AIRFLOW CHARACTERSTICS UNDER GRAIN AERATION AND DRYING CONDITIONS

by

GABIR ABDELGADIR ABDELMOHSIN

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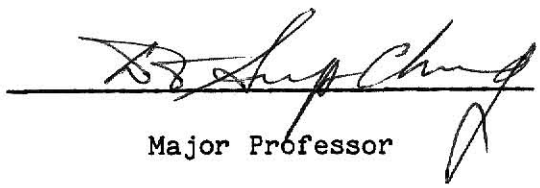
Department of Agricultural Engineering

Kansas State University

Manhattan, Kansas

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Approved by:



Major Professor

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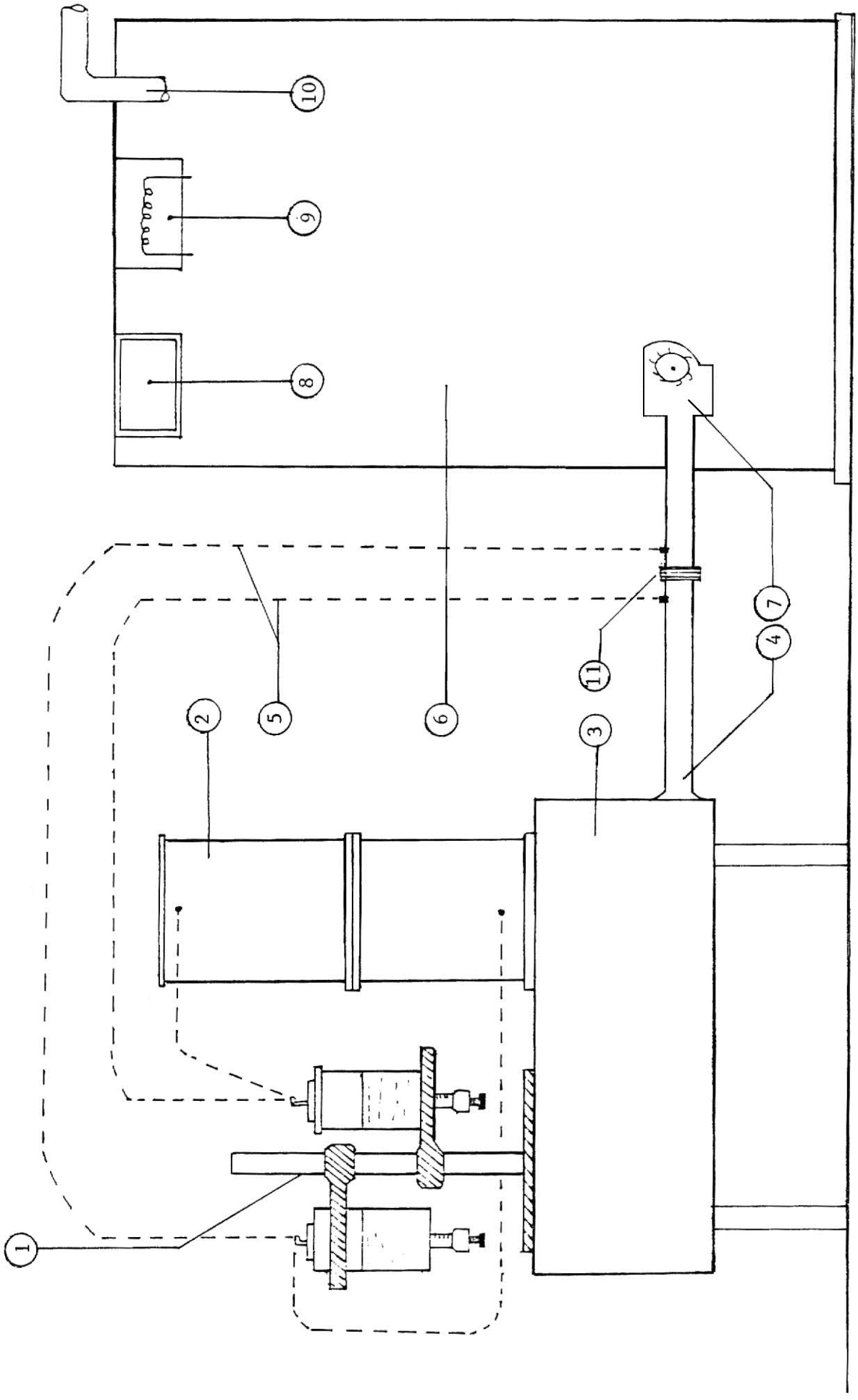


Fig. 1. Schamatic Diagram For The Experimental Set-up.

INTRODUCTION

It is a common practice to hold grain during the winter months, and more grain is being stored on farms before marketing, requiring proper and economic ways of preserving grain on the farm after harvest.

Grain drying is an energy intensive operation that will be increasingly affected by high fuel cost. To design drying and storage facilities requires a careful analysis of systems. Many factors influence the choice of equipment, but comparison of drying costs, performance, and capital costs are major factors in the decision. Because many systems and combinations of equipment are available, a systematic procedure for comparing optimized drying costs is needed to help farmers select the facilities best suited to their needs.

The most commonly used and effective grain conditioning method for preserving quality of grain during storage is aeration of grain by a low volume of natural air. Aeration is mainly used to cool the grain slowly and to prevent moisture migration by maintaining a uniform temperature throughout the grain mass; however, aeration is used in some parts of the United States to permit storage of 16 to 18% moisture grain from the time it is harvested until the following early spring. Furthermore, at some drying installations wet grain is held and aerated for short periods of time before it is dried, because dryers cannot keep up with the inflow of high moisture grain.

Determination of grain resistance to airflow is fundamental in the design of drying and aeration systems. In order to select a fan capable of overcoming the resistance offered by drying or aeration systems, one

has to know how much resistance will be developed in a particular bed of grain. The most common approach in estimating pressure drop through grain is to use experimental curves relating airflow and pressure drop (Ahmed et al., 1982). Shedd (1953), whose work is still regarded as the only available information practical enough to use, developed such curves for common seeds and grains. But its application is limited only to clean and dry grain. Haque et al. (1978) examined the effect of percent fine material in shelled corn at 12 % moisture content on airflow resistance through a bed of corn. He noted that broken and fine materials are continuously added during shelling, drying, and handling. Because the fine material has a higher resistance to airflow than does a mass of whole kernels, concentration of fine material causes a wide variation in resistance to airflow within a grain bed. In drying, the result is an inadequate drying of the core of fine material or overdrying of the remainder of the batch. The change in moisture content of grain during drying, storage, and handling influences packing characteristics of the grain; thus, this change in moisture content would affect the resistance to airflow through the grain bed.

Adequate information relating the amount of fine material and moisture content of grains to the airflow resistance is not available. Therefore, it is very important to know the characteristics of airflow within the grain bed with various percentages of fine material and moisture content in order to provide useful information about the aeration and drying process.

REVIEW OF LITERATURE

Recently Haque et al. (1978) used a clear plastic, cylindrical, vertical column to examine the effect of fine material in dry shelled corn at 12 % moisture content on airflow resistance. He reported that the pressure drop increased with the increased percentage of fines for the same airflow rate. The air pressure required to force air through a bed of grain is dissipated continuously due to friction and turbulence. Brooker et al. (1974) indicated that the pressure drop for airflow through any product depends on the airflow rate, the surface and shape characteristics of the product, the number, size and configuration of the voids, the variability of particle size, and the depth of the product bed.

Stephens and Foster (1976) studied the effect of the bin filling method on the segregation and distribution of fines and broken kernels. They concluded that nonuniform distribution of fine in grain bulk leads to nonuniform distribution of air used for aeration and drying. They also reported that airflow resistance through corn in a deep-filling bin was found to be 20 to 40% higher than that reported by Shedd and 100 to 300% greater for bins filled with mechanical spreaders.

There have been few studies done to investigate the effect of broken and fine material on static pressure and more work is needed in this area to understand the resistance of grain to airflow.

Shedd (1953) stated that for a given airflow rate the resistance for pressure was less for corn at 20 % or higher moisture than for the same corn after drying to lower moisture content by using the same

method of bin filling. Nissing (1958) worked with cotton seed to establish a relationship between airflow and the airflow resistance of the seed. He reported the amount of foreign matter and moisture content in the cotton seed, the bulk density, and the bed depth affect the horse power required to force air through the seed. Chung and Converse (1971) studied the changes on physical properties of corn and wheat caused by changes in moisture content relating to both adsorption and desorption of moisture. Their results were in agreement with the findings of Thompson and Isaacs (1967) who indicated that there was more void space in wheat than in corn at the same bulk density, due mainly to the higher true density of wheat. Patterson (1969) reported that the pressure drop through corn increases with an increase in moisture content by keeping porosity constant. Muchiri (1969) conducted tests with 8 to 28 % moisture (w.b.) corn and found that at an airflow rate of 10 m^3/min-t (8.93 cfm/ft^2) pressure drop does not vary with grain moisture content if the fractional volume is held constant.

Ahmed et al. (1982) conducted tests with 23 to 12 % moisture (w.b.) for corn, wheat, and sorghum. They found that static pressure drop in grains decreases with an increase in moisture content for the same level of airflow. They also reported that the effect of particle size, shape and surface, characteristics seems more pronounced than void fraction; for this reason, wheat exhibits much more pressure drop than corn, even though void fractions for both commodities remain almost the same. Patterson et al. (1971) found that static pressure drop for corn, 15 to 25 % (w.b.), increases with moisture, but decreases for navy beans. Osborne (1961) studied the resistance to airflow with a bed depth of

0.61 meter (2 feet) and air velocity below 5.3 m/min (17.5 ft/min). He noted that the results obtained can only be taken as a guide to the resistance to airflow, as the resistance will vary with change in bulk density which is in turn influenced by moisture content, degree of packing, and the kind of impurities present. Calderwood (1973) mentioned that the moisture content causes variation in resistance in seeds, but he did not specify what kind of effect the moisture has. Jindal and Thompson (1972) reported that for grain sorghum the pressure gradient did not change for 16.5 % moisture content but somewhat decreased with 8 % grain. Brown (1962) studied the variation of bulk density of wheat, barley, and oats with moisture content, and found that the bulk density decreases at higher moisture contents. Aas and Time (1960) found that the moisture effect on the pressure drop is dependent on the grain and moisture content range being tested. Brusewitz (1975) found that rewetted barley, corn, grain sorghum, oats, rye, soybeans, and wheat display a decrease in bulk density with increasing moisture content up to 30 % and an increase in bulk density at moisture higher than 30 %.

Stephens and Foster (1976) reported an increase in bulk density and airflow resistance for both dry and high moisture shelled corn in a bin filled by mechanical grain spreaders over the beds obtained without spreaders. The same conclusion was drawn by Stephens and Foster (1978) for wheat and grain sorghum. Lawton (1965) noted that the resistance to airflow depends on the type of seed and largely on the degree of packing and the presence of contaminants. Thompson and Isaacs (1967) reported that a high grain test weight or bulk density denoted a low percentage of void space. The reduction in void space associated with the grain as

it is dried probably accounts for the increased static pressure required to move a given quantity of air through the dry corn. They found that the porosity percent of voids or air space of bulk lots of shelled corn was influenced by differences in variety, kernel moisture content, amount of fine material, method of harvesting, and method of drying. They also found that the porosity of shelled corn increased with an increase in the kernel moisture content.

There have been many attempts made to describe the relation between static pressure drop and airflow rate in terms of:

1- Graphical curves, which is known as SHEDD'S CURVES

2- Emperical equations

3- Theoretical equations

Data on the airflow-static pressure relationship of a number of biological products have been published in graphical form in the American Society of Agricultural Engineers' yearbook (1980). These curves, known now as "Shedd's curves," are widely used and were adopted as ASAE Technical Data -D 272- (American Society of Agricultural Engineers' Yearbook, 1980).

Similar experimental curves were developed for various products. Stirniman (1931) worked with rough rice; Henderson (1943) with corn; Henderson (1944) with oats and soybeans; Shedd (1945) with ear corn; Shedd (1951) with soybeans, corn, oats, rough rice, red colves, and alsike colver; Day (1963) with crushed and noncrushed dry hay; Husain and Ojha (1969) with rough rice; Calderwood (1973) with rough and milled rice; Agrawal and Chand (1974) with rough rice; and Ahmed et al. (1982)

with wheat, corn, and sorghum. The use of these experimental curves has a definite advantage in convenience, but the accuracy of the pressure drop prediction may be poor because of insufficient consideration of the effects of variations due to some important factors, such as fine materials and moisture content. Shedd (1951) observed changes in a pressure drop of over 60 % at the same airflow rate when the filling method was changed. Shedd's curves are for loose fill condition which was obtained by pouring grain into a funnel, the outlet of which was held just above the surface of the grain in the bin. Shedd (1953) listed some arbitrary correction factors (based on judgement) to apply to values from Shedd's curves to account for variations in filling method, grain moisture content, and foreign materials in the grain. Practicality and simplicity made the use of Shedd's data very widespread among grain drying and aeration system designers.

Several studies have been made to obtain equations to fit experimental curves relating airflow and pressure drop. Henderson (1944) used the following equation:

$$V = K (\triangle P)^{c} \qquad [1]$$

where V = airflow rate, cfm/ft^2.

Delta P = static pressure drop per ft depth, inches of water.

K and c = constants.

Shedd (1953) also fitted his data to equation 1. He stated that a particular set of constants, K and c, give good prediction over only a narrow range of flow rates. This equation assumes a straight line rela-

tionship between static pressure and airflow rate on a log-log plot. Hukill and Ives (1955) proposed the following equation for Shedd's data:

$$\Delta P = \frac{a\ V^2}{\log_e (1 + b\ V)} \qquad [2]$$

where a and b = constants depending on the product.

This equation can be used to express the relationship between velocity and pressure drop, with good accuracy throughout the range of velocities reported, by proper selection of the constants a and b.

Haque et al. (1978) modified equation 2 and made it applicable for corn containing fines. The equation presented by them is of the form:

$$\Delta P = c_1\ V + c_2\ V^2 + c_3\ V\ (\ f\ m\ ) \qquad [3]$$

where fm = fine material percent, expressed as decimal.

c_1, c_2, c_3 = constants.

This equation could be used for an airflow ranging 5 - 25 m^3/min-t (15 - 75 cfm/ft^2). While Hukill and Ives' equation was based on a lower range of airflow 0.6 - 12 m^3/min-t (2 - 40 cfm/ft^2), equation 3 can be applied for a higher airflow rate.

Bern (1973) determined an equation to relate pressure drop to airflow rate through a bed of corn. The equation is:

$$\Delta P = A_n\ V^2 + B_n\ V + C_n \qquad [4]$$

where A_n, B_n, and C_n = grain characteristics coefficient.

He stated that the accuracy of equation 4 for pressure drop prediction is likely to be poor at the low flow rates.

Ahmed et al. (1982) modified equation 3 to replace the fine material with moisture content:

$$\Delta P = A\ V + B\ V^2 - C\ (MC)\ V \qquad [5]$$

where MC = moisture content, % w.b.

A, B, C = constant depending on the product.

They reported that the equation adequtely describes the relation between the static pressure drop and airflow rate with good accuracy throughout the range of velocities tested.

Ergun (1952) developed an equation by theoretical analysis. The equation is:

$$\Delta P_o = \frac{150\ (1-\epsilon)^2\ L\ \mu\ V}{\epsilon^3\ d^2\ g} + \frac{1.75(1-\epsilon)\ L\ \rho\ V^2}{\epsilon^3\ d\ g} \qquad [6]$$

where ϵ = void fraction (dimensionless decimal) on volume bases.

μ = fluid viscosity, lb-sec/ft^2.

ρ = fluid density, lb/ft^3.

ΔP_o = pressure drop, inches of water per ft.

d = equivalent particle diameter.

g = acceleration due to gravity, ft/sec^2.

L = bed depth, ft.

V = velocity, ft/sec.

The equation reflects all the independent variables on which the

pressure drop depends. Bakker-Arkema et al. (1969) and Patterson (1971) extended Ergun's equation to cover agricultural products such as shelled corn, cherry pits, and navy beans. Matthies and Petersen (1974) developed a similar equation for different biological products. Application of these types of theoretical equations is extremely difficult.

OBJECTIVES

The objectives of this investigation were:

1. To examine the effects of the moisture content and the broken kernels and fine materials in grain sorghum on airflow resistance; and

2. To develop a model that will predict the effects of moisture content and fine materials on airflow resistance.

EXPERIMENTAL DESIGN

To prevent confounding the time factor with controlled variables (air velocity, moisture content, and fine material), a complete randomization of the order in which we conducted the experiment was applied. The response variable was the static pressure drop. Void space was considered as an extraneous variable which affects the outcome of the experiment, but it is uncontrollable. We let the void space vary naturally with grain moisture content and fine material for a particular filling method, because this is the type of situation that actually occurs in grain storage.

We conducted the experiments with grain sorghum harvested in 1981. Five levels of moisture content (18.5, 16.5, 15, 13.5, and 12 % w.b.) and four levels of fine material (8, 4, 2, 0 %) were investigated. Each level of fine material was tested with four levels of moisture content for ten different airflow rates. Three replications were made at each treatment combination. A total of 48 different beds were prepared and tested for 10 airflow rates.

Table 1 shows the experimental variables and their levels.

Table 1. Levels of Experimental Variables.

Variable	Levels	No. of Levels
Airflow	Range from 0.025 to 0.19 m/s	10
Moisture Content (% w.b.)	12, 13.5, 15, 16.5 and 18.5	5
Fine Material	0, 2, 4 and 8 %	4

MATERIALS AND EQUIPMENT

The equipment used to conduct experiments was the same equipment used by Ahmed et al. (1982). Figure 1 shows a schematic diagram for the experimental set-up. The test column was constructed from 2.75 mm mild steel sheet rolled into 29.9 cm diameter and 30.5 cm long section. The sections were connected by flanges to increase and decrease the depth of the bed when necessary. The total test bed was 51720 cu cm. The floor of the test bin was constructed of perforated sheet metal with 2 mm diameter holes, totaling 14 % of the entire floor area. Three mm diameter and 50 mm long copper tube pressure taps were welded to the test column wall at 30.5 cm intervals, beginning approximately 7.6 cm above the bed floor, by first drilling 4 mm diameter holes on the wall. The taps protruded inside the column to make sure that air became static at the tap. The plenum chamber consisted of a 91.4x91.4x30.5 cm rectangular box made of 2.75 mm mild steel sheet.

Measurement of airflow to the test bin was made using a 25.4 mm throat diameter ASME nozzle and a Hook gauge manometer capable of measuring up to 305 mm of water with a smallest reading of 0.0254 mm. A 25.4 mm of water pressure differential across the nozzle corresponded to approximately 0.57 m^3/min air. The flow nozzle was placed between the blower and the plenum chamber with a 50 mm diameter plastic pipe.

The air was supplied by a fan equipped with a 0.56 kW (3/4 HP) variable speed motor. We regulated the air flow with a dial type controller. Temperature and relative humidity of supplied air were controlled by using steam, an electric heater, and a cooler.

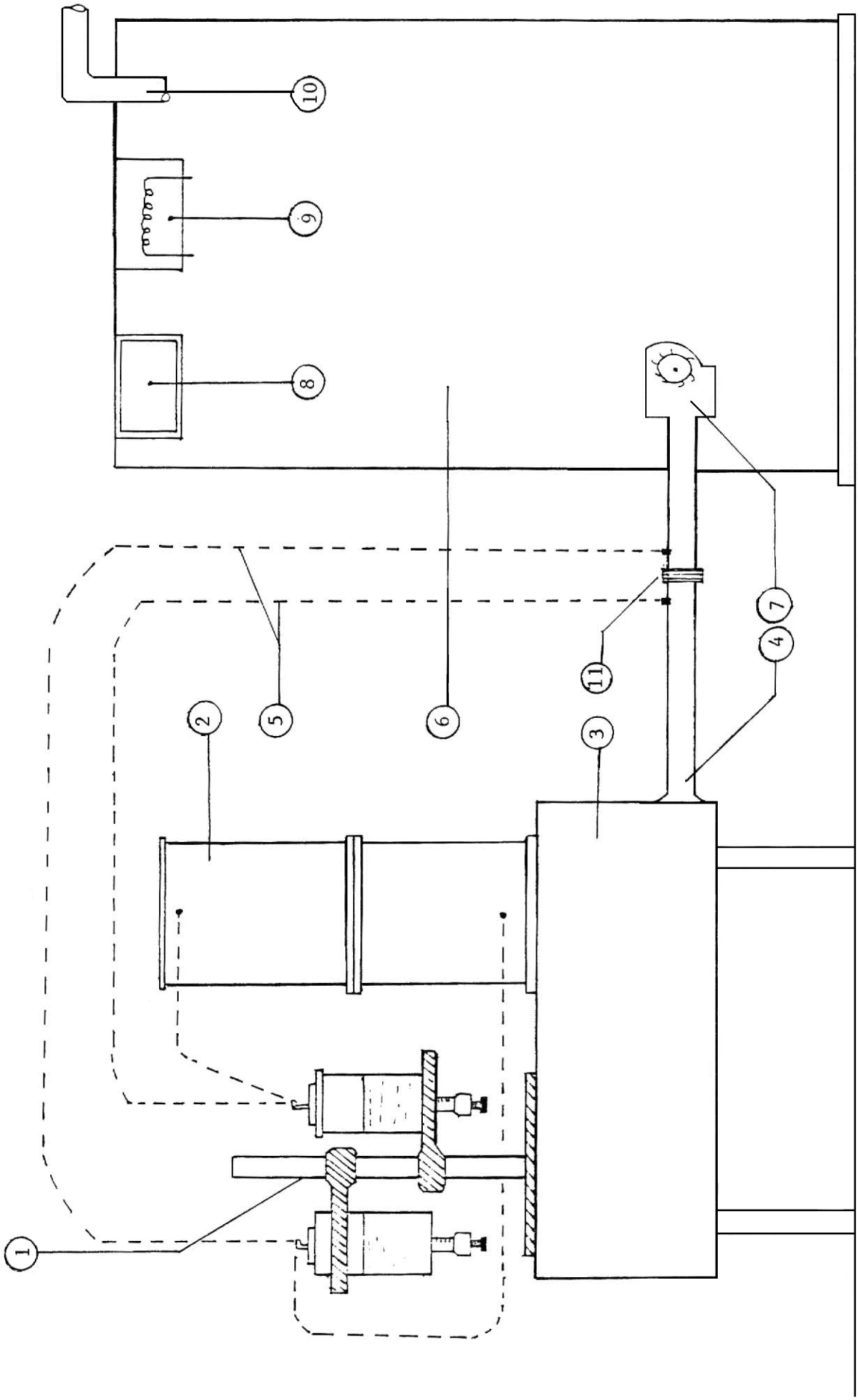


Fig. 1. Schamatic Diagram For The Experimental Set-up.

METHODS AND PROCEDURES

A grain cleaner was used to clean the grain. All foreign and fine material and broken kernels were collected for a later use. The fineness modulus (Henderson and Perry, 1976) for the grain sorghum used was found to be 5.05 and the average kernel size was found to be 3.45 mm. After mixing the grain with the desired percentage of fine, it was placed inside the test column. Fine materials include all broken kernels and foreign materials that pass readily through a 1.984 mm (5/64 of an inch) triangular hole sieve. We followed the loose filling method which was described by Shedd (1953). We poured the grain into a funnel, the outlet of which was held just above the grain surface, making sure to raise the funnel gradually as the filling progressed. The depth of the test bed was 73.7 cm. The section fixed for measurement consisted of a 61 cm portion with the first measurement taken 7.6 cm above the bottom of the test unit.

Prior to each test the temperature and relative humidity of the supply air inside the environmental chamber were controlled by an air conditioning unit and kept fairly constant, at approximately 26.6° C and 65% R.H. After the test bed was prepared, the fan was turned on, and the desired dial reading was set to control the airflow. Pressure differential across the nozzle was read from the Hook gauge manometer for calculating the airflow rate. The static pressure drop across the grain bed was read by the same Hook gauge manometer after properly closing the ASME nozzle taps. These procedures were repeated for all of the 48 beds. For airflow calculations we constructed a plot of pressure in Pascals against velocity of the air through an ASME nozzle (Figure 2.)

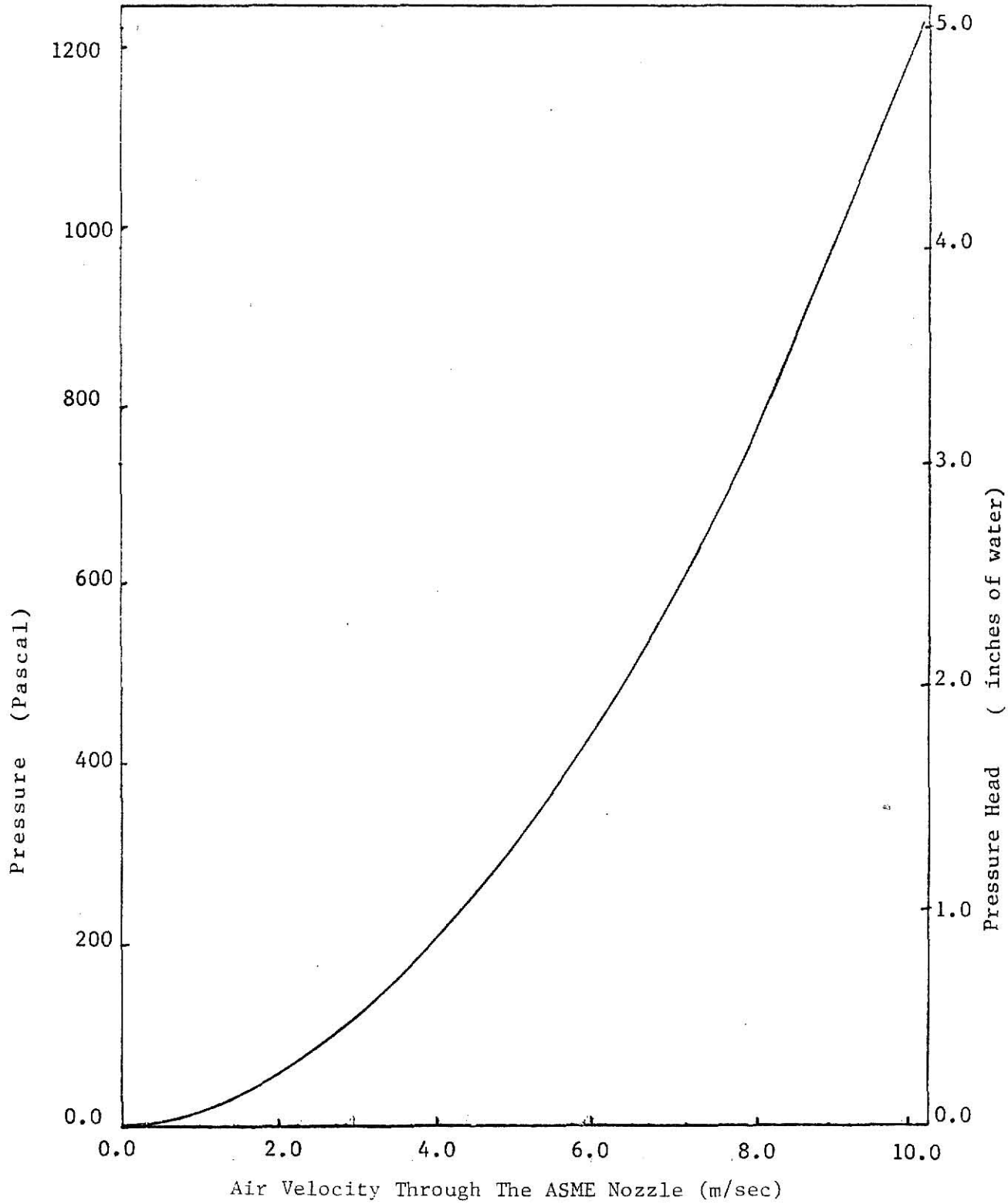


Fig. 2. Calibration Curve Of The ASME Nozzle.

RESULTS AND DISCUSSION

The experimental data collected from tests are presented in Tables 2 through 5, for various levels of moisture, fine material, and airflow rates, each with three replications. Also, average values of static pressure for three replications are tabluated in Tables 6 through 9. A small variation in moisture content took place during the test run and handling. The variation in the moisture is so small that, for practical purposes, we considered the three tests as three replications.

The average static pressure drops for three replications at four levels of moisture on each percentage of fine material were averaged and plotted on log-log graphs (Figures 3 through 6). For the purpose of comparison, Shedd's data (1953) were also plotted where we had clean grain (0% fines).

Figure 3 shows that all the curves run almost parallel to Shedd's curve for grain sorghum at 13.0 % moisture. The experimental curves for all moisture are to the left of Shedd's plot, which means that high moisture grain displays less resistance than dry grains. We can conclude from the above results that the static pressure increases with a decrease in moisture content. This pattern followed consistently over the range of moisture tested, except in the case of 12 % moisture content, which should be to the right of Shedd's curve but is on the left side. We attributed this to the particle size differential. The grain we used may have a larger particle size; in this case the static pressure tends to decrease, causing the graph to shift upwards. According to Booker et al. (1974), the pressure drop in the grain depends on the

following factors (1) air velocity, (2) shape and size of the grain kernel, (3) percentage of broken and fines in the bed, (4) moisture content of grain, (5) configuration of voids, and (6) depth of the grain bed. Ahmed (1982) reported a small variation from Shedd's data and attributed this to variation in variety. The effect of fine material at constant moisture content is shown in Figures 7 through 11. All the curves run almost parallel to each other, with the curve of the lowest percentage of fines appearing to the left of the others. This pattern appears in all levels of fines tested. We can conclude from the above result that static pressure increases with the increase of fine material.

In Tables 6 through 9 we observed that the maximum increment of 57 % in static pressure drop occurred between a moisture content of 16.5 and 12 % (w.b.) at the same airflow rate (0.03 m/sec) and same percentage of fine material (0.0 %). A minimum increment of 5 % was observed between moisture content of 18.5 and 16.5 % (w.b.) at the same airflow of (0.17 m/sec) and the same percent of fines (2 %). An increment of 123 % in static pressure drop was noticed, between 0 and 8 % fine material at the same moisture content (16.5 % w.b.) and the same airflow rate (0.03 m/sec). The minimum increment of 4 % was observed between percentage of fines, (2 and 4%) for the same moisture content (15 % w.b.) and the same airflow rate (0.17 m/sec).

Table 2. Air Velocity and Static Pressure Drop For Grain Sorghum at 0% Fine Materials at Different Moisture Levels.

