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Resistance of Potatoes to Airflow

F. Shahbazi[1]* and A. Rajabipour[2]

ABSTRACT

Knowledge of airflow resistance is an important consideration in designing an appropriate ventilation system and for proper fan selection. An airflow resistance device was designed and fabricated to measure the airflow resistance of potatoes. The device the composed of an air compressor, a rotameter, a cylindrical bin to contain the potatoes and an indined u-tube manometer. Airflow resistance of potatoes was measured as a relationship between the airflow rate and pressure drop per unit depth (Pa/m) at 12 airflow rates of 0.085 to 0.55 $m^3/s/m^2$. Two airflow resistance models, namely, Shedd's and Hukill and Ives', were fitted to measured data by using PROC NLIN of SAS. The effect of potato size below 120 g (small), at or above 120 g (large) and unsorted (mixed size), and bed depths of 25, 50, 75 and 100 cm of potatoes on resistance to airflow was determined. Results showed that the airflow resistance of small size potatoes for a 100 cm bed depth was 1.6 times higher than that for large size potatoes, and as the bed depth of potatoes was increased, the airflow resistance was increased.

Keywords: Airflow resistance, Bed depth, Potato size.

INTRODUCTION

Potato is a major crop in Iran. Potato production in Iran was about 3.6 million tones in 2004 (Habibi, 2004). Harvested potatoes must be stored and properly ventilated for subsequent processing. Hot spots and damage will occur if the bulk piles of potatoes are not ventilated. Losses during storage are dependent on many factors including length of storage time, potato temperature, ambient relative humidity and temperature, and the degree of mechanical and freezing injury (Wyse, 1978; Akeson *et al.*, 1974; Wyse and Peterson, 1979; Cole, 1977). It is necessary to distribute airflow for uniform heat transfer. Airflow resistance data is required to enable prediction of airflow uniformity within ventilated potatoes and determination of the fan power requirements to provide adequate airflow rates. Uniformity of airflow distribution in a bulk of potatoes may be influenced by the size and shape of the tubers, variation in directional resistance determined by the duct shape and piling method, and the amount of soil and dirt mixed with the potatoes. Irvine *et al.* (1993) studied the effects of the above factors on the airflow resistance of potatoes. Large potatoes had 41% of the airflow resistance of small potatoes. They also found that 'Russet Burbank' potatoes had a lower airflow resistance when the airflow was in a horizontal direction, compared with to vertical direction. Loose soil increased the airflow resistance in a vertical direction. Neale and Messer (1976) determined airflow resistance in of onions, carrots and potatoes and concluded that the soil or trash content of the crop had a greater effect on airflow resistance than variations in the physical properties of the crop itself. Small and Hodgkinson (1989) observed that soil contents in potato beds of up to 5% had no effect on the static pressure variation in round duct ventilation systems, but did have a small effect in half–

1. Lorestan University, Khoramabbad, Islamic Republic of Iran.
2. Department of Agricultural Machinery, Tehran University, Karaj, Islamic Republic or Iran.
* Corresponding author: email:shahbazi.f@lu.ac.ir

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round duct ventilation systems. Tabil *et al.* (1999) studied the airflow resistance of sugar beets and concluded that the bulk density and porosity of beets affected airflow resistance in beets. Higher bulk density and lower porosity resulted in a higher airflow resistance. Small beets had an airflow resistance as high as 1.9 times that of large beets. Tare in the beets increased their airflow resistance.

The objectives of this study were to measure the airflow resistance of potatoes, to fit the airflow resistance models (Shedd's and Hukill and Ives') to the experimental data and to determine the effects of potato size and bed depth on the resistance to airflow.

MATERIALS AND METHODS

Potato Samples

In this study, the cultivar of potatoes tested was Marfona selected from farms in Isfahan, Iran. The samples were obtained for testing after two months of bulk storage. A random selection of potatoes indicated that the mean weight was about 120 g. For these experiments, potatoes were sorted according to size as: a) small (those weighing less than 120 g), b) large (those weighing at or above 120 g), and c) mixed (unsorted) potatoes. Excess dirt was removed from each potato selected.

