the airlock through a feeding hopper with a slide gate. The capacity of the airlock feeder was 0.005 m^3/rev (0.177 ft^3/rev). Typical capacity of the system were: for rough rice, 2.88 t/h at 39.4 m/s air velocity and 3:1 A/S ratio; brown rice, 4.56 t/h at 39.4 m/s air velocity and 2:1 A/S; wheat, 1.83 t/h at 39.4 m/s air velocity and 5:1 A/S ratio; soybeans, 1.7 t/h

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[1]Trade names are used solely to provide specific information. Mention of trade name does not constitute a warranty of the product by Louisiana State University nor an endorsment of the product to the exclusion of other products not mentioned.

at 33 m/s air velocity and 5:1 A/S ratio.

A WEATHERtronics digital airmeter (model no. 2430) was installed in the blower air inlet duct to measure the velocity of the air flowing in the system. A kilowatt meter was also connected to determine the power consumption. Thermocouples were placed just upstream and downstream of the blower and at the cyclone outlet to record the air temperature.

The pipeline conveying the grain from the feeder had one vertical section, 3 horizontal sections, and a 45 inclined section (Figure 1). They were connected by one 90° elbow of 1.37 m (54 in.) radius, three 45° elbows of 0.91 m (36 in.) radius, and one 45° elbow of 1.55 m (61 in.) radius, respectively. The pipes were made of clear plastic, and the elbows were made of metal. Clear plastic pipes were used to allow for viewing and photographing of the grain movement during conveying. The pipe ID was 0.073 m (2.875 in.), and OD was 0.076 m (3 in.). Three differential pressure gages and two U-tube manometers were located at the five elbows to record the pressure drops. A 0.6 m (24 in.) diameter cyclone receiver at the end of the conveying pipe separated grain form the air and discharged grain into a bag.

<u>Statistical Design and Operating Parameters</u>

Air and grain flow rates were varied to achieve the desired air velocity and A/S ratio. The statistical design was a 5x4 factorial arrangement in a randomized block design with 3 replications. The factors controlled were air velocity and A/S ratio. The levels were:

1. Five air velocities of 26.1, 28.7, 33.0, 35.8 and 39.4 m/s (5150, 5650, 6500, 7050, 7750 fpm). The desired air velocity was obtained by changing pulleys on the blower and motor shafts.
2. Four A/S ratios (ratio of incoming air to weight of grain entering the air stream) of 0.125, 0.187, 0.312, and 0.624 m^3/min air per kg/min of grain (2:1, 3:1, 5:1, and 10:1 cfm air per lb/min of grain). The desired A/S ratio was obtained by adjusting the slide gate in the feed hopper.

The feed hopper was filled with sufficient grain to run the system for 30 s. A control sample was collected before running the grain through the system. Any grain sample was run through the system only once and a fresh sample was used for each replication. The electrical power, pressure drop across each elbow, and temperature at the inlet and at the cyclone were recorded during each test run. The conveyed grain was collected in a barrel placed under the cyclone receiver. The grain in the barrel was mixed and a 3000 g representative sample was taken for quality analysis.

<u>Quality Analysis</u>

Damage to rough and brown rice were assessed as broken and fissured kernels. Soybeans resulted in splits whereas wheat resulted in broken grains.

<u>Rough Rice.</u> All samples were divided using the Boerner divider

(USDA, 1984) to get representative subsamples. A 10 g subsample was hand shelled and used for fissure analysis (procedure described under brown rice). A 150 g subsample was used for the standard mill yield analysis (USDA, 1984). The white milled rice was divided in a Boerner divider to get a subsample of 50 g that was hand graded for brokens.

The percentage head yield (whole grain) was calculated with respect to the initial 150 g sample of rough rice after running the milled rice through the vibratory broken separator, (USDA, 1984). This head yield was reduced to a 50 g representative sample for hand grading. After hand grading for brokens, the percentage head yield was calculated with respect to the 50 g sample. Then, the final head yield with respect to the initial 150 g sample of rough rice was calculated by multiplying these two head yields. Similarly, the final head yield for the control sample, which was collected before conveying the grain through the system, was calculated.

