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Research/Penelitian

Pressure Drops and Minimum Spouting Velocity in Spouted Bed Dryers

"Pressure Drops" dan Kecepatan Minimum "Spouting" dalam Alat Pengering "Spouted Bed"

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ABSTRACT - Studi ini dirancang untuk membuat suatu hubungan antara "pressure drop" dan kecepatan aliran udara dalam suatu proses pengeringan dengan menggunakan spouted bed dryer. Percobaan dilakukan dengan menggunakan "column" penuh berdiameter 0,27 m dan menggunakan bahan jagung pipil dan "celcon". Percobaan dilakukan dengan berbagai ketinggian tumpukan yaitu 35 cm,40 cm, 43 cm, dan 57 cm dan suhu udara 24 °C, 35 °C, dan 40 °C. Hasil percobaan disajikan dalam bentuk kurva hubungan antara "pressure drop" (kpa) dan kecepatan aliran udara "superficial" (m/s). Secara umum kurva yang dihasilkan dalam percobaan dengan menggunakan "column" penuh ternyata mempunyai pola yang serupa dengan kurva berdasarkan percobaan dengan menggunakan setengah "column".

INTRODUCTION

Knowledge of spouted bed hydrodynamics e.g. pressure drop as well as minimum spouting velocity becomes important in finding out the effectiveness of gas flowrate through the bed. The importance of the gas flowrate in spouted bed drying applies to the minimum and maximum spouting speed, from which can be calculated the mass transfer rate (ALAMSYAH, 1990). In general spouting stability in terms of gas flowrate increases with the increasing particle size, increasing column diameter, decreasing to column diameter ratio, and decreasing bed depth (DO, 1988 and BARRET, 1987).

The majority of experimental spouted bed hydrodynamics have been carried out in experimental half column of diameter 0.3 m or less (LIM and GRACE, 1987). Studies on full column for both size of less than 0.3 m and larger in diameter are rare, but are crucial for the data which can be used for developing correlations and models. So far several correlations and models mostly are solely based on half column and small vessels. For examples, there are strong indications proposed by MATHUR and EPSTEIN (1974), KMIEC (1983) GREEN and BRIDGWATER (1983) FANE and MITCHELL (1984) ABDELRAZEK (1966) that well-known minimum spouting velocity correlation of MATHUR and GISHLER (1955) gives poor predictions when applied to full column of spouted beds.

In addition to the relationship between pressure drop and spouting velocity, several findings have been proposed by some investigator namely, GRBAVCIC, VUKOVIC, ZDANSKI, and LITMAN (1987), MANURUNG (1964), and MADONNA and LAMA (1960). Their findings were presented on figure 1, 2, and 3 respectively. As regards the relationship between pressure drop and minimum spouting velocity in drying corn in spouted beds using full column not much research have been done. Such studies should be conducted in order to get the best results which can be supported new correlations. This study was designed to make the relationship between pressure drop (kpa) across the bed and superficial air velocity (m/s).

MATERIALS AND METHOD

Materials :

(1) <u>corn</u>:
variety : yellow corn
sources : New South Wales - Australia (local)
specific weight : 1313.4 -1284 kg/m^3;
mean : 1299 kg/m^3
mean diameter : 0.7257 x 10^{-2} m
bulk density : 748.3 - 698.4 kg/m^3
porosity : 38.50 - 47.26 %

(2) celcon:

In this experiments besides corn, celcon were also used in finding out the relationship between pressure drop and superficial velocity using spouted bed dryers from which the results can be compared. The characteristics of celcon are as follow:

commercial name : CELCON LW 90
specific weight : 1400 kg/m^3
bulk density : 860 kg/m^3

Dimension of spouted bed:

bed length (mm) : 1100
column diameter (mm) : 270
orifice diameter (mm) : 50.8
top cone angle (°) : 60
bottom cone angle (°) : 30

Method :

The experimental method used was simple. At the start of the experiment the air was allowed to pass through, but with the control valve fully open (minimum flow rate). A diagram of the experiment was presented in Figure 4. The air flowrate through the bed is then gradually increased until the position of the air control valve was fully closed (maximum flowrate). When it was fully closed the reverse process was started. The valve was gradually reopened completely. Both measurements of air pressure drop and air velocity were recorded simultaneously at intervals during the closing and opening the valve. The moment when the particles started spouting was also monitored through the perspex windows.

