3/?

# STATIC PRESSURE DROP AS AFFECTED BY MOISTURE AND FOREIGN MATERIAL IN ROUGH RICE

by


Luis F. Gonzaga F.

B.S., Universidad Nacional de Loja, (Ecuador), 1982


---

A MASTER'S REPORT

Submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE


Department of Agricultural Engineering

Kansas State University

Manhattan, Kansas


1985

Approved by

Major Professor

ACKNOWLEDGEMENTS



The author wishes to express his thanks to Dr. Chung, Do Sup for his advice and guidance which let to the accomplishing of this work.

The author thanks the members of his committee: Dr. Hague, Ekramul and Dr. Nassar, Raja for their assistance and review of this work.

Deep appreciation is extended to Dr. Man Soo Kim, associate professor, Department of Agricultural Machinery Engineering, Chungnam National University, South Korea, who was at the Department of Agricultural Engineering, Kansas State University as a visiting professor, for his valuable help and encourgement during the investigation period.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

# INTRODUCTION

On modern grain farms, a significant quantity of grain is being stored on the farm before marketing. Aeration has become one of the most widely practiced and effective means of maintaining quality of stored grain. Relatively small amounts of air are forced through the grain in storage to maintain a uniform temperature at as low a level as is practical.

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 (Foster, 1967). Even more widespread is the use of aeration for holding wet grain for shorter periods of time, until it can be dried.

Grain drying is an energy intensive operation that will be increasingly affected by high fuel costs. To design drying and storage facilities requires a careful analysis of systems. Many factors influence the choice of equipment, but 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 cost is needed to help farmers select the facilities best suited to their needs.

Information as to resistance of grain to airflow and effect of moisture on static pressure drop is fundamental in the design of devices or structures for grain drying and aeration. 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.

Adequate information relating the amount of foreign 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 foreign material and moisture content in order to provide useful information for the aeration and drying processes.

# REVIEW OF LITERATURE

The effect of the moisture content of the product on resistance to airflow is not clear (Brooker, et al. 1974). There have been few studies done to investigate the effects of broken and foreign material on static pressure and more work is needed in this area to understand the resistance of grain to airflow.

Stirniman, et al. (1931) conducted tests on resistance to the passage of airflow through rough rice in a deep bin and found that the airflow rate per unit cross-sectional area of bin decreases linearly with the depth of rough rice when plotted on log paper at different static pressures. The equation for a static pressure of 4.0 in. of water was found to be:

$$Y = 78.0x^{-0.52} \qquad [1]$$

where

$X$ = depth of rough rice, ft.

$Y$ = airflow rate, $ft.^3 min.^{-1} ft^{-2}$.

He further reported that the relation between the static pressure and depth of rice for any bed depth could be expressed as percentage of pressure under rice and percentage of depth of rice quite accurately with an equation following the above form.

Shedd, (1951) provided a graph showing the resistance to airflow of loosely filled rough rice at 13.4 moisture (w.b.). In addition, it was noted that increasing moisture from 13.4 to 20.7% reduced resistance to airflow by 24 percent and changing the density of fill from 38.1 to 40.6 lb. per cu. ft. increased resistance to airflow by 33 percent. The variety or grain type of rough rice used in their test was not specified.

Husain and Ojha (1969) developed a general correlation relating the static pressure, airflow rate and depth of three Indian varieties of paddy rice. They found that the static pressure under the paddy is a parabolic function of rate of airflow, following the equation:

$$Ps = (md + c)\ Q^{od+e} \qquad [2]$$

where

Ps = static pressure, mm. of water

Q = airflow rate, $m^3 min.^{-1} m^{-2}$

d = depth of grain, cm.

m, c, o and e = constants

Calderwood (1973) studied the relative differences in resistance to airflow of long grain and medium grain rough rice and of brown and milled rice compared with the rough rice from which their material was processed. He concluded that medium grain rice offered more resistance to airflow than did long grain rice when test conditions were compared and brown and milled rice offered more resistance to airflow than did the rough rice from which they were processed.

Brooker, et al. (1984) indicated that the pressure drop for airflow through any product depends on the rate of airflow, 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 fine and broken kernels. They concluded that nonuniform distribution of fine in grain bulk leads to nonuniform distribution of air used for aeration and drying.

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. Empirical equations
3. Theorical equations

Data on the airflow-static pressure relationship of a number of biological products have been published since 1948 in graphical form in the American Society of Agricultural Engineer's Yearbook (1980). These curves are well known as "Shedd's Curves."

Similar experimental curves were developed for various products: Henderson (1943) worked with corn, Henderson (1944) with soybean and oats; Shedd (1945) with ear corn, Shedd (1951) with soybean, corn, oats, and rough rice; Nissing (1958) with cotton seed; Thompson and Isaacs (1967) with corn and wheat; Patterson (1969) with corn; Muchiri (1969) with corn; Haque, et al. (1978) with corn; Ahmed, et al. (1982) with wheat, corn and sorghum; and Chung, et al. (1984) with grain sorghum.

The use of their 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 foreign material and moisture content.

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

$$V = K\ (\Delta P)^{c} \qquad [3]$$

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

$$\Delta P = \frac{aV^2}{\log_e (1 + bV)} \qquad [4]$$

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 4 and made it applicable for corn containing fines. The equation presented by them is of the form:

$$\Delta P = c_1 V + c_2 V^2 + c_3 V (fm) \qquad [5]$$

where

fm = fine material percent, expressed as decimal.

$c_1$, $c_2$, $c_3$ = constants.

This equation could be used for an airflow range 5 - 25 $m^3$/min-t (15 - 75 cfm/ft$^2$). While Hukill and Ives' equation was based on a lower range of airflow .6 - 12 $m^3$/min-t (2 - 40 cfm/ft$^2$), equation 5 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:

$$\Delta P = A_n V^2 + B_n V + C_n \qquad [6]$$

where

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

He stated that the accuracy of equation 6 for pressure drop prediction is likely to be poor at the low flow rates.

Ahmed, et al. (1982) modified equation 5 to replace the fine material with moisture content. The equation of the form:

$$\Delta P = A\ V + B\ V^2 - C\ (MC)\ V \qquad [7]$$

where

MC = moisture content, % w.b.

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

They reported that the equation adequately 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:

$$\Delta P_o = \frac{150\ (1-\varepsilon)^2 u\ V}{\varepsilon^3 d^2 g} + \frac{1.75\ (1-\varepsilon)\ p\ V^2}{\varepsilon^3\ dg} \qquad [8]$$

where

$\varepsilon$ = void fraction (dimensionless decimal) on volume bases.

u = fluid viscosity, lb.sec/ft$^2$.

p = fluid density, lb/ft$^3$.

$\Delta P_o$ = 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.

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

## OBJECTIVES

The objectives of this investigation were:

1. To determine the effect of moisture content and foreign material in rough rice kernels on airflow resistance; and
2. To develop a mathematical model that will describe the effects of moisture content and foreign material on airflow resistance through rough rice.

## EXPERIMENTAL DESIGN

A complete randomization of the order in which we conducted the experiment was applied. The control variables are air velocity, moisture content, and foreign material and the response variable static pressure drop. Variables such as void fraction and grain surface characteristics are extremely difficult to measure. So we let the void space vary naturally with the grain surface and foreign material for a particular bin filling method which can be controlled by a farmer, because this is the type of situation that actually occurs in grain storage.

We conducted the experiment with long rough rice harvested in 1984. Four levels of moisture contents (moisture at harvest, moisture when dry, and two levels in between) and four levels of foreign materials (5, 3, 1, 0%) were investigated. Each level of foreign material was tested with four levels of moisture contents for 14 different airflow rates. Three replications were made at each treatment combination. A total of 48 different beds were prepared and tested for 14 airflow rates. The following table shows the experimental variables and their levels.

Table 1. Levels of Experimental Design.

| Variable | Levels | No. of Level |
|---|---|---|
| Airflow | Range from 0.0508 to 0.3810 m/sec | 14 |
| Moisture Content (% w.b.) | 19.5, 17.4, 15.2 and 11.8 | 4 |
| Foriegn Materials | 0, 1, 3 and 5% | 4 |

# MATERIALS AND EQUIPMENT

Figure 1 shows a schematic diagram for the experimental set-up. The test bin is a transparent plastic cylinder with an outside diameter of 15.24 cm. (14.22 cm inside diameter) and a height of 76.2 cm.

The cylinder is placed on a 76.8 x 76.8 x 30.5 cm. rectangular box plenum chamber made of 1.55 mm milled steel sheet. The floor of the test bin is made of a perforated steel sheet with 1.5 mm. diameter holes long. Copper tube pressure taps ( 4 mm in diameter and 50 mm long) are positioned at 30.5 cm intervals along the test column wall, beginning approximately 2 cm above the bed floor.

Measuring of airflow to the test bin was made using a 25.4 mm throat diameter ASME nozzle and a micromanometer capable of measuring up to 254 mm of water with a minimum reading of 0.0254 mm. Air velocity was controlled by the motor speed controller. A psychrometer was used for recording relative humidity. The air was supplied by a fan with a 0.52 KW (3/4 HP) variable speed motor. We regulated the airflow with a dial type controller.

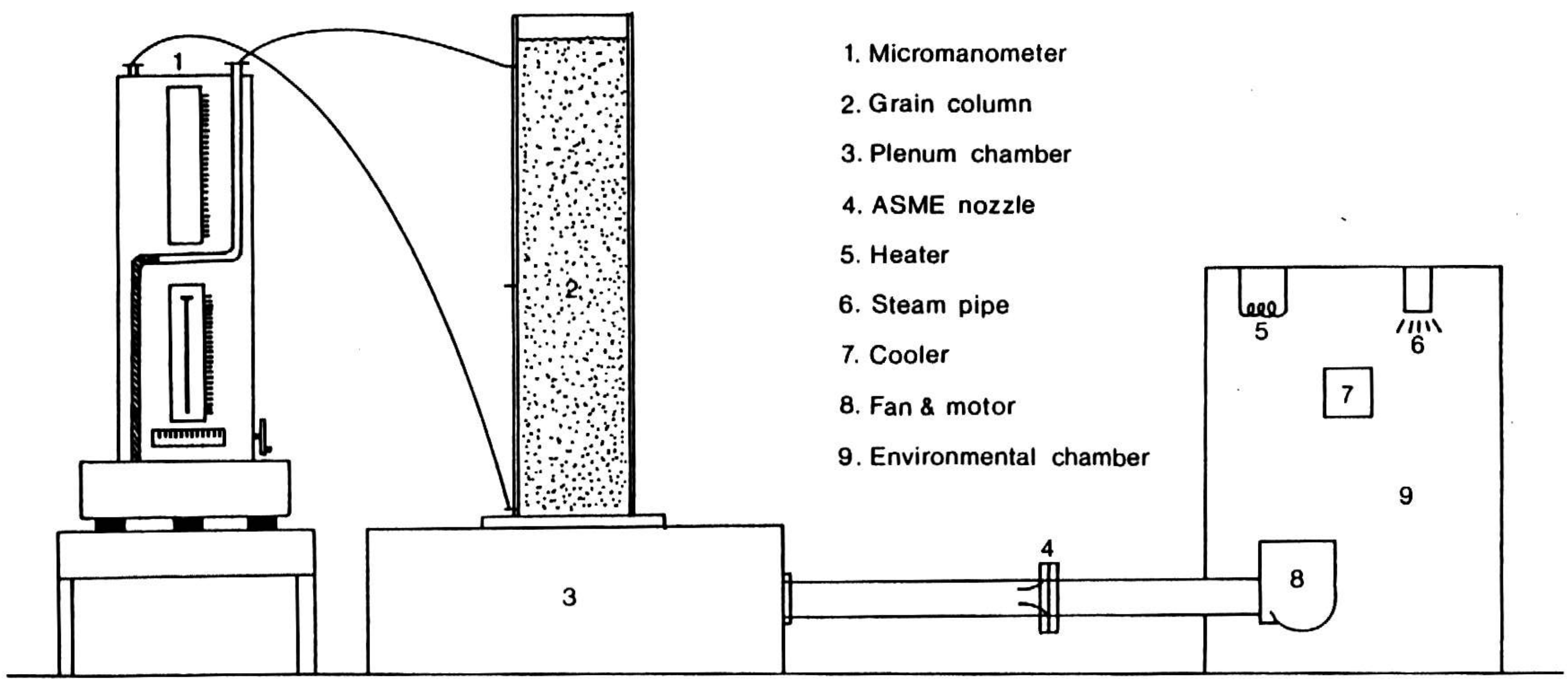


Fig. 1. Schematic Diagram for the Experimental Set-up

# METHODS AND PROCEDURES

Rough rice kernels of long grain "STAR BONNET" were used. A grain cleaner was used to clean the grain. All foreign material (rice straw and seeds) were collected for later use. After mixing the grain with the desired percentage of foreign material, we placed it inside the test column. Foreign material included all material remaining on a 3.0 x 25 mm oblong hole sieve, plus the material that will pass through a 1.5 x 25 mm oblong hole sieve.

The test bed was filled by a loose-fill method as described by Shedd (1953). We poured the grain into a funnel, the outlet of which was held just below the grain surface, making sure to raise the funnel gradually as the filling progressed.

Prior to each test, the temperature and relative humidity of the air supply inside the environmental chamber were controlled by an air conditioning unit and kept fairly constant at approximately 26° C and 60% RH. After the test bed was prepared, the fan was turned on, and a dial was set to control the airflow. Pressure differences across the nozzle were read from a micro-manometer for calculating the airflow rate. The static pressure drop across the measuring section of the grain bed was read by the same micro-manometer after the ASME nozzle taps were properly closed. These procedures were repeated for all the 48 beds.

For airflow measurements we constructed a plot of pressure in pascals against velocity of the air through on ASME nozzle (Fig. 2).

