MODELLING RESISTANCE TO AIRFLOW THROUGH BEDS OF AGROPYRON AND CORN. ESTIMATION OF POWER VENTILATION

D.E. CROZZA and A.M. PAGANO

Chemical Engng. Department, Univ. Nac. del Centro de la Prov. Buenos Aires, 7400 Olavarría, Argentina
dcrozza@fio.unicen.edu.ar
apagano@fio.unicen.edu.ar

***Abstract*— Resistances to airflow in beds of agropyron and corn employing vertical and horizontal airflow directions were measured, in order to show how designing an aeration system is affected by the size and the morphology of each kind of the grain. The airflow velocity range was 0.014-0.336 m^3/s-m^2. Pressure drops were higher when vertical airflow direction was used. Pressure-drops increased with airflow velocity for both airflow directions. At vertical airflow direction, airflow resistance of corn was in average 57% lower than agropyron, while at horizontal airflow direction was in average 76% lower, in the same order. Mathematical models from literature were used to adjust the experimental data with the aim to predict the airflow resistance. The analysis of variance (ANOVA) demonstrated that airflow direction, velocity, kind of grain and bulk density have effect on pressure drop. The estimation of the required power ventilation –based on the predictions of Mattei model- was also realized.**

***Keywords*— Pressure drop, aeration, resistance to airflow, power ventilation.**

I. INTRODUCTION

Argentina is among the world leaders in the harvest of cereals and oleaginous grains. Furthermore, it has an extensive specter of forage grains like agropyron and corn. The first one is now an important resource of animal feeding. The performance of this product in the Buenos Aires Province corresponds to 600 kg per hectare, approximately. This cultivate can be easily adapted to low-lying lands. Because of that, agropyron is used as complement of natural pasture in the breeding systems of Salado River depression.

As regards corn, its harvest occupies a preponderant place not only because of the volume but also due to fundamental applications in its chemical composition. Its presence is also very important in human as well as in animal food because of its contribution of vitamin A soluble in water, which is essential to stimulate the normal growing.

Knowledge of the resistance to airflow of beds of grains is fundamental to the design of grain drying and aeration systems (Shedd, 1951, 1953; Crozza *et al.*, 1995; Pagano *et al.* (1998a,b), 2000). Several variables like height and bed porosity, strange material, composition and bulk density, variety, kind of surface and seed moisture content, velocity and airflow direction, filling method, grain morphology, affect the design of an aeration system. Many studies have described the relationship among resistance to airflow and another physical parameters (Shedd, 1951, 1953; Ergun, 1952; Hukill and Ives, 1955; Mattei, 1969; Crozza *et al.*, 1995; Pagano *et al.* 1998 a,b, 2000; Reed *et al.*, 2001).

In 1996 the American Society of Agricultural Engineers (ASAE Standards, 1999) adopted curves for various grains that have been established by Shedd (1951,1953). Hukill and Ives (1955) proposed another equation, which was obtained representing data of Shedd. It is important to notice that their application is limited to only clean dry grains. Later, Patterson *et al.* (1971) and Bern and Charity (1975) (adopted by ASAE (1999)) presented a model as a simplification of Ergun equation.

The results of this study enhance our knowledge about how the size and morphology of two different grains -agropyron and corn-, affect the necessary airflow quantities required to obtain an efficient aeration in a packed bed.

Therefore, this research was conducted to: i) measure the pressure drop through beds of agropyron and corn at vertical and horizontal airflow directions, ii) to model these resistances employing empirical models, ii) examine the effects of two levels of airflow direction, two levels of kind of grain, two levels of bulk density with ten levels of air velocity on pressure drop and iii) estimate the power ventilation obtained from the information of the static pressure drop.

II. METHODS

A. Experimental Apparatus

Figure 1 shows a diagram of the experimental apparatus employed to measure the resistance to airflow of agropyron and corn beds, similar to the one used by Crozza *et al.* (1995) and Pagano *et.al.* (2000). It is integrated by three fundamental parts:

1) A metallic storage silo consisting in a cubic box with 0.35 m sides which was overturned 90º to obtain horizontal airflow direction. Two standard steel meshes N°18 were placed at the bottom and at the top of the silo to support the grain bed.

