STUDY IN THE AGRICULTURAL ENGINEERING
"STUDIES RELATED TO PADDY-RICE AND WHEAT GRAINS DURING STORAGE PERIODS

BY

NABIHA HASSAN ABOU-EL-HANA
B.Sc. (Agric. Engin.), University of Alexandria, 1978

THESIS

Submitted to the Graduate Division in
Partial Fulfillment of the Requirements
for the Degree of

MASTER OF SCIENCE

IN

Agricultural Mechanization
Faculty of Agriculture
Kafr El-Sheikh
TANTA UNIVERSITY
1986

Approved by:
Prof. Dr. S. M. Metwally
Dr. Sharaf S.
Dr. Abdel-Ghaffar E.

Date 25 / 9 /1986

Deposited in the Faculty library

ACKNOWLEDGEMENT

The author wishes to express his appreciation and sincere gratitude to Dr. Fathey I. Hindey for his supervision, excellent guidance and encouragement.

Apreciation is also given to professor Dr. Metwalli, M.M. head of Agricultural Mechanization Department, Dr. Saied M. Sharaf, Associate professor of Agricultural Engineering, Tanta University, and Dr. Ezzat A. M. Abdel-Ghaffar, Associate professor in Agricultural Engineering Department, Alexandria University for their scientific advice, helpful suggestions and constant encouragement.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

DEFINITION OF SYMBOLS

Symbol	Definition	Units
ΔP	Pressure drop of air per unit depth of grain test bin.	Pa/m
S_b	Bulk density of grain	kg/m^3
Q	Air flow rate per unit cross sectional area of grain test bin	$m^3/hr.m^2$
MC(w.b.)	Grain moisture content, wet basis	%
S_t	Grain true (solid) density	g/cm^3
K, a, b and c	Constants	-
ϵ	Void fraction (porosity) of grain	decimal
R^2	Coefficient of determination	-

ABSTRACT

Air flow resistance characteristic in grain beds was essential for engineers to make the right approach and decision to several engineering aspects such as new system design, improvement and economic operating conditions of natural and mechanical ventilating systems for drying, aeration and cooling processes. Since paddy rice and wheat are considered the major grain crops in Egypt, the experiments carried out to evaluate the pressure drop of the grain storage system for sizing the required ventilation fans and minimizing the energy losses. The principle objectives of this investigation were studying some of the physical properties of paddy rice and wheat. General mathematical relationships were determined to predict the pressure drop of air passage through beds of paddy rice (IR 28) and wheat (Sakha 61) of Egyptian varieties over wide range of air flow rate, bulk density and moisture content.

Cylindrical grain test bin was constructed of 3 mm galvanized sheet metal with 34 cm inside diameter and 65 cm high. It was connected to piping system which consisted of a centrifugal fan, air velocity controlling gate, an orifice plate, air steel pipes and air flexible tubing.

To obtain several levels of grain moisture contents a mixing and rewetting grain unit was designed to permit a volume of 0.2296 cubic meters.

Three inclined manometers were used to measure the pressure drop of air across the orifice plate, static pressure at the plenum chamber and the pressure drop of air across the test bin.

Four methods were used for filling the grain test bin, which were named loose filled, normal filled, vibrated fill and packed fill to obtain wide range of grain bulk density.

Air flow rates were designed in the range between 240 and 600 cubic meter per hour per square meter of cross sectional area of test bin. Clean paddy rice bulk densities, were obtained in the range between 595 to 705 kg/m^3. Moisture contents of paddy rice were planned in the range between 11% to 25% wet basis with 2.5% interval. Wheat bulk densities were obtained in the range between 710 to 810 kg/m^3. Moisture contents were designed of 10.48%, 13% and 19.92% wet basis.

Results of the experiments observation and predicted equations indicated that the pressures drop in beds of paddy rice and wheat under a given condition were directly proportional to air flow rate.

It was also noted that at the same level of moisture content the pressure drop of air flow increased as the bulk density of grain increased. In addition, the results indicated that paddy rice and wheat were to display a decrease in pressure drop of air with increasing moisture content.

One of the most important results obtained from this work is a general multiple relationship between the pressure drop per unit grain depth, as dependent variable and the air flow rate per unit of cross sectional area, moisture content, and grain bulk density, as independent variables.

As the moisture contents of paddy rice and wheat increased from 11% to 19% wet basis, the pressure of the air flow decreased by 20.42% and 10.37% respectively when other variables were held constants. Also, as the bulk density of paddy rice and wheat increased from 600 kgs/m^3 to 800 kgs/m^3 the pressure drops increased by 81.59% and 88.83%, respectively where other variables were held constants. In addition twice air flow rate passing through beds of paddy rice and wheat may cause 2.573 and 2.796 times increase in pressures drop , respectively when other variables were held constants .

INTRODUCTION

The air flow resistance through various grains and other agricultural products in deep bins has been studied by many researchers for several years. The purposes of their studies were to provide a useful information applicable on the resistance of grains and seeds to air flow. The information obtained is necessary for engineers to make the right approach to several engineering aspects such as new design, improvements and economic operating conditions of natural and mechanical ventilating systems for grain drying, aerating and cooling processes . Proper sizing of aeration equipment, involving fan power selection and piping system sizes required for completing the storage process of agricultural products. In addition, it results in reduction of energy used by the aeration fans.

At the present time, paddy rice and wheat are considered the major grain crops for human consumption in Egypt. The cultivated area represents about 0.952 and 1.037 million feddans for paddy rice and wheat, respectively (44) . Paddy rice crop is harvested at moisture content ranges from 18% to 25% wet basis during October and November months . Also , wheat crop is harvested at moisture content ranges from 14% to 16% wet basis during May and early June months.After paddy rice and wheat threshing processes,bulk of these grains will be stored in grain bins and immediately starting some of the preservation processes such as drying,aerating and cooling.

A survey of literature on the resistance of paddy rice and wheat of the Egyptian varieties to air flow revealed lack of information.The available published information was found to be of little value by any practical means and can not be generalized to suit conditions encountered in ventilating and storage of paddy rice and wheat of Egyptian varieties . An attempt has been made to obtain data and to provide useful information on the resistance of air flow through two types of grains,paddy rice of variety IR 28 and wheat of variety Sakha 61.

The pressure drop through beds of paddy rice and wheat, or in other word, the loss of pressure per unit depth of bed, may depend on air flow rate, the physical properties of the air, the grain bulk density , grain surface roughness, voids fraction , the grain moisture content , the grain depth, presence of foreign material, effect of bin wall, type, shape and size of perforated floor which supports the grain and method of filling the bins . The present study will include mainly three important variables which may lead to satisfactory estimation and predication of the pressure drop through beds of paddy rice and wheat. The variables were air flow rate per unit area of perforated floor which supports the grains, the bulk density and the moisture content of grains.

The purpose of the present study, on air flow resistance of paddy rice and wheat of Egyptian varieties, was initiated to develop a mathematical relationship to predict the pressure drop per unit length of path flow of air and the main variable factors which are known to affect it.

<u>Objectives</u>:

The principle objectives of the study were :

1. to study some of the physical properties of paddy rice and wheat.
2. to study the effect of air flow rate on the pressure drop of air passing through the grain test bin.
3. to study the effect of grain bulk density on the pressure drop of air.
4. to study the effect of grain moisture content on the pressure drop of air.
5. to develop mathematical relationships for predicting the pressure drop of air passing through beds of paddy rice, IR 28, and wheat, Sakha 61, which affected by air flow rate, bulk density and moisture content .

LITERATURE REVIEW

In order to provide useful information on the resistance to air flow through grain storage bins, it is necessary to study the main variable factors affecting the pressure drop. In this field of study several attempts were made by many researchers to provide the information which could be used to predict the pressure drop of air passing through beds of the grains.

Effect of Air Flow Rates on Pressure Drop

Henderson (1943) carried out the study to obtain some informations about the resistance of shelled corn and bin walls to air flow. The results were indicated that the relationship between the rate of flow and the pressure drop for a given depth of corn is of the form $Q = K\ P^c$ in which K is a function of the depth of the grain and c is the slope of the curve. K was found to be equal to $58.9\ D^{-0.66}$ and c equal to $0.562\ D^{0.089}$. The formula developed was simplified to be as follow :

$$Q = \frac{59\ P^{0.63}}{D^{0.66}}$$

where:

Q = Air flow (cubic feet per minute per sq.ft.)

P = Air pressure (inches of water).

D = Grain depth (feet).

Henderson (1944) extended the research to his previous investigation to study the resistance of storing soybeans and oats to air flow. He found that the relationship between the rate of flow and air pressure for a given depth of soybeans was also of the form $Q = K P^c$ where K is a function of depth of the grain and c is the slope of the curve. K was found to be $67 D^{-0.57}$ and c equal to $0.6 D^{0.648}$.

where : Q = Air flow rate (cubic feet per min.per sq.ft.)

P = Air pressure (inches of water)

D = Depth of grain (ft.)

Shedd (1953) carried out experiments on fine and coarse materials to study the effect of pressure drop on air flow rates. The data plotted were straight lines. The pressure flow relationship could be expressed by formules of the form $Q = a P^b$

In which : Q = air flow, cubic feet per minute per square foot of floor.

P = Pressure drop per foot depth of grain, inches of water.

a and b = Constants for any one lot and condition of grain.

The general slope of the curves was greater for fine than for coarse materials.

Sheldon et al. (1960) studied the resistance of shelled corn and wheat to low air flows ranging from 0.015 to 1.210 $m^3/min.m^2$. The results obtained were classified in two items : (a) The resistance to air flow increased more rapidly than the effect of grain depth . For instance , twice the depth of grain offered more than twice as much resistance . (b) The resistance increases slightly more rapidly than an increase in air flow above an air flow of 0.045 $m^3/min.m^2$. Below 0.045 m^3 per min per meter depth the resistance increases less rapidly than an increase in air flow.

Husain and Ojha (1969) studied the resistance to the passage of air flow through various grains and other agricultural products. They had measured pressure drop in a deep bin at various depths of grain and air flow rates. They concluded that the pressure-flow relationship could be expressed as $P_s = K Q^n$.

It was expected that these constants K and n may vary with particle size, porosity, moisture content and bed depth. Since all other variables were held constant, the variation of constants vary linearly with bed depth from 70 to 130 cm. Final modified equation was developed to study the effect of grain depth and air flow rates on the pressure drop:

$$P_s = (md + c)\ Q^{ad + e}$$

where : P_s = static pressure, mm W.G.

Q = air flow rate , $m^3/min.m^2$

d = depth of grain, cm

m,c,a and e = constants.

The constants K and n were functions of depth of bed and could be expressed as $K = md + c$ and $n = ad + e$

The final predicted equations for the three types of paddy rice relating the static pressure, air flow rate and depth of bed under the investigation were as follow.

$$P_s = (0.032\ d - 1.32)\ Q^{2.14 - 0.0089\ d} \qquad \text{(Dular)}$$

$$P_s = (0.045\ d - 1.22)\ Q^{1.52 - 0.0035\ d} \qquad \text{(Taichung native -1)}$$

$$P_s = (0.046\ d - 1.99)\ Q^{2.11 - 0.0076\ d} \qquad \text{(Patnai-23)}$$

Steele (1974) researched the effect of container diameter, moisture content, loose shelled kernels and foreign materials on the resistance to air flow. The relationship was obtained between apparent velocity and static pressure drop per foot for peanuts with different levels of loose shelled kernels and forign material. The equation may be represented by $V=a\Delta P^{0.62}$ with coefficient(a)dependent upon the percentage of void. The relationship between coefficient(a)and percentage of void was $a = 1560\ (\epsilon/100)^{2.48}$. Where ϵ equals percentage of void.

Akritidis and Siatras (1979) investigated the resistance of pumpkin seeds to air flow ranging from 1.59 to 31.88 $m^3/min.m^2$. Five levels of moisture content ranging from 30.47 to 6.9 percent wet basis were included in the study. The seeds were placed in a loosely filled bin. They found that the previous investigators agreed, in general, that the curves of the pressure drop versus air flow on log-log paper can be represented by straight lines over certain narrow ranges of air flow. These straight lines would be expressed by formulas of the form $Q = a\ P^b$.

where Q is the air flow per unit of cross sectional area.

P is the pressure drop per unit of depth

a,b are constants for a given set of conditions.

Hindey (1980) studied several variables affected on the pressure drop of air passing through beds of barley. The variables were the air flow, the bulk density and the percentage of moisture content wet basis.

Hindey predicted an universal equation to explain the relationship between the pressure drop and other variables. The predicted equation was as follows:

$$P = 0.198 \left[\frac{Q^{1.353} (0.001S)^{5.168}}{M^{0.422}} \right]$$

where :

P = pressure drop, (mm of water per meter depth of grain).

Q = rate of air flow, $m^3/hr . m^2$ of bin floor

S = bulk density of grain , kg/m^3

M = percentage moisture content of grain (wet basis)

Abdel-Ghaffar and Hindey (1984) studied the effect of air flow rate, Q, onion size, D, and pore space, E, on the pressure drop of air passing through beds of onions.

The relationship used between the pressure drop and air flow rate at constant onions size and pore space was in the following form.

$$P = K\ Q^{a}$$

where:

P = pressure drop, pascal per meter depth of onions.
Q = Air flow rate, $m^3/min\ .\ m^2$
K and a are constants for any given bulk of onions under a given condition and the units used. Numerical value of the constant (K) can be taken as a function of given condition and value of constant (a) is the slope of the line. The relationship developed in the case of medium size onions, (equivalent diameter, D = 0.048 meter and pore space, E = 0.368) was as follow:

$$P = 0.4683\ Q^{1.3952}$$

It was found that twice air flow rate may cause 2.6 time increase in pressure drop when other variables were held constant. General equation for onions was resulted which consists of three variables affected on pressure drop .

It may be written in the form :

$$P = K\,Q^{a}\,D^{b}\,E^{c}$$

The constants (K), (a), (b) and (c) were determined. The relationship between the variables in its general form was found to be presented as follows:

$$P = 0.004833 \left[\frac{Q^{1.3848}}{D^{0.9632}\,E^{1.682}} \right]$$

where:

P= Pressure drop, pascal per meter depth of onions.

Q= Air flow rates, cubic meter per minute per square meter of the area.

D= Onions equivalent diameter in meters.

E= Pore space, decimal.

The value 0.004833 was depending on these units and the material used (onions) under a given condition. The power exponent (a) was found in the range between 1.3365 and 1.4580 for the same condition.

Effect of Grain Bulk Density on Pressure Drop of Air Flow

Shedd (1951) studied the effect of the methods of filling a bin on resistance to air flow . All grains (soybeans, corn , oats and rough rice) were tested with the bin filled by two different methods which were called loose filled and packed fill. The loose filled was made by pouring the grain into a funnel which was held with the outlet just above the surface of grain in the bin. The packed fill was made by pouring the grain into place from one to two feet above the grain surface without use of the funnel and tapping the bin wall with wooden mallet to settle the grain after each foot of depth was added. A record was kept of the weight of grain added for each foot increase in depth.

The largest difference between loose and packed fill in the test was with corn at moisture content of 12.8% which contained 5% cracked grain and foreign material. The resistance pressure with packed fill was 60 percent greater than with loose fill. The smallest differences was with clean corn containing 20 % moisture, the resistance pressure with packed fill was only 20 percent greater than with loose fill.

Shedd (1953) added that the density was less and the resistance pressure for a given rate of air flow was less for a lot of grain at 20 percent or higher moisture than for the same lot of grain and the same method of filling after drying to lower moisture content.

Lawton (1965) noted that the resistance to air flow of seeds depends on the degree of packing and the presence of contaminats in addition to the properties which were measured.

Akritidis and Siatras (1979) found that the bulk density of pumpkin seeds was functioned to the moisture content. A minimum bulk density was found when the seeds were allowed to fall into place without any packing. The minimum value of the bulk density was obtained at about 19 percent wet basis moisture content. In addition to above, an air flow of 5 $m^3/min.m^2$ the resistance to air flow increases more rapidly than the increase in air flow.

Hindey (1980) studied the effect of change of grain bulk density on the resistance to air flow in a fixed bed of barley. The method of filling the test bin affected the density of grain and consequently had an effect on the pressure drop.As the bulk density of grain increased from loosely filled to fully compacted fill,the resistance to air flow increased at the same level of moisture content and the same quantity of air flow . This effect might be due to the reduction in the air spaces in the grain mass due to the compacting effect. This increase was found to be less in the grain at higher levels of moisture content than at lower levels. This is partially due to the density of grain at higher moisture content being less than that at lower moisture content.

Effect of Grain Moisture Content on Pressure Drop of Air Flow

Calderwood (1973) found that the moisture content and amount of packing caused variation in the amount of resistance for the same kind of seed. He used Shedd's data. He provided a graph showing the resistance to air flow of loosely filled rough rice at 13.4 percent moisture content, wet basis. It was noted that increasing moisture content from 13.4 to 20.7 reduced resistance to air flow by 24 percent and changing the density of fill from

38.1 to 40.6 lb per cuft increased resistance to air flow by 33 percent.

Akritidis and Siatras (1979) concluded that the effect of moisture content on resistance to air flow was determined by selecting points at air flow rates of 5, 10, 15, 20, 25 $m^3/min.m^2$. Below an air flow of 10 $m^3/min.m^2$, the moisture content did not significantly influence the static pressure drop. Above 10 $m^3/min.m^2$, when the moisture content decreased the pressure drop decreased to a minimum and then it increased.

Hindey(1980) studied the effect of moisture content of barley on the pressure drop of air. He concluded that the pressure drop of air was increased when the moisture content of barley was decreased. One of the important results obtained from his research indicated that as the moisture content increased from 12 to 26 percent wet basis, the pressure drop decreased by 28 % at constant air flow rate, grain density and depth of grain.

Effect of Grain Depth on Pressure Drop of Air Flow

Stirniman *et al* (1931) carried out the experiments on the resistance to the passage of air offered by columns of rice of varying depths. The results of experiments indicated that the relations between the static pressure and depth of rice, at any depth of rice, could be expressed quite accurately as percentage of pressure under the rice and percentage of the depth of the rice. In the case of the test a pressure of 8.47 inches(21.51 cm) of water was used under the 6.9 foot (210 cm) column of rice, the pressure existing at the point 4.5 foot(136.8 cm) below the top of the rice which was 65 percent of 6.9 feet (210 cm), was 4.74 inches (12.03 cm) of water, which was 56 percent of 8.47, the total pressure under the rice.

Henderson (1943) found that the effect of settling on 8 feet (243 cm) depth of clean corn reduced the rate of air flow to 85% of that previous to settling. Settling was produced by shaking and pounding the stack and by tamping .

Shedd (1951) carried out measurements of pressure at each foot of depth. It was found that resistance pressure increased in proportion to depth. There were small variations which may have been caused by variations in density of fill of grain. There was no consistent difference from bottom to top of bin in the weight of grain per cubic foot, and theorectically there is no reason to expect a variation in resistance pressure per foot of depth as long as there is no air leakage at bin walls. The survey measurements were run by Corbett (1954) on the resistance of barley in farm bin at, depths up to 15 feet (457 cm) showed that its resistance was nearly 50% less than that of oats, and indicated that its specific resistance did not increase with depth. The results were obtained by them indicated that the specific resistance of oats increases with grain depth, and that the rate of increase varies with air speed through the grain.

Osborne (1961) studied the resistance to air flow of various cereal grains and other seeds. It was used air velocities up to about 70 ft per min (21.3 m per min) and with a bed depth of 1 foot (30.4 cm). Two runs were carried out with a bed depth of 2 ft (60.8 cm) and at air velocities below 17.5 ft/min (5.33 m/min), such as might be used when aerating stored grain.

The results obtained can only be taken as a guide to the resistance to air flow, as the resistance will vary with change of bulk density which in turn is influenced by moisture content , degree of packing , and the amount and kind of impurities present. The effect of depth on the resistance to air flow has been dealt with by the authors previously mentioned.

Lawton (1965) measured the resistance to air flow of some common agricultural and horticultural seeds at bed depths of 6 and 12 inches (15.24 and 30.48 cm) and used air flows of up to 90 $ft^3/min.ft^2$ (27.43 $m^3/min.m^2$) . The resistance for 12 inches beds was found to be approximately 1.8 times that for a 6 inches (15.2 cm) bed.

Effect of voids in Grain Beds on Pressure Drop of Air Flow

Pore spaces in test bin which filled by grain is good indicator to evaluate the bulk density of the grain in the same volume of test bin. As the pore spaces increase in a test bin of grain, the weight of the grain, in the same volume, decreases. Consequently, the measured bulk density is also decreases. On other word, the bulk density of grain is affected by the volume of spaces between grain particles.

Zink (1935) pointed out that air space varies in different storages of grain depending somewhat on depths of grain, maturity and other physical differences.

Chung and Converse (1971) reported that the porosity of beds of wheat and corns was low at high bulk densities and at low grain moisture content.

Abdel-Ghaffar and Shokr (1982) studied the air flow resistance characteristics of potatoes storage as influenced by bulk density and size. A predicted equation was developed to evaluate the pressure drop per unit depth of potatoes storage in bin over ranges of air flow rates , bulk density and equivalent diameter. In addition, the measurements of pore spaces (voids) for several degrees of filling started from loosely filled potatoes is greatest in beds of the smallest pore space.

Abdel-Ghaffar and Hindey(1984) investigated the effect of pore space on the pressure drop of onion in test bin measurement. The pressure drop was greatest in beds of the smallest pore space at the same air flow rate and onions size. As the pore space decreased by 20 percent in a bed of onions the pressure drop increased by 1.45 times increase in pressure drop for the same air flow rate.

Effect of other Variables on Air Resistance

Henderson (1943) found that the size and shape of kernels affect the resistance to air flow. The void space found in corn has been reported as 40 percent. The increase in resistance due to the presence of foreign material partially filling the voids in corn was observed. The fineness of the foreign material tends to increase the grain pressure drop.

Shedd (1951) found that the foreign material mixed with the grain tends to increase the resistance to air flow if the foreign material is fine than the grain and to reduce the resistance to air flow if it is coarser than the grain .

Calderwood (1973) carried out the research to determine the relative difference in resistance to air flow of long-grain and medium- grain rough rice and of brown and milled rice compared with the rough rice from which these materials were processed. The amount of resistance to air flow varied widely from one kind of seed to another, depending upon size and shape.

He resulted that medium-grain rice offered more resistance to air flow than did long-grain rice when test conditions were comparable. In addition brown and milled rice offered more resistance to air flow than did the rough rice from which they were processed. The resistance to air flow of brown and milled long-grain rice was nearly the same, but the resistance of brown medium-grain rice was significantly greater than that of medium grain milled rice. Any practical method of filling a commercial size bin will result in some degrees of packing and storage density greater than the test weight of the material.

Steele (1974) studied the effect of container diameter on the resistance to air flow. No difference was observed in the static pressure-air flow relationship with container diameter.

Abdel-Ghaffar and Hindey(1984) studied the effect of onion size on the pressure drop. It was found a decrease of 20 percent in onions size may cause 1.24 times increase in pressure drop for the same air flow rate and pore space.

Fan Power for Grain Aeration

Nissing (1958) studied the possible differences in pressure as affected by seed cotton densities.

The bin was built to hold cotton up to depth of 7 ft with a cross-sectional area of 30.515 sq.ft. The air was pulled down ward through the seed cotton with a fan powered by a 30 hp electrical motor. Density, depth, air flow and static pressure constituted the four variables of the test. The horsepower requirements to force a known quantity of air through a column of seed cotton can readily be calculated from the static pressure as obtained from the graph or by the use of the predicted equation that has been derived for each curve. The suggested horsepower formula was as follows:

$$Hp = \frac{V \times P}{6356} \times \text{efficiency}$$

where : Hp = fan horsepower

V = rate of volume of air, cfm,

P_s = static pressure inches of water.

The horsepower calculated with the above formula should be multiplied by an efficiency factor of two, in order to determine to approximate actual horsepower required to operate the fan . In addition, the amount of foreign matter and moisture content in the cotton, and the density and depth were found to definitely affect the horsepower requirements to force air through the cotton.

Abdel-Ghaffar (1984) found that energy loss (air pressure drop) per unit bed depth of wheat and paddy rice for the design of grain conditioning systems can be predicted by using the general equation suggested by Ergun (1952) and Bern (1975).

$$\frac{\Delta P}{L} = B_0 + B_1 \left[\frac{(\frac{\rho_b}{\rho_s})^2 \mu_f V_s}{(1-\frac{\rho_b}{\rho_s})^3 D_p^2} \right] + B_2 \left[\frac{(\frac{\rho_b}{\rho_s}) \rho_f V_s^2}{(1-\frac{\rho_b}{\rho_s})^3 D_p} \right]$$

where: ρ_b and ρ_s are the bulk and true density of grain, respectively, kg/m^3, kg/m^3.

ρ_f and μ_f are the fluid density and viscosity, respectively, kg/m^3, $N\text{-}S/m^2$.

V_s is the air flow rate, $m^3/sec.m^2$.

D_p is the equivalent sperical diameter, m .

The terms B_o , B_1 and B_2 were referred to as grain characteristics coefficients. The coefficients were 1.383, 28.580 , and 6.683 for paddy rice and -3.796,81.473,and 0.311 for wheat. The researcher found that the energy required by fan used for aerated paddy rice was greater than of that for aerated wheat after harvesting.

Physical Properties of Grains

Brown (1962) studied the variation of bulk density of cereals with moisture content for rewetted of grains over a moisture content range from 10 to 30%. The samples were mixed by hand and left to sand in tins for seven days with occasional mixing by turning over the tins a few times during the working day. The results obtained indicated that, all varieties of wheat, barley and oats showed a decrease in bulk density at higher moisture content. It was shown that two curves for barley showed a decrease of bulk density with decrease of moisture content but this might have been due to method of rewetting.

