RESISTANCE TO AIR FLOW OF FRUITS IN BULK AND IN A CARTON

Hong Sun Yun, Young Kil Cho[1] and Kyung Kyu Park[2]

1) Processing Machinery Division, National Agricultural Mechanization Research Institute, Suweon, 441-100, Korea
2) Department of Agricultural Machinery, Kyung Pook National University, Daegu, 702-701, Korea

ABSTRACT

Pressure drop, as a function of air flow, was measured for tomatoes and mandarins in bulk with different sizes, stacking arrangements and bed porosities. Pressure drop was also measured on carton vent holes and on a carton of packed fruits. And the cumulative effects of air flow resistance of vent holes and packed fruits in bulk on the air flow resistance of a carton of fruits were evaluated. Equations were presented to describe pressure drop of bulk fruits, of an empty carton and of a carton of packed fruits as related to the air velocity, the bed porosity, the fruit diameter and the opening ratio of the vent hole.

Key Words : Resistance to air flow, Pressure drop, Pressure cooling

INTRODUCTION

In the pressure cooling system, fruits are packed in vented cartons and cooled by producing a different air pressure on opposite faces of vented cartons. So, in order to design of the pressure cooling system, the information such as resistance of cartons of packed fruits to air flow for selecting appropriate fan for the supply of cooling air is required. The air flow resistance of the material is usually referred to and measured by the pressure drop across a bed of material. The pressure drop of cartons of packed fruits normally depends on air flowrate, vent hole area of cartons and stacking conditions of fruits in cartons(depth, arrangements, porosity, size and shape etc.). Especially vent holes and packed fruits in bulk have a cumulative effects on the air flow resistance of a carton of fruits. Even though the pressure drop depends on those factors mentioned above, most of the pressure drop data for pressure cooling have been reported for fruits in bulk only.

The objective of this paper is to determine the resistance of air flow through tomatoes and mandarins in bulk and in a carton by experiments. The cumulative effects of vent holes and packed fruits in bulk on the air flow resistance of a carton of fruits will be evaluated. Also, equations for prediction of pressure drop of bulk fruits, of an empty carton and of a carton of packed fruits as a function of the air flow rate, the bed porosity, the fruit size and the opening ratio of the vent hole will be developed.

MATERIALS AND METHODS

Apparatus

Fig.1 shows a diagram of the experimental setup. The dimension of the rectangular test column was 40cm×40cm×120cm. The bottom of the test column was made of wire mesh to provide support for the fruit and negligible air flow resistance.

The air was sucked from the top of the test column to the air duct by a 550watt axial fan. The air duct was made of PVC pipe whose diameter is 135mm and length is 3m. The fan was controlled by a variable transformer to obtain the desired air flow rate.

Air flow rates were measured by a pitot tube and digital micromanometer had in a range of 0 to 200Pa, reading to 0.01Pa. The pitot tube was inserted into air duct, located at 2.35m from the air inlet.

The pressure drop was measured by sampling from 9 positions with pitot static heads mounted below the mesh floor and above the fruits stacking column. Pitot static heads were connected to a digital manometer reading to 2.5Pa.

Air Flow Resistance of Fruits in Bulk

Mandarins and tomatoes were used in the experiment. Average diameters were 4.89cm and 5.86cm for mandarin, and 6.35cm and 7.97cm for tomato. The diameter used here was the equivalent volume diameter. The square staggered and the staggered stacking patterns were used. Air flow rates were changed to cover superficial air velocities range of 0.1 to 1m/s. Bed depth were varied from 30cm to 90cm, and porosities were changed within the range of 0.25 to 0.45. The bed porosity was determined by the water displacement method.

Air Flow Resistance of Carton Vent Holes

In order to determine the pressure drop across vent holes, a series of tests were conducted with two layers of a steel plate(40cm×40cm) spaced 30cm apart with 1 rectangular vent hole each(simulating two sides of carton). The opening ratio of the vent hole were designed within the range of 2.5 to 20%.

Air Flow Resistance of a Carton of fruits

These tests were designed to evaluate the cumulative effects of air flow resistance of vent hole and packed fruits in bulk. Measurements were made on pressure drop across mandarins and tomatoes stacked between two steel plates spaced 30cm apart with 1 rectangular vent hole each(simulating a carton of fruits). Also, the opening ratio of the vent hole were designed within the range of 2.5 to 20%. Average diameters of mandarin and tomato used were 4.89cm and 6.35cm respectively. The staggered stacking pattern was used, and porosities were 0.29 for mandarin and 0.44 for tomato.