2) An impelling air system: a 0.55 kW -2760 rpm-centrifugal fan with an adjustable flow was used to force the air through a pipe of 0.0254 m diameter. The

flow was conducted across an orifice plate and then to a pyramidal plenum. In order to create a uniform velocity profile airflow was rectified passing through a honeycomb structure placed into the chamber.

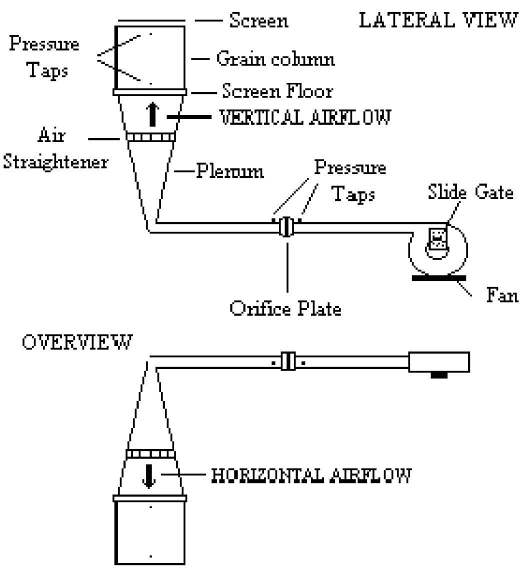


Fig. 1: Scheme of the experimental equipment for measuring resistance to airflow.

3) Measuring instrumentation: two piezometric rings each with four pressure-taps around the container at two levels 0.3048 m apart were installed. Analogic meters of differential pressure with different scales (Dwyer model- Series 2000 Magnehelic, accuracy/precision: ± 2% of full scale, ranges: 0-6 mmca, 0-25 mmca, 0-80 mmca, 0-25 cmca, minor division: 0.2 mmca, 0.5 mmca, 2.0 mmca y 0.5 cmca, respectively) were employed to measure the airflow velocities and their corresponding pressure-drops.

B. Characterization of grains samples

Agropyron: a clean sample of about 10.05 kg was used. The commercial analysis showed: no damaged grains or foreign materials, germinate power of 88%, 1000 seeds weight of 0.00590 kg, 13.8% d.b.(dry basis) moisture content.
Corn: a sample of 32.89 kg hard red corn was employed. The commercial analysis gave the following results: hectoliter weight 70.10, moisture content 12.54%d.b., factor 98, grade 3, damaged and broken grains 8% and 0.8%, respectively, without foreign materials and peck grains, 100 seeds weight of 0.03051 kg.

C. Grain density (ρ_g) and Equivalent diameter (d_e)

The particle density (ρ_g) for both grains -agropyron and corn- was determined in quadruplicate by picnometry using samples about 1-1.5 gr.
The average volume of a grain (V_g), and the equivalent diameter (d_e) of a sphere with the same volume of grain were calculated.

D. Bulk density (ρ_b) and Bed porosity (ε)

Bulk density was determined measuring the mass required to fill-up the silo and dividing it by the bed volume.

Bed porosity was evaluated using the equation developed by Mohsenin (1980) (Eq. 1) and it was evaluated in terms of bulk density (ρ_b) and kernel density (ρ_g), both in units of (kg/m^3).

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_g}\right)100 \qquad (1)$$

E. Filling method

The same filling method was used for both grains. The bin was charged by dropping of grains uniformly from the top of the cubic silo. By this procedure dense fill was obtained. Once the container was full, a steel mesh was placed at the top of the silo.

To study the effect of the airflow direction on the pressure-drop in bed, the silo was carefully turned down (see Fig. 1) to prevent changes in the bed porosity. This methodology allows annulling the effect of the grain orientation on the calculus of the airflow resistance.

F. Experimental design

Pressure-drops across the 0.35 m column of agropyron and corn were measured by triplicate in the ranges from 0.014 to 0.336 m^3/s-m^2.

The experimental design considered two levels of airflow direction (vertical and horizontal), two levels of kind of grain (agropyron and corn) and ten levels of airflow velocity (0.014; 0.034; 0.061; 0.097; 0.137; 0.194; 0.217; 0.238; 0.307 and 0.336 m^3/s.m^2) to determine the effect of these variables on the pressure-drop behaviour. The analysis of variance through the Fully-Factorial ANOVA procedure from SYSTAT (1990) was employed.