Chung and Converse (1971) investigated the effect of change moisture content on physical properties of corn and wheat and examined the effect of kernel shape and size on corn packing characteristics. The relationship resulted between test weight and moisture content was curvelinear for both wheat and corn. The data were linearized by converting the test weight into dry matter weight per quart. All wheat sample decreased in test weight as the moisture content increased. The porosity was low at high bulk densities and at low grain moisture content.

Brusewitz (1975) studied the bulk density and true density of several grains when rewetted to moisture of 15-45 percent moisture content wet basis. Bulk density reached a minimum value for barley, corn, oats, rye and wheat at about 30 percent moisture content and then increased with higher moisture. Oats was displayed a true density different when measured by water displacement than with an air pycnometer. The effect of particle size on bulk density was measured by comparing cracked with whole corn. The effect of cracking was to produce a bulk density curve less affect by moisture and with a lower absolute value.

Morita and Paul Singh (1979) carried out the study to experimentally determine physical dimensions, bulk density, specific gravity and surface area of short-grain rough rice. The results were showed that length, width, thickness, bulk density and specific gravity are linear function of moisture content.

Sabbah (1980) reported on the study of the physical properties such as dimensions, particle volume and bulk density of paddy rice and wheat. The correlations show that the three dimensions of a wheat particle increase as moisture content increases. However, only the width and the thickness of a rice particle increase as moisture increase. The length decrease as moisture content increases. For a moisture content ranges between 9.5 to 19.35% wet basis, the regression analysis indicated that no change in the volume of paddy rice particle as moisture content changed. The results indicated that paddy rice showed an increase in bulk density and solid density with increasing moisture content. Wheat showed a decrease in bulk density and **true** density with increasing moisture content.

Korayem and Soliman (1983) carried out a research work to study the effect of moisture content on the dimensions and density of paddy rice. The results showed that the three dimensions of paddy rice particles increase as moisture content increases by wetting and the particle density and bulk density appeared to be linearly dependent on moisture content.

EQUIPMENT AND TEST PROCEDURE

This chapter contains a detailed description of all equipment and measuring instruments and comprehensive presentation of test procedures to obtain the objectives of this investigation.

The experiments were concerning the air flow resistance characteristics of paddy rice and wheat as influenced by bulk density, wet basis moisture content and void fractions.

Test Equipment

Figure (1) shows the complete test apparatus of the air resistance and aeration system components used in this analysis. The following is a description of different components of the apparatus.

Cylindrical grain test bin

The cylindrical grain test bin used in these experiments was constructed of 3 mm galvanized sheet metal with 34 cm inside diameter and 65 cm high. The circular sectional area of 0.0908 square meters was determined.

A- Centrifugal fan.
B- A gate.
C- Flexible tubing.
E- Steel pipe.
F- Orifice plate.
D- Flexible tubing.
H- Plenum chamber.
G- Test bin.
N- Wooden base.
P- Pressure holes.
a,b,c,d and e: Pressure holes for measuring the pressure drop of air at different levels.

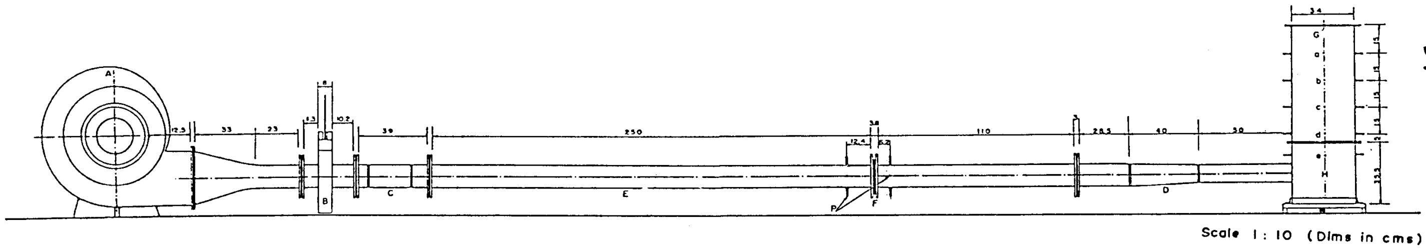


Fig.(1): Equipment of the device resistance air flow

The grain test bin permited a volume of 0.05902 cubic meters of grain to be tested. The cylindrical type of test bin produced a smooth inside surface to eleminate the effect of inside wall roughness to the air resistance. The inlet test bin openning was constructed from perforated sheet metal having large number of circular holes. The dimensions of the perforated sheets were: hole diameter, 1.5 cm, hole pitch, 1.7 cm, and sheet thickness, 3 cm as indicated in Figure(2).

The bin rested on an air plenum chamber. It works as a joint between the air pipe and the grain test bin to maintain a velocity inside the bin as uniform as possible across the cross sectional area. Air plenum chamber was constructed of 3 mm galvanized sheet metal with an inside cross sectional diameter of 34 cm and 35.5 cm high.

Twenty-small openings on the grain bin and the air plenum chamber sides formed five sets of tapping for pressure drop measurements. The first set of tapping points consisted of four openings at the same level below the perforated floor at distance of 10 cm. The other sets were located on the vertical distance of test bin at height of 5, 20, 35 and 50 above the perforated

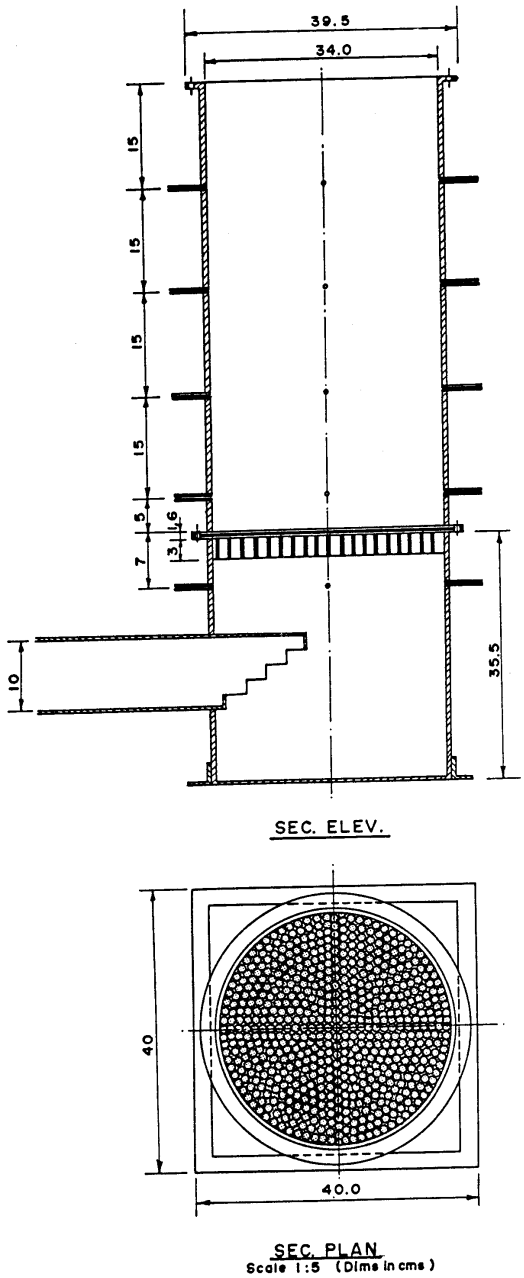


Fig.(2): Grain test bin (grain tank).

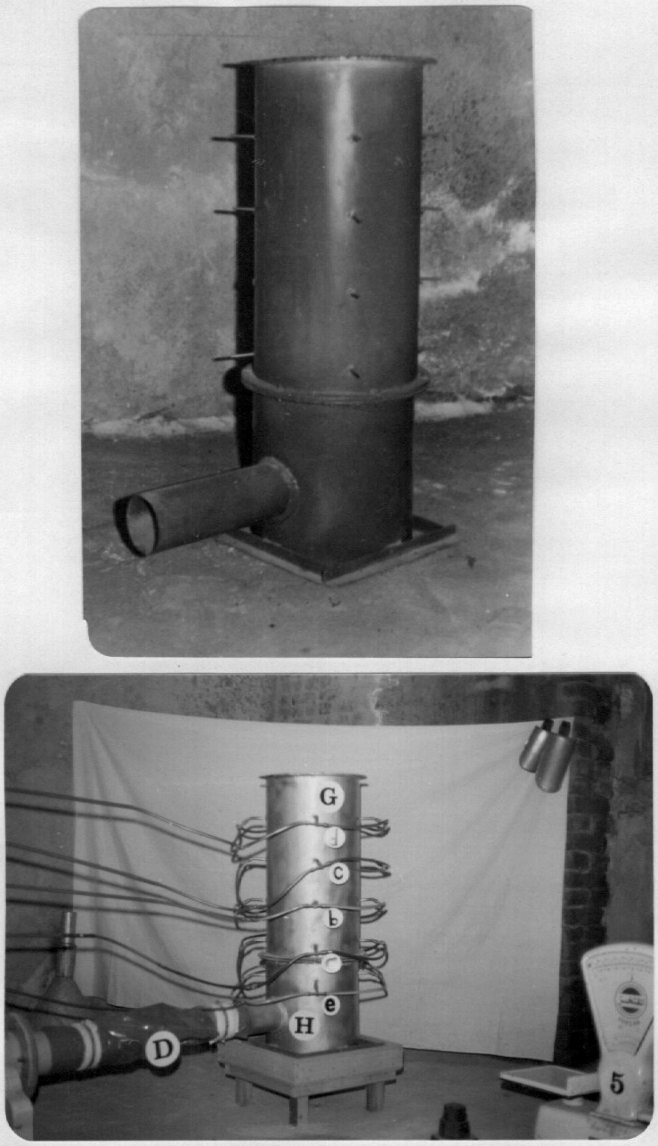


Fig. (3): Photographs of grain test bin .

flat floor . Each set of tapping holes were connected together by plastic tubes , to form one tube. Two sets of tapping holes were used to measure the pressure drop across the designed vertical distance. The distance between the two sets of tapping holes was 30 cms for measuring the pressure drop of air passage through the grains. Figure (2) shows the cylindrical grain test bin . Photographs of the cylindrical grain test bin were indicated in figure (3).

The ducting system

The ducting system consisted of a centrifugal fan an air velocity gate, an orifice plate, steel pipes and flexible tubing.

A centrifugal fan connected with an electric motor was used to force air through the grain test bin at different rates across 12.5 cm steel pipes diameter. The electrical motor power was 3 horsepower and 1415 R.P.M. The fan consisted of 16 blades with diameter of 30 cm. Flow was varied by a controlling gate mounted on the exit of the fan. A relatively long pipes of 12.5 cm inside diameter and 4.54 meter long

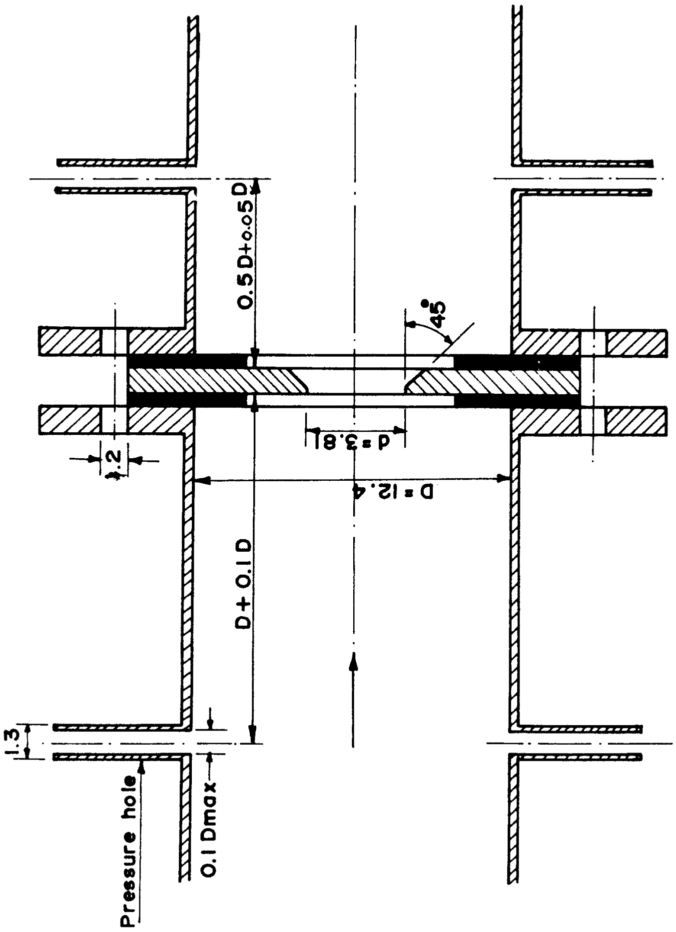


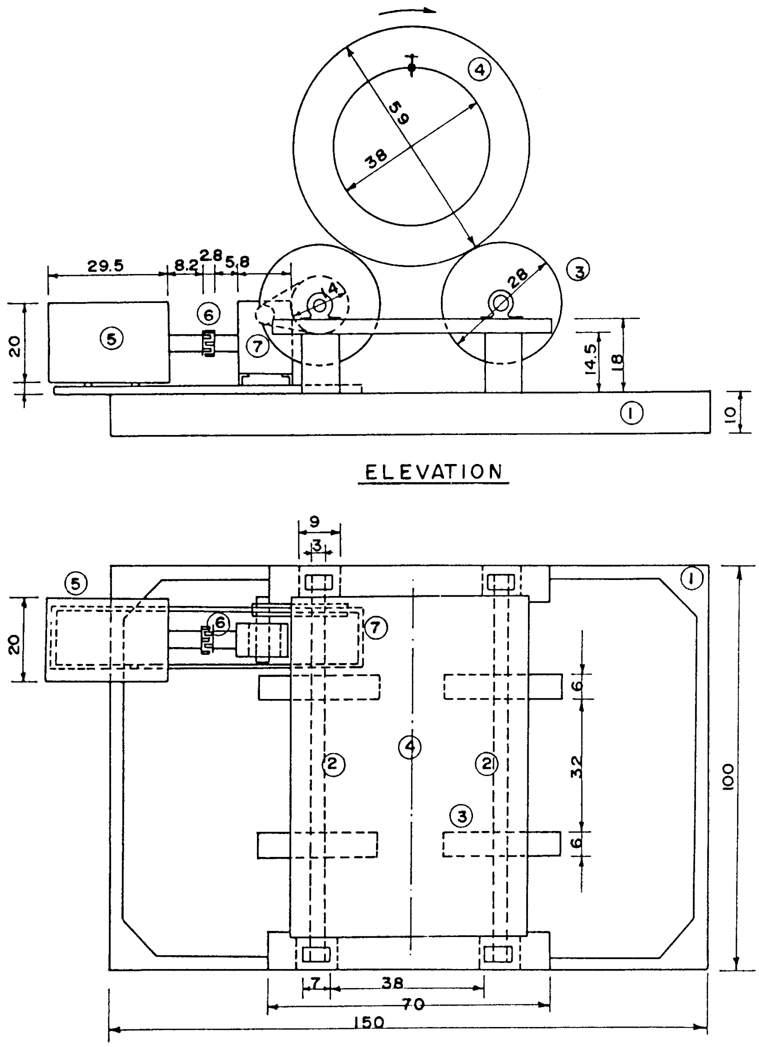
Fig.(4):Orifice plate with D and $\frac{D}{2}$ tappings.
Scale 1:2 (Dims in cms)

made of galvanized metal was used between the fan and the grain test bin. The length of pipe was essential to provide a fully developed air velocity distribution to measure accurately the air flow rate. Plastic flexible tubings were used to connect the galvanized pipes together having 73 cm long.

The rate of air flow was measured by an orifice plate. The orifice plate was located inside the galvanized pipe at a distance of 3.71 m from the fan.The orifice diameter was 3.8 cm perpendicular to upstream of air . Two pressure taps were located at distances from the orifice recommended by B.S. 1042: Part 1 : 1964 . The upstream pressure tap was located at a distance equivalent to the pipe diameter from the orifice. The downstream pressure tap was located at a distance $\frac{1}{2}$ of the pipe diameter . Figure (4) shows the orifice plate used in these experiments.

Mixing and rewetting grain unit

Elevation and plan of designed the unit for mixing and rewetting wheat and paddy rice under testing were



Scale 1:10 (Dims in cms)

1- Iron frame.
2- Two shafts.
3- Rollers.
4- A barrel.
5- An electric motor.
6- Safety coupling.
7- Gear box reduction.

Fig.(5): Mixing and rewetting grain unit.

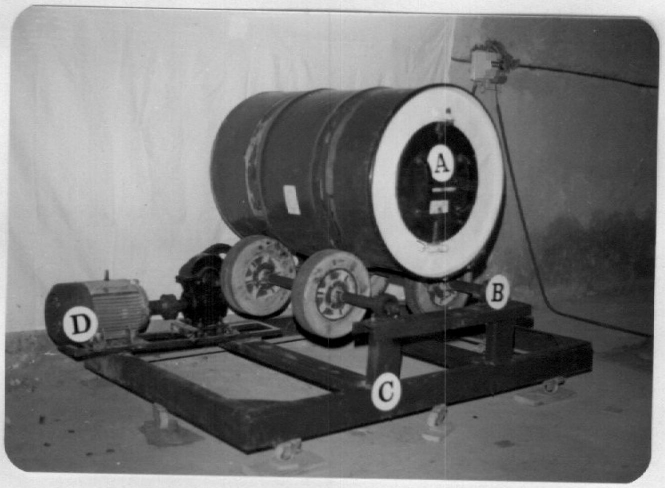


Fig. (6): A photograph of mixing and rewetting grain unit.

shown in figure (5). A photograph of the unit was represented in figure (6). It consisted of an rectangular iron frame with dimensions of 100 cm wide and 150 cm length. Two shafts rotated by means of an electric motor (3 horse-power) and 1410 R.P.M. A barrel, which was filled with grain, was resting on four rollers of 28 cm diameter each. The barrel dimensions were 59 cm diameter and 84 cm length. The mixing and rewetting grain unit permited a volume of 0.2296 cubic meters.

The rotating speed of barrel was 9 R.P.M. A gear box was constructed on the frame of the unit to reduce the revolution per minute from 1410 R.P.M. at the electric motor shaft to 9 R.P.M. at the grain barrel. The low speed of the grain barrel permitted the grain and additional water to be mixed and rewetted.

Instrumentation

Air flow rate measurements

An orifice plate was machined to permit measurements of air flow rates by measuring the pressure drop across the orifice. Two pressure taps were located from the orifice at distances of 12.4 and 6.2 cm.An calibrated inclined manometer was used to measure the drop of air across the orifice plate, see Appendix D. The minor scale division and ranges in mm water for the inclined section were 0.5 and 0-150 mm, respectively.

Pressure measurements

The pressure measuring system consisted of two manometers. The static pressure was measured at the plenum chamber by an inclined manometer. The range of scale was from 0 to 77.5 mm with minor division of 0.5 mm water. The pressure drop across the test bin between the two levels of a and c, as shown in figure (1), was measured by a calibrated inclined manometer with scale of 0-26 mm water and a minor division of 0.5 mm water, see Appendix D.

Temperature measurement

The temperatures of the flowing air through the grain test bin and ambient dry and wet were measured by using three degree celsius mercury glass thermometers.

Weigh measurement

Grain was weighed by a calibrated scale . The scale arm had a 25 kilograms with an accuracy of 5 grams. A balance with an accuracy of 0.0001 gram was used for weighing the grain for determining the solid density and the moisture content.

Moisture content measurement

Oven-drying method was used for measuring the grain moisture content. Cylinderical aluminium containers were used to be filled by grain samples. A desiccator was used for the purpose of measuring moisture content. The grain samples were placed in the oven at temperature of 105 °C for 24 hours. In addition for fast predetermination of rewetted grain moisture content , samples were grinded and were placed in the oven at temperature of 130 °C for 2 hours.

Technique Used for Preparing the Grain Moisture Content

One of the important variables affected on the pressure drop of air passed through grain bed is the grain moisture content. The grains were obtained at moisture contents of 11.22% and 10.48% for paddy rice and wheat, respectively. It is impossible to have a freshly harvested samples of paddy rice and wheat at different levels of moisture content . So, wetting the grain were nećessary for continuing the experimental work. The technique used for rewetting the grain was discussed by Hindey (1980). The steps used in this work were stepped as follows:

1. Three random samples, 25 grams each, were taken from the grain bulk to determine the initial moisture content by the oven method , 130°C for 2 hours period.
2. Fifty kilograms of grains were weighed and were filled the grain mixing and rewetting unit.
3. From the initial weight of grain and the measured value of initial moisture content, calculated quantity of water was added to the grain to bring it to

the second level of the moisture content, by spraying the water on the grain. The change on grain moisture content levels were ranged from 2.5 % to 3 % wet basis.

4. The mixing and rewetting unit was rotated at 9 r.p.m. for 24 hours period at least to transfer the grain from one level of moisture content.

5. Three random samples, 25 grams each, were taken to test the new moisture content at 130°C for 2 hours.

6. The grain was taken from the mixing and rewetting unit for running the experimental work at different levels of grain bulk density.

7. At the end of set of the experiments at this level of moisture content, the grain was mixed in the mixing and rewetting unit for rewetting grains to the next level of moisture content.

8. These procedures were repeated on the same bulk of paddy rice and wheat to obtain successive levels of moisture content used in these experiments.

Methods Used for Filling the Grain Test Bin

Grain bulk density was considered one of the important factor affected on the pressure drop. Four levels of grain bulk density at the same level of moisture content were experimented.

The technique used to obtain the four levels of grain bulk densities in the test bin was indicated in figure (7) and was stepped as follow :

1. The grains were poured into the test bin by a metal cone from height zero above the supported screen of grain bin. The cone was raised manually to keep the zero height above the grain. The process was continued until the test bin was completely filled with grain to the top edges of the bin sides. This method is called "Loosely filled". The weight of grain used to fill the test bin was recorded.
2. For the second grain bulk density, the grain was poured from a height of 65 cm, the edge of test bin, until the bin was completely filled with grain to the top edges of the bin sides. During pouring the grain, the cone

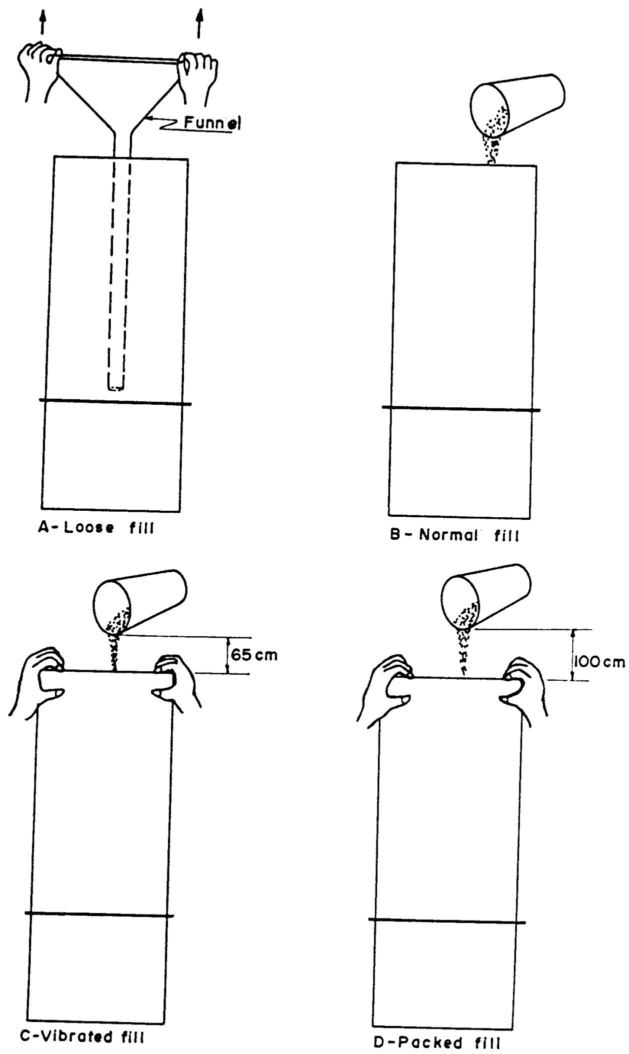


Fig.(7):Shows the methods of filling test bin .

was raised manually to keep the 65 cms height above the grain. This process was called "Normal filled".

3. The third grain bulk density was obtained by pouring the grain from 65 cm height during the vibration of the test bin. This process was named "vibrated fill" . The weight of grain used to fill the test bin was recorded.

4. The fourth grain bulk density was obtained by pouring the grain from height 100 cm. The test bin was also vibrated to form the packed fill. The weight of grain was recorded.

Test Procedures

Tests were designed into two groups of experiments. The first group of experiment was concerned with studying the pressure drop of air passage through beds of clean paddy rice at different levels of bulk density ranges from 595 kg/m^3 to 705 kg/m^3 and moisture content ranges from 11 to 25 percent wet basis.

The second group of experiments was involved with studying the energy loss due to the flow of air in beds of clean wheat at different levels of bulk density ranges from 710 to 810 kg/m^3 and grain moisture content ranges from 10.48 to 19.92 percent wet basis.

Paddy rice was obtanied from kafr El- Sheikh experimental farm, Faculty of Agriculture . Wheat was brought from a warehouse in kafr El-Sheikh.

Paddy rice and wheat were obtained at averages of moisture contents of 11.22% and 10.49% wet basis,respectively. The varieties of paddy rice and wheat used in the experiments were IR 28 and Sakha 61,respectively.

Before the experiments were run for evaluating the pressure drop of paddy rice and wheat several measurements of the physical properties were determined in the Agricultural Mechanization laboratory, Faculty of Agriculture at Kafr El-Sheikh city.

Dimensions, grain equivalent spherical diameters, grain mass densities, grain bulk densities, weight of a thousand grain particles, pore spaces (voids) and wet basis moisture contents percent of the wheat and paddy rice were measured and calculated.

