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PRESSURE DROP THROUGH SHELLED CORN AS AFFECTED BY AIRFLOW RATES, MOISTURE CONTENT AND AIR TEMPERATURE

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ABSTRACT

The pressure drop was measured in shelled corn beds for airflow rates in range from 290.04 to 870.13 m^3/ h per m^2 at grain moisture content in the range of 20 to 14 % (w.b.) and at air temperature in range of 313to 333 K . It was found that pressure drops increased by 250 and 257 % with increasing in airflow rates at 313 and 333 K at moisture content of about 14 ± 0.3 %, (w.b.) respectively. Decreasing the corn moisture content increased the resistance to airflow rat, while decreasing the air temperature increased the resistance to airflow rates.

The selection of a model was made using the results of shelled corn. A ***Shedd*** *– type equation (model 1), and an* ***Ergun*** *– type equation (model 2) were studied. Model 2 behaved better than model 1.*

INTRODUCTION

Corn is considered as one of the major important food crops in Egypt, where the total annual production of corn crop reached about 6.159 tera grams and the planted area reaches up to 1.770 M feddan (**C.R.T.C., 2001**). Shelled corn is used primarily as livestock feed, but some of it is used by the milling or processing industries in production of corn starch, corn oil, and other products **(ASHRAE, 1981).** Corn is usually harvested during September until October 15, and at the optimum moisture content of about 23 % (w. b.) **(C.R.T.C., 2001 and Brooker et al., 1992).**

Airflow resistance prediction is a fundamental knowledge to the design of efficient grain drying and aeration system. To select a fan to adequately deliver air through a grain bed, it is necessary to know how much resistance to be overcome.

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Generally, the pressure drop for airflow characteristics of the product depends on the number and size, configuration of the voids; the variability of particle size; and the depth of the product bed **(Brooker et al., 1992)**.

Brooker et al. (1978) stated that, moisture is removed to prevent the development of a favorable environment for the growth of molds and insects that normally cause spoilage. Drying is considered as a means of reducing growth of molds and insects.

Matouk (1981) measured the resistance of rough rice to airflow ranging from 780 to 1450 $m^3/h.m^2$ of bin floor and six levels of moisture content ranging from 14 to 29%, (d.b.). His results indicated that the resistance of rough rice to airflow depends on the airflow rate as well as on the rice moisture content. He found that the resistance to airflow at any level of moisture content increased with the increasing in the ranges under study, while it decreases with the same level of airflow rate.

Abou-El Hana (1986) carried out experiments 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. She found that the pressure drop in beds of paddy rice or wheat was directly proportional to air flow rate and density under a given condition.

Gunasekaran and Jackson (1988) determined the resistance to airflow of grain sorghum. They used grain sorghum at moisture levels of 16.5, 18.5, and 23% (w.b.). They revealed that the higher the moisture content, the lower the pressure drop at any given airflow rate.

Shoughy (2001) reported that, the static pressure drop in a bed of rough rice grain (Giza 101) was directly proportional to airflow rate and bulk density and inversely proportional to rough rice moisture content.

However, it is anticipated that drying of corn grain by utilizing heated air are considered an urgent matter. Therefore, the objective of the this study was (1) to determine pressure drops of shelled corn at several airflow rates, moisture contents, and air temperature; (2) to select a simple model, preferably based on the Ergun equation.

MATERIALS AND METHODS

Corn (TWC 310) which was harvested in RMC, Meet El - Deeba, Kafrelsheikh Governorate, during the season 2002, was used for the tests.

The corn was handled, picked at harvest moisture contents of about 23 % (w.b.) and shelled using a mechanical sheller. Samples were placed in plastic bags and stored in a 278.16 K (5 ^{o}C) refrigerator room. Prior to any experimental run, the shelled corn was taken out of the refrigerator and stored at room temperature for 24 hrs.