The pressure drop was measured by a U tube water manometer with one end connected to the pipe below the inlet orifice and the other connected to the pipe below the fountain section. Air velocity was obtained by measuring the static and dynamic pressure (in mm water) with annubar located in the pipe below the inlet orifice. This annubar was connected to the manometer. When the manometer readings were obtained, they were then converted into air velocities in meter/second. The pressure drop data were then corrected by a factor equal to the pressure drop in the same speed (a prior experiment performed over the complete range of air flow).

To get sufficient pressure drop versus air speed experimental results, nine (9) runs were conducted, each run with different bed height and temperature. Bed heights used were 35 cm, 40 cm, 43 cm, and 57 cm, while the temperatures were 24 °C, 30 °C, and 40 °C.

Calibration of annubar was conducted before calculating the air velocities. Calibration was conducted by rotameters. Two GEC series 2000 metric rotameters tube size 47 with float type K metre were used and connected in parllel to measure air flowrate. The lay out of calibration of the annubar is presented in figure 5. In this method rotameter reading were collected and air flowrate in litre/minute @ (15 °C and atm) can be obtained by calibrating chart supplied by manufacturer. Correction is required since the experiments were conducted at higher temperature and some information for rotameter are used (McCABE and SMITH, 1976).

In the calibration of annubar inclined manometer was used to measure different pressure in the annubar (static and dynamic pressure). Air pressures were also measured in order to obtain specific weight of air at annubar by U tube mercury manometer. In order to obtain accurate correction factor eight experiments were conducted in a range of temperature 25 °C, 35 °C, and 40 °C. The average correction factor obtained is 0.73 (one of the eight experimental data are presented in table 2).

RESULTS AND DISCUSSION

Results

Pressure drop versus air velocity

Results of nine (9) runs of the experiments are displayed as graphical representations of pressure drop across the bed (kpa) versus superficial air velocity (m/s) in the following figures. Results of those using corn are presented in figure 6 up to figure 11, and using celcon are presented in figure 12, 13, and 14. All figures show both increasing and decreasing air flow stages and present maximum pressure drop (as well as corresponding air velocity), minimum spouting velocity, and minimum spouting pressure drop due to spouting action as discussed by MATHUR and EPSTEIN (1974).

Minimum Spouting Velocity

The estimation values of the minimum spouting velocity is necessary to predict the air requirements for drying. In addition to that, the pressure drop across the bed may be a function of the minimum spouting speed because further increase in the speed does not significantly increase the pressure drop (ABDELRAZEK, 1969). The experimental values of the minimum spouting velocities of corn and celcon were compared with those predicted for various height by equation proposed by ABDELRAZEK (1969). Such equation is the modification of the well-known minimum spouting velocity of MATHUR and GISHLER (1955). The comparison between minimum spouting velocity of experiments and prediction are presented in table 1.

Table 1. The comparison between the minimum spouting velocity of the prediction and experimental (meter/second)

Materials	Run	Value	
		Experimental	Predicted*)
corn	1	2.60	16.80
corn	2	2.37	17.30
corn	3	2.27	17.40
corn	4	2.45	19.15
corn	5	2.39	19.50
corn	6	2.37	19.72
celcon	7	1.56	9.29
celcon	8	1.51	10.72
celcon	9	0.74	12.46

*) $$Vms = \frac{1}{1.74}\left\{(Dp/D)\,(d/D)^{0.33}\left[2gH\frac{({}^{\rho}p - {}^{\rho}g)}{\rho g}\right]^{0.5} - 0.25\right\}$$