Grain dimensions

Paddy rice and wheat physical dimensions were measured in three directions, length, width and thickness. The dimensions were measured at five levels of paddy rice moisture content and three levels of wheat moisture content . The method used for preparing samples of different levels of moisture content and the technique used during the experimental work will be discussed later.

For each level of moisture content, a sample contained 50 grain particles was dimensioned. The measured grain dimensions were recorded in table (A-1) in Appendix (A). A micrometer of type TGL 15046/I with small division of 0.01 mm was used for measuring the physical dimensions of paddy rice and wheat.

Grain equivalent spherical diameters

Grain equivalent spherical diameters were measured. Five random samples, each of 50 particles, were selected. The net volume of each sample was measured by dropping it in a container of a known volume . The container was filled with water and the net volume of the sample in cm was obtained. The paddy rice and wheat equivalent spherical diameters were calculated by the formula suggested by Löf and Hawley (1948). Table (A-2) shows the measured data and the calculated grain equivalent spherical diameter, Appendix (A).

$$D_p = \sqrt[3]{\frac{6}{\pi} \frac{\text{net volume of grain particles (cu.cm)}}{\text{number of particles}}}$$

Grains mass densities

To evaluate the mass densities of the paddy rice and wheat, three samples contained 1000 particles each, for each type of grain were tested. The samples were weighed with suitable sensible balance with an accuracy of 0.0001 gram. The volume of each sample was measured by the method explained above . Table (A-3) shows the measured data and the calculated values of grain mass densities, Appendix (A).

Grains bulk densities

The bulk densities of the paddy rice and wheat were determined by knowing the weight of grain filling a designed container of known volume. The container volume was 250 cu.cm. The grain was poured into the test container from a height of 30 cms to allowed the grain to fall free in the container. The process was repeated three times for each grain type at averages moisture contents of 12% and 11% wet basis of paddy rice and wheat, respectively. The measured data and the calculated values of grain bulk densities were recorded in table (A-3), Appendix (A).

Grains pore space (voids)

The void fractions (porosity) of grains were calculated by using the relationship between the porosity and grain bulk density which is given by the following equation:

$$\text{Void fractions} = \left[1 - \frac{\text{grain bulk density}}{\text{grain mass density}}\right]$$

Table (A-3) shows the calculated values of voids fraction of paddy rice and wheat at moisture contents of 12% and 11% wet basis, respectively.

Weight of a thousand grain particles

Three random samples were weighed for each grain type . Each sample contained of 1000 grain particles. Table (A-4) shows the weighed samples of paddy rice and wheat, Appendix (A).

Grains moisture contents, wet basis

Moisture contents of paddy rice and wheat were measured by oven-technique (105 °C for 24 hours). Three samples of 25 grams each were taken from the grain bulk to estimate the initial moisture contents of the samples. Table (A-5) shows the measured data and the calculated values of moisture contents, wet basis of paddy rice and wheat.

The averaged values of the physical properties of paddy rice and wheat used in these experiments were summarized in table (A-6), Appendix (A).

RESULTS AND DISCUSSION

The resistance to the passage of air flow through beds of biological and non-biological materials has been the subject of investigation for several years. The main purpose of the investigation was to provide a useful information on predicting the pressure drop of fluid in order to design, improvements and economic operating conditions of drying , aeration and cooling systems. The knowledge enables engineers to make the right decision to choose the correct fan or blower for a particular design. It also enables to make the right approach to any of the previous engineering aspects in ventilating systems. The pressure drop characteristics for the fluid flow through beds of grains are controlled by numerous variables. Some of these variables are related to the thermo-physical properties of the fluid passing through the packed bed, such as density, kinematic viscosity, mass velocity and gravity of fluid . Some variables are related to the geometrical characteristics of the packing material such as particle diameter, shape factor, surface roughness, surface area, fractional effective void, and orientation . Other variables are related to the configuration of the unit such as packing bed dimensions such as diameter and length and percent of opening in perforated screen. In spite of these variables, there is no actual theoretical equation that includes these variables. Most of the equations in this field are empirical and semi-empirical.In the experiments, three important variables were considered mainly in studying the pressure drop of air passing through beds of paddy rice of IR 28 variety and wheat of Sakha 61 variety. The variables were the air flow rate per unit of cross sectional area of test bin, bulk density and moisture content of grains.

Previous studies on the relationship between the pressure drop of air and one of the above variables has been approached in different ways. Whatever, the approach, it is generally agreed that the basic relationship between the pressure drop, ΔP, and the air flow rate, Q, as a variable is expressed by formulas of the form $\Delta P = K Q^a$ where K and a are constants for any given bulk of product under a given condition. This power low could be applied to develop a set of empirical equations describing the pressure drop of air passing through grain bin.

This acceptable mathematical relationship was concluded by many investigators. Shedd, 1945 was very interested in studying the linear air flow resistance of ear corn using a bin of nearly full size. Shedd's data lay close to an air flow pressure drop formula of the form $\Delta P = K\ Q^a$. Henderson, 1943, carried out experiments to study the resistance of shelled corn and bin walls to air flow. He found that the relationship between the rate of air flow per unit area, Q, and the pressure drop was formed by the form $Q = K\ P^a$.

Hindey,1980, developed a mathematical relationship in the form $P = K\ Q^a\ M^b\ S^c$ describing the pressure drop of air passing through barley which affected by air flow rate per unit cross sectional area,Q, barley bulk density, S, and moisture content wet basis of barley, M .

Abd-El-Ghaffar and Hindey,1984, studied the linear air flow resistance of onions with respect to change of air flow rate, Q, onions equivalent diameter, D, and pore space , E. The relationship between these variables fitted the experimental data was in the form:$P=K^aQ^bD^cE$.

D'Arcy , 1856 , as cited in Schneidegger concluded that the rate of fluid flow through a sand bed was proportional to the pressure drop through the bed. His equation was in the form $Q = K\ (\frac{\Delta P}{L})$

Furnas,1929, has developed an important equation to study the flow of gases through beds of broken solids.

The equation resulted was in the form $\frac{\Delta P}{L} = a\,Q^b$. So, according to the previous studies on predicting the pressure drop of air through biological and non-biological materials using the most acceptable predicting formula in power relationship, the effect of the variables under the study on the pressure drop will be discussed.

Pressure Drop-Air Flow Relationship at Constants Bulk Density and Moisture Content

Experimental results of air flow resistance of clean paddy rice are given in Appendix B. Six groups of experiments carried out at different levels of moisture content and grain density.Clean paddy rice experiments are shown in Appendix B . Air flow rates were in the range between 240 to 600 cubic meter per hour per square meter of cross sectional area of test bin. Clean paddy rice bulk densities were in the range between 595 to 705 kilograms per cubic meter which were classified to loose, normal , vibrated and packed fill . Moisture contents of paddy rice were in the range between 11.00% to 25.00% wet basis with 2.5% interval.

When the resistance of paddy rice to air flow is expressed as a pressure drop per unit bed depth, ΔP, plotted against the air flow rate per unit area, Q, the points show a curve on linear graph paper. These curves are more or less convex upward. Figures (8,9 and 10) are graphicals presentation of pressure drop-air flow data for various types of filling test bin with paddy rice and at moisture contents of 11.22% - 19.27% and 24.30% wet basis, respectively. When the same points are plotted on log-log paper, the points are close to a straight lines over certain narrow ranges of air flow. These straight lines are expressed and indicated by a power relationship of the following type :

$$\Delta P = K Q^a \qquad (1)$$

where:

ΔP = Pressure drop, pascal per meter depth of paddy rice.

Q = Air flow rate, cubic meter per hour per square meter of the cross-sectional area of test bin.

(K) and (a) are constants for any given bulk of paddy rice under a given condition and the units used.

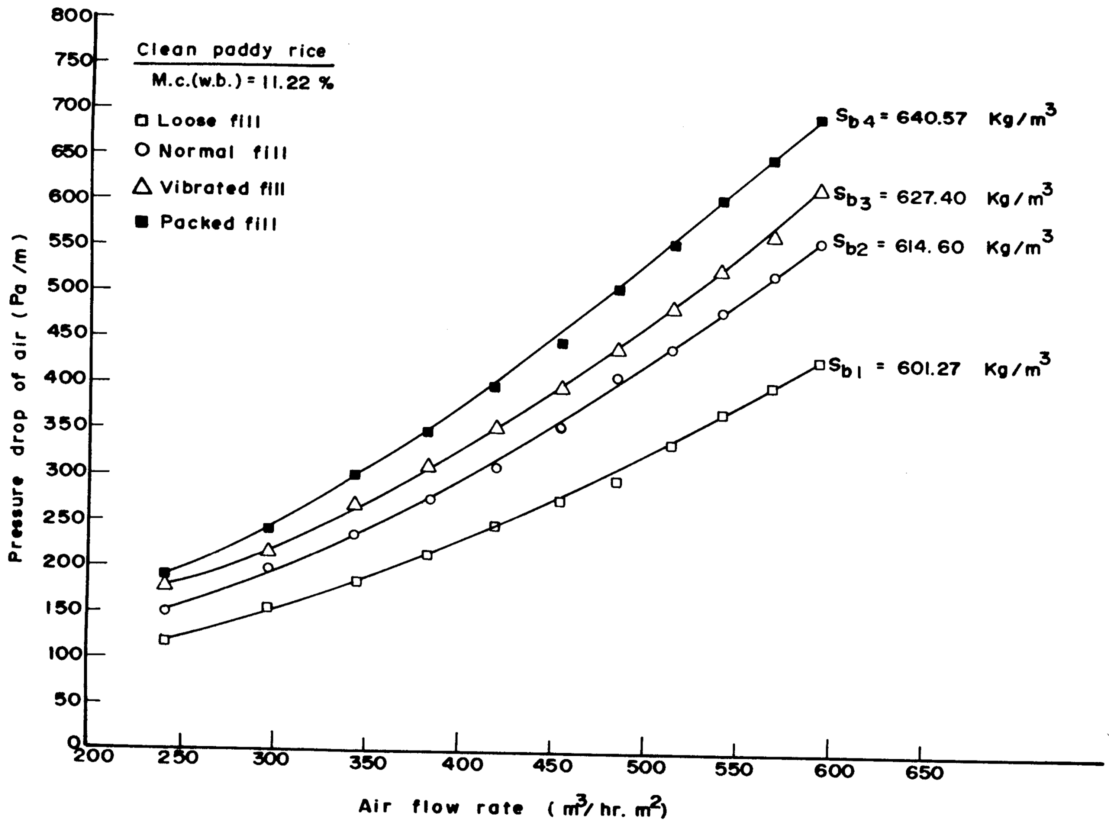


Fig.(8): Resistance of paddy rice to air flow at different levels of bulk density.

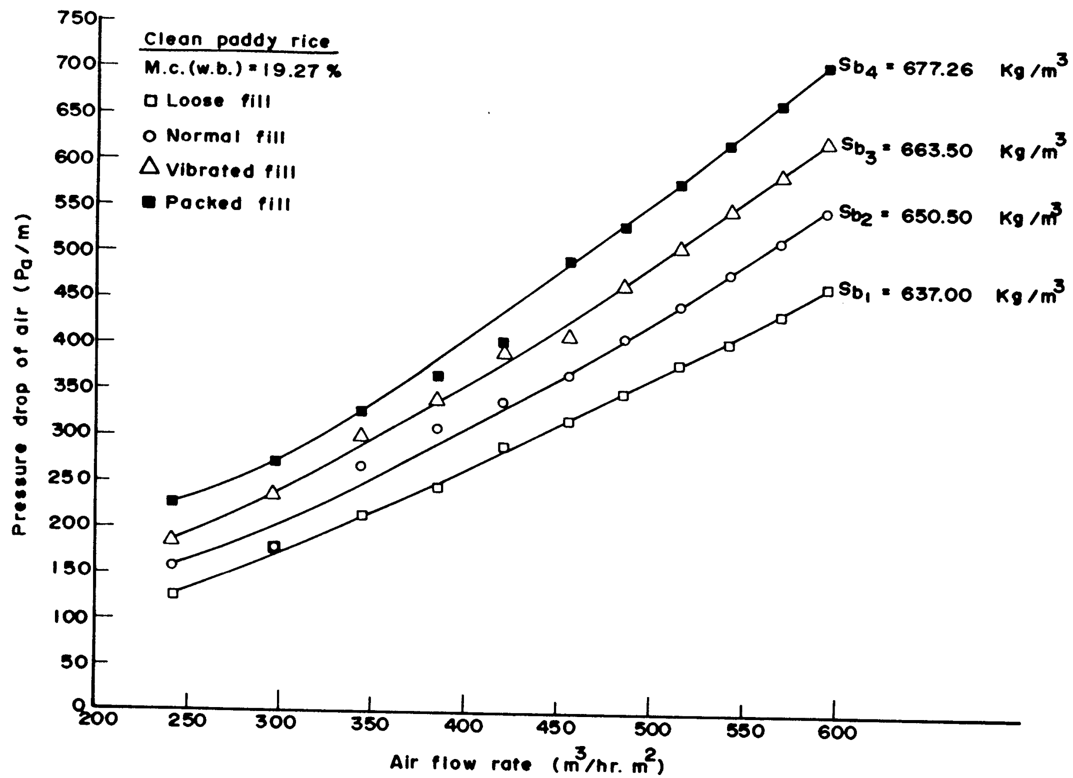


Fig.(9): Resistance of paddy rice to air flow at different levels of bulk density.

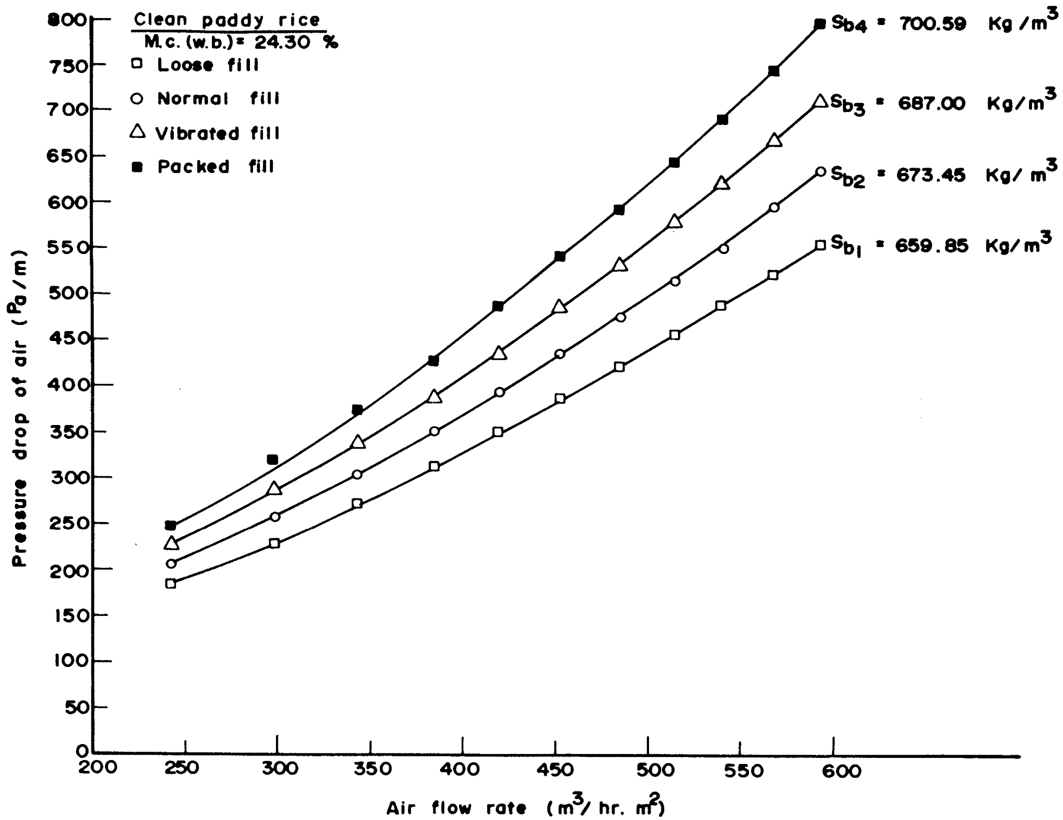


Fig.(10): Resistance of padde rice to air flow at different levels of bulk density.

Numerical value of the constant (K) can be taken as a function of a given condition and value of constant (a) is the slope of the line.

Figures (11, 12 and 13) represent plotts of data points of resistance of paddy rice to air flow at various bulk densities and at moisture contents of 11.22%, 19.27% and 24.30% on log-log papers. The previous investigators agreed , in general, that the curves of the pressure drop versus air flow on log-log paper can be presented by straight lines.

The above results, also, agreed with the results obtained by experiments on clean wheat of type Sakha 61. Three groups of experiments on resistance of clean wheat to air flow at various bulk densities and at moisture contents of 10.48%, 13.00% and 19.92% wet basis . Data recorded and calculated were shown in Appendix C .Figures (14, 15 and 16) represent plotts of data point of resistance of clean wheat to air flow at various bulk densities and at moisture contents of 10.48%, 13.00% and 19.92% wet basis. The points,also , show curves on linear graph paper. When these data points were plotted on log-log papers , the points lie close to a straight line indicating a power relationship in equation (1), as shown

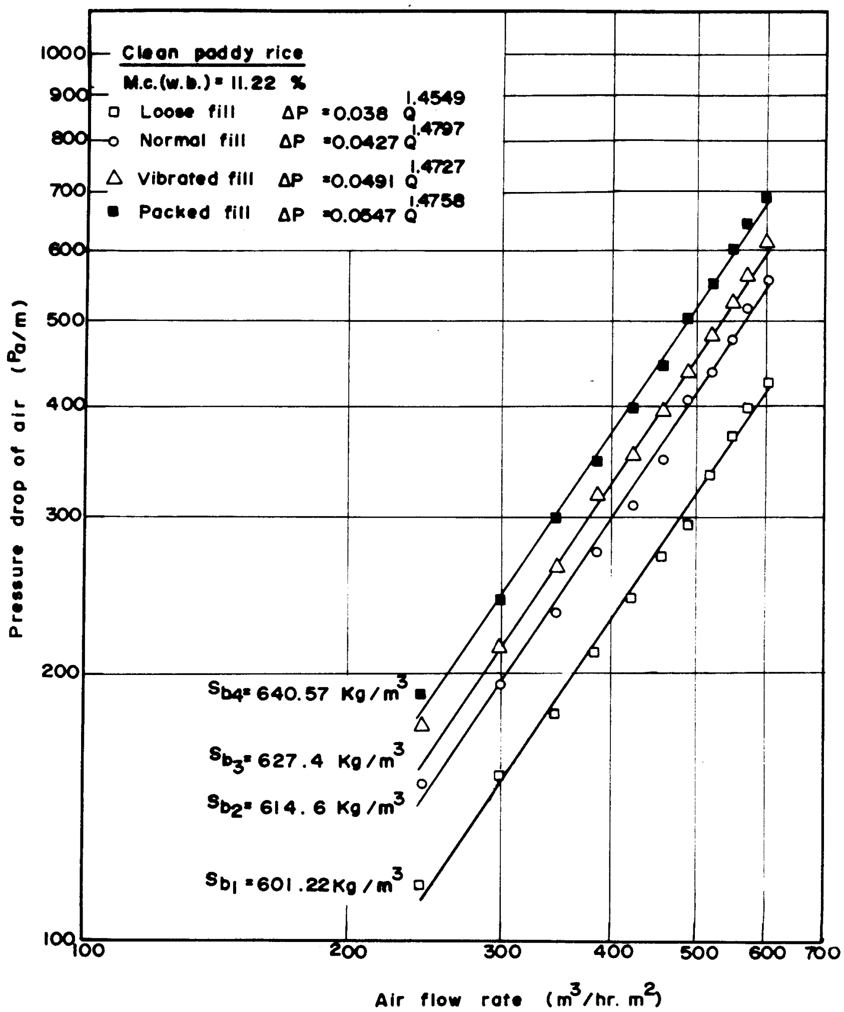


Fig.(11): Resistance of paddy rice to air flow at different levels of bulk density.

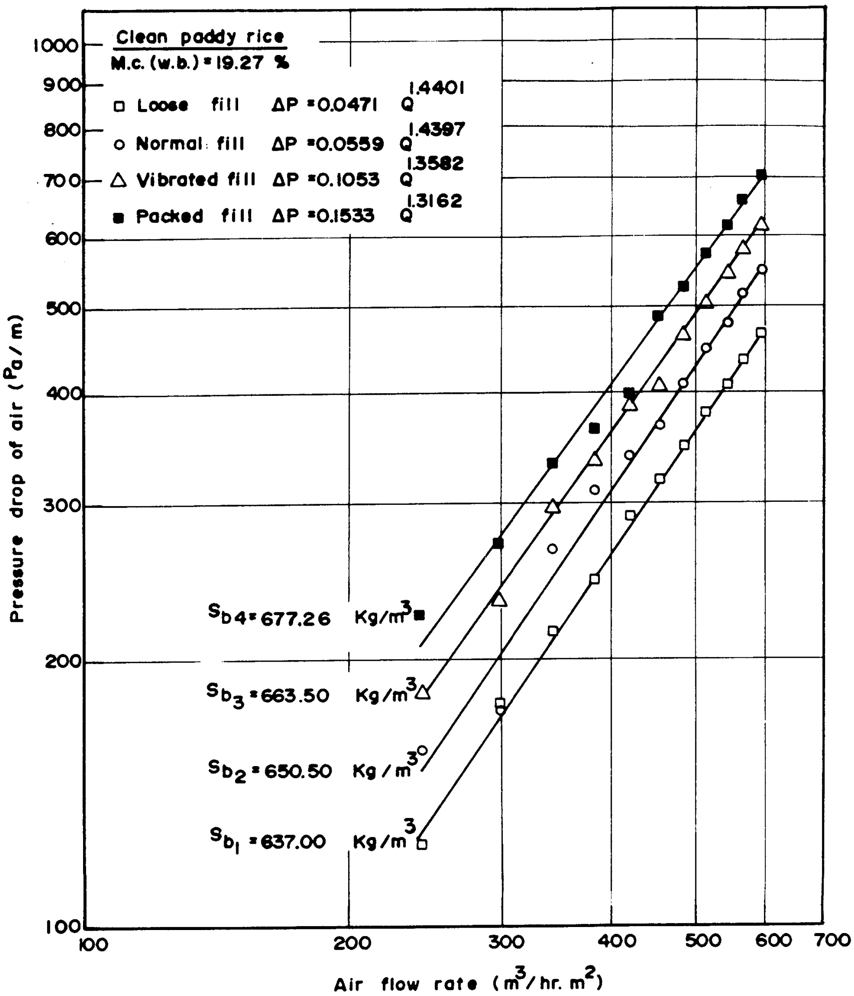


Fig.(12): Resistance of paddy rice to air flow at different levels of bulk density .

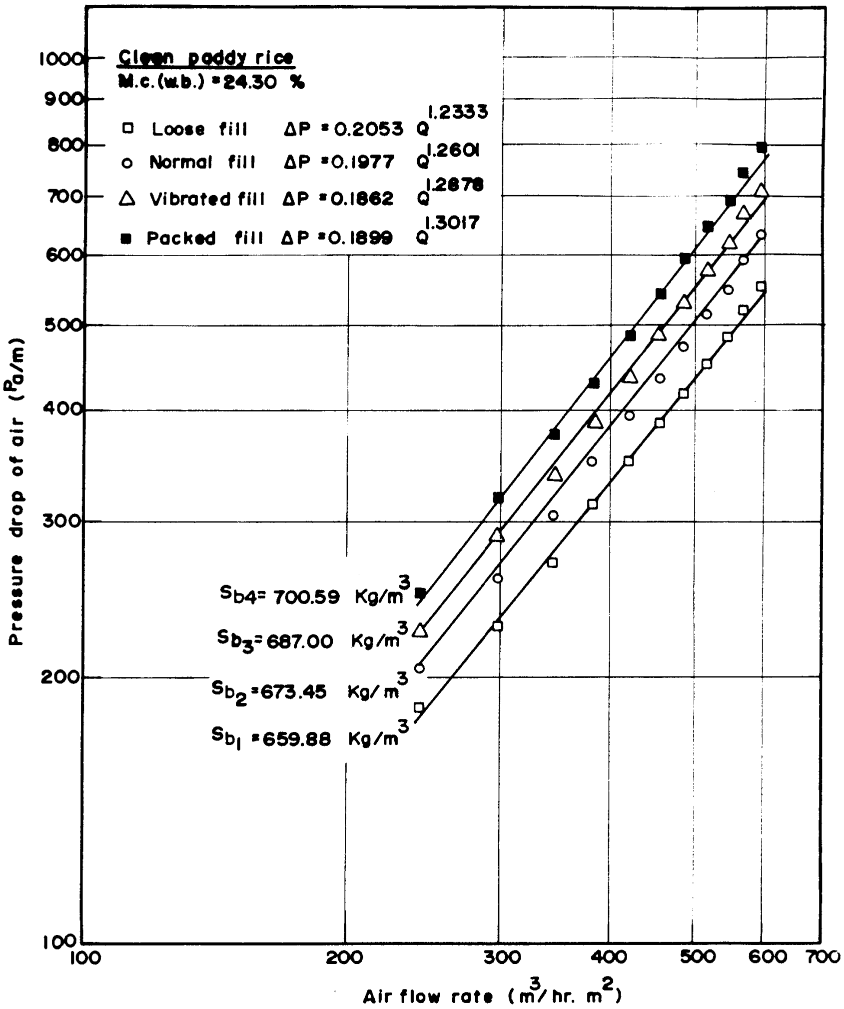


Fig.(13): Resistance of paddy rice to airflow at different levels of bulk density.