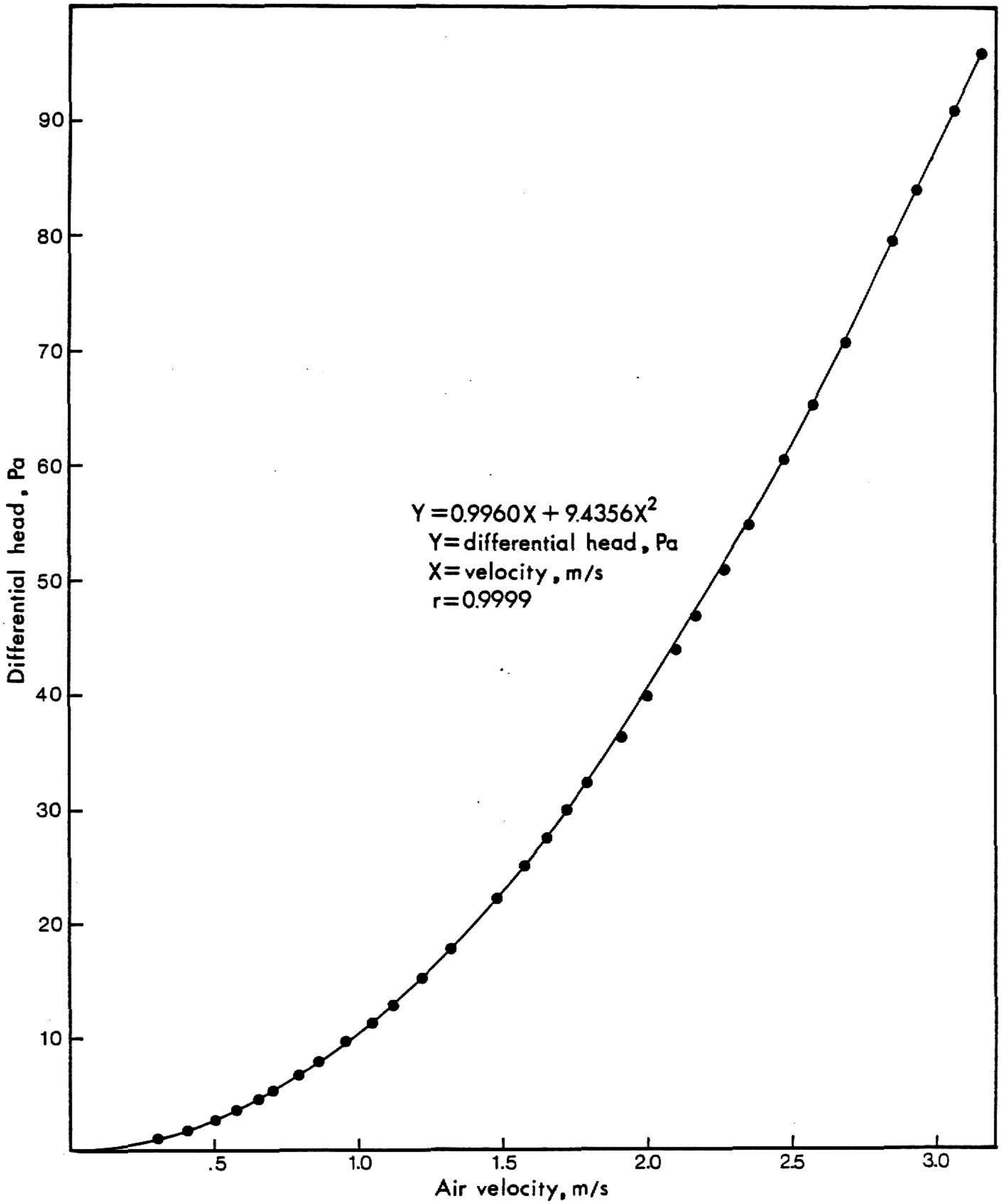


Fig. 2. Calibration Curve of the ASME nozzle.

# RESULTS AND DISCUSSION

The experimental data collected from tests are presented in Appendix Tables 2 through 5 for various levels of moisture, foreign material and airflow rates, each with three replications. Average values of static pressures for three replications are tabulated 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.

In Tables 6 through 9 it can be seen that the maximum increase in static pressure drop occurs with 11.8% moisture content and 0% foreign material and the minimum increase in static pressure drop occurs with 19.5% moisture content and 5% foreign material. This pattern appears in all 4 levels of moisture content tested. We can conclude from the above result that static pressure decreases with the increase of moisture content.

The average static pressure drop for three replications at four levels of moisture content at each percentage of foreign material were plotted against airflow rates 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% foreign material).

Figure 3 shows that all the curves run almost parallel to Shedd's curve for rough rice at 13.4% moisture content. The experimental curves for all moisture contents are to the left of Shedd's plot, which means that high moisture grain displays less airflow resistance than dry grains. We can conclude from the above results that the static pressure increases with a decrease in moisture content. This trend persisted consistently over the range of moisture tested, except in the case of 11.8% moisture content, which should be to the right of Shedd's curve but is on the left side. We attribute this to the particle size differential, taking into consideration that we don't know the variety or grain type of rough rice that Shedd used in his investigations.

The effect of foreign material at constant moisture content is shown in Figures 7 through 10. All the curves run almost parallel to each other, with the curve of the lowest percentage of foreign material appearing to the right of the others. This pattern appears in all levels of foreign material tested. We conclude from the above result that static pressure decreases with the increasing of foreign material. This phenomenon is completely opposite to that observed for other grains such as wheat, corn and grain sorghum. This phenomenon is attributed to the fact that foreign materials in rough rice are more coarse than grain kernels while fines and broken kernels in other grains are finer than the grain kernels.

Table 6. Average Static Pressure Drop Data for Rough Rice with 0% Foreign Material.

| Airflow $m^3/sec. m^2$ | Moisture Content (% w.b.) | Static Pressure Drop Pa/m |
|---|---|---|
| 0.0508 | 19.5 | 105.545 |
| 0.0762 | 19.5 | 170.436 |
| 0.1016 | 19.5 | 248.556 |
| 0.1270 | 19.5 | 333.691 |
| 0.1524 | 19.5 | 415.482 |
| 0.1778 | 19.5 | 517.109 |
| 0.2032 | 19.5 | 628.694 |
| 0.2286 | 19.5 | 745.505 |
| 0.2540 | 19.5 | 868.271 |
| 0.2794 | 19.5 | 1002.953 |
| 0.3048 | 19.5 | 1134.619 |
| 0.3302 | 19.5 | 1284.813 |
| 0.3556 | 19.5 | 1601.283 |
| 0.3810 | 19.5 | 1756.047 |

| Airflow $m^3/sec. m^2$ | Moisture Content (% w.b.) | Static Pressure Drop Pa/m |
|---|---|---|
| 0.0508 | 17.4 | 118.114 |
| 0.0762 | 17.4 | 192.884 |
| 0.1016 | 17.4 | 277.287 |
| 0.1270 | 17.4 | 371.240 |
| 0.1524 | 17.4 | 476.132 |
| 0.1778 | 17.4 | 595.226 |
| 0.2032 | 17.4 | 687.057 |
| 0.2286 | 17.4 | 869.495 |
| 0.2540 | 17.4 | 992.753 |
| 0.2794 | 17.4 | 1150.292 |
| 0.3048 | 17.4 | 1289.957 |
| 0.3302 | 17.4 | 1402.520 |
| 0.3556 | 17.4 | 1752.293 |
| 0.3810 | 17.4 | 1824.370 |

Table 6. (continued)

| Airflow $m^3/sec.\ m^2$ | Moisture Content (% w.b.) | Static Pressure Drop Pa/m |
|---|---|---|
| 0.0508 | 15.2 | 121.381 |
| 0.0762 | 15.2 | 198.763 |
| 0.1016 | 15.2 | 278.757 |
| 0.1270 | 15.2 | 375.486 |
| 0.1524 | 15.2 | 492.051 |
| 0.1778 | 15.2 | 622.472 |
| 0.2032 | 15.2 | 758.481 |
| 0.2286 | 15.2 | 898.717 |
| 0.2540 | 15.2 | 1053.809 |
| 0.2794 | 15.2 | 1240.735 |
| 0.3048 | 15.2 | 1345.380 |
| 0.3302 | 15.2 | 1604.629 |
| 0.3556 | 15.2 | 1907.874 |
| 0.3810 | 15.2 | 2053.497 |

| Airflow $m^3/sec.\ m^2$ | Moisture Content (% w.b.) | Static Pressure Drop Pa/m |
|---|---|---|
| 0.0508 | 11.8 | 126.929 |
| 0.0762 | 11.8 | 206.109 |
| 0.1016 | 11.8 | 297.123 |
| 0.1270 | 11.8 | 384.055 |
| 0.1524 | 11.8 | 522.008 |
| 0.1778 | 11.8 | 652.201 |
| 0.2032 | 11.8 | 805.253 |
| 0.2286 | 11.8 | 959.121 |
| 0.2540 | 11.8 | 1116.660 |
| 0.2794 | 11.8 | 1289.304 |
| 0.3048 | 11.8 | 1453.783 |
| 0.3302 | 11.8 | 1640.302 |
| 0.3556 | 11.8 | 2016.194 |
| 0.3810 | 11.8 | 2201.079 |

Table 7. Average Static Pressure Drop Data for Rough Rice with 1% Foreign Material.

| Airflow $m^3/sec.\ m^2$ | Moisture Content (% w.b.) | Static Pressure Drop Pa/m | Airflow $m^3/sec.\ m^2$ | Moisture Content (% w.b.) | Static Pressure Drop Pa/m |
|---|---|---|---|---|---|
| 0.0508 | 19.5 | 102.034 | 0.0508 | 17.4 | 112.484 |
| 0.0762 | 19.5 | 167.743 | 0.0762 | 17.4 | 184.232 |
| 0.1016 | 19.5 | 245.453 | 0.1016 | 17.4 | 264.065 |
| 0.1270 | 19.5 | 327.162 | 0.1270 | 17.4 | 350.427 |
| 0.1524 | 19.5 | 412.382 | 0.1524 | 17.4 | 440.787 |
| 0.1778 | 19.5 | 495.886 | 0.1778 | 17.4 | 547.556 |
| 0.2032 | 19.5 | 594.003 | 0.2032 | 17.4 | 650.407 |
| 0.2286 | 19.5 | 722.972 | 0.2286 | 17.4 | 786.480 |
| 0.2540 | 19.5 | 842.149 | 0.2540 | 17.4 | 916.102 |
| 0.2794 | 19.5 | 963.609 | 0.2794 | 17.4 | 1064.829 |
| 0.3048 | 19.5 | 1093.970 | 0.3048 | 17.4 | 1216.493 |
| 0.3302 | 19.5 | 1253.386 | 0.3302 | 17.4 | 1290.118 |
| 0.3556 | 19.5 | 1555.246 | 0.3556 | 17.4 | 1688.704 |
| 0.3810 | 19.5 | 1712.539 | 0.3810 | 17.4 | 1742.743 |

Table 7. (continued)

| Airflow $m^3/sec. m^2$ | Moisture Content (% w.b.) | Static Pressure Drop Pa/m |
|---|---|---|
| 0.0508 | 15.2 | 118.114 |
| 0.0762 | 15.2 | 186.769 |
| 0.1016 | 15.2 | 276.309 |
| 0.1270 | 15.2 | 368.304 |
| 0.1524 | 15.2 | 476.867 |
| 0.1778 | 15.2 | 598.166 |
| 0.2032 | 15.2 | 725.830 |
| 0.2286 | 15.2 | 883.209 |
| 0.2540 | 15.2 | 1020.505 |
| 0.2794 | 15.2 | 1187.841 |
| 0.3048 | 15.2 | 1247.428 |
| 0.3302 | 15.2 | 1411.988 |
| 0.3556 | 15.2 | 1772.782 |
| 0.3810 | 15.2 | 1808.451 |

| Airflow $m^3/sec. m^2$ | Moisture Content (% w.b.) | Static Pressure Drop Pa/m |
|---|---|---|
| 0.0508 | 11.8 | 119.419 |
| 0.0762 | 11.8 | 195.335 |
| 0.1016 | 11.8 | 285.942 |
| 0.1270 | 11.8 | 377.772 |
| 0.1524 | 11.8 | 490.092 |
| 0.1778 | 11.8 | 612.611 |
| 0.2032 | 11.8 | 750.230 |
| 0.2286 | 11.8 | 902.146 |
| 0.2540 | 11.8 | 1042.625 |
| 0.2794 | 11.8 | 1201.063 |
| 0.3048 | 11.8 | 1359.829 |
| 0.3302 | 11.8 | 1543.409 |
| 0.3556 | 11.8 | 1958.566 |
| 0.3810 | 11.8 | 2068.435 |

Table 8. Average Static Pressure Drop Data for Rough Rice with 3% Foreign Material.

| Airflow $m^3/sec.\ m^2$ | Moisture Content (% w.b.) | Static Pressure Drop Pa/m | Airflow $m^3/sec.\ m^2$ | Moisture Content (% w.b.) | Static Pressure Drop Pa/m |
|---|---|---|---|---|---|
| 0.0508 | 19.5 | 93.625 | 0.0508 | 17.4 | 100.157 |
| 0.0762 | 19.5 | 155.338 | 0.0762 | 17.4 | 159.173 |
| 0.1016 | 19.5 | 224.229 | 0.1016 | 17.4 | 228.150 |
| 0.1270 | 19.5 | 297.694 | 0.1270 | 17.4 | 306.266 |
| 0.1524 | 19.5 | 374.016 | 0.1524 | 17.4 | 383.817 |
| 0.1778 | 19.5 | 465.440 | 0.1778 | 17.4 | 481.355 |
| 0.2032 | 19.5 | 563.799 | 0.2032 | 17.4 | 581.841 |
| 0.2286 | 19.5 | 668.937 | 0.2286 | 17.4 | 697.671 |
| 0.2540 | 19.5 | 778.153 | 0.2540 | 17.4 | 806.476 |
| 0.2794 | 19.5 | 892.185 | 0.2794 | 17.4 | 928.264 |
| 0.3048 | 19.5 | 1030.299 | 0.3048 | 17.4 | 1064.177 |
| 0.3302 | 19.5 | 1169.065 | 0.3302 | 17.4 | 1207.431 |
| 0.3556 | 19.5 | 1446.273 | 0.3556 | 17.4 | 1503.330 |
| 0.3810 | 19.5 | 1614.587 | 0.3810 | 17.4 | 1705.764 |

Table 8. (continued)

| Airflow $m^3/sec. m^2$ | Moisture Content (% w.b.) | Static Pressure Drop Pa/m | Airflow $m^3/sec. m^2$ | Moisture Content (% w.b.) | Static Pressure Drop Pa/m |
|---|---|---|---|---|---|
| 0.0508 | 15.2 | 108.402 | 0.0508 | 11.8 | 111.585 |
| 0.0762 | 15.2 | 171.663 | 0.0762 | 11.8 | 185.866 |
| 0.1016 | 15.2 | 245.699 | 0.1016 | 11.8 | 274.675 |
| 0.1270 | 15.2 | 359.324 | 0.1270 | 11.8 | 370.997 |
| 0.1524 | 15.2 | 457.277 | 0.1524 | 11.8 | 465.440 |
| 0.1778 | 15.2 | 571.555 | 0.1778 | 11.8 | 581.594 |
| 0.2032 | 15.2 | 695.627 | 0.2032 | 11.8 | 713.832 |
| 0.2286 | 15.2 | 796.030 | 0.2286 | 11.8 | 853.822 |
| 0.2540 | 15.2 | 902.228 | 0.2540 | 11.8 | 996.260 |
| 0.2794 | 15.2 | 1081.808 | 0.2794 | 11.8 | 1147.434 |
| 0.3048 | 15.2 | 1182.126 | 0.3048 | 11.8 | 1303.343 |
| 0.3302 | 15.2 | 1337.218 | 0.3302 | 11.8 | 1431.747 |
| 0.3556 | 15.2 | 1647.648 | 0.3556 | 11.8 | 1839.226 |
| 0.3810 | 15.2 | 1734.416 | 0.3810 | 11.8 | 2001.339 |