RESULTS AND DISCUSSION

Air Flow Resistance of Fruits in Bulk

Fig.2 shows pressure drop of mandarins and tomatoes in bulk as a function of superficial air velocity for different porosities. A stacking with higher porosity always offered a lower air flow resistance than a stacking with lower porosity.

Fig.3 shows pressure drop of mandarins and tomatoes in bulk as a function of superficial air velocity for different stacking patterns. The staggered stacking arrangement produced higher increasing rate of pressure drop than square staggered arrangement. But Fig.3 shows that the bed porosity and the fruit diameter has a much greater effect than the stacking patterns.

To predict pressure drop of mandarins and tomatoes in bulk, Eq.(1) and (2) containing certain experimentally determined coefficient were developed.

Mandarin : $$\Delta P_f/L = 3.392 \frac{1}{\varepsilon^{1.075} \cdot D_p^{1.38}} \cdot \frac{\rho \cdot V^2}{2} \quad \text{------ (1)}$$

Tomato : $$\Delta P_f/L = 8.01 \times 10^{-6} \frac{1}{\varepsilon^{6.94} \cdot D_p^{3.8}} \cdot \frac{\rho \cdot V^2}{2} \quad \text{----- (2)}$$

Where, ΔP_f : Pressure drop of fruits in bulk(Pa), L : Bed depth(m),
ε : Bed porosity(decimal), D_p : Equivlant volume diameter(m),
ρ : Density of air(kg/m³), V : Superficial air velocity(m/s)

These equations were statistically very significant at the 1% level in t-tests and each regression variables were also very significant. The coefficient of determination(R^2) was greater than 0.98 for Eq.(1), and 0.99 for Eq.(2).

Air Flow Resistance of Carton Vent Holes

Fig.4 shows pressure drop of carton vent holes as a function of superficial air velocity for different opening ratio of vent hole. A carton with higher opening ratio of vent hole always offered a lower air resistance than a carton with lower opening ratio of vent hole.

To predict pressure drop of carton vent holes, Eq.(3) containing certain experimentally determined coefficient was developed.

$$\Delta P_b = 2.197 \cdot \frac{\rho V^2}{2} \cdot \frac{1}{O^2} \quad ------ \quad (3)$$

Where, ΔP_b : Pressure drop of a carton(Pa), O : Opening ratio of vent hole

Eq.(3) shows that the air flow resistance of the vent hole is proportional to the square of superficial air velocity and inverse propotional to the square of opening ratio of vent holes.

Eq.(3) was statistically very significant at the 1% level in t-tests and each regression variables were also very significant. The coefficient of determination(R^2) was greater than 0.99.

Air Flow Resistance of a Carton of fruits

Fig.5 shows pressure drop across a carton of fruits as a function of superficial air velocity for different opening ratio of vent hole. This figure indicated that a carton of fruits with higher opening ratio of vent hole always offered a lower air flow resistance than a carton of fruits with lower opening ratio of vent hole.

Fig.6 and 7 show the pressure drop across a carton of fruits compared with the sum of the pressure drop across the carton and across the fruit by themselves. These figures indicate that the pressure drop across a carton of fruits is always greater than the sum of the pressure drop across the carton and the fruit by themselves. There are high localized velocities in the vicinity of the vent hole, because the fruit disturb the flow past the vent holes and the pattern of air flow through fruits in a carton with vent holes is much different from the flow through bulk loads of fruits. Since the pressure drop is proportional to V^2, these high localized velocities produce a higher overall pressure drop across the fruit bed. The Eq.(4) and (5) of best fit for pressure drop across a carton of fruits were developed.

A carton of mandarins : $\Delta P_t = \Delta P_b + \Delta P_f \times O^{-1.4}$ ---- (4)

A carton of tomatoes : $\Delta P_t = \Delta P_b + \Delta P_f \times O^{-1.6}$ ---- (5)

Where, ΔP_t : Total Pressure drop of a carton of fruits(Pa)

Eq.(4) and (5) show that total pressure drop across a carton of fruits can be calculated as the sum of the pressure drop across the empty carton and the value multyply the pressure drop across the fruit in bulk by -1.5 power of the opening ratio of the vent hole.