Physical Properties

The bulk density (p_b) of each sample was determined each time the bin was filled, by weighing all potatoes prior to filling the 1 m^3 volume sample bin. Particle density (p_p) was determined by weighing individual potatoes first in air and then submerged in water and calculating their volume by the weight of water displaced. The porosity of the samples expressed in a percentage was calculated using the following relationship (Neale and Messer, 1976):

$$\text{Porosity} = [(p_p - p_b)/p_p] \times 100 \qquad (1$$

Average potato dimensions were determined by measuring 100 randomly selected potatoes of each sample using a digital micrometer. Shape factor (S) of samples was obtained using the following equation (ISIRI Standard):

$$S = [L^2/W.H] \times 100 \qquad (2$$

where L, W and H are the length, width and height of potatoes, respectively.

Airflow Test Apparatus

Resistance to airflow through the tested potatoes was determined in the form of a relationship between the airflow rate and pressure drop per unit depth. A schematic diagram of the apparatus used for airflow resistance measurement is shown in Figure 1. It consists of an air compressor, a rotameter, a plenum chamber, a screen plate, a potato bin, and an inclined u-tube manometer. The potato bin is a cylinder of 33 cm diameter and 120 cm height, made of 2 mm thick iron plate. A stainless steel screen plate located under the potato bin containing round holes of 4 mm diameter provided an expanded mesh floor of 40% open space. Pressure drops were measured across a 100 cm of potatoes in the bin at four levels. Four pressure taps were installed at 25, 50, 75 and 100 cm from the top of the potato level, on the cylinder wall to measure pressure difference at different depths.

Airflow Control and Measurement

Air was supplied by a compressor with an auxiliary storage tank added to dampen the pressure/flow oscillation caused by compressor cycling. Airflow rates were measured by an air rotameter. The rotameter is capable of measuring airflow rates of 200-1300 l/min, with accuracy of 5 L/min. The rotameter was equipped with a calibrated float supplied by the manufacturer. The airflow rate could be manually adjusted by a

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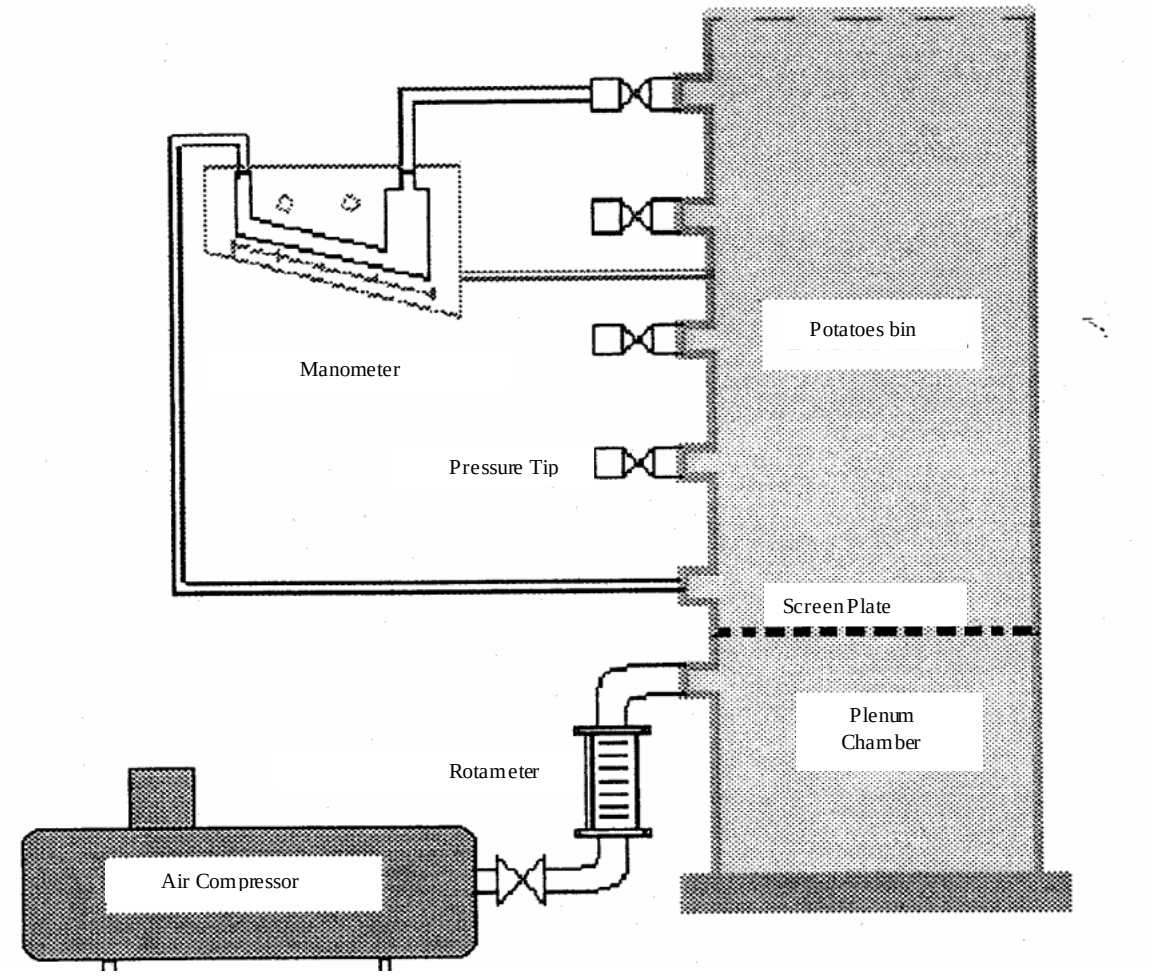