Moisture Content % (w.b.)	Replication - I -		Replication - II -		Replication - III -	
	Air Velocity m/sec	Static Pressure Drop in (Pa/m)	Air Velocity m/sec	Static Pressure Drop in (Pa/m)	Air Velocity m/sec	Static Pressure Drop in (Pa/m)
15	0.034	57.69	0.030	68.58	0.034	64.09
"	0.046	100.42	0.046	104.05	0.048	91.90
"	0.068	164.10	0.068	161.65	0.067	141.24
"	0.095	253.90	0.093	237.57	0.093	210.00
"	0.113	311.05	0.113	300.44	0.108	275.89
"	0.135	382.07	0.136	382.87	0.137	396.77
"	0.148	456.40	0.148	441.67	0.148	441.67
"	0.158	499.60	0.158	484.13	0.160	498.80
"	0.167	542.09	0.168	537.20	0.167	533.11
"	0.185	605.77	0.180	596.79	0.180	597.60
16.5	0.07	162.50	0.058	92.08	0.056	92.00
"	0.090	237.58	0.078	155.50	0.065	144.50
"	0.114	308.60	0.102	235.90	0.100	204.10
"	0.130	380.00	0.123	308.60	0.115	275.90
"	0.143	432.70	0.144	388.20	0.134	349.40
"	0.150	484.95	0.157	454.79	0.151	425.35
"	0.155	515.15	0.167	500.26	0.162	483.30
"	0.170	600.16	0.178	591.00	0.174	533.11
"	0.177	618.90	0.190	618.00	0.185	609.00

Table 2. (contiued)

Moisture Content % (w.b.)	Replication - I -		Replication - II -		Replication - III -	
	Air Velocity m/sec	Static Pressure Drop in (Pa/m)	Air Velocity m/sec	Static Pressure Drop in (Pa/m)	Air Velocity m/sec	Static Pressure Drop in (Pa/m)
12	0.031	72.66	0.033	72.48	0.033	69.39
"	0.048	108.99	0.045	103.68	0.047	105.32
"	0.067	172.76	0.067	163.28	0.067	164.00
"	0.091	225.32	0.0915	244.10	0.092	239.20
"	0.108	293.90	0.110	289.00	0.110	293.09
"	0.134	398.40	0.135	397.59	0.1333	386.97
"	0.148	482.49	0.146	459.02	0.148	453.01
"	0.160	528.62	0.160	524.95	0.160	506.17
"	0.168	559.60	0.167	551.89	0.167	557.91
"	0.179	616.79	0.180	625.12	0.179	620.77
13.5	0.031	66.13	0.033	66.13	0.031	65.31
"	0.047	102.02	0.047	102.50	0.047	102.87
"	0.069	154.30	0.068	166.55	0.067	151.30
"	0.093	235.12	0.0933	227.36	0.092	240.84
"	0.113	330.64	0.115	327.36	0.112	325.74
"	0.133	379.63	0.134	384.52	0.134	375.54
"	0.147	456.37	0.148	461.27	0.148	466.16
"	0.160	502.90	0.160	505.35	0.160	506.17
"	0.167	564.13	0.166	558.42	0.166	555.15
"	0.179	632.55	0.179	603.32	0.179	602.50

Table 3. Air Velocity and Static Pressure Drop For Grain Sorghum at 2% Fine Materials at Different Moisture Levels.

Moisture Content % (w.b.)	Replication - I -		Replication - II -		Replication - III -	
	Air Velocity m/sec	Static Pressure Drop in (Pa/m)	Air Velocity m/sec	Static Pressure Drop in (Pa/m)	Air Velocity m/sec	Static Pressure Drop in (Pa/m)
12	0.033	89.80	0.033	82.68	0.034	85.72
"	0.049	129.00	0.049	126.54	0.049	122.46
"	0.068	194.94	0.068	189.80	0.068	190.27
"	0.091	285.74	0.092	273.49	0.091	277.58
"	0.113	360.03	0.114	353.10	0.113	354.32
"	0.135	445.75	0.135	439.22	0.134	443.71
"	0.147	512.70	0.147	509.30	0.149	512.70
"	0.162	587.80	0.160	585.40	0.160	585.40
"	0.166	620.46	0.167	615.60	0.167	619.00
"	0.177	694,80	0.177	692.30	0.178	689.05
13.5	0.033	68.17	0.032	73.48	0.033	73.58
"	0.048	108.80	0.046	113.89	0.046	111.44
"	0.066	189.00	0.066	178.89	0.066	180.01
"	0.090	270.64	0.091	266.56	0.089	265.33
"	0.111	337.17	0.113	339.22	0.114	342.48
"	0.132	422.90	0.134	426.98	0.133	425.60
"	0.147	493.11	0.144	477.19	0.148	487.80
"	0.160	552.71	0.160	549.03	0.158	551.89
"	0.166	594.34	0.166	583.32	0.165	585.77
"	0.177	648.63	0.178	644.94	0.179	606.59

Table 3. (continued)

Moisture Content % (w.b.)	Replication - I -		Replication - II -		Replication - III -	
	Air Velocity m/sec	Static Pressure Drop in (Pa/m)	Air Velocity m/sec	Static Pressure Drop in (Pa/m)	Air Velocity m/sec	Static Pressure Drop in (Pa/m)
15	0.033	77.97	0.033	74.29	0.0335	80.00
"	0.048	109.40	0.048	127.77	0.047	113.07
"	0.068	186.55	0.067	183.70	0.063	162.46
"	0.091	242.06	0.090	241.25	0.090	239.61
"	0.110	309.42	0.110	307.78	0.113	302.07
"	0.133	393.10	0.133	385.34	0.133	386.98
"	0.147	454.74	0.147	450.66	0.147	448.61
"	0.160	514.66	0.158	508.62	0.159	512.70
"	0.166	559.65	0.166	555.92	0.167	553.11
"	0.179	603.33	0.177	600.00	0.178	596.80
16.5	0.033	81.64	0.034	74.00	0.031	74.88
"	0.047	118.38	0.046	115.11	0.047	116.34
"	0.068	187.79	0.066	177.57	0.067	186.41
"	0.092	258.80	0.091	253.90	0.090	265.30
"	0.111	324.93	0.110	334.73	0.112	339.20
"	0.133	410.65	0.133	424.53	0.133	433.10
"	0.147	487.80	0.147	499.84	0.147	503.72
"	0.162	582.91	0.160	584.55	0.160	582.91
"	0.166	615.16	0.166	516.43	0.167	617.61
"	0.179	683.74	0.179	680.88	0.188	687.82

Table 4. Air Velocity and Static Pressure Drop For Grain Sorghum at 4% Fine Materials at Different Moisture Levels.

Moisture Content % (w.b.)	Replication - I -		Replication - II -		Replication - III -	
	Air Velocity m/sec	Static Pressure Drop in (Pa/m)	Air Velocity m/sec	Static Pressure Drop in (Pa/m)	Air Velocity m/sec	Static Pressure Drop in (Pa/m)
13.5	0.025	77.60	0.030	83.30	0.033	84.90
"	0.043	120.00	0.043	124.10	0.045	123.30
"	0.069	200.80	0.069	206.50	0.069	205.00
"	0.091	289.80	0.091	297.20	0.091	288.20
"	0.111	368.20	0.111	377.20	0.113	369.80
"	0.133	455.60	0.134	475.10	0.133	476.00
"	0.147	532.30	0.147	539.60	0.147	536.40
"	0.160	602.50	0.160	610.50	0.160	604.10
"	0.168	656.4	0.167	658.60	0.167	661.40
"	0.180	715.20	0.180	711.10	0.180	716.40
15	0.030	77.60	0.030	81.64	0.030	79.20
"	0.045	115.93	0.043	117.60	0.045	116.70
"	0.066	185.32	0.067	197.60	0.067	195.94
"	0.091	275.13	0.092	282.50	0.091	276.80
"	0.113	352.70	0.113	355.10	0.113	356.80
"	0.134	463.80	0.134	438.40	0.134	436.80
"	0.148	511.90	0.147	502.90	0.148	511.00
"	0.163	573.10	0.160	565.80	0.158	561.70
"	0.167	606.50	0.167	604.10	0.167	604.10
"	0.177	667.00	0.180	658.90	0.178	656.40

Table 4. (contiued)

Moisture Content % (w.b.)	Replication - I -		Replication - II -		Replication - III -	
	Air Velocity m/sec	Static Pressure Drop in (Pa/m)	Air Velocity m/sec	Static Pressure Drop in (Pa/m)	Air Velocity m/sec	Static Pressure Drop in (Pa/m)
16.5	0.030	76.70	0.034	78.40	0.030	77.56
"	0.045	110.20	0.045	118.10	0.045	113.48
"	0.069	184.50	0.067	179.60	0.069	180.40
"	0.092	256.32	0.091	257.20	0.094	259.60
"	0.113	272.60	0.113	298.00	0.113	321.60
"	0.134	398.40	0.138	395.14	0.138	395.14
"	0.146	466.98	0.148	459.60	0.146	459.60
"	0.160	528.20	0.160	525.76	0.160	511.90
"	0.167	561.80	0.166	555.20	0.165	542.90
"	0.180	608.22	0.176	606.60	0.180	604.95
18.5	0.031	79.60	0.030	68.58	0.033	80.00
"	0.046	122.46	0.046	123.28	0.045	104.50
"	0.067	195.94	0.067	174.70	0.066	174.71
"	0.090	284.52	0.091	283.10	0.092	284.11
"	0.111	355.95	0.111	328.20	0.110	333.10
"	0.133	441.67	0.134	400.90	0.133	420.45
"	0.147	508.80	0.147	479.23	0.148	489.92
"	0.160	572.09	0.157	509.40	0.160	542.90
"	0.168	607.40	0.168	554.34	0.166	578.82
"	0.19	645.36	0.180	605.77	0.178	622.10

Table 5. Air Velocity and Static Pressure Drop For Grain Sorghum at 8% Fine Mterials at Different Moisture Levels.

Moisture Content % (w.b.)	Replication - I -		Replication - II -		Replication - III -	
	Air Velocity m/sec	Static Pressure Drop in (Pa/m)	Air Velocity m/sec	Static Pressure Drop in (Pa/m)	Air Velocity m/sec	Static Pressure Drop in (Pa/m)
13.5	0.029	111.08	0.028	107.00	0.031	114.30
"	0.046	178.00	0.046	178.00	0.046	183.70
"	0.065	289.00	0.065	266.10	0.065	299.00
"	0.091	412.30	0.091	398.00	0.091	420.40
"	0.112	520.00	0.113	509.40	0.113	524.10
"	0.132	648.20	0.134	629.40	0.132	648.00
"	0.146	746.20	0.147	726.60	0.147	747.80
"	0.156	811.50	0.156	809.90	0.155	811.50
15	0.030	109.10	0.033	111.00	0.029	102.80
"	0.047	171.40	0.044	175.50	0.047	168.20
"	0.065	278.40	0.065	257.20	0.066	280.00
"	0.092	400.00	0.091	369.00	0.092	400.00
"	0.113	509.40	0.113	509.00	0.110	467.00
"	0.134	638.40	0.134	635.20	0.134	551.30
"	0.145	721..70	0.145	724.90	0.146	723.50
"	0.158	801.70	0.158	800.10	0.150	811.50

Table 5. (contiued)

Moisture Content % (w.b.)	Replication - I -		Replication - II -		Replication - III -	
	Air Velocity m/sec	Static Pressure Drop in (Pa/m)	Air Velocity m/sec	Static Pressure Drop in (Pa/m)	Air Velocity m/sec	Static Pressure Drop in (Pa/m)
16.5	0.033	106.10	0.032	106.50	0.033	106.90
"	0.046	163.30	0.047	169.00	0.047	160.80
"	0.065	256.40	0.066	267.40	0.066	246.60
"	0.092	389.40	0.092	388.60	0.092	368.20
"	0.110	489.80	0.113	490.60	0.133	494.10
"	0.132	626.20	0.134	627.00	0.135	575.60
"	0.146	653.90	0.150	671.70	0.146	639.00
"	0.160	741.30	0.158	765.80	0.160	748.60
18.5	0.031	96.30	0.031	94.70	0.034	98.90
"	0.047	146.95	0.047	147.80	0.046	146.20
"	0.092	321.70	0.091	320.80	0.092	323.30
"	0.110	400.00	0.113	402.50	0.112	402.50
"	0.134	500.40	0.133	494.30	0.135	501.30
"	0.146	576.40	0.147	576.40	0.147	573.10
"	0.167	685.90	0.166	682.50	0.165	680.80

Table 6. Average Static Pressure Drop Data For Grain Sorghum With 0 % Fine Materials.

Air Velocity (m/s)	Moisture Content (% w.b.)	Static Pressure Drop (Pa/m)
0.03	16.5	42
0.05	16.5	80
0.07	16.5	133
0.09	16.5	190
0.11	16.5	263
0.14	16.5	367
0.17	16.5	500
0.03	15.0	51
0.05	15.0	100
0.07	15.0	151
0.09	15.0	212
0.11	15.0	280
0.14	15.0	394
0.17	15.0	560
0.03	13.5	58
0.05	13.5	105
0.07	13.5	173
0.09	13.5	237
0.11	13.5	314
0.14	13.5	430
0.17	13.5	587
0.03	12.0	66
0.05	12.0	125
0.07	12.0	182
0.09	12.0	251
0.11	12.0	332
0.14	12.0	455
0.17	12.0	620

Table 7. Averge Static Pressure Drop Data For Grain Sorghum With 2 % Fine Materials.

Air Velocity (m/s)	Moisture Content (% w.b.)	Static Pressure Drop (Pa/m)
0.03	16.5	72
0.05	16.5	124
0.07	16.5	185
0.09	16.5	245
0.11	16.5	315
0.14	16.5	424
0.17	16.5	547
0.03	15.0	77
0.05	15.0	135
0.07	15.0	198
0.09	15.0	265
0.11	15.0	343
0.14	15.0	454
0.17	15.0	588
0.03	13.5	85
0.05	13.5	141
0.07	13.5	209
0.09	13.5	282
0.11	13.5	363
0.14	13.5	490
0.17	13.5	628
0.03	12.0	89
0.05	12.0	155
0.07	12.0	228
0.09	12.0	302
0.11	12.0	390
0.14	12.0	530
0.17	12.0	660

Table 8. Average Static Pressure Drop Data For Grain Sorghum With 4 % Fine Materials.

Air Velocity (m/s)	Moisture Content (% w.b.)	Static Pressure Drop (Pa/m)
0.03	18.5	65
0.05	18.5	112
0.07	18.5	175
0.09	18.5	233
0.11	18.5	304
0.14	18.5	412
0.17	18.5	517
0.03	16.5	71
0.05	16.5	123
0.07	16.5	182
0.09	16.5	248
0.11	16.5	327
0.14	16.5	432
0.17	16.5	543
0.03	15.0	78
0.05	15.0	134
0.07	15.0	204
0.09	15.0	272
0.11	15.0	350
0.14	15.0	465
0.17	15.0	610
0.03	13.5	86
0.05	13.5	142
0.07	13.5	215
0.09	13.5	290
0.11	13.5	372
0.14	13.5	503
0.17	13.5	653

Table 9. Averge Static Pressure Drop Data For Grain Sorghum With 8 % Fine Materials.

Air Velocity (m/s)	Moisture Content (% w.b.)	Static Pressure Drop (Pa/m)
0.03	18.5	81
0.05	18.5	150
0.07	18.5	219
0.09	18.5	308
0.11	18.5	382
0.14	18.5	518
0.17	18.5	660
0.03	16.5	94
0.05	16.5	168
0.07	16.5	250
0.09	16.5	342
0.11	16.5	438
0.14	16.5	590
0.17	16.5	747
0.03	15.0	105
0.05	15.0	181
0.07	15.0	267
0.09	15.0	372
0.11	15.0	460
0.14	15.0	630
0.17	15.0	793
0.03	13.5	118
0.05	13.5	208
0.07	13.5	300
0.09	13.5	420
0.11	13.5	510
0.14	13.5	695
0.17	13.5	848

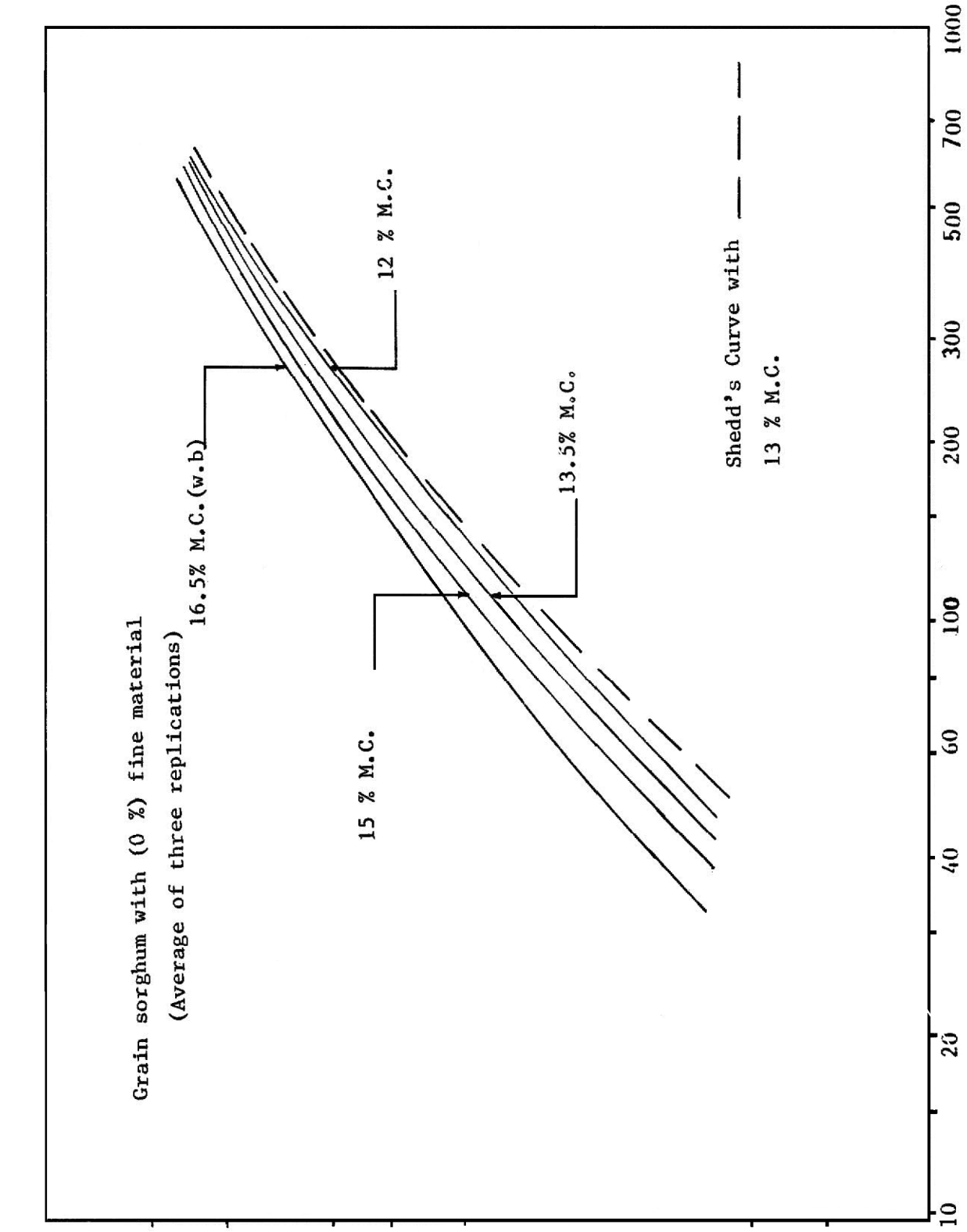


Fig. 3. Resistance of Grain Sorghum to Airflow at Different Moisture Contents.

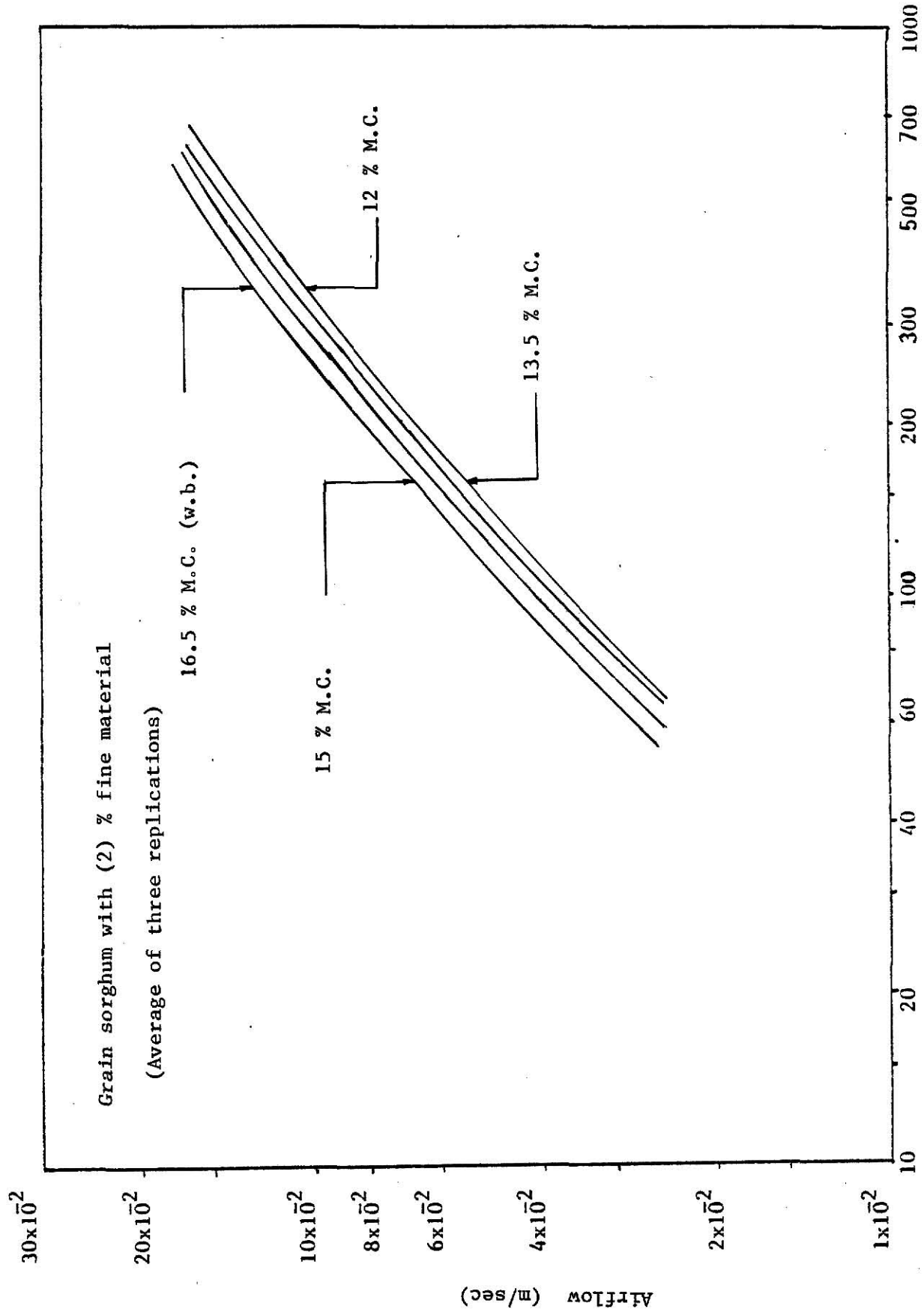


Fig. 4. Resistance of Grain Sorghum to Airflow at Different Moisture Contents.

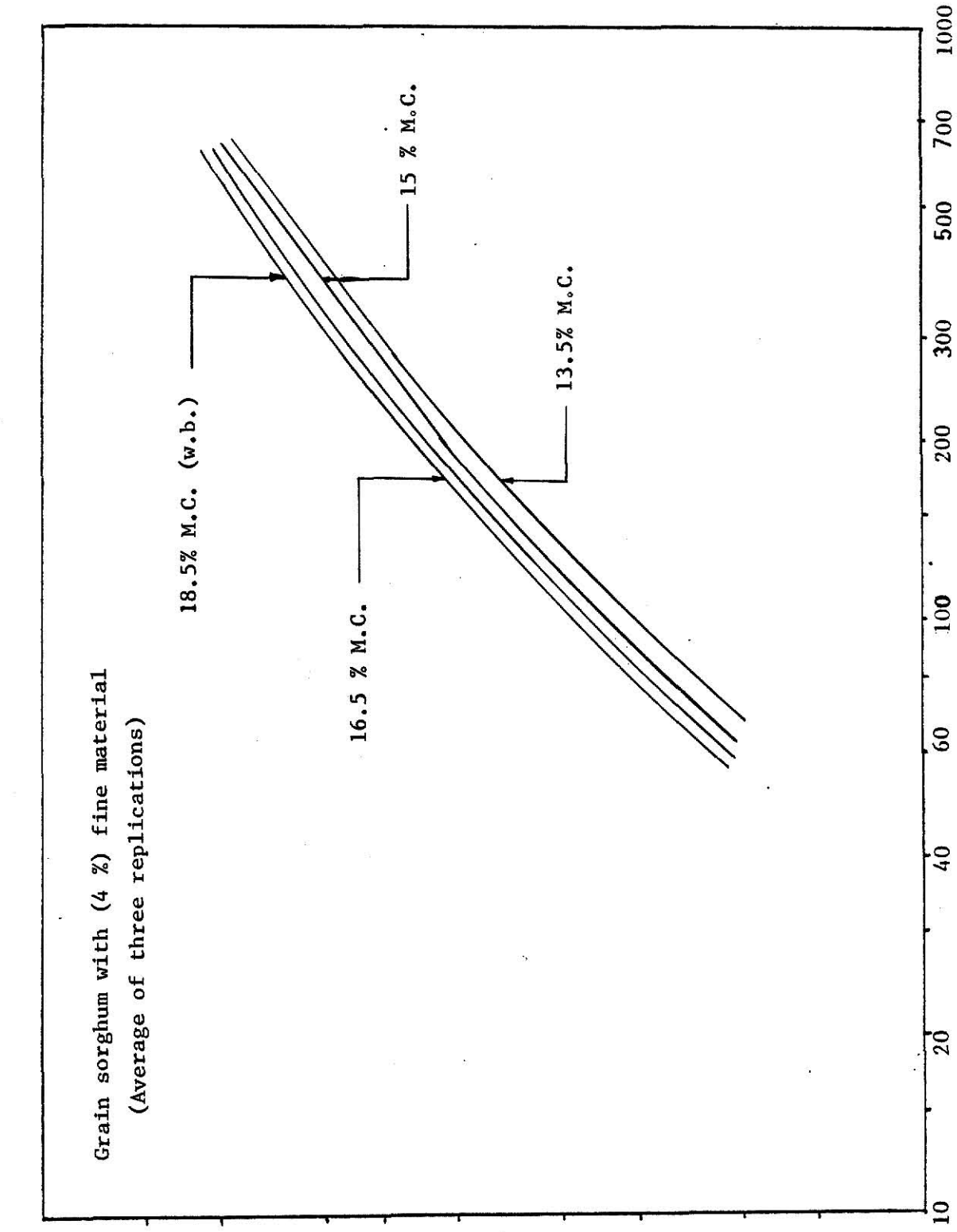


Fig. 5. Resistance of Grain Sorghum to Airflow at Different Moisture Contents.

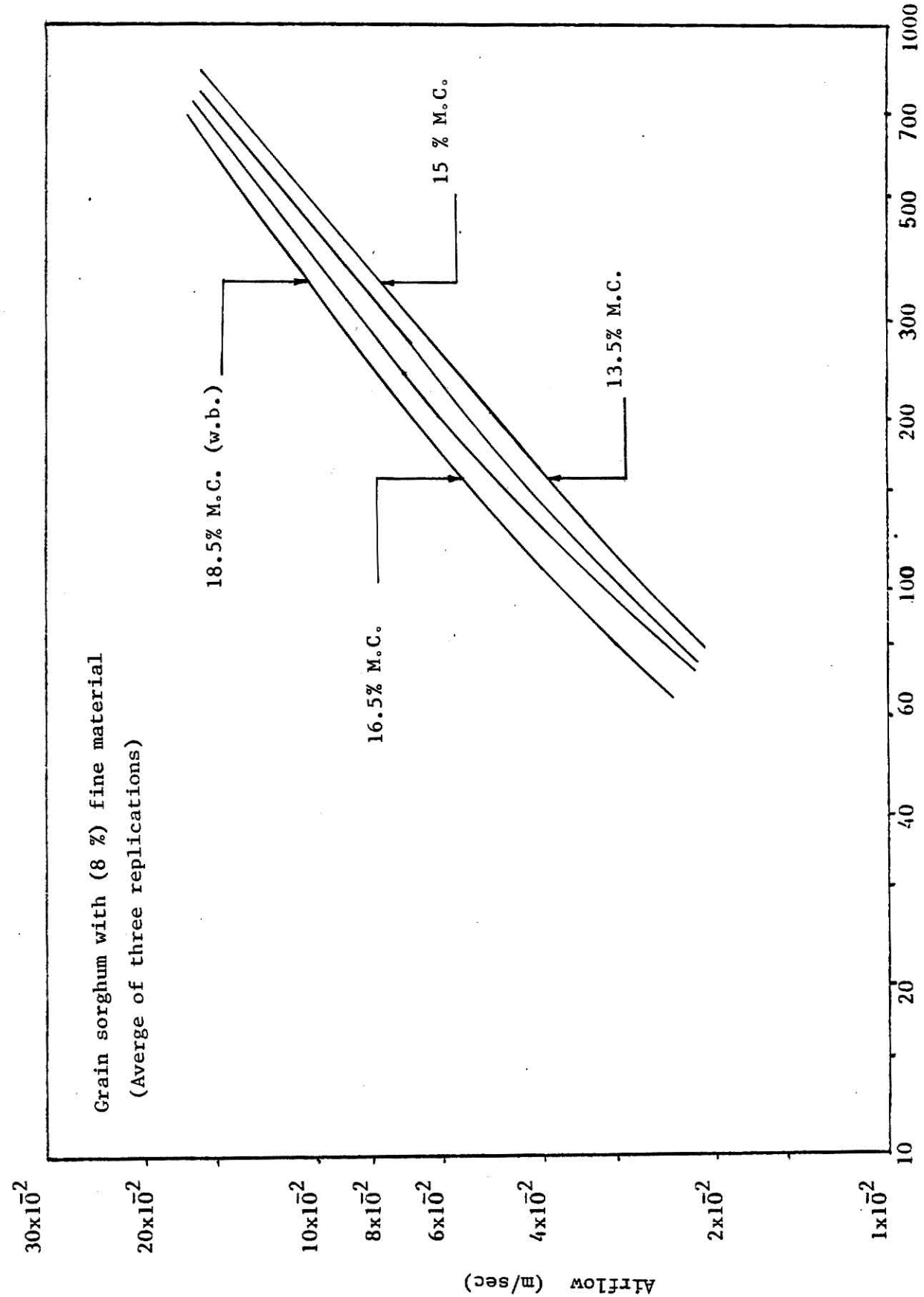


Fig. 6. Resistance of Grain Sorghum to Airflow at Different Moisture Contents.