Vms : equation for determining minimum spouting velocity proposed by ABDELRAZEK (1969).
Dp : diameter of particle (cm)
D : diameter of column (cm)
d : diameter of inlet nozzle (cm)
g : acceleration due to gravity (m/s^2)
H : bed heights (cm)
p : density of particle (kg/cm^3)
${}^{p}g$: density of air (kg/cm^3)

Discussion

Pressure drop versus air velocity

Generally the results shows the typical curves which usually presented by using half column (see figure 1, 2, and 3). The figures show a relatively constant pressure drop after the spouting occurs. Graphically it was found that the maximum pressure drop as well as corresponding to the air velocity could be observed easily. On the other hand the minimum spouting velocity and minimum spouting pressure drop on the curves were not clear. Also it was found in the decreasing air flowrate curves that pressure drop did not suddenly rise as air velocity reduced near the minimum spouting position. This may be due to the fact that the energy to penetrate the bed was no longer necessary. However the pressure drop curves of decreasing air flowrate still confirm with the theory presented by MATHUR and EPSTEIN (1974).

There are many possible sources of experimental error. In this study, the annubar was used to measure the air flowrate. It gave good accuracy and its error was about 4 %. In fact, the difficulty was in the measurement of the air velocity corresponding to the peak pressure and minimum spouting. The annubar was connected to the U tube manometer for measurement air velocity. The manometer readings which shows the difference between static and dynamic pressure were not easy to monitor, particularly in the period between the start and spouting point (peak pressure point) and at the moment when minimum spouting velocity was achieved.

Before the spouting occured it was found that the level of manometer reading showed apparently not to rise eventhough the air flowrate was increased, but when the spouting was nearly occured this level rose abruptly in such a way that fluctuations were observed in the fluid level, making reading difficult. To reduce this source of error, several repititions of each experiment were conducted. Also in measuring the minimum spouting velocity, rapid fluctuations in pressure drop occured. To overcome this, the air flowrate was reduced by controlling the valve very gently in order to obtain accurate values of minimum spouting speed.

The other things which required careful attention was the position of the U tube manometer connected for measurement of pressure drop across the bed. Since it is a static pressure measurement, any incorrect positioning will introduce an incorrect result. Therefore a correction method (MATHUR and EPSTEN, 1974) was involved by measuring the pressure drop in the empty bed.

Minimum spouting velocity

The predicted values of minimum spouting velocity were much higher than those found by experiment for both corn and celcon. This may be attributed to the roughness, so a relatively smaller fraction of the kinetic energy of the gas will be reduced by friction between particles. However such phenomena was not considered in the equation given so the predicted values of minimum spouting velocity were much higher than those of experimental results.

The other possibilities may be due to the fact that in correlating the equation ABDELRAZEK (1969) used half column and different geometries of spouted bed, such as diameter of inlet nozzle (d) and column *(D), and bed heights (H).* In his experiments the air inlet to column diameter ratio, d/D was 1/32 and the experimental values of the minimum spouting velocity was based on the shallows bed 1H/D Also in his experiments various materials were studied, namely polyethylene, polystyrene, millet, rice, barley, wheat, glass particles, and steel slots.

However in this study drying of experiments, the actual conditions were d/Dp = 0.1181 (Dp: particle diameter), and Dp/D = 0.0269. Also in this study, the experiment were conducted using full column of bed and two kinds of materials (e.g. corn and celcon) and basing on three bed heights. Based on results in table 1, it can be concluded that the above equation cannot be longer used in the test of spouted bed dryers.

CONCLUSIONS

The experiments of relationship between pressure drop across the bed and superficial air velocity and test (confirmation) of minimum spouting velocity in spouted bed have been conducted. These studies were performed basing on the spouted bed dryer (full column), limited parameters, and materials. The relationship between pressure drop through the bed and superficial air velocity displayed good results. Generally the curves present the typical curves as discussed by MATHUR and EPSTEIN (1974). Based on the experiments of minimum spouting velocity the equation of the minimum spouting velocity proposed by ABDELRAZEK (1969) cannot be longer used in the test of spouted bed dryers.