Test grain bin:

Three separate cylindrical grain bins, each holding 0.07547 m^3 of corn grain, were constructed of 1.5 mm-galvanized sheet metal with 1 m height and 0.31 m inside diameter. A steel screen supported by cross-shape steel bars was fixed in the grain column at a distance of 0.2 m from the bottom to carry the corn. Copper pipes having 4 mm and 5 mm inside and outside diameters respectively were inserted in prepared holes at the inside surface of corn column side-wall for measuring static pressure drop. Each column for drying system rested on an air plenum chamber, to maintain uniform velocity inside the grain bulk (Figure 1).

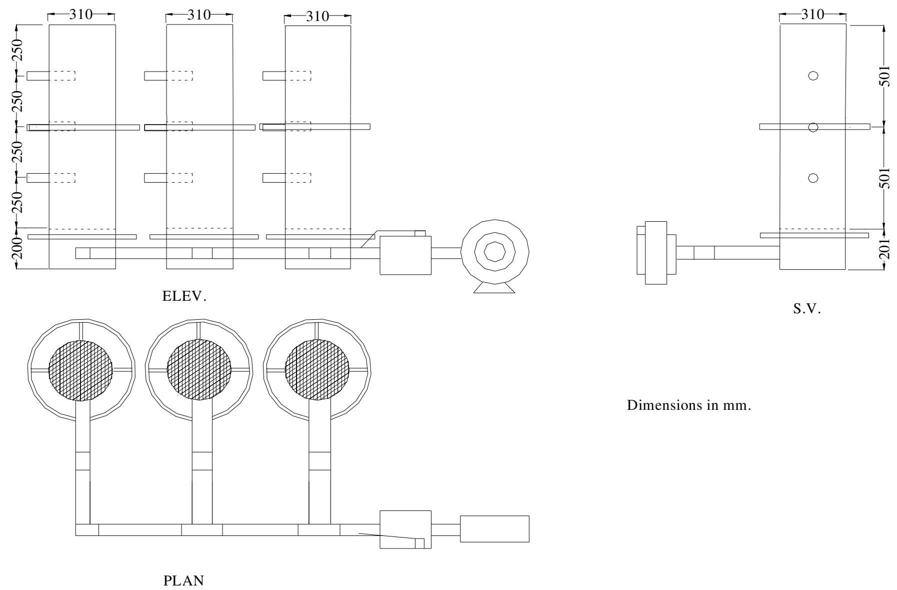

Figure 1: The geometrical drawing of forcing drying system.

Measurements and instrumentation:

1- Airflow Measurement:

An anemometer Vane Probe – BREMI – BRI 5080 was used for air velocity measurement. The unit is a self-contained direct reading portable instrument which is capable of measuring velocities from 0.2 to 40 m/s. Its accuracy is 0.1 m/s. The commonly accepted measuring unit of airflow rate on this field is cubic meter per hour per square meter of cross- sectional area for grain column (m^3/h. m^2).

2-Static Pressure drop:

The pressure drop was measured directly by using an inclined manometer. The pressure drop was measured at four-moisture content levels 20, 18, 16 and 14 ± 0.3 % (w.b.) through drying process running.

3-Moisture content determinations:

Moisture content of corn samples was determined on a wet-mass – basis by moisture tester PV-100. The apparatus was calibrated by oven - drying duplicate samples at (376.16 K (103 ^oC) for 72 hrs) as mentioned by the **ASAE (1998)**.

4-Temperature Measurements:

A temperature meter model (ERO, Electronic. MemocalR 81) was connected to an iron - Constantine thermocouple type (T) to measure air and grain temperatures for drying systems.

Simple and multiple regression analysis were calculated to represent the experimental data in linear and power forms. The drying data was analyzed in the form of linear equations and the pressure drop was represented in the form of power equations.

Selection of a model:

In order to interpret the results of Figure (2), two models, each containing two parameters were proposed. Model (1) is that of **Shedd**, who fitted data for several grains by considering the airflow to be a function of the pressure drop. Pressure drop (ΔP) is expressed as a function of airflow rate (Q) as follows:

$$\Delta P = k_1 Q^{a}{}_1 \qquad \ldots\ldots\ldots\ldots(1).$$

Where: k1 and a1, are constants (the nomenclature "model number" is used instead of the more precise "equation number" to avoid confusion with numbered equation).