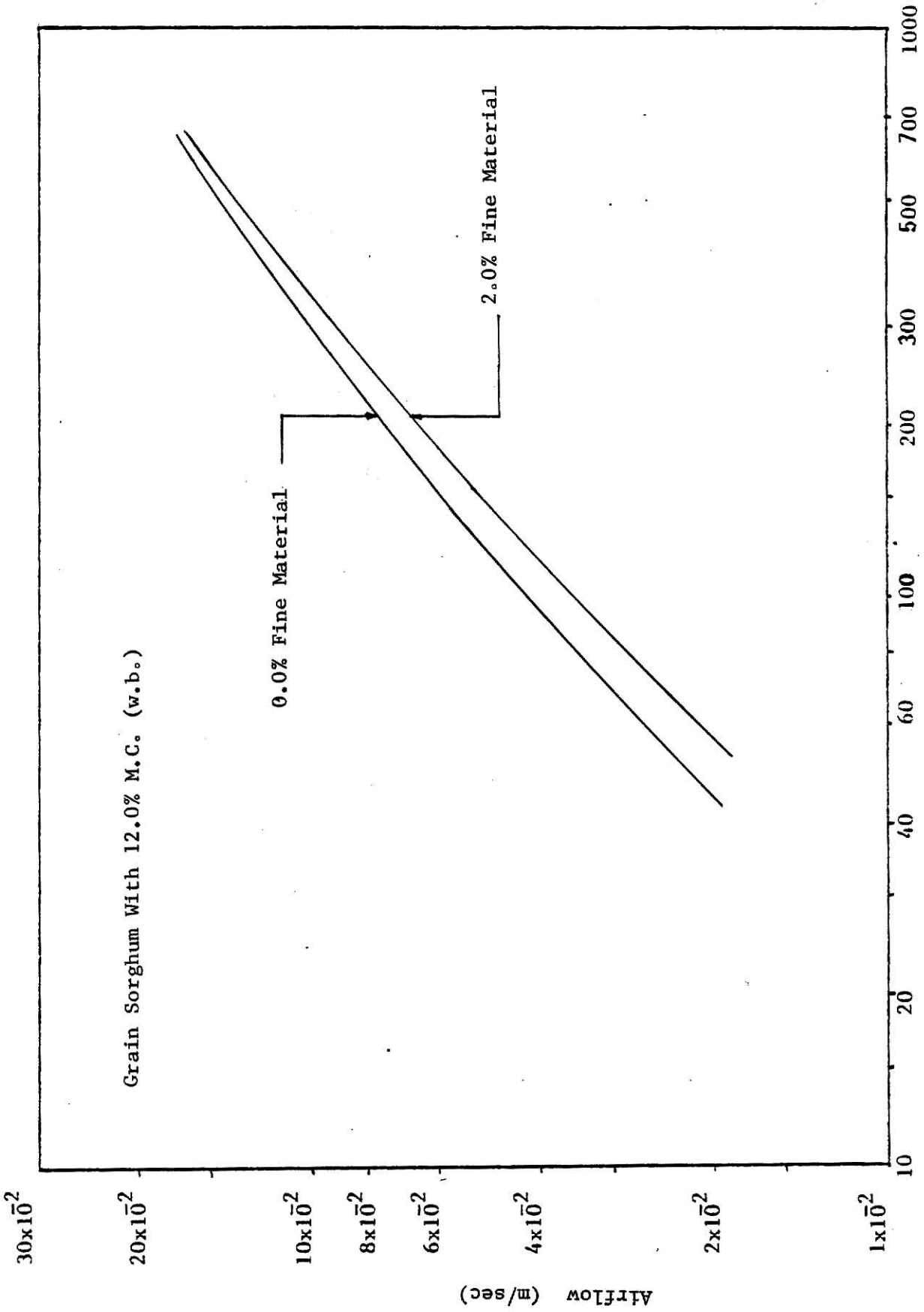


Fig. 7. Resistance of Grain Sorghum to Airflow at Different Percentage of Fines.

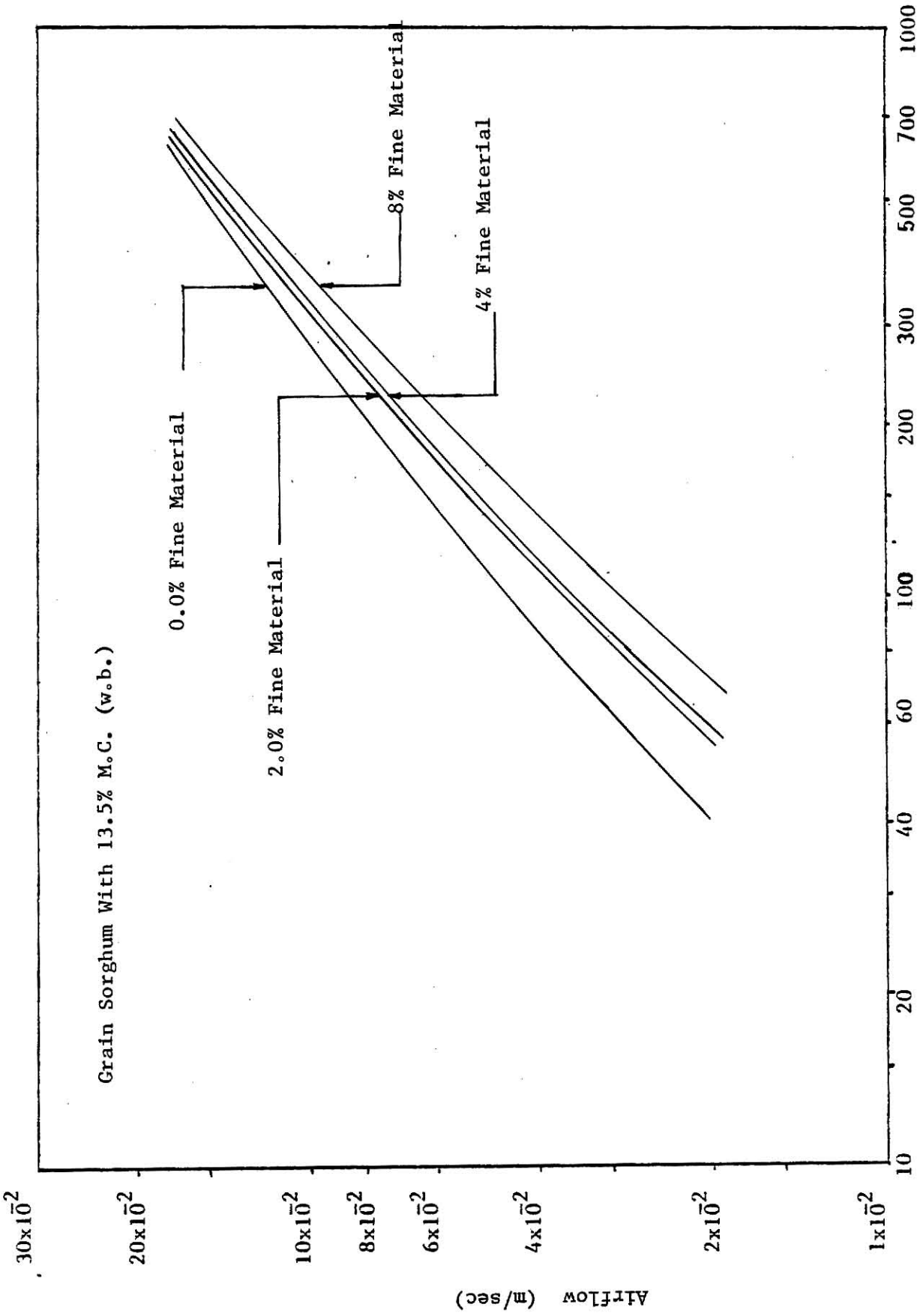


Fig. 8. Resistance of Grain Sorghum to Airflow at Different Percentage of Fines.

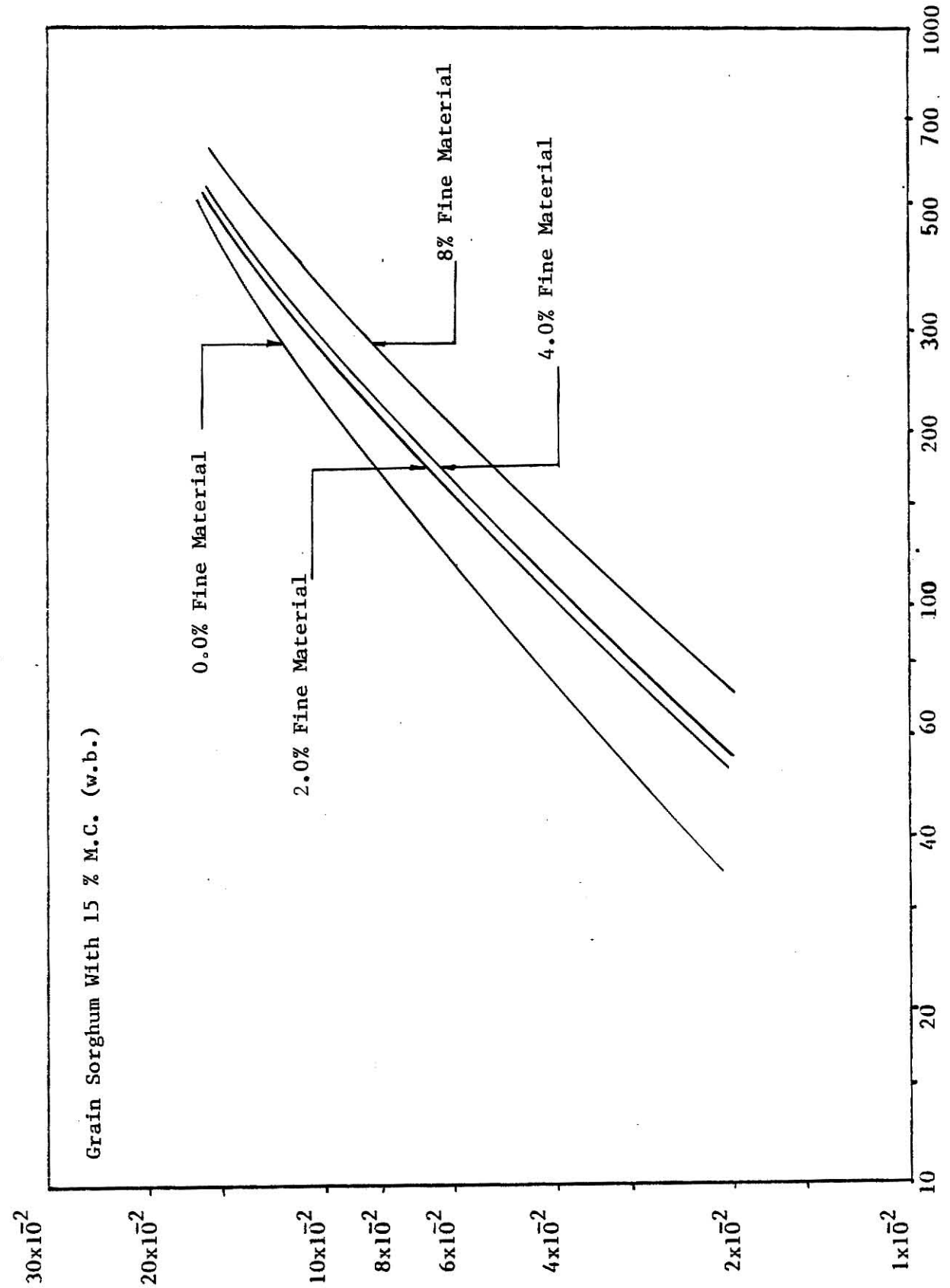


Fig. 9. Resistance of Grain Sorghum to Airflow at Different Percentage of Fines.

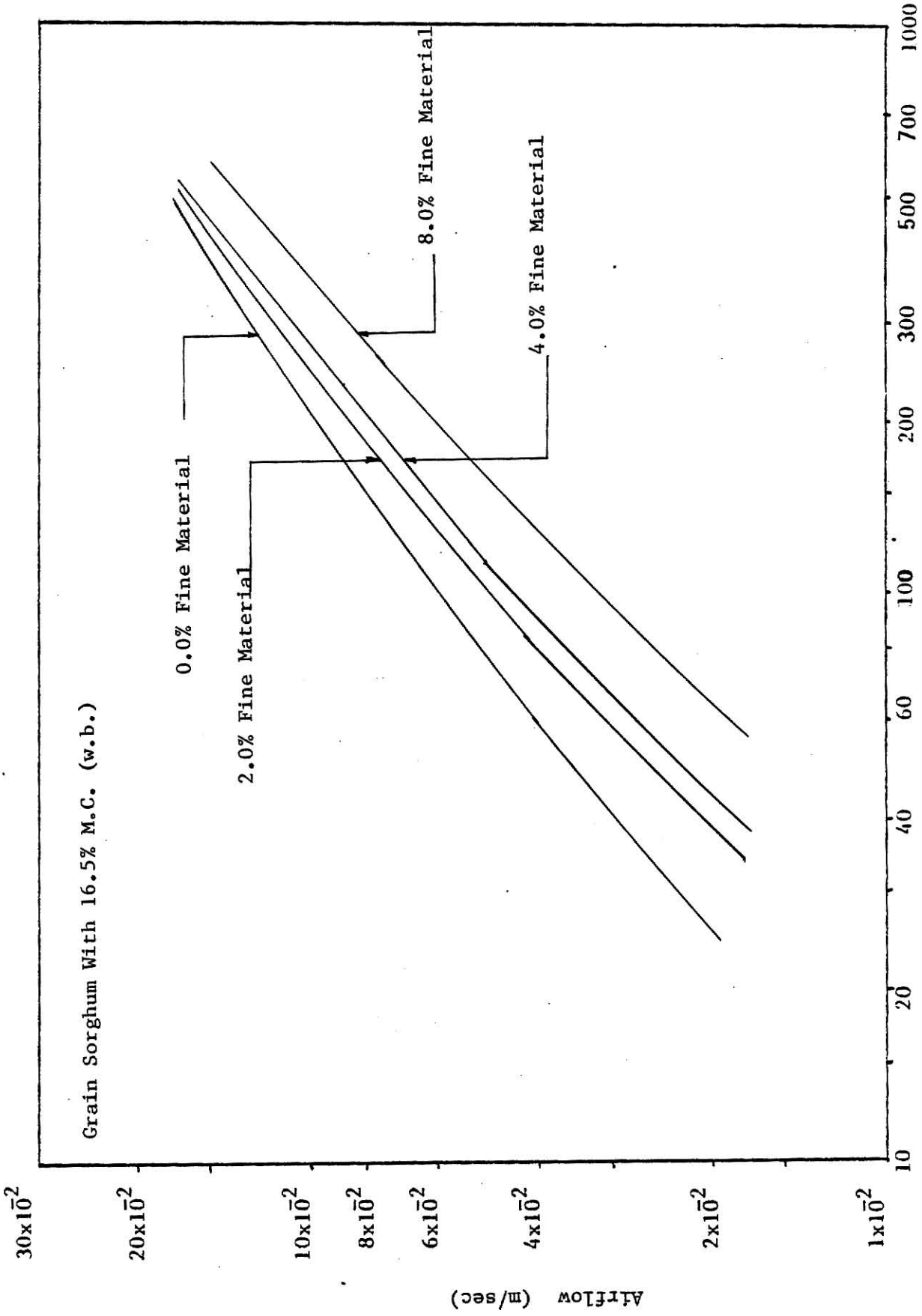


Fig. 10. Resistance of Grain Sorghum to Airflow at Different Percentage of Fines.

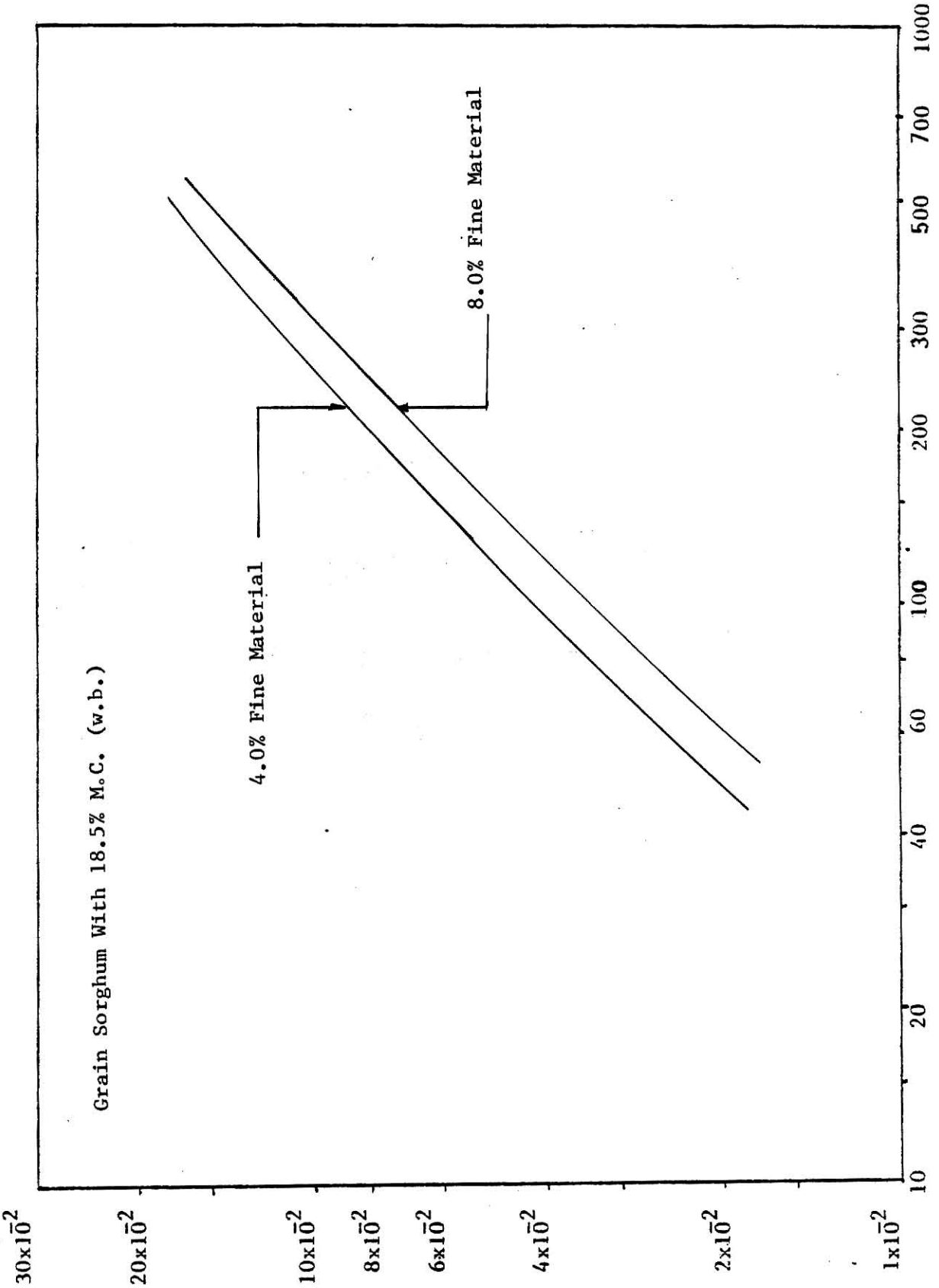


Fig. 11. Resistance of Grain Sorghum to Airflow at Different Percentage of Fines.

To analyze our data statistically, we need to have all the levels of airflow rate the same for every combination of moisture content and fine material. It can be seen from Tables 2 through 5 that we are unable to attain exactly the same air velocities. To overcome this difficulty, we interpolated from the static pressure drop corresponding to a fixed set of air velocities of 0.03, 0.05, 0.07, 0.09, 0.11, 0.14 and 0.17 m/s for the three replications from Figures 3 through 6. These pressure drop data with all treatment combinations were averaged and tabulated in Tables 6 through 9.

The independent variables were: air velocity, moisture content, and fine material. The dependent variable was the static pressure drop. Analysis of variance and multiple regression analysis were performed using a statistical computer package (SAS).

The following statistical model was used in analysing the data:

$$X_{ijk} = \mu + A_i + M_j + F_k + (A*M)_{ij} + (A*F)_{ik} + (M*F)_{jk} + \epsilon_{ijk}. \quad [7]$$

where X_{ijk} = Observed value (static pressure drop).

A_i = Average effect for the i treatment of air velocity.

M_j = Average effect for the j treatment of moisture content.

F_k = Average effect for the k treatment of fine material.

All other terms are interactions of the main effects

ϵ_{ijk} = The random error of static pressure.

The results of the analysis of variance show that all the main factors and their interactions significantly affect the static pressure, with the air velocity being the most significant effect followed by fine material and moisture content. The ANOVA table is shown in Table 10.

Table 10. Analysis of Variance for Static Pressure Drop for All Treatment Combination.

Source of Variation	Degrees of Freedom	Sum of Sq.	F-Value	Level of Signific.	Decision (1)
Airflow	6	3281021.3	13373.73	0.0001	Reject
Moisture Content	4	72363.9	442.44	0.0001	"
Fine Material	3	292897.2	2387.75	0.0001	"
AF*MC	24	22945.2	23.38	0.0001	"
AF*FM	18	67597.3	91.84	0.0001	"
MC*FM	8	4947.1	15.21	0.0001	"

(1) This decision is based on the null hypothesis that the group means for each effect are equal.

In order to select a model that will predict the effect of moisture and fine material, we followed the standard stepwise procedure to arrive at the following nonlinear regression model:

$$SP = A\,V + B\,V^2 + C\,(M.C.)\,V + D\,(F.M.)\,V \qquad [8]$$

where SP = Pressure drop per meter depth of grain, Pascal/m.

V = Air velocity, m/s

M.C. = Grain moisture content, % (w.b.)

F.M. = Fine material, %

A, B, C, D = Constants.

The values of constants evaluated are:

A = 4590.59

B = 7732.24

C = - 192.44

D = 196.76

This model fitted very well with our data. The coefficient of determination (R^2) (percentage of total variation around the mean, explained by the regression) was above 0.997 for this model. The computer programs for the analysis of variance and regression are presented in Appendix I.

The computer output compares the observed and predicted values, and shows a good agreement between them. Table 11 shows a comparison between randomly selected experimental values and values obtained using equation 8. Table 12 shows also a comparison between values read from Shedd's curve (1953) and those calculated by equation 8 at 13% (w.b.) moisture content.

Table 11. Comparison Betwween Experimental Data and Model Values.

Fine Mat.%	Moisture Content	Velocity m/s	P (Pa/m)		Percent Deviation
			Exp. Values	Model Values	
2	12	0.03	89.0	87.2	1.9
4	18.5	0.05	112.0	115.0	2.7
8	15	0.07	267.0	267.3	0.0
0	16.5	0.09	190.0	190.0	0.0
2	13.5	0.11	363.0	356.0	1.9
4	15	0.14	350.0	367.6	4.9
8	12	0.17	848.0	829.8	2.1

Table 12. Comparison Between Shedd's Data (1953) and Model Values.

Velocity (m/s)	Pressure Drop (Pa/m)		% Deviation From Shedd's Values
	Shedd's Values	Calculated By Equation 8.	
0.04	110	96	12
0.06	163	154	5
0.08	245	217	11
0.10	325	287	11
0.12	367	363	1
0.14	489	444	9

Design of an aeration system is commonly made based on Shedd's data. Shedd (1953) reported the following: "For high moisture grain use only 80 % of the indicated pressure drop for a given rate of flow. Packing of grain in a bin may cause 50 % higher resistance to airflow. When foreign material is mixed with grain, no specific correction can be recommended." So present practice usually ends up with higher power requirements than our study shows.

CONCLUSIONS

Within the range of moisture and fine materials investigated, the following conclusions were drawn from this study:

1. Static pressure drop in grain sorghum increases with the decrease in moisture content. The increment ranges from 5 to 58 % depending on airflow and moisture range tested.

2. Static pressure drop in grain sorghum increases with increase in fine and broken materials. The increment ranges from 4 to 123 % depending on what range of fine material is investigated.

3. The statistical model

$$SP = A\,V + B\,V^2 - C\,(M.C.)\,V + D\,(F.M.)\,V \qquad [9]$$

adequtely describes the relationship between static pressure drop, air velocity, grain moisture content, and fine and broken kernels.

4. The results of this study are expected to help designers of aeration systems and drying systems, and to give a better understanding and an accurate description of the static pressure behavior as affected by moisture content and fine materials.

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CHAPTER II

SIMULATION OF SHELLED CORN DRYING BY NATURAL AIR

INTRODUCTION

In general cereal grains must be dried to a certain level of moisture content before storing for a given period of time. Corn is frequently harvested at or above 22% moisture content, which requires immediate action in order to preserve the quality of the corn. Due to drying being an energy intensive operation, and the high cost of fuel energy, the conservation of energy is an important factor in grain drying operations. A few studies showed that natural air drying of grains offers potential for reducing energy requirements, and it is often most effective when used in combination drying (Morey et al., 1979) where the high temperature dryer reduces the moisture content to a level where drying can be completed in storage with ambient air.

According to Foster (1953), mechanical ventilation with unheated air offers certain advantages over heated air because it is less expensive, requires less supervision, and generally presents less fire hazard than with heated air. However, the effectiveness of unheated air drying is dependent on uncontrollable weather conditions and other factors like moisture ranges through which grain is to be dried, airflow rate, initial grain moisture content, grain depth, and harvesting dates. Thus, it becomes important to evaluate these factors and to establish the recommended conditions for drying the grain without objectionable quality deterioration. This requires the operation of a large number of field or laboratory facilities for several years, so this approach becomes prohibitive in funds and time required. Therefore, simulation by means of a computer program becomes the alternative to predict the feasibility of shelled corn drying by natural air. In this study a computer

simulation model for natural air drying developed and modified by Maurer (1977) and Chang (1978) was applied to establish recommended natural air drying systems for shelled corn at five areas in Kansas.

REVIEW OF LITERATURE

1. Kansas Corn Production

In order to determine the location for the simulation of the drying operation in Kansas, it was necessary to know the major districts for corn production. Table 1 shows corn production by districts in Kansas for five years (1975-1979) as reported by the Kansas Crop and Livestock Reporting Service (1980). Figure 1 shows the boundaries for each district in Kansas.

Table 1. Shelled Corn Production By Districts in Kansas.

Districts	Corn Production in Thousands of Tons				
	1975	1976	1977	1978	1979
NORTHWEST	459.01	585.39	581.90	557.95	617.16
WESTCENTRAL	433.53	454.06	445.44	376.50	433.60
SOUTHWEST	1489.41	1841.72	1571.80	1484.77	1416.46
NORTHCENTRAL	196.48	199.37	209.04	240.15	273.11
SOUTHCENTRAL	178.91	285.58	303.16	305.78	275.09
CENTRAL	90.02	94.28	74.72	90.05	108.17
NORTHEAST	365.55	421.49	354.08	439.24	608.34
EASTCENTRAL	182.45	219.30	278.72	126.18	372.30
SOUTHEAST	60.00	98.59	112.32	195.27	98.46

2. Harvest Dates In The Kansas Districts

Generally, the harvesting dates in the state of Kansas are:

start: September 10

most active: September 30 - November 10

end : November 30

Table 2 shows the percentage of corn harvested by specified dates at various districts in Kansas.

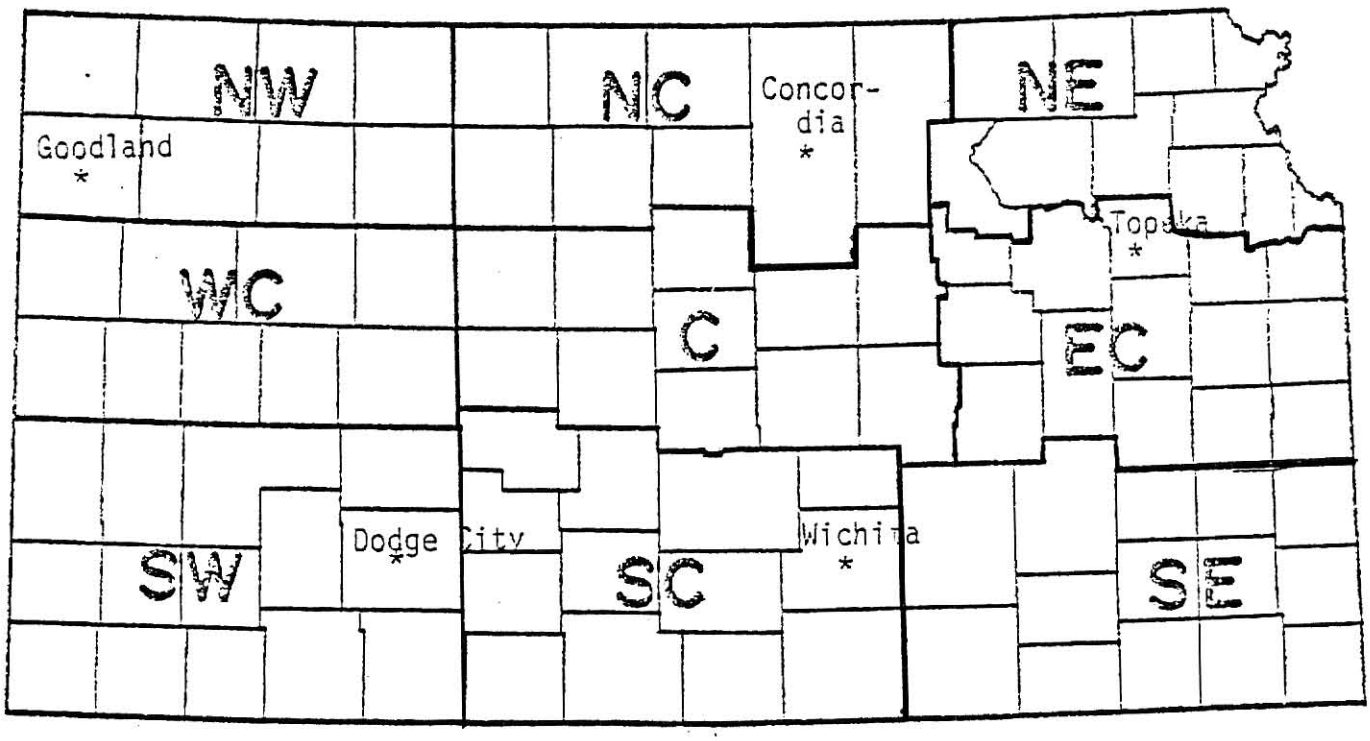


Figure 1. Kansas Districts. The Districts are Designated as Follows: Northwest (NW), Westcentral (WC), Southeast (SE), Northcentral (NC), Central (C), Southcentral (SC), Northeast (NE), Eastventral (EC), and Southwest (SW).

Table 2. The Percentage Harvested by Specified Dates at Various Districts in Kansas.(1)

Districts	September			October			November		
	10	20	30	10	20	30	10	20	30
Northwest	0	5	10	20	45	60	85	90	95
Westcentral	5	5	15	30	50	65	80	90	95
Southwest	0	5	15	30	55	70	85	95	100
Northcentral	0	5	10	25	50	65	85	90	95
Central	15	25	35	40	55	70	80	90	95
Southcentral	15	30	50	65	75	85	95	95	100
Northeast	5	15	20	35	50	60	75	85	90
Eastcentral	10	20	35	50	60	75	85	90	95
Southcentral	30	50	60	75	80	85	90	95	95
State	5	15	20	35	55	70	85	90	95

(1) Kansas Crop and Livestock Reporting Service. 1980. Corn Acreage and Production by Counties. Topeka, Kansas.

3. Climatological Summary of Kansas Weather

The Kansas Crop and Livestock Reporting Service (1980) describes Kansas weather as a distinctly continental type with large invigorating daily, seasonal, and annual temperature changes. The precipitation pattern is also subject to seasonal variation, with annual differences from west to east across the State much larger than variations from north to south. In addition to these short-time changes, there are occasional periods of drought in which several years with low rainfall and high temperatures follow, and periods of flood in which heavy rainfall recurs. Between these irregular extreme periods are individual years or periods of years in which more nearly normal temperatures and precipitation prevail. Often, no two years are alike.

Most of Kansas is subject to extreme temperatures of 43 to 45° C on the warm side and -32 to -35°C on the cold side. However, such extremes are the exception. Normally, days per year in which the temperature rises to 32°C or above range from 50 in the northeast to 80 in the south central. The number of days it reaches 38°C or higher averages 10 in the northeast and increases to about twice that number over the central third. The number of days per winter in which the maximum temperature does not rise above zero is about 15 for the Oklahoma border counties to almost double that near the Nebraska line. The number of mornings per year with a minimum of 0°C or lower is approximately 100 in the southeast and rises to 160 in the northwest. The number of days with 20°C or lower temperatures averages 10 annually in the extreme northwest but only 2 in the southcentral counties. The average freeze-free period extends over approximately 200 days in the southeast but is reduced to 150 days in the northwest.

Considering the importance of the yearly changes of weather in Kansas, it was necessary to analyze quantitatively the temperatures and relative humidities in the study areas. Figure 2 shows the average temperatures and relative humidities during October and November from 1963 to 1973 for the areas of Topeka, Dodge City, Wichita, Concordia, and Goodland.