Figure 1. Schematic diagram of the apparatus for measuring the airflow resistance of potatoes.

valve which was located in front of the rotameter.

Airflow Resistance Measurement

Airflow resistance is expressed as a static pressure drop per unit distance parallel to the direction of airflow. The first tap above the screen plate was chosen as the reference, the pressure difference between the first tap and all the other taps were measured and recorded. The taps extended into the bin 5 cm from the inside wall to avoid any wall effect on pressure measurements. Pressure differences between the taps were measured using the Dwyer model inclined u-tube manometer (Dwyer Instruments Inc, Michigan City, IN), with an accuracy of 0.25 Pa.

Experimental Design

In this experiment, the effects of potato size and bed depth on airflow resistance were studied. To measure the airflow resistance of potatoes, the bin was filled with the potatoes up to 100 cm height and pressure drops were measured for airflow rates of 0.085, 0.12, 0.17, 0.21, 0.25, 0.29, 0.34,

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0.38, 0.42, 0.47, 0.51, and 0.55 $m^3/s/m^2$. Each test was repeated four times and the bin was filled for each replication. To measure the effects of potato size on resistance to airflow, the potatoes sizes were: a) those weighing less than 120 g (small); b) those weighing more than 120 g (large); and c) unsorted potatoes (mixed size). Pressure drops of each sample were measured at the same 12 airflow rates of 0.085 to 0.55 $m^3/s/m^2$, at a constant bed depth of 100 cm. To determine the effects of the bed depth of potatoes on resistance to airflow, four different bed depths of 25, 50, 75, and, 100 cm at the same six airflow rates of 0.085 to 0.51 $m^3/s/m^2$, were used. Duncan's multiple range test was used to compare the means.

Airflow Resistance Analysis

Two models were used to fit the measured data. The first model was that of Shedd (1953), which represented by the following relationship:

$$\Delta P/L = A\,(V)^{B} \qquad (3$$

where,

$\Delta P/L$= Pressure drop per unit depth, Pa/m; V= Airflow rate per unit area, $m^3/s/m^2$; and A, B= Experimental constants for each test condition.

The second model was that of Hukill and Ives (1955), which is used in ASAE standard D272.3 (ASAE, 1996). This model is represented by the following relationship:

$$\Delta P/L = MV^2 / [\mathrm{Ln}\,(1+NV)] \qquad (4$$

where,

M, N= Experimental constants for each test condition.

The two models (Shedd's and Hukill and Ives') were fitted to the experimental data for the different test conditions using nonlinear regression analysis. The nonlinear regression program of SAS (SAS, 1987), was used to fit the models to the data and determine A and B of equation 3, and M and N of equation 4.