Model (2) is that of **Ergun**, who made a thorough study of the pressure drop versus air velocity relationship for particulate materials. He used particle sizes smaller than agricultural grain and developed an equation based on fluid – dynamic principles. **Ergun's** model has two – terms, the first term being a linear function of airflow and the second a function of Q^2. **Ergun's** model includes the influence of the bed void fraction, particle diameter and of air density and viscosity. For simplicity of use, factors other than velocity can be lumped in tow parameter for each agricultural grain, so model 2 becomes an **Ergun** – type equation of the form:

$$\Delta P = k_2 Q + a_2 Q^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2).$$

Where: k_2 and a_2, are constants.

The two models were fitted to experimental values at each moisture level by using non- linear least squares regression. Correlation coefficients (R^2) and standard deviation of the estimate (s_y). S_y express the average deviation between experimental and predicted values, and defined as follows:

$$s_y = \sqrt{\left(\frac{\sum_{i=1}^{N} \left(predicted_i - \exp erimental_i \right)^2}{(N-2)} \right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3).$$

Where N is the number of data points and $(N\text{-}2)$ is the number of degrees of freedom ***(Giner and Denisienia, 1996).***

RESULTS AND DISCUSSION

The experiments of shelled corn were carried out at three different levels of airflow rate (290, 580 and 870.1 $m^3/h.m^2$); four corn grain moisture contents [20, 18, 16 and 14 ± 0.3 % (w.b.)] and three air temperature levels (313, 323 and 333 K).

1- Effect of airflow rate on pressure drop:

There was an increase in pressure drop per unit depth as the airflow rate increased under all moisture content levels (20, 18, 16 and 14 ± 0.3 % (w.b.)) and for all air temperature levels (313, 323 and 333 K). Figure (2) and Table (1) showed that, changing the airflow rate from 290 to 870.1 m^3/h per m^2 of cross-sectional area of the test column increased the resistance to airflow by 250 %. This change was occurred at the minimum air temperature of about 313.13 K (40 ^oC) and at minimum moisture content 14 ± 0.3 % (w.b.). The corresponding increasing percentages at the maximum air temperature 333.13 K (60 ^oC) and the minimum moisture content of about 14 ± 0.3 % (w.b.) were 257 %.

2- Effect of grain moisture content on pressure drop:

Table (1) indicates the effect of grain moisture content on pressure drop through bulk grain. It can be observed that, the pressure drop generally increased with the decrease of grain moisture contents at all levels of airflow rates and air temperatures used. This increase in pressure drop might be due to the fact that at higher grain moisture contents of corn, the grain bulk could not be packed well causing more grain porosity and less bulk density which resulted in lower resistance to airflow.

3-The effect of temperature on pressure drop:

Table (1) shows that, higher temperatures of air reduced the airflow resistance. The reduction in pressure drop at the higher air temperature may be due to the air density gradient, which probably causes less friction to airflow and consequently decreases the airflow resistance through the grain bed as stated by **Abdallah (1999)**. Also, due to the increase in air viscosity which resulted in lower Reynolds number and resistance to airflow.

Table 1: Airflow resistance of grain (Pa/m) for combination of air temperature, moisture content and airflow rate using a forcing air flow method

Airflow rate, $m^3/h.m^2$	Air Temperature, K											
	313.16 (40 °C)				323.16 (50 °C)				333.16 (60 °C)			
	Moisture content,, %(w.b.)				Moisture content,, %(w.b.)				Moisture content,, %(w.b.)			
	20	18	16	14	20	18	16	14	20	18	16	14
290.04	103.005	117.72	137.34	152.055	93.195	112.815	127.53	147.15	73.575	93.195	117.72	137.37
580.09	240.345	274.68	299.205	313.92	215.82	245.25	284.49	299.205	171.675	186.39	206.01	230.535
870.13	451.26	480.69	505.215	534.645	413.64	461.07	495.405	515.025	402.21	431.64	461.07	490.5

4- Fitted data obtained by experimental with Shedd equation:

Results of airflow resistance obtained from this research work were plotted on linear scales as shown in Figure (2). This Figure showed that the plot of data points for pressure drop (P) as a dependent variable versus airflow rate (Q) as the independent variable for each level of air temperature and moisture content shows a curve on linear graph paper.