G. Pressure-drop modelling

Crozza *et al.* (1995) and Pagano *et al.* (1998a, 2000) discussed several empirical models by following recommendations studied by others researchers. Four of them were used to analyse the relationship between pressure drop and airflow rate.

Equation of Mattei (1969) (Eq. 2) -as a simplification of the known Ergun (1952) equation- which involves a linear and second-order term in air velocity reflecting the transition from laminar (lineal term) to turbulent (quadratic term) fluid, was used due its ease handling in mathematical models for predicting air pressure-patterns in stored grain masses:

$$\frac{DP}{L} = AQ_v + BQ_v^2, \qquad (2)$$

where DP/L is the pressure-drop per unit of bed depth (Pa/m), Q_v is the airflow velocity (m^3/s-m^2) and A, B are the constants for each particular grain.

The prediction of the airflow resistance through grains was also was based on Shedd´s equation (Shedd, 1953),

$$\frac{DP}{L} = aQ_v^{\,b}, \quad (3)$$

where a and b are constants for each particular grain.

The Hukill and Ives (1955) equation -recognised as a standard equation by the American Society of Agricultural Engineering (ASAE, 1999)- was too used to explore the relation between pressure-drop and airflow rate:

$$\frac{DP}{L} = \frac{cQ_v^2}{\ln(1+dQ_v)}, \quad (4)$$

where c and d are the constants for each particular grain. Equations of Mattei, Shedd, and Hukill and Ives are known as two-parameter models.

Another model of three parameters based also on the ASAE (1999) recommendations – the Bern and Charity (1975) equation- was analysed.

$$\frac{DP}{L} = a_1 + a_2\frac{\left(\frac{\rho_b}{\rho_g}\right)^2 Q_v}{\left(1-\frac{\rho_b}{\rho_g}\right)^3} + a_3\frac{\left(\frac{\rho_b}{\rho_g}\right) Q_v^2}{\left(1-\frac{\rho_b}{\rho_g}\right)^3}, \quad (5)$$

where a_1, a_2 and a_3 that are constants for each particular grain.

In this case, the prediction of pressure-drop per unit of bed depth is in function of airflow velocity and bulk density.

The parameter estimate was made and the goodness of fitting was quantified through five quantitative standards; four of them are described in Eqs. 6 to 9, the rest quantitative standard was the plot of the residuals.

The residual sum of squares *RSS* was defined as it shown in Eq. 6:

$$RSS = \sum_{i=1}^{m}\left(Mi - P_i\right)^2, \quad (6)$$

where M_i is the measured value, P_i is the value estimated through the fitting equation and m is the number of data points;

The standard error of the estimate *Sy* (conditional standard deviation of the dependent variable) was defined as it is shown in Eq. 7:

$$S_y = \sqrt{\frac{\sum_{i=1}^{m}(Mi - Pi)^2}{df}} = \sqrt{\frac{RSS}{df}} \quad (7)$$

where df are degrees of freedom of the fitting equation. If a large data set is available, the last expression can be simplified likes,

$$S_y \cong \sqrt{\frac{RSS}{m}}. \quad (8)$$

The mean relative percent deviation *MRD* (Eq. 9) gave a clear idea of the mean divergence of the estimated data respect to the measured data.

$$MRD = \frac{1}{m}\sum_{i=1}^{m}\frac{|M_i - P_i|}{M_i}\cdot 100\cdot \quad (9)$$

H. Estimation of power ventilation

At the time of designing an aeration system, is also important to have information about another parameter: the power ventilation (Giner, 1995). This was estimated based on the estimated airflow resistance.

$$P_{vent} = \frac{DP}{L}\cdot Q_{vv}\cdot V_S = DP/L\,Q_{vv}\cdot S\cdot H^2, \quad (10)$$

where P_{vent} is the ventilation power (W), H is the bed height (m), Q_{vv} represents the recommended airflow (m^3/s-m^3), V_s is the silo volume (m^3) and S is the silo area (m^2).

Recommended airflows for different postharvest operations –such as aeration of maintenance, cooling, in-bin grain drying and drying by aeration- can be obtained in literature (Friesen and Huminicki, 1986; Badiali, 2005; Pagano *et al*., 1998b, 2000). These values –ranged between 0.0012 to 0.050 m^3/s-m^3 according to the purpose- were used to estimate the ventilation power per unit of cross-area for silos with different heights.