The above work is just a preliminary study and much experimental on spouted bed hydrodynamics (e.g. pressure drop versus superficial air velocity and minimum spouting velocity) are needed to better analyze the accurate data with variation of bed height, air velocity, column diameter, inlet nozzle diameter, cone angle, materials, and temperatures which can be used to formulate semi-theoretical equations.

ACKNOWLEDGEMENTS

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Thanks are also due to the Faculty Workshop and Department of Chemical Engineering Unversity of NSW for their technical assistance.

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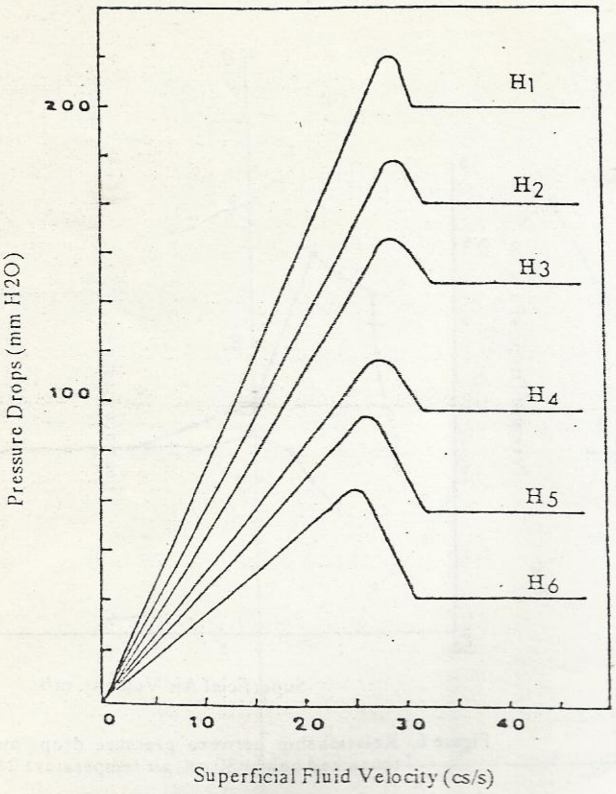

Figure 1. Spout pressure drop as a function of superficial velocity and bed height, Glass spheres : Dp= 2, 11 mm, D= 5, 03 cm, and d= 2,11 mm (GRBAVCIC et al. 1987)

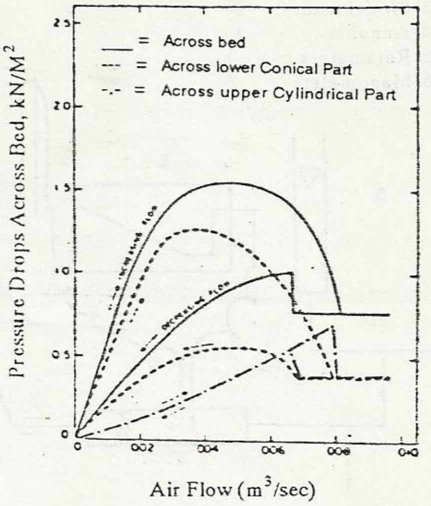

Figure 2. Pressure drop-flow rate curves of MANURUNG (1964)

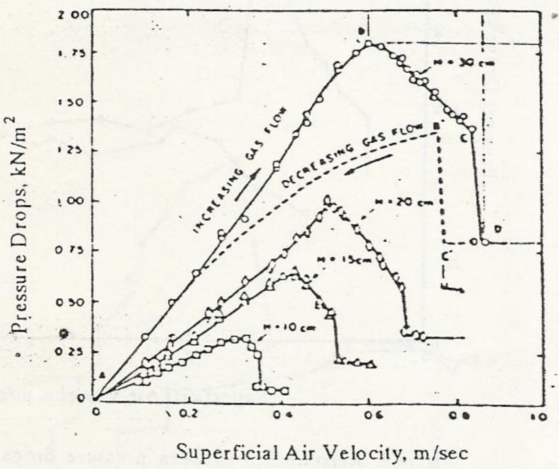

Figure 3. Typical pressure drop-flow rate curves (MADONA et al, 1960) Wheat:Dp= 3.6 mm, D= 15.2 cm, d= 1.27 cm.