RESULTS AND DISCUSSION

Airflow Resistance of Potatoes

The physical properties of potatoes are given in Table 1. Figure 2 shows a typical curve of the resistance of potatoes to airflow. Clearly, pressure drop increases with an increasing airflow rate. Similar trends were reported by Chau *et al.* (1985), for oranges, Abrams and Fish (1982) for bulk piles of sweet potatoes, Ganffney and Baird (1977) for bell peppers and, Tabil *et al.* (1999) for sugar beets. The estimated parameters, A and B for Shedd's model and M and N for Hukill and Ives' model and the correlation coefficients of R^2 for both models are shown in Table 2. The values of the correlation coefficients were greater than 0.97 in all tests indicating the good fit of the models. In Table 2, pressure drop per unit depth for airflow rate of 0.1 $m^3/s/m^2$ which is, in practice, used for the potato ventilation systems (Irvine *et al.*, 1993) was also calculated using both models. At this airflow rate,

Table1. Physical properties of potato samples.

Sample Size	Dimensions: (mm)			Shape factor	Bulk Density ($Kg.m^{-3}$)	Patrice Density ($Kg.m^{-3}$)	Porosity (%)
	Length	Width	Height				
<120g	6.41	50.83	4.32	163.14	782.00	1140.21	31.41
Mixed Size	8.02	60.78	5.08	186.74	735.00	1119.11	34.32
≥120g	11.27	80.05	6.61	238.69	746.05	1149.19	35.08

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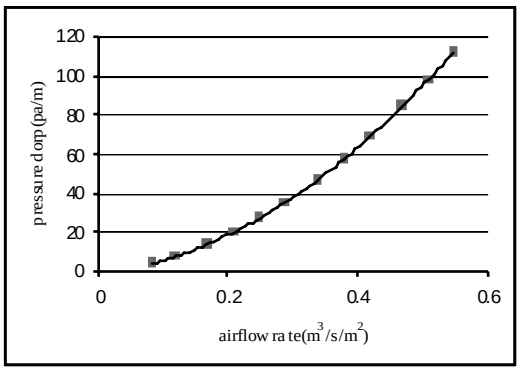

Figure 2. A typical curve of resistance of potatoes to airflow.

Shedd's and Hukill and Ives' models, predicted pressure drop values of 5.17 and 5.04 Pa/m, respectively, compared with an average actual experimental value of 4.99 Pa/m, (for mixed size potatoes). The value for B in the Shedd's model is the same as the amount for products of an equivalent shape, such as potatoes (Irvine *et al.*, 1993) and sugar beets (Tabil *et al.*, 1999), fruit (Guillou, 1960), oranges (Chau *et al.*, 1985) and roots and vegetables (Nale and Messer, 1976). For all these products, the constant B= 1.8, is obtained.

The values obtained for A and B in Shedd's model are nearly the same as the values reported by Irvine *et al.* (1993). They obtained A= 379.63 and B= 1.8522 for Norchip potatoes in a vertical airflow measurement, that are close to our values for A and B (340.95 and 1.8045, respectively). They also found the pressure loss to be equal to 5.34 Pa/m, at airflow rate of 0.1 $m^3/s/m^2$ using this model, whereas in this study it was found to be 5.17 Pa/m. This difference could be due to the difference in the size of the potato samples. The values obtained for M and N in the Hukill and Ives' model, are the same as the values reported by Tabil *et al.* (1999) for sugar beets. They also found the pressure drop to be equal to 4.24 Pa/m, at an airflow rate of 0.1 $m^3/s/m^2$ using this model. In this study, it was found to be 5.04 Pa/m for potatoes. This difference could be due to difference in size between sugar beets and potatoes.

Table 2. Estimated coefficients for the tow airflow resistance models studied[a].

Sample Size	Shedd's Model: $\Delta P/L = A(V)^B$				Hukill and Ives' Model: $\Delta P/L = MV^2/[Ln(1+NV)]$			
	A	B	R^2	$\Delta P/L$ (Pa m^{-1}) @V=0.1 $m^3 s^{-1} m^{-2}$	M	N	R^2	$\Delta P/L$ (Pa m^{-1}) @V=0.1 $m^3 s^{-1} m^{-2}$
<120g	340.95	1.6422	0.97	7.77	6919.30	119809	0.98	7.36
Mixed Size	329.70	1.8045	0.99	5.17	5612.52	674152	0.98	5.04
≥120g	307.45	1.9690	0.98	3.30	6120.56	128498492	0.97	3.73

[a] The data obtained for airflow rates of 0.085-0.55 $m^3/s/m^2$.