I. Experimental data

Physical properties –described in items C, D and E- for agropyron and corn are presented in Table 1.

Observed results of pressure-drop per unit of bed depth of agropyron and corn in function of airflow velocity using two different airflow directions -vertical and horizontal- can been observed in Fig. 2.

For all the tests, it can be noted that the resistance to airflow increased with the increase on the airflow rate. Doubling de airflow rate from 0.1 to 0.2 m^3/s-m^2, the airflow resistances increased in average 3 times for corn and 2.5 times for agropyron.

Grains of agropyron caused higher pressure-drops than corn grains at the same airflow rate. Pressure-drops for agropyron were from 44 to 1455 Pa/m for vertical airflow direction and from 15 to 670 Pa/m for horizontal airflow direction, when airflow rate varied in the range 0.014-0.336 m^3/s-m^2, while for corn, pressure-drops were from 15 to 757 Pa/m and from 3 to 194 Pa/m, in the same order and range of airflow rate.

In Fig. 2 can be seen that pressure-drop of corn grains at vertical airflow direction is practically the same of agropyron but using horizontal airflow direction, in the fully range of the work.

On the other hand, in the whole range of airflow and for both grains the airflow resistance at vertical airflow direction was always greater than the corresponding to horizontal airflow direction. The resistance presented animportant reduction when horizontal airflow direction was used. For example, at a fixed airflow velocity of 0.027 m^3/s-m^2, resistance of agropyron grains with vertical airflow direction was 3 times the resistance with horizontal airflow direction, while for corn, was 5.3 times, in the same order. At higher airflow velocities these differences declined; *i.e.* at 0.336 m^3/s-m^2,

Table 1: Physical properties of agropyron and corn.

Grains	ρ_g kg/m^3	$d_e \cdot 10^{-3}$ m	$V_g \cdot 10^{-9}$ m^3	ρ_b kg/m^3	ε %
Corn	721	7.86	7.93	1300	44.5
Agropyron	1201	2.48	2.54	767	36.1

resistance of agropyron grains with vertical airflow direction was 2.1 times the resistance with horizontal airflow direction, while for corn, was 3.9 times, in the same order.

These pronounced differences must be considered when the effect of airflow direction on the pressure-drop of both kinds of grains is compared. This effect can be attributed to the orientacion of the stacked grains (Jayas *et al.*, 1990).

When air is forced through a porous bed, the airflow resistance of grains provokes pressure by the dissipation energy due turbulence and friction. Combination of many factors affects pressure-drop across packed products like airflow rate and direction, characteristics of surface and shape of grains, size and configuration of voids inter particles, variability of size particle and bed depth of product.

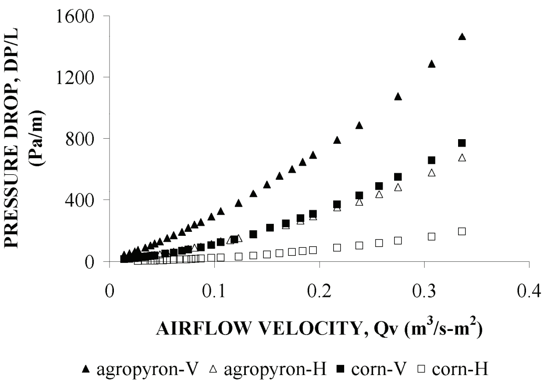


Fig. 2: Experimental data points of airflow resistance for agropyron and corn (V, H: vertical and horizontal airflow direction, respectively).

J. Modelling through two-parameter models

Equations of Mattei (Eq. 2), Shedd (Eq. 3) and Hukill and Ives (Eq. 4) were fitted to analyse the effect of airflow velocity on pressure-drop.

Nonlin procedure from SYSTAT (1990) was the statistical tool employed to determine all constants. Their associated coefficients R^2, *RSS*, S_y and *MRD*, are given in Table 2 for all tests conditions. Models adjustment was quantified through five quantitative standards (Eqs. 7, 8, 9 and 10); their pertinent results have been presented in Table 2.

From this table, the selection of the best model to fit the resistance to airflow of agropyron and corn, based on the comparison between their statistics, was done. Mattei model fitting provided the better adjust (see Fig. 3) because it gave R^2=1.000 in all cases, the lowest *RSS* and S_y values, and *MRD* were below 2%. Then, it was selected to predict the airflow resistance of corn and agropyron grains. On the other hand, the fact of Mattei equation derives from a simplification of Ergun equation provides it an important theoretical background that reinforces the selection.