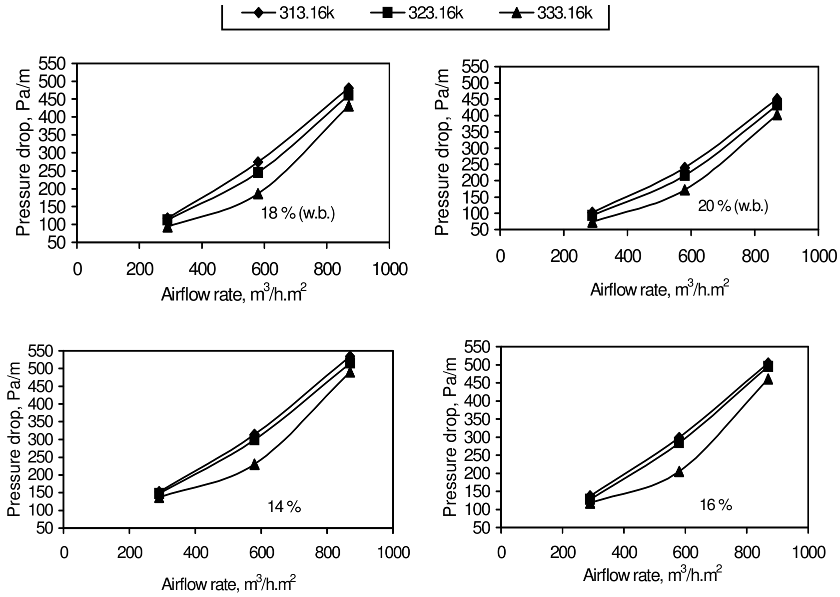

Figure 2:Variation of pressure drop as affected by airflow rate at different air temperatures and corn moisture content.

This indicates that the power relationship must fit the data obtained by experiments. The suggested formula as indicated by **Shedd** (1953) is in the following form:

$$\Delta P = k_1\ Q^{a}{}_1 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4).$$

Where:

ΔP = pressure drop of air, Pa/m;

Q = airflow rate, m^3/h per m^2 of cross-sectional area of the test bin; k and a, are constants for any given conditions.

A linear regression analysis was used to relate the airflow resistance to the airflow rate at various levels of air temperature and moisture content. The linear relationship on logarithmic transformation is presented as:

$$\text{Log}\ \Delta P = \text{Log}\ k_1 + a_1\ \text{Log}\ Q \qquad \ldots\ldots\ldots\ldots\ldots\ldots(5).$$

Where:

ΔP = pressure drop of air, Pa/m;

Q = airflow rate, m^3/h per m^2 of cross-sectional area of the test bin.

The following equations were developed to describe the relationship between (Q) and (ΔP)

$\Delta P = 0.031(Q)^{1.39}$; $\qquad$ ($R^2 = 0.956$) …………..…… (6).

At M C = 20 % (w.b.).

$\Delta P = 0.066(Q)^{1.29}$; ($R^2 = 0.952$) ……..…...…….. (7).

At M C= 18 % (w.b.).

$\Delta P = 0.14(Q)^{1.20}$; ($R^2 = 0.952$) ……..……….….. (8).

At M C= 16 % (w.b.).

$\Delta P = 0.25(Q)^{1.12}$; ($R^2 = 0.956$)……………….. (9).

At M C= 14 % (w.b.).

Using all data obtained under the different levels of air temperature from 313.16 to 333.16 K (40 to 60 ^{O}C) developed these four equations. Results from these equations and the experiment observations indicated that the pressure drop of air in beds of corn increased by increasing airflow rate. The accuracy of the relationships was measured by the coefficient of multiple determinations (R^2). The coefficient of determination was grater than 0.95 in most cases.

