Int. Agrophysics, 1994, 8, 169-175

MATHEMATICAL MODELLING OF AIR FLOW THROUGH WHEAT GRAIN LAYER

M. Babić, M. Tešić, M. Martinov, L. Babić

Institute of Agricultural Engineering, University of Novi Sad
Trg D. Obradovića 8, 21121 Novi Sad, Yugoslavia

A b s t r a c t. Geometrical properties of wheat kernel depend of wheat varieties. Size and shape are the characteristics usually expressed in dimensions and sphericity factor. Kernel moisture content has an influence both on dimension and sphericity. Starting from these hypotheses, the influence of different varieties and moisture contents on properties of steady-state and fluidized layer have been examined. The measurements were performed with the originally experimental apparatus with sufficient number of repeatings. Three characteristically wheat varieties were chosen and were investigated in four moisture content levels. The data were processed by adequate programmes and equations were provided which related wheat grain layer resistance and basic physical properties.

The equitation of Shedd, $\Delta p/h = A\,v^B$ type is most adequate for practice use. It is also convenient for steady-state of grain layer. The equitation of Ergun and Orning type can be acceptable as a sufficient one for fluidization layer. The constants in this formula are dependent of basic physical wheat kernel properties. These constants are different for different varieties and different grain moisture.

K e y w o r d s: wheat grain, air flow, mathematical modelling

INTRODUCTION

The knowledge of aerodynamic properties of grain is important for process designing and qualitative operation control. The air stream trough grain material or its fluidization is the process which regularly occurs in machines and devices in agricultural technics. There are for example: separation devices of wheat combine, aspiration grain separator, ventilation in storages, introduction points in pneumatic transport and grain dryers. It is necessary to know for designing and operation control air drop pressure dependence along the air stream in a stable and fluidization layer. It is of a special importance to know all these properties for the wheat kernel which is one of the most distributed crop.

Mathematical models which are used in researches and in practice [1,4] do not consider that influence of the basic physical properties on flow properties is relevant. However, the difference in length, shape, roughnes of the surface, the mass of separate kernels for various wheat varieties require the different mathematical models which express the air flow through the wheat layer [3].

Notation:

d	(m)	-particle diameter in layer
d_e	(m)	-kernel equivalent diameter
e	(%)	-kernel layer porosity
e_o	(%)	-stable kernel layer porosity
h	(m)	-layer height
h_o	(m)	-stable layer height
K_1, K_t	(-)	-constants in equation of Ergun and Orning

v (m s) -apparent air velocity
w (%) -moisture content
Δp (Pa) -pressure drop along air stream
μ_f (Pas) -dynamic viscosity of the air
ρ_f (kg/m^3) -density of air

MATERIAL AND METHOD

The choice of wheat varieties in this experiment is based on different physical properties relevant for this investigation. The kernel layer resistance during air stream, depends on density, size, shape, roughness and kernel porosity. The conventional declaration of the varieties according to their physical properties is simplified on expressing of the mass of 1 000 kernels and whole bulk mass. The interdependence of these properties is accepted as the represent of the different physical properties. The second criterium of wheat varieties was that all samples were taken from the same area (similar soil and technology). On the basis of these criteria the following Yugoslav varieties have been chosen: Rana Niska, Zvezda and Balkan. The samples were taken from Vrbas region in 1991.

Moisture content was considered as a factor within the values appearing in real process. Some physical properties of the tasted wheat samples are shown in Table 1.

The original experimental apparatus was designed in this purpose (Fig. 1). Sample (06) is placed in glass tube (05) on the perforated sheet metal (07), the air is directed by fan (03) through the measuring tube (02) where measuring orifice is placed. From air stream stabilizer (09), the air passes through deflector (08) which is made of plastic tube stocks of 3/4" and 3/8" dimensions. The task of the deflector is to neutralize the air stream whirling and to make homogeneous air velocity field along the glass tube section. The glass tube was perforated and on these openings the connectors for static pressure measurement were placed in front and behind the layer. The sieve is located at the end of glass tube for light kernel retaining which terminal velocity is smaller then air velocity in the glass tube (04). The measuring points scheme is shown in Table 1. One group of the measurement is about flow of the air stream through the layer, and second is laboratory determination of physical properties. The experiment starts with very low air velocity values. Air velocity increases up to the beginning of pneumatic transport of the light kernels. After that point velocity slowly drops to zero.

