밀의 함수율과 미세립자가 정압강하에 미치는 영향

Static Pressure Drop as Affected by Moisture and Fine Material in Wheat[*]

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要 約

공기통풍 건조시 공기흐름(airflow)에 대한 곡물저항(grain resistance)은 송풍시스템에서 fan의 선정시 매우 중요하다. 지금까지는 공기흐름에 대한 곡물저항은 주로 Shedd의 curve에 준하여 정해졌다. 그러나 실제의 경우 곡물수확 또는 건조시 기계적 원인에 의하여 미세립자(fine material)가 생성된다.

이에 본 연구에서 밀(red hard winter wheat)을 대상으로 송풍량, 함수율, 미세립자량이 정압강하(static pressure drop)에 미치는 영향을 규명하였고, 이러한 변수가 포함된 수학적 모델을 개발하였다. 독립변수는 0.051로부터 0.203 $m^3/m^2.sec$에 이르는 7단계의 각각 다른 송풍량과 3단계의 함수율(11, 13, 15% w.b), 4단계의 미세립자량(0, 2, 4, 8%)이고, 종속변수는 정압강하이다. 정압강하와 test bed에서의 송풍량은 micromanometer를 사용하여 측정하였다. 결과는 독립변수(송풍량, 함수율, 미세립자량)는 모두 정압강하에 significant하게 영향을 미치는 것으로 나타났다. 규정된 범위내에서 함수율이 증가함에 따라 정압강하는 최고 45%까지 감소되었고, 반면 미세립자량이 증가함에 따라 정압강하는 최고 195%까지 증가되었다. 수집된 data로서 다음과 같은 regression equation이 개발되었다($P=AV+BV^2+C(MO)V+D(FM)V$).

본 연구의 결과는 공기송풍시스팀에서 송풍량, 함수율, 미세립자량이 정압강하에 미치는 영향을 규명하였고, 에너지 절약적 송풍시스템을 설계하는 데 도움이 될 수 있을 것이다.

1. INTRODUCTION

In nearly every instance there is a certain amount of fine materials in the mixed grain when it is dried. Because the fine material has a higher resistance to airflow than a mass of whole kernels, concentration of fine materials can cause a wide variation in resistance to airflow and inadequate drying within a grain bed. In a drying bin, the result is inadequate drying of the core of fine materials or overdrying the remainder of the batch. But, there is not enough information relating the effects of fine materials and moisture content on pressure drop for several airflow rates in a wheat bed. So it is important to know the characteristics of airflow within wheat bed for several percentage of fine materials

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and moisture content in order to provide useful information for the aeration and drying process.

There are many factors that influence on static pressure drop in a grain bed during aeration. A lot of study has been conducted on the relationship of pressure drop and its factors. Brooker(1974) reported that the pressure drop for airflow through some grains depends on the rate of airflow, the surface and shape characteristics of the product, the number, size and configuration of the voids, the variability of the particle size, and the depth of product bed. Shedd(1953) found that for the same method of bin filling, corn with 20% moisture content has less resistance to a given airflow rate than the same corn dried to lower moisture content. He also reported that if foreign particles are smaller than the grain, resistance to airflow is increased; if foreign particles are larger than the grain, resistance to airflow is reduced.

Haque et al. (1978) conducted experiments with a loosely filled column of corn mixed with uniformly distributed fine materials, and showed that the pressure drop increased linearly with increase in fine materials up to about 20 percent. Since 1948, data on the airflow-static pressure relationship of a number of biological products have been published in graphical form in the American Society of Agricultural Engineers' Year Book. These curves, now known as "Shedd's curves" are widely used, and were adopted in 1948 as ASAE Technical Data D272 (American Society of Agricultural Engineers's Year Book, 1980). Many studies have involved the development of similar experimental curves for various products. Stirniman et al. (1931) worked with rough rice; Henderson (1943) with ear corn; Henderson (1944) with oats and soybeans; Shedd (1945) with ear corn, Shedd(1951) with soybeans, corn, oats, rough rice, red cloves, and alsike clover, Day(1963) with crushed and noncrushed dry hay; Husain and Ojaha(1969) with rough rice; Calderwood(1973) with rough and milled rice; and Agrawal et al. (1974) with rough rice. The use of these experimental curves has a definite advantage in convenience, but the accuracy of the pressure drop prediction may be poor, because of insufficient consideration of the effects of variations in some important factors, such as moisture content and amount of fine materials.

The objectives of this study were:

1. To examine the effects of moisture content and fines on static pressure drop in wheat bed.
2. To develop a mathematical model that will predict the effects of moisture content and fine materials on static pressure drop in wheat bed.

