Effect of Perforation Geometry and Tube Diameter of Vertical Aerator From LAMB Dryer on Air Distribution Uniformity

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ABSTRACT Laterally Aerated Moving Bed (LAMB) dryer consists of a perforated vertical inner tube that distributes hot air radially. Six different types of perforated tubes were tested to investigate the airflow pattern by analyzing the non-uniformity flow coefficient and pressure drop accordingly with different perforation geometry and tube diameter. High uniformity of air outlet from all perforated tubes was confirmed with the low value of non-uniformity flow coefficient with the range 0.000041 to 0.00055. Furthermore, circle shape perforated hole with 4 mm diameter has the highest pressure drop and rectangle hole with 5mm x 2mm dimension have the lowest pressure drop. 1inch diameter of the tube has the highest pressure drop. This finding will aid in the optimization of the perforated tube design for the LAMB dryer system.

KEYWORDS: Dryer; uniformity; LAMB dryer; perforated tube; pressure drop
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INTRODUCTION

The usage of a dryer is customary in the industrial field, especially in post-harvest handling of grain crops to preserve the product quality. The deterioration of the product's quality usually occurred due to the retention of excessive moisture inside the grain, consequently resulted in the growth of fungi. In a dryer, areas with insufficient airflow due to uneven air distribution in grain beds will produce uneven final moisture content, which leads to fungal growth. Therefore, it is necessary to minimize the uneven air distribution in the dryer.

Laterally Aerated Moving Bed dryer (in short named as LAMB dryer) is known to have a perforated vertical inner tube that distributes hot air radially across the height of the grain bed. To minimize the uneven air distribution in the LAMB dryer, it is necessary to understand and investigate the airflow pattern from the perforated tube as the core of the LAMB dryer's design for drying.

The perforated tube design followed a similar principle as flow distribution manifolds. A manifold is defined as a flow channel for which fluid enters or leaves through porous sidewalls due to the action of differential pressure. Manifolds are commonly categorized into four types, simple dividing or combining flow manifolds and parallel or reverse flow manifold systems (Bajura & Jones, 1976). The parallel and reverse flow systems are combinations of the primary dividing and combining flow manifolds interconnected by lateral branches. In the LAMB dryer system, the vertical perforated tube operates as a dividing flow where the hot air flows from the top inlet and aerates laterally through the perforated holes. In a dividing flow header, the primary fluid stream is decelerated due to the loss of fluid through the laterals. Therefore, the pressure will rise in the direction of flow if the effects of friction are small as can be demonstrated by applying a frictionless Bernoulli equation to the header flow stream. Frictional effects, however, would cause a decrease of pressure in the flow direction. Therefore, the possibility exists for obtaining a uniform pressure along with the dividing flow header by suitable adjustment of the flow parameters so that the pressure regain as a result of the flow branching balances the pressure losses due to friction.

In perforated pipes, variations in fluid pressure arise from pressure loss due to friction with the surface of the pipe, and the momentum of the main fluid produces a rise in the pressure due to continuous loss of fluid from the holes (Peladeau-Pigeon, 2012). Changes in pressure along the perforated pipe affect the flow rate distribution of fluid. Due to the capability of dividing ejecting fluid all along the tube, there will be changes in pressure in a longitudinal direction. Therefore, the flow released from orifices is known to be different from each other. According to Greskovich, the pressure drop in perforated pipe distributors has to be calculated (Greskovich & O'Bara, 1968). The methodology used in calculating pressure drop was to cut the pipe into discrete sections. The pressure drop in the perforated pipe was then calculated by applying the summation approach for each discrete section. There are few factors to be considered before describing the pressure forces existing in a pipe. Factors include friction term, flow inefficiencies, and momentum recovery contributions. Mokhtari discovered that the flow distribution changes qualitatively as it moves from low Re to high Re. Besides, the system aspect ratio (D_{pipe}/d_{exit}) was a factor that changes the uniformity of flow (Mokhtari *et al.*, 1997).

METHODOLOGY

Experimental Setup

A total of 6 different types of the perforated tube was tested to investigate the airflow uniformity. Each tube consists of different diameters, shapes, and sizes of perforated holes, the distance between the perforated holes and the total perforated hole (Table 1). The numbering begins from the top perforated hole until the perforated bottom hole. The experimental setup is, as shown in Figure 1. The operating parameters were inlet air velocity with 9.90 m/s at ambient temperature. Outlet air velocity and air pressure from perforated holes were determined with DIGI-SENSE Pressure and Flow Meter (Model 20250-13) which consist of ±0.3% accuracy.