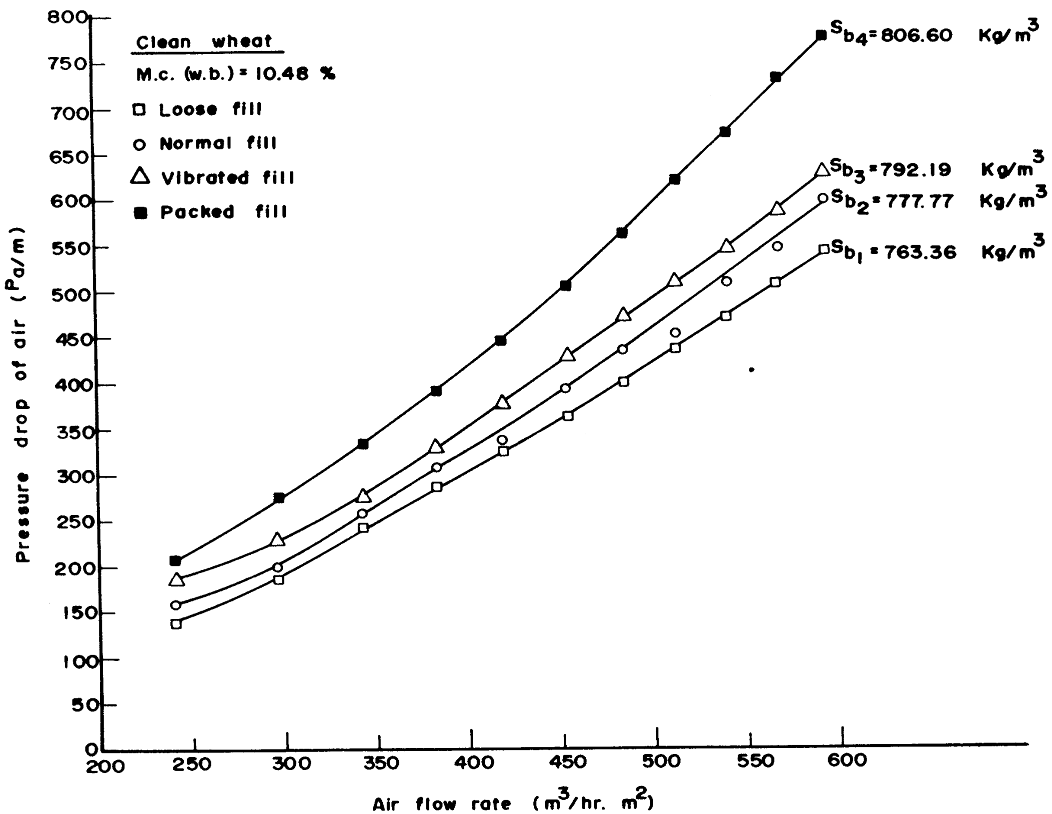


Fig.(14):Resistance of wheat to air flow at different levels of bulk density.

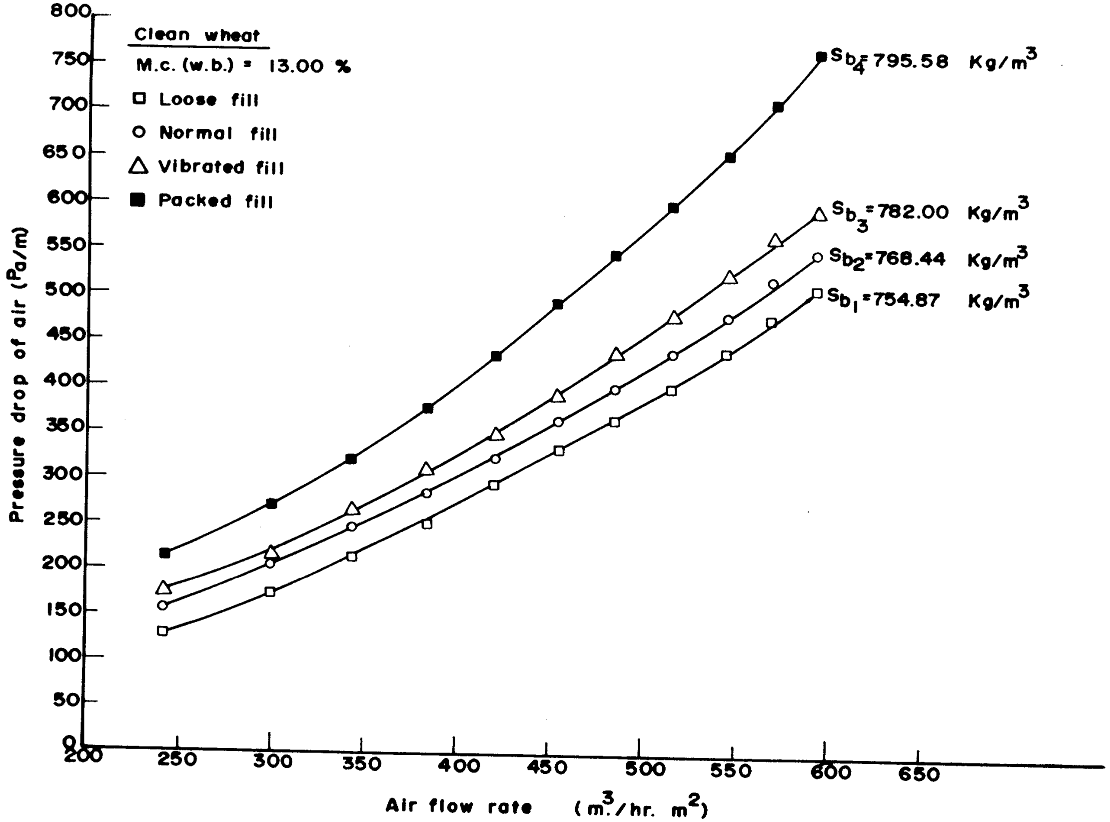


Fig.(15):Resistance of wheat to air flow at different levels of bulk density .

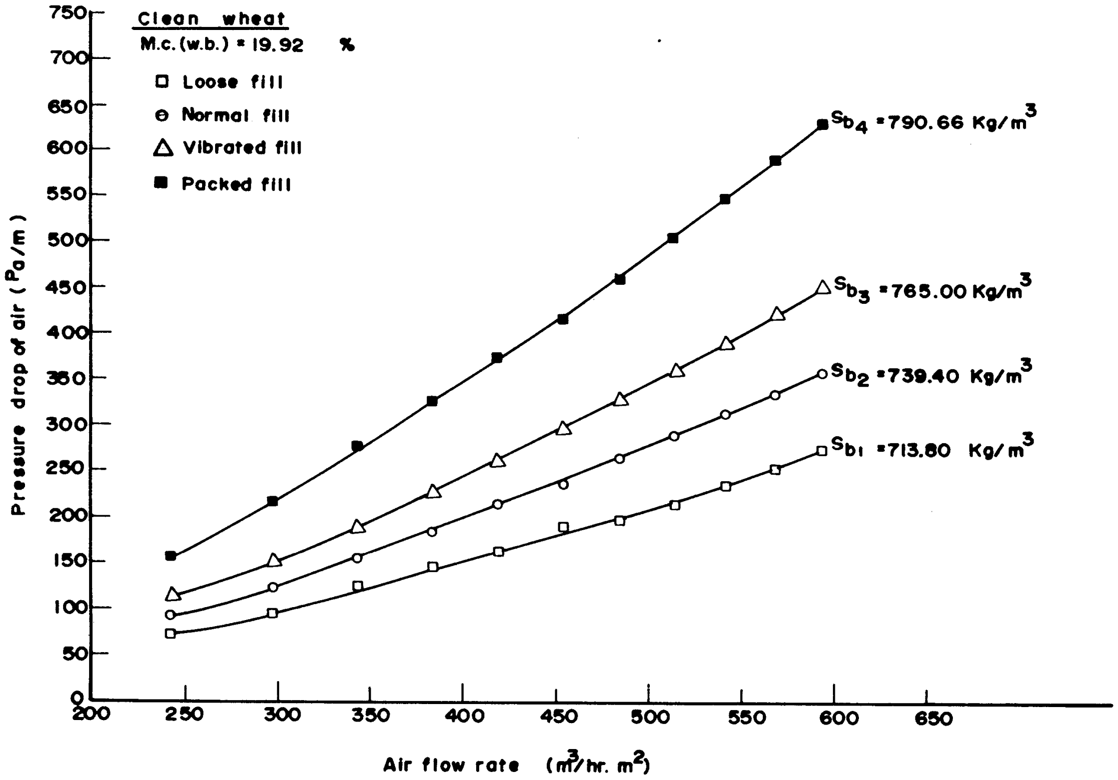


Fig. (16): Resistance of wheat to air flow at different levels of bulk density .

in figures (17, 18 and 19).

Since the relationship between the pressure drop of air, ΔP, and the air flow rate, Q, can be presented as a power relationship , the linear relationship between logs of pressure drop and air flow rate can be expressed as follows:

$$\log \Delta P = \log K + a \log Q \qquad (2)$$

The constants (K) and (a) in the previous relationship were determined for each set of condition by linear regression analysis involving transformation of the original data to logarithmic values , using a computer program in the computer unit of the central Research Laboratory in the Faculty of Agriculture , Alexandria University. The accuracy of the calculated equations and the experimental data points, the coefficient of multiple determination, R-squared, was calculated for each experiment. Tables (1 and 2) indicated the values of (K). (a) and R-squared for each set of experiments of clean paddy rice and clean wheat . Two examples are given to indicate the mathematical form of the previous relationship in the case of loose filled at moisture contents of 11.22% and 10.48% wet basis for paddy rice and wheat, respectively.

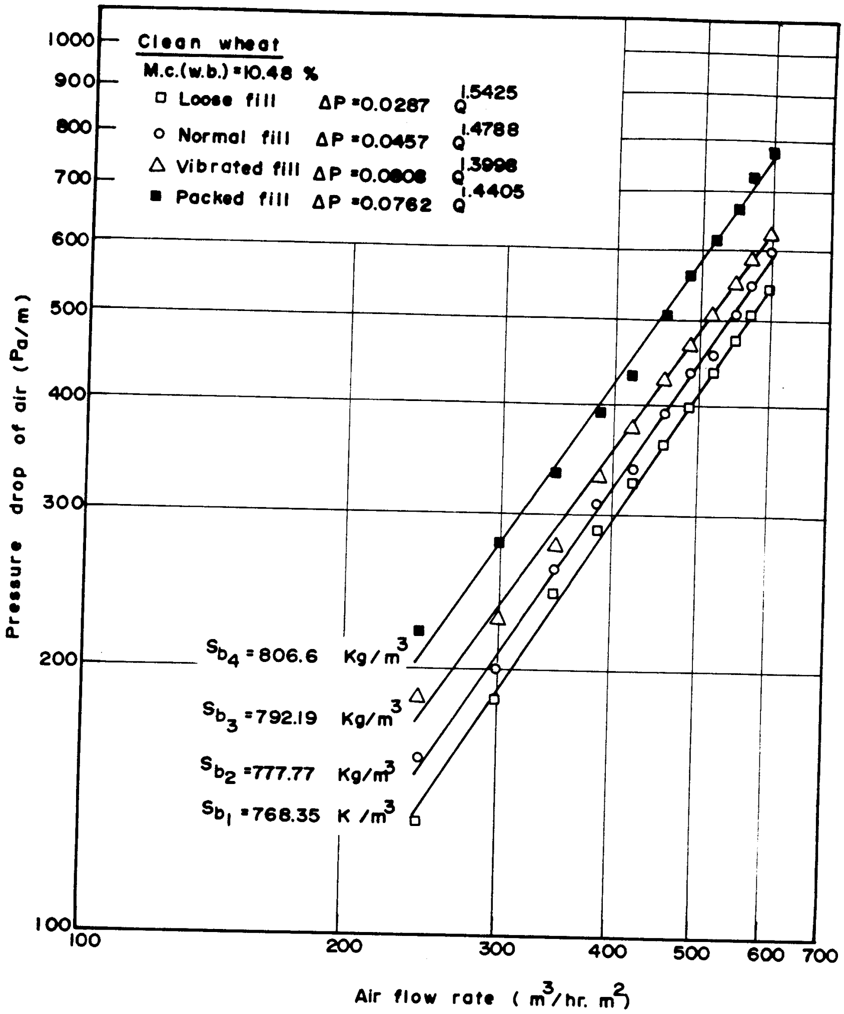


Fig.(17): Resistance of wheat to air flow at different levels of bulk density.

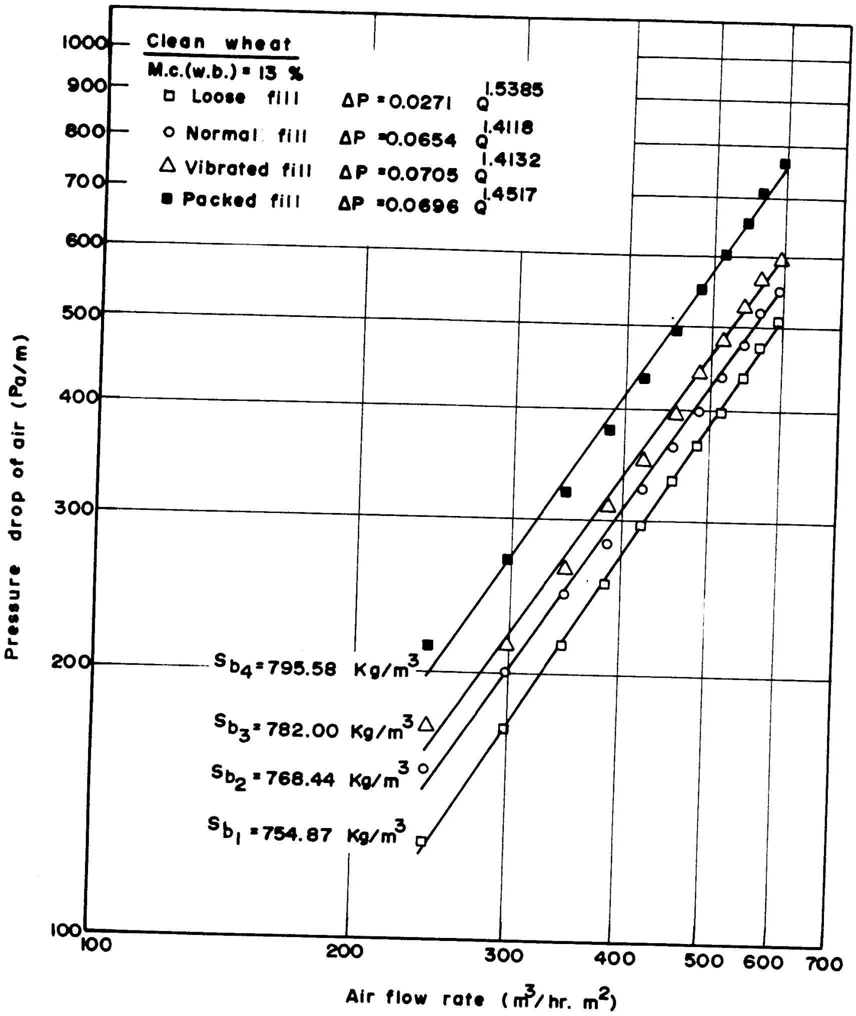


Fig.(18):Resistance of wheat to air flow at different levels of bulk density.

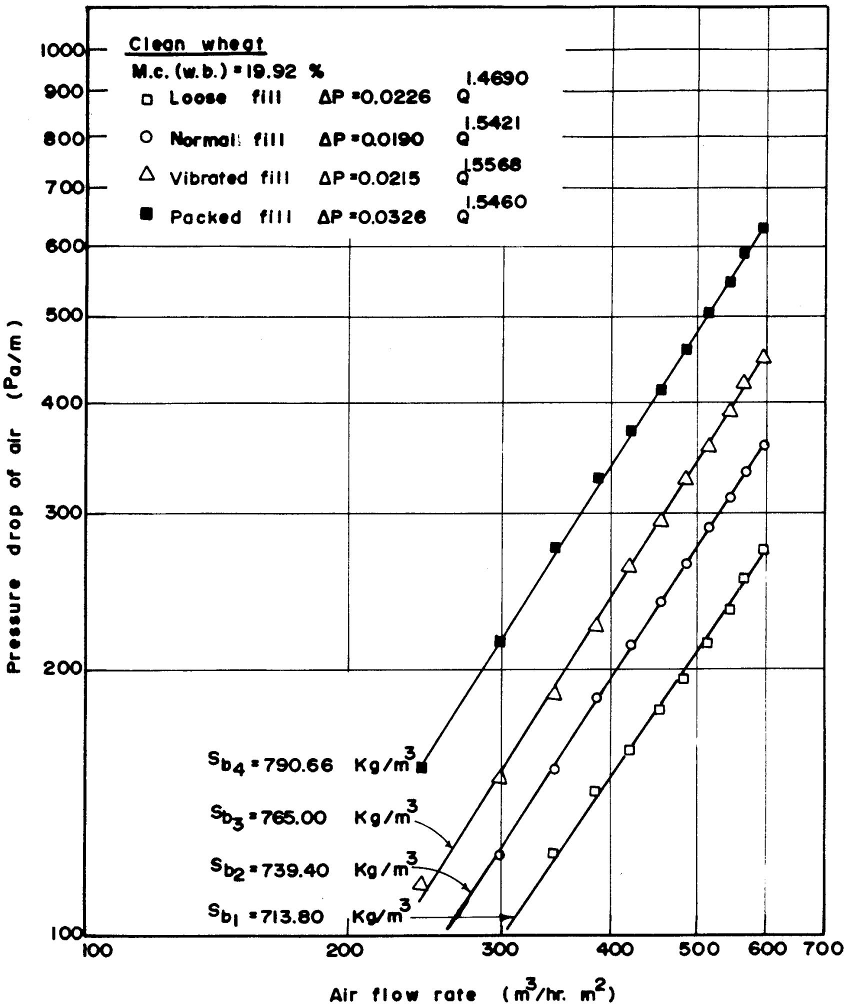


Fig.(19): Resistance of wheat to air flow at different levels of bulk density .

For paddy rice

$$\Delta P = 0.0380 \; Q^{1.3635} \qquad (3)$$

For wheat

$$\Delta P = 0.0287 \; Q^{1.5425} \qquad (4)$$

Results of the predicted equations and the experiments observations indicated that the pressure drop in beds of paddy rice or wheat under a given condition increased linearly with increasing air flow rate. It was also noted that at the same level of moisture content, the pressure drop increased as the bulk density of grain increased. This is inspected to be because of the reduction in the air spaces in the grain mass due to the compactness effect. This conclusion was obtained for all levels of moisture contents and different values of bulk density which were varying between loosely filled to fully compacted of paddy rice or clean wheat. For instance, at paddy rice moisture content of 19.27% wet basis and air flow rate of 515 $m^3/hr.m^2$, the pressures drop of air were 381.76,447.2, 507.12 and 575.5 Pa/m at bulk densities of 637, 650.5 , 663.5 and 677.26 kgs/m^3, respectively, as indicated in Figure (9). In addition, at a given level of moisture content, the value of the constant (K) increased as the grain bulk density increased from loosely filled to packed

Table (1): Calculated values of the constants K and a and R^2 for studying the effect of air flow rates on pressure drop of air through paddy rice.

The method of filling test bin	Moisture contents (wet basis) %																	
	11.22 ± 1			14.35 ± 1			17.00 ± 1			19.27 ± 1			21.53 ± 1			24.30 ± 1		
	K	a	R^2	K	a	R^2	K	a	R^2	K	a	R^2	K	a	R^2	K	a	R^2
Loose	0.0380	1.4549	0.9979	0.00745	1.699	0.9929	0.0169	1.5884	0.9900	0.0471	1.4401	0.9977	0.1196	1.3047	0.9995	0.2053	1.2333	0.99
Normal	0.0427	1.4797	0.9955	0.0247	1.5424	0.9344	0.0433	1.4734	0.9894	0.0559	1.4397	0.9825	0.1622	1.2767	0.9951	0.1977	1.2601	0.99
Vibrated	0.0491	1.4727	0.9863	0.04905	1.46508	0.9449	0.0572	1.4505	0.9981	0.1053	1.3582	0.9980	0.1739	1.2863	0.9983	0.1862	1.2878	0.99
Packed	0.0547	1.4758	0.9976	0.0645	1.4466	0.94879	0.1607	1.3052	0.9949	0.1533	1.3162	0.9878	0.2255	1.2617	0.9957	0.1899	1.3017	0.99

Air flow rates range from 240 to 600 m^3 / hr. m^2

Predicted equation is in the form $\Delta P = K Q^a$

Table (2): Calculated values of constants K and a, and R^2 for studying the effect of air flow rates on pressure drop of air passage through wheat at different levels of moisture content and methods of filling the test bin.

Methods of filling test bin	Moisture contents wet basis %								
	10.48 ± 1			13.00 ± 1			19.92 ± 1		
	K	a	R^2	K	a	R^2	K	a	R^2
Loose	0.0287	1.5425	0.9986	0.0271	1.5385	0.9996	0.0226	1.4690	0.9986
Normal	0.0457	1.4788	0.9963	0.0654	1.4118	0.9983	0.0190	1.5421	0.9993
Vibrated	0.0808	1.3998	0.9968	0.0705	1.4132	0.9966	0.0215	1.5568	0.9994
Packed	0.0762	1.4405	0.9958	0.0696	1.4517	0.9948	0.0326	1.5460	0.9995

- Air flow rates range from 240 to 600 $m^3/hr.m^2$.
- Predicted equation is in the form of $\Delta P = K Q^a$.

fill, as indicated in tables (1 and 2). For instance, at paddy rice moisture content of 17 % wet basis the values of the constant K are 0.0169, 0.0433, 0.0572 and 0.1607 for bulk densities of 617, 631.2, 644.78 and 658.35 kgs/m^3 , respectively . Therefore, the constants (K) can be taken as a function of grain density in this case. In addition, the value of exponent (a) is almost constant at different bulk densities . The variation in the value of (a) at a given level of moisture content and different levels of bulk density were very small . However, the curves in figures (11, 12, 13, 17, 18 and 19) were parallel . In all sets of experiments of paddy rice , the variation in the values of the slope of the lines (a) ranged between a minimum value of 1.2333 and a maximum value of 1.5884 with averaged value of 1.3635 . In wheat experiments , the variation in the values of the slope of the lines (a) ranged between a minimum value of 1.3998 and a maximum value of 1.5568 with averaged value of 1.4828.

The accuracy of the previous predicted equations was measured . When the observed values of the pressure drop were plotted against the calculated values from the above equations, the points lie close to a straight line inclined with angle equal to 45° as shown in tables (3 and 4) and in figures (20 and 21) for paddy rice and wheat, respectively.

Pressure Drop of Air at Different Bulk Densities and at Constant Moisture Content.

One of the purposes of the test explained here was to obtain data on the resistance offered by mainly paddy rice and clean wheat to air flow at different bulk densities. Three levels of air flow namely low, medium, and high (297,545 and 569 $m^3/hr.m^2$), were designed to complete this analysis. The method of filling the test bin controlled the bulk density of grains. Four methods of filling the test bin at constant moisture content which named loose filled, normal filled , vibrated fill and packed fill were taken into consideration in this analysis. The paddy rice bulk densities were ranged from 601.27 kg/m^3 to 640.57 kg/m^3 at moisture content of 11.22% wet basis, from 637 to 677.26 kg/m^3 at moisture content of 19.27% and from 659.88 to 700.59 kg/m^3 at moisture content of 24.3%. Also, the clean wheat bulk densities were ranged from 763.35 to 806.61 kg/m^3 at moisture content of 10.48%, from 754.87 to 795.58 kg/m^3 at moisture content 13% and from 713.8 to 790.66 kg/m^3 at moisture content of 19.92%. Tables(5 and 6)

Table (3): Shows the predicted values of the pressure drop of air compared to the observation values at several levels of moisture contents and two levels of bulk density of paddy rice.

Air flow rates $m^3/hr.m^2$	Paddy rice moisture content wet basis %							
	11.22 ± 1				19.27 ± 1			
	Paddy rice bulk density, S_b, kg/m^3							
	601.27		640.57		637.00		677.26	
	Obser-vation values	● Predi-cted values	Obser-vation values	■ Predi-cted values	Obser-vation values	⌀ Predi-cted values	Obser-vation values	⌀ Predi-cted values
242.74	116.00	112.18	188.03	181.12	123.90	128.192	225.00	211.28
297.29	153.87	150.66	242.16	244.29	178.06	171.65	270.60	275.89
343.29	182.33	185.74	301.99	302.07	213.67	211.16	336.00	324.12
383.81	213.67	218.48	347.58	356.14	245.00	247.97	364.67	361.00
420.44	245.10	249.46	398.86	407.42	290.59	282.75	398.80	435.37
454.13	273.50	279.07	444.40	456.51	319.00	315.95	490.00	481.86
485.48	296.29	307.53	504.27	503.77	347.58	347.83	527.00	526.11
514.93	336.18	335.04	252.70	549.52	381.76	378.62	575.50	568.51
542.79	370.37	361.74	606.84	593.95	404.50	408.47	618.00	609.34
569.28	398.86	387.71	646.70	637.23	433.00	437.48	663.80	648.78
594.59	427.35	413.04	692.00	679.48	464.39	465.77	706.50	687.01

● $\Delta P = 0.0380 \; Q^{1.4549}$ ⌀ $\Delta P = 0.0471 \; Q^{1.4401}$

■ $\Delta P = 0.0547 \; Q^{1.4758}$ ⌀ $\Delta P = 0.1533 \; Q^{1.3162}$

Table (4): Shows the predicted values of the pressure drop of air compared to the observation values at several levels of wheat moisture contents and two levels of bulk densities.