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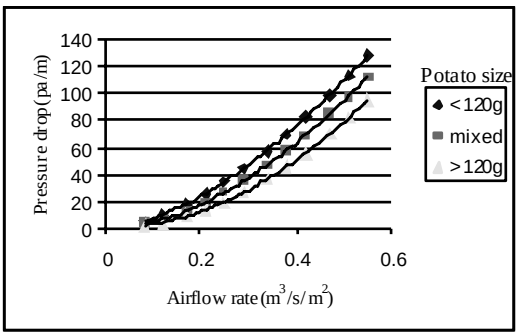

Figure 3. Airflow resistance for different potato sizes.

Effects of Potato Size

Data on the resistance to airflow for three potato sizes are shown in Figure 3. As shown in this Figure, at similar airflow rates, the pressure drop increases with decreasing potato size. Small potatoes had the highest pressure drop, followed by mixed size ones, and the lowest was that for the largest potatoes. This agrees with results obtained by Tabil *et al.* (1999) for sugar beets, and Irvine *et al.* (1993) for potatoes.

The values of constants A and B for Shedd's model and of M and N for the Hukill and Ives model, were estimated for each potato size and are listed in Table 2. The average pressure drop values at airflow rates of 0.17, 0.34, and 0.51 $m^3/s/m^2$ (which are in practice, used for ventilation systems) are given for three potato sizes in Table 3. As shown in this Table, the differences among the pressure drop values were significant at the 5% level at all three airflow rates. Small potatoes (<120 g) had the highest average pressure drop, followed by mixed size potatoes, and the lowest was that of the large potatoes (≥120 g). At an airflow rate of 0.34 $m^3/s/m^2$ the airflow resistance of small potatoes was 1.6 times higher than that of the large potatoes. This was due to the high density of small potatoes compared to other size ranges used. This was evident in the values of bulk density and porosity. Higher density and consequently lower porosity contributed to higher pressure drop valued for <120 g, potatoes (Table 1). Simi-

Table 3. Comparison of average pressure drop (ΔP/L) at airflow rates of 0.17, 0.34, and 0.51 $m^3/s/m^2$ for different potato sizes.

Sample Size	ΔP/L (Pa m^{-1}) @ V=0.17 $m^3 s^{-1} m^{-2}$	ΔP/L (Pa m^{-1}) @ V=0.34 $m^3 s^{-1} m^{-2}$	ΔP/L (Pa m^{-1}) @ V=0.51 $m^3 s^{-1} m^{-2}$
<120 g	18.57a* (2.51)**	57.98a (1.25)	112.83a (2.5)
Mixed Size	13.47b (2.04)	47.06b (1.25)	97.82b (2.04)
≥ 120 g	9.38c (2.04)	36.74c (2.39)	81.65c (4.26)

* Mean values followed by the same letter in each column are not significantly difference according to Duncan's new multiple range test at the 5% level of probability.
** Numbers in brackets are standard deviation (SD) n= 4.

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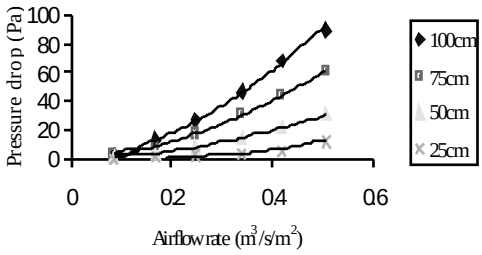

Figure 4. Airflow resistance of potatoes at different bed depths.

lar observations have been reported by Yang and Williams (1966) for grain sorghum and Li and Sokhansanj (1994) for alfalfa seeds, i.e. that pressure drop generally increased with increasing bulk density.