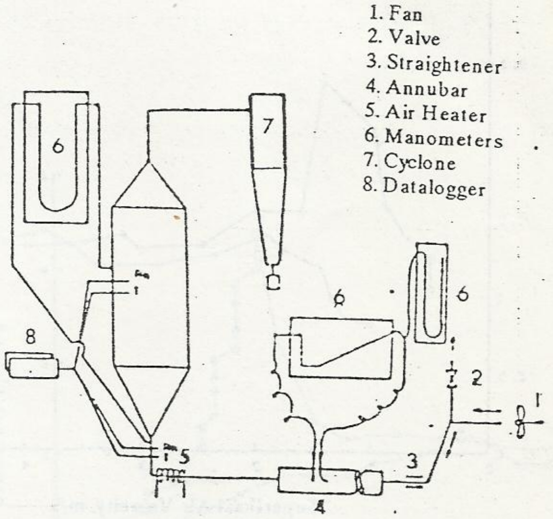

Figure 4. The diagram of experiment of relationship between pressure drops and air velocity

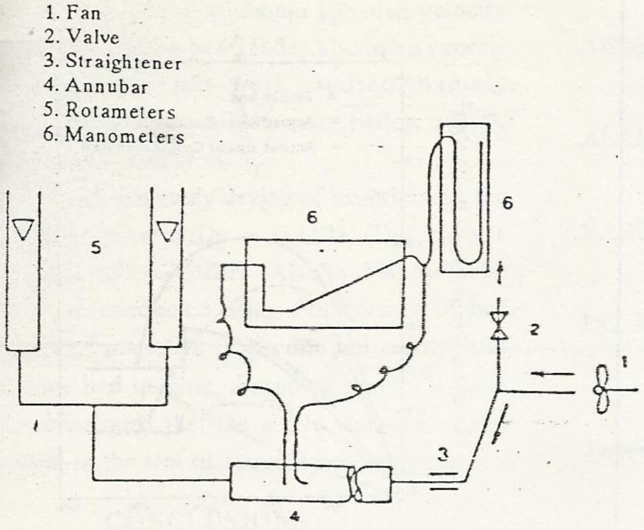

Figure 5. The layout of calibration of the annubar

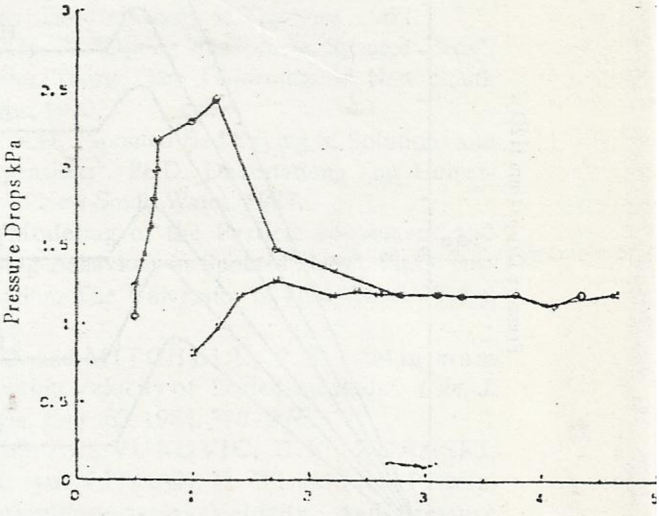

Figure 6. Relationship between pressure drops and air velocit
(corn:bed height 30 cm, air temperature 24C)