Air flow rates Q $m^3/hr.m^2$	Wheat moisture content wet basis %							
	13.00 ± 1				19.92 ± 1			
	Wheat bulk density , S_b, kg/m^3							
	754.87		795.58		713.80		790.66	
	Observation values	•Predicted values	Observation values	■Predicted values	Observation values	∅Predicted values	Observation values	∅Predicted values
242.74	128.20	124.21	213.67	201.89	71.22	72.09	156.69	158.72
297.29	173.79	169.55	270.65	270.97	96.86	97.09	216.52	217.14
343.29	216.50	211.45	321.90	333.90	122.50	119.94	276.35	271.23
383.81	253.56	250.95	378.90	392.61	145.29	141.31	327.63	322.30
420.44	296.20	288.63	435.89	448.16	162.39	161.55	373.20	371.07
454.13	333.30	324.89	492.80	501.23	179.48	180.92	415.95	418.04
485.48	364.67	359.95	549.86	552.23	196.58	199.56	461.54	463.48
514.93	401.91	394.00	601.14	601.52	213.67	217.60	507.00	507.66
542.79	438.74	427.16	655.20	649.34	233.60	235.11	549.86	550.75
569.28	475.78	459.61	712.20	695.85	253.50	252.16	592.59	592.85
594.59	509.97	491.35	769.20	741.21	273.50	268.80	632.48	634.10

• $\Delta P = 0.0271\ Q^{1.5350}$ ∅ $\Delta P = 0.0226\ Q^{1.4690}$

■ $\Delta P = 0.0696\ Q^{1.4517}$ ∅ $\Delta P = 0.0326\ Q^{1.5460}$

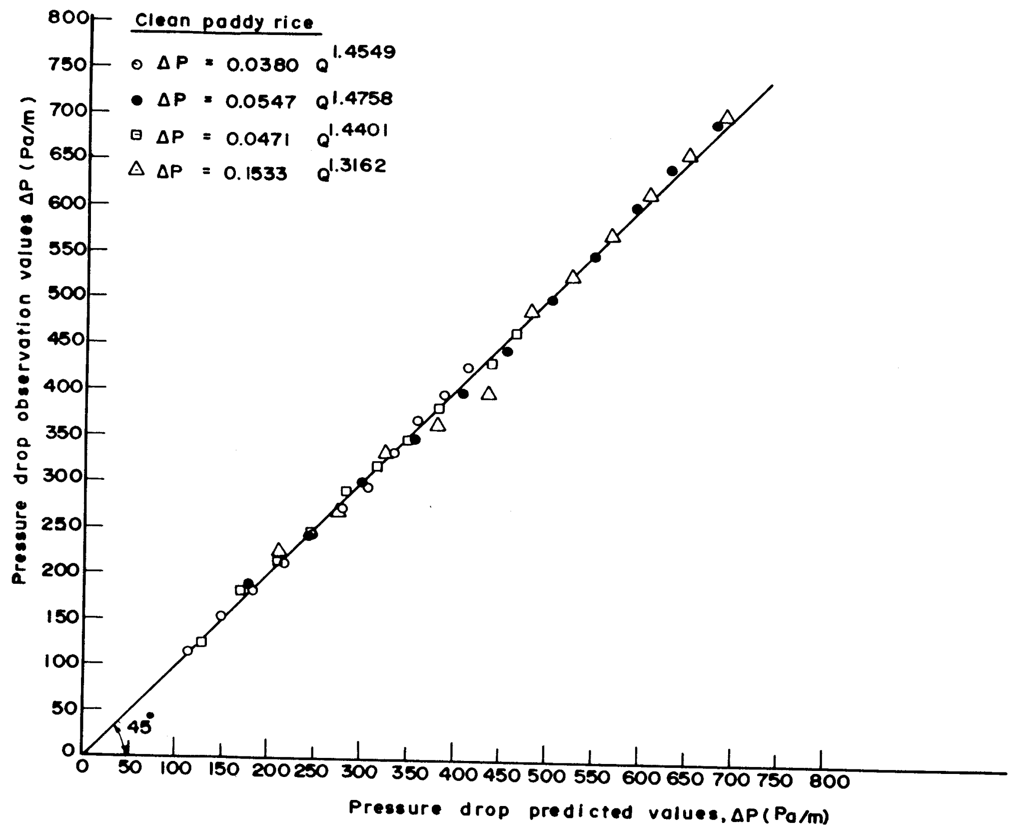


Fig.(20): Observed and predicted values of pressure drop of air in paddy rice.

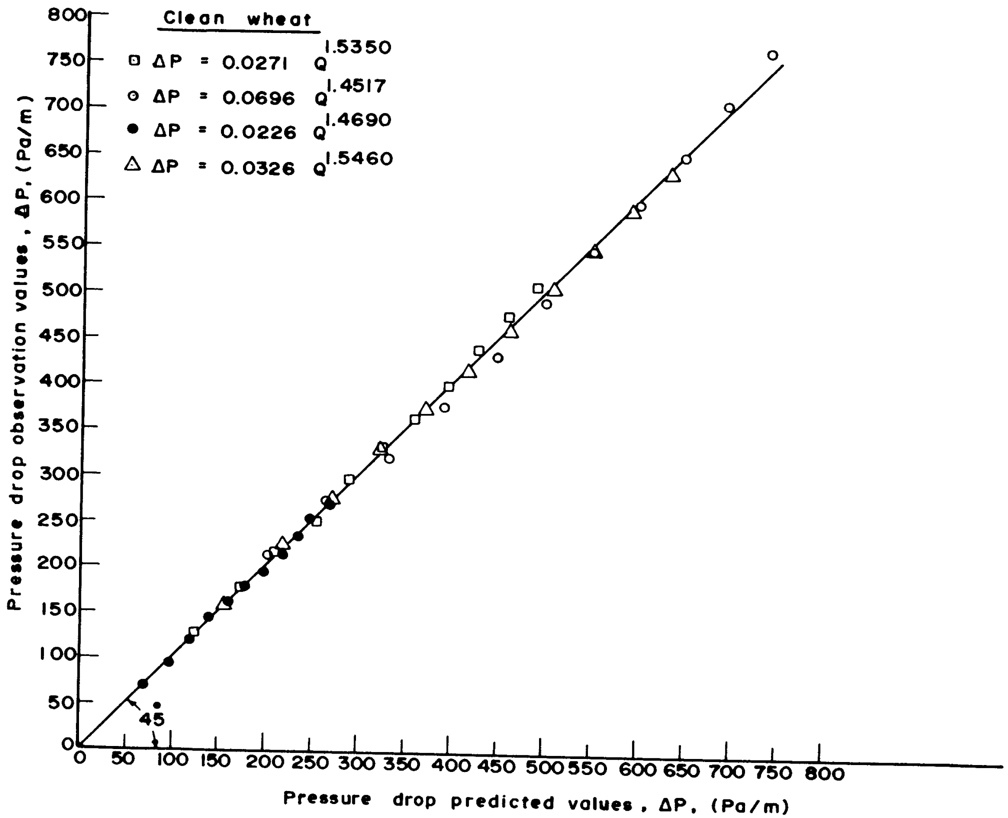


Fig.(21): Observed and predicted values of pressure drop of air in clean wheat.

Table (5): **Effect of paddy rice bulk densities on the pressure drop of air at low, medium and high air flow rates per unit cross sectional area of test bin.**

Air flow rates $m^3/hr.m^2$	Paddy rice moisture content wet basis %											
	11.22 ± 1				19.27 ± 1				24.30 ± 1			
	Paddy rice bulk density, S_b, kg/m^3											
	601.27	614.60	627.40	640.57	637.00	650.50	663.50	677.26	659.88	673.45	687.00	700.59
	Pressure drop of are, ΔP, Pa / m											
297.29	153.87	196.58	192.30	242.16	158.00	176.63	236.40	270.60	227.92	257.83	287.75	319.00
454.13	273.50	354.70	398.88	444.40	319.09	367.50	411.68	490.00	384.60	435.89	487.18	541.30
569.28	398.86	521.30	566.91	646.70	433.05	515.67	586.89	663.80	521.37	595.44	669.50	743.50

Predicted equation is in the form $\Delta P = K S_b^a$.

Table (6): Observation values of wheat bulk densities and the pressure drop of air at low, medium and high air flow rates per unit cross sectional area of test bin.

Air flow rates Q $m^3/hr.m^2$	Wheat moisture content wet basis %											
	10.48 ± 1				13.00 ± 1				19.92 ± 1			
	Wheat bulk densities, S_b, kg/m^3											
	763.35	777.77	792.19	806.61	754.87	768.44	782.00	795.58	713.80	739.40	765.00	790.66
	Pressure drop of air, ΔP, Pa/m											
297.29	185.18	199.43	227.92	276.35	173.79	202.28	216.52	270.65	96.86	122.50	150.99	216.52
454.13	360.40	391.72	427.35	504.27	333.30	364.67	393.16	492.80	179.48	239.30	296.29	415.95
569.28	507.12	544.16	584.00	729.34	475.78	518.52	564.10	712.20	253.50	336.18	421.56	592.59

Predicted equation is in the form $\Delta P = K S_b^a$.

show data obtained by experiments on the resistance of clean paddy rice and clean wheat which affected by the bulk densities at low , medium and high air flow rates per unit cross sectional bin area and at selected grain moisture contents. Data were plotted on ordinary papers in figures (22 and 23) where the horizontal line represents the grain bulk densities in, kg/m^3 , and the vertical line represents the pressure drop of air in Pa/m . The graphs of the data show the curves shape. When these data were plotted on a log-log paper, the relationship becomes linear. So, the relationship fitts the experimental data on studying the effect of bulk density on the pressure drop of air flow by linear regression analysis involving transformation of the original data to logarithmic values.

The relationship of the following type was suggested

$$\Delta P = K\, S_b^a \qquad (5)$$

$$\text{Log}\ \Delta P = \log K + a \log S_b \qquad (6)$$

where:

ΔP is the pressure drop of air per unit depth of grain, Pa/m

S_b is the bulk density of grain, kg/m^3

K and a are constants under a given condition and the units used.

The constant (K) and (a) in the previous relationship were determined for each set of condition. Tables (7 and 8) show the calculated values of the constants K, a and the coefficient of multiple determination which is equal to the value of R^2 for both paddy rice and wheat, respectively.

The predicted values and the data obtained by experiments were plotted in figures (24 and 25). An example is given here,for each type of grain to indicate the mathematical form of the previous relationship . For paddy rice at medium air flow rate of 454.13 $m^3/hr.m^2$ and at moisture content of 11.22% wet basis, the relationship was as follow :

$$\Delta P = 12909.67 (0.001\ S_b)^{7.4965} \qquad (7)$$

The value of R^2 was 0.9549

For clean wheat at medium air flow rate of 454.13 $m^3/hr.m^2$ and at moisture content of 10.48% wet basis, the relationship was as follow :

$$\Delta P = 1759.43 \quad (0.001\ S_b)^{5.949} \qquad (8)$$

The value of R^2 was 0.9654.

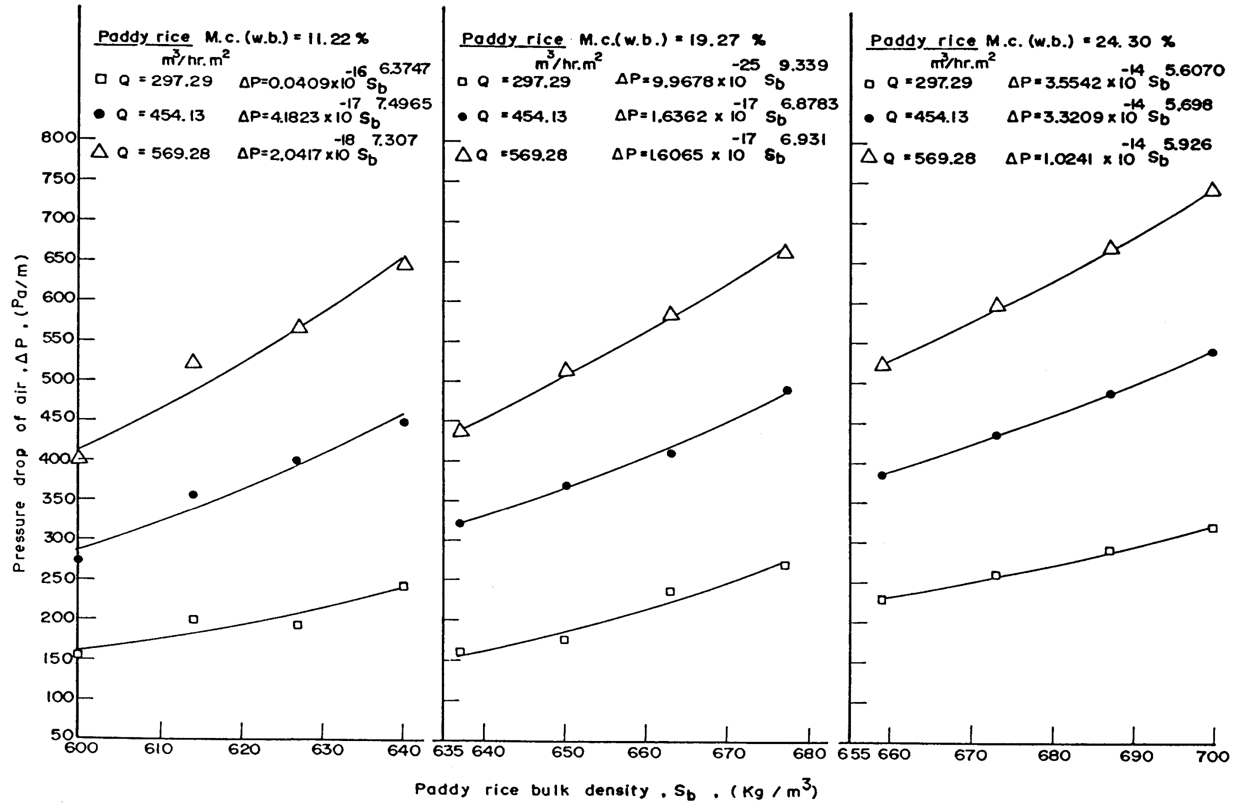


Fig. (22): Paddy rice bulk densities versus pressure drop of air at three levels of air flow rate and three levels of moisture content .

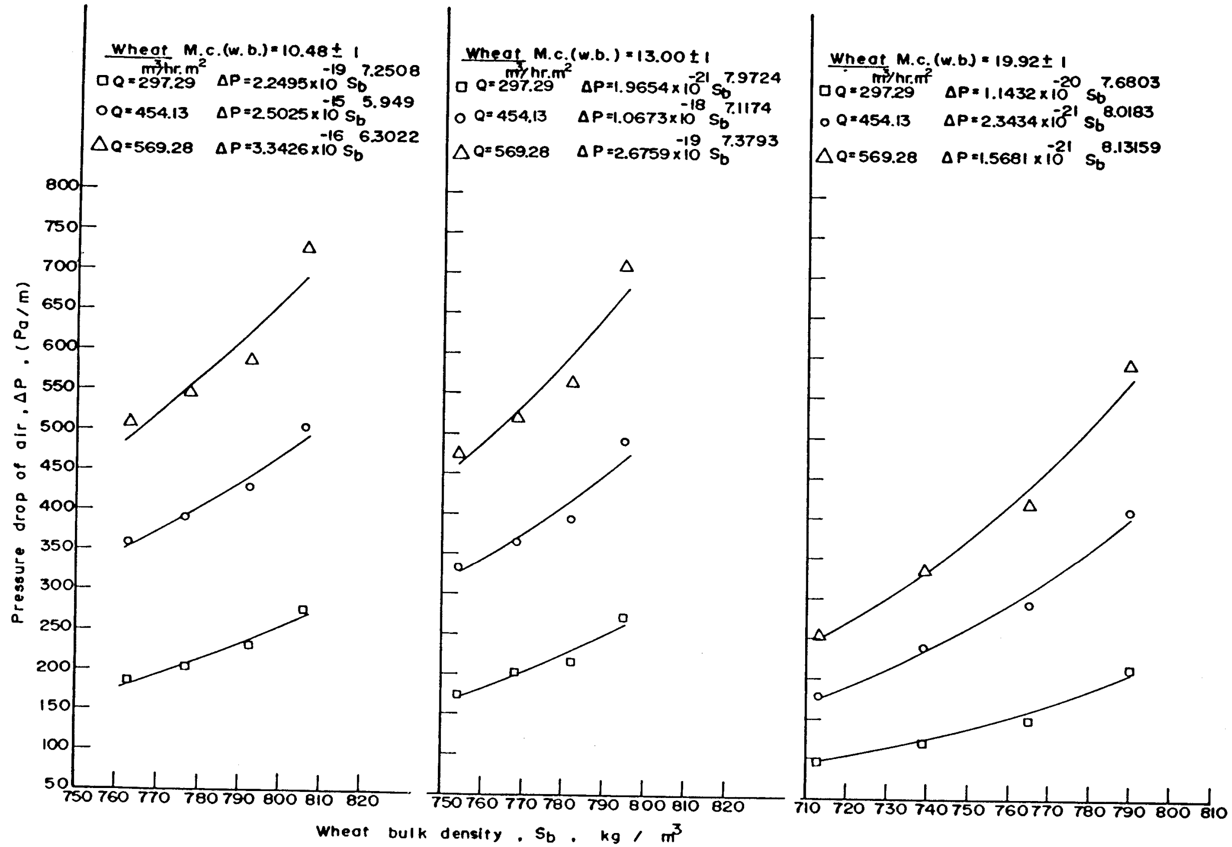


Fig.(23): Wheat bulk densities versus pressure drop of air at three levels of air flow rate and three levels of moisture content.

Table (7): Calculated values of the constants K and a for the relationship of pressure drop of air passing through paddy rice at different values of paddy rice bulk densities and at low, medium and high air flow rates.

Air flow rates $m^3/hr.m^2$	Moisture content wet basis %								
	11.22 ± 1			19.27 ± 1			24.30 ± 1		
	K	a	R^2	K	a	R^2	K	a	R^2
297.29	3.0409×10^{-16}	6.3747	0.8737	9.9678×10^{-25}	9.339	0.9654	3.5542×10^{-14}	5.6070	0.9989
454.13	4.1823×10^{-19}	7.4965	0.9549	1.6362×10^{-17}	6.8783	0.9938	3.3209×10^{-14}	5.698	0.9990
569.28	2.0417×10^{-18}	7.307	0.9478	1.6065×10^{-17}	6.931	0.9938	1.02419×10^{-14}	5.926	0.9980

Predicted equation is in the form of $\Delta P = K S_b^a$

Table (8): Calculated values of the constants K and a for the relationship of pressure drop of air passing through wheat at different values of wheat bulk densities at low, medium and high air flow rates.

Air flow rates $m^3/hr.m^2$	Moisture content wet basis %								
	10.48 ± 1			13.00 ± 1			19.92 ± 1		
	K	a	R^2	K	a	R^2	K	a	R^2
297.29	2.2495×10^{-19}	7.2508	0.9588	1.9654×10^{-21}	7.9724	0.9577	1.1432×10^{-20}	7.6803	0.9809
454.13	2.5025×10^{-15}	5.949	0.9654	1.0673×10^{-18}	7.1174	0.9251	2.3434×10^{-21}	8.0183	0.9915
569.28	3.3426×10^{-16}	6.3022	0.9026	2.6759×10^{-19}	7.3793	0.9239	1.5681×10^{-21}	8.1315	0.9925

Predicted equation is in the form of $\Delta P = K\, S_b^a$

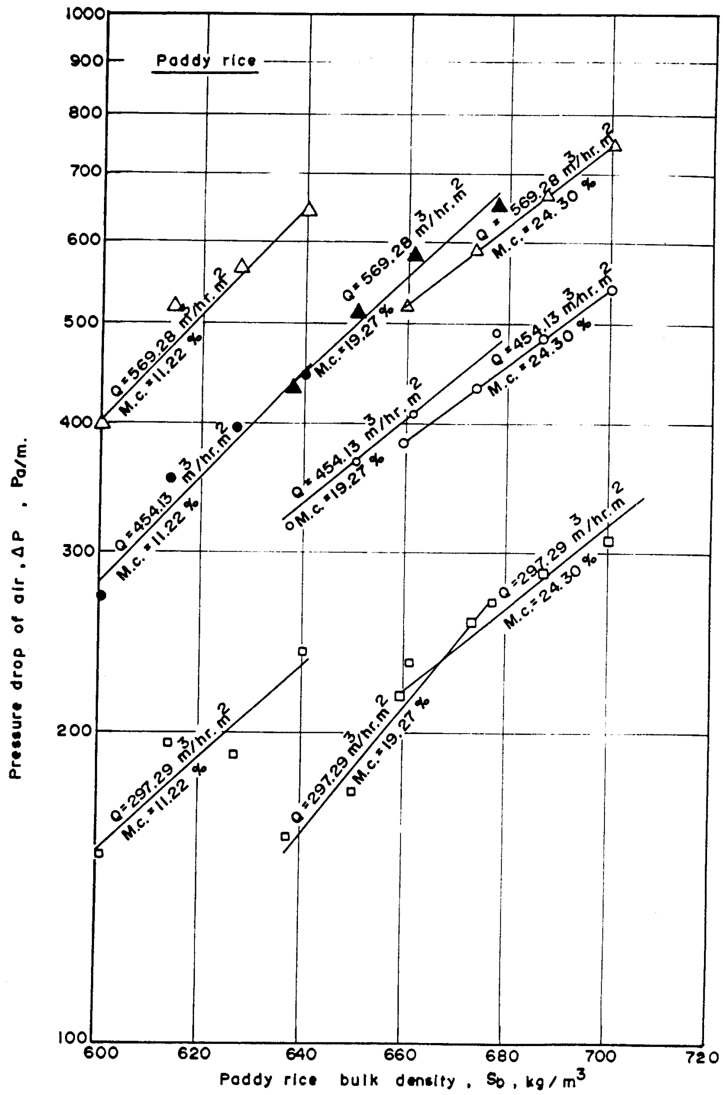


Fig.(24):Predicted and experimental values of pressure drop of air passing through different levels of paddy rice bulk density.

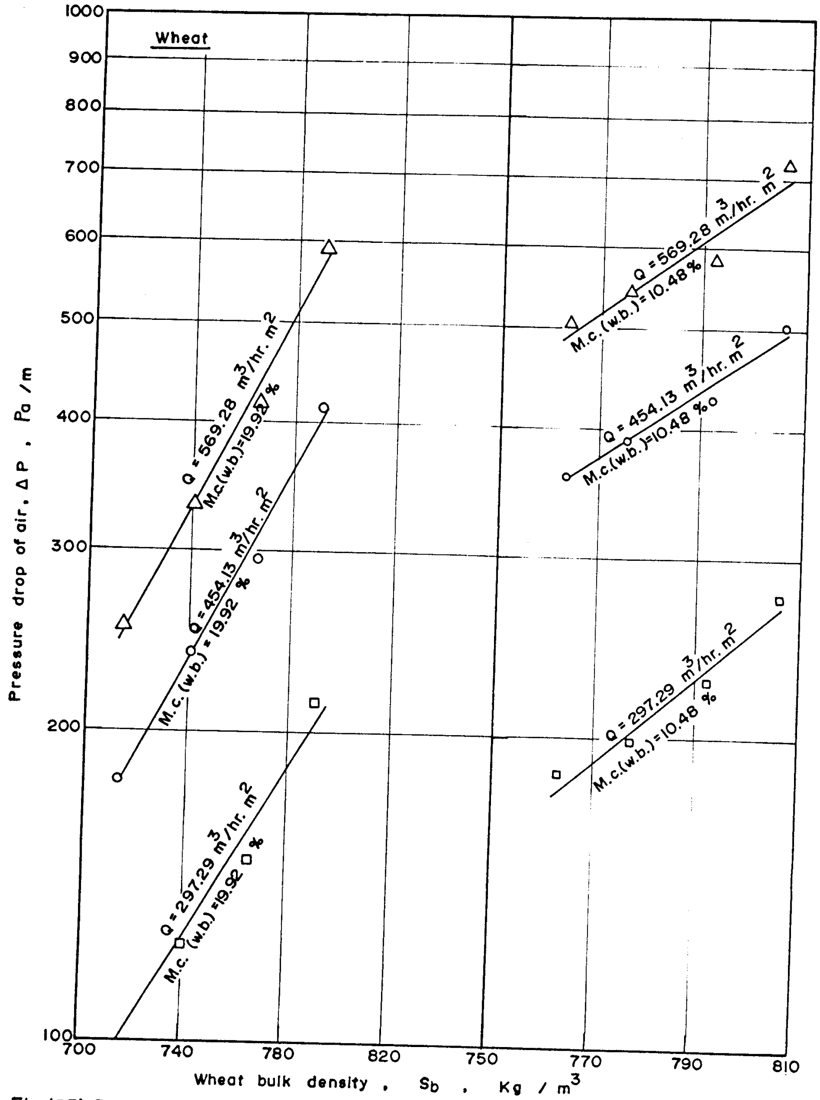


Fig.(25): Predicted and experimental values of pressure drop of air passing through different levels of wheat bulk density.

Data in tables (5 and 6) and figures (22 and 23) for paddy rice and clean wheat show that as the bulk densities of grain increased nonlinearly from loosely filled to packed fill, the resistance of air passing through grains increased at the same level of moisture content and the same quantity of air flow. In other meaning direct proportional was shown between the grain bulk density and pressure drop of air passing through the grain test bin. At loosely filled, the voids fraction (spaces in the grain mass) between grains particles has a value greater than the fully compacted fill. However, the increase in the pressure drop is believed to be due to smaller air passages and consequently more fraction to air flows through the beds. The voids fraction reflects the value of the bulk density of grain in the test bin. The increase of the grain bulk density is also believed to be due to smaller voids fraction in test bin. In paddy rice, the values of the constant(a) which represents the slope of the regression line varies with the values of moisture contents at constant air flow rate. At air flow rate of 569.28 $m^3/hr.m^2$ the values of the constant(a) at moisture contents of 11.22% , 19.27% and 24.30% were 7.307 , 6.931 and 5.926 respectively. The reduction of the value of the constant (a) was found to be due to the increase of moisture content of paddy rice. For all the set of paddy rice experiments, the slope of the non-linear relationship between the bulk density and the pressure drop of air was decreased when the moisture content increased. The averages values of the slopes were 7.0594, 7.7161 and 5.7436 at moisture contents of 11.22%, 19.27% and 24.30% , respectively. At high value of moisture content of 24.30%,the values of the constant(a)were almost equals at small, medium and high air flow rates. So, the variation of the slope at high moisture contents was very small and it can be neglected.