2. Experimental Design

The controlled variables are moisture content and amount of fine materials, and the response variable is static pressure drop. Red hard winter wheat was used in this experiment. Three levels of moisture content (15, 13 and 11% w.b.) and four levels of fine materials (0, 2, 4, 8%) were investigated. The percentages of the fine materials are determined based on the weight of tested wheat including fine materials. In this experiment, fine materials can be fines, broken wheat kernels and some foreign materials. Each level of moisture content was tested with four levels of fine materials for seven different airflow rates. Three replications were made at each treatment combination. A total of 36 different beds were prepared and tested for seven airflow rates. Table 1 shows the experimental variables and their levels.

Table 1. Experimental variables and their levels

Variables	Levels	No. of levels
Airflow rates	from 0.051 to 0.203m^3/m^2. sec	7
Moisture content	11, 13, 15% w.b.	3
Fine materials	0, 2, 4, 8%	4

3. Materials and Procedures

The experimental set-up consisted of fan, airflow controller, pipe, 1 inch ASME nozzle, air chamber, test bed and micromanometer. Figure 1 shows a schematic diagram for the experimental set-up. The test column was made of transparent plastic, and its height, diameter, thickness and total volume are respectively 77.5 cm, 15.2 cm, 0.64 cm and 11790㎤ The floor of the test bed was constructed of sheet metal with 1.6 mm diameter holes, totaling 22% of the entire floor area. 5 mm diameter and 38 mm long copper tube pressure taps welded to the test column wall at 30.5 cm intervals, beginning approximately 2.0 cm above the test bed floor, by first drilling 6 mm diameter holes on the wall. The taps protruded inside the column to make sure that air became static at the tap. the plenum chamber consisted of a 91.4 × 91.4 × 30.5 cm rectangular box made of 2.75 mm mild steel sheet. Measurement of airflow to the test bed was made using a 25.4 mm throat diameter ASME nozzle and a micromanometer capable of measuring up to 254 mm of water with a smallest reading of 0.0254 mm. A 25.4 mm of water pressure differential across the nozzle corresponded to approximately 0.57m^3/min. airflow rate. The flow nozzle was placed between the blower and the plenum chamber with a 50 mm diameter plastic pipe. The air was supplied by a fan equipped with 0.37KW variable speed motor, and amount of air was controlled with a dial type air controller.

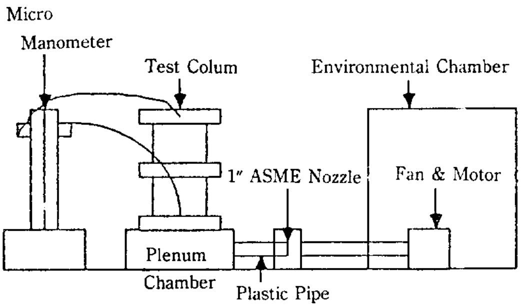

Fig. 1. Schematic diagram for experimental set-up

Before the experiment was begun, the wheat was cleaned with using cleaner. All fine materials and broken kernels were collected for later use. Fine materials were defined as broken grain and other matter that passed through a 1.625 × 9.525mm slotted perforations sieve. At each test, wheat was conditioned by natural air drying to meet the required moisture content. After conditioning it to the required moisture content, clean wheat and fine materials was mixed as uniformly as possible to obtain a uniform distribution of fine materials in grain bed. The test bed was filled by a loose filling mathed as described by Shedd(1953). The wheat was loaded to the test bed through the funnel, the outlet of which was held just above the grain surface making sure to raise the funnel gradually as the filling progressed. The test bed was filled approximately 67cm in each test.

After the test bed was prepared, the fan was turned on, and airflow was controlled with dial type controller and was checked with micromanometer in flow nozzle. After setting the dial to the required pressure differential corresponding to airflow in the flow nozzie, the pressure drop across the wheat bed was read by the same micromanometer after properly closing the ASME nozzle taps. These procedures were repeated for all of the 36 beds, 252 times pressure reading were taken between top and bottom taps.

4. Results and Discussions

Static pressure drop data, average of three replications, collected from test are tabulated in Table 2. A small variation in moisture content took place during the test run and handling. The variation in moisture content is so small that, for practical purposes, the three tests are considered as three replications. The average static pressure drop data for three replications at three levels of moisture content on each percentage of fine materials were averaged and presented on graphs(Fig. 2 through 3). For comparisons, Shedd's curve(1953) were also plotted (Fig. 2).