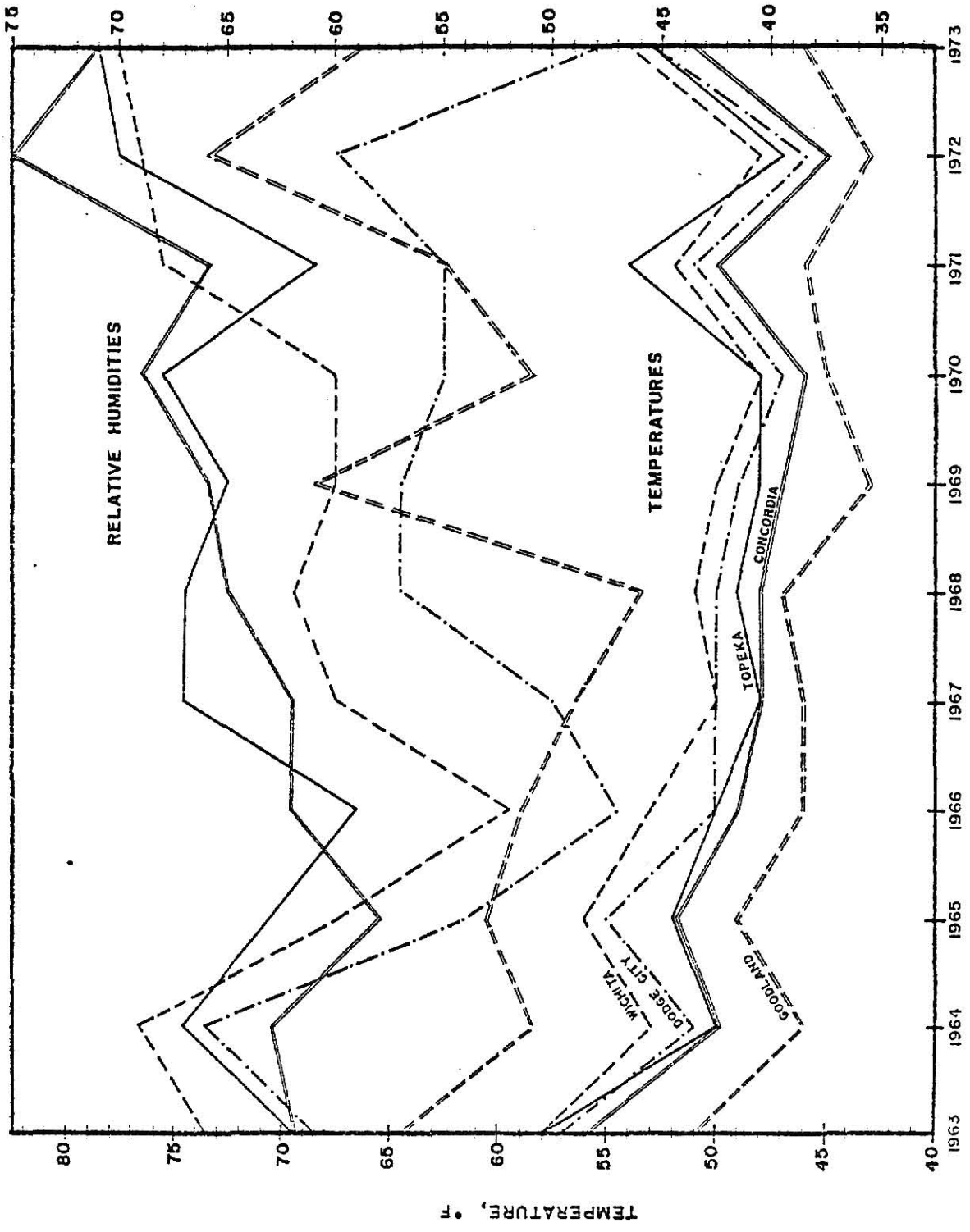


Figure 2. Average Temperature and Relative Humidity During October and November in Five Areas of Kansas.

4. Shelled Corn Drying By Natural Air

Illanes (1981), who conducted tests to see the potential of natural air drying in Kansas to dry grain sorghum by means of a simulation using a computer program, concluded that it is feasible to dry grain sorghum by natural air under Kansas weather conditions using certain drying systems. He noted that the higher the drying air temperature, initial moisture content, and longer length of drying period and lower airflow, the higher the grain deterioration. He also reported that changes in yearly weather conditions can drastically change the results of the drying operation. Flood et al. (1972) used a digital computer simulation to evaluate natural air corn drying systems. They reported that it is feasible to dry corn using natural air without any supplemental heat, and the grain could be dried to less than 18 % moisture content (w.b.) without loss of grade. They also reported that intermittent fan operation (off when all grain was below 18 %) reduced operating cost and over drying. Morey et al. (1979) evaluated management procedures for ambient air drying systems using simulation. They concluded that (1) continuous fan operation, under an appropriate fall shut-off and spring start-up procedure, is preferable to management strategies which involve turning off the fan based on relative humidity, temperature, or a time clock; (2) filling the bin over a period of time allows an increase in allowable initial moisture content of up to 3 percentage points; (3) increasing airflow to 2.2 m^3/min-t for a full bin allows the initial moisture content to be increased to as much as 27 percent on a delay-fill schedule, but fan power and depth restrictions may limit this application; and (4) stirring offers potential advantages for reducing

maximum dry matter decomposition and minimizing over-drying.

The solar energy subcommittee of the Midwest Plan Service (1980), prepared a low temperature and solar grain drying handbook which includes some results for corn drying by natural air. Table 3 shows some results.

Table 3. Low Temperature and Solar Grain Drying Handbook Results (1980) Based on Weather Data for Des Moines, Iowa for Corn Drying.

	Bin #1 10 HP 1.1 cfm/bu 3.13" SP 2.5 F from fan	Bin #2 10 HP 1.1 cfm/bu 3.13" SP 2.5 F from fan 2.5 F supp. (electric)	Bin #3 20 HP 1.4 cfm/bu 4.64" SP 3.8 F from fan
Date start	Oct. 15	Oct. 15	Oct 15
Initial M.C. % w.b.	22	22	22
Date dry	Nov. 30	Nov. 22	Nov. 13
M.C. range, %	13.3 to 15.5	12.1 to 15.2	12.5 to 15.4
Avg. final M.C. % w.b.	14.2	13.2	13.4
Temp. range, F	34.5 to 34	41 to 39.2	44.8 to 42.7
Fan hours, drying	1,104	912	696
kWh Used	9,685	16,027	12,212

Converse et al. (1978) conducted a test for the temperature of in-storage grain drying using solar energy as supplemental heat and concluded that drying rates were most dependent on airflow rate, but solar heat increased the drying rate during each test period.

Performance of low-temperature, solar-heated, and ambient air drying systems has also been evaluated by Brooker et al. (1978) and Morey et al. (1979). These studies showed that grain drying by natural air was an effective and efficient method of drying and that drying could be completed within safe storage limits if airflow rates were matched with

initial moisture contents. Results also showed that by increasing airflow rates 10 to 15 percent, ambient air drying was equivalent to solar supplemental heat drying. Experimental and simulated results (Morey 1979) have indicated that adding 1 to 2 ^{o}C temperature rise to the drying air with electrical or fossil fuel sources significantly increases the energy requirement per unit of water removed compared to ambient air drying. Converse, et al. (1978) concluded that the drying rate was mainly dependent on airflow rate, and grain deterioration was confined to upper grain layers and mainly in areas of reduced airflow rate due to fine material in the grain.

The U.S. Department Of Agriculture recommended the following maximum grain depth and minimum airflows for natural air drying for corn.

Table 4. USDA Recommended Conditions for Natural Air Drying of corn. (1)

Grain Moisture Content (w.b.)%	Recommended Depth of Grain (meter)	Recommended Minimum Airflow (m^3/min-t)
25	1.98	5.6
20	3.00	3.4
18	3.67	2.3
16	4.88	1.1

(1) USDA 1965. Drying Shelled Corn and Small Grain. Farmers Bull. 2214.

All of the experiments and the results mentioned above indicate that shelled corn drying by natural air was feasible for specified conditions of airflow rate, grain depth, and initial moisture content, but actually there are no specific recommended conditions for applying ambient air drying in the areas of corn production in Kansas.

5. Index of Grain Deterioration

Grain deterioration is the most important factor which needs to be controlled during storage. This deterioration is a function of the respiration or oxidation of the grain and is highly dependent on the temperature and moisture content of the grain (Thompson, 1972). Steele et al.(1969) measured carbon dioxide production from shelled corn held under various conditions and related this to dry matter decomposition of the shelled corn. Families of curves were presented to permit calculation of permissible storage times as a function of the temperature, moisture content, and mechanical damage of the corn kernals.

Their studies indicated that with a 0.5 percent dry matter decomposition, corn loses some quality but keeps its market grade. Thus, 0.5 percent decomposition is about the limit without a reduction in grade. Other tests used to determine the condition of grain and predict its future storage behavior include: (1) visual observation; (2) increased fungal population; (3) decrease in germinability or viability; (4) heating; (5) production of toxins; and (6) various biochemical changes, including those that result in mutiness, souring, high fat acidity, or bitterness.

OBJECTIVES

The general objectives of this work are to evaluate shelled corn drying performance by means of a simulation computer program, and to predict the feasibility of practicing corn drying by natural air in various districts in the State of Kansas.

The specific objectives are:

1. To show the effects of changes in yearly weather conditions on the natural air drying performance.

2. To examine the effect of airflow rates on the dry matter loss and grain drying rate along the bed depth for various initial grain moisture content.

3. To determine the drying time necessary to reach a grain moisture for safe storage.

4. To determine recommendable airflow rates for a given grain depth and initial moisture content.

DIGITAL COMPUTER SIMULATION PROGRAM

The computer program used is called KSUDRYER, which was developed by Samual G. Maurer in cooperation with Dr. Harry B. Pfost (Kansas State University, Food and Feed Grain Institute, 1978).

The model developed was tested against actual drying results obtained in tests conducted by the USDA Grain and Marketing Research Center, Manhattan, Kansas, and was found to be acceptable.

The following four sections were extracted from the report prepared by Maurer and Pfost (1978).

I. General Description

KSUDRYER is a program written to predict drying performance of natural or supplementally heated air grain dryers. The program reads in the design parameters of grain type and condition, load-in data, fan curves, and fan management control variables. The program then computes the final conditions of grain and air for each layer within the bin at each time interval. Outputs consist of: input parameters, input weather data, interpolated weather data for further study, intermediate grain conditions, final grain conditions, energy requirements, and drying time required.

II. Input Requirements

A. JCL

```
//JOBNAME JOB (SSN, ACCT NUMBER), 'YOUR NAME', TIME=(,XX)
```

Should the user specify values for external files, NVALID, NOUTWR, NTABLE additional JCL may be required in these locations. This example has NREAD=5, NPRINT=6, NWTHR=3.

```
//EXEC FORG, P=KSUDRYER
//STEPLIB DD DSN=DSKN7.LOADLIB,DISP=SHR.
```

Should the user specify values for external files, NVALID, NOUTWR additional JCL may be required in these locations. This example has NREAD=5, NPRINT=6, NWTHR=3, NTABLE=13.

```
//GO.FT03F001 DD DDNAME=SYSIN1
//SYSIN1 DD *
     Weather Data Deck
/*
```

i.e.:

```
//GO.FT13F001 DD SYSOUT=A,DCB=(RECFM=UA, BLKSIZE=133)
//GO.SYSIN DD *
     Problem Decks
/*
```

B. Weather Data Decks

The program allows multiple sets of weather data to be used during a single job. However, a problem deck and file number (NWTHR) must be supplied for each weather deck. Each weather deck consists of card images of the following format (4(I3,I2,I3,I2,F4.2,2X),2X,A4,A2,8X). The first field numbers are:

1. NPS - Number of weather data points to be read in this weather deck
2. IDT - Indicating variable for weather data time interval

0 - Mixed time interval or missing data

1,2,3,4 etc. - Time increment of consistent weather data (hours)

3. IDMY - Dummy variable, blank space
4. IYR - Year of weather collection, i.e., 58=1958
5. ELEV - Elevation of weather station above sea level in thousands of feet, used for calculation of atmospheric pressure if actual data not available

6 - 10 are repeated for each weather data point:

6. IDAY - Julian Day i.e., (1-365) of weather measurement
7. IHR - Hour of the day (0-23) of weather measurement
8. IDB - Dry bulb temperature (F)
9. IRH - Relative humidity (percent)
10. RATM - Atmospheric pressure if available (inches of Hg)
11. WDNT - Weather data station identification maximum of six alphameric characters, required only on first card (A4,A2)

C. Problem decks

CARD #1: Title card format (20A4)

This card contains 80 characters of information used for labeling and identification of all tables, reports and output.

CARD #2: File and indicator variables FORMAT(5A4,10I5,10X)

LOCATION - Alphameric array containing identification of the desired location of drying bin. Cross reference gainst weather data should a mix occur.

IG - Indicating variable for grain type

1 Yellow Dent Corn

2 Rough Rice

3 Grain Sorghum

4 Soybean

5 Millet

6 Chick-Pea

7 Sesame Seed

8 Groundnut in Pod

9 Wheat

ITALC - Interval of calculation, used as the model time base (HOURS)

I/O JCL must be supplied for these file numbers.

NWTHR - Input file number containing weather data

NWTHR=NREAD I=NWTHR=0, weather data reused

I/O JCL must be supplied for these file numbers.

NOUTWR - Output file number for consistent weather to be written. Default=0

If NOUTWR equals 0, no data is written.

NFILLS - Number of sequential grain files to be placed in bin (1,2 or 3). (DEFAULT=1)

NTHICK - Desired layer thickness to be used in mathematical model (inches). If blank, 30 layers are assumed and thickness calculated, based on full bin.

Note: I/O JCL must be supplied for these file numbers.

NVALID - File number of tape driven on which validation data will be written. JCL must be supplied when used. (DEFAULT=0)

If NVALID=0, validation data will not be written.

Note: I/O JCL must be supplied for these file numbers.

NTABLE - File number on which intermediate data is printed.

JCL must be supplied. DEFAULT=0

If NTABLE equal 0, intermediate data written

INOUT - Indicating variable for control of intermediate output

DEFAULT=0

0 - No intermediate output

1 - Top layer of each fill

2 - Data on each layer for each printing increase

IPRINC - Increment of printing (HOUR) DEFAULT=0

Intermediate output printed every IPRINC hours

CARD #3: Bin management commands FORMAT (2I5,5F10.0,2X)

LADY - Julian Date (1-365) which grain is loaded into bin.

No DEFAULT

LHR - Clock Time (0 - 23) Hour that bin is loaded.

No DEFAULT

MW - Average grain moisture wet basis for fill (real

percent or decimal). No DEFAULT

TGN - Average grain temperature (F) for the fill

No DEFAULT

FTGRN - Feed of grain added for the fill

No DEFAULT

PDG - Percent damaged grain - stain test (Steele 1967)

DEFAULT = 30 %

FM - Fine material - Thrus of 12/64 Screen (percent or decimal)

DEFAULT = 2.5 %

NOTE: CARD #3 is repeated for each desired sequential grain fill (NFILLS).

CARD #4: Fan management control commands FORMAT(I5,5X,4I5, 2F5.0,F10.0,30X)

IC - Desired control method 1 < IC < 4. DEFAULT = 1

1 - Continuous aeration - high speed fan only

2 - Timer controlled aeration, high, low, off

3 - Humidistat controlled aeration, high, low, off

4 - #2 and 3 combined with #3 given priority

FON - Hour of the day (0 - 23) when the fan is turned on low speed from being off (Integer)

FHI - Hour of the day (0 - 23) when the fan is turned on high speed from being off (Integer)

FLOW - Hour of the day (0 - 23) when the fan is on low speed from being high (Integer)

FOFF - Hour of the day (0 - 23) when the fan is turned off from being on low speed (Integer)

RSHFT - Relative humidity control point (decimal or percent) above which fan operates on low speed, below which the fan operates on high speed

RHOFF - Relative humidity control point (decimal or percent) above which fan is off, below which the fan operates on low speed

ADHEAT - Amount of added heat by the use of a supplemental heater, (BTU/HR)

CARD #5: High speed fan curve identification and data

FANIDH - High speed fan identification - 20 alphameric

characters

FAN(2,1) - High speed fan curve coefficient A

DEFAULT = 0

FAN(2,2) - High speed fan curve coefficient B

FAN(2,3) - High speed fan curve coefficient C

FANEFT - Fan efficiency - mechanical efficiency

(decimal or percent). DEFAULT = 50 %

CARD #6: Low speed fan curve identification and data

FORMAT(5A4,5F10.0,10X)

FANIDL - Low speed fan identification - 20 characters

FAN(1,1) - Low speed fan curve coefficient A

NO DEFAULT

FAN(1,2) - Low speed fan curve coefficient B

DEFAULT = 0

FAN(1,3) - Low speed fan curve coefficient C

DEFAULT = 0

FANEFF - Low speed fan efficiency (decimal or percent).

DEFAULT = 50 %

CARD #6 is required for two speed fan management.

III. Output from the Program

Output from the program consists of four sections.

Section 1: Weather data and identification

This section includes the weather station identification and an exact reprint in card image form of weather data as read by DATAIN subroutine from file NWTHR. The second portion is the weather data printed

out with the time pointer in a display form, listing dry bulb, relative humidity, and atmospheric pressure with the Lagrangian time base (dayx24+HR). The third and final portion is the resulting homogeneous weather data with no missing data points at the desired interval of calculation (ITCALC). This data is then communicated to the time subroutine to begin the modeling process.

Section 2: Initial model conditions as selected by the user

This section identifies:

1. The type of grain to be stored and initial conditions.

2. The fan size and configuration.

3. The bin management procedures, when and how much grain is loaded in the drying bin.

4. The fan management procedures, which indicate the time and amount of drying or aeration to take place as well as the energy required for each combination.

Section 3: Intermediate output (user controlled, subroutine OUTPUT)

Grain conditions are monitored and displayed at the desired printing increment (IPRINC). The quantity of output is controlled by the intermediate output variable (INOUT). Also, data tape files are created on file (NVALID) if an experimental validation study is desired; this type file is then upward compatible with the Lagrangian AOV difference

table program (LAGRANGE).

When the grain has been successfully dried or the grain has deteriorated below marketable levels (DMLOSS > 0.5 %), or all supplied weather data used, a final report is generated. This final report is identified with the user supplied title of the study (T), followed by the average, maximum, and occurring layer for grain moisture content and percent dry matter loss. Hours of fan operation are given in a table for each combination of speed (IS) and fills (IFILL). Next is an account of the energy consumption of the study, which includes the fan energy, heater supplied energy, and total energy required for the experiment.

PROCEDURE

The main factors affecting performances of drying systems by natural air are: (1) weather conditions, (2) initial moisture content, and (3) airflow used. In this study, all of these factors were considered as well as the variability of yearly weather in five areas of Kansas. In the following section, a list of assumptions and parameters, criteria used for evaluating the results, fan selection, and the drying systems tested are discussed.

Total airflow rate was calculated with the assumption that a bin of a 6-meter diameter was used. The assumption and parameters tested are:

1. A single fill and continuous fan operation.
2. Conditions of shelled corn.
   a - Initial moisture contents, 24, 21 and 18 % (w.b.)
   b - Percent damage (stain-test, Steele 1969): 20 %
   c - Percent fine material: 3 %
   d - Number of modeled layer: 10
3. Grain temperatures for the different districts were estimated on the basis of weather data about the time of drying.
4. The study areas were chosen according to the importance in corn production (see Table 1). They are: Concordia, Dodge City, Goodland, Topeka, and Wichita.

   Official weather data was collected in intervals of three hours during 11 years (1963 - 1973) for the chosen areas, but for the simulation only two years were selected as is shown in Table 5. The selection of the two years was made on the basis of the temperature and relative humidity from 11 years for each chosen

weather station (see Figure 2). The chosen years were classified as: year of normal temperature and normal relative humidity, and year relatively cold and humid.

Table 5. Stations, Periods and Years Examined.

Station	Period Tested	Normal Year	Year Relatively Cold and Humid
Topeka	Oct. 5 to Nov. 15	1965	1972
Dodge City	Oct. 20 to Nov. 30	1971	1972
Wichita	Oct. 15 to Nov. 25	1968	1972
Concordia	Oct. 15 to Nov. 25	1968	1972
Goodland	Oct. 20 to Nov. 30	1966	1969

The grain depth and airflow rate combination govern the fan selection. The procedure was followed according to the computer program guide:

The fan static pressure equation is

$$FANSP(Q) = FA + FB*Q + FC*Q*Q$$

where FANSP(Q) = static pressure at the fan outlet, inches of water

Q = airflow rate/area, cfm/sq ft

FA, FB and FC = Constants for the selected fan

To find FA, FB, and FC, the following procedure must be followed:

1. select a fan of a given speed to be used.
2. perform a regression analysis of the data for this fan to obtain

the constants for the equation of the form:

$$SP = A + B\,V + C\,V^2$$

where SP = static pressure, inches of water

V = airflow rate, cfm

A, B, C = constants

since Q = airflow rate(cfm)/cross sectional area (ft^2)

$$SP = A + B\,Q\,(AREA) + C\,Q^2\,(AREA)^2$$

or FA = A

FB = B*(Area)

FC = C x $(Area)^2$

For a fixed airflow rate according to the statement of the program: "When fan static pressure equals the grain pressure, then the airflow of the system will be equal to Q for those combinations of depth, fan curve, and grain curve." FA values were taken at these conditions in order to get the airflow rate required. FB, FC and fan efficiency were assumed to be zero, zero, and 0.50 respectively.

Criteria of failure or success

Dry matter loss was primarily taken as a criterion of failure or success, but for the purpose of evaluation, final moisture content distribution and drying time were also considered as a limiting factor of the failure or success of the drying system tested. A dry matter loss greater than 0.5 % was considered as a failure of the operating conditions.

It was estimated that a desirable final average moisture content of less than 14 % (w.b.) with extremes no greater than 15.5 % (w.b.) and no less than 12 % (w.b.) are necessary to avoid overdrying. To have a successful operation, drying front much reach the top and all grain must be dried before it is spoiled, within a drying period of 1029 hours.

Three levels of initial moisture contents (24, 21, and 18 % w.b.), six levels of airflow rate range from 0.556 to 3.4 m^3/min-t (0.5 to 3 cfm/bu) were used. All combinations of moisture contents and airflow rates were tested with four levels of grain depths (2.54, 3.0, 4.1, and 5.1 m).

The general procedure of the simulation consisted of:

1. Fix a combination of initial grain moisture content and airflow rate and run the program for various possible grain depths for each chosen year and each area to be tested.

2. Evaluate the computer output according to the criteria noted in the previous page, i.e., consider it a successful drying system if the dry matter loss was less than 0.5 % and extremes of moisture content were less than 15.5 % and greater than 12 % with an average of about 14 %. First we started with the extreme combination; for example, 18 % m.c., 3.4 m^3/min-t airflow rate, and depth of 2.54 m; if this combination failed it would be excluded from further investigation. If the combination succeeded, a lower airflow rate would be tried. The procedure was repeated until the combination used failed to dry the corn successfully; then the last successful combination was considered the recommended maximum grain depth and minimum allowable airflow rate for that particular moisture content.

RESULTS AND DISCUSSIONS

The computer print-outs for all drying systems tested, were tabluated in Tables 6 through 13 and presented in Appendix II. The initial moisture content, bed depth, airflow rate, and static pressure represent the input data, while the minimum and maximum moisture content, dry matter loss, and drying time were listed as ouput. The output was evaluated for success or failure according to the designed criteria. The drying was considered successful if the dry matter loss was less than 0.5%, and if the extremes of moisture content were less than 15.5% and greater than 12% with an average of about 14%, and the drying could be accomplished in 1029 hours. A complete computer run was listed in Appendix III as an example of input and ouput from the program.

Tables 14 through 18 show the successful shelled corn drying systems by natural air for all five stations investigated. In these tables the combination of airflow, grain depth, and fan time that dried the corn successfully for three initial moisture contents (24, 21, and 18% w.b.) are shown. Drying period tested was between 5th of October and 30th of November.

Table 14 shows the results for the Topeka area. The analysis of the results showed that an airflow rate of 1.12 m^3/min-t was needed in a normal year with 18% moisture content and 5.10 m depth, while for the same depth and the same initial moisture content in a relatively cold and humid year, an airflow rate of 2.24 m^3/min-t was needed. This shows clearly that changes in yearly weather conditions has a great influence on the results of the drying operation. In normal year with 24% initial

moisture content, an airflow rate of 1.96 m^3/min-t was needed while for 18% moisture corn, only 1.12 m^3/min-t airflow rate was required to accomplish the drying at the same grain depth. This illustrates that initial moisture content is an important factor in selecting the airflow required for the drying operation.

Table 15 shows the results for the Concordia area for a normal year. Successful corn drying was not possible in cold and humid year. In cold and humid years, the use of supplemental heat is suggested to prevent grain spoilage. It is observed that lower initial moisture content requires less airflow rate than higher initial moisture content. Generally the Concordia area requires higher airflow rate than Topeka area for all drying systems. This is due mainly to a higher average air temperature and lower average relative humidity at Topeka area than at Concordia area (Figure 2).

Table 16 shows the results for the Goodland area for normal year and cold and humid year. It was observed in the cold and humid year the results were similar to those for Topeka area. Generally Goodland area requires less airflow rate than Concordia, due mainly to a lower average relative humidity at the Goodland area (Figure 2), although there is no significant difference between the average temperature of the two areas.

Table 17 shows the results for wichita area, where during a cold and humid year, corn cannot be dried successfully by natural air within the limits of the investigation. The results for a normal year were close to those for the Concordia area, but with 21% initial moisture content in Wichita, a higher airflow was needed than in Concordia area.

In general, the results do not differ greatly from Concordia's results. Table 18 shows a summary of the results obtained for the Dodge City area, using two years with three initial moisture contents along with the successful drying combinations of airflow rates, depth, and drying time. It was observed that for a relatively cold and humid year, the only successful drying system is with 18% initial moisture content, 2.86 m^3/min-t airflow rate, and 5.10 m depth. The results for the normal year in Dodge City area appear to be close to those of the Goodland area. This could be attributed to the fact that Dodge City has a higher average temperature while Goodland has a lower average relative humidity, so both criteria tend to compensate each other to yield a similar drying potential.

Generally, all the stations investigated follow a similar pattern which could be summarized as follows: (1) for the same initial moisture content, more time was needed for a relatively cold and humid year, than a normal year. Furthermore, a higher airflow rate and a lower grain depth were needed; and (2) for the same depth, more airflow was needed for higher initial moisture content and more drying time was required.

These results can be compared to the results shown in Table 3 for Des Moines, Iowa. Three bins with different airflow rates and different levels of supplemental heat were compared for drying time. The airflow rates presented in Table 3 were less than those in Tables 14 - 18. This is mainly due to the results in Table 3 being obtained by using supplemental heat, in addition to the differences in weather conditions of the two areas. It will be noticed that weather conditions are the main factor affecting the drying systems by natural air.

In comparing the values in Tables 14 - 18 with those recommended by USDA (Table 4), there was significant difference in airflow rates. USDA recommends higher airflow rates. This could be attributed to the fact that USDA recommendations were more generalized and intended to cover a large area, because no location was specified. Generally, the feasibility of using natural air for the drying operation was, greatly influenced by weather condition, initial moisture content, grain depth, and airflow used.

Table 14. Successful Shelled Corn Drying by Natural Air for Topeka Area.

Year	Initial Moisture Content % (w.b.)	Airflow Rate (m^3/min-t)	Depth (m)	Drying Time (hrs)
Normal Year (1965)	24	1.96	5.10	573
	21	1.68	5.10	456
	18	1.12	5.10	573
Year Relatively Cold and humid (1972)	24	2.67	5.10	387
	21	2.52	5.10	306
	18	2.24	5.10	240

Table 15. Successful Shelled Corn Drying by Natural Air for Concordia Area.

Year	Initial Moisture Content % (w.b.)	Airflow Rate (m^3/min-t)	Depth (m)	Drying Time (hrs)
Normal Year (1968)	24	2.80	4.10	408
	21	2.24	5.10	393
	18	1.68	5.10	402
Year Relatively Cold and humid	24	x	x	x
	21	x	x	x
	18	x	x	x

x - Indicates unseccessful drying.

Table 16. Successful Shelled Corn Drying by Natural Air for Goodland Area.

Year	Initial Moisture Content % (w.b.)	Airflow Rate (m^3/min-t)	Depth (m)	Drying Time (hrs)
Normal Year (1966)	24	2.52	5.10	405
	21	2.24	5.10	318
	18	1.32	5.10	435
Year Relatively Cold and Humid (1969)	24	2.86	4.10	645
	21	2.52	5.10	504
	18	2.24	5.10	465

Table 17. Successful Shelled Corn Drying by Natural Air for Wichita Area.

Year	Initial Moisture Content % (w.b.)	Airflow Rate (m^3/min-t)	Depth (m)	Drying Time (hrs)
Normal Year (1968)	24	3.10	4.10	390
	21	2.52	5.10	330
	18	1.68	5.10	411
Year relatively Cold and Humid	24	x	x	x
	21	x	x	x
	18	x	x	x

x - Indicates unseccessful drying.

Table 18. Successful Shelled Corn Drying by Natural Air for Dodge City Area.

Year	Initial Moisture Content % (w.b.)	Airflow Rate (m^3/min-t)	Depth (m)	Drying Time (hrs)
Normal Year (1971)	24	2.52	5.10	489
	21	2.24	5.10	458
	18	1.68	5.10	492
Year Relatively Cold and Humid (1972)	24	x	x	x
	21	x	x	x
	18	2.67	5.10	454

x - indicates unseccessful drying

Figures 3 and 4 show the effect of airflow on the drying rate for two different weather conditions in the Concordia area. In Figure 3, which is for a normal year, airflow rates of 3.10, 2.80, and 1.68 m^3/min-t were presented for drying of corn with 24% initial moisture content at 5.10 m depth. The last two airflow rates have a slower drying rate and both failed to dry the corn to the required level of moisture content. when an airflow of 3.10 m^3/min-t was used, the drying rate increased and the corn was dried successfully. In Figure 4, which is for a relatively cold and humid year, even a highest airflow rate of 3.4 m^3/min-t did not dry the grain to the required level of moisture content, although it can be observed that an airflow of 3.10 m^3/min-t succeeded in drying the grain in the normal year.

Drying results vary considerably from year to year according to the weather conditions. It can also be observed that the longer the drying time, the larger the difference in the final grain moisture content for different airflow rates.

Figure 5 shows the effect of depth on dry matter loss in a normal year for the Concordia area with two different levels of airflow rates (2.5, and 2.75 m^3/min-t). Clearly, higher grain depth and lower airflow rate yield more dry matter loss. Notice that the difference in dry matter loss between the two airflow rates gets larger as the depth increases; i.e, the dry matter loss does not increase at a constant rate, but follows an increasing rate of accumulation. Figure 6 for the Topeka area in a normal year with two airflow rates of 1.75, and 2.00 m^3/min-t, shows the similar trends as in Figure 5, for Concordia area but the Topeka area resulted in higher dry matter loss. These figures

show that dry matter loss increases with the increase in depth and decreases with an increase in airflow rate.