At clean wheat, the values of(a) were increased with respect to increase the values of moisture contents. So, small change in bulk density results rapid change in resistance of air passing through the grain. At air flow rate of 569.28 $m^3/hr.m^2$, the values of the constant(a) were 6.3022, 7.3793 and 8.1315 at moisture contents of 10.48%, 13.00% and 19.92%, respectively. Also, at high moisture content the variation of the slopes was very small. This result agreed with the results obtained of paddy rice at high moisture content.

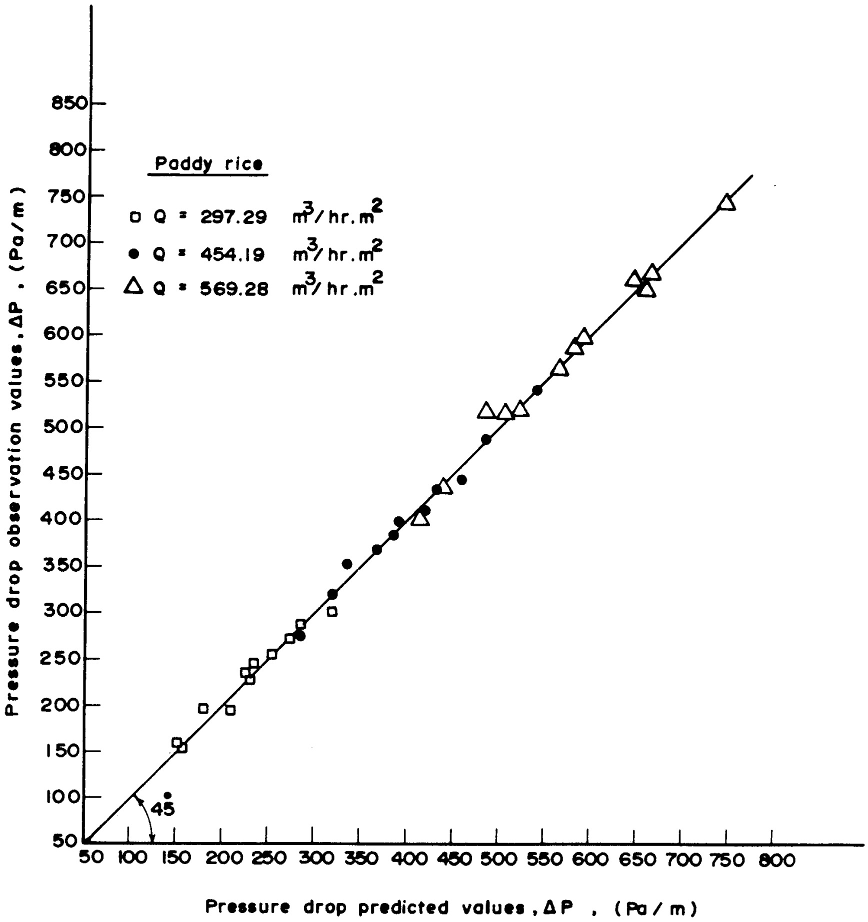


Fig.(26): Observed and calculated values of pressure drop of paddy rice.

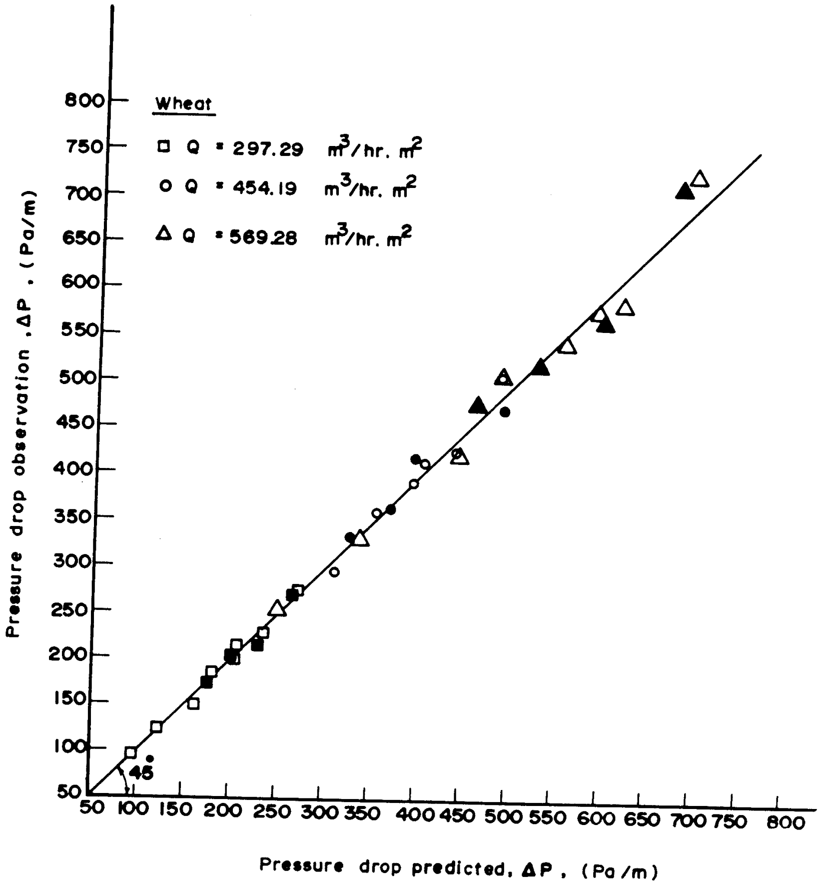


Fig.(27): Observed and calculated values of pressure drop of wheat.

Table (9): **Shows the predicted values of the pressure drop of air compared to the observation values for studying the effect of paddy rice bulk densities on the pressure drop of air at several levels of moisture content and at low, medium and high air flow rates per unit cross sectional area of test bin.**

Air flow rates $m^3/hr.m^2$	Paddy rice moisture content wet basis %											
	11.22 ± 1				19.27 ± 1				24.30 ± 1			
	Paddy rice bulk densities, S_b, kg/m^3											
	601.27	614.60	627.40	640.57	637.00	650.50	663.50	677.26	659.88	673.45	687.00	700.59
	Pressure drop of air, ΔP, Pa/m											
297.29	158.02	181.73	207.25	236.60	153.62	186.86	224.78	272.28	228.81	256.47	286.78	320.07
454.13	284.91	335.80	391.92	457.97	317.35	366.60	420.05	483.75	385.98	433.45	485.55	542.88
569.28	413.66	485.55	564.48	657.01	437.89	506.40	580.84	669.64	523.03	590.08	664.02	745.76

Table (10): Shows the predicted values of the pressure drop of air compared to the observation values for studying the effect of wheat bulk densities on the pressure drop of air at several levels of moisture content and at low, medium and high air flow rates per unit cross sectional area of test bin.

Air flow rates $m^3/hr.m^2$	Wheat moisture content, wet basis %											
	10.48 ± 1				13.00 ± 1				19.92 ± 1			
	Wheat bulk densities, S_b, kg/m^3											
	763.35	777.77	792.19	806.61	754.87	768.44	782.00	795.58	713.80	739.40	765.00	790.66
	Pressure drop of air, ΔP, Pa/m											
297.29	179.53	205.62	234.91	267.74	172.58	198.92	228.69	262.33	93.48	123.58	160.51	206.80
454.13	352.93	394.50	440.05	489.90	324.52	368.40	417.24	471.64	178.10	236.25	310.39	404.38
569.28	491.57	553.10	620.99	695.76	461.47	526.32	598.83	679.96	250.74	333.93	440.41	575.94

The accuracy of the previous equation was measured by the coefficient of multiple determination which is equal to the value of R^2 indicated in the range from 0.8737 to 0.999 for set of experiments of paddy rice and from 0.9026 to 0.9925 for set of experiments of clean wheat. In addition, when the observed values of the pressure drop were plotted against the calculated values from the equations, the point lie close to a straight line inclined with an angle equal to 45° as shown in figures (26 and 27) for paddy rice and clean wheat, respectively. Tables (9 and 10) show the predicted values of pressure drop of air of paddy rice and wheat, respectively.

Pressure Drop - Air Flow Relationship at Different Bulk Density and at Constant Moisture Content

Pressure drop of air passing through beds of paddy rice or wheat was found to be affected by two independent variables as previously indicated.The variables are the air flow rate per unit cross sectional area, Q, and the bulk density of grain. These two variables may be inserted in the right hand side of the relationship of $\Delta P = K Q^a$ as independent variables to indicate their effect on the pressure drop. The relationship was shown as follows:

$$\Delta P = K\, Q^{a}\, S_b^{b} \qquad (9)$$

The linear relationship between the pressure drop, ΔP, air flow rate, Q, and grain density, S_b , can be expressed as follows:

$$\text{Log}\,\Delta P = \text{Log}\,K + a \log Q + b \log S_b \qquad (10)$$

The constants K, a and b and the coefficient of multiple determination, R^2, were determined for paddy rice and wheat at different levels of moisture content. Table (11)shows the calculated values of the constants K, a and b for paddy rice. The ranges for appling the constants in table (11) and in equation (11) are the air flow rates range from 240 to 600 $m^3/hr.m^2$ and the paddy rice bulk densities from 595 to 705 kg/m^3.

For instance, the pressure drop of air passing through paddy rice at moisture content 19.27% wet basis as follows:

$$\Delta P = 1.5273\; Q^{1.3885}\, (0.001\, S_b)^{6.997} \qquad (11)$$

For clean wheat, table (12) shows the calculated values of the constants K, a and b at three levels of moisture content of 10.48%, 13.00% and 19.92% wet basis . The ranges

Table (11): Calculated values of the constants K, a and b for studying the effect of air flow rates and paddy rice bulk densities on pressure drop air at five levels of moisture content.

Serial No.	Moisture content wet basis %	Values of constants			Coeff. of determination R^2
		K	a	b	
1	11.22	6.3863×10^{-23}	1.4708	7.4670	0.9871
2	17.00	1.0119×10^{-24}	1.4544	8.0947	0.9887
3	19.27	1.5598×10^{-21}	1.3885	6.9970	0.9908
4	21.53	9.1230×10^{-20}	1.2821	6.4516	0.9973
5	24.30	2.7214×10^{-17}	1.2707	5.5972	0.9976

Predicted equation is in the form of $\Delta P = K\ Q^a\ S_b^b$.

Table (12): Calculated values of the constants K, a and b for studying the effect of air flow rate and wheat bulk density on pressure drop of air at three levels of moisture content.

Serial No.	Moisture contents wet basis %	Values of constants			Coeff. of determin-ation R^2
		K	a	b	
1	10.48	2.6010×10^{-20}	1.4654	6.3259	0.9910
2	13.00	7.4204×10^{-24}	1.4538	7.5674	0.9903
3	19.92	3.3916×10^{-25}	1.5285	7.9414	0.9953

Predicted equation is in the form of $\Delta P = K\, Q^a\, S_b^b$.

for applying the calculated constants in table (12) and in equation (12) are:Air flow rate from 240 to 600 $m^3/hr.m^2$ and clean wheat bulk density from 710 to 810 kg/m^3.

For instance, the pressure drop of air passing through wheat at moisture content 19.92% wet basis was presented as follows:

$$\Delta P = 0.2262\ Q^{1.5285}\ (0.001\ S_b)^{7.9414} \qquad (12)$$

The importance of these multiple formulas can be applied for wide range which includes independent two variables, the air flow rate and the bulk density of grain. In addition, the prediction of air pressure drop can not be obtained by applying equations from the type $\Delta P = K\ Q^a$ if one or more from the other variables changed than that originally observed.

Pressure Drop of Air at Different Moisture Content Wet Basis and Constant Bulk Density

Moisture content of grains is useful in determining the market grade of grain . It is also important in management decisions relating to conditioning and storage of grain. So, the research work was extended to study the effect of moisture content of paddy rice and wheat on the pressure drop of air passing through the grain test bin.

The relationship was in the following form:

$$\Delta P = K \ MC^{a} \qquad (13)$$

The nonlinear relationship between the pressure drop and the moisture content wet basis percentage can be expressed as follows:

$$\text{Log} \ \Delta P = \log K + a \log \ MC \qquad (14)$$

The constants of the values K and a were determined. Two levels of air flow rates per unit of cross sectional area of test bin of 454.13 and 569.28 $m^3/hr.m^2$ were selected. A level of grain bulk density was choosen. The bulk densities of paddy rice and clean wheat were 649.04 and 765 kg/m^3, respectively. Moisture content ranges from 14.35% to 21.53% wet basis for paddy rice. Moisture contents were 10.48%, 13.00% and 19.92% wet basis for clean wheat. Tables (13 and 14) show the constants of the value K and a for paddy rice and wheat, respectively.

For instance, the predicted pressure drop per unit depth for air passing through paddy rice at 569.28 $m^3/hr.m^2$ and

Table (13): Calculated values of the constants K and a for the relationship of pressure drop of air passing through paddy rice at constant bulk density of 649 kg/m^3.

Air flow rates $m^3/hr.m^2$	The constants		Coeff. of determination R^2
	K	a	
454.13	2358.96	-0.623	0.951
569.28	4916.24	-0.7627	0.9989

Predicted equation is in the form of $\Delta P = K\ MC^a$

Table (14): Calculated values of the constants K and a for the relationship of pressure drop of air passing through wheat at constant bulk density of 765 kg/m^3.

Air flow rates $m^3/hr.m^2$	The constants		Coeff. of determination R^2
	K	a	
454.13	1193.8	-0.4898	0.8691
569.28	1102.2	-0.315	0.8232

Predicted equation is in the form of $\Delta P = K\ MC^a$

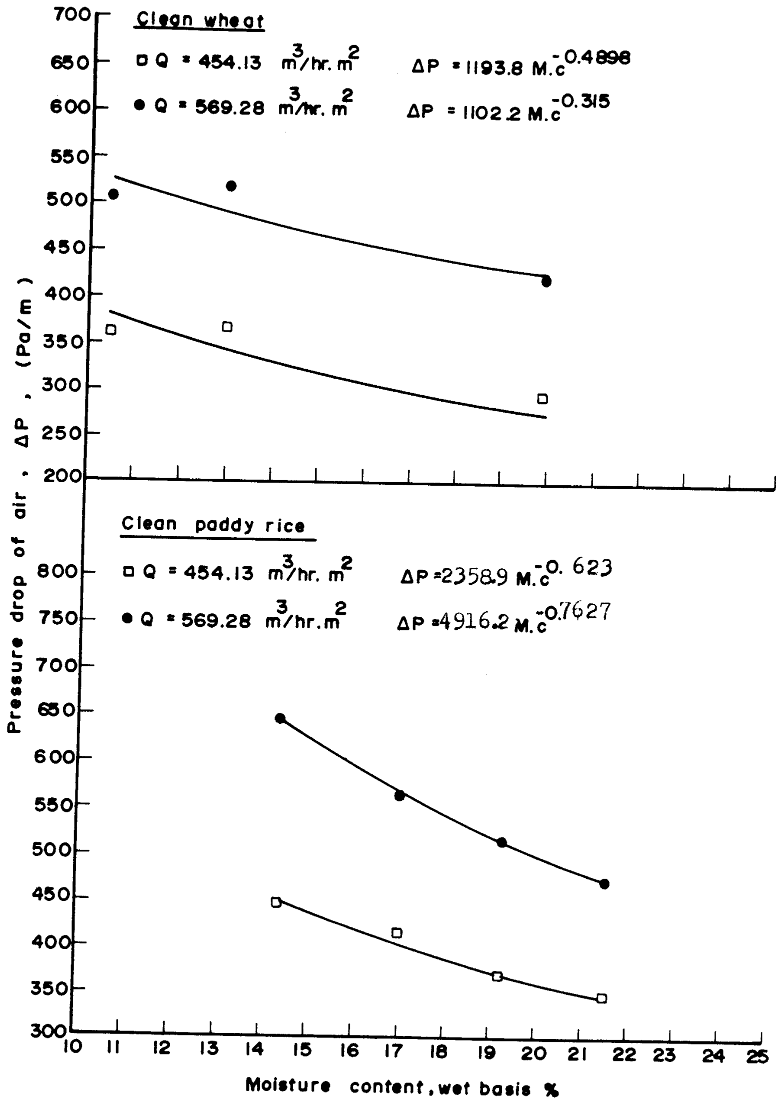


Fig.(28):Observations and predicted values of pressure drops as effected by moisture contents for clean paddy rice and clean wheat.

grain bulk density of 649 kgs/m^3 was as follows:

$$\Delta P = 4916.24\ MC^{-0.7627} \qquad (15)$$

For clean wheat, the predicted pressure drop per unit depth for air passing through grain bulk density of 765 kg/m^3 and air flow rate of 569.28 $m^3/hr.m^2$ was as follows:

$$\Delta P = 1102.2\ MC^{-0.315} \qquad (16)$$

Figure (28) shows the observations and the predicted values of the pressure drop of air as affected by grain moisture contents for paddy rice and wheat, respectively.

The results obtained indicated that paddy rice and clean wheat were found to display a decrease in pressure drop of air with increasing moisture content. This invers relationship may be related to the increase of the pore space between the grain particles. The voids in grains increase when the volume of the grain particle increases. Consequently the volume of the grain particle is affected by the voids fraction which increases when the volume of grain particle increases. On other word, the moisture content affects on the bulk density of grain. It was found that as the moisture content increases the bulk densities

Table (15): Show the effect of paddy rice moisture contents on the pressure drop of air at constant bulk density of 649 kg/m^3.

Air flow rates ($m^3/hr{\cdot}m^2$)	Moisture contents wet basis %			
	14.35	17.00	19.27	21.53
	Pressure drop of air, Δ P, Pa/m			
454.13	444.4	413	367.5	347.5
569.28	646.7	564	515.67	472.9

Table (16): Show the effect of wheat moisture contents on the pressure drop of air at constant bulk density of 765 kg/m^3.

Air flow rates ($m^3/hr.m^2$)	Moisture contents wet basis %		
	10.48	13.00	19.92
	Pressure drop of air, Δ P, Pa/m		
454.13	360.4	364.67	296.29
569.28	507.12	518.52	421.65

of paddy rice and clean wheat decreased. This results agreed with experiments running on barley, corn, sorghum, oats and soybeans by Hindey (1980), Browne (1962), Brusewitz (1975).

The Relationship Between the Pressure Drop and Air Flow Rates, Grain Bulk Densities and Grain Moisture contents

In practice, the use of relationships of the type $\Delta P = K\ Q^a$ or $\Delta P = K\ Q^a\ S_b^b$ are always subject to several approximations which may lead to unsatisfactory estimation of the power required to operate the system . However, these relationships were essential in the present work to understand easily the effect of each single variable on the pressure drop. This enabled the study of other variables through multiple relationships.

One of the important results obtained from this work is a multiple relationship between the pressure drop, ΔP, as dependent variable and the air flow rate, Q , moisture content, MC, and grain bulk density, S_b , as independent variables.

The relationship between these variables may be written in the form :

$$\Delta P = K\ Q^{a}\ S_b^{b}\ MC^{c} \qquad (17)$$

The nonlinear relationship between the pressure drop and the other three variables can be expressed as follows:

$$\text{Log}\ \Delta P = \log (K) + a \log (Q) + b \log (S_b) + c \log (MC) \qquad (18)$$

The constants K, a, b and c and the coefficient of multiple determination were determined by a standard regression model. The relationship between the variables in its general form for the paddy rice at different values of air flow rates, bulk density, and moisture contents was found to be presented as follows :

$$\Delta P = 3.8819 \left[\frac{Q^{1.3635} (0.001\ S_b)^{5.8833}}{MC^{0.4184}} \right] \qquad (19)$$

where:

ΔP = pressure drop , Pascal per meter depth of paddy rice.

Q = air flow rate, cubic meter per hour per square meter of the cross sectional area.

S_b = paddy rice bulk density, kilogram per cubic meter.

MC = percentage moisture content of paddy rice(wet basis).

The value 3.8819 is depending on these units and the material used (paddy rice) under a given condition.

The coefficient of multiple determination (R^2) of the above predicted equation was 95.67%. The range of application of the above predicted equation has been found to be presented as follows:

Q : in the range between 240 to 600 cubic meter per hour per square meter.

S_b : From loosely fill paddy rice to fully compacted fill. Bulk density in the range between 595 to 705 kgs/m^3 .

MC : The moisture content in the range between 11.00% to 25.00% wet basis.

The previous relationship can be applied to predict the value of the pressure drop within the indicated limits of the variables. The accuracy of the relationship was measured by several methods among which are the following:

1. The coefficient of multiple determination, R-squared, was calculated and was found to be equal 95.67%.
2. The predicted values of the pressure drop agreed closely with those values observed across bed of

paddy rice. Table (17) indicates several values for observed and predicted pressure drop.

Also, the relationship between the pressure drop of air passing through the test bin of clean wheat ΔP, Pascal/m , and the other variables such as air flow rate, Q, $m^3/hr.m^2$, bulk density, S_b, kg /m^3 and moisture content MC, percent wet basis was found to be presented as follows:

$$\Delta P = 0.5053 \left[\frac{Q^{1.4828} \ (0.001 \ S_b)^{7.6216}}{MC^{0.2004}} \right] \qquad (20)$$

The coefficient of multiple determination (R^2) for the above predicted equation was 98.67%. The range of application of the above predicted equation has been found to be presented as follows :

Q : In range between 240 to 600 $m^3/hr.m^2$.

S_b : Bulk density in the range between 710 to 810 kgs/m^3.

MC : Moisture content in the range between 10.48 to 19.92% wet basis.

The previous relationship can be applied to predict the value of the pressure drop at wide ranges of air flow rates and bulk densities and at narrow range of moisture

Table (17): Observed and predicted values of pressure drop of paddy rice.

Air flow rates $m^3/hr.m^2$	Bulk density of paddy rice kg/m^3	Moisture content wet basis %	Pressure drop, ΔP, Pa / m	
			Observed	Predicted
297.29	640.57	11.22	242.16	242.03
343.29	620.86	14.35	222.00	221.06
569.28	617.00	17.00	396.00	395.60
514.93	650.50	19.27	447.20	446.88
242.74	670.39	21.53	182.30	182.63
485.00	687.00	24.30	532.76	515.92

contents. Although the predicted equation has considered three independent variables, more experimental work are needed at wide range of moisture content of clean wheat. It should be noted that most of information obtained by many investigators are given in a form of tables, figures and simple relationships between two variables mainly the pressure drop and the air flow rate under fixed levels of the other variables.

CONCLUSIONS

Predicting the pressure drop when a fluid flows through grain storage systems has been great deal of interest. This is due to the fact that knowledge are required to make the right decision to choose fan or blower for grain drying, aerating, and cooling systems. In addition, the powers requirement of the systems to be calculated for any proposed operating conditions are needed. So, experiments have been carried out to measure the pressure drop of air passing through beds of mainly, paddy rice of IR 28 variety and clean wheat of Sakha 61 variety. Three important and essential variables were considered to obtain data used in this study. The variables were air flow rate, bulk density and moisture content of grain.

The recorded data were analyzed to determine suitable relationships from which to predict the pressure drop in beds of paddy rice and wheat. So, the analysis of the results of the present study on clean paddy rice and clean wheat led to the following finding and concul-sions regarding the effect of change the air flow rate per unit cross sectional area of test bin , moisture content wet basis, and grain bulk density in fixed beds of paddy rice and wheat.

1. The pressure flow relationship could be expressed as $P = K Q^a$ for the Egyptian varieties of paddy rice and wheat.

2. The pressure drop in beds of paddy rice or wheat was directly proportional to air flow rate and bulk density under a given condition.

3. Several general mathematical relationships were developed for pressure drop prediction in beds of paddy rice or wheat under a given condition.

4. The pressure drop of air in different beds of paddy rice and wheat decreased with increasing moisture content for the same air flow rate and bulk density.

5. The method of filling the test bin paddy rice or wheat affected the density of grain and consequently had affected on the pressure drop . The pressure drop was directly proportional to the method of filling the test bin from loosely filled to fully compacted fill,because of the reduction in the air spaces in the grain mass.

6. As the moisture contents of paddy rice and wheat increased from 11 to 19 percent wet basis, the pressure drops decreased by 20.42 and 10.37 percent,respectively at constant air flow rate and constant grain density. This is due to the change in the shape of grain particles with smooth surfaces at higher moisture content.

7. As the bulk density of paddy rice increased from 600 kgs/m^3 to 700 kgs/m^3 , the pressure drop increased by 59.6 percent and the bulk density of wheat increased from 700 kgs/m^3 to 800 kgs/m^3, the pressure drop increased by 63.8% percent at constant air flow rate and constant moisture content.

8. Twice air flow rate passing through beds of paddy rice and wheat may cause (2.573) and (2.7949) times increase in pressures drop, respectively when other variables were held constants.

9. One of the most important results obtained from this experimental work are the following relationships:

For paddy rice:

$$P = 3.8819 \left[\frac{Q^{1.3635} (0.001\ S_b)^{5.8833}}{MC^{0.4184}} \right]$$

For wheat:

$$P = 0.5053 \left[\frac{Q^{1.4828}\ (0.001\ S_b)^{7.6216}}{MC^{0.2004}} \right]$$

The relationships can be applied for good prediction of the pressure drop in beds , P , (Pa / m), of uniform clean samples of paddy rice and wheat over the designed air flow rate, Q, ($m^3/hr.m^2$), bulk density, S_b, (kg/m^3) and moisture content, MC, percentage.