Table 9. Average Static Pressure Drop Data for Rough Rice with 5% Foreign Material

| Airflow $m^3/sec. m^2$ | Moisture Content (% w.b.) | Static Pressure Drop Pa/m | Airflow $m^3/sec. m^2$ | Moisture Content (% w.b.) | Static Pressure Drop Pa/m |
|---|---|---|---|---|---|
| 0.0508 | 19.5 | 85.463 | 0.0508 | 17.4 | 89.247 |
| 0.0762 | 19.5 | 139.012 | 0.0762 | 17.4 | 142.602 |
| 0.1016 | 19.5 | 203.251 | 0.1016 | 17.4 | 206.516 |
| 0.1270 | 19.5 | 273.858 | 0.1270 | 17.4 | 278.104 |
| 0.1524 | 19.5 | 342.018 | 0.1524 | 17.4 | 352.792 |
| 0.1778 | 19.5 | 422.014 | 0.1778 | 17.4 | 442.992 |
| 0.2032 | 19.5 | 516.046 | 0.2032 | 17.4 | 531.148 |
| 0.2286 | 19.5 | 612.858 | 0.2286 | 17.4 | 635.633 |
| 0.2540 | 19.5 | 711.627 | 0.2540 | 17.4 | 733.176 |
| 0.2794 | 19.5 | 820.518 | 0.2794 | 17.4 | 843.209 |
| 0.3048 | 19.5 | 938.550 | 0.3048 | 17.4 | 959.367 |
| 0.3302 | 19.5 | 1066.870 | 0.3302 | 17.4 | 1090.784 |
| 0.3556 | 19.5 | 1339.320 | 0.3556 | 17.4 | 1361.299 |
| 0.3810 | 19.5 | 1463.415 | 0.3810 | 17.4 | 1509.534 |

Table 9. (continued)

| Airflow $m^3/sec. m^2$ | Moisture Content (% w.b.) | Static Pressure Drop Pa/m | Airflow $m^3/sec. m^2$ | Moisture Content (% w.b.) | Static Pressure Drop Pa/m |
|---|---|---|---|---|---|
| 0.0508 | 15.2 | 106.932 | 0.0508 | 11.8 | 108.156 |
| 0.0762 | 15.2 | 163.009 | 0.0762 | 11.8 | 168.317 |
| 0.1016 | 15.2 | 228.720 | 0.1016 | 11.8 | 249.370 |
| 0.1270 | 15.2 | 327.733 | 0.1270 | 11.8 | 338.100 |
| 0.1524 | 15.2 | 408.953 | 0.1524 | 11.8 | 427.484 |
| 0.1778 | 15.2 | 507.559 | 0.1778 | 11.8 | 533.189 |
| 0.2032 | 15.2 | 644.039 | 0.2032 | 11.8 | 654.242 |
| 0.2286 | 15.2 | 694.488 | 0.2286 | 11.8 | 787.949 |
| 0.2540 | 15.2 | 735.705 | 0.2540 | 11.8 | 914.472 |
| 0.2794 | 15.2 | 965.079 | 0.2794 | 11.8 | 1051.358 |
| 0.3048 | 15.2 | 1069.482 | 0.3048 | 11.8 | 1205.062 |
| 0.3302 | 15.2 | 1196.899 | 0.3302 | 11.8 | 1363.176 |
| 0.3556 | 15.2 | 1498.268 | 0.3556 | 11.8 | 1699.482 |
| 0.3810 | 15.2 | 1703.153 | 0.3810 | 11.8 | 1854.409 |