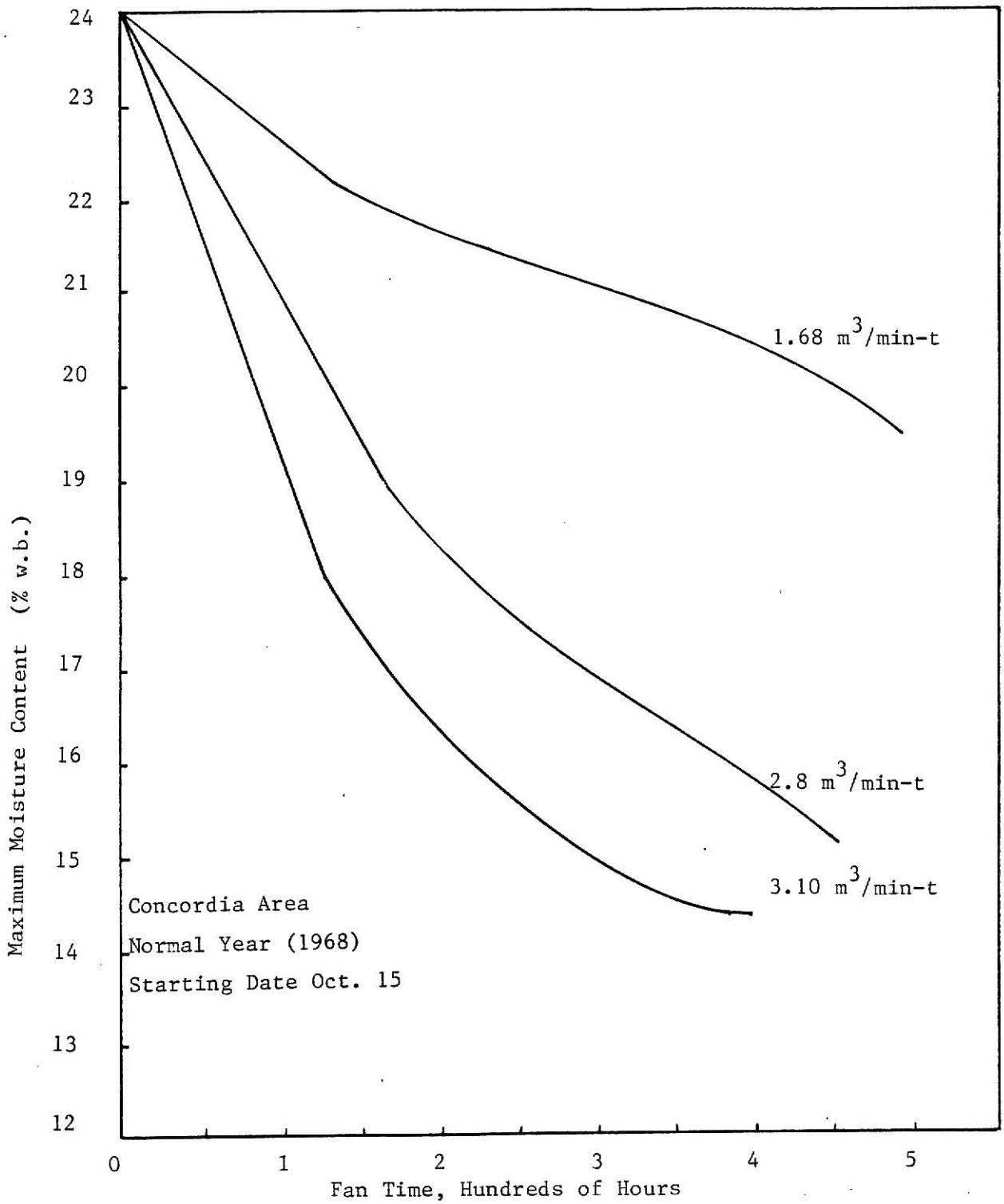


Fig. 3. Effect of Airflow on Drying Rate For Shelled Corn at 24% Initial Moisture Content and 5.1 Meters Bed Depth.

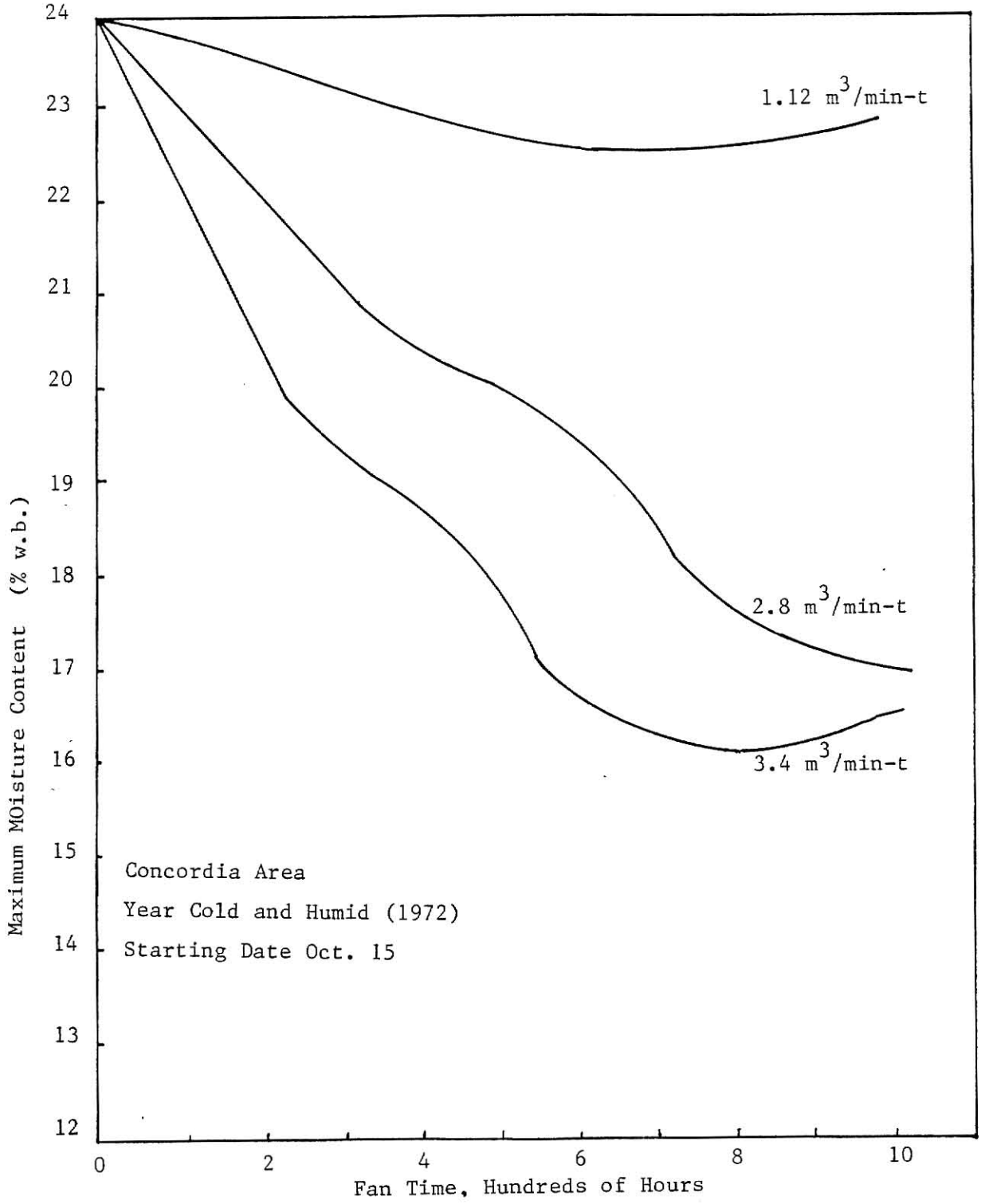


Fig. 4. Effect of Airflow on Drying Rate for Shelled Corn at 24% Initial Moisture Content and 5.10 Meters Bed Depth.

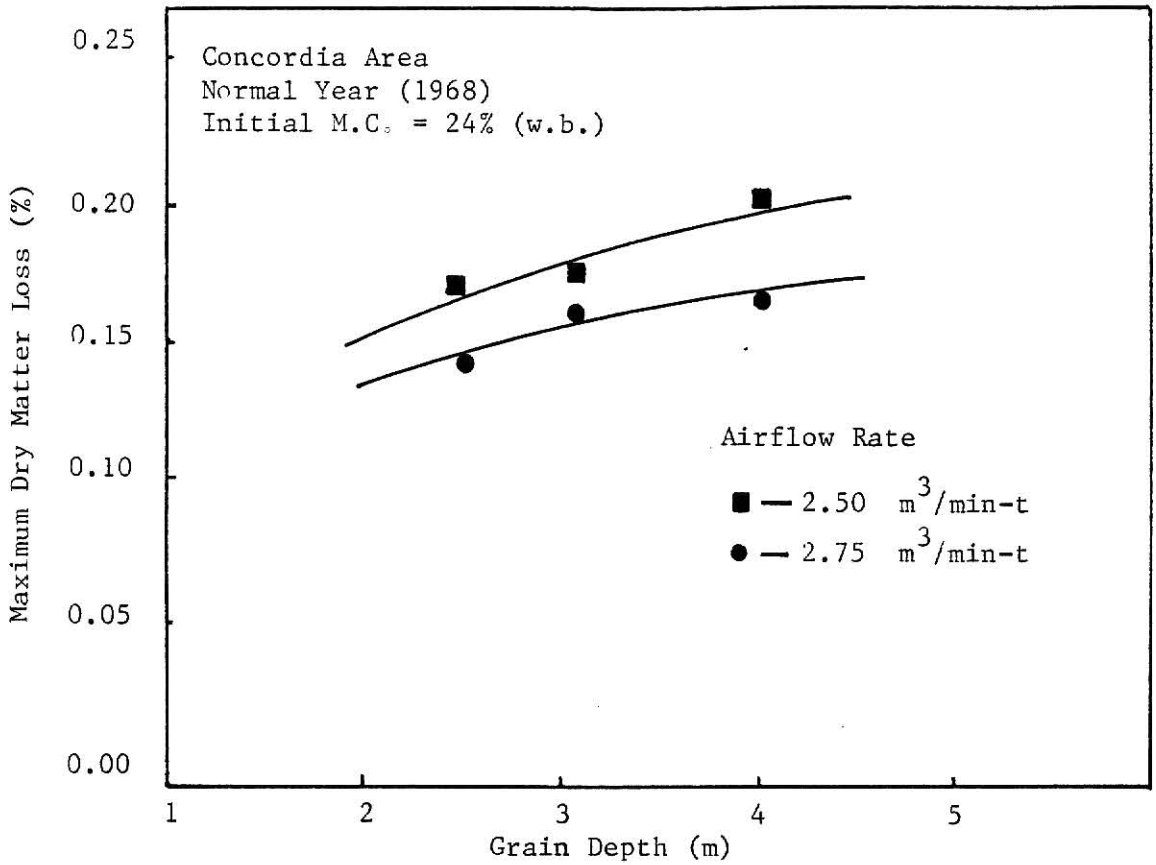


Fig. 5. Effect of Grain Depth on Dry Matter Loss.

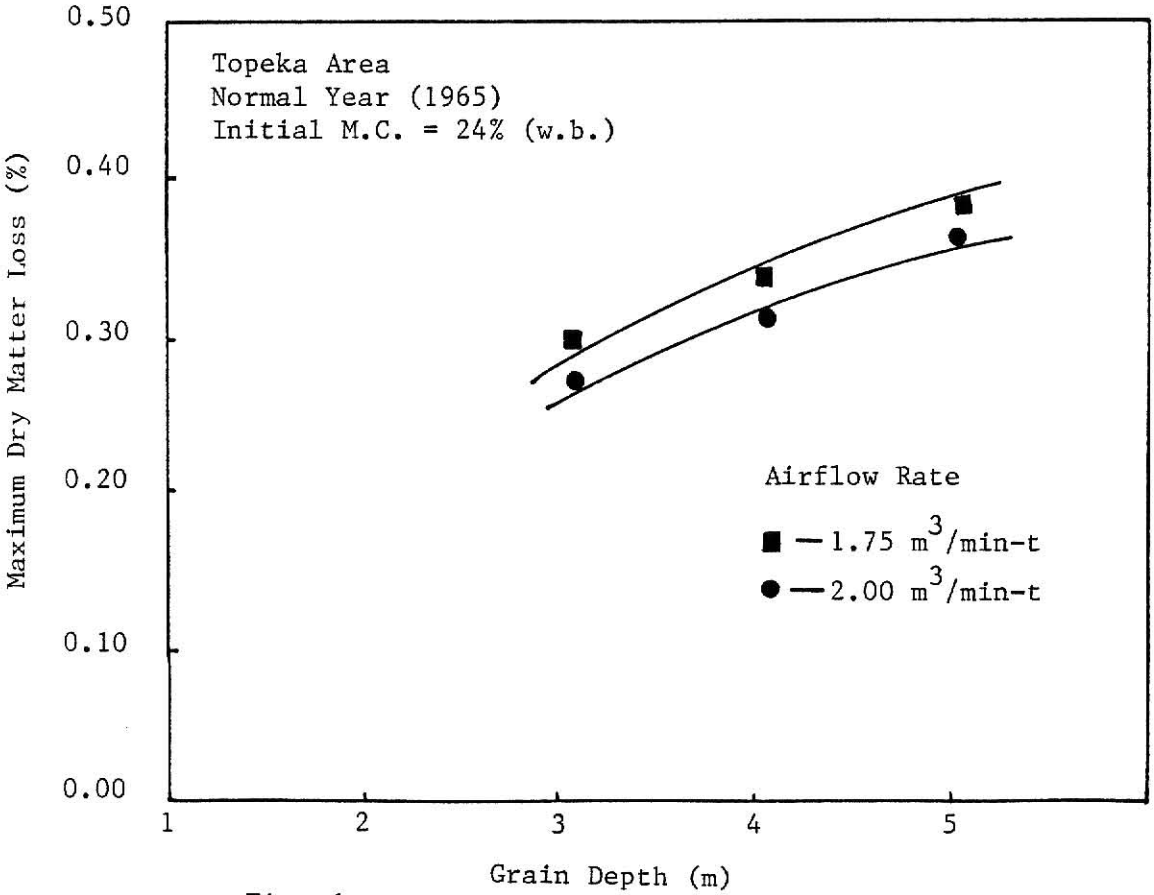


Fig. 6. Effect of Grain Depth on Dry Matter Loss.

SUMMARY AND CONCLUSIONS

A computer program was used to simulate the drying performance of shelled corn by natural air. The effect of yearly weather conditions was analyzed, using weather data for two different years: a normal year, and a relatively cold and humid year. Five different weather stations (Topeka: 1965, and 1972; Concordia: 1968, and 1972; Dodge City: 1971, and 1972; Goodland: 1966, and 1969; Wichita: 1968, and 1972) were selected. Tests were run for three initial moisture contents with various airflow rates and Grain depths.

The following conclusions were made for natural air drying systems in Kansas.

Natural air drying of shelled corn in Kansas is feasible using the following drying systems: when a year with normal temperature and relative humidity is expected in Topeka and Goodland areas, maximum grain depth of 5.10 m can be used with initial moisture content of 24, 21, and 18% (w.b.) and airflow rates of 2.52, 2.24, and 1.32 m^3/min-t, respectively; and in Concordia, wichita, and Dodge City areas, maximum grain depth of 4.10 m can be used with initial moisture content of 24, 21, and 18% (w.b.), and airflow rates of 3.10, 2.52, and 1.68 m^3/min-t, respectively. When a cold and humid year is expected in Topeka and Goodland areas, maximum grain depth of 5.10 m can be used with initial moisture contents of 24, 21, and 18% (w.b.), and airflow rates of 2.86, 2.52, and 2.24 m^3/min-t, respectively. In Concordia, Wichita, and Dodge City areas, 24 and 21% initial moisture corn cannot be dried successfully by natural air in a cold and humid year.

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APPENDICES

APPENDIX I

ANALYSIS OF VARIANCE AND REGRESSION

```
NOTE: THE JOB RC102000 HAS BEEN RUN UNDER RELEASE 79.5 OF SAS AT KANSAS STATE UNIVERSITY (CO3066).

NOTE: SAS OPTIONS SPECIFIED ARE:
      SERT=4


1          DATA OLD;
2          INPUT AF MC FM SP;
3          CARDS;

NOTE: DATA SET WORK.OLD HAS 112 OBSERVATIONS AND 4 VARIABLES. 529 OBS/TRK.
NOTE: THE DATA STATEMENT USED 0.46 SECONDS AND 160K.

116        PROC GLM;
117        CLASSES AF MC FM;
118        MODEL SP=AF MC FM AF*MC AF*FM MC*FM;
119        LSMEANS AF MC FM AF*MC AF*FM MC*FM/STDERR PDIFF;

NOTE: THE PROCEDURE GLM USED 23.30 SECONDS AND 256K AND PRINTED PAGES 1 TO 3.

120        PROC GLM;
121        CLASSES AF MC FM;
122        MODEL SP=AF MC FM;
123        LSMEANS AF MC FM;

NOTE: THE PROCEDURE GLM USED 1.66 SECONDS AND 180K AND PRINTED PAGES 4 TO 6.

124        DATA NEW;SET OLD;
125        IF AF=1 THEN AF=.03;
126        IF AF=2 THEN AF=.05;
127        IF AF=3 THEN AF=.07;
128        IF AF=4 THEN AF=.09;
129        IF AF=7 THEN AF=.17;
130        IF AF=6 THEN AF=.14;
131        IF AF=5 THEN AF=.11;
132        IF MC=16 THEN MC=16.5;
133        IF MC=13 THEN MC=13.5;

NOTE: DATA SET WORK.NEW HAS 112 OBSERVATIONS AND 4 VARIABLES. 529 OBS/TRK.
NOTE: THE DATA STATEMENT USED 0.38 SECONDS AND 160K.

134        PROC GLM;
135        MODEL SP=AF AF*AF MC FM AF*MC AF*FM MC*FM/P;

NOTE: THE PROCEDURE GLM USED 1.84 SECONDS AND 178K AND PRINTED PAGES 7 TO 9.


NOTE: SAS INSTITUTE INC.
      SAS CIRCLE
      BOX 8000
```

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SP

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	13	4049773.70535714	311521.05425824	354.43	0.0001	0.979174	9.5523
ERROR	98	86136.28571429	878.94169096		STD DEV		SP MEAN
CORRECTED TOTAL	111	4135909.99107143			29.64695079		310.36607143

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
AF	6	3708422.55357142	703.20	0.0001	6	3708422.55357142	703.20	0.0001
MC	4	39151.27678571	11.14	0.0001	4	88913.26785714	25.29	0.0001
FM	3	302199.87500000	114.61	0.0001	3	302199.87500000	114.61	0.0001

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SP

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	63	4133947.32440476	65618.21149849	1604.79	0.0001	0.999525	2.0603
ERROR	48	1962.66666667	40.88888889		STD DEV		SP MEAN
CORRECTED TOTAL	111	4135909.99107143			6.39444203		310.36607143

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
AF	6	3708422.55357142	15115.85	0.0001	6	3281021.31632650	13373.73	0.0001
MC	4	39151.27678571	239.38	0.0001	4*	72363.86904762	442.44	0.0001
FM	3	302199.87500000	2463.59	0.0001	3*	292857.16518518	2387.75	0.0001
AF*MC	24	11629.16071429	11.85	0.0001	24	22945.19047619	23.38	0.0001
AF*FM	18	67597.33333333	91.84	0.0001	18	67597.33333333	91.84	0.0001
MC*FM	8	4947.12500000	15.12	0.0001	8	4947.12500000	15.12	0.0001

* NOTE: OTHER TYPE IV TESTABLE HYPOTHESES EXIST WHICH MAY YIELD DIFFERENT SS.

NOTE: THE JOB RCLO213G HAS BEEN RUN UNDER RELEASE 79.5 OF SAS AT KANSAS STATE UNIVERSITY (00306).

NOTE: SAS OPTIONS SPECIFIED ARE:
SOURCE

```
1           DATA OLD;
2           INPUT AF MC EM SP;
3           CARDS;
```

NOTE: DATA SET WORK.OLD HAS 112 OBSERVATIONS AND 4 VARIABLES. 529 OBS/TRK.
NOTE: THE DATA STATEMENT USED 0.40 SECONDS AND 160K.

```
116         DATA NEW;SET OLD;
117         IF AF=1 THEN AF=.03;
118         IF AF=2 THEN AF=.05;
119         IF AF=3 THEN AF=.07;
120         IF AF=4 THEN AF=.09;
121         IF AF=7 THEN AF=.17;
122         IF AF=6 THEN AF=.14;
123         IF AF=5 THEN AF=.11;
124         IF MC=16 THEN MC=16.5;
125         IF MC=13 THEN MC=13.5;
```

NOTE: DATA SET WORK.NEW HAS 112 OBSERVATIONS AND 4 VARIABLES. 529 OBS/TRK.
NOTE: THE DATA STATEMENT USED 0.32 SECONDS AND 160K.

```
126         PROC GLM;
127         MODEL SP=AF AF*AF AF*MC AF*EM/NOINT P;
```

NOTE: THE PROCEDURE GLM USED 1.48 SECONDS AND 176K AND PRINTED PAGES 1 TO 3.

```
128         PROC GLM;
129         MODEL SP=AF AF*AF AF*MC*EM/NOINT P;
```

NOTE: THE PROCEDURE GLM USED 1.36 SECONDS AND 176K AND PRINTED PAGES 4 TO 6.

NOTE: SAS USED 176K MEMORY.

NOTE: SAS INSTITUTE INC.
SAS CIRCLE
BOX 8000
CARY, N.C. 27511

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SP

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	4	14493171.85286626	3623292.96321656	12817.19	0.0001	0.997898	5.4915
ERROR	108	31373.14713374	290.49210309		STD DEV		SP MEAN
UNCORRECTED TOTAL	112	14524545.00000000			17.04382889		310.36607143

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
AF	1	14393345.39293331	49548.16	0.0001	1	311957.59204111	1073.89	0.0001
AF*AF	1	103418.24999200	356.01	0.0001	1	103418.24999200	356.01	0.0001
AF*MC	1	28737.56369048	98.93	0.0001	1	135662.80390394	467.01	0.0001
AF*FM	1	367667.54624547	1265.67	0.0001	1	367667.54624547	1265.67	0.0001

PARAMETER	ESTIMATE	T FOR HO: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
AF	4590.52332706	32.77	0.0001	140.08389436
AF*AF	7732.24329675	18.87	0.0001	409.80200969
AF*MC	-192.44734995	-21.61	0.0001	8.90530311
AF*FM	196.76937276	35.58	0.0001	5.53071867

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL
1	42.00000000	49.41538055	-7.41538055
2	51.00000000	58.07551130	-7.07551130
3	58.00000000	66.73564205	-8.73564205
4	66.00000000	75.39577280	-9.39577280
5	72.00000000	61.22112292	10.77887708
6	77.00000000	69.88125367	7.11874633
7	85.00000000	78.54138442	6.45861558
8	89.00000000	87.20151516	1.79848484
9	65.00000000	64.36673454	0.63326546
10	71.00000000	73.02686529	-2.02686529
11	78.00000000	81.68699603	-3.68699603
12	86.00000000	90.34712678	-4.34712678
13	91.00000000	97.97821927	-6.97821927
14	94.00000000	96.63835002	-2.63835002
15	105.00000000	105.29848077	-0.29848077
16	118.00000000	113.95861151	4.04138849
17	80.00000000	90.09121089	-10.09121089
18	100.00000000	104.52476213	-4.52476213
19	105.00000000	118.95831338	-13.95831338
20	125.00000000	133.39186463	-8.39186463
21	124.00000000	109.76744816	14.23255184
22	135.00000000	124.20099941	10.79900059
23	141.00000000	138.63455066	2.36544934
24	153.00000000	151.06810190	1.93189810
25	112.00000000	115.01013419	-3.01013419

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SP

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL
26	123.00000000	129.44368544	-6.44368544
27	134.00000000	143.97723669	-9.97723669
28	142.00000000	158.31078793	-16.31078793
29	150.00000000	154.36260875	-4.36260875
30	163.00000000	163.79615999	-0.79615999
31	181.00000000	183.22971124	-2.22971124
32	208.00000000	197.66326249	10.33673751
33	153.00000000	156.95283586	-3.95283586
34	151.00000000	157.15980760	-6.15980760
35	173.00000000	177.36677935	-4.36677935
36	182.00000000	197.57375109	-15.57375109
37	185.00000000	164.49956805	20.50043195
38	198.00000000	184.70653979	13.29346021
39	209.00000000	204.91351153	4.08648847
40	228.00000000	225.12048328	2.87951672
41	175.00000000	171.83932849	3.16067151
42	182.00000000	192.04630023	-10.04630023
43	204.00000000	212.25327198	-8.25327198
44	215.00000000	232.46024372	-17.46024372
45	219.00000000	226.93279286	-7.93279286
46	250.00000000	247.13976461	2.86023539
47	267.00000000	267.34673635	-0.34673635
48	300.00000000	287.55370809	12.44629191
49	190.00000000	190.00025547	-0.00025547
50	212.00000000	215.98064771	-3.98064771
51	237.00000000	241.96103995	-4.96103995
52	251.00000000	267.94143220	-16.94143220
53	245.00000000	225.41748256	19.58251744
54	265.00000000	251.39737481	13.60212519
55	282.00000000	277.37726705	4.62173295
56	302.00000000	303.35865929	-1.35865929
57	233.00000000	234.85431742	-1.85431742
58	248.00000000	260.83470966	-12.83470966
59	272.00000000	286.81510190	-14.81510190
60	290.00000000	312.79549415	-22.79549415
61	308.00000000	305.68877161	2.31122839
62	342.00000000	331.66916386	10.33083614
63	372.00000000	357.64955610	14.35044390
64	420.00000000	383.62994834	36.37005166
65	253.00000000	249.23346971	13.76653029
66	280.00000000	280.98728245	-0.98728245
67	314.00000000	312.74109520	1.25890480
68	332.00000000	344.49490794	-12.49490794
69	315.00000000	292.52169172	22.47830828
70	343.00000000	324.27500446	18.72499554
71	363.00000000	356.02831720	6.97118280
72	390.00000000	387.78262994	2.21737006
73	304.00000000	304.05510099	-0.05510099
74	327.00000000	335.80891373	-8.80891373
75	350.00000000	367.56272647	-17.56272647
76	372.00000000	399.31653921	-27.31653921

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SP

OBSERVATION	OBSERVED VALUE	PREDICTED VALUE	RESIDUAL
77	362.00000000	390.63054500	-28.63054500
78	438.00000000	422.38435774	15.61564226
79	460.00000000	454.13817048	5.86182952
80	510.00000000	485.89190323	24.10809677
81	376.00000000	349.68165603	26.31834397
82	392.00000000	390.09559951	1.90440049
83	430.00000000	430.50954300	-0.50954300
84	456.00000000	470.92348649	-15.92348649
85	424.00000000	404.77512040	19.22487960
86	454.00000000	445.18906389	8.81093611
87	490.00000000	485.60300739	4.39699262
88	530.00000000	526.01695087	3.98304913
89	412.00000000	419.45464128	-7.45464128
90	432.00000000	459.86858477	-27.86858477
91	465.00000000	500.28252826	-35.28252826
92	503.00000000	540.69647175	-37.69647175
93	518.00000000	529.64157003	-11.64157003
94	590.00000000	570.05551352	19.94448648
95	630.00000000	610.46945701	19.53054299
96	695.00000000	650.88340050	44.11659950
97	500.00000000	464.04788027	35.95211973
98	560.00000000	513.12195451	46.87804549
99	587.00000000	562.19602875	24.80397125
100	620.00000000	611.27010298	8.72989702
101	547.00000000	530.94708701	16.05291299
102	588.00000000	580.02116125	7.97883875
103	628.00000000	629.09523549	-1.09523549
104	660.00000000	678.16930972	-18.16930972
105	517.00000000	548.77221952	-31.77221952
106	543.00000000	597.84629375	-54.84629375
107	610.00000000	646.92036799	-36.92036799
108	653.00000000	695.99444222	-42.99444222
109	660.00000000	682.57063299	-22.57063299
110	747.00000000	731.64470723	15.35529277
111	793.00000000	780.71878147	12.28121853
112	848.00000000	829.79285570	18.20714430

SUM OF RESIDUALS	-30.46634094
SUM OF SQUARED RESIDUALS	31373.14713374
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000000
FIRST ORDER AUTOCORRELATION	0.66072678
DURBIN-WATSON D	0.66622737

APPENDIX II

SUMMERY OF THE COMPUTER PRINT-OUTS

Table 6. Simulation Results for Concordia Station.

Period: Oct. 15 to Nov. 25

% Damage : 20
% Fines : 3.0

	Input				Output				Observation
	% Initial Most. Cont.	Depth, m	Airflow m^3/min-t	Fan Constant, FA	% Moisture Content Bottom (Min.)	Top (Max.)	% DML Max	Drying Time, hrs	Failure or Success
1968	24	2.54	3.10	2.34	13.29	15.48	0.1401	384	S
	24	2.54	2.80	1.51	13.44	15.33	0.1715	456	S
	24	2.54	2.65	1.4	14.79	16.46	0.1885	1029	F
	24	3.10	3.40	3.023	12.48	15.48	0.1505	396	S
	24	3.10	3.10	2.67	12.08	15.46	0.1581	411	S
	24	3.10	2.80	2.334	13.04	15.03	0.1703	456	S
	24	4.10	3.40	6.170	12.32	15.33	0.1477	354	S
	24	4.10	3.10	5.413	12.12	15.42	0.1570	381	S
	24	4.10	2.80	4.70	12.69	15.37	0.1637	408	S
	21	2.54	2.65	1.4	11.52	15.26	0.0820	411	S
	21	2.54	1.96	0.942	15.44	18.33	0.0999	645	F
	21	2.54	2.13	1.04	12.42	15.40	0.0560	414	S
	21	2.54	1.68	0.776	15.38	18.24	0.1092	645	F
	21	2.54	1.43	0.64	13.20	16.70	0.0810	645	F
	21	3.10	2.86	2.4	11.62	15.32	0.0792	420	S
	21	3.10	2.52	2.01	12.55	15.32	0.0837	411	S
	21	3.10	2.32	1.8	14.00	15.48	0.1180	411	S
	21	3.10	1.96	1.434	15.37	18.08	0.0987	645	F
	21	4.10	2.80	4.700	13.40	15.46	0.0777	336	S
	21	4.10	2.52	4.025	12.84	15.44	0.0831	403	S
	21	4.10	2.32	3.61	13.20	15.39	0.0870	339	S
	21	5.10	2.80	8.240	12.98	15.35	0.0764	294	S
	21	5.10	2.24	5.92	10.97	15.37	0.0882	393	S
	21	5.10	0.84	1.65	15.64	16.19	0.1672	1029	F
	18	2.54	1.43	0.64	14.00	15.50	0.0431	493	S
	18	2.54	1.40	0.622	14.87	17.97	0.0435	645	F
	18	2.54	1.12	0.474	14.92	17.66	0.0476	645	F
	18	3.10	2.24	1.717	13.87	15.49	0.0338	333	S
	18	3.10	1.96	1.434	12.92	15.46	0.0368	404	S
	18	3.10	1.68	1.175	13.16	15.47	0.0397	435	S
	18	4.10	2.34	3.61	12.23	15.19	0.0323	311	S
	18	4.10	1.96	2.821	13.54	15.47	0.0351	363	S
	18	4.10	1.68	2.288	13.30	15.49	0.0391	411	S
	18	5.10	2.24	5.896	13.82	15.35	0.0323	288	S
	18	5.10	1.96	4.290	13.25	15.46	0.0375	363	S
	18	5.10	1.68	3.900	12.98	15.44	0.0390	402	S
1972	24	2.54	2.65	1.4	18.18	19.53	0.1808	1029	F
	21	2.54	2.65	1.4	14.23	16.17	0.1560	645	F
	18	2.54	2.65	1.4	13.30	16.06	0.0535	645	F

Table 7. Simulation Results for Goodland Station.