5- Fitted data obtained by experimental with Ergun equation:

The suggested formula as indicated by **Ergun** (1952) is in the following form:

$$\Delta P = k_2Q + a_2Q^2 \quad \text{………………….…………… (10).}$$

Where:

ΔP = pressure drop of air, Pa/m;

Q = airflow rate, m^3/h per m^2 of cross-sectional area of the test bin; and k and a = constants for any given conditions.

A linear regression analysis was used to relate the airflow resistance to the airflow rate at various levels of air temperature and moisture content. The following equations were developed to describe the relationship between (Q) and (ΔP):

$\Delta P = 64.3 - 0.07Q + 0.00055Q^2$; ($R^2 = 0.975$) ..………………(11).

At M = 20 % (w.b.).

$\Delta P = 75.2 - 0.05Q + 0.00056Q^2$; ($R^2 = 0.971$) ……………….(12).

At M = 18 % (w.b.).

$\Delta P = 80.1 + 0.01Q + 0.00052Q^2$; ($R^2 = 0.969$) ………...…….(13).

At M = 16 % (w.b.).

$\Delta P = 106.3 - 0.03Q + 0.00057Q^2$; ($R^2 = 0.976$) …..……..(14).

At M = 14 % (w.b.).

Using all data obtained under the different levels of air temperature from 313.16 to 333.16 K (40 to 60 ^{O}C) developed these four equations. Results from these equations and the experiment observations indicated that the pressure drop of air in beds of corn increased by increasing airflow rate.

The accuracy of the relationships was measured by the coefficient of multiple determinations (R^2). The coefficient of determination was grater than 0.969 in most cases.

6- Selection of a model:

Model (1) [Eqn.(1)] predicted with an average s_y of 38.66 Pa/m (mean of values at the four moisture levels). Model (2) [Eqn. (2)] showed a better behavior, (the best) with an average s_y of 27.47 Pa/m.

Figure (3) shows observed and predicted pressure drop using Shedd equation with coefficient of determination was grater than 0.9524. Also, Figure (3) shows observed and predicted pressure drop using Ergun equation with coefficient of determination was grater than 0.9644.

Table 2: Results of fitting equations to experimental pressure drop vs airflow rate curves of shelled corn at several grain moisture content.

Moisture content % (w.b.)	Model 1 **(Shedd)** [Eqn. (1)]		Model 2 **(Ergun)** [Eqn. (2)]	
	R^2	s_y Pa/m	R^2	s_y Pa/m
20	0.956	38.5	0.975	24.52
18	0.952	43.34	0.971	28.31
16	0.952	36.17	0.969	30.17
14	0.956	36.63	0.976	26.88

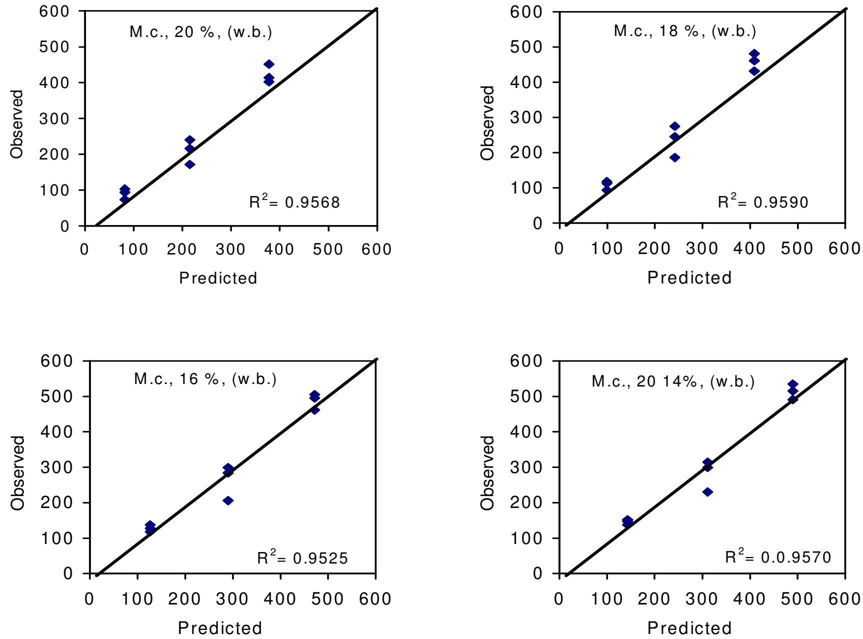

Figure 3: Observed and predicted pressure drop at different moisture content of corn with Shedd equation.