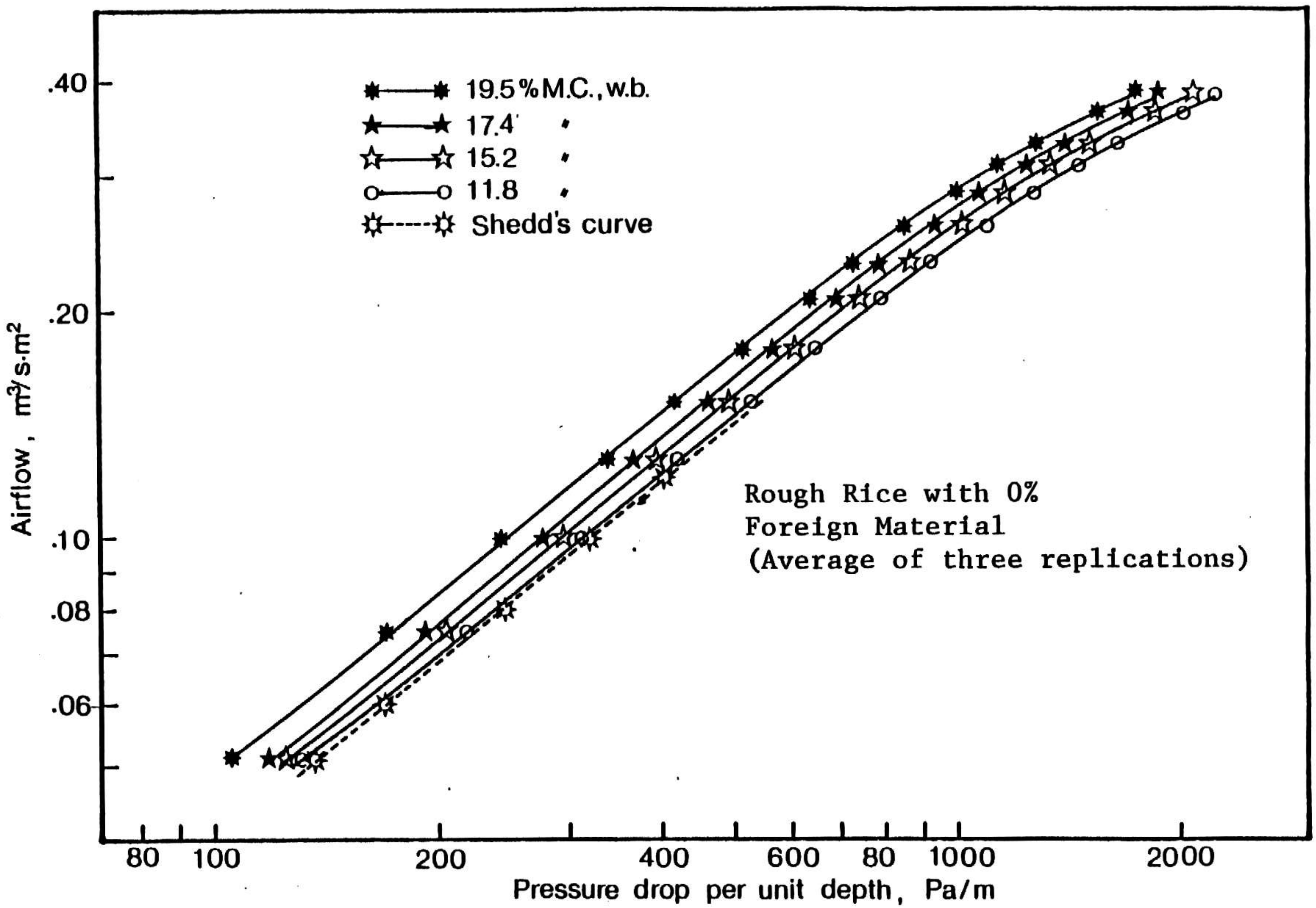


Fig. 3. Resistance of Rough Rice to Airflow at Different Moisture Contents

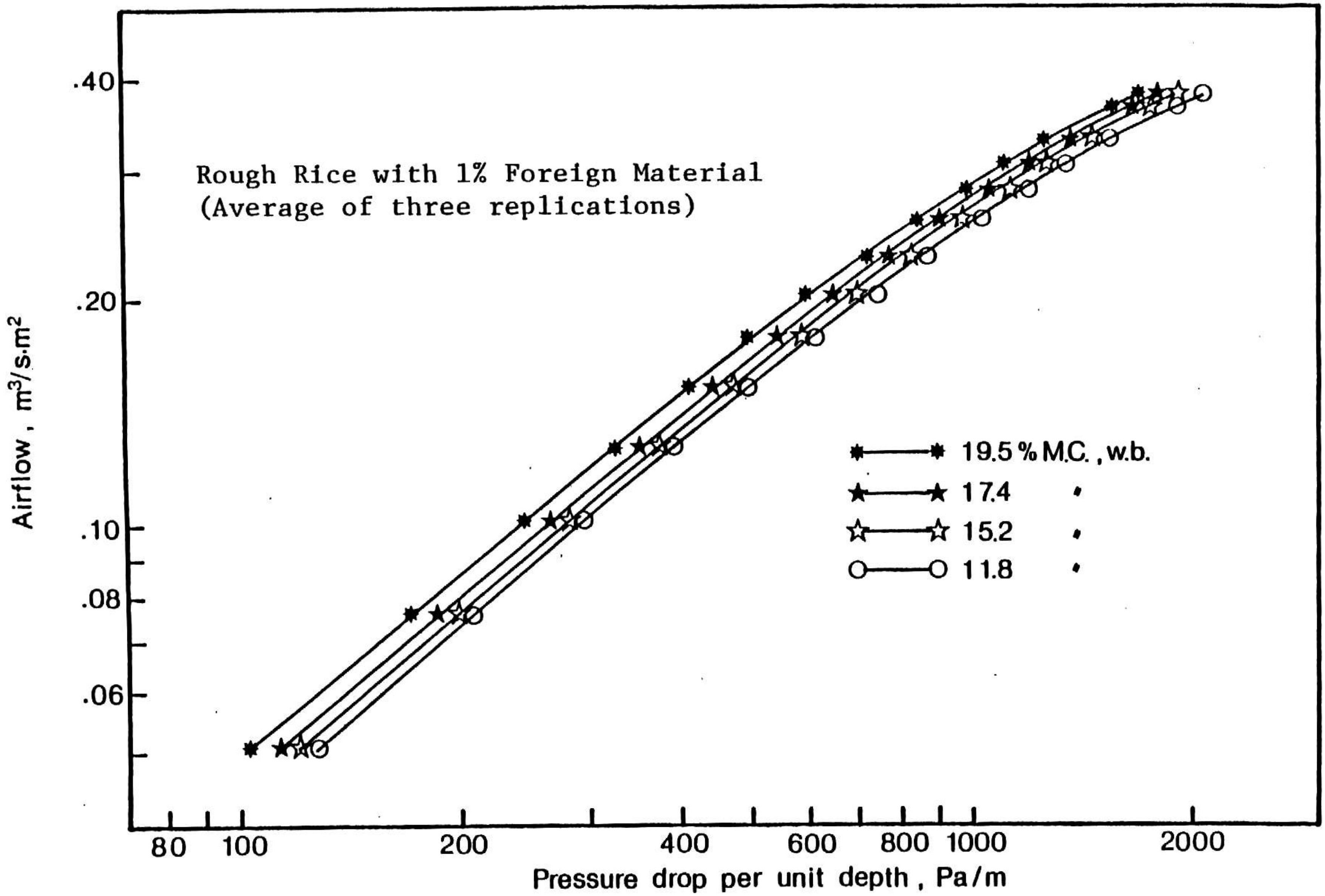


Fig. 4. Resistance of Rough Rice to Airflow at Different Moisture Contents

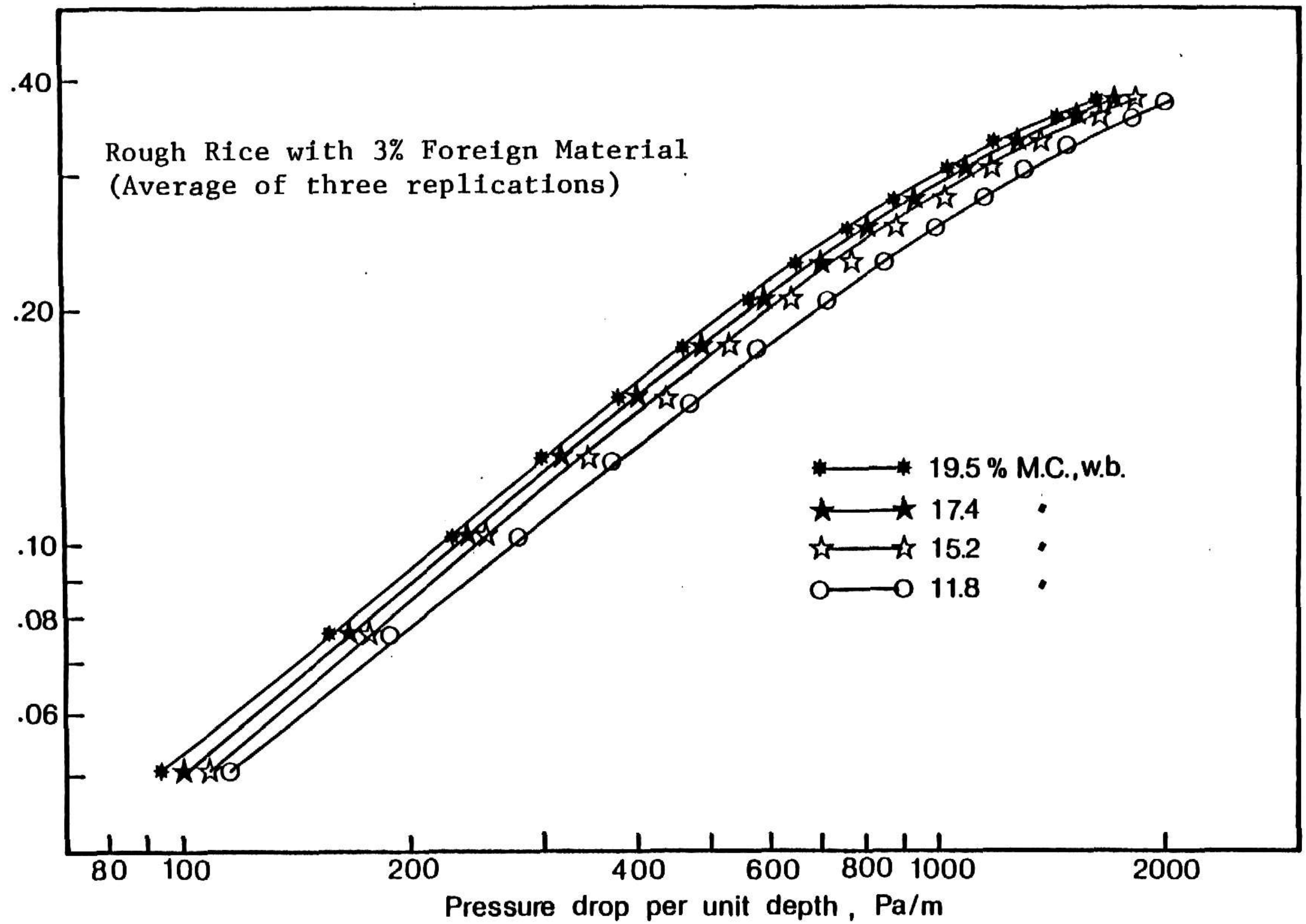


Fig. 5. Resistance of Rough Rice to Airflow at Different Moisture Contents

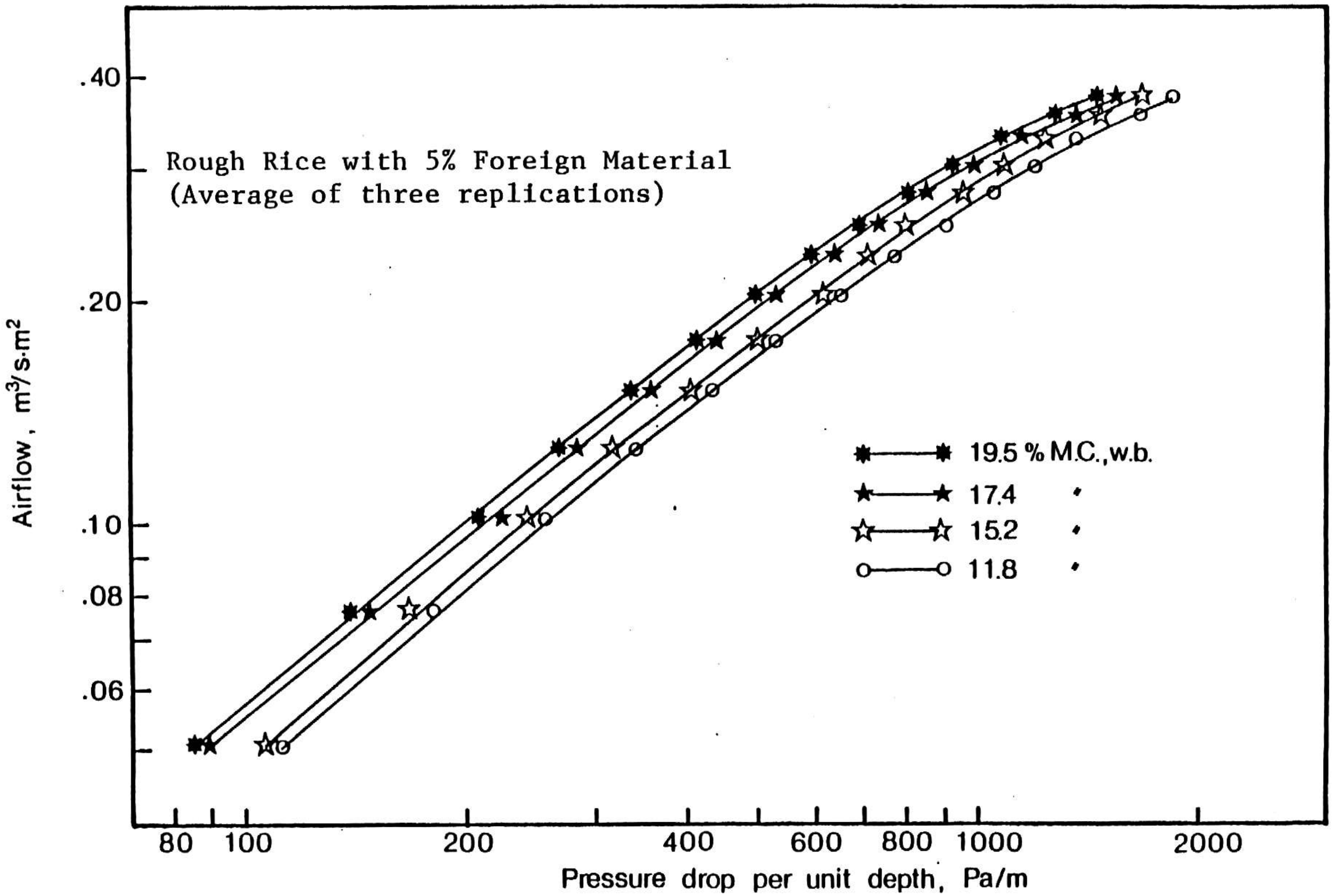


Fig. 6. Resistance of Rough Rice to Airflow at Different Moisture Contents.

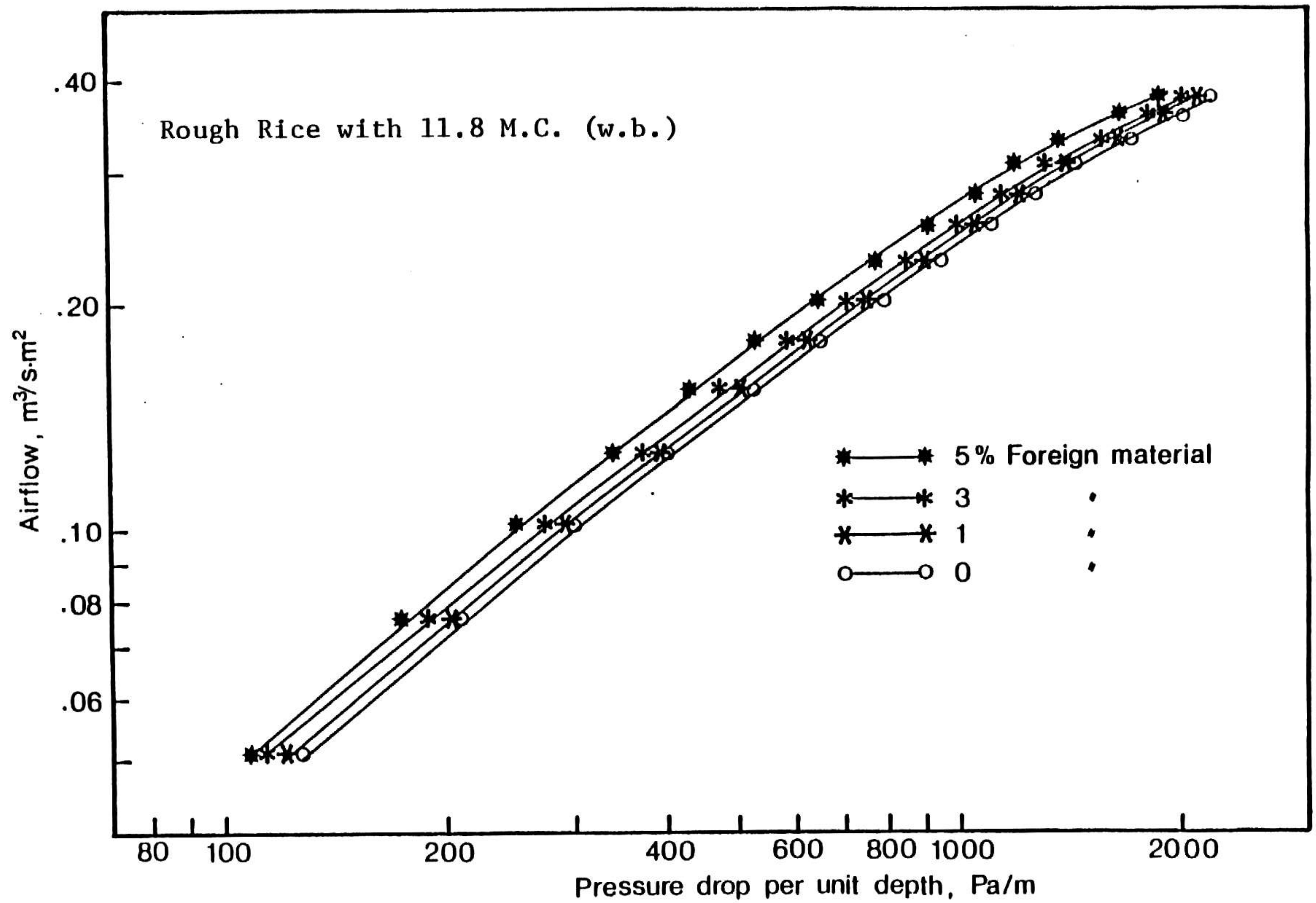


Fig. 7. Resistance of Rough Rice to Airflow at Different Percentages of Foreign Material.

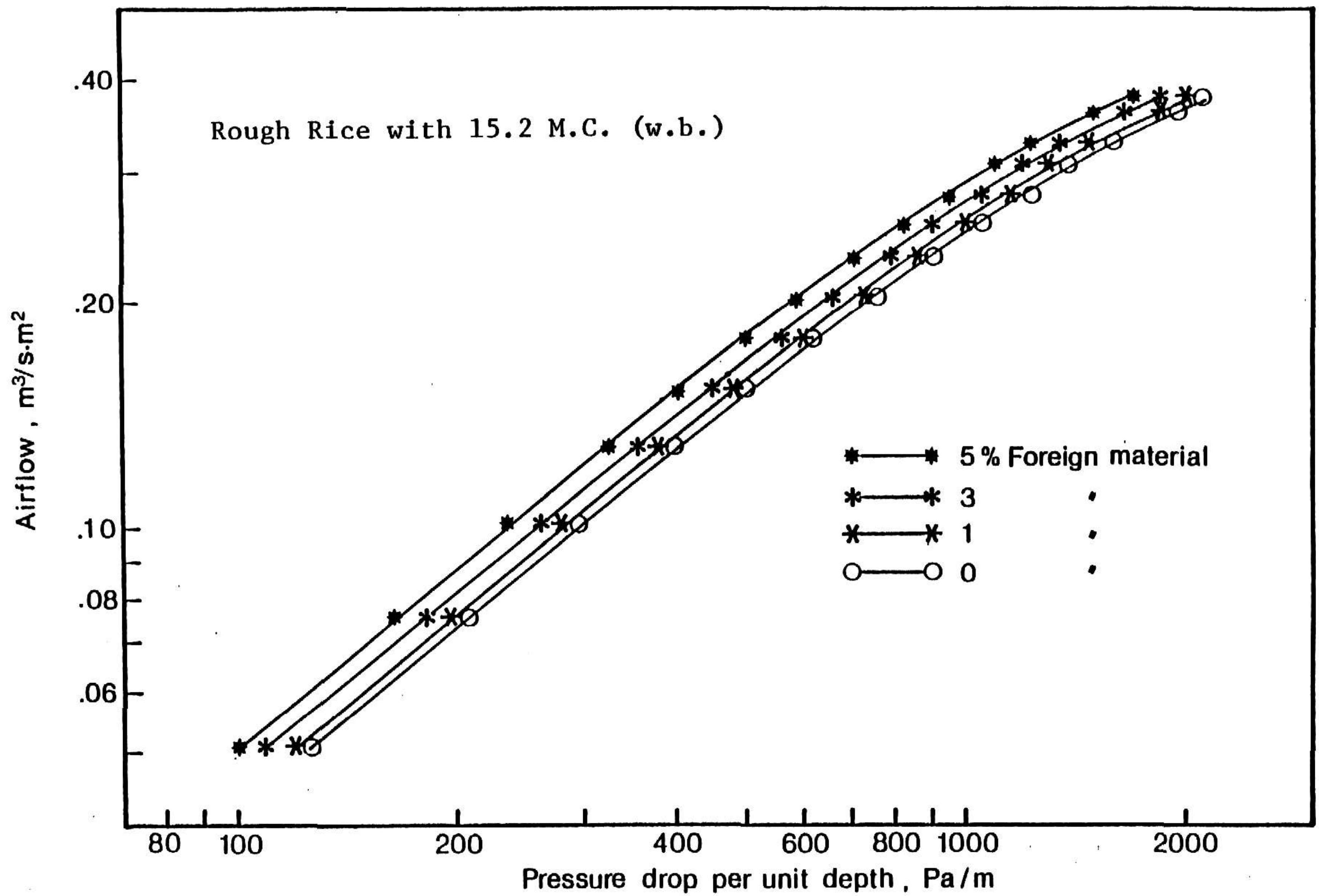


Fig. 8. Resistance of Rough Rice to Airflow at Different Percentages of Foreign Material.

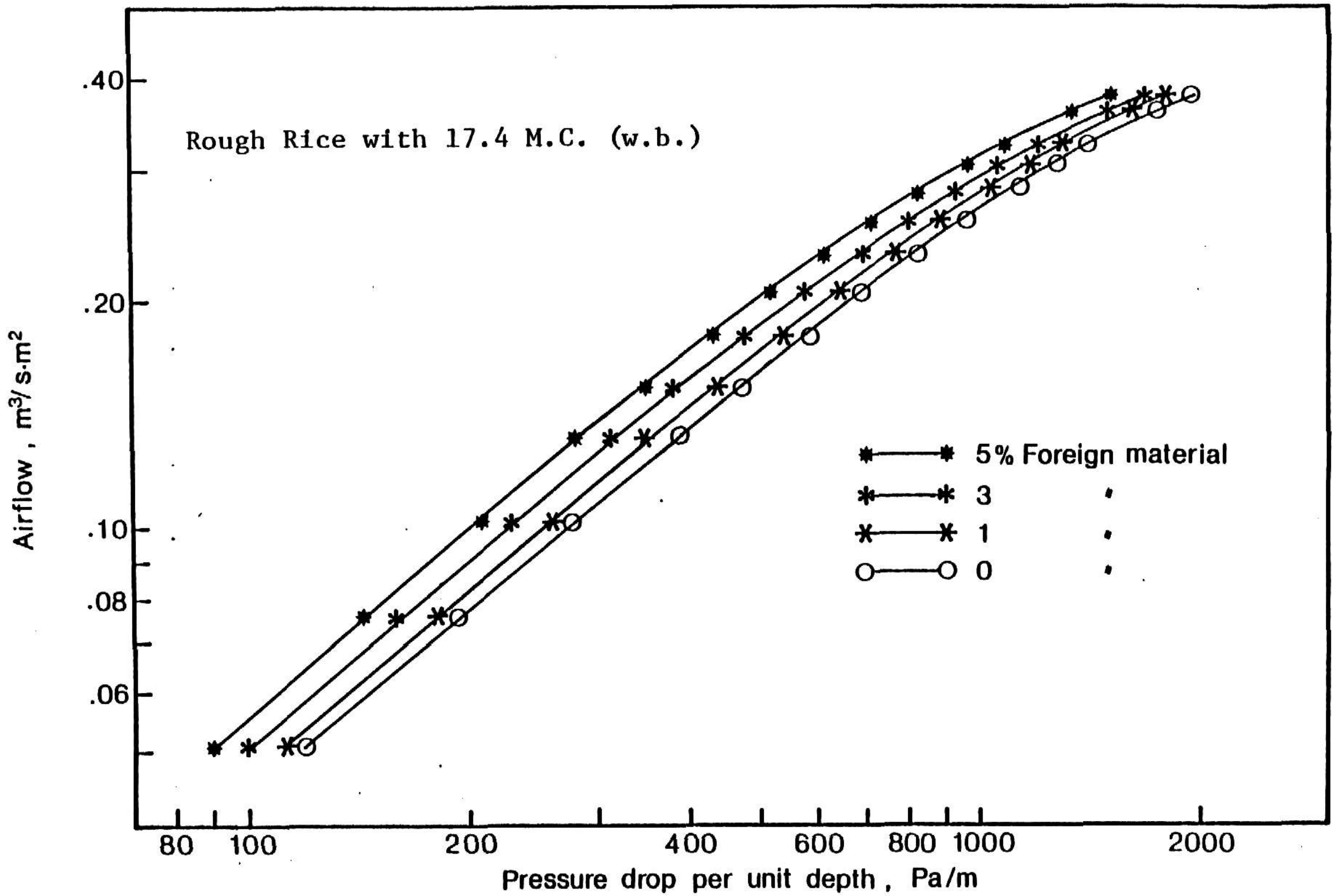


Fig. 9. Resistance of Rough Rice to Airflow at Different Percentages of Foreign Material.