Experimental method which has been applied in this research was specific scientific method and results were statistically determinated. The GRAPHER programme has been used for the graphic presentation of investigation results.

RESULTS AND DISCUSSION

Figure 2 presents the experimental results for three different grain varieties (Table 1) with very close moisture content (Rana Niska w=14.11 %, Balkan w=13.96 %, Zvezda w=13.82 % wet basis).

Figure 3 shows experimental results for different grain moisture content on one wheat variety (Rana Niska). The characteristic shapes

Table 1. Basic physical properties of wheat grain sample

Variety	1 000 kern. mass (g)	Bulk density (kg/m^3)	Porosity (%)	Moisture content (%)	Angle of repose (^{o})	Eqiv. diam. 10^{-3} (m)
Balkan	41.07	797.3	38.5	13.96	31.19	4.01
Zvezda	42.96	823.0	36.8	13.82	30.78	3.99
Rana Niska	36.26	822.0	37.7	14.11	32.29	3.88
Rana Niska	38.04	861.7	36.1	10.94	30.05	3.87
Rana Niska	41.59	744.9	39.9	19.08	38.80	3.89

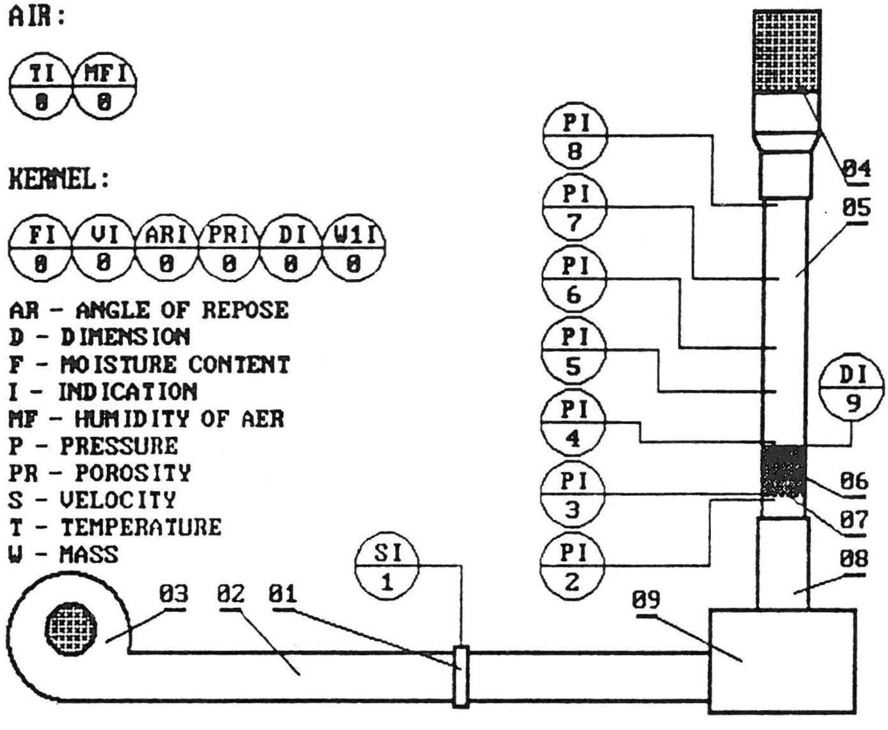

Fig. 1. Experimental device.1 - orifice, 2 - measure pipe, 3 - fan, 4 - sieve, 5 - glass pipe, 6 - sample 7 - perforate plate, 8 - strainghtener, 9 - buffer.