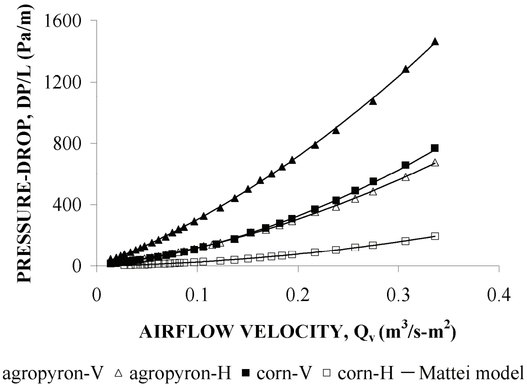


Fig. 3: Experimental data points and predicted curves by Mattei model (full lines) of airflow velocity vs. pressure-drop for agropyron and corn. (V, H: vertical and horizontal airflow direction, respectively).

Furthermore, if it would be important to make an order of priorities as a function of the results obtained from Table 2, it can be concluded that after Mattei equation, Hukill and Ives model (recommended by ASAE) also gave a good fitting. Finally, the fitting with Shedd model resulted no reasonable (*MRD*>17%), compared with the other models.

Respect to the constants of the models, Table 2 shows that different values were obtained for each test with different kind of grain and airflow direction.

It is evident that parameter like morphology and size of grains, superficial characteristics, airflow direction, content moisture of grains, bulk density, porosity of the bed, etc., have important influence on airflow resistance. Then, to know the effect of the grain/bed variables on the airflow resistance results essential when an aeration system must be designed because these variables provoke important changes on airflow resistance values. Also, a good knowledge of them allows the optimisation of the aeration and the saving of energy.

K. Effect of variables on pressure-drop

A lot of parameters before mentioned have an important weight on the pressure-drop due to the presence of random variations and the determination of their significance on airflow resistance it is not effortless (Reed *et al.*, 2001).

With the aim of quantify the influence of the studied variables airflow direction (*D*), velocity (Q_v), kind of grain (*G*) and bulk density (ρ_b) and their interactions on pressure-drop, in this work an ANOVA (analysis of variance) procedure was performed. Table 3 summarises the analysis of variance. From these results, it can been concluded that the four variables *D*, Q_v, *G* and ρ_b have significant (99% confidence level) effects on pressure-drop for both grains agropyron and corn, while their interactions have not significance.

Table 2: Model coefficients and statistics for Eqs. 2, 3 and 4. (V, H: vertical and horizontal, respectively).

Model	Grain	Airflow direction	Coefficients for equations and statistics							
Mattei			A	ASE_A	B	ASE_B	R^2	*RSS*	S_y	*MRD%*
	Agropyron	V	2474.5	2.685	5507.97	10.884	1.000	42.2	0.93	1.70
	Agropyron	H	828.52	2.686	3470.57	10.802	1.000	12.4	0.45	1.12
	Corn	V	662.78	2.798	4827.23	11.133	1.000	3.45	0.25	1.27
	Corn	H	98.86	2.618	1422.93	10.619	1.000	0.18	0.04	0.60
Shedd			a	ASE_a	b	ASE_b	R^2	*RSS*	S_y	*MRD%*
	Agropyron	V	5799.6	5.482	1.287	0.001	0.999	252.0	2.67	8.72
	Agropyron	H	3149.3	7.089	1.437	0.002	0.999	50.99	1.25	8.13
	Corn	V	4235.5	9.587	1.581	0.002	0.999	72.9	1.47	17.01
	Corn	H	1273.0	11.797	1.736	0.007	1.000	1.68	0.23	8.97
Hukill and Ives			c	ASE_c	d	ASE_d	R^2	*RSS*	S_y	*MRD%*
	Agrop.	V	14102	441.47	5.964	0.280	1.000	58.08	1.08	2.75
	Agrop.	II	10369	331.73	14.306	0.881	1.000	16.65	0.60	2.38
	Corn	V	17284	624.28	35.763	3.294	1.000	26.48	0.90	10.01
	Corn	H	7047.8	311.13	184.09	32.043	1.000	0.83	0.16	6.00

Table 3: Results of the ANOVA analysis.