Eq.(4) and (5) were statistically very significant at the 1% level in t-tests and each regression variables were also very significant. The coefficient of determination(R^2) was greater than 0.99 for Eq.(4) and 0.96 for Eq.(5).

CONCLUSIONS

The resistance to air flow through mandarins and tomatoes in bulk vary for the fruit size, porosity and stacking arrangement. A stacking with higher porosity always produces a lower air flow resistance than a stacking with lower porosity. The bed porosity and the fruit diameter have a much greater effect than the stacking patterns. It is possible to have an experimental equation that predicts the pressure drop of fruits in bulk as related to the air velocity, the bed porosity and the fruit diameter.

The resistance to air flow of the vent hole is proportional to the square of superficial air velocity and inverse propotional to the square of opening ratio of vent holes.

The pressure drop across a carton of fruits is always greater than the sum of the pressure drop across the carton and the fruit by themselves. It is possible to have an experimental equation that predicts the pressure drop of a carton of fruits as related to the pressure drop across the empty carton and the fruit by themselves and the opening ratio of the vent hole.

REFERENCES

1. Chau, K.V., Gaffney, J.J., Baird, C.D. and Church, G.A. 1985. Resistance to Air Flow of Oranges in Bulk and in Cartons. TRANSACTIONS of the ASAE. 28(6) : 2083-2088.

2. Neale, M.A. and Messer. H.J.M 1976. Resistance of Root and Bulb Vegetables to Airflow. J. Agric. Eng. Res. 21 : 221-231.

3. Patterson, F.W., Bakker-Arkema and Bickert. W.G. 1971. Static Pressure-Air Flow Relationships in Packed Beds of Granular Biological Materials such as Grain. TRANSACTIONS of the ASAE. 14(1) : 172-174, 178.

4. Wang. J.K. and K. Tunpun. 1969. Forced-air Precooling of Tomatoes in Cartons. TRANSACTIONS of the ASAE. 12(6) : 804-806.