Brown Rice. The samples were divided using the Boerner divider to get representative subsamples of 25 g. Two 25 g subsamples were taken from each treatment combination and replication. The subsamples were hand graded for brokens. Similarly, a 10 g subsample was analyzed for fissures as follows: the rice was placed in a petri dish, and each grain was viewed over a fiber-optic light source. The light passed through the grain, and any fissure or crack could be easily seen. The increase in amount of broken and fissured kernels between test and control samples showed the damage in conveying.

Wheat. The samples were divided using the Boerner divider (USDA, 1984) to get representative subsamples. A 50 g subsample was hand graded for brokens. Any wheat kernel that was not completely intact (whole) was considered "broken". Two subsamples were analyzed for each air velocity, A/S ratio, and replication. The weight of broken grains from the conveyed sample was recorded and was compared with that of the control sample.

Soybeans. The sample was divided in a Boerner divider, and a 1000 g representative sample was taken for analysis. Foreign material such as other grain kernels, cockle burrs, sticks, and soybean pods were hand picked from this sample. A set of sieves was assembled by placing a 0.397 cm by 1.9 cm (10/64 x 3/4 in) slotted hole sieve on top of a 0.3175 cm (8/64) round hole sieve. The top sieve was oriented such that the slots were parallel to the direction of motion. The sieves were placed in front of the body with elbows close to the sides. The sieves were held level so the soybeans moved lengthwise along the top sieve perforations in gentle, steady side sieving motion. The sieves were moved from right to left approximately 25.4 cm (10 in.) and returned from left to right. This operation was repeated five times (USDA Grain inspection handbook,1977). All materials including soybeans that passed through the round hole sieve and any material other than soybeans remaining on the top of the sieves after sieving were considered as foreign materials. Soybeans with more than 1/4 broken off were considered as splits. The 0.397 cm by 1.9 cm

(10/64 x 3/4 in.) sieve did not separate all the splits. The material remaining on the top sieve and the material that passed through was visually examined for splits and splits were removed by hand. The percentage of splits was calculated as follows:

Weight of representative sample	= 125 gm
Weight of fine foreign material	= x gm
Weight of splits	= y gm
Weight of portion used to calculate percentage splits	= (125 - x) gm
Percentage splits	= 100 * y / (125 - x)

The data were analyzed statistically (SAS/STAT Guide, 1985) to determine the factors that significantly contributed to damage during pneumatic conveying. Means were separated where applicable by Duncan's Multiple Range Tests.

RESULTS AND DISCUSSIONS

Effect of Air Velocity

The effect of air velocity on damage in rice is shown in Table 1. Pneumatic conveying caused an increase in the amount of damaged kernels, however, the difference between conveying air velocities was small for each type of rice. Medium grain rough rice was less susceptible to damage than long grain rough rice (Figure 2.). This could be due the higher strength of the medium grains due to their smaller length to width ratio. Conveying medium grain rough rice in a pneumatic conveyor resulted in an increase of about 3 points in percent broken kernels while long grain rough rice had an increase of about 5.4 points. However there was no varietal differences in increase in amount of fissured kernels. A high percentage of brokens probably resulted from kernels that were initially fissured and pneumatic conveying mainly caused the rice to fissure. The amount of brokens in long grain brown rice was only slightly higher than in long grain rough rice while the amount of fissures was much lower (Figure 2). It was expected that pneumatic conveying of rough rice would result in lower amount of damaged kernels because the rice grain is protected by the husk. Shelling and milling of the rough rice after pneumatic conveying may have contributed to the amount of brokens and fissures in the sample.

Percent brokens in wheat and percent splits in soybeans due to conveying air velocity are also shown in Table 1. Pneumatic conveying damage to wheat is small when compared to rice and soybeans. As air velocity was increased, the brokens in wheat decreased, but the difference was not statistically significant. The lowest conveying velocity of 26.1 m/s produced the highest amount of splits in soybeans and damage to soybeans decreased significantly as air velocity increased. The percentage of splits was not significantly different for air velocities from 28.7 to 39.4 m/s. The bivariate air velocity X air to solid (A/S) ratio interaction was not significant for all five types of grains. It was found that 26.1 m/s was the lowest air velocity that could be used for conveying in this particular system. At lower velocities, plugging of the lines occurred and it was difficult to convey the grains.

Effect of Air to Solid (A/S) Ratio

Air to solid (A/S) ratio was significantly associated with the percentage of fissured grains in both varieties of rough rice ($p<0.05$) but did not affect the amount of brokens (Table 2). A/S ratio also had a significant effect on brokens in wheat ($p<0.05$) and splits in soybeans (Table 2).