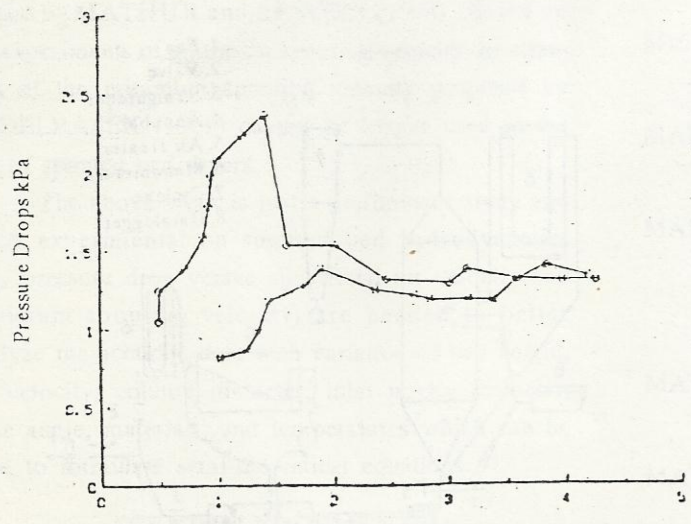

Figure 7. Relationship between pressure drops and air velocity
(corn:bed height 30 cm, air temperature 35C)

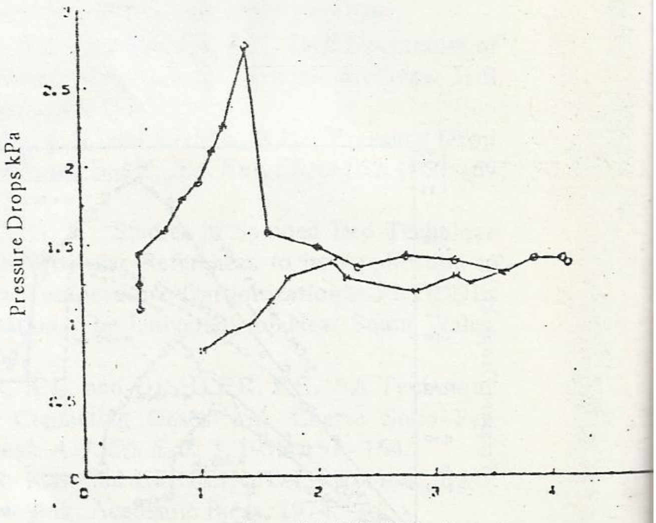

Figure 8. Relationship between pressure drops and air veloci
(corn:bed height 30 cm, air temperature 40C)