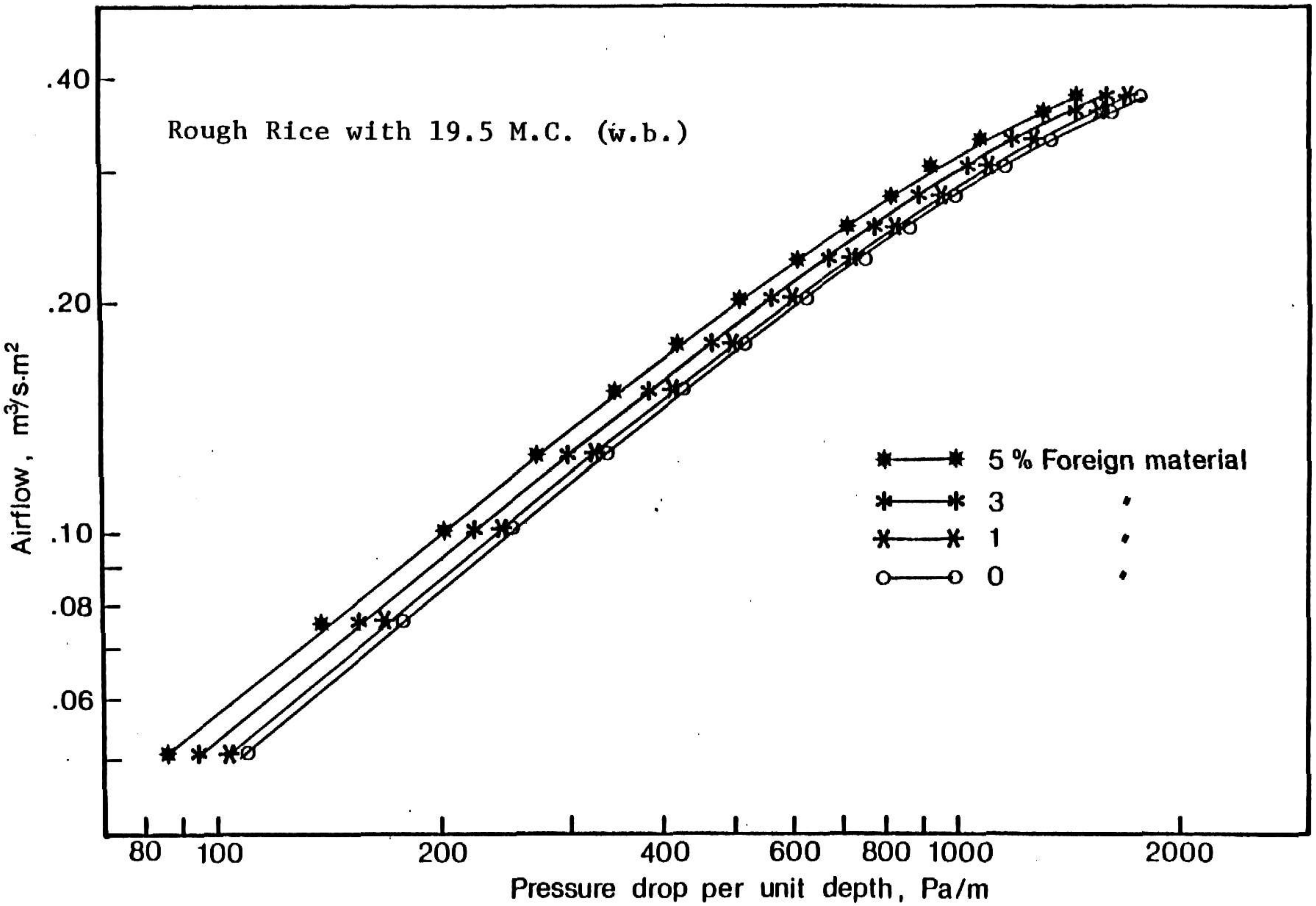


Fig. 10. Resistance of Rough Rice to Airflow at Different Percentages of Foreign Material.

To analyze our data statistically, we needed to have all the levels of airflow rate the same for every combination of moisture content and foreign material. Because we were unable to obtain exactly the same air velocity, for each replication we interpolated the static pressure drops at fixed set of air velocities. 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 foreign 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 analyzing the data:

$$X_{ijk} = u + A_i + M_j + F_k + (A*M)_{ij} + (A*F)_{ik} + (M*F)_{jk} + \varepsilon_{ijk} \qquad [9]$$

where

$X_{ijk}$ = observed value (static pressure drop).

$u$ = overall mean.

$A_i$ = 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 foreign material.

All other terms are interactions of the main effects.

$\varepsilon_{ijk}$ = the random error of static pressure

In this analysis we assumed that the between bed and within bed mean square errors are the same, hence one error term was used.

The results of the analysis of variance in Table 10 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 moisture content and foreign material.

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

| Source of Variation | Degrees of Freedom | Sum of Sq. | F-Value | Decision (1) |
|---|---|---|---|---|
| Airflow | 13 | 61466448.065 | 10266.93 | Reject |
| Moisture Content | 3 | 1077217.237 | 799.70 | " |
| Foreign Material | 3 | 943470.052 | 682.89 | " |
| AF * MC | 39 | 518075.200 | 28.85 | " |
| AF * FM | 39 | 372783.652 | 20.76 | " |
| MC * FM | 9 | 25304.653 | 6.11 | " |

(1) This decision is based on the null hypothesis that the group means for each effect are equal at = 0.01.

In order to select a model that will predict the effects of moisture and foreign material on the static pressure drop, we followed the standard stepwise procedure to arrive at the following nonlinear regression model:

$$SP = a\,(AF) + b\,(AF)^2 - c\,(MC)\,(AF) - d\,(FM)\,(AF) \qquad [10]$$

where

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

AF = air velocity, m/s.

MC = grain moisture content, %(w.b.)

FM = foreign material, %.

a,b,c,d = constants.

The values of constants evaluated are:

a = 3749.15

b = 8289.97

c = 117.12

d = 164.23

This model described our results very well. 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 the Appendix.

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 10.

Table 11. Comparison Between Experimental Data and Model Values

| Foreign Material % | Moisture Content (% w.b.) | Air Vel. m/s | SP (Pa/m) Exp. Val. | SP (Pa/m) Model Val. | Percentage Deviation |
|---|---|---|---|---|---|
| 5% | 19.5 | 0.3810 | 1463.42 | 1448.81 | 0.99 |
| 3% | 19.5 | 0.2540 | 778.15 | 781.88 | 0.48 |
| 3% | 17.4 | 0.1524 | 389.81 | 378.25 | 1.45 |
| 3% | 15.2 | 0.1016 | 276.31 | 268.93 | 2.67 |
| 1% | 17.4 | 0.1032 | 650.41 | 656.65 | 0.95 |
| 0% | 15.2 | 0.0508 | 121.38 | 121.41 | 0.03 |
| 0% | 19.5 | 0.3810 | 1756.05 | 1761.66 | 0.32 |

# CONCLUSIONS

Within the range of moisture content and foreign material investigated, the following conclusions were drawn from this study:

1. Static pressure drop in rough rice increases with decreasing moisture content. The degree of increase depends on the airflow and moisture tested.

2. Static pressure drop in rough rice decreases with an increase in foreign material. The degree of decrease depends on the airflow and foreign material examined.

3. Static pressure drop in rough rice increases with an increase in airflow. The degree of increase depends on the amount of foreign material and the moisture content in the bed

4. The statistical model

$$SP = a\ (AF) + b\ (AF)^2 - c\ (MC)\ (AF) - d\ (FM)\ (AF)$$

adequately describes the relationship between static pressure drop, air velocity, grain moisture content, and foreign material.

## REFERENCES


1. Agrawal, K. K. and P. Chand. 1974. Pressure drop across fixed beds of rough rice. Trans. of the ASAE 17(3): 560-5631.

2. Americna Society of Agricultural Engineering. 1980 ASAE Yearbook.

3. Brooker, D. B., F. M. Bakker-Arkema, and C. W. Hall, 1974. Drying cereal grains. The AVI Publishing Co., Inc., Westport, Ct.

4. Calderwood, D. L., 1973. Resistance to airflow of rough, brown and milled rice. Trans. of the ASAE 16(3): 525-527, 532.

5. Chung, D. S. and H. H. Converse, 1971. Effect of moisture content on some physical properties of grains. Trans. of the ASAE 14(4): 612-614, 620.

6. Chung, D. S., G. Abdelmoshin and M. S. Kim, 1984. Resistance of grain sorghum to airflow. ASAE paper No. 84-3529.

7. Haque, E., G. H. Foster, D. S. Chung, and F. S. Lai, 1978. Static pressure drop across a bed of corn mixed with fines. Trans. of the ASAE 21(5): 991-1000.

8. Haque, E., Y. N. Ahmed, and C. W. Deyoe, 1982. Static pressure drop in a fixed bed of grain as affected by grain moisture content. Trans. of the ASAE 25(4): 1095-1098.

9. Henderson, S. M., 1943. Resistance of shelled corn and bin walls to airflow. Agr. Engg. 24(11): 267-269, 274.

10. Henderson, S. M. and R. L. Perry, 1976. Agricultural Process Engineering. The AVI Publishing Co., Inc., Westport, Ct.

11. Hukill, W. V. and N. C. Ives, 1955. Radial airflow resistance of grain. Agr. Engg. 36(5): 332-335.

12. Husain, A. and T. P. Ojha, 1969. Resistance to the passage of air through rough rice. J. Agr. Engg. Res. 14(1): 47-53.

13. Shedd, C. K., 1945. Resistance of ear corn to airflow. Agr. Engg. 26(1): 19-20, 23.

14. Shedd, C. K., 1951. Some new data on resistance of grain to airflow. Agr. Engg. 32(9): 493-495, 520.

15. Shedd, C. K., 1953. Resistance of grains and seeks to airflow. Agr. Engg., 34(9): 616-619.

16. Stirniman, E. J., Bodnar, G. P., and Bates, E. N., 1931. Test on resistance to the passage of air through rough rice in a deep bin. Agr. Engg. 12(5): 145-148.

# APPENDIX

Table 2. Air Velocity and Static Pressure Drop for Rough Rice at 0% Foreign Materials at Different Moisture Content.

| Moisture Content | Air Velocity | Static Pressure Drop in (Pa/m) | | |
|---|---|---|---|---|
| % (w.b.) | m/sec | $R_1$ | $R_2$ | $R_3$ |
| 19.5 | 0.0508 | 112.65 | 98.36 | 105.71 |
| 19.5 | 0.0762 | 171.01 | 169.78 | 170.60 |
| 19.5 | 0.1016 | 247.74 | 248.96 | 248.96 |
| 19.5 | 0.1270 | 330.60 | 335.90 | 334.67 |
| 19.5 | 0.1524 | 416.71 | 412.22 | 417.52 |
| 19.5 | 0.1778 | 518.33 | 514.66 | 518.33 |
| 19.5 | 0.2032 | 632.20 | 624.45 | 629.35 |
| 19.5 | 0.2286 | 748.52 | 741.99 | 746.07 |
| 19.5 | 0.2540 | 874.64 | 861.17 | 868.92 |
| 19.5 | 0.2794 | 1010.14 | 996.26 | 1002.38 |
| 19.5 | 0.3048 | 1142.78 | 1122.38 | 1138.70 |
| 19.5 | 0.3302 | 1295.83 | 1275.43 | 1283.18 |
| 19.5 | 0.3556 | 1607.24 | 1593.36 | 1603.16 |
| 19.5 | 0.3810 | 1775.39 | 1737.85 | 1754.99 |
| 17.4 | 0.0508 | 117.95 | 119.18 | 117.14 |
| 17.4 | 0.0762 | 191.42 | 194.68 | 192.64 |
| 17.4 | 0.1016 | 278.35 | 275.90 | 277.53 |
| 17.4 | 0.1270 | 366.91 | 375.49 | 371.40 |
| 17.4 | 0.1524 | 471.40 | 483.64 | 473.44 |
| 17.4 | 0.1778 | 579.55 | 597.51 | 608.53 |
| 17.4 | 0.2032 | 694.65 | 679.74 | 687.30 |
| 17.4 | 0.2286 | 860.35 | 889.33 | 858.72 |
| 17.4 | 0.2540 | 999.12 | 987.69 | 991.36 |
| 17.4 | 0.2794 | 1145.23 | 1150.94 | 1154.62 |
| 17.4 | 0.3048 | 1298.70 | 1302.36 | 1268.90 |
| 17.4 | 0.3302 | 1397.70 | 1421.95 | 1387.66 |
| 17.4 | 0.3556 | 1742.74 | 1758.66 | 1752.25 |
| 17.4 | 0.3810 | 1820.29 | 1815.39 | 1824.37 |

Table 2. (continued)

| Moisture Content % (w.b.) | Air Velocity m/sec | Static Pressure Drop in (Pa/m) | | |
|---|---|---|---|---|
| | | $R_1$ | $R_2$ | $R_3$ |
| 15.2 | 0.0508 | 119.99 | 127.75 | 116.32 |
| 15.2 | 0.0762 | 184.48 | 195.09 | 216.72 |
| 15.2 | 0.1016 | 257.94 | 276.31 | 302.02 |
| 15.2 | 0.1270 | 376.30 | 374.67 | 375.49 |
| 15.2 | 0.1524 | 510.58 | 485.68 | 497.97 |
| 15.2 | 0.1778 | 582.00 | 632.61 | 653.02 |
| 15.2 | 0.2032 | 733.42 | 754.64 | 746.48 |
| 15.2 | 0.2286 | 815.86 | 898.72 | 981.57 |
| 15.2 | 0.2540 | 1032.99 | 1061.15 | 1067.28 |
| 15.2 | 0.2794 | 1212.17 | 1260.73 | 1249.31 |
| 15.2 | 0.3048 | 1310.12 | 1344.40 | 1381.54 |
| 15.2 | 0.3302 | 1603.16 | 1600.30 | 1610.51 |
| 15.2 | 0.3556 | 1901.92 | 1906.81 | 1914.98 |
| 15.2 | 0.3810 | 1999.05 | 2042.31 | 2119.04 |
| 11.8 | 0.0508 | 148.97 | 97.95 | 133.87 |
| 11.8 | 0.0762 | 216.31 | 202.44 | 199.99 |
| 11.8 | 0.1016 | 313.45 | 284.47 | 375.49 |
| 11.8 | 0.1270 | 341.61 | 406.91 | 403.65 |
| 11.8 | 0.1524 | 559.56 | 508.95 | 497.93 |
| 11.8 | 0.1778 | 698.32 | 640.37 | 618.74 |
| 11.8 | 0.2032 | 861.98 | 798.72 | 755.05 |
| 11.8 | 0.2286 | 1017.08 | 959.12 | 900.76 |
| 11.8 | 0.2540 | 1204.00 | 1112.17 | 1033.40 |
| 11.8 | 0.2794 | 1384.81 | 1276.24 | 1206.86 |
| 11.8 | 0.3048 | 1568.47 | 1448.48 | 1344.40 |
| 11.8 | 0.3302 | 1748.46 | 1629.28 | 1543.57 |
| 11.8 | 0.3556 | 2137.41 | 2019.46 | 1891.30 |
| 11.8 | 0.3810 | 2332.91 | 2223.94 | 2046.80 |