The fissures in long grain rough rice increased with the A/S ratio, and was significantly lower at the lowest A/S ratio of 2:1. A reverse trend was observed for medium grain rough rice where the highest A/S ratio of 10:1 produced the lowest increase in fissured kernels. No reason could be ascertained for the observed trends except that differences in rice variety and experimental uncertainty may be contributing factors. The amounts of brokens and fissures in long grain brown rice were not significantly different at all A/S ratio investigated. In the case of wheat and soybeans, the lowest grain damage was observed at A/S ratio of 5:1 followed by A/S ratio of 2:1, respectively.

Damages to grains during pneumatic conveying generally arise from impact between the grains, at walls and at bends. The less turbulent the interchange in the flow pattern, the less damage is expected. Reduced turbulence could be caused by such factors as the grains moving in a continuous mass with little interaction between the particles or flowing smoothly at an ideal density and velocity in the conveyor. At the lowest A/S ratio of 2:1, a dense flow pattern was observed. The grains had a tendency to accumulate and drag at the bottom of the conveying path as they were initially discharged from the airlock. Then they moved in a continuous mass thus contributing to the lower damage observed at the highest feedrate. However, such a high feedrate is not recommended for practical purposes because of vibrations in the system, especially in the last pipe section and cyclone separator. The same behavior was observed for all types of grains used in the study. For wheat and soybean, an A/S ratio of 5:1 with an air velocity of 35.5 to 39.4 m/s may have created an ideal conveying condition within the range of the experiment in terms of minimum damage to the grains.

System Performance

Energy Requirements. As the grain flow rate increased, the specific energy (Wh/kg) consumed decreased. This was true for all the grains. There was little difference in the total power consumption between different conveying velocities for a particular A/S ratio. However, a very small increase in power requirement was observed as the velocity increased (Table 3). It was found that the power requirement decreased as the A/S ratio increased because more power was required to convey a larger mass. The system operated more efficiently at higher conveying velocities, and this was reflected in the ease of grain flow.

Pressure Drop. Table 3 also shows the pressure drop in the system. The pressure drop was the highest across the first elbow, starting from the airlock feeder, and decreased at the subsequent elbows. The pressure drops across the fourth and the fifth elbows were very small. In general, pressure drops decreased for each elbow with increasing A/S ratio and increased with increasing air velocity. For the lowest A/S ratio of 2:1 (maximum grain flow), the pressure drop was the highest for all the elbows.

CONCLUSIONS

1. Damages in grains increased due to pneumatic conveying. The amount of damaged grains tended to decrease with increasing conveying air velocity. However, the difference between conveying velocities was small for each type of grain.
2. Medium grain rough rice was less susceptible to damage than long grain rough rice during pneumatic conveying. Long grain rough rice was not more resistant to damage than long grain brown rice. The amount of damage in wheat was small when compared to rice and soybeans.
3. The amount of brokens and fissures tended to increase in long grain rough rice as the A/S ratio increased. No particular trend was observed for the other grains. The optimal A/S ratio for conveying rough rice was 3:1 and resulted in a smooth flow of grains. An A/S ratio of 2:1 caused irregular flow and system vibrations. For wheat and soybeans, an A/S ratio of 5:1 resulted in the lowest amount of grain damage.
4. Electrical power requirements increased with an increase in conveying air velocity and with a decrease in air to solid (A/S) ratio.
5. Pressure drops across elbows decreased with increasing A/S ratio and increased with increasing air velocities.