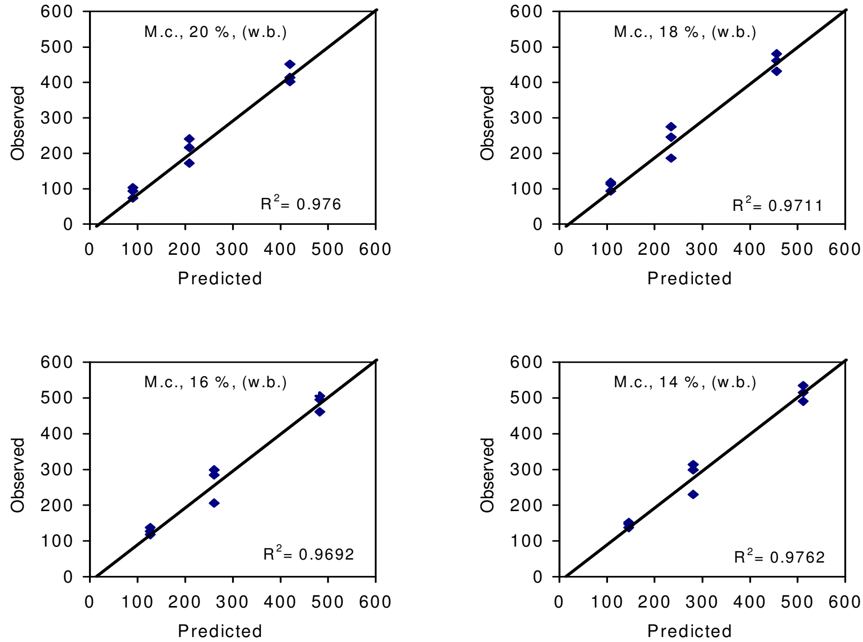

Figure 3: Observed and predicted pressure drop at different moisture content of corn Ergun equation.

CONCLUSION

Analysis of the results of the present research led to the following conclusions:

1-The pressure drop in beds of corn grain increased by increasing airflow rates.

2-Decreasing the corn moisture content increased the resistance to airflow rate.

3-Decreasing the air temperature increased the resistance to airflow rates.

4-The two-parameter, **Ergun**-type expression fitted the results best in the airflow range (290.04 - 870.13 $m^3/h.m^2$). This can be described to its two-term nature with a linear function of velocity for low (laminar) airflows and a quadratic function for high (turbulent) airflows.

REFERENCES

Abdallah, S. E. 1999. Application of solar energy collector by a plastic greenhouse for drying and aerating of wheat crop. M. Sc. thesis, Agric. Mech. Dept., Fac.of Agric., Kafr El-Sheikh, Tanta Univ., Egypt.

Abou El – Hana, N. H. 1986. Studies related to paddy rice and wheat grains during storage periods "Unpublished M. Sc. Thesis, Agric. Mech., Dept., Fac. of Agric., Kafr El Sheikh, Tanta Univ., Egypt.

ASAE. 1998. ASAE S 352.2 DEC 97. Moisture measurement-ungrounded grain and seeds. ASAE standards 1998 St. Joseph, MI,USA. **ASHRAE 1981.** Fundamentals Handbook, Drying of specific crops. Am. Soc. Heating, Refrigeration, and Air-Conditioning Engrs, New York.

Brooker, D. B.; F. W. Baker – Arkema; and C. W. Hall. 1978. Drying cereal grain. 2nd Edition. AVI publishing Co., Westport, Conn., INC., USA.

Brooker, D. B.; F. W. Baker – Arkema; and C. W. Hall. 1992. Drying and storage of grain and oilseed. Van, Nostrand, Reinhold, New York.

Ergun, S. 1952. Fluid flow through packed columns. Chemical Engineering Progress, 48: 89-94.

