A Novel Technique for Determination of Vapor Transmission Rate through Textiles

Dr. Akshaya Jena, Director of Research
Dr. Krishna Gupta*, President
Porous Materials, Inc, 83 Brown Road, Ithaca, NY 14850
*(607) 257 –1670. Info@ pmiapp.com

Abstract

A novel technique for precise, accurate and fast determination of vapor transmission rate through textiles is discussed. Vapor at a constant pressure is maintained on one side of the textile and the increase in pressure of the vapor on the other side is measured. The technique was used to investigate two textiles. The vapor permeability of the textiles is almost five orders of magnitude lower than their air permeability. The air permeability of the textiles are identical, however, they show strong differences in vapor permeability.

Introduction

Modern textiles are finding wide application in high tech areas of many industries. Such applications require pore size, pore distribution, pore volume, liquid permeability, gas permeability and vapor permeability to be controlled and monitored within narrow limits. Instruments are now available to evaluate textiles for the required properties. In this investigation an instrument designed to measure vapor transmission through textiles is described and two commercial textiles have been examined for water vapor transmission. Airflow rates through these textiles have also been measured. The results have been critically examined.

Technique

Water Vapor Transmission Analyzer

The principle of the water vapor transmission analyzer is illustrated in Figure 1. The system is evacuated after placing the sample in the sample chamber. Water vapor is brought in to the sample chamber on one side of the sample and the pressure of the vapor is maintained at a constant value. The increase in pressure of the water vapor on the other side of the sample is continuously monitored. The vapor transmission rates are calculated from the measured values of pressure.

The Water Vapor Transmission Analyzer was designed based on this principle. The completely automated instrument used in this study is shown in Figure 2. Use of windows based software made operation, data acquisition and data reduction simple and operator involvement minimal. Very low flow rates were detectable because of the ability of the instrument to accurately measure very small increments in pressure. Highly reproducible, accurate and objective data were obtained. The transmission rate may be determined as functions of pressure and temperature.

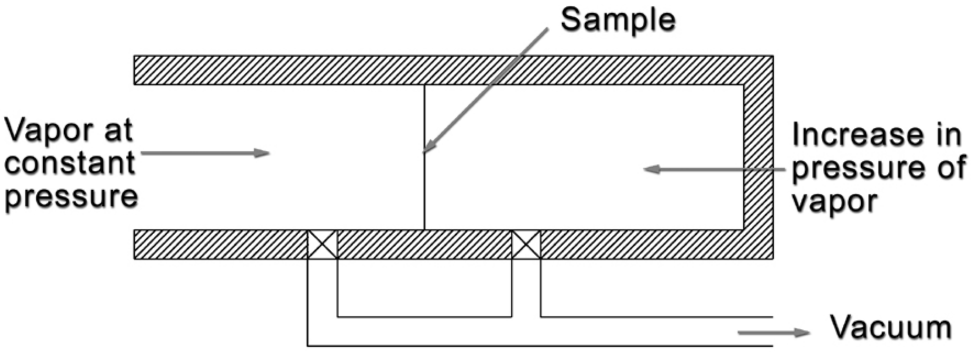


Figure 1. Principle of water vapor transmission analyzer.

Figure 2. The PMI Water vapor analyzer used in this study.

Capillary Flow Porometry

In this instrument gas flow rate through a sample is accurately measured as a function of differential pressure. Gas permeability is computed from the gas flow rate in any desired unit including Darcy, Gurley and Frazier. This instrument can also measure flow rates through a sample whose pores have been filled with a wetting liquid [1]. Such data can be used to compute other important characteristics of textiles like the largest pore diameter, mean flow pore diameter and pore distribution [2]. Figure 3 illustrates the principle of the technique. The sketch in Figure 4 illustrates the capability of the instrument.