Period: Oct. 20 to Nov. 30

% Damage : 20
% Fines : 3.0

	Input				Output				Observation
	% Initial Most. Cont.	Depth, m	Airflow m^3/min-t	Fan Constant, FA	% Moisture Content Bottom (Min.)	% Moisture Content Top (Max.)	% DML Max	Drying Time, hrs	Failure or Success
1966	24	2.54	2.65	1.40	11.44	15.21	0.0798	640	S
	24	2.54	2.52	1.31	14.00	15.11	0.0797	645	S
	24	2.54	2.13	1.04	14.80	16.21	0.0913	645	F
	24	3.10	2.86	2.4	14.00	14.29	0.0747	645	S
	24	3.10	2.52	2.01	13.93	14.82	0.0801	645	S
	24	3.10	2.24	1.717	14.45	15.48	0.0881	645	F
	24	4.10	3.10	5.413	13.95	14.24	0.0713	423	S
	24	4.10	2.86	4.84	13.32	13.65	0.0755	645	S
	24	4.10	2.52	4.028	13.47	15.46	0.0809	456	S
	24	5.10	2.80	8.24	13.02	15.46	0.0782	312	S
	24	5.10	2.67	7.52	12.87	15.08	0.0824	372	S
	24	5.10	2.52	7.037	13.88	15.17	0.0849	405	S
	21	2.54	2.13	1.40	13.75	15.30	0.0417	465	S
	21	2.54	1.96	0.942	14.00	14.85	0.0444	645	S
	21	2.54	1.68	0.776	14.67	15.56	0.0484	645	F
	21	2.54	1.43	0.64	13.96	16.56	0.0537	645	F
	21	3.10	2.52	2.01	13.91	14.45	0.0361	453	S
	21	3.10	2.32	1.80	13.22	14.86	0.0389	454	S
	21	3.10	1.96	1.434	14.34	14.67	0.0444	645	F
	21	4.10	2.80	4.700	13.12	15.36	0.0334	267	S
	21	4.10	2.52	4.028	13.28	15.43	0.0363	300	S
	21	4.10	2.32	3.61	13.50	14.48	0.0388	426	S
	21	5.10	2.80	8.24	13.32	15.46	0.0334	228	S
	21	5.10	2.52	7.037	12.33	15.37	0.0365	270	S
	21	5.10	2.24	5.92	12.50	15.36	0.0412	318	S
	18	2.54	1.43	0.64	11.90	15.50	0.0184	441	S
	18	2.54	1.20	0.52	13.84	15.37	0.0204	519	S
	18	2.54	1.12	0.474	14.00	15.24	0.0214	645	S
	18	2.54	0.81	0.32	13.99	16.64	0.0244	645	F
	18	3.10	1.68	1.175	13.75	14.42	0.0166	447	S
	18	3.10	1.40	0.93	13.91	15.12	0.0188	436	S
	18	3.10	1.16	0.75	13.83	15.48	0.0208	531	S
	18	4.10	1.68	2.288	13.56	15.48	0.0168	300	S
	18	4.10	1.39	1.77	13.45	15.17	0.0607	444	S
	18	4.10	1.12	1.347	14.29	14.99	0.0214	645	F
	18	5.10	1.68	3.900	13.35	15.50	0.0170	288	S
	18	5.10	1.40	3.037	14.00	15.50	0.0193	369	S
	18	5.10	1.32	2.80	13.33	15.34	0.0199	435	S

Table 8. Simulation Results for Goodland Station.

Period: Oct 20 to Nov. 30

% Damage : 20
% Fines : 3.0

	Input				Output				Observation
	% Initial Most. Cont.	Depth, m	Airflow m^3/min-t	Fan Constant, FA	% Moisture Content Bottom (Min.)	Top (Max.)	% DML Max	Drying Time, hrs	Failure or Success
1969	24	2.54	2.65	1.40	11.20	15.40	0.0177	590	S
	24	2.54	2.13	1.04	16.33	19.98	0.1156	645	F
	24	3.10	2.86	2.40	11.60	15.40	0.0999	645	S
	24	4.10	2.86	4.84	13.51	14.68	0.0993	645	S
	24	5.10	2.67	7.52	11.93	15.39	0.1022	552	S
	21	2.54	2.13	1.04	11.65	15.90	0.0563	1029	F
	21	5.10	2.52	7.037	11.85	15.27	0.0466	504	S
	18	2.54	1.43	0.64	12.15	15.88	0.0235	645	F
	18	3.10	2.32	1.80	13.60	15.39	0.0204	591	S
	18	4.10	2.32	3.61	12.98	15.35	0.200	528	S
	18	5.10	2.24	5.92	12.51	15.33	0.0193	465	S

Table 9. Simulation Results for Dodge City Station.

Period: Oct 20 to Nov. 30

% Damage : 20
% Fines : 3.0

	Input				Output				Observation
	% Initial Most. Cont.	Depth, m	Airflow m^3/min-t	Fan Constant, FA	% Moisture Content Bottom (Min.)	% Moisture Content Top (Max.)	% DML Max	Drying Time, hrs	Failure or Success
1971	24	2.54	2.65	1.4	10.87	15.41	.1669	600	S
	24	2.54	2.52	1.31	12.16	15.42	.1666	624	S
	24	2.54	2.24	1.12	13.55	15.30	.1814	645	S
	24	2.54	2.13	1.04	12.01	17.09	.1849	645	F
	24	2.54	1.43	0.64	12.27	21.77	.2184	645	F
	24	3.10	2.86	2.4	11.51	15.43	.1559	561	S
	24	3.10	2.52	2.01	12.74	15.43	.1683	600	S
	24	3.10	2.24	1.717	13.57	15.76	.1806	645	S
	24	3.10	2.32	1.80	11.65	15.48	.1768	639	S
	24	4.10	2.86	4.84	12.49	15.43	.1556	507	S
	24	4.10	2.52	4.028	12.64	15.48	.1653	555	S
	24	4.10	2.32	3.61	13.41	15.40	.2370	597	S
	24	5.10	2.80	8.24	13.03	15.45	.1551	417	S
	24	5.10	2.52	7.037	13.08	15.48	.1697	489	S
	24	5.10	2.24	5.92	14.30	16.20	.6236	1029	F
	21	2.54	2.13	1.04	11.05	15.48	.0872	606	S
	21	2.54	1.96	0.932	13.47	15.57	.0896	645	F
	21	2.54	1.43	0.64	13.86	16.17	.2176	1029	F
	21	3.10	2.52	2.01	13.68	15.45	.0789	531	S
	21	3.10	2.24	1.717	13.23	15.50	.0844	579	S
	21	3.10	2.80	2.334	13.75	15.10	.0735	516	S
	21	4.10	2.80	4.70	13.63	15.36	.0719	408	S
	21	4.10	2.52	4.028	13.79	15.48	.0771	471	S
	21	4.10	2.24	3.400	13.02	15.40	.0830	528	S
	21	5.10	2.80	8.24	13.85	15.49	.0708	324	S
	21	5.10	2.52	7.037	13.81	15.47	.0752	390	S
	21	5.10	2.24	5.92	11.21	15.46	.0978	458	S
	18	2.54	1.96	0.932	13.75	15.42	.0335	531	S
	18	2.54	1.68	0.776	13.08	15.39	.0358	600	S
	18	2.54	1.43	0.64	13.85	16.50	.0376	1029	F
	18	3.10	2.24	1.717	13.76	15.02	.0315	498	S
	18	3.10	1.96	1.434	13.88	15.38	.0334	519	S
	18	3.10	1.68	1.175	13.49	15.46	.0358	587	S
	18	4.10	2.24	3.400	13.90	14.75	.0309	453	S
	18	4.10	1.96	2.821	13.98	14.96	.0331	488	S
	18	4.10	1.68	2.288	13.77	15.43	.0356	528	S
	18	5.10	2.24	5.896	13.86	14.80	.0300	342	S
	18	5.10	1.96	4.290	14.00	15.39	.0341	411	S
	18	5.10	1.68	3.900	13.89	15.07	.0354	492	S

Table 10. Simulation Results for Dodge City Station.

Period: Oct 5 to Nov. 15

% Damage : 20
% Fines : 3.0

	Input				Output				Observation
	% Initial Most. Cont.	Depth, m	Airflow m^3/min-t	Fan Constant, FA	% Moisture Content Bottom (Min.)	Top (Max.)	% DML Max	Drying Time, hrs	Failure or Success
1972	24	2.54	2.65	1.4	12.95	15.80	0.1234	1029	F
	21	2.54	2.65	1.4	14.34	17.53	0.0543	1029	F
	18	2.54	2.65	1.4	11.67	15.46	0.0214	501	S
	18	2.54	2.13	1.04	14.34	17.34	0.0237	645	F
	18	3.10	2.86	2.4	12.78	15.31	0.0576	450	S
	18	5.10	2.86	4.84	12.14	15.28	0.0183	354	S
	18	5.10	2.67	7.52	13.12	14.77	0.0177	354	S

Table 11. Simulation Results for Wichita Station.

Period: Oct. 15 to Nov. 25

% Damage : 20
% Fines : 3.0

	Input				Output				Observation
	% Initial Most. Cont.	Depth, m	Airflow m^3/min-t	Fan Constant, FA	% Moisture Content Bottom (Min.)	% Moisture Content Top (Max.)	% DML Max	Drying Time, hrs	Failure or Success
1968	24	2.54	3.10	2.34	13.19	15.29	.1717	402	S
	24	2.54	2.80	1.51	15.68	16.91	.2120	645	F
	24	2.54	2.65	1.40	14.94	15.88	.2300	1029	F
	24	3.10	3.64	3.397	12.90	15.40	.1750	384	S
	24	3.10	3.40	3.023	13.26	15.35	.1814	405	S
	24	3.10	3.10	2.67	13.12	15.50	.1965	426	S
	24	4.10	3.64	6.975	12.98	15.46	.1668	315	S
	24	4.10	3.40	6.170	12.95	15.36	.1774	354	S
	24	4.10	3.10	5.413	13.21	15.37	.1870	390	S
	21	2.54	2.65	1.40	12.78	15.44	.1015	420	S
	21	2.54	2.52	1.31	13.09	15.35	.1051	441	S
	21	2.54	2.24	1.12	15.30	16.90	.1143	645	F
	21	3.10	3.10	2.670	13.37	15.40	.0909	363	S
	21	3.10	2.80	2.334	13.33	15.39	.0961	402	S
	21	3.10	2.52	2.01	13.55	15.46	.1043	423	S
	21	4.10	3.10	5.413	13.11	15.43	.0885	306	S
	21	4.10	2.86	4.850	12.29	15.11	.0930	342	S
	21	4.10	2.52	4.028	13.16	15.48	.0998	387	S
	21	5.10	2.80	8.240	13.23	15.38	.0919	291	S
	21	5.10	2.67	7.52	11.48	15.21	.0953	311	S
	21	5.10	2.52	7.037	13.05	15.44	.0978	330	S
	21	5.10	2.24	5.92	11.88	15.32	.1068	399	S
	18	2.54	2.13	1.04	12.60	15.47	.0440	411	S
	18	2.54	1.68	0.776	13.93	15.33	.0495	468	S
	18	2.54	1.43	0.64	13.77	16.73	.0537	645	F
	18	3.10	2.32	1.80	13.20	15.43	.0413	351	S
	18	3.10	1.96	1.434	13.58	15.38	.0456	417	S
	18	3.10	1.68	1.175	13.96	15.44	.0492	466	S
	18	4.10	2.32	3.61	12.75	15.33	.0394	300	S
	18	4.10	1.96	2.821	13.75	15.33	.0438	390	S
	18	4.10	1.68	2.288	13.40	15.40	.0490	453	S
	18	5.10	2.24	5.92	13.40	15.49	.0660	548	S
	18	5.10	1.96	4.290	13.98	15.43	.0456	366	S
	18	5.10	1.68	3.900	13.15	15.35	.0476	411	S
1972	24	2.54	2.65	1.40	17.33	17.62	.2057	1029	F
	21	2.54	2.65	1.40	11.60	16.48	.0327	1029	F
	18	2.54	2.65	1.40	16.80	17.11	.0613	1029	F

Table 12. Simulation Results for Topeka Station.

Period: Oct. 5 to Nov. 15

% Damage : 20
% Fines : 3.0

	Input				Output				Observation
	% Initial Most. Cont.	Depth, m	Airflow m^3/min-t	Fan Constant, FA	% Moisture Content Bottom (Min.)	% Moisture Content Top (Max.)	% DML Max	Drying Time, hrs	Failure or Success
1965	24	2.54	2.65	1.40	13.75	14.96	.2425	550	S
	24	2.54	2.13	1.04	13.53	15.42	.3160	603	S
	24	2.54	1.68	0.776	14.25	17.25	.4042	645	F
	24	2.54	1.43	0.64	12.88	19.48	.4435	645	F
	24	3.10	2.86	2.40	12.95	15.42	.2740	605	S
	24	3.10	2.32	1.80	13.71	15.30	.2756	543	S
	24	3.10	1.96	1.434	13.35	15.42	.3426	630	S
	24	4.10	2.86	4.84	13.48	15.40	.1880	360	S
	24	4.10	2.32	3.61	13.19	15.41	.2603	459	S
	24	4.10	1.96	2.821	13.78	15.49	.3338	564	S
	24	5.10	2.52	7.037	13.65	15.41	.2125	354	S
	24	5.10	2.24	5.92	12.88	15.43	.2616	414	S
	24	5.10	1.96	4.290	13.64	15.43	.3650	573	S
	21	2.54	2.13	1.04	12.29	15.46	.1240	544	S
	21	2.54	1.68	0.776	13.91	15.37	.1614	615	S
	21	2.54	1.43	0.64	13.03	15.88	.1872	645	F
	21	3.10	2.24	1.717	13.72	14.42	.1109	552	S
	21	3.10	1.96	1.434	13.87	14.57	.1347	570	S
	21	3.10	1.68	1.175	13.80	15.29	.1607	603	S
	21	4.10	2.24	3.400	13.97	14.54	.1063	402	S
	21	4.10	1.96	2.821	13.95	14.91	.1301	456	S
	21	4.10	1.68	2.288	14.00	15.23	.1563	528	S
	21	5.10	2.24	5.92	12.26	15.19	.0975	324	S
	21	5.10	1.96	4.29	13.89	15.47	.1411	411	S
	21	5.10	1.68	3.900	13.91	15.48	.1543	456	S
	18	2.54	2.65	1.40	13.52	14.76	.0386	558	S
	18	2.54	1.43	0.64	12.97	15.38	.0462	381	S
	18	2.54	1.20	0.52	13.74	15.09	.0695	567	S
	18	2.54	0.81	0.32	13.00	16.68	.0813	645	F
	18	3.10	1.68	1.175	13.92	14.27	.0508	570	S
	18	3.10	1.40	0.930	13.99	14.56	.0615	560	S
	18	3.10	1.16	0.75	13.86	15.21	.0709	564	S
	18	4.10	1.68	2.288	13.92	14.10	.0493	447	S
	18	4.10	1.39	1.77	13.73	14.97	.0615	450	S
	18	4.10	1.12	1.347	13.87	14.98	.0729	630	S
	18	5.10	1.68	3.900	14.00	14.65	.0468	354	S
	18	5.10	1.32	2.80	13.58	15.27	.0636	411	S
	18	5.10	1.12	2.25	13.81	14.95	.0736	573	S

Table 13. Simulation Results for Topeka Station.

Period: Oct 5 to Nov. 15

% Damage : 20
% Fines : 3.0

	Input				Output				Observation
	% Initial Most. Cont.	Depth, m	Airflow m^3/min-t	Fan Constant, FA	% Moisture Content Bottom (Min.)	Top (Max.)	% DML Max	Drying Time, hrs	Failure or Success
1972	24	2.54	2.65	1.40	12.20	15.50	.2516	580	S
	24	2.54	2.13	1.04	15.38	16.39	.2834	645	F
	24	3.10	2.86	2.40	12.98	15.08	.2252	532	S
	24	4.10	2.86	4.84	13.21	15.48	.2243	432	S
	24	5.10	2.67	7.52	12.15	15.46	.1870	387	S
	21	2.54	2.13	1.04	15.32	16.60	.1277	1029	F
	21	5.10	2.52	7.037	12.08	15.13	.1089	506	S
	18	2.54	2.13	1.04	12.07	15.45	.0474	321	S
	18	2.54	1.43	0.64	14.92	17.00	.0564	1029	F
	18	3.10	2.32	1.80	13.21	15.29	.0449	391	S
	18	4.10	2.32	3.61	12.56	15.40	.0435	361	S
	18	5.10	2.24	5.92	12.54	15.11	.0425	240	S

APPENDIX III

AN EXAMPLE OF INPUT AND OUTPUT FROM COMPUTER PROGRAM

```
//RCL04798 JOB (XXXXXXXXX,XXXXXXXX),'ABDELMOHSIN GABIR',TIME=(,19)       JOB 254
***ROUTE PRINT OS
// EXEC FORTGG,P=KSUDRYER
//STEPLIB DD DSN=DSKN7.LOADLIB,DISP=SHR
//GO.FT03F001 DD DDNAME=SYSIN1
//SYSIN1 DD *
//GO.FT13F001  DD SYSOUT=A,DCB=(RECFM=UA,BLKSIZE=133)
//GO.SYSIN DD *

KSU003I REGION SIZE -  256K, MAXIMUM CORE USED -  104K,  TIME =  10.42.12
KSU004I EXCP COUNT - UR 602       7,  UR 642     676,  UR 680       0,  UR 643       0,  DA 26E       0,  UR 601      56
KSU004I EXCP COUNT - UR 644       0
KSU001I STEP   1 GO       EXECUTION TIME =            9.76 SEC     RETURN CODE =     0

KSU002I JOB RCL04798 EXECUTION TIME =            9.76 SEC



 HASP-II V3.1 JOB STATISTICS --      69 CARDS READ --       697 LINES PRINTED --       0 CARDS PUNCHED --    COPY    1 OF    1
```

FINAL REPORT OF: KSUDRYER FANMANAGEMENT USING USDA TEST 1-N FOR EVALUATION OF FANMANAGEMENT 1

GRAIN MOISTUPE CONTENT(W.B.) AVE: 0.1241 MAX: 0.1390 LAYER OBSERVED: 1

PERCENT DRY MATTER LOSS (STEELE,69) AVE: 0.1145 MAX: 0.1764 LAYER OBSERVED: 10

FAN OPERATION TIME SHEET(HOURS OF FAN OPERATION TO DATE)

	NUMBER OF FILLS 1	2	3
LOW SPEED ^	0		
HIGH SPEED ^	645		

DRYING STUDY DURATION: 645 HOURS
FAN OPERATION 645 HOURS
HOURS OF NO FAN OPERATION: 0 HOURS

ENERGY REQUIRED FOR FAN OPERATION TO DATE(KWH)

	NUMBER OF FILLS 1	2	3
LOW SPEED ^	0.0		
HIGH SPEED ^	12.222		

TOTAL ENERGY REQUIRED FOR FAN OPERATION: 12.2224 KWH/FT2
ENERGY FOR SUPPLEMENTAL HEATER: 0.0 KWH/FT2

TOTAL ENERGY REQUIRED FOR THIS STUDY: 12.2224 KWH/FT2

LIST OF WEATHER DATA CARD DECK

WEATHER STATION IDENTIFICATION IS : D-13 9

```
215 3  071 2.58  293 3 5083 0.0  293 6 4986 0.0  293 9 5077 0.0
29312 6054 0.0   29315 6442 0.0   29318 5951 0.0   29321 5269 0.0
294 0 4880 0.0   294 3 4583 0.0   294 6 4383 0.0   294 9 5174 0.0
29412 6742 0.0   29415 7039 0.0   29418 6160 0.0   29421 5475 0.0
295 0 5183 0.0   295 3 4993 0.0   295 6 4893 0.0   295 9 5093 0.0
29512 6456 0.0   29515 6549 0.0   29518 5760 0.0   29521 4977 0.0
296 0 4786 0.0   296 3 4193 0.0   296 6 4393 0.0   296 9 4693 0.0
29612 5662 0.0   29615 6054 0.0   29618 5364 0.0   29621 4683 0.0
297 0 4483 0.0   297 3 4289 0.0   297 6 4489 0.0   297 9 5280 0.0
29712 6356 0.0   29715 7240 0.0   29718 6256 0.0   29721 5867 0.0
298 0 5480 0.0   298 3 5380 0.0   298 6 5186 0.0   298 9 5870 0.0
29812 6857 0.0   29815 7351 0.0   29818 6863 0.0   29821 6375 0.0
299 0 5984 0.0   299 3 5887 0.0   299 6 6087 0.0   299 9 6187 0.0
29912 6290 0.0   29915 6281 0.0   29918 5683 0.0   29921 5486 0.0
300 0 5064 0.0   300 3 4963 0.0   300 6 5257 0.0   300 9 5562 0.0
30012 6346 0.0   30015 6737 0.0   30018 6058 0.0   30021 5477 0.0
301 0 5480 0.0   301 3 5186 0.0   301 6 4889 0.0   301 9 5760 0.0
30112 6252 0.0   30115 4583 0.0   30118 3893 0.0   30121 3492 0.0
302 0 3292 0.0   302 3 3192 0.0   302 6 3092 0.0   302 9 3189 0.0
30212 3289 0.0   30215 3392 0.0   30218 3392 0.0   30221 3492 0.0
303 0 3492 0.0   303 3 3492 0.0   303 6 3389 0.0   303 9 3485 0.0
30312 4168 0.0   30315 5041 0.0   30318 4249 0.0   30321 3762 0.0
304 0 3370 0.0   304 3 3573 0.0   304 6 3582 0.0   304 9 4373 0.0
30412 5353 0.0   30415 6046 0.0   30418 5555 0.0   30421 5171 0.0
305 0 5269 0.0   305 3 5283 0.0   305 6 5486 0.0   305 9 5590 0.0
30512 4680 0.0   30515 5639 0.0   30518 4563 0.0   30521 4265 0.0
306 0 4068 0.0   306 3 3970 0.0   306 6 3485 0.0   306 9 4952 0.0
30612 5534 0.0   30615 5437 0.0   30618 4351 0.0   30621 3564 0.0
307 0 3269 0.0   307 3 3166 0.0   307 6 2966 0.0   307 9 3652 0.0
30712 4929 0.0   30715 5423 0.0   30718 4748 0.0   30721 4268 0.0
308 0 4268 0.0   308 3 3973 0.0   308 6 3679 0.0   308 9 4268 0.0
30812 5944 0.0   30815 6637 0.0   30818 5851 0.0   30821 5166 0.0
309 0 4880 0.0   309 3 4683 0.0   309 6 4283 0.0   309 9 4565 0.0
30912 4946 0.0   30915 5039 0.0   30918 4245 0.0   30921 3361 0.0
310 0 3061 0.0   310 3 2672 0.0   310 6 2475 0.0   310 9 2961 0.0
31012 3737 0.0   31015 4133 0.0   31018 3648 0.0   31021 2966 0.0
311 0 2769 0.0   311 3 2672 0.0   311 6 2478 0.0   311 9 3259 0.0
31112 4342 0.0   31115 4932 0.0   31118 4340 0.0   31121 4241 0.0
312 0 4249 0.0   312 3 4158 0.0   312 6 3873 0.0   312 9 4170 0.0
31212 5253 0.0   31215 6030 0.0   31218 4841 0.0   31221 3662 0.0
313 0 3464 0.0   313 3 3267 0.0   313 6 2872 0.0   313 9 3953 0.0
31312 5529 0.0   31315 5922 0.0   31318 5135 0.0   31321 4644 0.0
314 0 4155 0.0   314 3 4060 0.0   314 6 3865 0.0   314 9 4153 0.0
31412 6424 0.0   31415 7216 0.0   31418 5630 0.0   31421 4742 0.0
315 0 4644 0.0   315 3 4251 0.0   315 6 4151 0.0   315 9 4941 0.0
31512 6726 0.0   31515 7221 0.0   31518 6135 0.0   31521 5249 0.0
316 0 5340 0.0   316 3 4946 0.0   316 6 4258 0.0   316 9 5145 0.0
31612 6730 0.0   31615 7521 0.0   31618 6139 0.0   31621 5639 0.0
317 0 5364 0.0   317 3 5074 0.0   317 6 4959 0.0   317 9 5148 0.0
31712 7131 0.0   31715 7511 0.0   31718 6427 0.0   31721 5145 0.0
318 0 4551 0.0   318 3 4055 0.0   318 6 4243 0.0   318 9 5039 0.0
31812 6132 0.0   31815 6727 0.0   31818 5542 0.0   31821 4859 0.0
319 0 4874 0.0   319 3 5089 0.0   319 6 5193 0.0   319 9 5490 0.0
31912 6470 0.0   31915 6668 0.0   31918 6278 0.0   31921 6181 0.0
```

LISTING OF WEATHER DATA WITH THE TIME POINTER

```
50 83 13.414 7035   49 86 13.414 7038   50 77 13.414 7041   60 54 13.414 7044   64 42 13.414 7047   59 51 13.414 7050
52 69 13.414 7053   48 80 13.414 7056   45 83 13.414 7059   43 83 13.414 7062   51 74 13.414 7065   67 42 13.414 7068
70 39 13.414 7071   61 60 13.414 7074   54 75 13.414 7077   51 83 13.414 7080   49 93 13.414 7083   48 93 13.414 7086
50 93 13.414 7089   64 56 13.414 7092   65 49 13.414 7095   57 60 13.414 7098   49 77 13.414 7101   47 86 13.414 7104
41 93 13.414 7107   43 93 13.414 7110   46 93 13.414 7113   56 62 13.414 7116   60 54 13.414 7119   53 64 13.414 7122
46 83 13.414 7125   44 83 13.414 7128   42 89 13.414 7131   44 89 13.414 7134   52 80 13.414 7137   63 56 13.414 7140
72 40 13.414 7143   62 56 13.414 7146   58 67 13.414 7149   54 80 13.414 7152   53 80 13.414 7155   51 86 13.414 7158
58 70 13.414 7161   68 57 13.414 7164   73 51 13.414 7167   68 63 13.414 7170   63 75 13.414 7173   59 84 13.414 7176
58 87 13.414 7179   60 87 13.414 7182   61 87 13.414 7185   62 90 13.414 7188   62 81 13.414 7191   56 83 13.414 7194
54 86 13.414 7197   50 64 13.414 7200   49 63 13.414 7203   52 57 13.414 7206   55 62 13.414 7209   63 46 13.414 7212
67 37 13.414 7215   60 58 13.414 7218   54 77 13.414 7221   54 80 13.414 7224   51 86 13.414 7227   48 89 13.414 7230
57 60 13.414 7233   62 52 13.414 7236   45 83 13.414 7239   38 93 13.414 7242   34 92 13.414 7245   32 92 13.414 7248
31 92 13.414 7251   30 92 13.414 7254   31 89 13.414 7257   32 89 13.414 7260   33 92 13.414 7263   33 92 13.414 7266
34 92 13.414 7269   34 92 13.414 7272   34 92 13.414 7275   33 89 13.414 7278   34 85 13.414 7281   41 68 13.414 7284
50 41 13.414 7287   42 49 13.414 7290   37 62 13.414 7293   33 70 13.414 7296   35 73 13.414 7299   35 82 13.414 7302
43 73 13.414 7305   53 53 13.414 7308   60 46 13.414 7311   55 55 13.414 7314   51 71 13.414 7317   52 69 13.414 7320
52 83 13.414 7323   54 86 13.414 7326   55 90 13.414 7329   46 80 13.414 7332   56 39 13.414 7335   45 63 13.414 7338
42 65 13.414 7341   40 68 13.414 7344   39 70 13.414 7347   34 85 13.414 7350   49 52 13.414 7353   55 34 13.414 7356
54 37 13.414 7359   43 51 13.414 7362   35 64 13.414 7365   32 69 13.414 7368   31 66 13.414 7371   29 66 13.414 7374
36 52 13.414 7377   49 29 13.414 7380   54 23 13.414 7383   47 48 13.414 7386   42 68 13.414 7389   42 68 13.414 7392
39 73 13.414 7395   36 79 13.414 7398   42 68 13.414 7401   59 44 13.414 7404   66 37 13.414 7407   58 51 13.414 7410
51 66 13.414 7413   48 80 13.414 7416   46 83 13.414 7419   42 83 13.414 7422   45 65 13.414 7425   49 46 13.414 7428
50 39 13.414 7431   42 45 13.414 7434   33 61 13.414 7437   30 61 13.414 7440   26 72 13.414 7443   24 75 13.414 7446
29 61 13.414 7449   37 37 13.414 7452   41 33 13.414 7455   36 48 13.414 7458   29 66 13.414 7461   27 69 13.414 7464
26 72 13.414 7467   24 78 13.414 7470   32 59 13.414 7473   43 42 13.414 7476   49 32 13.414 7479   43 40 13.414 7482
42 41 13.414 7485   42 49 13.414 7488   41 58 13.414 7491   38 73 13.414 7494   41 70 13.414 7497   52 53 13.414 7500
60 30 13.414 7503   48 41 13.414 7506   36 62 13.414 7509   34 64 13.414 7512   32 67 13.414 7515   28 72 13.414 7518
39 53 13.414 7521   55 29 13.414 7524   59 22 13.414 7527   51 35 13.414 7530   46 44 13.414 7533   41 55 13.414 7536
40 60 13.414 7539   38 65 13.414 7542   41 53 13.414 7545   64 24 13.414 7548   72 16 13.414 7551   56 30 13.414 7554
47 42 13.414 7557   46 44 13.414 7560   42 51 13.414 7563   41 51 13.414 7566   49 41 13.414 7569   67 26 13.414 7572
72 21 13.414 7575   61 35 13.414 7578   52 49 13.414 7581   53 40 13.414 7584   49 46 13.414 7587   42 58 13.414 7590
51 45 13.414 7593   67 30 13.414 7596   75 21 13.414 7599   61 39 13.414 7602   56 39 13.414 7605   53 64 13.414 7608
50 74 13.414 7611   49 59 13.414 7614   51 48 13.414 7617   71 31 13.414 7620   75 11 13.414 7623   64 27 13.414 7626
51 45 13.414 7629   45 51 13.414 7632   40 55 13.414 7635   42 43 13.414 7638   50 39 13.414 7641   61 32 13.414 7644
67 27 13.414 7647   55 42 13.414 7650   48 59 13.414 7653   48 74 13.414 7656   50 89 13.414 7659   51 93 13.414 7662
54 90 13.414 7665   64 70 13.414 7668   66 68 13.414 7671   62 78 13.414 7674   61 81 13.414 7677
```