Table 2. Average static pressure data at different fine levels in wheat beds (average of three replications)

Moisture (%, w.b.)	Airflow rate (m^3/m^2. sec)	Fine materials (%) 0	2	4	8
11	0.051	183	229	334	534
	0.076	294	371	531	810
	0.102	420	535	786	1121
	0.127	575	710	1036	1463
	0.152	730	908	1316	1790
	0.178	910	1136	1620	2160
	0.203	1090	1399	1918	2518
13	0.051	162	215	310	447
	0.076	264	351	493	660
	0.102	379	499	715	926
	0.127	407	663	941	1234
	0.152	636	838	1171	1543
	0.178	802	1050	1440	1836
	0.203	968	1253	1724	2151
15	0.051	160	201	289	371
	0.076	246	321	453	581
	0.102	352	470	641	793
	0.127	486	620	870	1073
	0.152	604	781	1050	1306
	0.178	758	989	1303	1609
	0.203	904	1194	1621	1927

1) Effects of Moisture Content

Fig. 2. shows that all the curves run almost parallel to Shedd's curve for wheat 11% moisture content. The experimental curves for all moisture content are to the left of Shedd's curve which means that high moisture content wheat displays less resistance than dry wheat. A conclusion is drawn from above results that the static pressure drop increases with a decrease in moisture content. This pattern followed consistently over the range of moisture contents tested. At 11% moisture content clean wheat bed, the experimental data and Shedd's curve are not exactly same. This differences may come from many factors. According to Brooker et al. (1974), several factors are involved in determining static pressure drop such that surface texture, void space, variability of particle size, and depth of product bed. Abdelmohsin(1982) found some difference between his experiment results and Shedd's data, and he attributed those variations to particle size.

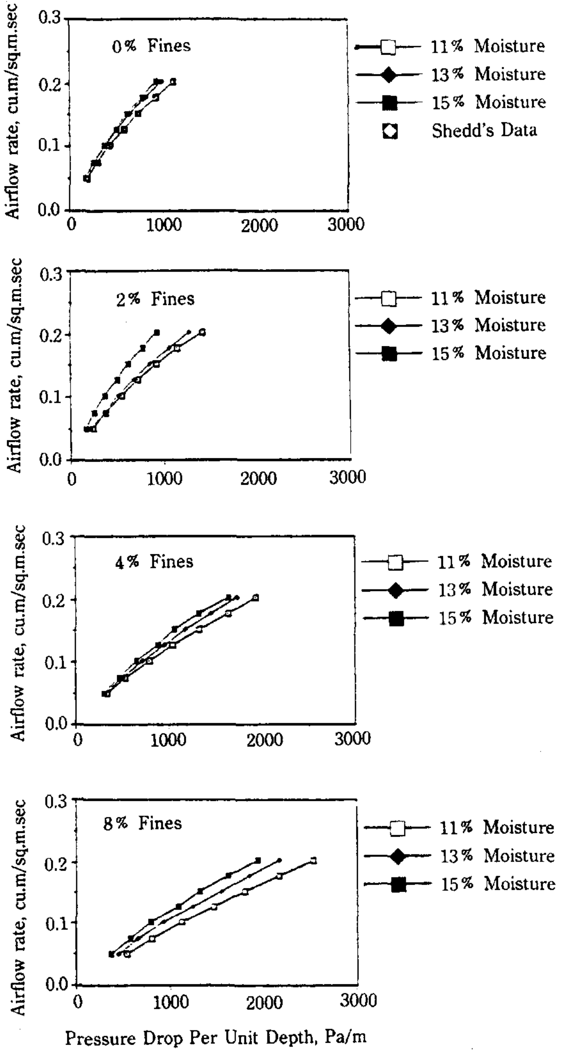

Fig. 2. Resistance of wheat to airflow at different moisture

2) Effects of Fine Materials

The effect of fine materials at each level of moisture content is shown in Fig. 3. All the curves run almost parallel to each other, with the curve of the lowest percentage of fines appearing to the left of the others. This pattern appears in all levels of fines tested. A conclusion can be drawn from the above result that static pressure drop increases with the increase of fine material. In Table 2, the maximum static pressure drop, 2518pa per meter, occured at 11% moisture content and 8% fine materials at an airflow rate of $0.203m^3/m^2 \cdot sec$; the minimum static pressure drop, 160pa per m, occured at 15% moisture content and 0% fine materials at an airflow rate of $0.051m^3/m^2$. sec. The greatest difference in static pressure drops at the same moisture content and same airflow rate was observed at 11% moisture content and $0.051m^3/m^2$. sec, between 0 and 8% fines, the static pressure drops were respectively 183,540 pa per m, giving an increment of 195%; and the smallest increment was 18% at 15% moisture content, $0.203m^3/m^2 \cdot sec$, between 4 and 8% fines, $0.051m^3/m^2 \cdot sec$ between 11% and 15% moisture content, and its increment was 45%; the smallest was observed between 13% and 15% moisture content, 0% fines and $0.051m^3/m^2 \cdot sec$, and its increment was 1.2%.