Table 3. Air Velocity and Static Pressure Drop for Rough Rice at 1% Foreign Materials at Different Moisture Content.

| Moisture Content | Air Velocity | Static Pressure Drop in (Pa/m) | | |
|---|---|---|---|---|
| % (w.b.) | m/sec | $R_1$ | $R_2$ | $R_3$ |
| 19.5 | 0.0508 | 106.61 | 101.22 | 98.77 |
| 19.5 | 0.0762 | 168.56 | 167.74 | 166.93 |
| 19.5 | 0.1016 | 244.88 | 246.11 | 245.29 |
| 19.5 | 0.1270 | 320.39 | 333.86 | 327.33 |
| 19.5 | 0.1524 | 407.73 | 399.97 | 428.67 |
| 19.5 | 0.1778 | 494.66 | 497.11 | 495.89 |
| 19.5 | 0.2032 | 602.00 | 606.49 | 573.43 |
| 19.5 | 0.2286 | 719.14 | 726.48 | 723.22 |
| 19.5 | 0.2540 | 835.05 | 848.52 | 842.80 |
| 19.5 | 0.2794 | 962.39 | 964.83 | 963.61 |
| 19.5 | 0.3048 | 1093.40 | 1094.62 | 1093.81 |
| 19.5 | 0.3302 | 1246.04 | 1260.33 | 1253.80 |
| 19.5 | 0.3556 | 1550.09 | 1560.71 | 1554.18 |
| 19.5 | 0.3810 | 1712.13 | 1714.17 | 1710.13 |
| 17.4 | 0.0508 | 118.36 | 107.34 | 111.83 |
| 17.4 | 0.0762 | 194.27 | 171.42 | 186.93 |
| 17.4 | 0.1016 | 280.79 | 244.88 | 266.51 |
| 17.4 | 0.1270 | 369.36 | 326.51 | 355.49 |
| 17.4 | 0.1524 | 463.64 | 408.14 | 450.58 |
| 17.4 | 0.1778 | 566.90 | 513.44 | 562.41 |
| 17.4 | 0.2032 | 670.16 | 619.55 | 661.59 |
| 17.4 | 0.2286 | 817.09 | 737.09 | 805.25 |
| 17.4 | 0.2540 | 950.96 | 859.94 | 937.49 |
| 17.4 | 0.2794 | 1101.15 | 1019.93 | 1073.40 |
| 17.4 | 0.3048 | 1260.73 | 1168.09 | 1220.74 |
| 17.4 | 0.3302 | 1306.04 | 1261.96 | 1302.36 |
| 17.4 | 0.3556 | 1714.99 | 1672.95 | 1678.26 |
| 17.4 | 0.3810 | 1763.15 | 1714.99 | 1750.09 |

Table 3. (continued)

| Moisture Content % (w.b.) | Air Velocity m/sec | Static Pressure Drop in (Pa/m) $R_1$ | $R_2$ | $R_3$ |
|---|---|---|---|---|
| 15.2 | 0.0508 | 116.73 | 115.50 | 122.03 |
| 15.2 | 0.0762 | 181.21 | 186.11 | 193.05 |
| 15.2 | 0.1016 | 264.88 | 277.53 | 286.51 |
| 15.2 | 0.1270 | 352.22 | 373.04 | 379.57 |
| 15.2 | 0.1524 | 446.09 | 489.76 | 494.66 |
| 15.2 | 0.1778 | 593.43 | 596.29 | 604.86 |
| 15.2 | 0.2032 | 723.22 | 738.73 | 715.46 |
| 15.2 | 0.2286 | 886.47 | 886.06 | 877.09 |
| 15.2 | 0.2540 | 1025.24 | 1021.16 | 1015.04 |
| 15.2 | 0.2794 | 1191.76 | 1185.23 | 1186.45 |
| 15.2 | 0.3048 | 1263.59 | 1240.73 | 1237.88 |
| 15.2 | 0.3302 | 1371.34 | 1408.89 | 1455.87 |
| 15.2 | 0.3556 | 1780.29 | 1779.48 | 1773.35 |
| 15.2 | 0.3810 | 1812.53 | 1804.37 | 1808.45 |
| 11.8 | 0.0508 | 125.30 | 114.28 | 118.48 |
| 11.8 | 0.0762 | 200.40 | 192.23 | 193.25 |
| 11.8 | 0.1016 | 300.39 | 287.33 | 269.98 |
| 11.8 | 0.1270 | 403.24 | 382.83 | 371.61 |
| 11.8 | 0.1524 | 512.69 | 484.05 | 476.60 |
| 11.8 | 0.1778 | 644.85 | 611.39 | 583.63 |
| 11.8 | 0.2032 | 794.23 | 748.93 | 710.16 |
| 11.8 | 0.2286 | 950.14 | 905.25 | 850.64 |
| 11.8 | 0.2540 | 1092.17 | 1048.91 | 986.71 |
| 11.8 | 0.2794 | 1252.98 | 1215.43 | 1134.78 |
| 11.8 | 0.3048 | 1408.48 | 1383.17 | 1287.84 |
| 11.8 | 0.3302 | 1588.06 | 1597.04 | 1445.01 |
| 11.8 | 0.3556 | 2052.93 | 1946.40 | 1877.84 |
| 11.8 | 0.3810 | 2132.92 | 2090.48 | 1980.28 |

Table 4. Air Velocity and Static Pressure Drop for Rough Rice at 3% Foreign Materials at Different Moisture Content.

| Moisture Content % (w.b.) | Air Velocity m/sec | Static Pressure Drop in (Pa/m) | | |
|---|---|---|---|---|
| | | $R_1$ | $R_2$ | $R_3$ |
| 19.5 | 0.0508 | 99.59 | 89.79 | 91.42 |
| 19.5 | 0.0762 | 162.03 | 152.64 | 151.42 |
| 19.5 | 0.1016 | 232.64 | 216.72 | 223.25 |
| 19.5 | 0.1270 | 312.22 | 288.14 | 292.63 |
| 19.5 | 0.1524 | 387.32 | 364.06 | 370.59 |
| 19.5 | 0.1778 | 480.38 | 455.07 | 460.79 |
| 19.5 | 0.2032 | 575.88 | 553.02 | 562.41 |
| 19.5 | 0.2286 | 686.49 | 650.98 | 669.34 |
| 19.5 | 0.2540 | 798.72 | 762.40 | 773.42 |
| 19.5 | 0.2794 | 912.19 | 870.15 | 894.23 |
| 19.5 | 0.3048 | 1052.99 | 1002.40 | 1035.44 |
| 19.5 | 0.3302 | 1190.53 | 1142.78 | 1173.80 |
| 19.5 | 0.3556 | 1478.68 | 1427.66 | 1432.56 |
| 19.5 | 0.3810 | 1652.54 | 1591.73 | 1599.49 |
| 17.4 | 0.0508 | 98.77 | 99.99 | 101.63 |
| 17.4 | 0.0762 | 159.17 | 158.77 | 159.58 |
| 17.4 | 0.1016 | 228.56 | 226.92 | 228.96 |
| 17.4 | 0.1270 | 306.10 | 305.69 | 306.92 |
| 17.4 | 0.1524 | 379.57 | 385.69 | 386.10 |
| 17.4 | 0.1778 | 480.78 | 484.87 | 478.33 |
| 17.4 | 0.2032 | 579.55 | 580.37 | 585.68 |
| 17.4 | 0.2286 | 697.91 | 697.10 | 697.91 |
| 17.4 | 0.2540 | 805.66 | 807.29 | 806.48 |
| 17.4 | 0.2794 | 927.69 | 930.55 | 926.47 |
| 17.4 | 0.3048 | 1063.20 | 1064.83 | 1064.42 |
| 17.4 | 0.3302 | 1205.64 | 1208.08 | 1208.49 |
| 17.4 | 0.3556 | 1503.98 | 1502.35 | 1503.57 |
| 17.4 | 0.3810 | 1669.28 | 1671.32 | 1670.50 |

Table 4. (continued)

| Moisture Content | Air Velocity | Static Pressure Drop in (Pa/m) | | |
|---|---|---|---|---|
| % (w.b.) | m/sec | $R_1$ | $R_2$ | $R_3$ |
| 15.2 | 0.0508 | 106.12 | 108.56 | 110.60 |
| 15.2 | 0.0762 | 171.42 | 175.50 | 168.15 |
| 15.2 | 0.1016 | 245.70 | 248.96 | 242.43 |
| 15.2 | 0.1270 | 358.75 | 359.16 | 359.98 |
| 15.2 | 0.1524 | 457.11 | 501.60 | 413.03 |
| 15.2 | 0.1778 | 572.21 | 575.47 | 566.90 |
| 15.2 | 0.2032 | 697.51 | 701.59 | 687.71 |
| 15.2 | 0.2286 | 796.27 | 800.76 | 790.97 |
| 15.2 | 0.2540 | 901.57 | 905.25 | 899.94 |
| 15.2 | 0.2794 | 1085.23 | 1089.32 | 1070.95 |
| 15.2 | 0.3048 | 1183.19 | 1186.86 | 1176.25 |
| 15.2 | 0.3302 | 1338.69 | 1342.77 | 1330.12 |
| 15.2 | 0.3556 | 1648.87 | 1652.14 | 1641.93 |
| 15.2 | 0.3810 | 1754.99 | 1763.15 | 1685.20 |
| 11.8 | 0.0508 | 107.34 | 112.65 | 114.86 |
| 11.8 | 0.0762 | 188.56 | 175.50 | 193.46 |
| 11.8 | 0.1016 | 278.76 | 263.66 | 281.61 |
| 11.8 | 0.1270 | 370.18 | 364.47 | 378.34 |
| 11.8 | 0.1524 | 469.36 | 453.85 | 473.03 |
| 11.8 | 0.1778 | 591.80 | 568.53 | 584.45 |
| 11.8 | 0.2032 | 724.85 | 695.46 | 721.18 |
| 11.8 | 0.2286 | 868.51 | 833.82 | 859.94 |
| 11.8 | 0.2540 | 1014.63 | 973.81 | 1000.34 |
| 11.8 | 0.2794 | 1165.23 | 1128.09 | 1148.90 |
| 11.8 | 0.3048 | 1311.75 | 1283.99 | 1314.20 |
| 11.8 | 0.3302 | 1479.50 | 1457.46 | 1358.28 |
| 11.8 | 0.3556 | 1841.51 | 1822.33 | 1853.76 |
| 11.8 | 0.3810 | 2014.97 | 1973.34 | 2015.79 |

Table 5. Air Velocity and Static Pressure Drop for Rough Rice at 5% Foreign Materials at Different Moisture Content.

| Moisture Content | Air Velocity | Static Pressure Drop in (Pa/m) | | |
|---|---|---|---|---|
| % (w.b.) | m/sec | $R_1$ | $R_2$ | $R_3$ |
| 19.5 | 0.0508 | 90.20 | 83.26 | 82.85 |
| 19.5 | 0.0762 | 143.26 | 137.54 | 136.32 |
| 19.5 | 0.1016 | 211.41 | 199.99 | 198.35 |
| 19.5 | 0.1270 | 283.65 | 271.00 | 266.92 |
| 19.5 | 0.1524 | 353.04 | 336.71 | 336.30 |
| 19.5 | 0.1778 | 435.07 | 416.30 | 414.67 |
| 19.5 | 0.2032 | 532.62 | 514.25 | 501.19 |
| 19.5 | 0.2286 | 634.24 | 604.04 | 600.39 |
| 19.5 | 0.2540 | 731.38 | 705.26 | 698.32 |
| 19.5 | 0.2794 | 840.76 | 812.19 | 808.52 |
| 19.5 | 0.3048 | 958.71 | 938.71 | 918.31 |
| 19.5 | 0.3302 | 1088.91 | 1061.97 | 1049.73 |
| 19.5 | 0.3556 | 1357.87 | 1332.57 | 1306.44 |
| 19.5 | 0.3810 | 1506.02 | 1326.04 | 1435.82 |
| 17.4 | 0.0508 | 90.20 | 89.79 | 87.75 |
| 17.4 | 0.0762 | 146.11 | 142.85 | 138.77 |
| 17.4 | 0.1016 | 208.96 | 206.52 | 204.07 |
| 17.4 | 0.1270 | 277.53 | 279.17 | 277.53 |
| 17.4 | 0.1524 | 353.04 | 353.85 | 351.41 |
| 17.4 | 0.1778 | 444.87 | 443.24 | 440.78 |
| 17.4 | 0.2032 | 533.03 | 532.21 | 528.13 |
| 17.4 | 0.2286 | 636.69 | 635.88 | 634.24 |
| 17.4 | 0.2540 | 733.83 | 734.24 | 731.38 |
| 17.4 | 0.2794 | 844.03 | 844.84 | 840.76 |
| 17.4 | 0.3048 | 959.94 | 960.75 | 957.49 |
| 17.4 | 0.3302 | 1090.13 | 1092.58 | 1089.72 |
| 17.4 | 0.3556 | 1359.09 | 1365.22 | 1359.50 |
| 17.4 | 0.3810 | 1506.84 | 1514.19 | 1507.66 |