Table 1. The details of the perforated tubes

Aerator no.	Tube diameter, inch	Shape of the perforated hole	Perforated hole dimension, mm	Perforated hole distance (Pitch), cm	Total number of perforated holes
1	1	Rectangle	5 x 2	7	16
3	1	Circle	4	7	24
4	1	Circle	4	7	16
7	1	Square	3 x 3	7	16
8	1.5	Circle	4	7	18
9	2	Circle	4	5.2	32

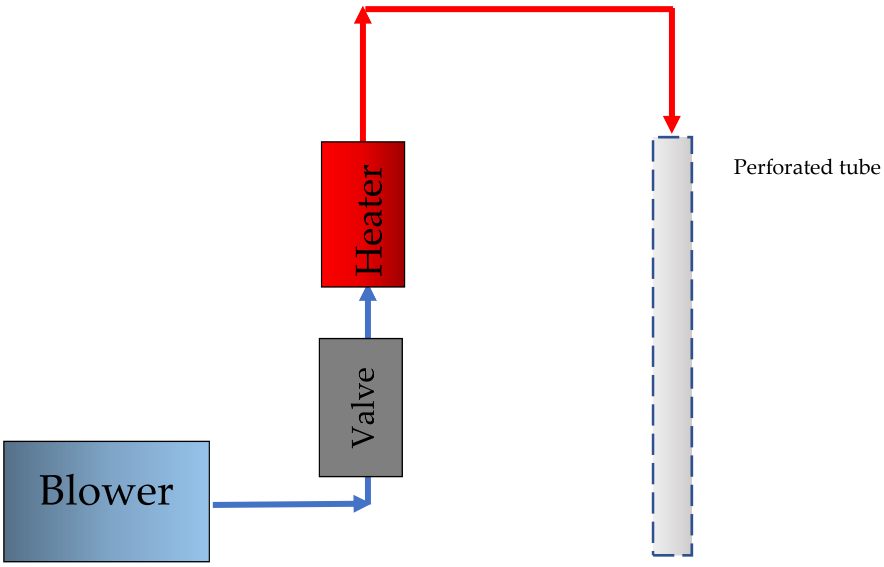

Figure 1. Schematic diagram of the experimental setup for air profiling of perforated tube

The Non-Uniformity Flow Coefficient and Pressure Drop

The non-uniformity flow coefficient was used to estimate the flow distribution among the perforated holes, with the dimensionless variables, β_i and Φ used to evaluate the flow distribution. β_i represents the flow ratio for the i^{th} outlet, and Q is the total flow rate (L/min) of the perforated holes. The definition is given in Equation (1) below:

$$\beta_i = \frac{Q_i}{Q} \qquad (1)$$

The concept of standard deviation as used to define the non-uniformity, Φ, and characterize the influence of flow ratios in the system (Chiou, 1982) as in Equation (2):

$$\Phi = \sqrt{\frac{\sum_{i=1}^{n}(\beta - \beta_1)^2}{N}} \qquad (2)$$

where N is the total number of outlets in the manifold and β_1 is the average flow ratio for the total number of outlets and can be calculated by using the following Equation (3):

$$\beta_1 = \frac{\sum_{i=1}^{n}\beta_i}{N} \qquad (3)$$

A larger value of Φ indicates lower uniformity. For this reason, optimal values of perforated are required to minimize the Φ value.

As for the pressure drop, a pressure difference between the first perforated hole and the subsequent perforated hole was measured. The flow rate distribution of fluid is affected by the changes in pressure along the perforated tube. Due to the capability of dividing ejecting fluid all along the pipe, there will be changes in pressure in a longitudinal direction shown in Equation (4).

$$\Delta P = P_1 - P_n \qquad (4)$$

where P_n is the subsequent perforated hole, with $n = 1, 2, 3\ldots.$

Effect of Perforation Geometry on The Uniformity of Air Distribution

Three perforated tubes (Aerator 1, 4, and 7) with different perforation geometries (circular, rectangular, and square) were chosen to investigate the air profile. The perforated tubes consist of constant tube diameter of 1 inch, 7 cm pitch, and 16 total perforations. The operation condition was set with 9.90 m/s of inlet velocity and ambient temperature.