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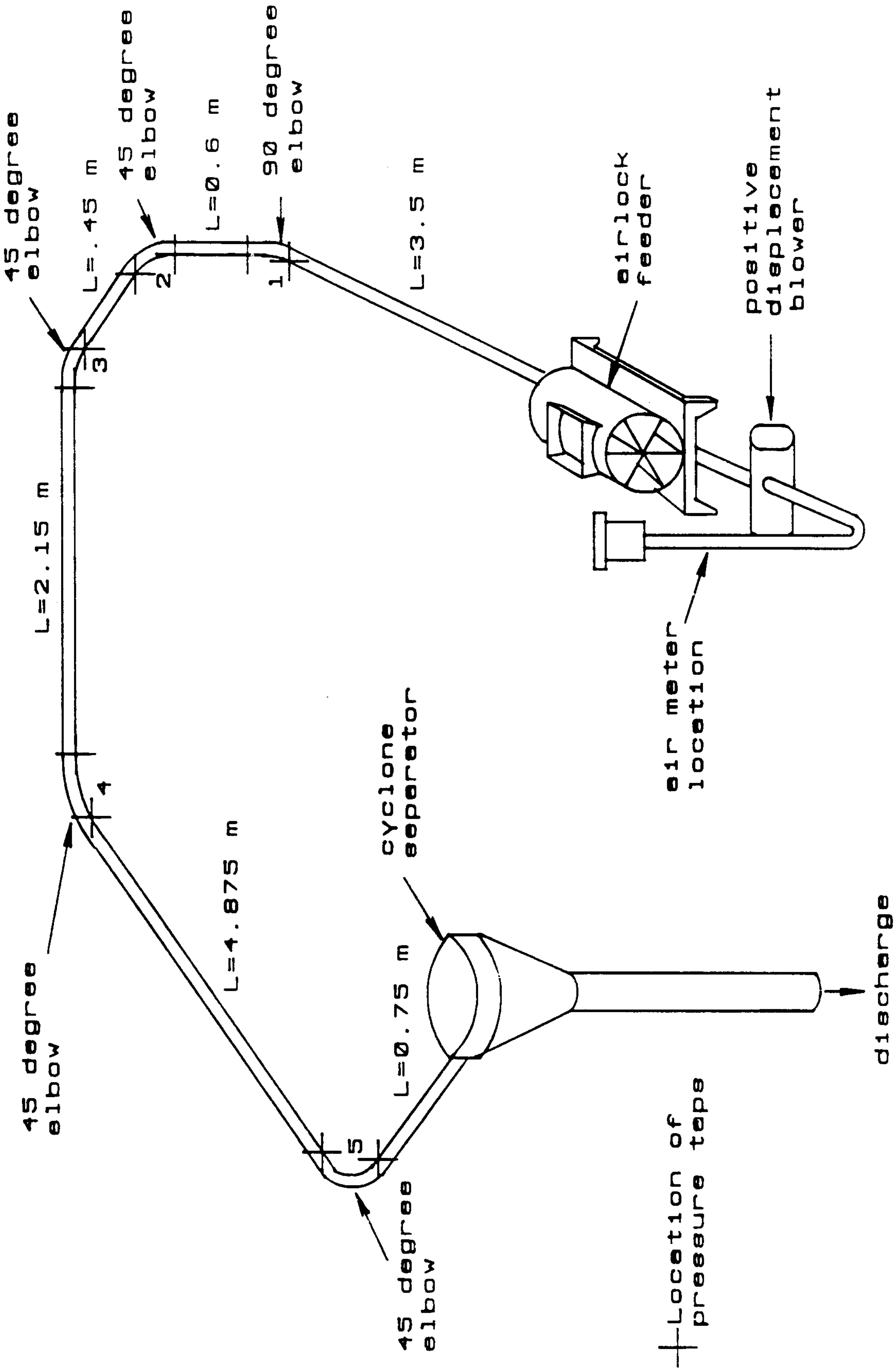

Figure 1. Configuration of pneumatic conveying system

Table 1. Effect of air velocity on damages in grains

Air Vel. (m/s)	Long Grain Rough Rice %Brokens	Long Grain Rough Rice %Fissures	Medium Grain Rough Rice %Brokens	Medium Grain Rough Rice %Fissures	Long Grain Brown Rice %Brokens	Long Grain Brown Rice %Fissures
26.1	57.88 a*	8.22 b	56.22 a	23.47 b	8.15 a	6.05 a
28.7	58.48 a	9.78 a	54.46 b	25.07 a	---	---
33.0	58.48 a	8.92 b	54.62 b	24.43 a	7.71 a	5.90 a
35.8	56.55 a	9.86 a	54.28 b	24.47 a	---	---
39.4	56.15 a	9.92 a	55.28 a	25.87 a	8.01 a	5.16 a

Air Vel.	Wheat %Brokens	Soybeans %Splits
26.1	----	9.32 a
28.7	0.31 a	8.00 b
33.0	0.32 a	7.76 b
35.5	0.28 a	---
39.4	0.28 a	8.21 b