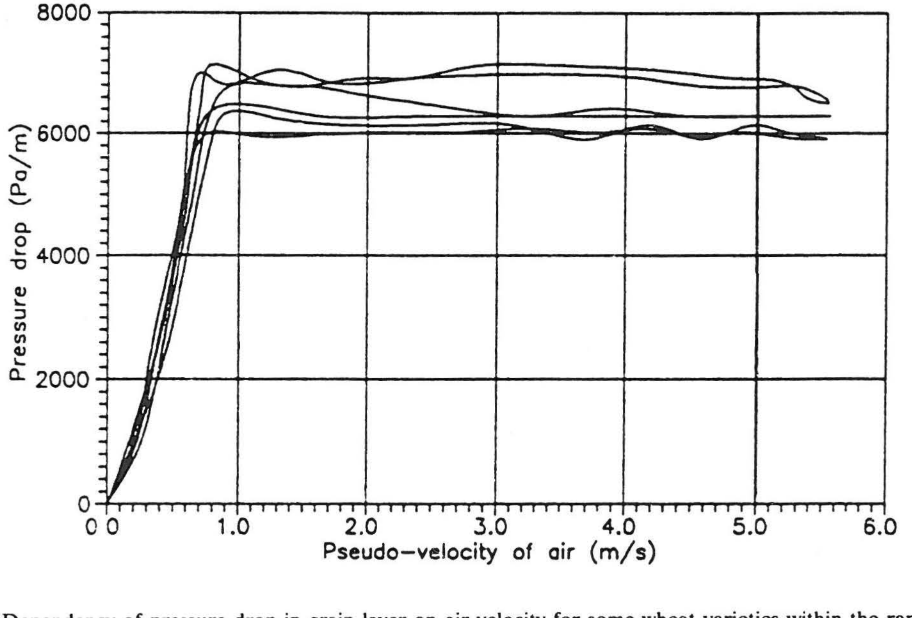

Fig. 2. Dependency of pressure drop in grain layer on air velocity for some wheat varieties within the range of moisture content 11 - 19 %.

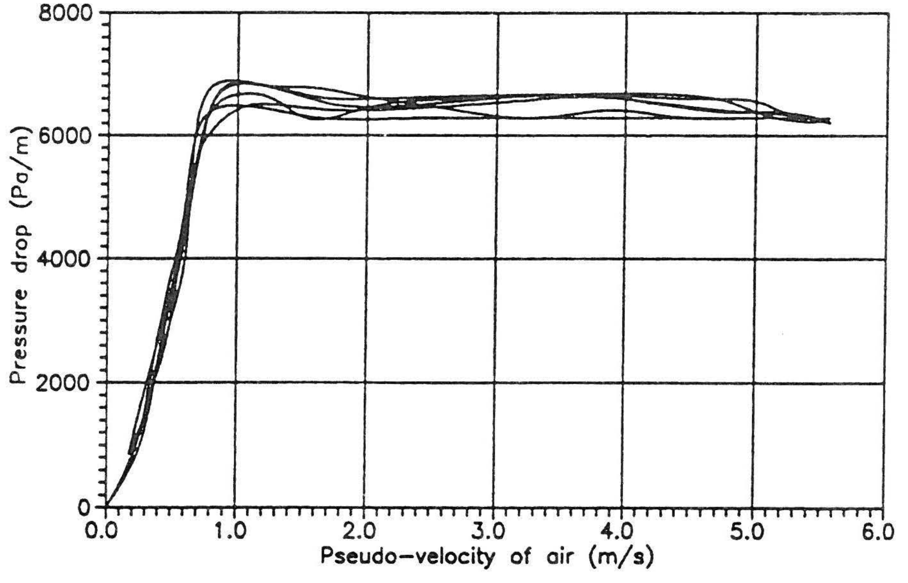

Fig. 3. Dependency of air pressure drop in grain layer for analysed wheat varieties.

given in these diagrams (Figs 2 and 3) are mainly in accordance with the literature sources [1,4]. In a phase of the particularly stable layer air drop pressure change at the air velocity increase is significant and has got a monotonous rising character. Term dp/dv is rising constantly. At the end of this phase air pressure drop is decreasing and after that it is approximately constant. Before the pneumatic transport occurs air pressure drop slightly decreases. The appearance of hysteresis was confirmed while the air velocity is decreasing.