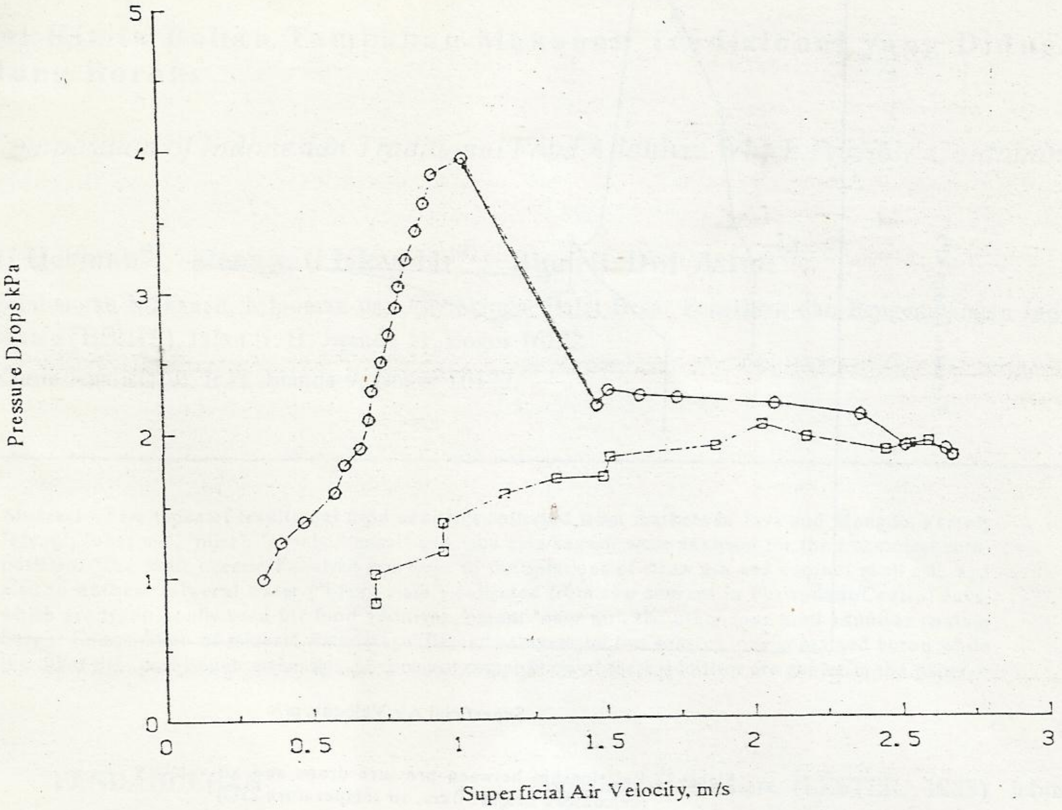

Figure 9. Relationship between pressure drops and air velocity (corn:bed height 40 cm, air temperature 24C)

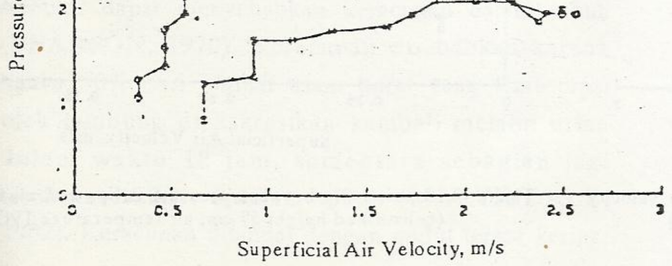

Figure 10. Relationship between pressure drops and air velocity (corn:bed height 40 cm, air temperature 35C)

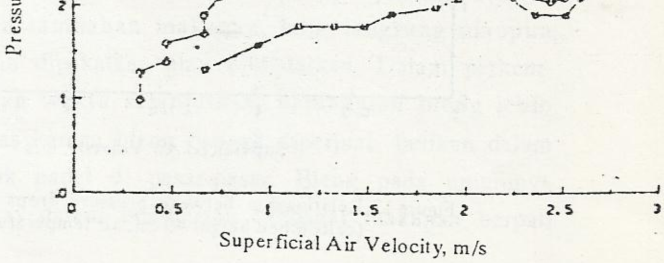

Figure 11. Relationship between pressure drops and air velocity (corn:bed height 40 cm, air temperature 40C)