* means with the same letter are not significantly different ($p<.05$)
--- Data not collected

<u>% Damaged Grains in Control samples</u>:

Long Grain Rough Rice:	%Brokens=52.12	%Fissures= 6.50
Medium Grain Rough Rice:	%Brokens=52.00	%Fissures=21.52
Long Grain Brown Rice:	%Brokens= 2.45	%Fissures= 4.83
Wheat:	%Brokens= 0.19	
Soybeans:	%Splits= 6.00	

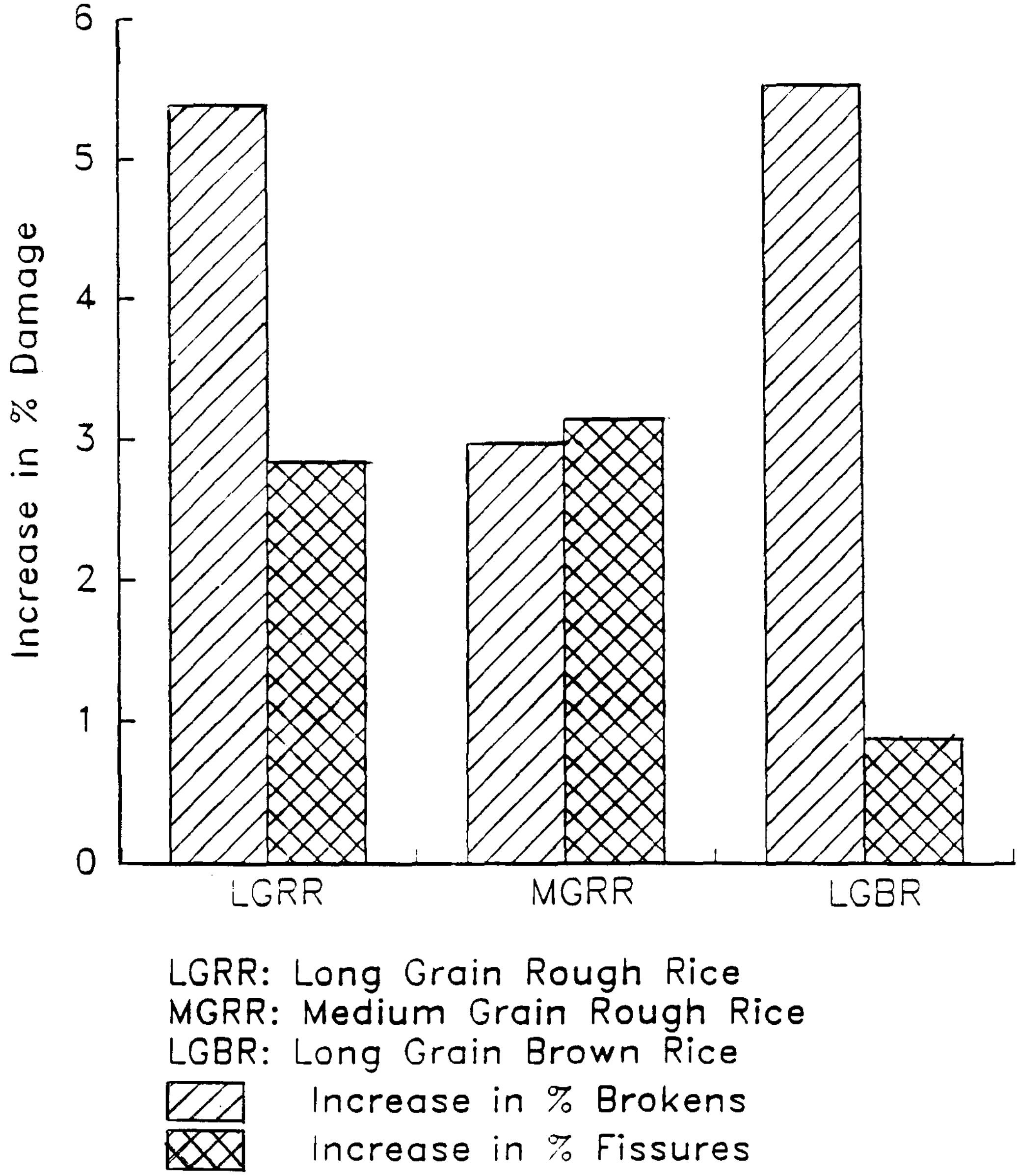

Figure 2. Increase in % Damage During Pneumatic Conveying

Table 2. Effect of air to solid (A/S) ratio on damages in grains

A/S Ratio	Long Grain Rough Rice %Brokens	Long Grain Rough Rice %Fissures	Medium Grain Rough Rice %Brokens	Medium Grain Rough Rice %Fissures	Long Grain Brown Rice %Brokens	Long Grain Brown Rice %Fissures
2:1	56.62 a*	8.26 b	55.06 a	25.89 a	7.75 a	5.51 a
3:1	57.65 a	9.65 a	54.86 a	24.77 a	---	---
5:1	57.94 a	9.90 a	55.49 a	25.29 a	8.01 a	6.19 a
10:1	57.83 a	10.33 a	54.48 a	23.25 a	8.11 a	5.26 a

A/S Ratio	Wheat %Brokens	Soybeans %Splits
2:1	0.31 a	8.00 b
3:1	0.33 a	8.11 b
5:1	0.23 b	7.60 b
10:1	0.32 a	9.52 a

* means with the same letter are not significantly different ($p<.05$)
--- Data not collected

<u>%Damaged Grains in Control samples</u>:

Long Grain Rough Rice: %Brokens=52.12 %Fissures= 6.50
Medium Grain Rough Rice: %Brokens=52.00 %Fissures=21.52
Long Grain Brown Rice: %Brokens= 2.45 %Fissures= 4.83
Wheat: %Brokens= 0.19
Soybeans: %Splits= 6.00

Table 3. **Pressure drops and power for pneumatic conveying of grains.**

		Pressure Drop (kg/cm^2) at points* 1	2	3	4	5	Power (kW)	Specific Energy (Wh/kg)