Giner, S. A. and E. Denisienia (1996). Pressure drop through wheat as affected by air velocity, moisture content and fines. J. Agric. Eng Res. 63, 73-86.

Gunasekaran, S. and C. Y. Jackson (1988). Resistance to airflow of grain sorghum. Transactions of the ASAE, 31 (4): 1237-1240.

Matouk, A.M. (1981). Resistance of rice grain to airflow. J.Agric. Sc., Mansoura University, 6(2): 223-234.

Shedd, K. C. 1953. Resistance of grains and seeds to airflow. Agricultural Engineering, 34 (9): 616-619.

Shoughy, M. M. (2001). Utilization of natural air for drying and aeration of rough rice stored in bins. Unpublished Ph.D. Thesis. Department of Agricultural Mechanization, Faculty of Agricultural, Kafr El-Sheikh, Tanta University, Egypt.

C.R.T.C. (2001) التوصيات الفنية لمحصول الذرة – الحملة القومية لمحصول الذرة – مركز البحوث الزراعية.

الملخص العربي

الانخفاض في الضغط خلال الذرة المفرط وتأثره بمعدل سريان الهواء ، المحتوي الرطوبي للحبوب و درجة حرارة الهواء

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تعتبر مقاومة الحبوب لسريان الهواء أثناء مروره داخل مرقد الحبوب عاملا هاما في تصميم وأداء نظام التجفيف. و كان الهدف من أجراء البحث هو (1) تعين الانخفاض في الضغط للذرة المفرط عند معدلات سريان متعددة ، محتويات رطوبية للحبوب ودرجات حرارة مختلفة لهواء التجفيف (2) اختيار نموذج بسيط يلائم البيانات التجريبية المتحصل عليها0 تم استخدام نظام للتجفيف مكون من ثلاث خزانات أسطوانية من الصاج بقطر داخلي 0.31م وارتفاع الخزان 1متر بالإضافة لوجود غرفة هواء بارتفاع 0.2م أسفل الخزانات. والخزانات متصلة عن طريق مواسير طولية أسطوانية بمروحه طارده مركزية لدفع الهواء. وتم استخدام المانومتر المائل لقياس الانخفاض في الضغط للهواء داخل خزانات التجفيف.

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استخدم في التجارب حبوب الذرة المفرط (هجين ثلاثي 310). وتم أيضا استخدام ثلاث معدلات لسريان الهواء (290- 580 – 870.1 م3/ ساعة لكل متر مربع من مساحة مقطع الخزان)، وثلاث مستويات من درجات حرارة الهواء (313 –323- 333 كلفين)0 تم قياس الانخفاض في الضغط أثناء التجفيف عند أربع محتويات رطوبة للحبوب وهي 20، 18، 14،16 % علي أساس رطب.

أظهرت نتائج المعادلات المتنبأ بها وملاحظات التجارب أن انخفاض الضغط في مراقد حبوب الذرة يزداد بزيادة معدل سريان الهواء. بينما يزداد انخفاض ضغط الهواء المار في حبوب الذرة كلما انخفض المحتوى الرطوبى (أي كلما ارتفعت قيم الكثافة الظاهرية) عند أي معدل لسريان الهواء. بينت النتائج أيضا أن ارتفاع درجة الحرارة يؤدي إلى سرعة حركة الهواء خلال مرقد الحبوب وانخفاض كثافة الهواء وزيادة لزوجته وبالتالي قلة احتكاك سريان الهواء بالحبوب. حيث انه بتغير درجة حرارة الهواء من 313 إلى 333 كلفن أدى إلى انخفاض مقاومة سريان الهواء.

تم أيضا الوقوف علي أن أفضل النماذج الرياضية المختبرة ملائمة للبيانات التجريبية وإعطاء تنبأ عالي هو النموذج الثاني **Ergun Equation** وذلك لانخفاض الانحراف القياسي له 27.47 بسكال/متر بالإضافة لارتفاع معامل التقدير أكثر من 0.97 وتلك القيم متوسط القيم عند الأربع محتويات رطوبية المستخدمة.