By analysing Fig. 2, the conclusion can be derived that there is functional difference between air drop pressure in grain layer and air velocity for different varieties. In the field of air flow through the wheat grain stable layer analytic model has been determined for the tested varieties. Kumar and Muir [3] recommended Shedd's equation as most adequate in field of stable layer. Researches confirmed this attitude. Following equations has been derived:

Zvezda: $\Delta p/h_0 = 9207\, v^{1.504}$ (1)

Rana Niska: $\Delta p/h_0 = 10094 v^{1.593}$ (2)

Balkan: $\Delta h/h_0 = 8120\, v^{1.289}$. (3)

Graphic presentation of the measuring and fitting results by using afore mentioned equations (Eqs (1), (2) and (3)) are shown in Fig. 4.

The influence of one of the most important physical grain properties, moisture content, on aerodynamic properties can be analysed in Fig. 3. The grains of lower moisture content obviously influence the appearance of bigger air stream resistance. The resistance of grain with higher moisture content is smaller what can be explained by its lesser surface roughness since the moisture 'lubricates' the grain surface. However, this is not the only influence to the aerodynamic conditions over the air flow through the layer. The moisture content is within grain itself, so it influences the bulk density change.

Influence of moisture content on grain length was analysed too. Sufficient number of samples were analysed and by statistical processing following correlation came out:

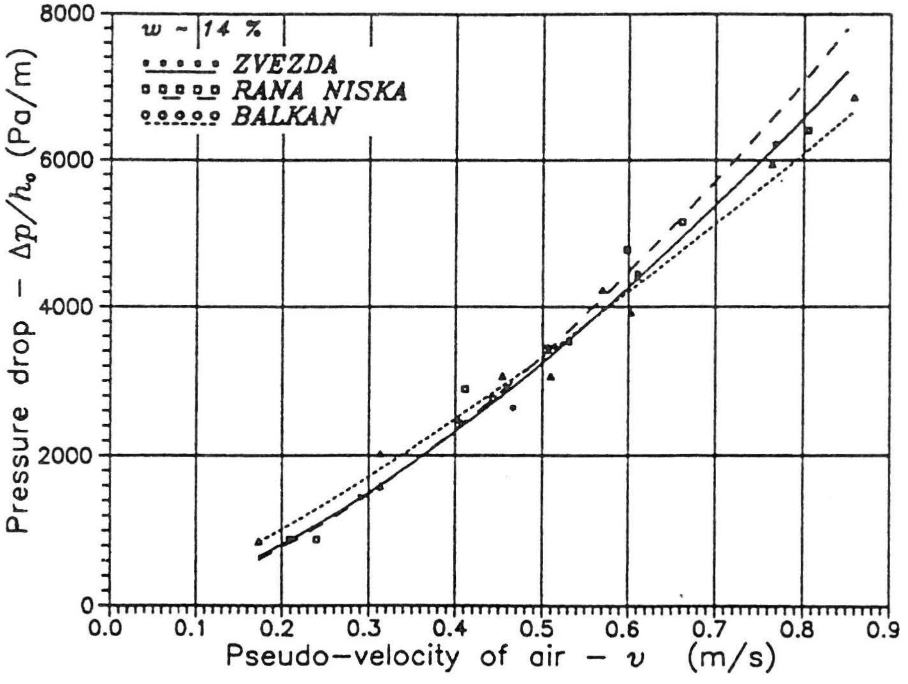

Fig. 4. Dependency of drop pressure in stable grain layer on air velocity for different wheat varieties.