<u>Rough Rice</u>								
Air Velocity (m/s)	26.1	.052	.042	.035	.003	.002	2.50	1.38
	28.7	.040	.028	.017	.001	.001	2.46	1.25
	33.0	.048	.036	.024	.002	.002	2.56	1.06
	35.8	.054	.045	.027	.005	.002	2.80	1.15
	39.4	.060	.054	.033	.003	.002	2.90	1.12
A/S Ratio	2:1	.094	.074	.043	.003	.004	3.84	.97
	3:1	.056	.047	.034	.002	.002	2.56	.97
	5:1	.037	.030	.021	.004	.001	2.19	1.37
	10:1	.028	.022	.017	.003	.001	2.00	2.52
<u>Brown Rice</u>								
Air Velocity (m/s)	26.1	.031	.027	.013	.002	.002	2.75	1.52
	33.0	.065	.046	.029	.003	.004	2.75	1.14
	39.4	.066	.054	.027	.004	.003	3.61	1.39
A/S Ratio	2:1	.091	.068	.033	.006	.005	4.17	1.05
	5:1	.047	.040	.023	.002	.002	2.88	1.80
	10:1	.030	.024	.016	.001	.002	2.11	2.66
<u>Wheat</u>								
Air Velocity (m/s)	26.1	.050	.034	.022	.003	.003	2.40	.50
	33.0	.064	.039	.025	.002	.003	2.66	1.10
	35.8	.057	.041	.027	.002	.002	2.83	1.17
	39.4	.066	.051	.031	.003	.002	3.37	1.30
A/S Ratio	2:1	.098	.067	.044	.004	.005	3.73	.94
	3:1	.064	.044	.027	.002	.002	3.01	1.14
	5:1	.046	.031	.020	.002	.002	2.38	1.49
	10:1	.029	.022	.013	.002	.001	2.12	2.68
<u>Soybeans</u>								
Air Velocity (m/s)	26.1	.061	.046	.037	.003	.003	3.25	1.79
	28.7	.036	.025	.015	.002	.002	2.35	1.19
	33.0	.054	.039	.024	.003	.003	2.85	1.18
	39.4	.064	.053	.039	.004	.002	3.31	1.27
A/S Ratio	2:1	.097	.071	.048	.005	.003	4.36	1.09
	3:1	.065	.048	.035	.004	.004	2.92	1.10
	5:1	.045	.035	.025	.002	.002	2.42	1.51
	10:1	.033	.026	.019	.002	.001	2.08	2.63

* pressure drops across elbows in the conveying line at the points 1 through 5 in Figure 1.