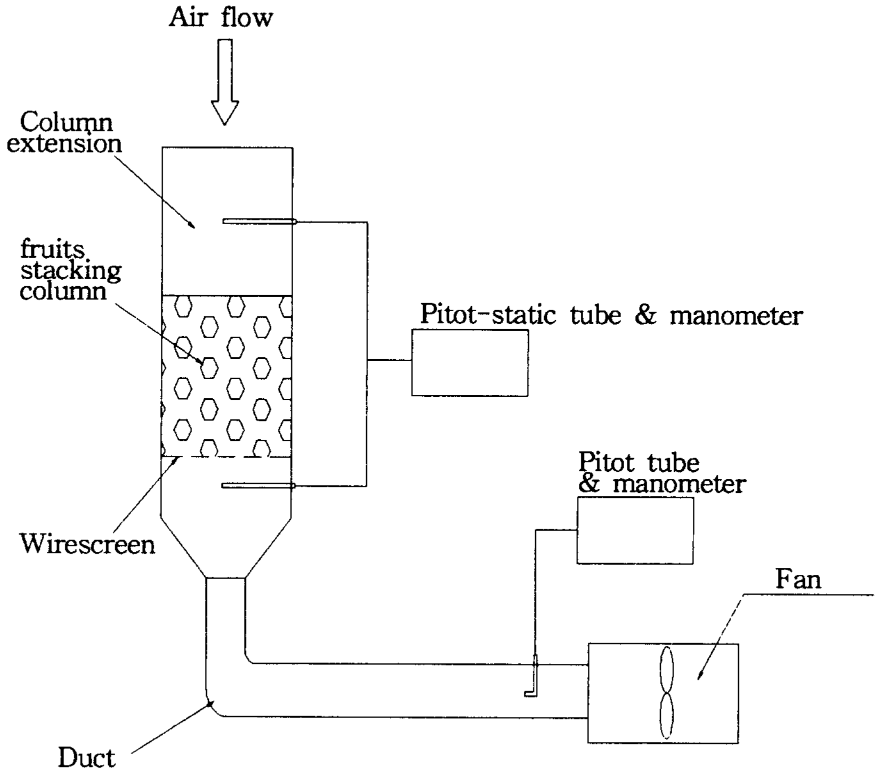
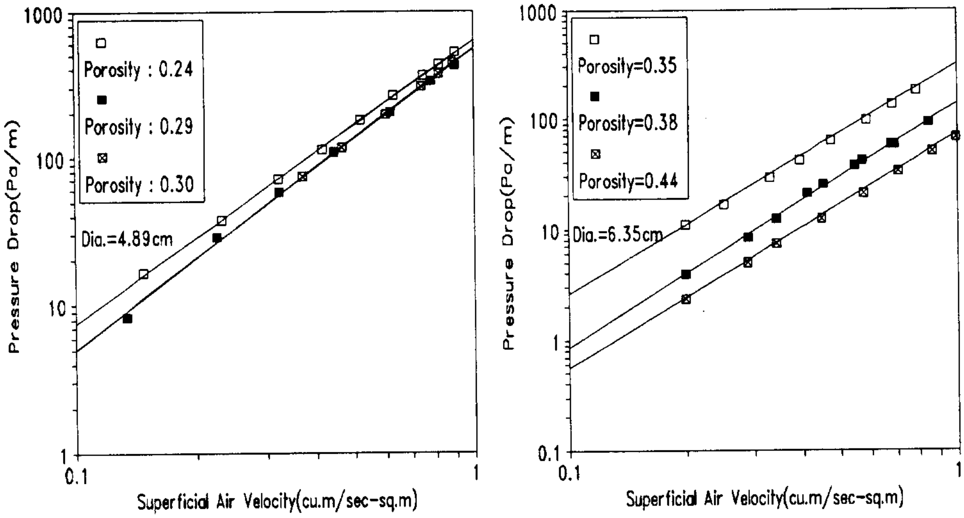
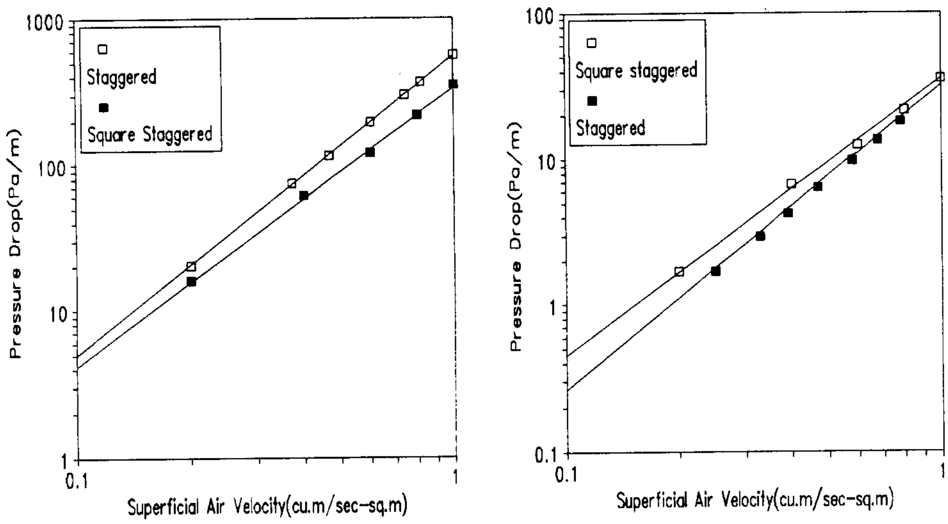


Fig.1. Diagram of experimental setup for measuring airflow resistance.



(a) Mandarin (b) Tomato

Fig.2. Airflow resistance of fruits in bulk for different porosities (staggered arrangement).



(a) Mandarin (b) Tomato

Fig.3. Airflow resistance of fruits in bulk for different stacking patterns.