3) Model Development

To analyze the data statistically, this experimental design was regarded as split plot and factorial design. The appropriate model for the analysis of variance is this:

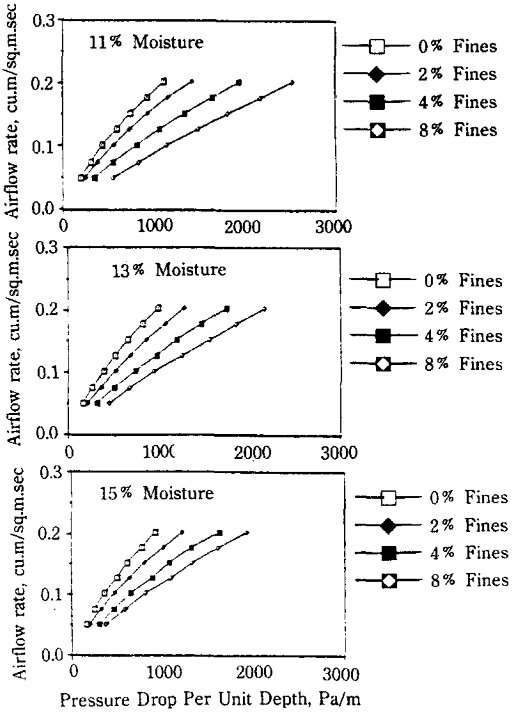

Fig. 3. Resistance of wheat to airflow at different fines

$$P = u + (MO)_i + (FM)_j + (AF)_k + (MO \times FM)_{ij} + (MO \times AF)_{jk} + (FM \times AF)_{jk} + (MO \times FM \times AF)_{ijk}$$

where,

P = measured value (static pressure drop)

$(MO)_i$ = effect of i treatment of moisture content

$(FM)_j$ = effect of j treatment of moisture content

$(AF)_k$ = effect of k treatment of airflow rate

All other terms are interactions of the main effects

With the data SAS package program was run for the analysis of variance of each effect and regression modeling. The results of the analysis of variance show that all main factors and their interactions significantly affect the static pressure, with the airflow rate being the most significant effect followed by fine material and moisture content. ANOVA table is shown in Table 3.

Table 3. ANOVA table for static pressure drop

SOURCE	DF	SS	FVALUE	PR<F	DECISION
MOISTURE	2	1616030	1579	0.0001	REJECT
FINES	3	19707951	12842	0.0001	REJECT
AIRFLOW	6	45539913	14838	0.0001	REJECT
MO*FI	6	604288	196	0.0001	REJECT
MO*AF	12	342344	55	0.0001	REJECT
FI*AF	18	3571173	387	0.0001	REJECT
MO*FI*AF	36	72802	3	0.0001	REJECT

* This decision is based on the null hypothesis that the group means for each effect are equal.

In order to select a model that will predict the effect of moisture contents and fine materials, the standard stepwise procedure was used to arrive at the following nonlinear regression model.

$$P = AV + BV^2 + C(MO)V + D(FM)V$$

where,

P = Pressure drop per meter depth of grain, Pa/m

V = Airflow rate, m^3/m^2. sec

MO = Moisture content %(w.b)

FM = Fine materials, %

A,B,C,D = Constants

The values of constants estimated are:

$A = 7530.85$

$B = 13736.95$

$C = -391.17$

$D = 744.52$

This model fitted very well with the data. The coefficient of determination (R^2) was above 0.995 for this model. Abdelmoshin (1983) reported that this type of regression model adequately explained the effect of airflow rate, moisture content, and fine material on static pressure drop, where his test material was grain sorghum.

The computer output compares the observed and predicted values, and shows a good agreement between them. Table 4 shows a comparison between randomly selected experimental values and values obtained using equation.

5. CONCLUSTIONS

Within the range of moisture contents and fine materials investigated, the following conclusions were drawn from this study.

1. Static pressure drop in wheat increased with

Table 4. Comparison of static pressure drops between experimental and model values

Moisture (w.b., %)	Fines (%)	Airflow rate (m^3/m^2. sec)	Pressure drop Exp.	Pressure drop Model	Percent deviation
11	0	0.051	182	191	4.7
11	4	0.076	531	537	1.1
13	8	0.203	2231	2235	0.1
15	2	0.178	954	964	1.0
13	8	0.127	1233	1265	2.5
15	2	0.152	781	769	1.4
13	2	0.102	373	374	0.0

the decrease in moisture content. The increment ranges from 1.2% to 45% depending on airflow rate and moisture ranges tested.

2. Static pressure drops in wheat increase in proportion to the percentage of fine materials. The increment ranges from 18% to 195% depending on the range of fine materials investigated.

3. The statistical model

$$P=AV+BV^2+C(MO)V+D(FM)V$$

adequately describes the relationship among static pressure drop, airflow rate, moisture content, and fine materials.

4. The results of this study are expected to help designers of aeration systems, and to give a better understanding and an accurate description of the static pressure behavior as affected by moisture content and fine materials.

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