WEATHER DATA AS CALCULATED BY WEATHER SUBROUTINE AND COMUNICATED TO THE TIME SUBROUTINE

50.0	0.83	13.414	293	3	49.0	0.86	13.414	293	6	50.0	0.77	13.414	293	9	60.0	0.54	13.414	293	12
64.0	0.42	13.414	293	15	59.0	0.51	13.414	293	18	52.0	0.69	13.414	293	21	48.0	0.80	13.414	294	0
45.0	0.83	13.414	294	3	43.0	0.83	13.414	294	6	51.0	0.74	13.414	294	9	67.0	0.42	13.414	294	12
70.0	0.39	13.414	294	15	61.0	0.60	13.414	294	18	54.0	0.75	13.414	294	21	51.0	0.83	13.414	295	0
49.0	0.93	13.414	295	3	48.0	0.93	13.414	295	6	50.0	0.93	13.414	295	9	64.0	0.56	13.414	295	12
65.0	0.49	13.414	295	15	57.0	0.60	13.414	295	18	49.0	0.77	13.414	295	21	47.0	0.86	13.414	296	0
41.0	0.93	13.414	296	3	43.0	0.93	13.414	296	6	46.0	0.93	13.414	296	9	56.0	0.62	13.414	296	12
60.0	0.54	13.414	296	15	53.0	0.64	13.414	296	18	46.0	0.83	13.414	296	21	44.0	0.83	13.414	297	0
42.0	0.89	13.414	297	3	44.0	0.89	13.414	297	6	52.0	0.80	13.414	297	9	63.0	0.56	13.414	297	12
72.0	0.40	13.414	297	15	62.0	0.56	13.414	297	18	58.0	0.67	13.414	297	21	54.0	0.80	13.414	298	0
53.0	0.80	13.414	298	3	51.0	0.86	13.414	298	6	58.0	0.70	13.414	298	9	68.0	0.57	13.414	298	12
73.0	0.51	13.414	298	15	68.0	0.63	13.414	298	18	63.0	0.75	13.414	298	21	59.0	0.84	13.414	299	0
58.0	0.87	13.414	299	3	60.0	0.87	13.414	299	6	61.0	0.87	13.414	299	9	62.0	0.90	13.414	299	12
62.0	0.81	13.414	299	15	56.0	0.83	13.414	299	18	54.0	0.86	13.414	299	21	50.0	0.64	13.414	300	0
49.0	0.63	13.414	300	3	52.0	0.57	13.414	300	6	55.0	0.62	13.414	300	9	63.0	0.46	13.414	300	12
67.0	0.37	13.414	300	15	60.0	0.58	13.414	300	18	54.0	0.77	13.414	300	21	54.0	0.80	13.414	301	0
51.0	0.86	13.414	301	3	48.0	0.89	13.414	301	6	57.0	0.60	13.414	301	9	62.0	0.52	13.414	301	12
45.0	0.83	13.414	301	15	38.0	0.93	13.414	301	18	34.0	0.92	13.414	301	21	32.0	0.92	13.414	302	0
31.0	0.92	13.414	302	3	30.0	0.92	13.414	302	6	31.0	0.89	13.414	302	9	32.0	0.89	13.414	302	12
33.0	0.92	13.414	302	15	33.0	0.92	13.414	302	18	34.0	0.92	13.414	302	21	34.0	0.92	13.414	303	0
34.0	0.92	13.414	303	3	33.0	0.89	13.414	303	6	34.0	0.85	13.414	303	9	41.0	0.68	13.414	303	12
50.0	0.41	13.414	303	15	42.0	0.49	13.414	303	18	37.0	0.62	13.414	303	21	33.0	0.70	13.414	304	0
35.0	0.73	13.414	304	3	35.0	0.82	13.414	304	6	43.0	0.73	13.414	304	9	53.0	0.53	13.414	304	12
60.0	0.46	13.414	304	15	55.0	0.55	13.414	304	18	51.0	0.71	13.414	304	21	52.0	0.69	13.414	305	0
52.0	0.83	13.414	305	3	54.0	0.86	13.414	305	6	55.0	0.90	13.414	305	9	46.0	0.80	13.414	305	12
56.0	0.39	13.414	305	15	45.0	0.63	13.414	305	18	42.0	0.65	13.414	305	21	40.0	0.68	13.414	306	0
39.0	0.70	13.414	306	3	34.0	0.85	13.414	306	6	49.0	0.52	13.414	306	9	55.0	0.34	13.414	306	12
54.0	0.37	13.414	306	15	43.0	0.51	13.414	306	18	35.0	0.64	13.414	306	21	32.0	0.69	13.414	307	0
31.0	0.66	13.414	307	3	29.0	0.66	13.414	307	6	36.0	0.52	13.414	307	9	49.0	0.29	13.414	307	12
54.0	0.23	13.414	307	15	47.0	0.48	13.414	307	18	42.0	0.68	13.414	307	21	42.0	0.68	13.414	308	0
39.0	0.73	13.414	308	3	36.0	0.79	13.414	308	6	42.0	0.68	13.414	308	9	59.0	0.44	13.414	308	12
66.0	0.37	13.414	308	15	58.0	0.51	13.414	308	18	51.0	0.66	13.414	308	21	48.0	0.80	13.414	309	0
46.0	0.83	13.414	309	3	42.0	0.83	13.414	309	6	45.0	0.65	13.414	309	9	49.0	0.46	13.414	309	12
50.0	0.39	13.414	309	15	42.0	0.45	13.414	309	18	33.0	0.61	13.414	309	21	30.0	0.61	13.414	310	0
26.0	0.72	13.414	310	3	24.0	0.75	13.414	310	6	29.0	0.61	13.414	310	9	37.0	0.37	13.414	310	12
41.0	0.33	13.414	310	15	36.0	0.48	13.414	310	18	29.0	0.66	13.414	310	21	27.0	0.69	13.414	311	0
26.0	0.72	13.414	311	3	24.0	0.78	13.414	311	6	32.0	0.59	13.414	311	9	43.0	0.42	13.414	311	12
49.0	0.32	13.414	311	15	43.0	0.40	13.414	311	18	42.0	0.41	13.414	311	21	42.0	0.49	13.414	312	0
41.0	0.58	13.414	312	3	38.0	0.73	13.414	312	6	41.0	0.70	13.414	312	9	52.0	0.53	13.414	312	12
60.0	0.30	13.414	312	15	48.0	0.41	13.414	312	18	36.0	0.62	13.414	312	21	34.0	0.64	13.414	313	0
32.0	0.67	13.414	313	3	28.0	0.72	13.414	313	6	39.0	0.53	13.414	313	9	55.0	0.29	13.414	313	12
59.0	0.22	13.414	313	15	51.0	0.35	13.414	313	18	46.0	0.44	13.414	313	21	41.0	0.55	13.414	314	0
40.0	0.60	13.414	314	3	38.0	0.65	13.414	314	6	41.0	0.53	13.414	314	9	64.0	0.24	13.414	314	12
72.0	0.16	13.414	314	15	56.0	0.30	13.414	314	18	47.0	0.42	13.414	314	21	46.0	0.44	13.414	315	0
42.0	0.51	13.414	315	3	41.0	0.51	13.414	315	6	49.0	0.41	13.414	315	9	67.0	0.26	13.414	315	12
72.0	0.21	13.414	315	15	61.0	0.35	13.414	315	18	52.0	0.49	13.414	315	21	53.0	0.40	13.414	316	0
49.0	0.46	13.414	316	3	42.0	0.58	13.414	316	6	51.0	0.45	13.414	316	9	67.0	0.30	13.414	316	12
75.0	0.21	13.414	316	15	61.0	0.39	13.414	316	18	56.0	0.39	13.414	316	21	53.0	0.64	13.414	317	0
50.0	0.74	13.414	317	3	49.0	0.59	13.414	317	6	51.0	0.48	13.414	317	9	71.0	0.31	13.414	317	12
75.0	0.11	13.414	317	15	64.0	0.27	13.414	317	18	51.0	0.45	13.414	317	21	45.0	0.51	13.414	318	0
40.0	0.55	13.414	318	3	42.0	0.43	13.414	318	6	50.0	0.39	13.414	318	9	61.0	0.32	13.414	318	12
67.0	0.27	13.414	318	15	55.0	0.42	13.414	318	18	48.0	0.59	13.414	318	21	48.0	0.74	13.414	319	0
50.0	0.89	13.414	319	3	51.0	0.93	13.414	319	6	54.0	0.90	13.414	319	9	64.0	0.70	13.414	319	12
66.0	0.68	13.414	319	15	62.0	0.78	13.414	319	18	61.0	0.81	13.414	319	21					

SIMULATION OF NATURAL-AIR GRAIN CONDITIONING ** KANSAS STATE UNIVERSITY ** DEPARTMENT OF GRAIN SCIENCE AND INDUSTRY

TITLE: KSUDRYER FANMANAGEMENT USING USDA TEST 1-N FOR EVALUATION OF FANMANAGEMENT 1 INVESTIGATOR: ABDELMOHSIN GA

BIN LOCATION: DODGE CITY,KANSAS **** WEATHER IDENTIFICATION: D-13 9 **** TYPE OF GRAIN: YELLOW DENT CORN

INITIAL GRAIN CONDITIONS AT EACH FILL

		#1	#2	#3	
MOISTURE CONTENT	=	0.24	0.0	0.0	WET BASIS
GRAIN TEMPERATURE	=	70.0	0.0	0.0	DEGREES F.
FINE MATERIAL	=	0.03	0.0	0.0	THRUS OF 12/64"
PERCENT DAMAGE	=	20.0	0.0	0.0	STAIN TEST %
DEPTH OF GRAIN	=	13.3	0.0	0.0	FEET

BIN MANAGEMENT

DATE BIN WAS FILLED (DAY,HOUR) FILL #1 293, 3
#2 0, 0
#3 0, 0
WHEN WEATHER DATA STARTS 293, 3
HOW LONG CAN MODEL RUN 26 DAYS

MATHEMATICAL MODEL EMPIRICAL GRAIN CONSTANTS

CHUNG-PFOST EQUILIBRIUM MOISTURE EQUATION
A= 1110.4299 B= 16.9534 C= 21.8947

KAZARIAN-HALL SPECIFIC HEAT EQUATION
CA= 0.350 CB= 0.851

DENSITY EQUATION DRYING CONSTANT
B0= 49.35 B1=-27.83 DC= 0.020

MATHEMATICAL MODEL ATTRIBUTES

TIME TEST STARTS: 293, 3 (DAY,HOUR)
TIME INCREMENT: 3 HR

FILL	#1	#2	#3
NUMBER OF MODELED LAYERS:	10		
THICKNESS OF EACH LAYER :	1.3		

FAN MANAGEMENT

TYPE OF FAN MANAGEMENT USED:
CONTINOUS OPERATION OF FAN AT HIGH SPEED

	FAN SPEED	FILL #1	#2	#3
AIRFLOW RATE IN BIN (CFM/SQ.FT.)	LOW	0.0		
	HIGH	22.32		
POWER TO RUN FAN @ CFM (KILOWATTS/HOUR)	LOW	0.0		
	HIGH	0.0189		
STATIC PRESSURE (INCHES WATER)	LOW	0.0		
	HIGH	3.6100		

FAN TYPE		COEFFICIENTS			FAN EFFICIENCY
LOW	(NO LOW SPEED FAN)	0.0	0.0	0.0	0.0
HIGH	HIGH SPEED AERATION	3.6100	0.0	0.0	0.50

TIME	DRYING BED HEIGHT ABOVE BIN FLOOR (INCHES) GRAIN MOISTURES (WB) AT EACH SENSING LOCATION 1-11-21	2-12-22	3-13-23	4-14-24	5-15-25	6-16-26	7-17-27	8-18-28	9-19-29	10-20-30
7038	7.885 0.2327	23.735 0.2378	39.629 0.2355	55.534 0.2384	71.452 0.2364	87.377 0.2388	103.313 0.2372	119.254 0.2391	135.204 0.2378	151.157 0.2392
7041	7.862 0.2312	23.653 0.2355	39.479 0.2334	55.319 0.2364	71.180 0.2349	87.053 0.2371	102.934 0.2354	118.821 0.2375	134.719 0.2360	150.622 0.2379
7044	7.840 0.2297	23.591 0.2343	39.381 0.2324	55.186 0.2352	71.008 0.2335	86.837 0.2356	102.680 0.2344	118.528 0.2359	134.385 0.2350	150.249 0.2363
7047	7.818 0.2283	23.532 0.2333	39.298 0.2317	55.083 0.2346	70.889 0.2330	86.701 0.2350	102.523 0.2337	118.347 0.2351	134.177 0.2341	150.014 0.2356
7050	7.760 0.2245	23.383 0.2312	39.097 0.2305	54.855 0.2340	70.646 0.2327	86.450 0.2348	102.267 0.2336	118.086 0.2350	133.910 0.2339	149.738 0.2353
7053	7.689 0.2197	23.199 0.2285	38.850 0.2291	54.573 0.2332	70.347 0.2324	86.145 0.2348	101.962 0.2336	117.784 0.2351	133.611 0.2340	149.443 0.2353
7056	7.637 0.2162	23.062 0.2263	38.656 0.2276	54.343 0.2323	70.093 0.2318	85.876 0.2344	101.684 0.2335	117.501 0.2350	133.327 0.2340	149.158 0.2354
7059	7.607 0.2141	22.977 0.2247	38.531 0.2265	54.185 0.2314	69.909 0.2311	85.670 0.2338	101.461 0.2330	117.265 0.2347	133.082 0.2337	148.904 0.2351
7062	7.583 0.2125	22.911 0.2234	38.429 0.2254	54.053 0.2305	69.752 0.2303	85.491 0.2331	101.261 0.2324	117.048 0.2341	132.850 0.2334	148.659 0.2346
7065	7.564 0.2112	22.856 0.2223	38.344 0.2245	53.943 0.2297	69.618 0.2296	85.336 0.2324	101.088 0.2318	116.856 0.2336	132.642 0.2329	148.436 0.2341
7068	7.564 0.2112	22.855 0.2222	38.340 0.2244	53.936 0.2295	69.607 0.2295	85.320 0.2322	101.065 0.2315	116.825 0.2333	132.602 0.2326	148.386 0.2337
7071	7.545 0.2099	22.806 0.2215	38.277 0.2242	53.868 0.2295	69.539 0.2295	85.255 0.2324	101.003 0.2317	116.767 0.2334	132.546 0.2327	148.331 0.2337
7074	7.476 0.2051	22.634 0.2192	38.058 0.2233	53.635 0.2294	69.312 0.2299	85.043 0.2330	100.811 0.2324	116.595 0.2341	132.395 0.2333	148.198 0.2343
7077	7.401 0.1997	22.442 0.2164	37.804 0.2220	53.353 0.2290	69.025 0.2301	84.765 0.2334	100.550 0.2331	116.358 0.2349	132.184 0.2342	148.014 0.2352
7080	7.355 0.1964	22.315 0.2141	37.618 0.2203	53.124 0.2278	68.765 0.2293	84.484 0.2329	100.260 0.2329	116.065 0.2349	131.893 0.2344	147.730 0.2355
7083	7.332 0.1947	22.248 0.2126	37.512 0.2191	52.985 0.2268	68.597 0.2284	84.291 0.2322	100.044 0.2323	115.834 0.2345	131.649 0.2339	147.476 0.2353
7086	7.322 0.1940	22.218 0.2119	37.461 0.2185	52.916 0.2262	68.511 0.2279	84.189 0.2317	99.927 0.2318	115.700 0.2340	131.503 0.2336	147.318 0.2348
7089	7.315 0.1935	22.193 0.2112	37.418 0.2179	52.856 0.2256	68.435 0.2274	84.099 0.2312	99.824 0.2314	115.585 0.2336	131.376 0.2333	147.179 0.2344

7092	7.317 0.1937	22.197 0.2111	37.418 0.2178	52.851 0.2255	68.425 0.2272	84.084 0.2310	99.803 0.2312	115.557 0.2334	131.341 0.2331	147.137 0.2341
7095	7.314 0.1934	22.185 0.2107	37.398 0.2175	52.824 0.2253	68.394 0.2271	84.050 0.2310	99.767 0.2312	115.520 0.2333	131.302 0.2330	147.096 0.2341
7098	7.260 0.1895	22.044 0.2085	37.207 0.2164	52.611 0.2248	68.173 0.2271	83.831 0.2311	99.554 0.2314	115.317 0.2337	131.109 0.2334	146.911 0.2344
7101	7.196 0.1847	21.873 0.2054	36.965 0.2145	52.324 0.2237	67.859 0.2265	83.503 0.2309	99.223 0.2314	114.986 0.2338	130.784 0.2336	146.595 0.2347
7104	7.159 0.1819	21.765 0.2031	36.799 0.2129	52.111 0.2223	67.610 0.2254	83.224 0.2300	98.923 0.2310	114.672 0.2333	130.457 0.2334	146.260 0.2344
7107	7.147 0.1811	21.727 0.2020	36.731 0.2118	52.014 0.2213	67.485 0.2245	83.074 0.2292	98.748 0.2302	114.474 0.2326	130.242 0.2329	146.029 0.2338
7110	7.139 0.1804	21.691 0.2007	36.658 0.2106	51.908 0.2203	67.348 0.2236	82.911 0.2284	98.560 0.2294	114.263 0.2318	130.012 0.2324	145.780 0.2331
7113	7.144 0.1808	21.697 0.2004	36.654 0.2101	51.889 0.2197	67.314 0.2231	82.860 0.2278	98.493 0.2289	114.179 0.2313	129.910 0.2318	145.660 0.2325
7116	7.152 0.1814	21.716 0.2006	36.678 0.2102	51.914 0.2197	67.338 0.2230	82.882 0.2277	98.511 0.2287	114.192 0.2311	129.916 0.2316	145.659 0.2323
7119	7.151 0.1813	21.710 0.2003	36.663 0.2100	51.893 0.2196	67.313 0.2230	82.854 0.2277	98.483 0.2287	114.163 0.2311	129.886 0.2316	145.627 0.2322
7122	7.125 0.1794	21.640 0.1990	36.566 0.2093	51.783 0.2193	67.200 0.2230	82.744 0.2278	98.378 0.2290	114.067 0.2314	129.799 0.2319	145.548 0.2325
7125	7.079 0.1759	21.515 0.1966	36.387 0.2079	51.571 0.2185	66.969 0.2226	82.506 0.2277	98.141 0.2291	113.835 0.2316	129.576 0.2322	145.336 0.2329
7128	7.055 0.1740	21.443 0.1949	36.271 0.2065	51.419 0.2174	66.789 0.2218	82.304 0.2271	97.924 0.2287	113.608 0.2314	129.344 0.2321	145.102 0.2329
7131	7.044 0.1732	21.405 0.1937	36.201 0.2053	51.317 0.2163	66.657 0.2209	82.146 0.2263	97.742 0.2280	113.405 0.2308	129.124 0.2316	144.869 0.2325
7134	7.043 0.1731	21.392 0.1930	36.167 0.2046	51.259 0.2155	66.578 0.2202	82.046 0.2256	97.622 0.2274	113.268 0.2302	128.969 0.2311	144.698 0.2320
7137	7.048 0.1735	21.400 0.1928	36.168 0.2043	51.251 0.2152	66.559 0.2198	82.017 0.2253	97.583 0.2270	113.217 0.2298	128.907 0.2307	144.624 0.2317
7140	7.063 0.1747	21.438 0.1934	36.218 0.2046	51.310 0.2154	66.623 0.2200	82.085 0.2254	97.654 0.2271	113.290 0.2299	128.980 0.2307	144.696 0.2316
7143	7.060 0.1744	21.429 0.1931	36.206 0.2046	51.298 0.2155	66.618 0.2203	82.089 0.2258	97.669 0.2275	113.316 0.2302	129.017 0.2310	144.743 0.2319
7146	7.020 0.1713	21.323 0.1912	36.059 0.2036	51.134 0.2152	66.451 0.2204	81.930 0.2262	97.524 0.2281	113.190 0.2309	128.911 0.2317	144.658 0.2326
7149	6.946 0.1655	21.126 0.1877	35.789 0.2017	50.824 0.2143	66.125 0.2202	81.605 0.2264	97.211 0.2286	112.896 0.2316	128.640 0.2325	144.412 0.2334

7152	6.914 0.1630	21.033 0.1954	35.640 0.2000	50.629 0.2129	65.895 0.2192	81.349 0.2257	96.938 0.2282	112.613 0.2314	128.355 0.2326	144.131 0.2337
7155	6.898 0.1617	20.981 0.1940	35.550 0.1987	50.507 0.2119	65.744 0.2184	81.175 0.2250	96.745 0.2276	112.404 0.2309	128.133 0.2322	143.900 0.2335
7158	6.890 0.1611	20.949 0.1828	35.488 0.1976	50.414 0.2109	65.624 0.2175	81.032 0.2243	96.581 0.2270	112.222 0.2304	127.935 0.2317	143.688 0.2330
7161	6.892 0.1612	20.940 0.1813	35.453 0.1966	50.353 0.2100	65.540 0.2168	80.928 0.2237	96.460 0.2265	112.086 0.2299	127.785 0.2313	143.525 0.2326
7164	6.896 0.1616	20.945 0.1815	35.445 0.1961	50.331 0.2095	65.504 0.2164	80.880 0.2233	96.400 0.2262	112.017 0.2296	127.706 0.2310	143.438 0.2324
7167	6.896 0.1616	20.941 0.1812	35.436 0.1960	50.319 0.2094	65.494 0.2165	80.873 0.2235	96.400 0.2264	112.022 0.2298	127.718 0.2312	143.454 0.2325
7170	6.864 0.1590	20.854 0.1795	35.314 0.1951	50.182 0.2092	65.357 0.2163	80.747 0.2240	96.291 0.2271	111.934 0.2305	127.651 0.2319	143.408 0.2332
7173	6.816 0.1551	20.722 0.1768	35.125 0.1935	49.958 0.2084	65.117 0.2165	80.507 0.2241	96.060 0.2275	111.721 0.2312	127.459 0.2327	143.241 0.2340
7176	6.790 0.1530	20.642 0.1747	34.993 0.1917	49.782 0.2070	64.907 0.2156	80.272 0.2235	95.810 0.2272	111.462 0.2311	127.199 0.2328	142.986 0.2343
7179	6.790 0.1530	20.620 0.1730	34.927 0.1901	49.673 0.2056	64.761 0.2144	80.094 0.2225	95.605 0.2264	111.235 0.2304	126.958 0.2325	142.733 0.2338
7182	6.802 0.1539	20.631 0.1720	34.908 0.1889	49.623 0.2045	64.682 0.2135	79.989 0.2217	95.477 0.2257	111.086 0.2298	126.789 0.2319	142.549 0.2335
7185	6.817 0.1552	20.659 0.1718	34.928 0.1885	49.629 0.2039	64.673 0.2130	79.968 0.2213	95.445 0.2254	111.044 0.2295	126.737 0.2316	142.486 0.2332
7188	6.829 0.1562	20.679 0.1715	34.938 0.1879	49.625 0.2034	64.657 0.2127	79.944 0.2211	95.416 0.2253	111.012 0.2294	126.704 0.2315	142.452 0.2331
7191	6.847 0.1576	20.715 0.1715	34.968 0.1876	49.644 0.2031	64.667 0.2125	79.949 0.2210	95.418 0.2253	111.015 0.2295	126.709 0.2316	142.460 0.2333
7194	6.838 0.1569	20.681 0.1703	34.902 0.1863	49.547 0.2020	64.544 0.2117	79.806 0.2205	95.264 0.2250	110.854 0.2293	126.544 0.2316	142.295 0.2333
7197	6.814 0.1549	20.608 0.1683	34.777 0.1844	49.370 0.2003	64.323 0.2103	79.549 0.2194	94.976 0.2241	110.547 0.2290	126.222 0.2310	141.960 0.2330
7200	6.822 0.1556	20.610 0.1673	34.748 0.1830	49.304 0.1988	64.217 0.2090	79.405 0.2181	94.798 0.2230	110.336 0.2279	125.986 0.2305	141.700 0.2321
7203	6.790 0.1530	20.514 0.1648	34.589 0.1806	49.084 0.1967	63.941 0.2072	79.081 0.2166	94.431 0.2217	109.930 0.2267	125.551 0.2297	141.237 0.2310
7206	6.774 0.1517	20.466 0.1633	34.501 0.1791	48.953 0.1951	63.768 0.2057	78.867 0.2152	94.179 0.2204	109.643 0.2256	125.229 0.2286	140.881 0.2300
7209	6.764 0.1509	20.433 0.1623	34.441 0.1779	48.863 0.1940	63.647 0.2047	78.719 0.2143	94.005 0.2196	109.444 0.2248	125.006 0.2278	140.635 0.2292

7212	6.760 0.1506	20.420 0.1619	34.416 0.1774	48.823 0.1934	63.595 0.2043	78.655 0.2140	93.931 0.2193	109.363 0.2245	124.916 0.2275	140.537 0.2289
7215	6.746 0.1494	20.378 0.1608	34.347 0.1764	48.730 0.1926	63.482 0.2038	78.530 0.2137	93.800 0.2192	109.228 0.2244	124.780 0.2275	140.401 0.2290
7218	6.704 0.1459	20.264 0.1584	34.179 0.1746	48.522 0.1914	63.247 0.2030	78.279 0.2133	93.541 0.2191	108.969 0.2245	124.524 0.2277	140.150 0.2292
7221	6.667 0.1428	20.163 0.1563	34.033 0.1731	48.341 0.1903	63.044 0.2025	78.065 0.2130	93.324 0.2191	108.755 0.2247	124.318 0.2280	139.954 0.2296
7224	6.668 0.1429	20.147 0.1548	33.977 0.1715	48.246 0.1889	62.914 0.2014	77.907 0.2123	93.148 0.2186	108.568 0.2244	124.126 0.2279	139.762 0.2296
7227	6.683 0.1441	20.169 0.1542	33.980 0.1705	48.220 0.1878	62.858 0.2003	77.825 0.2114	93.043 0.2179	108.444 0.2239	123.988 0.2275	139.615 0.2294
7230	6.705 0.1460	20.204 0.1533	33.989 0.1693	48.196 0.1865	62.803 0.1993	77.742 0.2105	92.936 0.2172	108.319 0.2233	123.847 0.2271	139.461 0.2290
7233	6.730 0.1481	20.243 0.1524	34.000 0.1680	48.173 0.1851	62.744 0.1981	77.652 0.2095	92.820 0.2164	108.180 0.2227	123.689 0.2265	139.287 0.2285
7236	6.730 0.1481	20.240 0.1522	33.985 0.1672	48.134 0.1841	62.679 0.1971	77.560 0.2086	92.704 0.2157	108.043 0.2220	123.535 0.2260	139.116 0.2281
7239	6.718 0.1470	20.207 0.1515	33.933 0.1664	48.062 0.1833	62.586 0.1965	77.451 0.2081	92.583 0.2153	107.913 0.2217	123.397 0.2257	138.972 0.2279
7242	6.714 0.1467	20.166 0.1488	33.829 0.1641	47.902 0.1814	62.383 0.1951	77.216 0.2072	92.325 0.2147	107.640 0.2214	123.115 0.2255	138.686 0.2278
7245	6.740 0.1488	20.199 0.1473	33.820 0.1622	47.843 0.1794	62.270 0.1932	77.052 0.2055	92.116 0.2133	107.393 0.2202	122.836 0.2246	138.380 0.2270
7248	6.766 0.1510	20.248 0.1470	33.848 0.1608	47.832 0.1777	62.214 0.1915	76.951 0.2039	91.972 0.2118	107.208 0.2189	122.613 0.2234	138.123 0.2259
7251	6.793 0.1533	20.306 0.1472	33.897 0.1598	47.853 0.1765	62.202 0.1902	76.904 0.2026	91.890 0.2107	107.093 0.2178	122.467 0.2223	137.946 0.2250
7254	6.821 0.1555	20.367 0.1478	33.957 0.1592	47.893 0.1756	62.217 0.1892	76.892 0.2017	91.851 0.2098	107.028 0.2169	122.376 0.2215	137.831 0.2242
7257	6.846 0.1576	20.427 0.1485	34.020 0.1587	47.940 0.1748	62.242 0.1884	76.893 0.2008	91.830 0.2090	106.986 0.2162	122.314 0.2209	137.750 0.2235
7260	6.868 0.1593	20.482 0.1495	34.083 0.1584	47.992 0.1742	62.278 0.1877	76.912 0.2002	91.830 0.2084	106.969 0.2156	122.281 0.2203	137.703 0.2231
7263	6.889 0.1610	20.537 0.1506	34.150 0.1583	48.052 0.1738	62.326 0.1872	76.944 0.1996	91.849 0.2079	106.974 0.2152	122.274 0.2200	137.685 0.2227
7266	6.912 0.1629	20.599 0.1518	34.227 0.1583	48.125 0.1735	62.389 0.1868	76.996 0.1992	91.889 0.2075	107.005 0.2149	122.296 0.2197	137.700 0.2225
7269	6.932 0.1645	20.653 0.1529	34.293 0.1582	48.186 0.1731	62.439 0.1864	77.035 0.1988	91.917 0.2072	107.023 0.2146	122.307 0.2195	137.705 0.2223

7272	6.952 0.1660	20.706 0.1541	34.362 0.1582	48.251 0.1728	62.494 0.1859	77.078 0.1984	91.950 0.2068	107.047 0.2143	122.324 0.2193	137.717 0.2222
7275	6.969 0.1673	20.754 0.1552	34.422 0.1582	48.306 0.1725	62.540 0.1855	77.112 0.1979	91.972 0.2065	107.060 0.2140	122.330 0.2191	137.718 0.2221
7278	6.984 0.1685	20.798 0.1563	34.479 0.1582	48.357 0.1721	62.580 0.1851	77.140 0.1975	91.988 0.2061	107.066 0.2137	122.328 0.2188	137.710 0.2219
7281	6.992 0.1692	20.825 0.1572	34.515 0.1580	48.385 0.1717	62.595 0.1845	77.140 0.1969	91.974 0.2056	107.039 0.2133	122.291 0.2185	137.665 0.2217
7284	6.996 0.1695	20.845 0.1582	34.547 0.1580	48.413 0.1713	62.611 0.1840	77.142 0.1964	91.962 0.2051	107.015 0.2129	122.256 0.2182	137.622 0.2214
7287	6.999 0.1697	20.856 0.1585	34.566 0.1583	48.435 0.1713	62.629 0.1837	77.151 0.1960	91.961 0.2048	107.005 0.2126	122.239 0.2180	137.598 0.2213
7290	6.985 0.1686	20.821 0.1581	34.523 0.1581	48.383 0.1708	62.566 0.1833	77.076 0.1956	91.875 0.2045	106.910 0.2124	122.136 0.2178	137.490 0.2211
7293	6.948 0.1657	20.729 0.1566	34.403 0.1572	48.243 0.1701	62.408 0.1827	76.904 0.1951	91.692 0.2041	106.720 0.2122	121.942 0.2177	137.295 0.2211
7296	6.927 0.1641	20.676 0.1556	34.327 0.1564	48.147 0.1692	62.298 0.1818	76.762 0.1943	91.531 0.2035	106.543 0.2117	121.755 0.2174	137.100 0.2209
7299	6.915 0.1631	20.644 0.1550	34.282 0.1559	48.094 0.1684	62.203 0.1809	76.652 0.1934	91.397 0.2027	106.389 0.2110	121.583 0.2163	136.914 0.2205
7302	6.915 0.1631	20.647 0.1553	34.286 0.1559	48.033 0.1680	62.138 0.1802	76.619 0.1927	91.345 0.2020	106.317 0.2104	121.493 0.2163	136.309 0.2200
7305	6.921 0.1635	20.668 0.1561	34.320 0.1560	48.116 0.1678	62.214 0.1799	76.633 0.1922	91.345 0.2016	106.305 0.2099	121.467 0.2159	136.772 0.2197
7308	6.931 0.1644	20.694 0.1565	34.359 0.1567	48.169 0.1681	62.272 0.1800	76.691 0.1922	91.401 0.2014	106.356 0.2098	121.515 0.2157	136.815 0.2195
7311	6.931 0.1643	20.699 0.1570	34.377 0.1572	48.195 0.1684	62.302 0.1800	76.722 0.1921	91.431 0.2014	106.386 0.2098	121.545 0.2157	136.847 0.2196
7314	6.913 0.1630	20.661 0.1567	34.338 0.1574	48.161 0.1685	62.272 0.1801	76.696 0.1923	91.411 0.2017	106.374 0.2101	121.543 0.2161	136.855 0.2200
7317	6.874 0.1598	20.563 0.1552	34.214 0.1568	48.023 0.1680	62.125 0.1799	76.545 0.1923	91.262 0.2019	106.233 0.2105	121.415 0.2166	136.743 0.2205
7320	6.854 0.1582	20.515 0.1545	34.150 0.1562	47.943 0.1674	62.028 0.1792	76.432 0.1918	91.137 0.2016	106.103 0.2104	121.285 0.2167	136.619 0.2209
7323	6.846 0.1575	20.493 0.1541	34.119 0.1558	47.899 0.1667	61.964 0.1784	76.346 0.1910	91.032 0.2009	105.981 0.2099	121.151 0.2164	136.478 0.2207
7326	6.850 0.1579	20.511 0.1547	34.149 0.1562	47.933 0.1667	61.995 0.1782	76.368 0.1906	91.043 0.2005	105.982 0.2096	121.144 0.2162	136.466 0.2206
7329	6.863 0.1589	20.547 0.1556	34.199 0.1566	47.990 0.1669	62.053 0.1781	76.424 0.1904	91.094 0.2004	106.029 0.2095	121.188 0.2161	136.509 0.2206