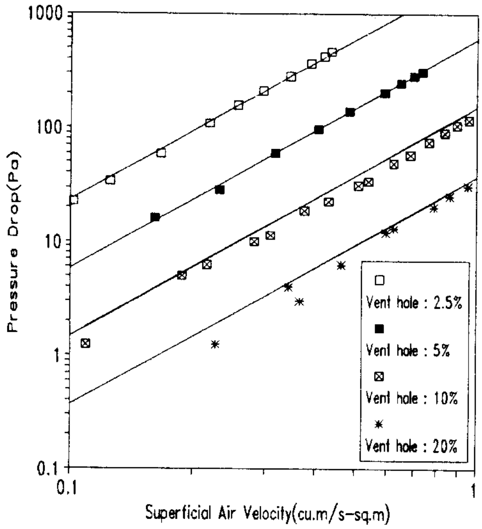
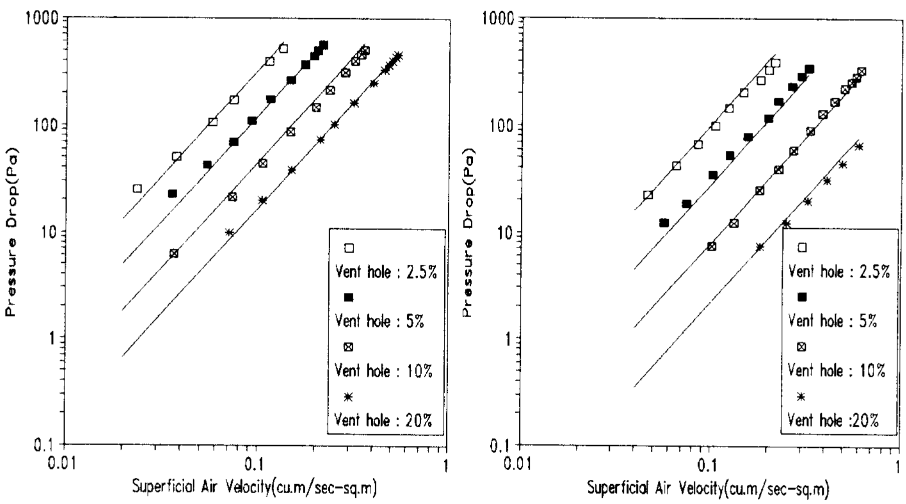


Fig.4. Airflow resistance of a carton for different opening ratio of vent hole.



(a) Mandarin (b) Tomato

Fig.5. Airflow resistance across a carton of fruits for different opening ratio of vent hole.

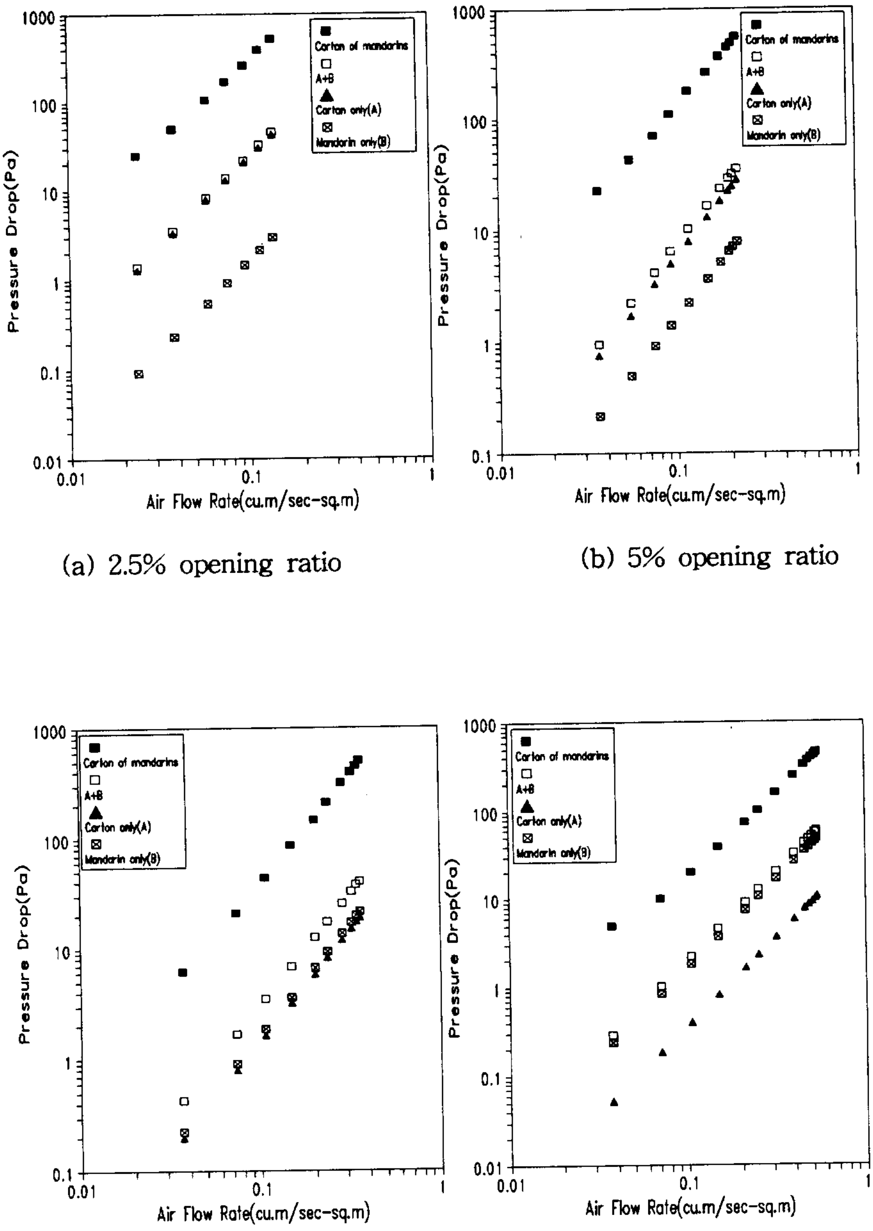
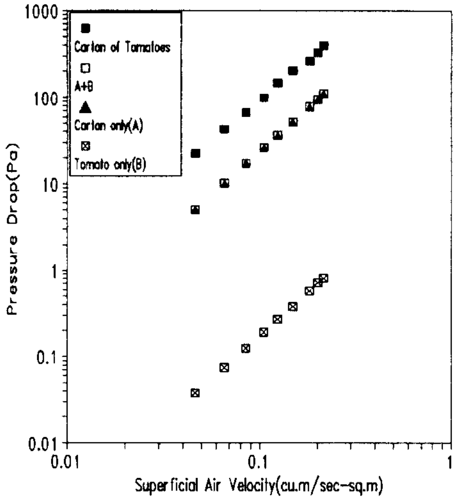
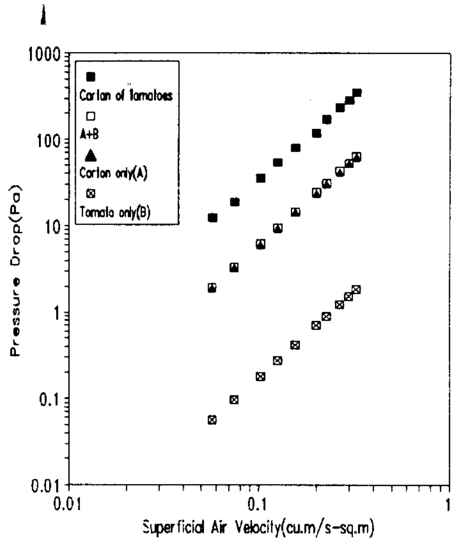