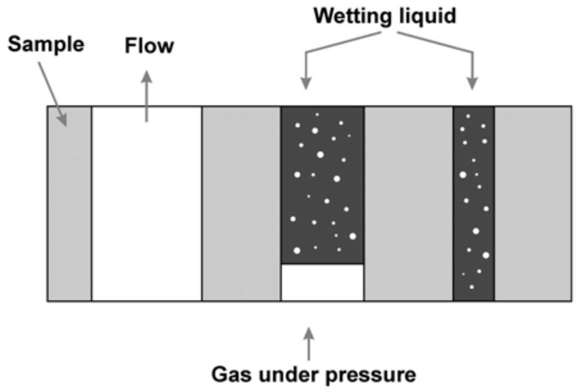
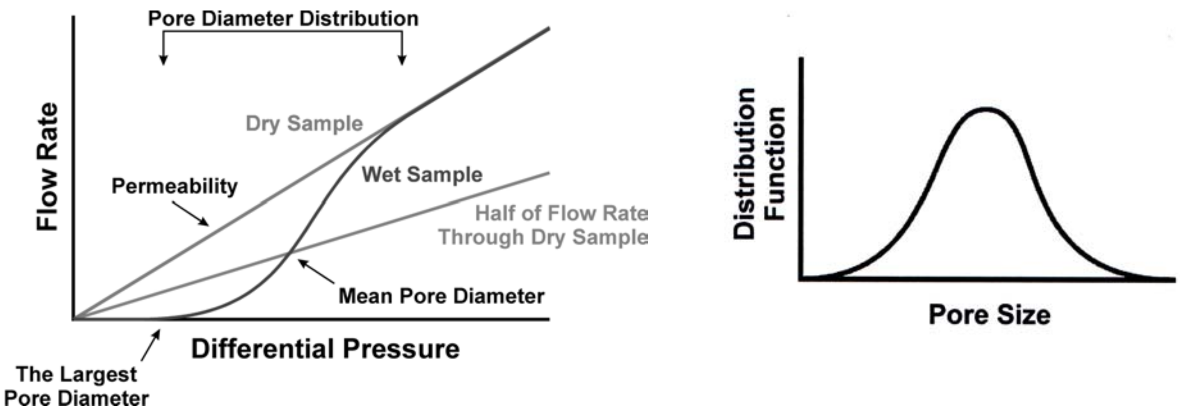


Figure 3 Principle of capillary flow porometry.



(a) Pore size and permeability (b) Pore distribution

Figure 4. Capabiliy of capillary flow porometry.

Results and Discussion

Material

Two commercially available textiles having different water vapor transmission characteristics were investigated. The investigated textiles were designated textile #1 and textile #2.

Water Vapor Transmission Rate

The pressure rise of water vapor on the outlet side of the water vapor transmission analyzer is shown in Figure 5 for the two textiles. For both textiles, temperature of the test was 300 K, inlet pressure was 0.54 psi and cross-sectional area was 3.464 cm^2. The sample thickness for textile #1 was 0.0809 cm and that for textile #2 was 0.0294 cm. Although the differential pressure experienced by textile # 2 is higher because of its lower sample thickness, the transmission rate through this textile is much less.