Table 5. (continued)

| Moisture Content % (w.b.) | Air Velocity m/sec | Static Pressure Drop in (Pa/m) | | |
|---|---|---|---|---|
| | | $R_1$ | $R_2$ | $R_3$ |
| 15.2 | 0.0508 | 106.12 | 108.16 | 106.52 |
| 15.2 | 0.0762 | 162.84 | 163.25 | 162.85 |
| 15.2 | 0.1016 | 228.56 | 228.15 | 229.37 |
| 15.2 | 0.1270 | 328.14 | 330.18 | 324.88 |
| 15.2 | 0.1524 | 407.73 | 409.77 | 409.36 |
| 15.2 | 0.1778 | 506.09 | 509.76 | 506.91 |
| 15.2 | 0.2032 | 641.60 | 636.69 | 653.83 |
| 15.2 | 0.2286 | 697.51 | 694.65 | 691.38 |
| 15.2 | 0.2540 | 735.87 | 736.28 | 735.05 |
| 15.2 | 0.2794 | 926.47 | 963.20 | 964.83 |
| 15.2 | 0.3048 | 1073.40 | 1057.07 | 1077.89 |
| 15.2 | 0.3302 | 1199.92 | 1183.19 | 1207.68 |
| 15.2 | 0.3556 | 1501.94 | 1486.02 | 1506.84 |
| 15.2 | 0.3810 | 1710.09 | 1685.20 | 1714.17 |
| 11.8 | 0.0508 | 111.01 | 106.12 | 107.34 |
| 11.8 | 0.0762 | 162.85 | 171.83 | 170.19 |
| 11.8 | 0.1016 | 235.09 | 254.27 | 258.76 |
| 11.8 | 0.1270 | 323.65 | 337.12 | 353.45 |
| 11.8 | 0.1524 | 411.40 | 430.58 | 440.38 |
| 11.8 | 0.1778 | 515.07 | 531.80 | 552.62 |
| 11.8 | 0.2032 | 633.84 | 654.65 | 674.24 |
| 11.8 | 0.2286 | 761.17 | 788.11 | 814.64 |
| 11.8 | 0.2540 | 888.51 | 914.22 | 940.75 |
| 11.8 | 0.2794 | 1020.34 | 1050.14 | 1083.60 |
| 11.8 | 0.3048 | 1161.56 | 1208.08 | 1245.63 |
| 11.8 | 0.3302 | 1321.95 | 1363.18 | 1403.99 |
| 11.8 | 0.3556 | 1650.91 | 1701.11 | 1746.82 |
| 11.8 | 0.3810 | 1795.80 | 1854.98 | 1912.53 |

```
1       S A S   L O G    OS SAS 82.3        OS/MVT JOB XPPS3452 STEP SAS       PROC                  14:49 THURSDAY, JANUARY 10, 1985

NOTE: THE JOB XPRS3452 HAS BEEN RUN UNDER RELEASE 82.3 OF SAS AT KANSAS STATE UNIVERSITY (03010001).

NOTE: SAS OPTIONS SPECIFIED ARE:
      NOINCLUDE NOGRAPHICS   SORT=4

1          DATA;
2          INPUT AF 1-5 MC 7-8 FM 10 SP 12-18;
3          CARDS;

NOTE: DATA SET WORK.DATA1 HAS 224 OBSERVATIONS AND 4 VARIABLES. 529 OBS/TRK.
NOTE: THE DATA STATEMENT USED 0.29 SECONDS AND 212K.

228        PROC PRINT;

NOTE: THE PROCEDURE PRINT USED 0.61 SECONDS AND 206K AND PRINTED PAGES 1 TO 4.

229        PROC GLM;
230        CLASSES AF MC FM;
231        MODEL SP=AF MC FM AF*MC AF*FM MC*FM;
232        LSMEANS AF MC FM AF*MC AF*FM MC*FM/STDERR PDIFF;
```

SAS 14:49 THURSDAY, JANUARY 10, 1985 6

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SP

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F VALUE | PR > F | R-SQUARE | C.V. |
|---|---|---|---|---|---|---|---|
| MODEL | 106 | 64403298.86126723 | 607578.29114403 | 1319.31 | 0.0001 | 0.799164 | 2.6799 |
| ERROR | 117 | 53881.52229666 | 460.52583160 | | ROOT MSE | | SP MEAN |
| CORRECTED TOTAL | 223 | 64457180.38356389 | | | 21.45986560 | | 800.77304018 |

| SOURCE | DF | TYPE I SS | F VALUE | PR > F | DF | TYPE III SS | F VALUE | PR > F |
|---|---|---|---|---|---|---|---|---|
| AF | 13 | 61466448.06460433 | 10266.93 | 0.0001 | 13 | 61466448.06460386 | 10266.93 | 0.0001 |
| MC | 3 | 1077217.23707064 | 779.70 | 0.0001 | 3 | 1077217.23707062 | 779.70 | 0.0001 |
| FM | 3 | 943470.05554815 | 682.89 | 0.0001 | 3 | 943470.05554814 | 682.89 | 0.0001 |
| AF*MC | 39 | 518075.19951851 | 20.85 | 0.0001 | 39 | 518075.19951850 | 20.85 | 0.0001 |
| AF*FM | 39 | 372783.65184052 | 20.76 | 0.0001 | 39 | 372783.65184052 | 20.76 | 0.0001 |
| MC*FM | 9 | 25304.65268508 | 6.11 | 0.0001 | 9 | 25304.65268508 | 6.11 | 0.0001 |

GENERAL LINEAR MODELS PROCEDURE

LEAST SQUARES MEANS

| AF | SP LSMEAN | STD ERR LSMEAN | PROB > \|T\| HO:LSMEAN=0 | LSMEAN NUMBER |
|---|---|---|---|---|
| 0.127 | 340.01331 | 5.36497 | 0.0001 | 1 |
| 0.254 | 901.93450 | 5.36497 | 0.0001 | 2 |
| 0.381 | 1797.10562 | 5.36497 | 0.0001 | 3 |
| 0.0508 | 107.97244 | 5.36497 | 0.0001 | 4 |
| 0.0762 | 174.20275 | 5.36497 | 0.0001 | 5 |
| 0.1016 | 252.13137 | 5.36497 | 0.0001 | 6 |
| 0.1524 | 433.59956 | 5.36497 | 0.0001 | 7 |
| 0.1778 | 540.43906 | 5.36497 | 0.0001 | 8 |
| 0.2032 | 656.28306 | 5.36497 | 0.0001 | 9 |
| 0.2286 | 782.18956 | 5.36497 | 0.0001 | 10 |
| 0.2794 | 1051.90212 | 5.36497 | 0.0001 | 11 |
| 0.3048 | 1180.86231 | 5.36497 | 0.0001 | 12 |
| 0.3302 | 1330.89187 | 5.36497 | 0.0001 | 13 |
| 0.3556 | 1661.29500 | 5.36497 | 0.0001 | 14 |

PROB > |T| HO: LSMEAN(I)=LSMEAN(J)

| I/J | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | . | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| 2 | 0.0001 | . | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| 3 | 0.0001 | 0.0001 | . | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| 4 | 0.0001 | 0.0001 | 0.0001 | . | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| 5 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | . | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| 6 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | . | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| 7 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | . | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| 8 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | . | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| 9 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | . | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| 10 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | . | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| 11 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | . | 0.0001 | 0.0001 | 0.0001 |
| 12 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | . | 0.0001 | 0.0001 |
| 13 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | . | 0.0001 |
| 14 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | . |

NOTE: TO ENSURE OVERALL PROTECTION LEVEL, ONLY PROBABILITIES ASSOCIATED WITH PRE-PLANNED COMPARISONS SHOULD BE USED.

| MC | SP LSMEAN | STD ERR LSMEAN | PROB > \|T\| HO:LSMEAN=0 | PROB > \|T\| HO: LSMEAN(I)=LSMEAN(J) I/J | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|---|---|
| 12 | 896.596536 | 2.867695 | 0.0001 | 1 | . | 0.0001 | 0.0001 | 0.0001 |
| 15 | 831.707339 | 2.867695 | 0.0001 | 2 | 0.0001 | . | 0.0001 | 0.0001 |
| 17 | 760.450375 | 2.867695 | 0.0001 | 3 | 0.0001 | 0.0001 | . | 0.0001 |
| 20 | 714.337911 | 2.867695 | 0.0001 | 4 | 0.0001 | 0.0001 | 0.0001 | . |

NOTE: TO ENSURE OVERALL PROTECTION LEVEL, ONLY PROBABILITIES ASSOCIATED WITH PRE-PLANNED COMPARISONS SHOULD BE USED.