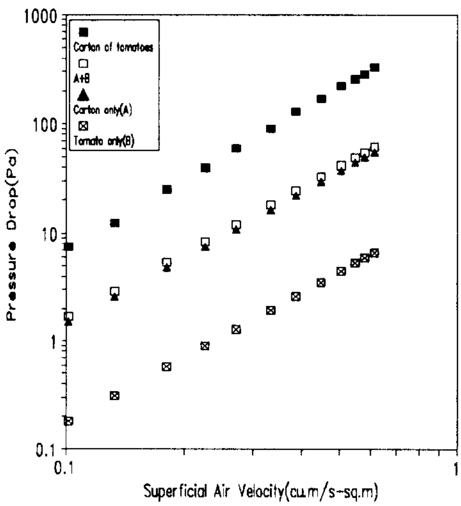
Fig.6. Airflow resistance for a carton of mandarins, for a carton, and for mandarins in bulk.



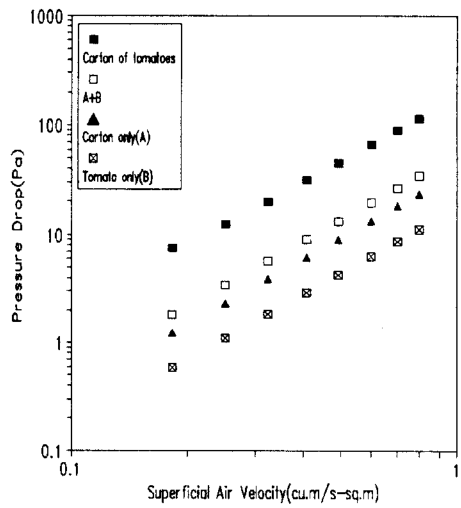
(a) 2.5% opening ratio



(b) 5% opening ratio



(c) 10% opening ratio



(d) 20% opening ratio

Fig.7. Airflow resistance for a carton of tomatoes, for a carton, and for tomatoes in bulk.