Zvezda: $d_e=3.8225+0.01182\,w$ (4)

Rana Niska: $d_e=3.8699+0.00069\,w$ (5)

Balkan: $d_e=3.7508+0.01891\,w$. (6)

The influence of moisture content on equivalent grain diameter is significantly relevant at Balkän and Zvezda varieties and is irrelevant for Rana Niska. So conclusion can be derived that attention should be directed on influence of the grain moisture content on flow properties as well as for the grain surface condition because moisture content influences on the grain length. In field of the fluidization layer where $e>e_o$ according to literature [1,4] Ergun and Orning equation. This equation is valid up to second critical velocity which is:

$$\Delta p/h = K_l\,(1-e)^2\mu_f\,v\,e^{-3}d^{-2}+$$

$$0.5\,K_t\,(1-e)\,\rho_f\,v^2\,e^{-3}\,d^{-1} \quad (7)$$

Using this equation the problem about definition of both constants K_l and K_t are in fact the functions of the basic physical properties.

Besides the equation (Eq. (7)), real porosity value of material is present without data or functional dependence of the air velocity. The pressure drop value in field of the fluidization layer is approximately constant up to second critical velocity. In Fig. 5 middle pressure drop values of air flow through grain layer are marked.

By analysing the Fig. 5 follows the conclusion that there are the differences in pressure drop for different varieties so it means for grain of different physical properties.

If one wants to use Ergun and Orning equation or some other equations confirmed in literature [4], than it should be known the dependency of the layer porosity versus air velocity. Experimental results in this field are shown in graph (Fig. 6). Analysis of this graph shows irrelevant differences. For different varieties proper fit could be obtained by using polynomial of four and five degree. But, however, significant number of experiment

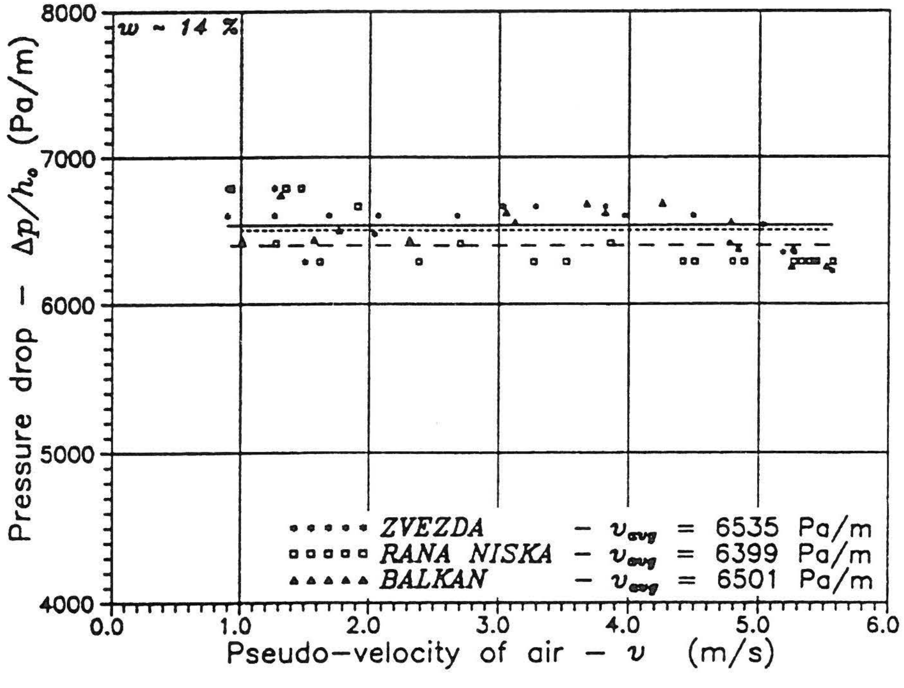

Fig. 5. Air flow pressure drop through fluidization grain layer of different wheat varieties.