REFERENCES

1 - Abdel-Ghaffar, E.A.M. and A.H.Z. Shokr. 1982. Air flow resistance characteristics of potatoes as influenced by bulk density and size. Alex. Jour. Agric. Res., paper No.: 2.

2 - Abdel-Ghaffar, E.A.M. 1984. Energy loss due to the flow of air in storage bins of wheat and paddy rice. Alex. Jour. Agric. Res., paper No: 4 .

3 - Abdel-Ghaffar, E.A.M. and F.I. Hindey. 1984. Linear air flow resistance of onions. J. Agric. Res., Tanta Univ. 10, No. 3: 720-735.

4 - Agrawal, K.K. and Prem Chand. 1974. Pressure drop across fixed beds of rough rice. Transactions of the ASAE. 17, No. 3: 560-563.

5 - Akritidis, B.C. and A.J. Siatras. 1979. Resistance of pumpkin seeds to air flow. Transactions of the ASAE, 22, No. 6: 1414-1416.

6 - Berggren, P.W. 1939. Voids in granular materials. Agric. Eng. 20, No. 6: 233-234.

7 - Bern, C.J. 1975. Air flow resistance characteristics of corn as influenced by bulk density. ASAE. paper No. 75-3510.

8_ British Standards Institution. 1964. Methods for the measurement of fluid flow in pipes. Part I, orifice plates, nozzlas and venturi tubes, B.S. 1042. Part I, 117-123.

9_ Browne, A.D. 1962 . Variation of the bulk density of cereals with moisture content. J. Agric. Eng. Res. 7, No. 4: 288-290.

10_Brusewitz, G.H. 1975 . Density of rewetted high moisture grains. Transactions of the ASAE.18, No. 5: 935-938.

11_Calderwood , D.L. 1973. Resistance to air flow of rough, brown and milled rice. Transactions of the ASAE.16, No. 3: 525-527; 532.

12_Calderwood, D.L., R.R. Cogburn, B.D. Webb, and M.A. Marchetti. 1984. Aeration of rough rice in long term storage. Transactions of the ASAE . 27, No. 5: 1579-1586.

13_Chung, D.S. and H.H. Converse. 1971. Effect of moisture content on some physical properties of grain. Transactions of the ASAE.14, No. 4: 612-614; 620.

14_Corbett, G.G. 1954 . The resistance to air flow of oats barley in ventilated bin. The British Society for Research in Agric. Eng. 3-10.

15. Ergun, S. 1952. Fluid flow through packed columns. Chem. Eng. Prog. 48, No. 2 : 89-94.

16. Furnas, C.C. 1929. Flow of gases through beds of broken solids. U.S. Bureau of Mines Bulletin. 307.

17. Grama, N.S., C.J. Bern, R.C. Hurburgh and Jr. 1984. Air flow resistance of mixtures of shelled corn and fines. Transactions of the ASAE. 27, No. 1 : 268-272.

18. Gunaseharan, S.V.K. Jindal and G.C. Shove. 1983. Resistance to air flow of paddy (rough rice) in shallow depths. Transactions of the ASAE. 26, No. 2 : 601-605.

19. Henderson, S.M. 1943. Resistance of shelled corn and bin walls to air flow. Agric. Eng. St. Joseph, Mich. 24, No. 11 : 367-368: 374.

20. Henderson, S.M. 1944. Resistance of soybeans and oats to air flow. Agric. Eng. St. Joseph, Mich. 25, No. 4 : 127 - 128.

21. Henderson, S.M. 1953. Moisture content determinations. Agric. Eng, St. Joseph, Mich. 34, No. 2 : 108-110.

22. Hindey, F.I. 1980. The air flow resistance of ryegrass and barley. Ph.D. Thesis, University of Newcastle upon Tyne, England.

23 _ Hukill, W.V. and C.N. Ives. 1955. Radial air flow resistance of grain. Agric. Eng. St. Joseph, Mich. 36, No. 7:462-466.

24 _ Husain, Ashfaq and T.P. Ojha. 1969. Resistance to the passage of air through rough rice. J. Agric. Eng. Res. 14, No. 1: 47-53.

25 _ Korayem, Y.A. and S.N. Soliman. 1983. Effect of moisture content of rough rice on its physical properties. Com. Agrisci. & Dev. Res. Alex. 5, No. 39: 1-15.

26 _ Kunze, R.O. and C.W. Hall. 1967. Moisture adsorption characteristics of brown rice. Transactions of the ASAE 10, No. 4: 448-450; 453.

27 _ Lawton, J. P. 1965. Resistance to air flow of some common seeds. J. Agric. Eng. Res. 10, No. 4: 298-300.

28 _ Löf, G.O., and R.W. Hawley. 1948 . Unsteady state heat transfer between air and loose solids. Industrial and Engineering Chemistry Journal 40, No. 6 : 1061-1070.

29 _ Matthies, H.J. and H. Petersen. 1974. New data for calculating the resistance to air flow of stored granular materials. Transactions of the ASAE. 17, No. 6: 1144-1149.

30 _ Morita, T. and R. Paul Singh. 1979. Physical and thermal properties of short grain rough rice. Transactions of the ASAE. 22, No. 6: 630-636.

31. Nissing, T.J. 1958. Resistance seed cotton to air flow. Agric. Eng. St. Joseph, Mich. 39 : No. 3 : 160-163; 165.

32. Osborne, E.L. 1961. Resistance to air flow of grain and other seeds. J.Agric. Eng. Res. 6 No. 2 119-122.

33- Sabbah, M.A. 1980. Drying and storing rice and wheat, project sponsored by U.S.D.A, PL-480 Report No. 3.

34. Schneidegger, A.E. 1957. The physice of flow through porous media. The Macmillan Co. New York.

35. Shedd, C.K. 1946. Resistance of ear corn to Airflow. Agric. Eng., St. Joseph, Mich. 26, No. 1 : 19 - 20, 23.

36. Shedd, C.K. 1951. Some new data on resistance of grains to air flow. Agric. Eng. St. Joseph, Mich. 32, No. 9 : 493-495; 520.

37. Shedd, C.K. 1953. Resistance of grains and seeds to air flow. Agric. Eng. St. Joseph, Mich. 34, No. 9 : 616-619.

38. Sheldon, W.H., W.C. Hall, and K.J. Wang 1960. Resistance of shelled corn and wheat to low air flow. Transactions of the ASAE. 3, No. 2 : 92-94.

39. Steele, J.L. 1974. Resistance of peanuts to air flow. Transactions of the ASAE. 17, No. 3 : 573-577.

40. Stirniman, E.J., G.P. Bodnar, and E.N. Bates. 1931. Tests on resistance to the passage of air through rough rice in a deep bin. Agric. Eng. St. Joseph, Mich. 12, No. 5 : 145-148.

41. Warner, R.G.M. and D.A. Brown. 1962. Investigations into oven methods of moisture content mresurement for grain. J. Afric. Eng. Res. 8, No. 4 : 289-305.

42. Wratten, T.F., W.D. Poole, J.L. Chesness, S. Bal and V. Ramarao. 1969. Physical and thermal properties of rough rice. Transactions of the ASAE. 12, No. 6 : 801-803.

43. Zink J. Frank. 1935. Specific gravity and air space of grains and seeds. Agric. Eng. St. Joseph, Mich. 16, No. 11; 439-440.

٤٤ـ انتاج المحاصيل ـ ١٩٨٠

على على الخشن ـ محمد ابراهيم شعلان ـ كلية الزراعة ـ جامعة الاسكندرية ٠

ومحمود محمد حبيب ـ كلية الزراعة ـ جامعة طنطا ٠

A P P E N D I C E S

APPENDIX A

Initial Physical Properties Data of Paddy Rice and Wheat

Table (A-1): Shows the effect of moisture content on wheat dimensions (length , width and thickness).

Serial No.	Moisture content wet basis % 10.48 Length L(mm)	Width W(mm	Thick-ness T(mm)	13.00 Length L(mm)	Width W(mm)	Thick-ness T(mm)	19.92 Length L (mm)	Width W(mm)	Thick-ness T(mm)
1	6.75	3.50	3.10	7.25	3.40	3.05	7.15	3.40	3.00
2	7.00	3.70	3.25	6.55	3.60	3.30	6.65	3.70	3.45
3	6.75	3.85	2.75	6.65	3.40	3.25	6.60	3.80	3.05
4	7.00	3.40	2.45	6.20	3.55	2.95	6.40	3.35	2.75
5	5.85	3.10	3.40	7.15	2.80	2.85	7.05	3.30	3.00
6	6.65	3.45	3.10	6.15	3.45	3.00	6.30	3.60	2.85
7	6.75	3.35	2.70	6.50	3.75	2.95	6.70	3.60	3.15
8	6.65	3.05	2.85	7.00	3.20	2.90	6.70	3.05	2.70
9	5.15	3.35	3.35	7.25	2.40	3.15	6.80	3.65	2.80
10	6.65	3.30	3.10	6.70	3.35	3.00	6.60	3.40	2.85
11	5.90	2.80	2.35	6.25	2.90	3.25	6.50	3.60	2.55
12	6.30	3.35	2.80	6.60	3.80	2.60	6.75	2.95	3.05
13	6.65	2.70	3.00	6.75	3.40	2.85	6.45	3.30	2.55
14	6.40	3.00	2.95	6.65	3.65	2.85	6.65	3.10	2.65
15	6.80	3.30	2.55	6.35	3.35	2.80	6.40	3.15	2.90
16	6.60	3.20	3.05	6.70	2.95	2.40	6.70	3.05	2.75
17	6.35	2.90	2.35	6.00	3.30	2.65	6.65	2.90	2.45
18	6.60	3.75	2.75	6.50	3.55	2.50	7.30	3.70	2.90
19	6.35	2.85	3.15	6.55	3.15	2.50	6.60	3.05	2.80
20	6.60	3.40	2.60	6.35	3.35	2.30	7.05	2.90	3.00
21	6.35	3.55	3.25	7.00	3.65	3.15	6.65	3.55	2.95
22	6.25	3.45	3.00	7.10	3.50	2.90	6.40	3.60	2.75
23	6.45	3.30	2.10	5.75	3.25	2.90	6.55	3.80	2.85
24	6.55	3.60	2.85	6.35	3.40	2.90	6.60	3.05	3.15
25	6.75	2.85	2.95	6.70	2.85	3.00	5.65	3.50	2.60
26	6.65	2.85	2.45	6.15	3.45	2.95	6.75	3.45	2.55
27	6.50	3.05	2.80	6.65	3.75	3.05	5.65	3.65	2.45
28	6.60	3.40	3.05	6.45	3.05	3.05	6.40	3.55	2.95
29	6.60	3.60	3.05	7.20	3.05	2.75	6.15	3.35	3.20
30	6.15	3.35	2.50	6.60	2.75	2.85	6.60	3.20	3.20
31	6.85	3.15	3.00	6.70	3.35	3.00	6.80	3.50	2.95
32	6.75	3.15	2.80	6.60	3.05	2.95	6.30	3.35	2.65
33	6.20	3.25	2.65	5.75	3.35	2.75	6.75	3.10	2.95
34	6.45	3.30	2.95	6.15	3.40	2.95	6.35	3.40	2.75
35	6.60	3.10	2.50	6.15	3.60	2.90	6.90	3.25	2.75
36	6.70	3.55	2.75	6.65	3.50	2.80	6.80	3.45	3.20
37	6.20	3.50	3.15	7.00	3.45	2.60	6.90	3.15	2.90
38	6.35	3.45	3.05	6.55	3.85	2.40	6.90	3.80	3.20
39	6.75	3.35	2.75	6.35	3.35	3.30	6.55	3.30	2.85
40	6.20	3.55	2.25	5.85	2.85	2.95	7.60	3.30	3.00
41	6.85	3.90	2.75	6.65	3.85	3.05	7.00	3.40	3.40
42	6.25	3.10	2.30	6.00	3.65	2.80	7.00	3.10	2.95
43	6.05	3.00	2.95	7.00	3.45	2.30	6.00	2.90	2.75
44	7.10	3.25	2.75	6.60	3.55	2.30	6.75	3.65	2.90
45	6.05	3.30	2.75	6.45	3.20	3.00	6.35	3.10	2.90
46	6.60	3.30	2.80	6.55	3.25	2.95	6.85	3.40	2.80
47	6.10	3.85	2.80	6.55	3.25	2.90	6.20	3.45	3.00
48	6.40	3.35	2.75	6.75	3.40	2.60	6.40	3.45	2.90
49	6.35	3.30	2.30	5.75	3.25	2.40	6.35	3.00	3.10
50	6.85	2.85	2.80	6.70	3.15	2.90	6.20	3.05	2.30
Average	6.479	3.297	2.805	6.544	3.314	2.846	6.587	3.347	2.882

Table (A-1):Shows the effect of moisture content on paddy rice dimensions (length,width and thickness).

Serial No.	Moisture content wet basis % 11.92 Length L(mm)	Width W(mm)	Thick-ness T(mm)	13.84 Length L(mm)	Width W(mm)	Thick-ness T(mm)	15.95 Length L(mm)	Width W(mm)	Thick-ness T(mm)	20.45 Length L(mm)	Width W(mm)	Thick-ness T(mm)	25.95 Length L(mm)	Width W(mm)	Thick-ness T(mm)
1	8.25	2.60	2.05	8.55	2.50	1.90	8.50	2.90	1.95	8.05	2.80	2.10	8.40	2.65	2.15
2	8.15	2.80	1.90	8.75	2.75	2.00	8.65	2.95	2.05	8.75	2.75	2.05	8.05	2.75	2.15
3	8.45	2.70	1.95	8.10	2.75	1.95	8.10	2.80	1.70	8.45	2.75	2.00	9.00	2.95	2.10
4	8.45	2.85	2.00	8.30	2.65	2.00	8.40	2.70	1.95	7.15	2.60	2.10	8.40	2.45	2.00
5	8.20	2.70	2.00	7.85	2.70	1.95	8.85	2.75	2.00	8.10	2.85	2.05	8.55	2.75	1.95
6	8.85	2.90	2.00	7.60	2.65	1.90	8.70	2.75	2.00	8.65	2.75	2.05	8.45	2.95	2.05
7	8.65	2.75	2.00	8.65	2.90	1.95	8.10	2.95	2.05	8.35	2.80	2.05	8.40	2.65	2.00
8	7.90	2.75	1.95	8.40	2.70	2.05	8.10	2.60	2.05	8.65	2.80	2.00	9.00	2.75	1.95
9	8.80	2.75	2.05	8.55	2.50	2.00	8.10	2.60	2.05	8.70	2.70	2.05	8.05	2.75	2.25
10	8.25	2.90	1.95	8.15	2.75	2.00	8.35	2.95	1.95	8.55	2.65	2.15	6.35	2.75	1.90
11	8.15	2.60	2.00	8.45	2.75	2.05	8.05	2.55	2.15	8.30	2.75	1.90	8.25	2.95	2.10
12	7.95	2.75	1.90	8.80	2.60	1.95	8.05	2.75	2.00	8.50	2.65	1.90	8.55	2.75	2.10
13	7.45	2.55	1.85	7.70	2.50	2.00	8.30	2.85	1.95	8.20	2.70	1.95	8.75	2.60	2.00
14	8.15	2.55	2.05	8.10	2.65	2.05	8.10	2.75	1.95	8.25	2.70	1.90	9.10	2.75	2.05
15	8.35	2.80	1.95	8.35	2.80	2.00	8.35	2.80	2.00	8.90	2.60	2.05	8.30	2.75	2.05
16	7.90	2.65	2.05	7.95	2.40	2.05	8.45	2.75	2.00	7.95	2.55	2.10	8.40	2.95	1.90
17	8.05	2.65	1.95	7.95	2.65	2.05	8.80	2.75	2.05	8.55	2.70	1.85	8.85	2.95	2.15
18	7.80	2.60	1.90	7.20	2.60	2.10	8.15	2.65	1.95	8.30	2.80	2.00	8.35	2.75	2.00
19	7.45	2.85	1.85	7.85	2.80	2.05	7.75	2.70	2.10	8.90	2.65	2.00	8.30	2.75	2.00
20	7.40	2.75	2.00	8.30	2.70	1.90	8.15	2.75	2.15	8.60	2.90	2.00	8.45	2.75	2.00
21	8.20	2.70	2.00	8.00	2.75	2.05	8.35	2.85	2.05	8.75	2.75	2.05	8.60	2.60	2.00
22	8.25	2.60	2.00	8.15	2.70	1.95	8.25	2.80	2.05	8.40	2.65	2.10	8.35	2.70	2.05
23	8.75	2.50	2.00	8.55	2.70	2.00	8.35	2.40	2.05	8.40	2.75	1.95	8.40	2.75	2.05
24	7.50	2.65	2.05	8.60	2.75	2.10	8.10	2.75	2.00	8.00	2.80	2.05	8.05	2.75	2.05
25	8.20	2.55	1.85	8.70	2.75	1.85	8.20	2.75	2.00	9.15	3.00	2.05	7.75	2.50	2.00
26	7.95	2.70	2.00	8.30	2.55	2.00	8.75	2.80	2.10	8.55	2.50	2.10	8.70	2.55	2.05
27	8.60	2.75	1.75	8.85	2.75	1.95	7.80	2.75	2.05	8.45	2.75	2.05	8.65	2.95	2.05
28	8.40	2.80	1.90	8.35	2.70	2.05	8.40	2.75	2.15	8.15	2.55	1.95	8.70	2.85	2.05
29	8.70	2.45	2.00	8.40	2.75	1.90	8.35	2.65	2.05	8.00	2.70	2.10	8.45	2.65	2.05
30	8.05	2.65	2.00	7.70	2.40	2.10	8.05	2.70	2.00	8.35	2.65	1.95	8.80	2.75	1.75
31	8.30	2.80	1.85	7.70	2.45	1.90	8.25	2.70	2.15	8.40	2.65	2.15	8.10	2.85	2.05
32	7.65	2.50	1.75	8.05	2.75	2.00	8.65	2.75	2.05	7.80	2.75	2.15	8.30	2.75	1.90
33	7.65	2.60	1.95	8.60	2.70	2.05	8.55	2.55	1.95	8.40	2.85	1.95	8.55	2.70	2.15
34	7.80	2.85	1.85	8.55	2.80	1.95	8.40	2.70	2.00	8.20	2.80	2.00	8.35	2.75	2.15
35	8.55	2.65	2.00	7.95	2.75	2.00	8.75	2.80	2.00	8.75	2.80	2.05	8.30	2.90	1.90
36	8.05	2.75	1.95	8.10	2.75	2.00	8.55	2.75	2.05	8.40	2.85	1.95	8.70	2.85	2.10
37	8.55	2.75	1.95	8.55	2.55	2.15	8.40	2.70	2.00	8.35	2.65	2.00	9.05	2.70	2.05
38	7.95	2.75	1.90	7.55	2.70	1.85	8.65	2.85	2.15	8.90	2.75	2.05	8.25	2.80	1.90
39	7.90	2.65	2.05	8.20	2.70	2.05	8.40	2.55	2.05	7.95	2.75	2.00	8.50	2.85	2.10
40	8.05	2.70	1.90	8.40	2.80	1.95	8.05	2.65	1.95	8.35	2.65	2.05	8.10	2.80	2.10
41	7.85	2.65	2.05	8.80	2.75	2.00	8.40	2.80	2.00	6.15	2.75	2.15	6.20	2.50	2.05
42	7.70	2.50	1.85	8.25	2.70	2.05	8.55	2.70	2.00	8.35	2.70	2.05	8.30	2.75	2.00
43	7.55	2.65	2.00	7.55	3.05	2.05	8.50	2.65	2.05	8.65	2.75	2.05	8.65	2.75	2.25
44	8.30	2.65	1.95	9.00	2.70	1.95	8.30	2.75	2.05	7.65	2.65	2.05	8.55	2.70	2.05
45	7.85	2.40	1.85	7.85	2.70	2.00	7.75	2.65	1.95	8.70	2.65	1.95	8.65	2.85	1.95
46	8.00	2.70	2.00	8.05	2.75	1.95	8.55	2.60	1.85	8.15	2.85	2.00	7.65	2.70	2.00
47	7.75	2.50	1.85	8.40	2.75	2.00	8.45	2.75	2.10	8.35	2.75	2.15	8.05	2.70	1.95
48	8.25	2.75	2.00	8.70	2.75	1.85	8.05	2.80	2.05	8.80	2.70	1.95	8.80	2.85	1.95
49	8.05	2.80	1.95	6.85	2.55	1.90	8.35	2.55	1.75	8.45	2.75	2.15	8.30	2.75	1.85
50	8.85	2.70	2.05	8.05	2.60	1.95	8.15	2.70	1.95	8.40	2.85	2.00	8.25	2.75	1.95
verage	8.200	2.682	1.952	8.206	2.705	1.989	8.326	2.727	2.009	8.384	2.737	2.024	8.447	2.748	2.050

Table (A-2): Shows grain equivalent spherical diameter of paddy rice and wheat.

Serial No.	Particles No.	Paddy rice		Wheat	
		Volume (mm^3)	D_p (mm)	Volume (mm^3)	D_p (mm)
1	50	10	3.367	16	3.938
2	50	9.7	3.333	15.5	3.8975
3	50	9.8	3.345	17	4.0193
4	50	9.8	3.345	16.5	3.979
5	50	9.9	3.3356	16	3.855
Average			3.349		3.938

Table (A-3): Shows the measured data and the calculated values of weight of a thousand grain particles, grain mass densities bulk density and grains pore space of wheat and paddy rice.

	Paddy rice			Wheat		
	1	2	3	1	2	3
Weight of 1000 grains , gram	20.985	23.056	23.485	41.533	40.723	43.067
True volume , cm^3	16	17.5	17	32	32.5	33.6
True density , S_t , g/cm^3	1.311	1.317	1.381	1.297	1.253	1.23
Bulk volume , cm^3	32	34	35.5	60	59	63
Bulk density , S_b , g/cm^3	0.655	0.678	0.661	0.692	0.69	0.68
Porosity , ϵ , decimal	0.500	0.514	0.5209	0.466	0.449	0.468

Porosity equation.

$$\epsilon = 1 - \frac{S_b}{S_t}$$

Table (A-4): Determinated weight of a thousand grain particles of paddy rice and wheat.

Grain of crop	Weight (gm)			
	1	2	3	Average
Paddy rice	20.985	23.056	23.485	22.508
Wheat	41.533	40.723	43.067	41.774

Table (A-5): Shows the measured data and calculated values of moisture contents, wet basis of paddy rice and wheat.

	Paddy rice			Wheat		
	1	2	3	1	2	3
Weight of wet sample (g)	24.0984	25.8714	25.1772	25.045	24.56	24.9841
Weight of dry sample (g)	21.9199	22.9479	22.0622	22.1348	22.0144	22.14
Weight of water	2.1796	2.9235	3.115	2.9102	2.5456	2.844
Moisture content wet basis %	13.194	11.30	12.372	11.61	10.36	11.38

Table (A-6): Averaged values of the physical properties of wheat and paddy rice obtained by experiments.

Serial No.	Physical properties items	Type of grain: Paddy rice IR 28	Type of grain: Wheat of Sakha 61
1	Dimensions		
	1. Length, L, mm	8.447	6.479
	2. Width, W , mm	2.737	3.314
	3. Thickness,T,mm	1.989	2.846
2	Equivalent spherical diameter, D_p, mm	3.349	3.938
3	True density, S_t, gram/cm^3	1.336	1.276
4	Bulk density, S_b, gram/cm^3	0.661	0.687
5	Voids fraction, ϵ , decimal	0.511	0.461
6	Weight of a 1000 particles, gram	22.508	41.774
7	Moisture content percent wet basis, M.C. (w.b.) %	12.28	11.38

A P P E N D I X   B

Paddy Rice Experimental Data

Table (B-1): Air flow resistance measured data in beds of clean paddy rice (IR 28) at moisture content 11.22% wet basis .

Serial No.	Air flow rates $m^3/hr.m^2$	Type of filling test bin			
		Loose	Normal	Vibrated	Packed
		Paddy rice bulk densities, S_b, kg/m^3			
		601.27	614.60	627.40	640.57
		Pressure drop of air in Pascal per meter			
1	242.74	116.00	150.99	176.63	188.03
2	297.29	153.87	196.58	215.00	242.16
3	343.29	182.33	236.46	267.80	301.99
4	383.81	213.67	276.35	311.90	347.58
5	420.44	245.10	310.50	354.70	398.86
6	454.13	273.50	354.70	398.88	444.40
7	485.48	296.29	410.20	441.50	504.27
8	514.93	336.18	441.59	485.75	552.70
9	542.79	370.37	481.48	527.00	606.84
10	569.28	398.86	521.30	566.90	646.70
11	594.59	427.35	558.40	618.20	692.00

Date of experiment : 27-5-1985.
Laboratory temperature: 29°C

Table (B-2): Air flow resistance measured data in beds of clean paddy rice (IR 28) at moisture content 14.35% wet basis .

Serial No.	Air flow rates $m^3/hr.m^2$	Type of filling test bin			
		Loose	Normal	Vibrated	Packed
		Paddy rice bulk densities, S_b, kg/m^3			
		610.60	620.86	631.00	641.22
		Pressure drop of air in Pascal per meter			
1	242.74	85.47	122.50	162.39	190.88
2	297.29	119.60	158.00	203.67	236.46
3	343.29	153.80	199.50	248.95	293.44
4	383.81	185.18	240.40	290.84	353.27
5	420.44	213.60	270.20	344.00	396.01
6	454.13	240.09	300.59	395.00	447.29
7	485.48	270.00	341.63	411.40	484.33
8	514.93	299.14	379.77	455.00	541.31
9	542.79	321.90	411.00	501.53	592.59
10	569.28	347.50	437.12	537.50	638.18
11	594.59	401.70	492.60	595.38	676.60

Date of experiment : 30-5-1985.
Laboratory temperature: 30°C.