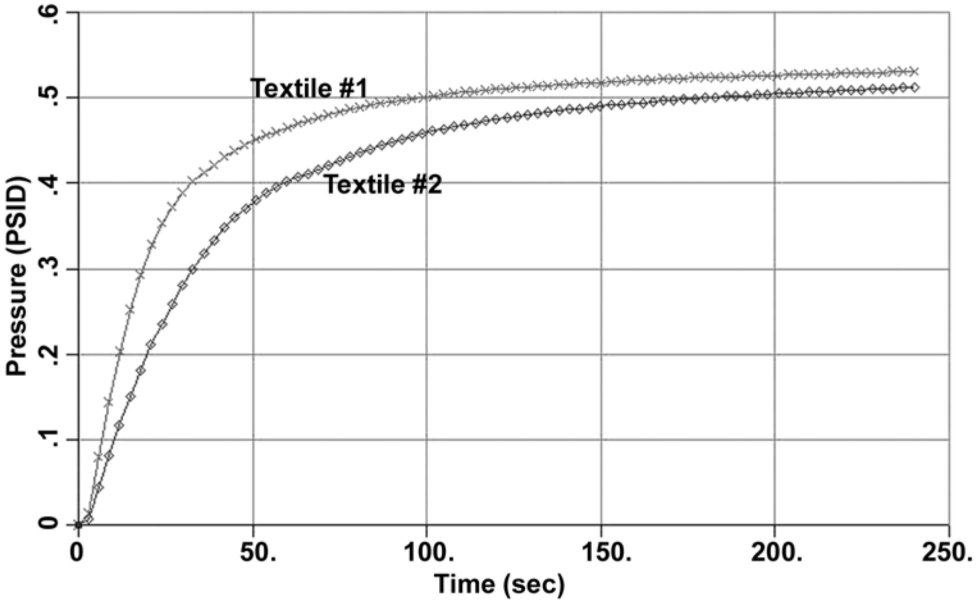


Figure 5. Change of pressure on the outlet side of two textiles in the water vapor transmission analyzer

The increase of pressure on the outlet side is due to transfer of water vapor through the sample to the outlet side. The molar rate of vapor transfer through the sample may be written as [3]:

$$dn/dt = - K (dp/dl) \qquad (1)$$

where n is the moles of vapor transferred through unit area of the sample in time, t; (dp/dl) is the pressure gradient across the thickness, l of the sample; and K is the permeability in moles per unit area, unit time and unit pressure gradient. In terms of the constant inlet pressure p_0, outlet pressure p_i and thickness of the sample l_0:

$$dn/dt = K [(p_0 - p_i) / l_0] \qquad (2)$$

The rate of pressure increase in the sample chamber is given by:

$$dp_i/dt = (RT/V_0) (dn_c/dt) \qquad (3)$$

where R is the gas constant, T is the test temperature, V_0 is the volume of chamber on the outlet side of sample, n_c is the moles of water vapor in the chamber. (dn_c/dt) is equal to the rate of transfer, (dn/dt) of Equation 2 times the surface area A of the sample. Substituting from Equation 2:

$$dp_i/dt = (RTAK / V_0 l_0) (p_0 - p_i) \qquad (4)$$

This equation reduces to:

$$\ln (p_0 - p_i) = -(RTAK / V_0 l_0)\, t + c \qquad (5)$$

where c is a constant. Equation 5 shows that the plot of $\ln (p_0 - p_i)$ versus t should have a slope equal to the negative of $(RTAK / V_0 l_0)$, which is a measure of water vapor permeability through the textile sample. A typical plot of $\ln (p_0 - p_i)$ against time is shown in Figure 6. Initially the slope is zero as there seems to be no transfer of vapor through the sample during a small initial incubation period. After the incubation period, the rate of transfer becomes appreciable. However, the transfer rate decreases with increase in time.