7332	6.881 0.1604	20.593 0.1564	34.260 0.1569	48.059 0.1670	62.123 0.1781	76.491 0.1903	91.158 0.2003	106.090 0.2094	121.249 0.2161	136.572 0.2207
7335	6.848 0.1577	20.521 0.1560	34.160 0.1551	47.912 0.1652	61.933 0.1764	76.260 0.1889	90.892 0.1992	105.798 0.2086	120.937 0.2156	136.246 0.2203
7338	6.826 0.1560	20.456 0.1542	34.054 0.1535	47.766 0.1635	61.741 0.1746	76.021 0.1871	90.607 0.1976	105.470 0.2072	120.570 0.2144	135.846 0.2193
7341	6.792 0.1532	20.369 0.1526	33.936 0.1526	47.624 0.1626	61.575 0.1737	75.829 0.1861	90.388 0.1966	105.225 0.2063	120.300 0.2135	135.552 0.2185
7344	6.778 0.1520	20.327 0.1516	33.871 0.1517	47.534 0.1614	61.455 0.1725	75.678 0.1849	90.206 0.1955	105.012 0.2052	120.060 0.2125	135.288 0.2177
7347	6.770 0.1513	20.304 0.1510	33.835 0.1512	47.482 0.1606	61.380 0.1715	75.576 0.1838	90.075 0.1944	104.854 0.2043	119.875 0.2117	135.078 0.2169
7350	6.766 0.1510	20.293 0.1508	33.817 0.1509	47.453 0.1601	61.335 0.1707	75.509 0.1829	89.985 0.1936	104.740 0.2034	119.739 0.2110	134.919 0.2162
7353	6.782 0.1524	20.321 0.1503	33.835 0.1505	47.460 0.1595	61.324 0.1700	75.477 0.1821	89.930 0.1927	104.663 0.2027	119.639 0.2103	134.801 0.2156
7356	6.790 0.1530	20.341 0.1508	33.865 0.1508	47.491 0.1594	61.350 0.1696	75.492 0.1816	89.929 0.1921	104.645 0.2021	119.606 0.2097	134.752 0.2151
7359	6.766 0.1510	20.281 0.1493	33.786 0.1503	47.401 0.1589	61.248 0.1691	75.377 0.1811	89.803 0.1917	104.508 0.2017	119.459 0.2094	134.597 0.2148
7362	6.730 0.1481	20.189 0.1481	33.663 0.1494	47.258 0.1582	61.090 0.1686	75.207 0.1807	89.623 0.1914	104.321 0.2015	119.269 0.2093	134.406 0.2148
7365	6.692 0.1449	20.089 0.1460	33.521 0.1480	47.084 0.1570	60.888 0.1676	74.980 0.1798	89.376 0.1908	104.060 0.2011	118.997 0.2091	134.129 0.2147
7368	6.676 0.1435	20.041 0.1448	33.444 0.1468	46.978 0.1557	60.748 0.1662	74.806 0.1785	89.169 0.1896	103.822 0.2001	118.735 0.2083	133.847 0.2142
7371	6.680 0.1439	20.043 0.1442	33.431 0.1461	46.944 0.1548	60.688 0.1650	74.714 0.1772	89.043 0.1884	103.663 0.1989	118.544 0.2072	133.629 0.2133
7374	6.683 0.1441	20.045 0.1439	33.425 0.1457	46.925 0.1541	60.651 0.1642	74.653 0.1762	88.955 0.1873	103.546 0.1979	118.399 0.2063	133.457 0.2124
7377	6.686 0.1444	20.049 0.1437	33.422 0.1454	46.913 0.1536	60.623 0.1635	74.605 0.1754	88.884 0.1864	103.451 0.1970	118.280 0.2054	133.314 0.2116
7380	6.688 0.1446	20.054 0.1438	33.428 0.1454	46.915 0.1533	60.616 0.1630	74.584 0.1747	88.845 0.1857	103.394 0.1963	118.203 0.2048	133.219 0.2110
7383	6.681 0.1439	20.035 0.1434	33.403 0.1452	46.883 0.1530	60.574 0.1626	74.529 0.1742	88.776 0.1852	103.310 0.1958	118.105 0.2043	133.107 0.2105
7386	6.652 0.1415	19.962 0.1421	33.305 0.1445	46.770 0.1525	60.449 0.1621	74.395 0.1738	88.633 0.1848	103.158 0.1955	117.947 0.2041	132.944 0.2104
7389	6.626 0.1393	19.897 0.1410	33.222 0.1440	46.678 0.1522	60.352 0.1620	74.294 0.1737	88.529 0.1849	103.055 0.1955	117.846 0.2042	132.848 0.2106

7392	6.626 0.1393	19.889 0.1404	33.200 0.1435	46.643 0.1516	60.302 0.1614	74.229 0.1731	88.452 0.1844	102.969 0.1953	117.755 0.2041	132.757 0.2106
7395	6.630 0.1397	19.895 0.1402	33.200 0.1432	46.632 0.1510	60.275 0.1606	74.183 0.1723	88.385 0.1837	102.884 0.1947	117.655 0.2037	132.647 0.2104
7398	6.642 0.1407	19.915 0.1399	33.211 0.1427	46.630 0.1504	60.256 0.1598	74.142 0.1714	88.322 0.1828	102.798 0.1939	117.550 0.2030	132.525 0.2099
7401	6.663 0.1425	19.957 0.1399	33.248 0.1423	46.654 0.1497	60.260 0.1590	74.124 0.1705	88.279 0.1813	102.730 0.1930	117.459 0.2023	132.414 0.2092
7404	6.670 0.1430	19.980 0.1406	33.282 0.1425	46.690 0.1496	60.291 0.1586	74.143 0.1699	88.281 0.1812	102.714 0.1923	117.424 0.2016	132.363 0.2087
7407	6.681 0.1440	20.013 0.1415	33.335 0.1432	46.755 0.1500	60.361 0.1587	74.211 0.1697	88.343 0.1809	102.767 0.1920	117.468 0.2013	132.397 0.2084
7410	6.659 0.1422	19.964 0.1410	33.281 0.1434	46.705 0.1502	60.317 0.1589	74.173 0.1699	88.310 0.1810	102.738 0.1921	117.444 0.2015	132.379 0.2086
7413	6.615 0.1384	19.853 0.1391	33.137 0.1424	46.544 0.1497	60.147 0.1587	74.000 0.1699	88.138 0.1812	102.572 0.1924	117.288 0.2019	132.237 0.2091
7416	6.595 0.1367	19.799 0.1379	33.055 0.1413	46.436 0.1486	60.011 0.1576	73.836 0.1688	87.950 0.1803	102.366 0.1918	117.070 0.2016	132.015 0.2092
7419	6.621 0.1389	19.843 0.1378	33.096 0.1408	46.460 0.1477	60.011 0.1565	73.807 0.1676	87.888 0.1791	102.273 0.1907	116.949 0.2007	131.872 0.2085
7422	6.648 0.1412	19.904 0.1380	33.149 0.1403	46.498 0.1470	60.029 0.1556	73.800 0.1665	87.853 0.1780	102.208 0.1897	116.856 0.1998	131.754 0.2077
7425	6.669 0.1430	19.948 0.1381	33.184 0.1394	46.512 0.1460	60.017 0.1544	73.759 0.1653	87.781 0.1768	102.105 0.1885	116.723 0.1987	131.593 0.2068
7428	6.666 0.1427	19.942 0.1381	33.175 0.1391	46.491 0.1454	59.980 0.1536	73.698 0.1643	87.692 0.1757	101.987 0.1874	116.577 0.1977	131.421 0.2059
7431	6.655 0.1417	19.912 0.1374	33.130 0.1386	46.432 0.1446	59.900 0.1527	73.594 0.1632	87.561 0.1746	101.828 0.1864	116.390 0.1968	131.208 0.2050
7434	6.633 0.1399	19.855 0.1364	33.052 0.1378	46.334 0.1438	59.782 0.1518	73.454 0.1623	87.397 0.1736	101.638 0.1854	116.176 0.1959	130.972 0.2043
7437	6.604 0.1375	19.781 0.1349	32.947 0.1367	46.204 0.1428	59.627 0.1508	73.273 0.1612	87.190 0.1726	101.405 0.1845	115.919 0.1951	130.693 0.2036
7440	6.590 0.1363	19.753 0.1349	32.907 0.1356	46.138 0.1417	59.533 0.1496	73.148 0.1599	87.033 0.1713	101.216 0.1833	115.698 0.1940	130.445 0.2027
7443	6.594 0.1366	19.754 0.1343	32.894 0.1350	46.108 0.1408	59.481 0.1486	73.068 0.1588	86.922 0.1700	101.071 0.1820	115.521 0.1928	130.236 0.2016
7446	6.614 0.1383	19.796 0.1344	32.932 0.1346	46.133 0.1402	59.488 0.1477	73.053 0.1577	86.879 0.1689	100.999 0.1808	115.417 0.1917	130.102 0.2005
7449	6.638 0.1403	19.847 0.1348	32.984 0.1343	46.177 0.1397	59.520 0.1471	73.067 0.1569	86.870 0.1680	100.964 0.1798	115.356 0.1907	130.013 0.1996

7452	6.645 0.1409	19.871 0.1355	33.020 0.1345	46.215 0.1396	59.552 0.1468	73.089 0.1564	86.877 0.1673	100.952 0.1790	115.322 0.1899	129.958 0.1988
7455	6.642 0.1407	19.865 0.1355	33.013 0.1345	46.207 0.1395	59.539 0.1465	73.067 0.1559	86.843 0.1667	100.902 0.1784	115.255 0.1892	129.874 0.1982
7458	6.632 0.1398	19.840 0.1352	32.984 0.1344	46.175 0.1394	59.503 0.1463	73.024 0.1556	86.790 0.1663	100.838 0.1779	115.178 0.1887	129.785 0.1978
7461	6.619 0.1387	19.810 0.1347	32.947 0.1343	46.134 0.1392	59.459 0.1461	72.974 0.1553	86.733 0.1660	100.773 0.1776	115.104 0.1884	129.702 0.1975
7464	6.625 0.1392	19.821 0.1348	32.954 0.1339	46.130 0.1387	59.442 0.1455	72.944 0.1547	86.687 0.1653	100.711 0.1770	115.028 0.1879	129.613 0.1971
7467	6.639 0.1404	19.852 0.1351	32.984 0.1335	46.152 0.1383	59.451 0.1449	72.937 0.1540	86.661 0.1645	100.663 0.1762	114.959 0.1872	129.526 0.1964
7470	6.657 0.1419	19.895 0.1356	33.034 0.1336	46.199 0.1379	59.488 0.1444	72.959 0.1533	86.665 0.1637	100.646 0.1753	114.920 0.1863	129.466 0.1957
7473	6.681 0.1439	19.950 0.1363	33.099 0.1337	46.261 0.1377	59.542 0.1440	73.000 0.1527	86.690 0.1630	100.652 0.1745	114.905 0.1856	129.430 0.1950
7476	6.686 0.1444	19.971 0.1371	33.137 0.1344	46.308 0.1378	59.589 0.1439	73.043 0.1524	86.723 0.1625	100.672 0.1739	114.909 0.1849	129.418 0.1944
7479	6.689 0.1446	19.981 0.1375	33.157 0.1349	46.338 0.1381	59.624 0.1440	73.078 0.1523	86.754 0.1623	100.695 0.1736	114.922 0.1845	129.419 0.1940
7482	6.674 0.1434	19.947 0.1371	33.119 0.1349	46.302 0.1382	59.590 0.1441	73.044 0.1523	86.717 0.1621	100.653 0.1733	114.874 0.1843	129.365 0.1937
7485	6.647 0.1411	19.880 0.1360	33.034 0.1344	46.208 0.1380	59.491 0.1439	72.941 0.1521	86.610 0.1619	100.541 0.1732	114.757 0.1841	129.245 0.1936
7488	6.629 0.1396	19.833 0.1351	32.969 0.1338	46.129 0.1374	59.398 0.1433	72.834 0.1515	86.487 0.1613	100.404 0.1726	114.606 0.1837	129.084 0.1933
7491	6.620 0.1388	19.810 0.1347	32.939 0.1336	46.094 0.1371	59.355 0.1429	72.778 0.1509	86.417 0.1607	100.316 0.1719	114.502 0.1830	128.965 0.1928
7494	6.615 0.1384	19.801 0.1347	32.930 0.1337	46.084 0.1370	59.341 0.1426	72.756 0.1505	86.383 0.1601	100.267 0.1713	114.436 0.1824	128.883 0.1923
7497	6.631 0.1397	19.838 0.1352	32.974 0.1338	46.128 0.1368	59.379 0.1423	72.734 0.1500	86.397 0.1595	100.264 0.1706	114.416 0.1817	128.846 0.1917
7500	6.643 0.1407	19.872 0.1361	33.024 0.1343	46.184 0.1369	59.434 0.1421	72.834 0.1496	86.435 0.1590	100.289 0.1700	114.424 0.1811	128.837 0.1911
7503	6.652 0.1415	19.900 0.1369	33.070 0.1350	46.244 0.1374	59.503 0.1424	72.904 0.1496	86.502 0.1587	100.347 0.1696	114.472 0.1807	128.873 0.1907
7506	6.627 0.1394	19.838 0.1358	32.990 0.1345	46.156 0.1371	59.408 0.1421	72.803 0.1493	86.392 0.1583	100.227 0.1692	114.341 0.1803	128.733 0.1904
7509	6.580 0.1354	19.718 0.1336	32.830 0.1333	45.971 0.1363	59.208 0.1415	72.589 0.1488	86.167 0.1579	99.991 0.1687	114.093 0.1799	128.476 0.1901

7512	6.559 0.1336	19.676 0.1335	32.771 0.1319	45.882 0.1350	59.089 0.1403	72.440 0.1475	85.987 0.1566	99.780 0.1675	113.854 0.1758	128.212 0.1892
7515	6.569 0.1344	19.688 0.1329	32.768 0.1313	45.863 0.1343	59.049 0.1393	72.375 0.1463	85.892 0.1553	99.652 0.1661	113.690 0.1775	128.013 0.1880
7518	6.584 0.1357	19.718 0.1330	32.797 0.1310	45.883 0.1338	59.056 0.1386	72.364 0.1455	85.857 0.1542	99.588 0.1649	113.595 0.1762	127.885 0.1868
7521	6.604 0.1374	19.760 0.1331	32.837 0.1307	45.915 0.1334	59.076 0.1380	72.368 0.1447	85.842 0.1533	99.548 0.1639	113.528 0.1751	127.789 0.1857
7524	6.611 0.1381	19.777 0.1333	32.864 0.1314	45.951 0.1334	59.113 0.1381	72.403 0.1445	85.868 0.1529	99.561 0.1632	113.522 0.1743	127.763 0.1849
7527	6.609 0.1379	19.774 0.1335	32.867 0.1317	45.960 0.1337	59.125 0.1382	72.415 0.1444	85.876 0.1526	99.559 0.1628	113.507 0.1738	127.733 0.1843
7530	6.573 0.1348	19.688 0.1321	32.758 0.1312	45.844 0.1336	59.008 0.1382	72.298 0.1444	85.758 0.1525	99.439 0.1626	113.382 0.1736	127.602 0.1841
7533	6.533 0.1313	19.584 0.1302	32.622 0.1303	45.692 0.1331	58.849 0.1380	72.135 0.1443	85.592 0.1524	99.270 0.1625	113.212 0.1735	127.430 0.1840
7536	6.511 0.1294	19.525 0.1288	32.537 0.1293	45.586 0.1323	58.723 0.1372	71.991 0.1435	85.431 0.1517	99.092 0.1618	113.018 0.1729	127.223 0.1836
7539	6.501 0.1285	19.497 0.1282	32.494 0.1287	45.529 0.1316	58.650 0.1364	71.899 0.1427	85.317 0.1508	98.954 0.1609	112.855 0.1720	127.037 0.1828
7542	6.508 0.1292	19.513 0.1282	32.506 0.1284	45.533 0.1312	58.642 0.1358	71.874 0.1419	85.271 0.1498	98.883 0.1598	112.757 0.1709	126.911 0.1818
7545	6.524 0.1306	19.546 0.1283	32.539 0.1282	45.560 0.1308	58.659 0.1353	71.878 0.1412	85.257 0.1490	98.848 0.1588	112.696 0.1698	126.824 0.1808
7548	6.524 0.1306	19.546 0.1283	32.539 0.1282	45.558 0.1307	58.652 0.1350	71.861 0.1407	85.226 0.1483	98.799 0.1580	112.625 0.1689	126.729 0.1798
7551	6.524 0.1305	19.547 0.1285	32.543 0.1283	45.563 0.1307	58.655 0.1348	71.857 0.1404	85.212 0.1478	98.770 0.1573	112.579 0.1682	126.664 0.1791
7554	6.475 0.1263	19.427 0.1264	32.390 0.1275	45.397 0.1304	58.486 0.1348	71.689 0.1404	85.044 0.1478	98.600 0.1572	112.404 0.1680	126.483 0.1788
7557	6.405 0.1200	19.246 0.1229	32.149 0.1256	45.124 0.1295	58.197 0.1343	71.393 0.1403	84.746 0.1478	98.303 0.1572	112.108 0.1680	126.187 0.1789
7560	6.379 0.1177	19.174 0.1210	32.036 0.1239	44.973 0.1279	58.011 0.1328	71.174 0.1389	84.495 0.1465	98.022 0.1561	111.801 0.1670	125.859 0.1782
7563	6.373 0.1171	19.152 0.1202	31.996 0.1230	44.912 0.1269	57.924 0.1317	71.058 0.1376	84.348 0.1451	97.841 0.1546	111.583 0.1656	125.605 0.1768
7566	6.378 0.1176	19.156 0.1196	31.986 0.1224	44.886 0.1261	57.880 0.1308	70.993 0.1366	84.257 0.1440	97.721 0.1534	111.431 0.1642	125.418 0.1755
7569	6.386 0.1183	19.168 0.1193	31.989 0.1219	44.878 0.1255	57.857 0.1301	70.952 0.1358	84.195 0.1430	97.633 0.1522	111.314 0.1630	125.271 0.1743

7572	6.390	19.180	32.004	44.891	57.864	70.949	84.177	97.596	111.254	125.186
	0.1187	0.1196	0.1220	0.1254	0.1297	0.1352	0.1423	0.1514	0.1620	0.1733
7575	6.392	19.186	32.016	44.907	57.882	70.965	84.189	97.598	111.243	125.158
	0.1189	0.1198	0.1222	0.1255	0.1298	0.1351	0.1420	0.1509	0.1614	0.1726
7578	6.351	19.084	31.884	44.762	57.734	70.819	84.045	97.455	111.099	125.010
	0.1152	0.1180	0.1214	0.1252	0.1298	0.1352	0.1421	0.1509	0.1613	0.1724
7581	6.303	18.957	31.709	44.560	57.515	70.591	83.813	97.221	110.864	124.775
	0.1108	0.1153	0.1198	0.1243	0.1293	0.1349	0.1420	0.1508	0.1613	0.1725
7584	6.286	18.907	31.626	44.444	57.368	70.413	83.606	96.987	110.603	124.493
	0.1092	0.1133	0.1183	0.1229	0.1279	0.1337	0.1408	0.1497	0.1603	0.1717
7587	6.281	18.888	31.585	44.375	57.268	70.280	83.437	96.780	110.357	124.207
	0.1087	0.1129	0.1171	0.1216	0.1265	0.1322	0.1392	0.1481	0.1587	0.1702
7590	6.284	18.886	31.566	44.337	57.208	70.195	83.324	96.636	110.178	123.992
	0.1091	0.1122	0.1163	0.1206	0.1254	0.1310	0.1379	0.1467	0.1573	0.1687
7593	6.314	18.936	31.596	44.345	57.192	70.154	83.255	96.536	110.045	123.823
	0.1118	0.1114	0.1154	0.1196	0.1243	0.1299	0.1367	0.1454	0.1558	0.1673
7596	6.317	18.950	31.619	44.370	57.212	70.163	83.248	96.507	109.990	123.738
	0.1121	0.1119	0.1156	0.1195	0.1240	0.1293	0.1359	0.1444	0.1547	0.1661
7599	6.326	18.975	31.657	44.415	57.258	70.206	83.283	96.530	109.996	123.724
	0.1129	0.1127	0.1160	0.1197	0.1239	0.1290	0.1355	0.1437	0.1539	0.1652
7602	6.294	18.894	31.552	44.297	57.135	70.081	83.157	96.401	109.861	123.580
	0.1099	0.1112	0.1153	0.1193	0.1238	0.1290	0.1354	0.1436	0.1536	0.1648
7605	6.246	18.773	31.388	44.107	56.930	69.868	82.940	96.182	109.639	123.356
	0.1055	0.1088	0.1138	0.1185	0.1234	0.1288	0.1353	0.1435	0.1535	0.1647
7608	6.229	18.722	31.300	43.980	56.764	69.662	82.697	95.904	109.328	123.014
	0.1039	0.1072	0.1120	0.1167	0.1216	0.1271	0.1337	0.1420	0.1522	0.1636
7611	6.283	18.834	31.415	44.086	56.854	69.732	82.741	95.917	109.306	122.954
	0.1089	0.1076	0.1118	0.1161	0.1208	0.1261	0.1325	0.1406	0.1506	0.1621
7614	6.343	18.968	31.553	44.219	56.973	69.834	82.822	95.974	109.335	122.953
	0.1145	0.1088	0.1114	0.1156	0.1201	0.1252	0.1315	0.1395	0.1494	0.1608
7617	6.361	19.012	31.602	44.244	56.977	69.814	82.776	95.902	109.232	122.817
	0.1161	0.1097	0.1106	0.1146	0.1191	0.1242	0.1304	0.1383	0.1481	0.1594
7620	6.358	19.014	31.608	44.240	56.957	69.775	82.715	95.812	109.112	122.663
	0.1158	0.1104	0.1103	0.1140	0.1183	0.1232	0.1293	0.1370	0.1467	0.1580
7623	6.371	19.052	31.668	44.314	57.037	69.853	82.784	95.866	109.145	122.670
	0.1169	0.1115	0.1112	0.1145	0.1183	0.1230	0.1288	0.1363	0.1457	0.1569
DEWPT	476.6343	75.0000	0.1100	0.0473	0.0474	7.0000	-0.00008190			
DEWPT	476.6321	75.0000	0.1100	0.0473	0.0473	8.0000	-0.00007102			
DEWPT	476.6309	75.0000	0.1100	0.0473	0.0473	9.0000	-0.00006646			
DEWPT	476.6304	75.0000	0.1100	0.0473	0.0473	10.0000	-0.00006447			
7626	6.298	18.867	31.420	44.027	56.722	69.518	82.434	95.501	108.763	122.270
	0.1103	0.1079	0.1090	0.1130	0.1173	0.1222	0.1281	0.1356	0.1450	0.1561

7629	6.244 0.1053	18.731 0.1054	31.242 0.1076	43.822 0.1120	56.497 0.1165	69.276 0.1215	82.176 0.1274	95.228 0.1349	108.473 0.1443	121.962 0.1554
7632	6.221 0.1032	18.689 0.1057	31.185 0.1060	43.730 0.1103	56.370 0.1149	69.115 0.1200	81.982 0.1260	95.001 0.1335	108.213 0.1428	121.668 0.1540
7635	6.247 0.1056	18.728 0.1045	31.199 0.1049	43.718 0.1090	56.328 0.1135	69.040 0.1184	81.870 0.1243	94.849 0.1317	108.019 0.1410	121.430 0.1521
7638	6.278 0.1085	18.793 0.1047	31.259 0.1041	43.759 0.1080	56.345 0.1123	69.028 0.1171	81.827 0.1228	94.770 0.1300	107.900 0.1392	121.266 0.1502
7641	6.286 0.1092	18.815 0.1052	31.284 0.1039	43.777 0.1075	56.350 0.1116	69.016 0.1162	81.792 0.1217	94.708 0.1288	107.806 0.1377	121.134 0.1486
7644	6.294 0.1100	18.835 0.1057	31.318 0.1046	43.821 0.1078	56.397 0.1115	69.059 0.1159	81.826 0.1212	94.727 0.1280	107.804 0.1367	121.106 0.1474
7647	6.300 0.1105	18.856 0.1056	31.357 0.1055	43.875 0.1084	56.460 0.1118	69.126 0.1159	81.892 0.1210	94.787 0.1276	107.852 0.1361	121.136 0.1465
7650	6.285 0.1091	18.823 0.1063	31.323 0.1057	43.847 0.1086	56.437 0.1121	69.108 0.1161	81.876 0.1211	94.771 0.1275	107.831 0.1358	121.107 0.1461
7653	6.255 0.1063	18.748 0.1050	31.240 0.1062	43.763 0.1081	56.344 0.1117	69.007 0.1158	81.770 0.1209	94.659 0.1272	107.713 0.1354	120.980 0.1457
7656	6.288 0.1094	18.820 0.1054	31.305 0.1052	43.806 0.1071	56.364 0.1106	69.004 0.1147	81.742 0.1197	94.606 0.1261	107.634 0.1343	120.874 0.1445
7659	6.353 0.1153	18.970 0.1073	31.481 0.1056	43.986 0.1070	56.539 0.1102	69.168 0.1141	81.890 0.1189	94.732 0.1250	107.733 0.1330	120.942 0.1431
7662	6.438 0.1230	19.178 0.1107	31.742 0.1071	44.268 0.1075	56.831 0.1107	69.466 0.1142	82.187 0.1187	95.022 0.1246	108.008 0.1323	121.197 0.1421
7665	6.514 0.1296	19.368 0.1143	31.991 0.1089	44.544 0.1082	57.120 0.1112	69.763 0.1144	82.486 0.1187	95.318 0.1243	108.296 0.1318	121.470 0.1414
7668	6.574 0.1348	19.530 0.1181	32.218 0.1111	44.806 0.1092	57.398 0.1117	70.050 0.1147	82.777 0.1187	95.607 0.1241	108.579 0.1314	121.741 0.1408
7671	6.584 0.1357	19.594 0.1220	32.357 0.1140	44.995 0.1109	57.612 0.1122	70.281 0.1158	83.028 0.1194	95.869 0.1244	108.844 0.1313	122.002 0.1404
7674	6.591 0.1363	19.628 0.1238	32.436 0.1163	45.116 0.1125	57.757 0.1128	70.440 0.1165	83.200 0.1198	96.048 0.1246	109.023 0.1313	122.177 0.1401
7677	6.602 0.1373	19.673 0.1258	32.522 0.1179	45.233 0.1135	57.887 0.1130	70.570 0.1163	83.324 0.1195	96.163 0.1241	109.126 0.1306	122.263 0.1394
7680	6.622 0.1390	19.736 0.1277	32.625 0.1196	45.365 0.1146	59.033 0.1133	70.714 0.1159	83.457 0.1189	96.281 0.1234	109.224 0.1297	122.337 0.1382

NUMBER OF ITERATIONS	**** STATUS OF INTERATION COUNTERS 1	2	3	4	5	6	**** 7	8	9	10
SPZERO SUBROUTINE	0	4	0	0	0	0	0	0	0	0
DEWPT SUBROUTINE	0	0	66	110	37	1	0	0	0	1
EQLBRM SUBROUTINE	3	68	125	12	0	0	0	0	0	0

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AIRFLOW CHRACTERSTICS UNDER GRAIN AERATION AND DRYING CONDITIONS

by

GABIR ABDELGADIR ABDELMOHSIN

B.S., University of Khartoum, (SUDAN), 1979

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ABSTRACT

The objectives of the first phase of the study were: (1) to study the effect of moisture content and broken and fine materials on airflow resistance in a grain sorghum bed; and (2) to develop models that will predict the effects of moisture content and fine material on airflow resistance.

Ten levels of airflow (ranging from 0.025 to 0.19 m/s), five levels of moisture content (ranging from 12 to 18.5 %) (w.b.), and four levels of fine material (0, 2, 4 and 8%) were investigated.

Tests were carried out using a Hook gauge manometer to measure both static pressure across the ASME nozzle and airflow rate across the test bed. An environmental chamber was used to control the temperature and humidity of the supplied air.

The results showed that all main factors significantly affect the static pressure drop across the grain bed. Increasing moisture content decreases the static pressure up to 57 %, while increasing the fine material increases the static pressure drop to a maximum of 130 %.

The following equation describes the relation between static pressure, airflow, moisture content, and fine material:

$$\triangle P = A V + B V^2 + C (M.C.) V + D (F.M.) V$$

where $\triangle P$ = static pressure drop per meter depth of grain, Pa/m.

V = air velocity, m/s.

M.C. = moisture content, % (w.b.).

FM = fine material and broken kernals, %.

A, B, C, and D = are constants.

This model fits our data very well, with the correlation coefficient (R^2) above 0.998. The values of constants estimated are:

A = 4590.59

B = 7732.24

C = -192.44

D = 196.76

For the second phase of the study, a simulation for drying of shelled corn using natural air in five different areas in the state of Kansas was performed with a computer simulation model. Tests were run for initial moisture contents of 24, 21, 18 % (w.b.) with various airflow rates and grain depths. Performance evaluations included grain deterioration, final moisture content distribution, and fan operation time. The effect of changes in yearly weather conditions on the drying method was also analysed. Drying simulations were made for two kinds of drying weather conditions: a cold and humid year; and normal year. The stations and years selected were Topeka: 1965 and 1972; Concordia: 1968 and 1972; Dodge City: 1971 and 1972; Goodland: 1966 and 1969; and Wichita: 1968, and 1972.

The following conclusions were drawn, based on the results obtained:

Natural air drying of shelled corn in Kansas is feasible using the following drying systems: when a year with normal temperature and relative humidity is expected in Topeka and Goodland areas, maximum grain depth of 5.10 m can be used with initial moisture content of 24, 21, and

18% (w.b.) and airflow rates of 2.52, 2.24, and 1.32 m^3/min-t, respectively; and in Concordia, wichita, and Dodge City areas, maximum grain depth of 4.10 m can be used with initial moisture content of 24, 21, and 18% (w.b.), and airflow rates of 3.10, 2.52, and 1.68 m^3/min-t, respectively. When a cold and humid year is expected in Topeka and Goodland areas, maximum grain depth of 5.10 m can be used with initial moisture contents of 24, 21, and 18% (w.b.), and airflow rates of 2.86, 2.52, and 2.24 m^3/min-t, respectively. In Concordia, Wichita, and Dodge City areas, 24 and 21% initial moisture corn cannot be dried successfully by natural air in a cold and humid year.