Effects of Potato Beds Depth

Figure 4 shows the effect of bed depth on airflow resistance of potatoes at various airflow rates. As the bed depth of potatoes increases, the pressure drop at the same airflow rates also increases. Potatoes at a 100 cm bed depth, had the highest pressure drop, followed by the 50, and 75 cm depths; the lowest was that of the 25cm bed depth. This is similar to the observations of Irvine *et al.* (1993) for potatoes, Dairo and Ajibola (1994) for sesame seeds and Jayas *et al.* (1987) for canola. The average pressure drop at airflow rates of 0.17, 0.34, and 0.51 $m^3/s/m^2$ for four different bed depths of potatoes are shown in Table 4. As shown in this Table, the differences among the pressure drops were significant at the 5% level, at all four different bed depths. The pressure drop at the 100 cm bed depth (at 0.51 $m^3/s/m^2$) is the highest (97.82 Pa), followed by the 75 and 50 cm bed depths (61.72 Pa, and 30.51 Pa), with the lowest at the 25 cm depth (6.31 Pa). This is due to the fact that, as the bed increases, the distance the airflow increases too, resulting in higher frication between potatoes and air.

Table 4. Comparison of average pressure drop (ΔP) at airflow rates of 0.17, 0.34, and 0.51 $m^3/s/m^2$ for different bed depths of potatoes.

Bed Depth (cm)	ΔP/L(Pa) @ V=0.17 $m^3 s^{-1} m^{-2}$	ΔP/L(Pa) @V=0.34 $m^3 s^{-1} m^{-2}$	ΔP/L(Pa) @ V=0.51 $m^3 s^{-1} m^{-2}$
100	13.47a* (2.04)**	47.06a (1.25)	97.82a (2.04)
75	8.89b (3.14)	30.19b (3.88)	61.72b (3.75)
50	4.25c (1.44)	14.74c (1.43)	30.51c (2.61)
25	1.35d (1.062)	3.15 d (1.44)	6.31d (1.20)

* Mean values followed by the same letter in each column are not significantly difference according to Duncan's new multiple range test at the 5% level of probability.
** Numbers in brackets are standard deviation (SD) n=4.

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CONCLUTIONS

The following conclusion can be drawn from this study:

1) Sedd's and Hukill and Ives' models were fitted to the experimental data, at airflow rates of 0.085 to 0.55 $m^3/s/m^2$.

2) Small potatoes had an airflow resistance as high as 1.6 times that of large potatoes.

3) Bed depth of potatoes affected airflow resistance. Increasing bed depth resulted in higher airflow resistance.

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مقاومت توده سیب زمینی به عبور جریان هوا

ف. ا. شهبازی و ع. رجبی پور

چکیده

پایه و اساس طراحی سیستم‌های تهویه برای محصولات کشاورزی و انتخاب دمنده مناسب برای آنها, میزان مقاومت به عبور جریان هوای محصول است. برای اندازه‌گیری مقاومت به عبور جریان هوا در توده سیب‌زمینی، دستگاهی طراحی و ساخته شد که شامل : کمپرسور هوا، رتامتر(بده‌سنج جریان هوا)، مخزن محصول و فشارسنج بود. مقاومت به عبور جریان هوا در توده سیب‌زمینی بصورت رابطه بین سرعت جریان هوا وافت فشار در واحد عمق توده محصول در ۱۲ سرعت جریان هوا از ۰/۰۸۵ تا $m^3/s/m^2$ ۰/۵۵ به دست آمد. مدل‌های مربوط به شید و هوکیل و ایویس با استفاده از برنامه SAS، با داده‌های مقاومت برازش داده شدند. همچنین اثر اندازه غده‌ها و عمق توده غده‌ها بر مقاومت به عبورجریان هوا اندازه‌گیری شد. اندازه‌گیری اثر اندازه غده‌ها بر مقاومت به عبور جریان هوا، درسه گروه: کوچک (وزن کمتر از ۱۲۰گرم)، بزرگ (وزن بیشتر از۱۲۰ گرم) و مخلوطی از کوچک وبزرگ انجام شد و اثرعمق توده محصول بر مقاومت به عبور جریان هوا در چهار عمق مختلف توده ۲۵, ۵۰, ۷۵ و ۱۰۰ سانتیمتر اندازه‌گیری شد. نتایج نشان داد که در یک عمق ثابت (۱۰۰ سانتیمتر), مقاومت به عبور جریان هوای غده‌های کوچک ۱/۶ برابر غده‌های بزرگ بود و با افزایش عمق توده سیب‌زمینی, مقاومت به عبور جریان هوا افزایش پیدا کرد.

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