Table (B-3): Air flow resistance measured data in beds of clean paddy rice (IR 28) at moisture content 17.00% wet basis.

Serial No.	Air flow rates $m^3/hr.m^2$	Type of filling test bin			
		Loose	Normal	Vibrated	Packed
		Paddy rice bulk densities, S_b, kg/m^3			
		617.00	631.20	644.78	658.35
		Pressure drop of air in Pascal per meter			
1	242.74	94.00	133.90	162.39	210.80
2	297.29	153.80	185.18	219.37	270.60
3	343.29	190.88	264.90	284.90	327.60
4	383.81	222.00	284.90	313.39	378.90
5	420.44	253.50	319.09	370.37	427.30
6	454.13	284.90	356.12	413.00	470.00
7	485.48	313.39	393.16	452.99	512.80
8	514.93	341.88	427.30	490.00	555.50
9	542.79	367.50	458.69	527.00	598.00
10	569.28	396.00	490.00	564.00	641.00
11	594.59	421.65	518.50	601.00	683.70

Date of experiment : 2-6-1985.
Laboratory temperature : 30.5 °C.

Table (B-4): Air flow resistance measured data in beds of clean paddy rice (IR 28) at moisture content 19.27% wet basis .

Serial No.	Air flow rates $m^3/hr.m^2$	Type of filling test bin			
		Loose	Normal	Vibrated	Packed
		Paddy rice bulk densities, S_b, kg/m^3			
		637.00	650.50	663.50	677.26
		Pressure drop of air in Pascal per meter			
1	242.74	123.90	158.00	185.18	225.00
2	297.29	178.06	176.63	236.40	270.60
3	343.29	213.67	267.80	299.00	336.00
4	383.81	245.00	310.54	339.00	364.67
5	420.44	290.59	341.88	390.30	398.80
6	454.13	319.00	367.50	411.68	490.00
7	485.48	347.58	410.25	467.20	527.00
8	514.93	381.76	447.20	507.12	575.50
9	542.79	404.50	481.40	549.86	618.00
10	569.28	433.00	515.67	586.89	663.80
11	594.59	464.39	547.00	623.90	706.50

Date of experiment : 5-6-1985.
Laboratory temperature : 29 °C

Table (B-5): Air flow resistance measured data in beds of clean paddy rice (IR 28) at moisture content 21.53% wet basis .

Serial No.	Air flow rates $m^3/hr.m^2$	Type of filling test bin			
		Loose	Normal	Vibrated	Packed
		Paddy rice bulk densities, S_b, kg/m^3			
		657.30	670.39	683.00	696.52
		Pressure drop of air in Pascal per meter			
1	242.74	156.69	182.30	207.90	242.00
2	297.29	202.28	235.00	256.40	293.40
3	343.29	242.00	270.65	313.39	344.70
4	383.81	279.20	336.18	364.80	404.50
5	420.44	316.24	364.60	413.00	455.80
6	454.13	347.50	381.70	450.00	507.00
7	485.48	381.70	427.30	484.30	541.30
8	514.93	413.00	470.00	527.00	598.20
9	542.79	441.50	507.00	575.60	641.00
10	569.28	472.90	541.30	612.53	686.60
11	594.59	507.00	576.90	646.70	732.00

Date of experiment : 8-6-1985.
Laboratory temperature : 28.5 °C

Table (B-6): Air flow resistance measured data in beds of clean paddy rice (IR 28) at moisture content 24.30% wet basis .

Serial No.	Air flow rates $m^3/hr.m^2$	Type of filling test bin			
		Loose	Normal	Vibrated	Packed
		Paddy rice bulk densities , S_b, kg/m^3			
		659.88	673.45	687.00	700.59
		Pressure drop of air in Pascal per meter			
1	242.74	185.18	206.55	225.00	247.80
2	297.29	227.92	257.83	287.75	319.00
3	343.29	270.65	304.84	339.00	373.00
4	383.80	313.39	351.85	387.40	427.30
5	420.44	350.42	393.16	435.89	484.30
6	454.13	384.60	435.89	487.18	541.30
7	485.48	418.80	475.78	532.76	592.50
8	514.93	453.00	515.67	578.35	643.87
9	542.79	484.33	552.70	621.00	692.30
10	569.28	521.37	595.44	669.50	743.50
11	594.59	552.70	635.30	712.00	794.80

Date of experiment : 11-6-1985.
Laboratory temperature : 28.5 °C

A P P E N D I X C

Wheat Experimental Data

Table (C-1): Air flow resistance measured data in beds of clean wheat (Sakha 61) at moisture content 10.48 % wet basis .

Serial No.	Air flow rates $m^3/h.m^2$	Type of filling test bin			
		Loose	Normal	Vibrated	Packed
		Wheat bulk densities, S_b , kg/m^3			
		763.35	777.77	792.19	806.60
		Pressure drop of air in Pascal per meter			
1	242.74	133.90	159.50	185.18	219.00
2	297.29	185.18	199.43	227.92	276.00
3	343.29	242.16	259.26	276.35	333.33
4	383.81	287.75	307.69	330.48	390.31
5	420.44	324.78	336.18	378.90	447.29
6	454.13	360.40	391.73	427.35	504.27
7	485.48	398.86	435.89	470.08	561.25
8	514.93	435.89	453.00	507.00	618.23
9	542.79	472.93	507.12	544.00	669.50
10	569.28	507.12	544.16	584.00	729.34
11	594.59	541.30	598.20	626.78	774.93

Date of experiment : 5/7/1985.
Laboratory temperature: 28°C.

Table (C-2): Air flow resistance measured data in beds of clean wheat (Sakha 61) at moisture content 13.00% wet basis .

Serial No.	Air flow rates $m^3/hr.m^2$	Type of filling test bin			
		Loose	Normal	Vibrated	Packed
		Wheat bulk densities, S_b, kg / m3			
		754.87	768.44	782.00	795.58
		Pressure drop of air in Pascal per meter			
1	242.74	128.20	156.69	173.79	213.67
2	297.29	173.79	202.28	216.52	270.65
3	343.29	216.50	247.86	264.95	321.90
4	383.81	253.56	284.90	310.50	378.90
5	420.44	296.20	324.78	350.42	435.89
6	454.13	333.30	364.67	393.16	492.80
7	485.48	364.67	401.71	441.50	549.86
8	514.93	401.71	438.74	481.48	601.14
9	542.79	438.74	478.63	524.20	655.20
10	569.28	475.78	518.52	564.10	712.20
11	594.59	509.97	549.86	595.40	769.20

Date of experiment : 8/7/1985.
Laboratory temperature : 27°C.

Table (C-3): Air flow resistance measured data in beds of clean wheat (Sakha 61) at moisture content 19.92 % wet basis.

Serial No.	Air flow rates $m^3/hr.m^2$	Type of filling test bin			
		Loose	Normal	Vibrated	Packed
		Wheat bulk densities, S_b,kg/m^3			
		713.80	739.40	765.00	790.66
		Pressure drop of air in pascal per meter			
1	242.74	71.22	91.16	113.96	156.69
2	297.29	96.86	122.50	150.99	216.52
3	343.29	122.50	153.80	188.00	276.35
4	383.81	145.29	185.18	225.00	327.00
5	420.44	162.39	213.67	262.00	373.20
6	454.13	179.48	239.30	296.29	415.95
7	485.48	196.58	264.95	327.63	461.54
8	514.93	213.67	290.59	358.97	507.00
9	542.79	233.60	313.39	390.30	549.86
10	569.28	253.50	336.18	421.65	592.59
11	594.59	273.50	358.97	452.90	632.48

Date of experiment : 11/7/1985.

Laboratory temperature: 31 °C .

A P P E N D I X   D

Pressure Manometers Calibration

Table (D-1): Air flow meter calibration across the orifice plate.

No.	Inclined manometer (H_2O mm)	Dwyer manometer (H_2O mm)
1	0.0	0.0
2	2.5	3.048
3	3	3.56
4	4.5	5.08
5	7	7.62
6	10.75	11.684
7	16.0	17.27
8	21.25	23.11
9	23.5	25.146
10	34.5	36.83
11	41	43.18
12	47.5	50.8
13	53	57.9
14	60	63.0
15	66.5	68.58
16	73.5	76.2
17	78	81.8
18	82.5	86.4
19	85.75	88.9
20	91.0	93.98
Mean	$\bar{x}$ = 40.0875	$\bar{y}$ = 42.2044

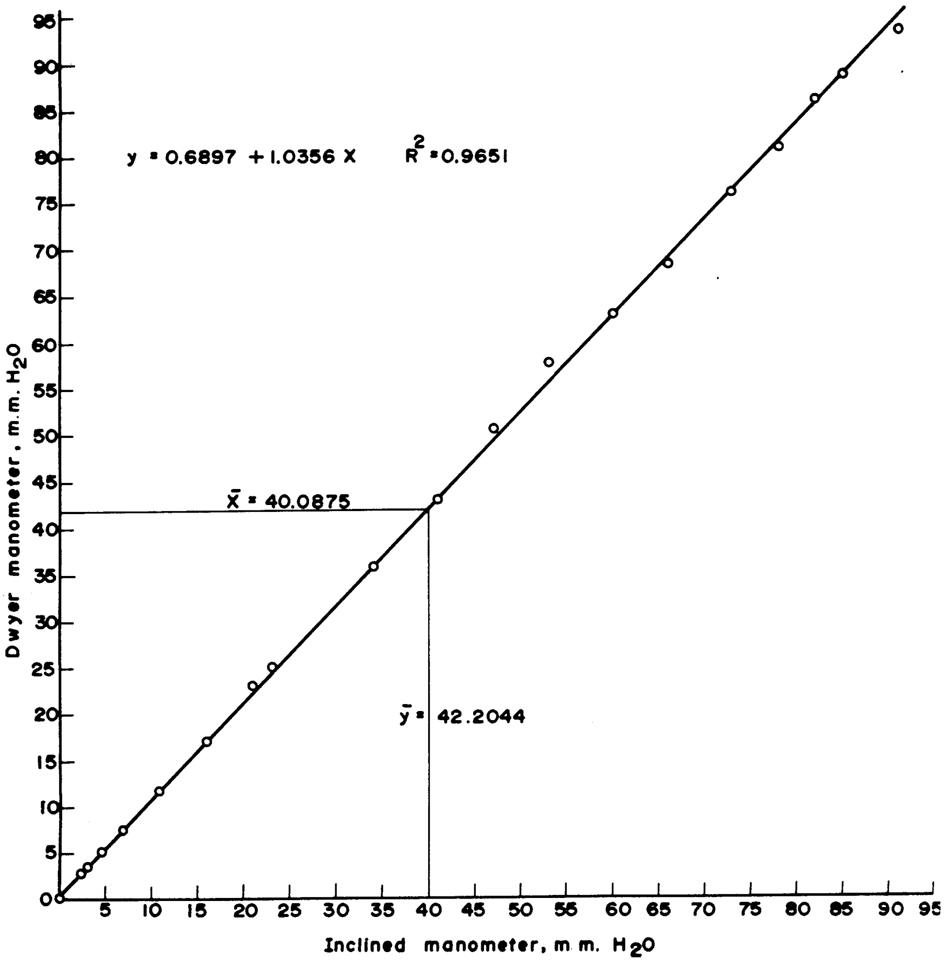


Fig.(29): Inclined manometer calibration (minimum division of 1 m.m., inclined angle 30°) across the arifice plate .

Table (D-2): Air flow meter calibration across the grain bed.

No.	Inclined manometer (H_2O mm)	Dwyer manometer (H_2O mm)
1	0.0	0.0
2	4.4421	4.9
3	6.8809	7.336
4	8.5358	9.398
5	10.452	11.43
6	12.0198	13.208
7	14.3715	15.494
8	16.4619	17.78
9	18.8136	20.32
10	20.7298	22.225
11	22.0363	23.623
12	23.2557	24.892
13	25.259	27.94
Mean	$\bar{x}$ = 14.096	$\bar{y}$ = 15.257

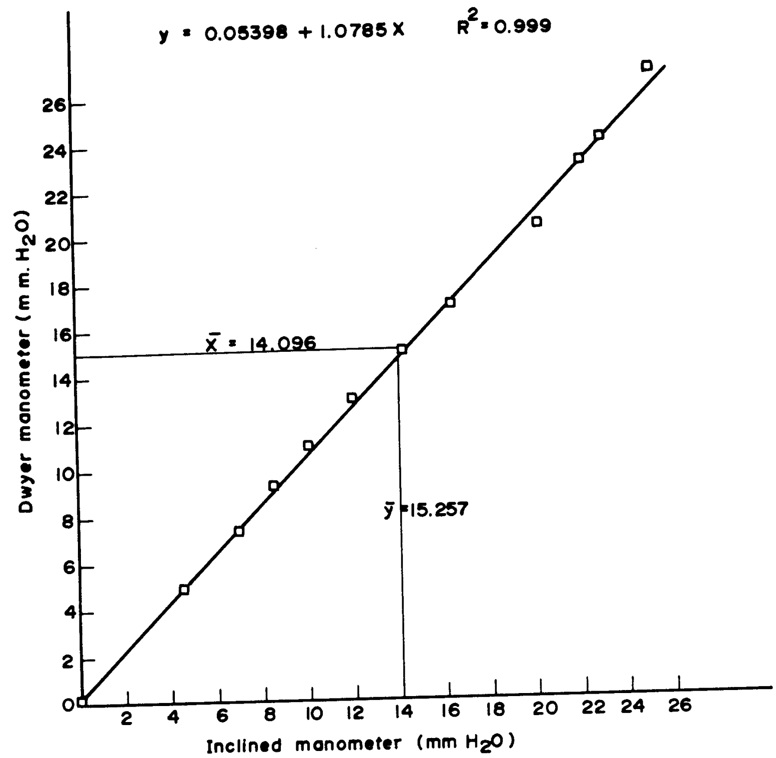


Fig.(30):Inclined manometer calibration (minimum division of ½ m m and inclined angle 5°) across grain bed .

" بسم الله الرحمن الرحيم "

الملخص العربي

مقاومة سريان الهواء فى مراقد من الارز الشعير والقمح له أهمية فى تصميم انظمة تجفيف وتهوية وتبريد الحبوب فى المخازن وكذلك فى تصميم واختيار المراوح وخفض الطاقة المستخدمة فى عمليات تخزين الحبوب.

نظرا لحصاد محصولى الارز عند محتوى رطوبى من ١٨٪ الى ٢٥٪ والقمح عند محتوى رطوبى ١٤٪ الى ١٦٪ على أساس رطب ويلزم اجراء عمليات التهوية لخفض وحفظ المحتوى الرطوبى عند المستوى الآمن للتخزين. فانه يلزم تحديد معدلات دفع هواء التهوية لوحدة المساحات من قاعدة مخزن الحبوب وكذلك انخفاض ضغط الهواء المار فى الحبوب لوحدة الأطوال.

يستهدف هذا البحث دراسة العوامل التى تؤثر على انخفاض الضغط فى مراقد من الارز الشعير من النوع IR 28 وكذلك القمح من النوع سخا ٦١ واستنباط معادلات تصف الانخفاض فى ضغط الهواء كدالة لمعدلات سريان الهواء لوحدة المساحات وكثافة الحبوب الظاهرية والمحتوى الرطوبى للحبوب كلا على حده وكذلك من أغراض البحث دراسة رياضية عامة تصف الانخفاض فى ضغط الهواء كدالة لمعدلات سريان الهواء لوحدة المساحات وكثافة الحبوب الظاهرية والمحتوى الرطوبى للحبوب تمكن مصمم انظمة التهوية فى مخازن الحبوب من استخدامها وأيضا دراسة الخواص الطبيعية لمحصولى الارز الشعير والقمح من حيث الأبعاد والكثافة الظاهرية والحقيقية ونسبة الفراغات والقطر المكافىء للحبوب ووزن ألف حبة.

تم تصميم وأنشاء مرقد الحبوب ويتكون من خزان من الصاج المجلفن بطول ٦٥ر متر وبقطر ٣٤ر متر ومساحة مقطعه ٠٩٠٨ر متر مربع وذات حجم ٠٥٩٠٢ر متر مكعب يرتكز على أرضيه مثقبة على ارتفاع ٣٥ر متر من قاع الخزان ويوجد به أربع مستويات من الثقوب على ارتفاع:

٥ ـ ٢٠ ـ ٣٥ ـ ٥٠ سم وكل مستوى يتكون من أربع ثقوب تتجمع عن طريق وصلات نحاسية ومنها الى الأنابيب البلاستيك حتى يمكن قياس الانخفاض فى الضغط بين مستويين

المسافة بينهم ٣٠ سم .

ويتكون الجهاز من مروحة طاردة مركزية ذات ريش منحنية للخلف وقدرة الموتور ٣ حصان وعدد لفاته ١٤١٥ لفة / دقيقة . ويبلغ طول ماسورة الهواء ٤ و٤ متر وهى من الصاج المجلفن ويوجد بها على بعد ٧٠ر٣ متر من المروحة جهاز قياس معدلات سريان الهواء Orifice Plate .

أيضا تم تصميم جهاز وحدة خلط وترطيب لاتمام عملية الترطيب للحبوب ورفع محتواها الرطوبى الى النسبة المطلوبة فى خلال ٢٤ ساعة تشغيل ويتكون من هيكل أبعاده ١٥٠ × ١٠٠ سم به عمودين يدور أحدهما بواسطة موتور قدرته ٣ حصان وعدد لفاته ١٤١٠ لفة /دقيقة . ويرميل يحتوى على الحبوب ذات قطر ٥٩ سم وطول ٨٤ سم وبحجم ٢٢٩٦ر متر مكعب ويدور ب ٩ لفات فى الدقيقة وتتم عملية تخفيض السرعة بواسطة وحدة التخفيض المتصلة بالموتور . تم قياس الانخفاض فى ضغط الهواء بواسطة مانومترات زجاجية مائلة ذات دقة قدرها ٥ر مم لقياس الانخفاض فى الضغط بين مستويين فى خزان الحبوب (٣٠ سم) وكذلك سرعة سريان هواء التهوية . أمكن تعيين المحتوى الرطوبى بطريقة الفرن ويتم تعيين الرطوبة بطريقتين الأولى بوضع الحبوب كاملة لمدة ٢٤ ساعة عند درجة حرارة ١٠٥°م والثانية وضع الحبوب المطحونة لمدة ساعتين عند درجة حرارة ١٣٠° م.

أستخدمت أربع طرق لملىء صندوق الحبوب وذلك للحصول على أربع مستويات مختلفة من الكثافة الظاهرية عند مستوى واحد من المحتوى الرطوبى ويطلق على هذه المستويات الملىء بالراحة Loose filled ثم الملىء العادى Normal filled يليه الملىء بالهز Vibrated fill والملىء بالكبس Packed fill

صممت التجارب لدراسة العوامل التى تؤثر فى انخفاض ضغط الهواء فى خزان الحبوب لتكون كالآتى :

- معدلات دفع الهواء من ٢٤٠ الى ٦٠٠ متر^3/ ساعة . لكل متر مربع من مساحة مقطع الخزان للأرز الشعير والقمح .
- الكثافة الظاهرية للأرز الشعير فى المدى من ٥٩٥ الى ٧٠٥ كجم/ م^3 والمحتوى

الرطوبى للأرز الشعير فى المدى ١١٪ الى ٢٥٪ على أساس رطب.

- الكثافة الظاهرية للقمح فى المدى ٧١٠ الى ٨١٠ كجم / م^{٣} .
- المحتوى الرطوبى للقمح فى المدى من ١٠٪ الى ٢٠٪ على أساس رطب .

وقد أجريت التجارب بمعمل هندسة التصنيع الزراعى بقسم الميكنة الزراعية بكلية الزراعة بكفرالشيخ-جامعة طنطا .

تم تحليل البيانات المستنتجة من التجارب بأستخدام وحدة الحاسب الآلى بالمعمل المركزى بكلية الزراعة-جامعة الاسكندرية .

وقد أختير التمثيل الرياضى ليكون دالة آسية للمتغيرات كلا على حده وأيضا المتغيرات مجتمعة فى علاقة واحدة حيث تم استنباط معادلات رياضية تربط بين الانخفاض فى ضغط الهواء فى مراقد الارز الشعير والقمح كدالة لمعدل سريان الهواء لوحدة المساحات والكثافة الظاهرية والمحتوى الرطوبى على أساس رطب.

وتتلخص النتائج المتحصل عليها من التجارب والتحليل الرياضى فى الآتى :

١ - يمكن أن تمثل العلاقة بين انخفاض ضغط الهواء ΔP ومعدل مرور الهواء Q بالعلاقة على الصورة : $\Delta P = K Q^{a}$ للأرز الشعير والقمح للأنواع المصرية .

٢ - انخفاض ضغط الهواء فى مراقد الأرز الشعير والقمح يتناسب طرديا مع معدل مرور الهواء وكذلك الكثافة الظاهرية ويتناسب عكسيا مع المحتوى الرطوبى للحبوب.

٣ - طريقة ملئ خزان الحبوب بالأرز أو القمح تؤثر فى مقاومة الحبوب لمرور هواء التهوية بحيث أن انخفاض ضغط الهواء يتناسب طرديا مع طريقة الملئ بالراحة Loose filled الى الملئ بالكبس Packed fill

٤ - عند زيادة المحتوى الرطوبى للأرز الشعير من ١١٪ الى ١٩٪ على أساس

رطب ينخفض ضغط الهواء بمقدار ٢ر٤٢٠٪ وأيضا عند زيادة المحتوى الرطوبي للقمح من ١١ ٪ الى ١٩ ٪ على أساس رطب يسبب أنخفاض فى ضغط الهواء بمقدار ٣٧ر١٠٪ وهذا يرجع الى درجة تغير شكل الحبة ونعومة سطحها عند امتصاصها للماء • وذلك عند ثبات المتغيرات الأخرى •

٥ــ عند زيادة الكثافة الظاهرية للارز الشعير من ٦٠٠ كجم / م ٣ الى ٧٠٠ كجم/م ٣ تزداد المقاومة لسريان الهواء بمقدار ٦ر٥٩٪ وايضا عند زيادة الكثافة الظاهرية للقمح من ٧٠٠ كم/م٣ الى ٨٠٠ كجم/م٣ تزداد المقاومة لسريان الهواء بمقدار ٨ر٦٣٪ عند ثبات المتغيرات الاخرى •

٦ ــ عند مضاعفة معدل مرور الهواء فى مرقد الأرز الشعير بسبب زيادة مقدارها ٧٣ ٥ر٢ مضروبة فى مقدار الزيادة فى انخفاض ضغط الهواء وأيضا بالنسبة للقمح عند مضاعفة معدل مرور الهواء بسبب زيادة مقدارها ٧٩٦ر٢ مضروبة فى مقدار الزيادة فى انخفاض الضغط عند ثبات المتغيرات الأخرى •

٧ ــ أحد النتائج المهمة والمتحصل عليها من التجارب هو أستنتاج معادلتين رياضيتين للتنبوء بحساب أنخفاض ضغط الهواء • فى مخازن الأرز الشعير وكذلك فى مخازن القمح كدالة لثلاثة متغيرات •

بالنسبة للأرز الشعير :

$$\Delta \text{ض} = (\text{٣ر٨٨١٩}) \left[\frac{\text{س}^{\text{١ر٣٦٣٥}} \times (\text{٠٫٠١ك})^{\text{٥ر٨٨٣٣}}}{\text{م}^{\text{٠ر٤١٨٤}}} \right]$$

بالنسبة للقمح :

$$\Delta \text{ض} = (\text{٠ر٠٠٥٣}) \left[\frac{\text{س}^{\text{١ر٤٨٢٨}} \times (\text{٠٫٠١ك})^{\text{٧ر٦٢١٦}}}{\text{م}^{\text{٠ر٢٠٠٤}}} \right]$$

حيث أن :

Δ ض = أنخفاض ضغط الهواء بوحدات باسكال / متر من ارتفاع الخزان •

س = معدل دفع الهواء بوحدات $م^3$ / ساعة لكل متر مربع من مساحة قاعدة الخزان •

ك = الكثافة الظاهرية للحبوب بوحدات كجم / $م^3$ •

م = المحتوى الرطوبى للحبوب على أساس رطب كنسبة مئوية •

مما سبق يتضح أن هذا البحث بمعادلاته الرياضية يمكن المهندس المصمم لمخـازن الحبوب من استخدام المعادلتين الرياضيتين السابق ذكرهما للارز الشعير والقمح في تحديد قدرة المروحة المطلوبة وذلك بايجاد الانخفاض في ضغط الهواء المار في مخزن الحبوب في أنظمة تهوية وتبريد وتجفيف الحبوب في المخازن كدالة لمعدلات دفع الهواء لوحدة المساحات من الخزان والكثافة الظاهرية للحبوب (وهى دالة لطريقة ملء الخزان) وأيضا المحتوى الرطوبى المراد تخزينها .

بسم الله الرحمن الرحيم

دراسات على مجال الهندسة الزراعية

دراسات تتعلق بمحاصيل الحبوب (الأرز او القمح أو الذرة) أثناء فترات تخزينها من وجهة نظر الهندسة الزراعية

بحث مقدم

من

نبيهة حسن أبو الهنا

بكالوريوس علوم زراعية (هندسة زراعية) جامعة الاسكندرية ١٩٧٨م

للحصول على درجة الماجستير في العلوم الزراعية (الميكنة الزراعية)

كلية زراعة كفر الشيخ - جامعة طنطا

قسم الميكنة الزراعية

١٩٨٦