Effect of Tube Diameter on The Uniformity of Air Distribution

Three perforated tubes (Aerator 3, 8, and 9) with different tube diameter was chosen to investigate the air profile. The perforated tubes consist of constant perforation size of 4 mm, 7 cm pitch, and circle shape perforation geometry. The operation condition was set with 9.90 m/s of inlet velocity and ambient temperature.

RESULTS AND DISCUSSION

Effect of Perforation Geometry on The Uniformity of Air Distribution

In Table 2, all perforated tube has the smallest value of non-uniformity flow coefficient, which indicates that most of the air velocity outlet consist of the uniform pattern along the perforated tube. By comparing among the perforated tubes, aerator 1 has the highest value of non-uniformity flow coefficient, and aerator 7 has the smallest value for non-uniformity flow coefficient. Circular geometry perforated outlets provide a high non-uniform air pattern due to the flow resistance from geometry shape (Chen & Sparrow, 2009), with the flow separation is created as the fluid attempts to turn abruptly from an axial flow to an outflow which possesses a considerable amount of outward momentum. As for pressure drop, Figure 2 shows the aerator 4 with a perforated circle hole has the highest value of pressure drop compared to the other perforated tube. The pressure drops for aerator 4 increase as the location of the perforated hole increased, which shows the air pressure outlet increases when it flowed downward with less resistance from the geometry shape of the perforated hole.

Table 2. The non-uniformity flow coefficient for the perforated tube with different outlet geometry.

Aerator	The non-uniformity flow coefficient, (Φ)
1	0.00055
4	0.00051
7	0.00045

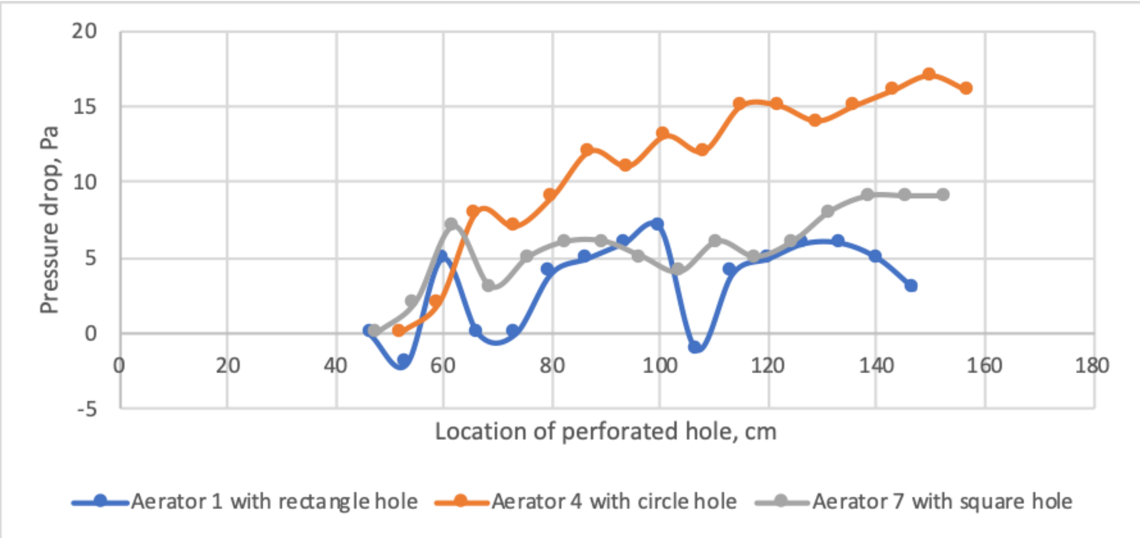

Figure 2. Pressure drop from different location of the perforated hole with different geometry.

Effect of Tube Diameter on The Uniformity of Air Distribution

In Table 3, all perforated tube has the smallest value of non-uniformity flow coefficient, which indicates that most of the air velocity outlet consist of the uniform pattern along the perforated tube. The pitch of each perforated tube has a similar pitch value, which affects the value of non-uniformity. By comparing among the perforated tubes, aerator 8 has the highest value of non-uniformity flow coefficient, and aerator 3 has the smallest value for non-uniformity flow coefficient. As for pressure drop, Figure 3 shows all perforated tube has almost similar pattern up to 60 cm point perforated hole. Onward from 60 cm point perforated hole, aerator 3 with 1-inch tube diameter has the highest pressure drop meanwhile aerator 8, and 9 has a similar pattern until 159 cm point perforated hole.