Source	*Sum of Squares*	*DF*	*Mean Square*	*F-Ratio*	*P*
D	816976.2	1	816976.2	26.274	0.000
Q_v	2493340.0	9	277038.8	8.909	0.000
G	687834.3	1	687834.3	22.121	0.000
ρ_b	687834.3	1	687834.3	6.252	0.017
$D*Q_v$	474295.2	9	47637.9	0.131	0.997
$G*Q_v$	345451.3	9	38383.5	0.106	0.998
$D*G$	40141.9	1	40141.9	0.110	0.745
Q_v*D*G	10740.4	9	1193.4	0.003	1.000

L. Modelling through three-parameter models

In Fig. 2 can be noted that –at fixed airflow direction- the higher airflow resistance corresponded to the small grain (agropyron). Then, can be concluded that the resistance to airflow increases with decrease in the size of grain. On the other hand, for a fixed filling method of the silo, the grain size is directly associated with the bulk density ρ_b.

Taking this into account and based on the results obtained from variance analysis, a three-parameter model (Eq. 5) was explored. Constants a_1, a_2 and a_3 were determined for both grains (Table 4) using the Nonlin procedure from SYSTAT (1990).

Bern and Charity model proposed by ASAE (ASAE, 1999) gave also a good agreement with experimental data. The regression analysis showed R^2=1.000 and mean relative divergence (*MRD*) minor than 3.4% in all cases. A good fit (R^2= 1.000) of the experimental data in both airflow directions was obtained.

Figure 4 also shows the good agreement of this model with the experimental data, for both grains and airflow directions.

Again, this figure demonstrates the pronounced differences that arise when comparing these two kind of grains. It is evident that this dissimilarity is related to the size of the grain. The obtained data from Table 1 confirms this affirmation, since the grain of agropyron is 3.2 times smaller than the one of corn, so the bulk density of this grain is 3.3 times greater than agropyron (see Table 1).

This model of three variables incorporates the grain and bed characteristics, fundamental variables for the designing of an adequate aeration system to guarantee safe storage of grains.

M. Estimation of power ventilation

Equation. (10) was applied using recommended airflows in the range from 0.001 to 0.05 $m^3/s\text{-}m^3$ for different heights of silo. Figures 5a and 6a show the resulting curves for corn and agropyron, respectively.

Also, taking into account that in order to select the appropriated fan the relation static pressure drop-recommended airflow must be known (Giner, 1995), Figures 5b and 6b were constructed to dispose a more wide relationship between these variables.

Table 4: Parameters of Bern and Charity model (Eq. 5) for agropyron and corn with vertical and horizontal airflow directions. (V, H: vertical and horizontal, respectively).

Grain	Airflow direction	Coefficients of Eqn. (5) and statistics									
		a_1	ASE_{a1}	a_2	ASE_{a2}	a_3	ASE_{a3}	R^2	*RSS*	S_y	*MRD%*
Agropyron	V	4.03	3.67	279.84	6.76	417.88	13.16	1.00	1449.9	7.62	1.90
Agropyron	H	-0.36	2.59	96.41	4.43	255.54	8.19	1.00	396.2	4.15	1.31
Corn	V	1.75	2.48	195.66	11.29	367.5	743.09	1.00	896.6	5.76	3.34
Corn	H	0.45	0.52	26.63	2.26	229.26	3.67	1.00	19.39	0.88	2.57