SAS 14:49 THURSDAY, JANUARY 10, 1985 8

GENERAL LINEAR MODELS PROCEDURE

LEAST SQUARES MEANS

| FM | SP LSMEAN | STD ERR LSMEAN | PROB > \|T\| HO:LSMEAN=0 | PROB > \|T\| HO: LSMEAN(I)=LSMEAN(J) I/J | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|---|---|
| 0 | 882.764000 | 2.867695 | 0.0001 | 1 | . | 0.0001 | 0.0001 | 0.0001 |
| 1 | 834.533589 | 2.867695 | 0.0001 | 2 | 0.0001 | . | 0.0001 | 0.0001 |
| 3 | 776.706911 | 2.867695 | 0.0001 | 3 | 0.0001 | 0.0001 | . | 0.0001 |
| 5 | 709.067661 | 2.867695 | 0.0001 | 4 | 0.0001 | 0.0001 | 0.0001 | . |

```
1       S A S   L O G    OS SAS 82.3        OS/MVT JOB XPRS3351 STEP SAS      PROC                   12:17 WEDNESDAY, JANUARY 9, 1985

NOTE: THE JOB XPRS3351 HAS BEEN RUN UNDER RELEASE 82.3 OF SAS AT KANSAS STATE UNIVERSITY (03010001).

NOTE: SAS OPTIONS SPECIFIED ARE:
      NOINCLUDE NOGRAPHICS  SORT=4


1           DATA;
2           INPUT AF 1-5 MC 7-8 FM 10 SP 12-18;
3           CARDS;

NOTE: DATA SET WORK.DATA1 HAS 224 OBSERVATIONS AND 4 VARIABLES. 529 OBS/TRK.
NOTE: THE DATA STATEMENT USED 0.26 SECONDS AND 212K.

228         PROC PRINT;

NOTE: THE PROCEDURE PRINT USED 0.57 SECONDS AND 206K AND PRINTED PAGES 1 TO 4.

229         PROC GLM;
230         MODEL SP=AF AF*AF AF*MC AF*FM/NOINT P;

NOTE: THE PROCEDURE GLM USED 0.94 SECONDS AND 276K AND PRINTED PAGES 5 TO 10.

231         PROC GLM;
232         MODEL SP=AF AF*AF AF*MC*FM/NOINT P;

NOTE: THE PROCEDURE GLM USED 0.88 SECONDS AND 276K AND PRINTED PAGES 11 TO 16.
NOTE: SAS USED 276K MEMORY.

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

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SP

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F VALUE | PR > F | R-SQUARE | C.V. |
|---|---|---|---|---|---|---|---|
| MODEL | 4 | 207624548.36686128 | 51906137.09171531 | 24305.62 | 0.0001 | 0.997742 | 5.7709 |
| ERROR | 220 | 469823.47711137 | 2135.56125960 | | ROOT MSE | | SP MEAN |
| UNCORRECTED TOTAL | 224 | 208094371.84397265 | | | 46.21213325 | | 800.77304018 |

| SOURCE | DF | TYPE I SS | F VALUE | PR > F | DF | TYPE III SS | F VALUE | PR > F |
|---|---|---|---|---|---|---|---|---|
| AF | 1 | 199839088.39141715 | 93576.85 | 0.0001 | 1 | 3765691.18363377 | 1763.33 | 0.0001 |
| AF*AF | 1 | 5022327.43230956 | 2351.76 | 0.0001 | 1 | 5022327.43230970 | 2351.76 | 0.0001 |
| AF*MC | 1 | 1491122.03675462 | 698.23 | 0.0001 | 1 | 1491122.03675461 | 698.23 | 0.0001 |
| AF*FM | 1 | 1272010.50637995 | 595.63 | 0.0001 | 1 | 1272010.50637995 | 595.63 | 0.0001 |

| PARAMETER | ESTIMATE | T FOR H0: PARAMETER=0 | PR > \|T\| | STD ERROR OF ESTIMATE |
|---|---|---|---|---|
| AF | 3749.15450496 | 41.99 | 0.0001 | 89.28263610 |
| AF*AF | 8289.97303612 | 48.49 | 0.0001 | 170.94508688 |
| AF*MC | -117.11641510 | -26.42 | 0.0001 | 4.43217799 |
| AF*FM | -164.22904733 | -24.41 | 0.0001 | 6.72915669 |

| OBSERVATION | OBSERVED VALUE | PREDICTED VALUE | RESIDUAL |
|---|---|---|---|
| 1 | 105.54500000 | 92.86020713 | 12.68479287 |
| 2 | 118.11400000 | 110.70874879 | 7.40525121 |
| 3 | 121.38100000 | 122.60777656 | -1.22677656 |
| 4 | 126.92900000 | 140.45631823 | -13.52731823 |
| 5 | 170.43600000 | 155.33538771 | 15.10061229 |
| 6 | 192.88400000 | 182.10820020 | 10.77579980 |
| 7 | 198.76300000 | 199.95674186 | -1.19374186 |
| 8 | 206.10900000 | 226.72955435 | -20.62055435 |
| 9 | 248.55600000 | 228.50728629 | 20.04871371 |
| 10 | 277.28700000 | 264.20436961 | 13.08263039 |
| 11 | 278.75700000 | 288.00242516 | -9.24542516 |
| 12 | 297.12300000 | 323.69950848 | -26.57650848 |
| 13 | 333.69100000 | 312.37590288 | 21.31509712 |
| 14 | 371.24000000 | 356.99725704 | 14.24274296 |
| 15 | 375.48600000 | 386.74482647 | -11.25882647 |
| 16 | 384.05500000 | 431.36618062 | -47.31118062 |
| 17 | 415.48200000 | 406.94123749 | 8.54076251 |
| 18 | 476.13200000 | 460.48686247 | 15.64513753 |
| 19 | 492.05100000 | 496.18394579 | -4.13294579 |
| 20 | 522.00800000 | 549.72957077 | -27.72157077 |
| 21 | 517.10900000 | 512.20329009 | 4.90570991 |
| 22 | 595.22600000 | 574.67318591 | 20.55281409 |
| 23 | 622.57200000 | 616.31978312 | 6.25221688 |
| 24 | 652.20100000 | 678.78967893 | -26.58867893 |
| 25 | 628.69400000 | 628.16206071 | 0.53193929 |

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SP

| OBSERVATION | OBSERVED VALUE | PREDICTED VALUE | RESIDUAL |
|---|---|---|---|
| 26 | 687.05700000 | 699.55622735 | -12.49922735 |
| 27 | 758.48100000 | 747.15233845 | 11.32866155 |
| 28 | 805.25300000 | 818.54650509 | -13.29350509 |
| 29 | 745.50500000 | 754.81754934 | -9.31254934 |
| 30 | 869.49500000 | 835.13598681 | 34.35901319 |
| 31 | 898.71700000 | 888.68161179 | 10.03538821 |
| 32 | 959.12100000 | 969.00004926 | -9.87904926 |
| 33 | 868.27100000 | 892.16975597 | -23.89875597 |
| 34 | 992.75300000 | 981.41246427 | 11.34053573 |
| 35 | 1053.80000000 | 1040.90760314 | 12.89239686 |
| 36 | 1116.66000000 | 1130.15031144 | -13.49031144 |
| 37 | 1002.95000000 | 1040.21868061 | -37.26868061 |
| 38 | 1150.29000000 | 1138.38565974 | 11.90434026 |
| 39 | 1240.73000000 | 1203.83031250 | 36.89968750 |
| 40 | 1289.30000000 | 1301.99729163 | -12.69729163 |
| 41 | 1134.61000000 | 1198.96432326 | -64.35432326 |
| 42 | 1289.95000000 | 1306.05557322 | -16.10557322 |
| 43 | 1345.38000000 | 1377.44973987 | -32.06973987 |
| 44 | 1453.78000000 | 1484.54098983 | -30.76098983 |
| 45 | 1284.81000000 | 1368.40668391 | -83.59668391 |
| 46 | 1402.52000000 | 1484.42220471 | -81.90220471 |
| 47 | 1604.62000000 | 1561.76588524 | 42.85411476 |
| 48 | 1640.30000000 | 1677.78140603 | -37.48140603 |
| 49 | 1601.28000000 | 1548.54576258 | 52.73423742 |
| 50 | 1752.29000000 | 1673.48555420 | 78.80444580 |
| 51 | 1907.87000000 | 1756.77874862 | 151.09125138 |
| 52 | 2016.19000000 | 1881.71854025 | 134.47145975 |
| 53 | 1756.04000000 | 1739.38155925 | 16.65844075 |
| 54 | 1824.37000000 | 1873.24562171 | -48.87562171 |
| 55 | 2053.49000000 | 1962.48833001 | 91.00166999 |
| 56 | 2201.07000000 | 2096.35239247 | 104.71760753 |
| 57 | 102.03400000 | 84.51737153 | 17.51662847 |
| 58 | 112.48400000 | 102.36591319 | 10.11808681 |
| 59 | 118.11400000 | 114.26494096 | 3.84905904 |
| 60 | 119.41900000 | 132.11348262 | -12.69448262 |
| 61 | 167.74300000 | 142.82113430 | 24.92186570 |
| 62 | 184.23200000 | 169.59394679 | 14.63805321 |
| 63 | 186.76200000 | 187.44248845 | -0.68048845 |
| 64 | 195.33500000 | 214.21530094 | -18.88030094 |
| 65 | 245.45300000 | 211.82161508 | 33.63138492 |
| 66 | 264.06500000 | 247.51869840 | 16.54630160 |
| 67 | 276.30900000 | 271.31675395 | 4.99224605 |
| 68 | 285.94200000 | 307.01383727 | -21.07183727 |
| 69 | 327.16200000 | 291.51881387 | 35.64318613 |
| 70 | 350.42700000 | 336.14016803 | 14.28683197 |
| 71 | 368.30400000 | 365.88773746 | 2.41626254 |
| 72 | 377.77200000 | 410.50909161 | -32.73709161 |
| 73 | 412.38200000 | 381.91273067 | 30.46926933 |
| 74 | 440.78700000 | 435.45835566 | 5.32864434 |
| 75 | 476.86700000 | 471.15543898 | 5.71156102 |
| 76 | 490.09200000 | 524.70106396 | -34.60906396 |

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SP

| OBSERVATION | OBSERVED VALUE | PREDICTED VALUE | RESIDUAL |
|---|---|---|---|
| 77 | 495.88600000 | 483.00336548 | 12.88263452 |
| 78 | 547.55600000 | 545.47326129 | 2.08273871 |
| 79 | 598.16600000 | 587.11985850 | 11.04614150 |
| 80 | 612.61100000 | 649.58975431 | -36.97875431 |
| 81 | 594.00300000 | 594.79071829 | -0.78771829 |
| 82 | 650.40700000 | 666.18488494 | -15.77788494 |
| 83 | 725.83000000 | 713.78099603 | 12.04900397 |
| 84 | 750.23000000 | 785.17516268 | -34.94516268 |
| 85 | 722.97200000 | 717.27478912 | 5.69721088 |
| 86 | 786.48000000 | 797.59322659 | -11.11322659 |
| 87 | 883.20900000 | 851.13885157 | 32.07014843 |
| 88 | 902.14600000 | 931.45728905 | -29.31128905 |
| 89 | 842.14900000 | 850.45557795 | -8.30657795 |
| 90 | 916.10200000 | 939.69828625 | -23.59628625 |
| 91 | 1020.50000000 | 999.19342512 | 21.30657488 |
| 92 | 1042.62000000 | 1088.43613342 | -45.81613342 |
| 93 | 963.60900000 | 994.33308479 | -30.72408479 |
| 94 | 1064.82000000 | 1092.50006392 | -27.68006392 |
| 95 | 1187.84000000 | 1157.94471668 | 29.89528332 |
| 96 | 1201.06000000 | 1256.11169581 | -55.05169581 |
| 97 | 1093.97000000 | 1148.90730963 | -54.93730963 |
| 98 | 1216.49000000 | 1255.99855960 | -39.50855960 |
| 99 | 1247.42000000 | 1327.39272624 | -79.97272624 |
| 100 | 1359.82000000 | 1434.48397620 | -74.66397620 |
| 101 | 1253.38000000 | 1314.17825249 | -60.79825249 |
| 102 | 1290.11000000 | 1430.19377328 | -140.08377328 |
| 103 | 1411.98000000 | 1507.53745381 | -95.55745381 |
| 104 | 1543.40000000 | 1623.55297461 | -80.15297461 |
| 105 | 1555.24000000 | 1490.14591335 | 65.09408665 |
| 106 | 1688.70000000 | 1615.08570497 | 73.61429503 |
| 107 | 1772.78000000 | 1698.37889939 | 74.40110061 |
| 108 | 1958.56000000 | 1823.31869102 | 135.24130898 |
| 109 | 1712.53000000 | 1676.81029222 | 35.71970778 |
| 110 | 1742.74000000 | 1810.67435468 | -67.93435468 |
| 111 | 1808.45000000 | 1899.91706298 | -91.46706298 |
| 112 | 2068.43000000 | 2033.78112543 | 34.64887457 |
| 113 | 93.62500000 | 67.83170032 | 25.79329968 |
| 114 | 100.15700000 | 85.68024198 | 14.47675802 |
| 115 | 108.40200000 | 97.57926975 | 10.82273025 |
| 116 | 111.58500000 | 115.42781141 | -3.84281141 |
| 117 | 155.33800000 | 117.79262749 | 37.54537251 |
| 118 | 159.17300000 | 144.56543998 | 14.60756002 |
| 119 | 171.66300000 | 162.41398164 | 9.24901836 |
| 120 | 185.86600000 | 189.18679413 | -3.32079413 |
| 121 | 224.22900000 | 178.45027267 | 45.77872733 |
| 122 | 228.15000000 | 214.14735599 | 14.00264401 |
| 123 | 245.69900000 | 237.94541154 | 7.75358846 |
| 124 | 274.67500000 | 273.64249486 | 1.03250514 |
| 125 | 297.69400000 | 249.80463585 | 47.88936415 |
| 126 | 306.26600000 | 294.42599001 | 11.84000999 |
| 127 | 359.32400000 | 324.17355944 | 35.15044056 |

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SP

| OBSERVATION | OBSERVED VALUE | PREDICTED VALUE | RESIDUAL |
|---|---|---|---|
| 128 | 370.99700000 | 368.79491359 | 2.20208641 |
| 129 | 374.01600000 | 331.85571705 | 42.16028295 |
| 130 | 383.81200000 | 385.40134203 | -1.58934203 |
| 131 | 457.27700000 | 421.09842535 | 36.17857465 |
| 132 | 465.44000000 | 474.64405033 | -9.20405033 |
| 133 | 465.44000000 | 424.60351625 | 40.83648375 |
| 134 | 481.35500000 | 487.07341206 | -5.71841206 |
| 135 | 571.55500000 | 528.72000927 | 42.83499073 |
| 136 | 581.59400000 | 591.18990508 | -9.59590508 |
| 137 | 563.79900000 | 528.04803346 | 35.75096654 |
| 138 | 581.84100000 | 599.44220010 | -17.60120010 |
| 139 | 695.62700000 | 647.03831120 | 48.58868880 |
| 140 | 713.83200000 | 718.43247784 | -4.60047784 |
| 141 | 668.93700000 | 642.18926868 | 26.74773132 |
| 142 | 697.67100000 | 722.50770615 | -24.83670615 |
| 143 | 796.03000000 | 776.05333113 | 19.97666887 |
| 144 | 853.82200000 | 856.37176861 | -2.54976861 |
| 145 | 778.15300000 | 767.02722191 | 11.12577809 |
| 146 | 806.47600000 | 856.26993021 | -49.79393021 |
| 147 | 902.22800000 | 915.76506908 | -13.53706908 |
| 148 | 996.26000000 | 1005.00777738 | -8.74777738 |
| 149 | 892.18500000 | 902.56189314 | -10.37689314 |
| 150 | 928.26400000 | 1000.72887227 | -72.46487227 |
| 151 | 1081.80000000 | 1066.17352503 | 15.62647497 |
| 152 | 1147.43000000 | 1164.34050416 | -16.91050416 |
| 153 | 1030.29000000 | 1048.79328238 | -18.50328238 |
| 154 | 1064.17000000 | 1155.88453235 | -91.71453235 |
| 155 | 1182.12000000 | 1227.27869899 | -45.15869899 |
| 156 | 1303.34000000 | 1334.36994895 | -31.02994895 |
| 157 | 1169.06000000 | 1205.72138963 | -36.66138963 |
| 158 | 1207.43000000 | 1321.73691043 | -114.30691043 |
| 159 | 1337.21000000 | 1399.08059096 | -61.87059096 |
| 160 | 1431.74000000 | 1515.09611175 | -83.35611175 |
| 161 | 1446.27000000 | 1373.34621489 | 72.92378511 |
| 162 | 1503.33000000 | 1498.28600652 | 5.04399348 |
| 163 | 1647.64000000 | 1581.57920093 | 66.06079907 |
| 164 | 1839.22000000 | 1706.51899256 | 132.70100744 |
| 165 | 1614.58000000 | 1551.66775816 | 62.91224184 |
| 166 | 1705.76000000 | 1685.53182061 | 20.22817939 |
| 167 | 1734.41000000 | 1774.77452892 | -40.36452892 |
| 168 | 2001.33000000 | 1908.63859137 | 92.69140863 |
| 169 | 85.46300000 | 51.14602911 | 34.31697089 |
| 170 | 89.21900000 | 68.99457077 | 20.22442923 |
| 171 | 106.93200000 | 80.89359854 | 26.03840146 |
| 172 | 108.15600000 | 98.74214020 | 9.41385980 |
| 173 | 139.01200000 | 92.76412068 | 46.24787932 |
| 174 | 142.60200000 | 119.53693317 | 23.06506683 |
| 175 | 163.00900000 | 137.38547483 | 25.62352517 |
| 176 | 168.31700000 | 164.15828732 | 4.15871268 |
| 177 | 203.25100000 | 145.07893025 | 58.17206975 |
| 178 | 206.51600000 | 180.77601357 | 25.73998643 |

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SP

| OBSERVATION | OBSERVED VALUE | PREDICTED VALUE | RESIDUAL |
|---|---|---|---|
| 179 | 228.72000000 | 204.57406912 | 24.14593088 |
| 180 | 249.37000000 | 240.27115244 | 9.09884756 |
| 181 | 273.85800000 | 208.09045783 | 65.76754217 |
| 182 | 278.10400000 | 252.71181198 | 25.39218802 |
| 183 | 327.73300000 | 282.45938142 | 45.27361858 |
| 184 | 338.10000000 | 327.08073557 | 11.01926443 |
| 185 | 342.01800000 | 281.79870342 | 60.21929658 |
| 186 | 352.79200000 | 335.34432841 | 17.44767159 |
| 187 | 408.95300000 | 371.04141173 | 37.91158827 |
| 188 | 427.48400000 | 424.58703671 | 2.89696329 |
| 189 | 422.01400000 | 366.20366702 | 55.81033298 |
| 190 | 442.99200000 | 428.67356283 | 14.31843717 |
| 191 | 507.55900000 | 470.32016004 | 37.23883996 |
| 192 | 533.18900000 | 532.79005585 | 0.39894415 |
| 193 | 516.04600000 | 461.30534863 | 54.74065137 |
| 194 | 531.14800000 | 532.69951527 | -1.55151527 |
| 195 | 644.03900000 | 580.29562637 | 63.74337363 |
| 196 | 654.24200000 | 651.68979301 | 2.55220699 |
| 197 | 612.85800000 | 567.10374824 | 45.75425176 |
| 198 | 635.63300000 | 647.42218572 | -11.78918572 |
| 199 | 694.48800000 | 700.96781070 | -6.47981070 |
| 200 | 787.94900000 | 781.28624817 | 6.66275183 |
| 201 | 711.62700000 | 683.59886586 | 28.02813414 |
| 202 | 733.17600000 | 772.84157417 | -39.66557417 |
| 203 | 735.70500000 | 832.33671304 | -96.63171304 |
| 204 | 914.47200000 | 921.57942134 | -7.10742134 |
| 205 | 820.51800000 | 810.79070149 | 9.72729851 |
| 206 | 843.20900000 | 908.95768063 | -65.74868063 |
| 207 | 965.07900000 | 974.40233338 | -9.32333338 |
| 208 | 1051.35000000 | 1072.56931252 | -21.21931252 |
| 209 | 938.55000000 | 948.67925513 | -10.12925513 |
| 210 | 959.36700000 | 1055.77050510 | -96.40350510 |
| 211 | 1069.48000000 | 1127.16467174 | -57.68467174 |
| 212 | 1205.06000000 | 1234.25592170 | -29.19592170 |
| 213 | 1066.87000000 | 1097.26452678 | -30.39452678 |
| 214 | 1090.78000000 | 1213.28004757 | -122.50004757 |
| 215 | 1196.89000000 | 1290.62372810 | -93.73372810 |
| 216 | 1363.17000000 | 1406.63924890 | -43.46924890 |
| 217 | 1332.32000000 | 1256.54651643 | 75.77348357 |
| 218 | 1361.29000000 | 1381.48630806 | -20.19630806 |
| 219 | 1498.26000000 | 1464.77950248 | 33.48049752 |
| 220 | 1699.48000000 | 1589.71929410 | 109.76070590 |
| 221 | 1463.41000000 | 1426.52522410 | 36.88477590 |
| 222 | 1509.53000000 | 1560.38928655 | -50.85928655 |
| 223 | 1703.15000000 | 1649.63199485 | 53.51800515 |
| 224 | 1854.40000000 | 1783.49605731 | 7C.90394269 |

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: SP

| | |
|---|---|
| SUM OF RESIDUALS | 525.53098726 |
| SUM OF SQUARED RESIDUALS | 469823.47711085 |
| SUM OF SQUARED RESIDUALS - ERROR SS | -0.00000053 |
| FIRST ORDER AUTOCORRELATION | 0.41734683 |
| DURBIN-WATSON D | 1.15426332 |

# STATIC PRESSURE DROP AS AFFECTED BY MOISTURE AND FOREIGN MATERIAL IN ROUGH RICE

by

Luis F. Gonzaga F.

B.S., Universidad Nacional de Loja, (Ecuador), 1982

---

AN ABSTRACT OF A MASTER'S REPORT

Submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agricultural Engineering

Kansas State University

Manhattan, Kansas

1985

ABSTRACT

The objectives of this investigation were (1) to determine the effects of moisture content and foreign material in rough rice kernels on airflow resistance, and (2) to develop a mathematical model that will describe the effects of moisture content and foreign materials on airflow resistance.

Fourteen levels of airflow (ranging from 0.0508 to 0.3810 m/s), four levels of moisture content (ranging from 11.8 to 19.5% w.b.), and four levels of foreign material (0, 1, 3 and 5%) were investigated.

Tests were carried out using a micromanometer to measure both static pressures across the ASME nozzle in airflow measurement and 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, while increasing the foreign material decreases the static pressure drop.

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

$$SP = a\,(AF) + b\,(AF)^2 - c\,(MC)\,(AF) - d\,(FM)\,(AF)$$

where

SP = static pressure drop per meter depth of grain, pa/m.

AF = air velocity, m/s.

MC = moisture content, % (w.b.).

FM = foreign material, %.

a, b, c, and d are constants.

This model fits our data very well, with $R^2$ above 0.997. The values of constants estimated are:

$a = 3749.15$

$b = 8289.97$

$c = 777.12$

$d = 164.23$