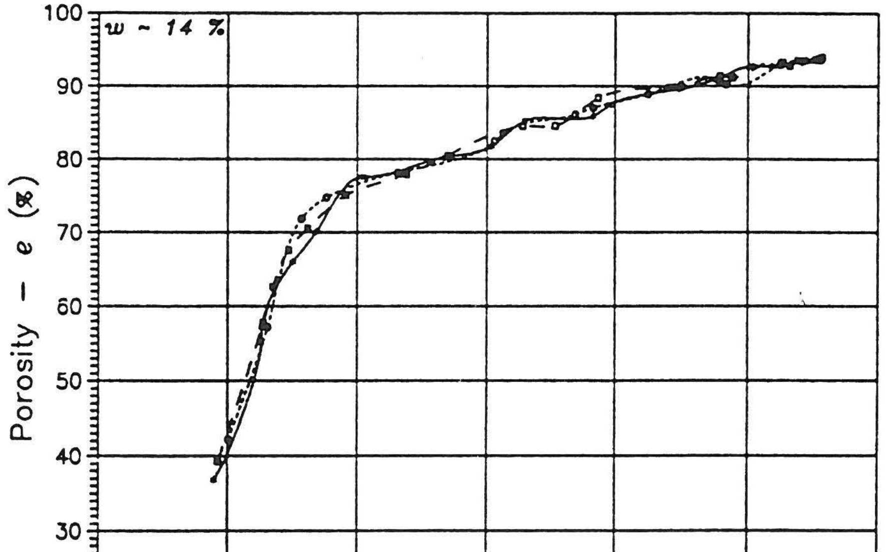

Fig. 6. Dependency of grain layer porosity on apparent air velocity for different wheat varieties. Explanations as in Fig. 4.

should be carried out. It is to be pointed out that porosity value is not constant for certain air velocity. It is coordinate function in direction of the air flow (in Fig. 6 middle value has been taken). In calculating the layer porosity middle value following relation has been used:

$$e = 100 - (100 - e_o) h_o / h \quad (8)$$

Fluctuation of layer porosity values (and middle value) is important in each condition. The fluctuations are present in condition of the air transfer by piston through the layer.

CONCLUSIONS

It has been experimentally established that varieties of wheat with different physical properties have different functional dependency of the pressure drop by air velocity in grain layer. Grain moisture content influences on aerodynamic properties so that the air drop pressure along the air stream in the layer is bigger the moisture content is lower.

The Shedds equation is most suitable for determination of the pressure drop over the flow through stable grain layer (Eqs (1), (2) and (3)). These equations should be improved by involving physical properties functions instead of the constants.

The determination of the pressure drop should be carried out with more details, so it is enable for now to involve quantitative influence of the basic physical properties. It is very interesting question about porosity dependence form the air velocity through the layer.

Further research has to be continued for establishing the general algorithm which will mathematical interpretation express quantitative influence of the basic physical properties of the grain. This algorithm should be basis for the possible usage in computer processes control.

Basic physical properties which have to be presented in mathematical model are: porosity, equivalent diameter, sphericity, bulk density, mass of 1 000 kernels and angle of repose.

REFERENCES

1. **Beck T.**: Messverfahren zur Beurteilung des Stoffeigenschaftseinflusses auf die Leistung der Trennprozesse im Mahdrescher. Fortschritt-Berichte VDI, Reihe 14, No 54, VDI Verlag, Dusseldorf, 1992.
2. **Gorial B.Y., O' Callaghan J.R.**: Aerodynamic properties of grain/straw materials. J. Agric. Eng., 46, 275-290, 1991.
3. **Kumar A., Muir W.E.**: Airflow resistance of wheat and barley affected by airflow direction, filling method and dockage. Trans. ASAE, 29(5), 1423-1426, 1986,
4. **Šašić M.**: Transport fluida i čvrstih materijala cevima. Naućna knjiga, Beograd, 1990.