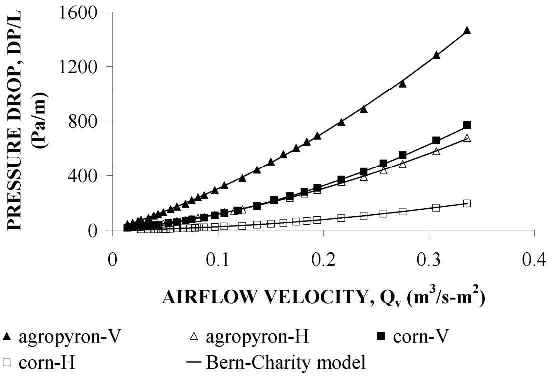
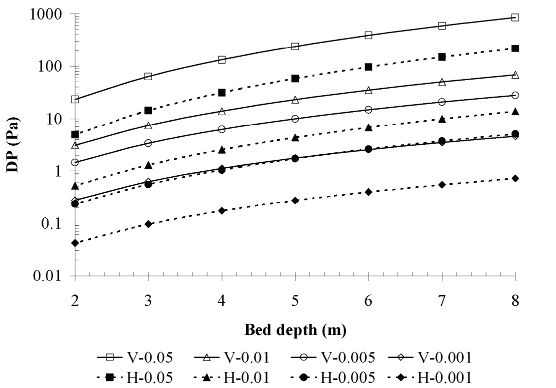
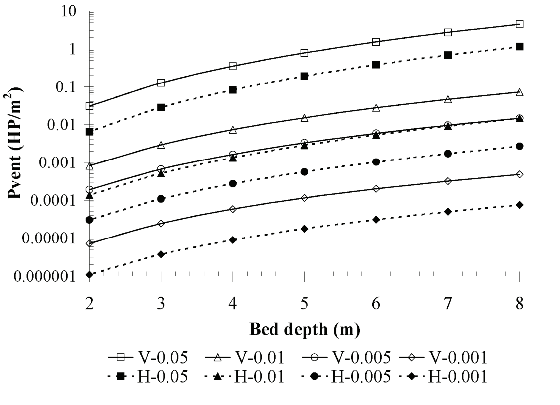


Fig. 4: Experimental data points and predicted curves by Bern-Charity model (dotted lines) of airflow velocity vs. pressure-drop for agropyron and corn. (V, H: vertical and horizontal airflow direction, respectively).



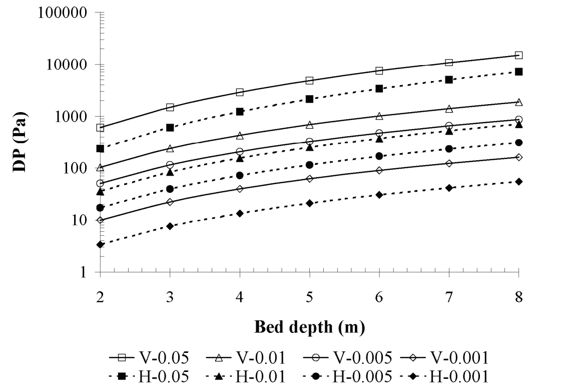
(a)



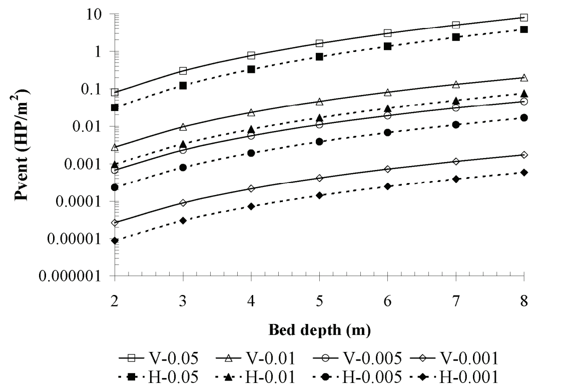
(b)

Fig. 5: Estimated ventilation power per unit of cross-area (a) and static pressure-drop (b) and for corn at several recommended airflows (range 0.001-0.05 m^3/s-m^3) in function of the silo height (V: Vertical airflow direction, H: Horizontal airflow direction).

With the aim of describe the use of the preceding graphs, the following example was constructed: in the dryeration operation, corn grain charged in a silo with a spreader up to 7 m (bed volume=281 m^3) must be cooled impelling air through the stored mass in vertical direction. For this purpose, the recommended airflow is between 0.005 and 0.01 m^3/s-m^3 (Friesen and Huminicki, 1986); then, the linear velocity (Q_v) in the grain bed will be between 0.035 and 0.07 m^3/s-m^2. Static pressure-drop per unit of bed depth (*DP/L*) estimated by Mattei model results in the range from 29-70 Pa/m; consequently, static pressure-drops (*DP*) in Fig. 5b are between 20.8 and 50.1 mmwc (490-204 Pa). Using Fig. 5a, the ventilation-power results between 0.0096 and 0.046 HP/m^2; therefore, a fan 0.4-1.8 HP with will be a priori necessary. However, in this first estimation, additional looses related to the presence of foreign material (fines) mixed with grain, friction of air in distribution ducts, reduction in the fan efficiency (due poor maintenance) and filling of the spreader have not been considered yet. The presence of foreign material finer than the grain produces an effect of increase in the airflow resistance (ASAE, 1999). This effect and others such as the bed compacting due to use of spreaders, cause an increase in bulk density that can be assumed of about 50% plus over the airflow resistance of clean grain (Giner, 1995). The pressure looses in ducts supplying air to grain conditioning systems result from friction, restriction to airflow, changes in direction or cross-sectional area of the flow stream (Brooker *et al*,