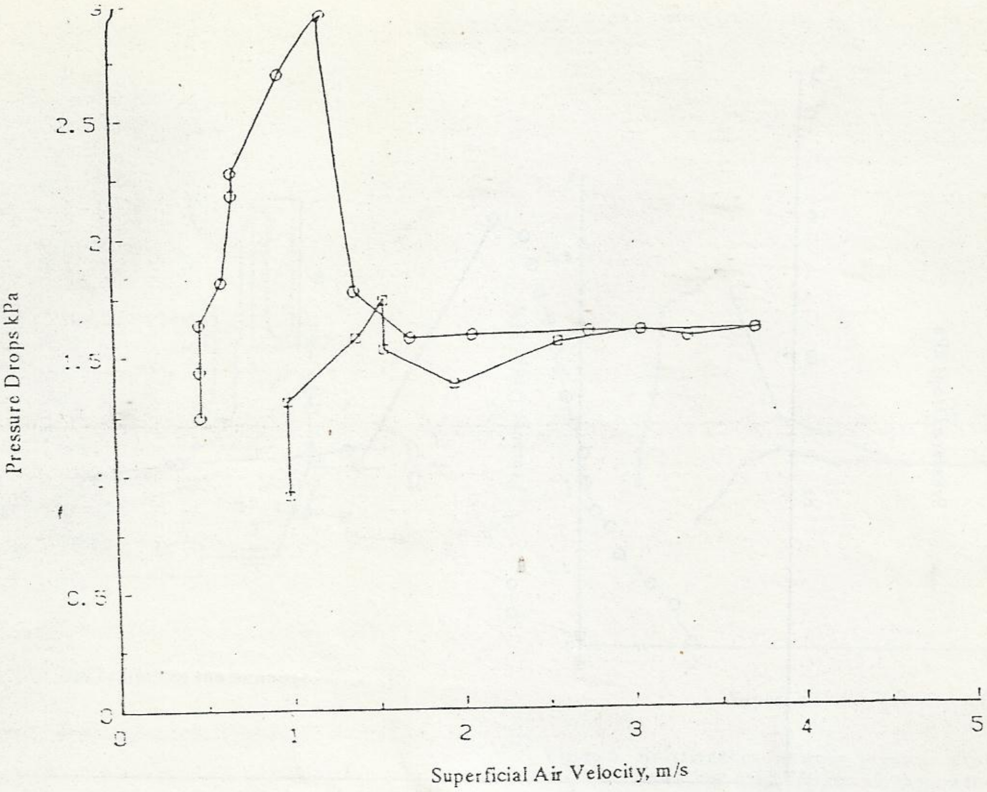

Figure 12.Relationship between pressure drops and air velocity
(celcon:bed height 30 cm, air temperature 21C)

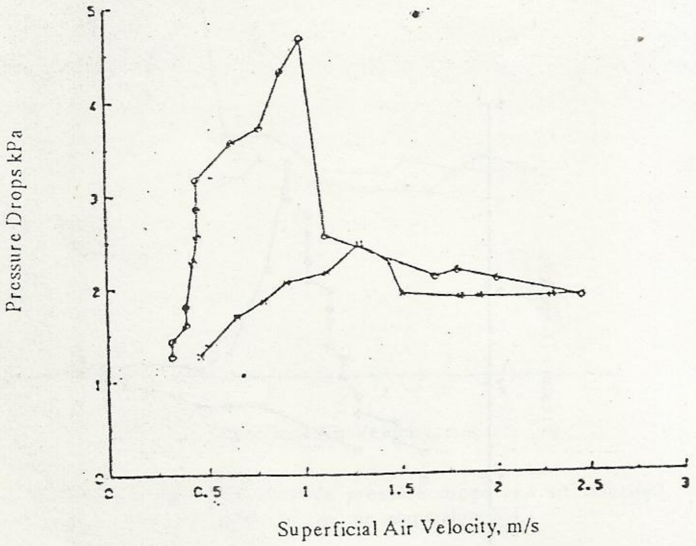

Figure 13.Relationship between pressure drops and air velocity
(celcon:bed height 40 cm, air temperature 21C)

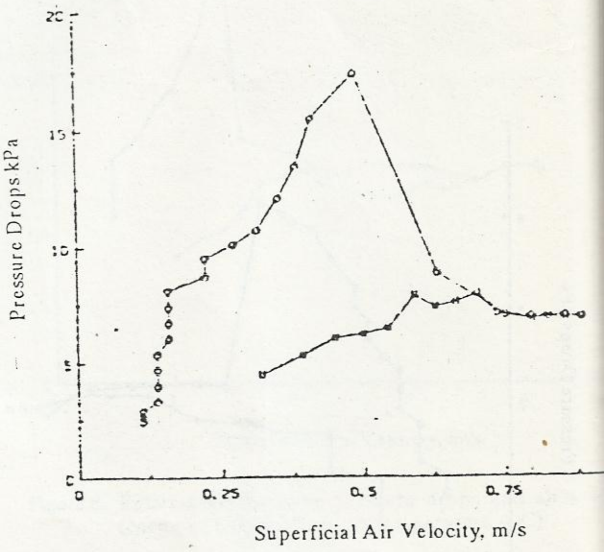

Figure 14.Relationship between pressure drops and air ve
(celcon:bed height 57 cm, air temperature 19C)