Table 3. The non-uniformity flow coefficient from the perforated tube with different tube diameter.

Aerator	The non-uniformity flow coefficient, (Φ)
3	0.000041
8	0.000086
9	0.000048

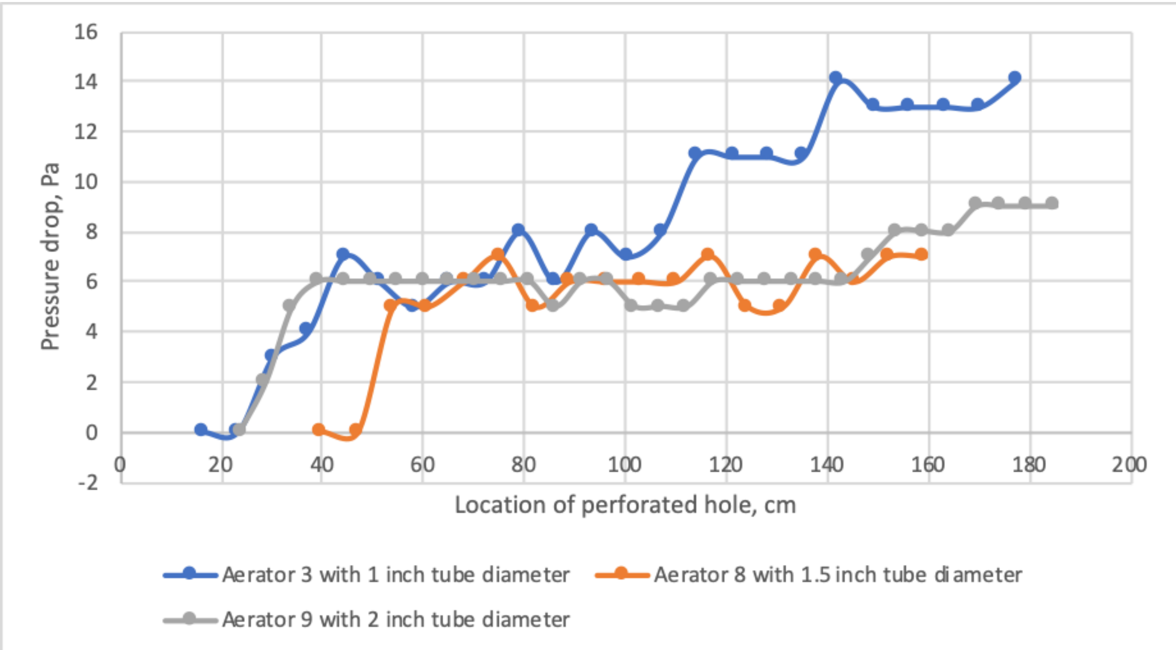

Figure 3. Pressure drop from different location of the perforated hole with different tube diameter.

CONCLUSION

Six different types of the perforated tube were tested to investigate the airflow pattern. The non-uniformity flow coefficient and pressure drop analysis were done accordingly towards different parameters, the effect of perforation geometry and the effect of pipe diameter. Based on the study, all perforated tube has shown the minimal value of non-uniformity flow coefficient with the range of 0.000041 to 0.00055. The value indicates a high uniformity of air outlets from the perforated tube. Aerator 4 has the highest pressure drop, which has a 4 mm diameter of a perforated circle hole. Aerator 1 with a rectangle hole (5mm x 2mm) has the lowest pressure drop, though inconsistency of pressure changes occurs along the perforated tube. As for the comparison between different tube diameters, aerator 3 with a 1-inch diameter perforated tube has the highest pressure drop when it reaches location 60 cm point perforation hole onward. The airflow pattern from the outlet perforated tube can be improved and modified by optimizing operating conditions and the design parameters of the perforated tube, which is the geometry of the perforated hole, the perforation size and tube diameter. With an optimized perforated tube, the LAMB dryer has the potential to control the drying pattern for biomass and lessen the maldistribution of hot air hence avoid an uneven drying process.

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