(a)



(b)

Fig. 6: Estimated ventilation power per unit of cross-area (a) and static pressure drop (b) for agropyron at several recommended airflows (range 0.001-0.05 m^3/s-m^3) in function of the silo height (V: Vertical airflow direction, H: Horizontal airflow direction).

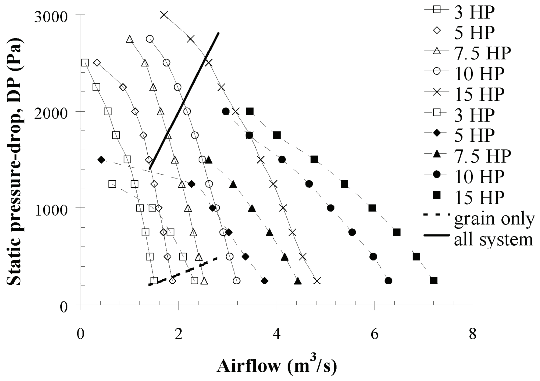


Fig. 7: System curves (weighty full-lines without symbols) and relation air delivery-static pressure (lines with symbols) for typical centrifugal fans with different number of revolutions per minute (full lines: 3450 rpm, dotted lines: 1750 rpm).

1992) can be considered of about 30% plus over the pressure-drop in the grain bed (Giner, 1995). At last, the efficiency of the fan can be reduced of about 50% or more when a poor program of maintenance is applied (ASAE, 1999; Giner, 1995). Then, the real required power ventilation for the aeration system will be approximately 4 times the power ventilation dissipated through the clean grain bed. Consequently, the needed fan will must be of about 1.5-7.4 HP. In the market, fans can be selected in different ranges (Friesen and Huminicki, 1986). The following graph (Fig. 7) shows the curves of air delivery versus static pressure for typical centrifugal fans (typically presented in units of Pa and litres per second) and the system curve. The intersection of these two curves (fan curve and system curve) determines the point at which the system will operate. Based on this figure, the most adequate fan for the cooling process results of 10 HP-3450 rpm, which provides a mean value of 2107 lt/s of airflow (0.0075 m^3/s-m^3, 0.053 m^3/s-m^2), and can dissipates approximately 1350 Pa. Centrifugal fans are usually recommended when systems must be operate at pressures of 1200 Pa or more (Brooker *et al.*, 1992). The calculated ventilation power results some higher than the predicted by Eq. (11) including additional pressure looses, but it must be considered that in engineering design a margin of security is often procure.

If horizontal airflow direction could be used for the purpose of the foregoing example, the resulting needed ventilation-power should be between 0.3-1.5 HP.

III. CONCLUSIONS

Form the present work, the following conclusions can be drawn:

- Resistance to airflow increase with the increase on the airflow rate.
- Pressure-drop for agropyron are 44-1455 Pa/m for vertical airflow direction and 15-670 Pa/m for horizontal airflow direction in the range 0.014-0.336 m^3/s-m^2, while pressure-drop for corn are 15-757 Pa/m and 3-194 Pa/m, in the same order and range of airflow rate.
- Grains of agropyron cause higher pressure-drops than corn grains at the same airflow rate.
- Airflow resistance of corn grains at vertical airflow direction is practically the same of agropyron at horizontal airflow direction.
- For both grains, airflow resistance at vertical airflow direction is greater than the corresponding to horizontal airflow direction.
- Mattei model is the most accurate for predicting airflow resistance of agropyron and corn, followed by Bern and Charity model.
- Power ventilation depends strongly of airflow velocity and direction, and grain/bed characteristics. So, it is evident the importance of know their effects to optimize the design and operation of grain conservation.

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Received: November 25, 2004.
Accepted: August 29, 2005.
Recommended by Subject Editor G. Meira.