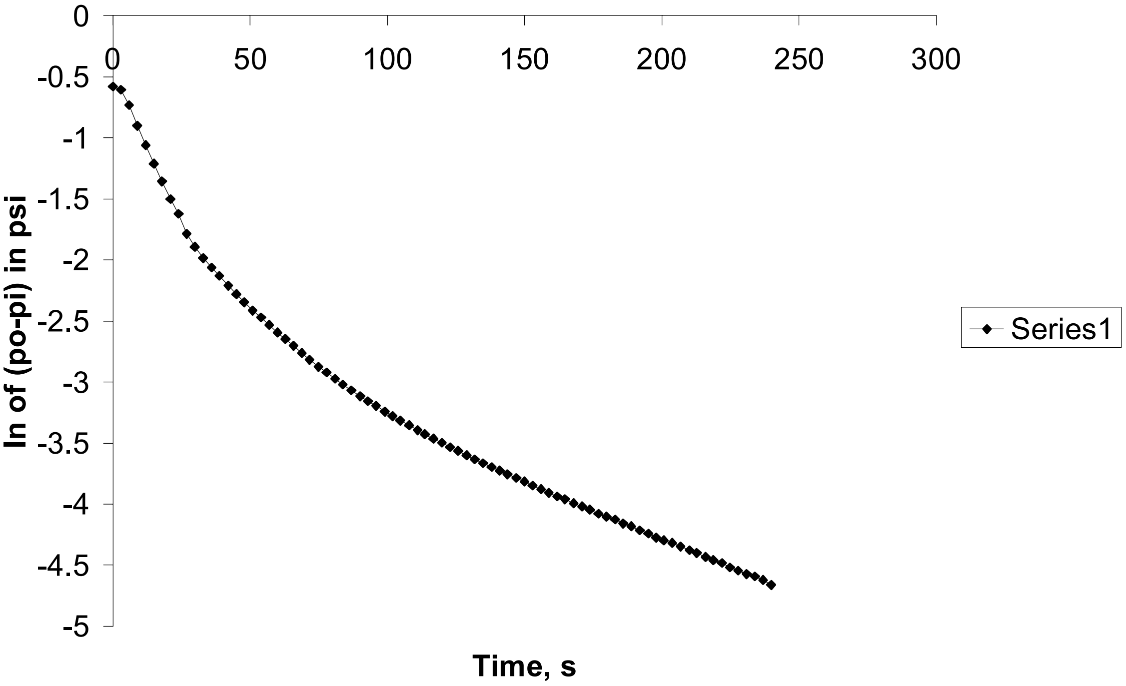
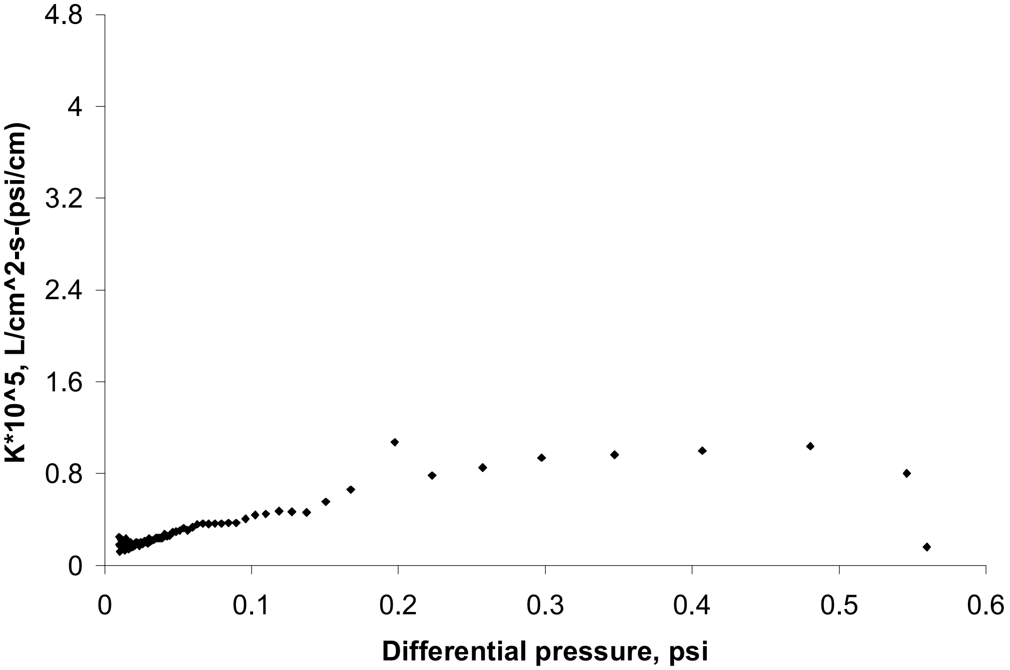


Figure 6. Variation of $\ln (p_0 - p_i)$ with time for textile # 1.

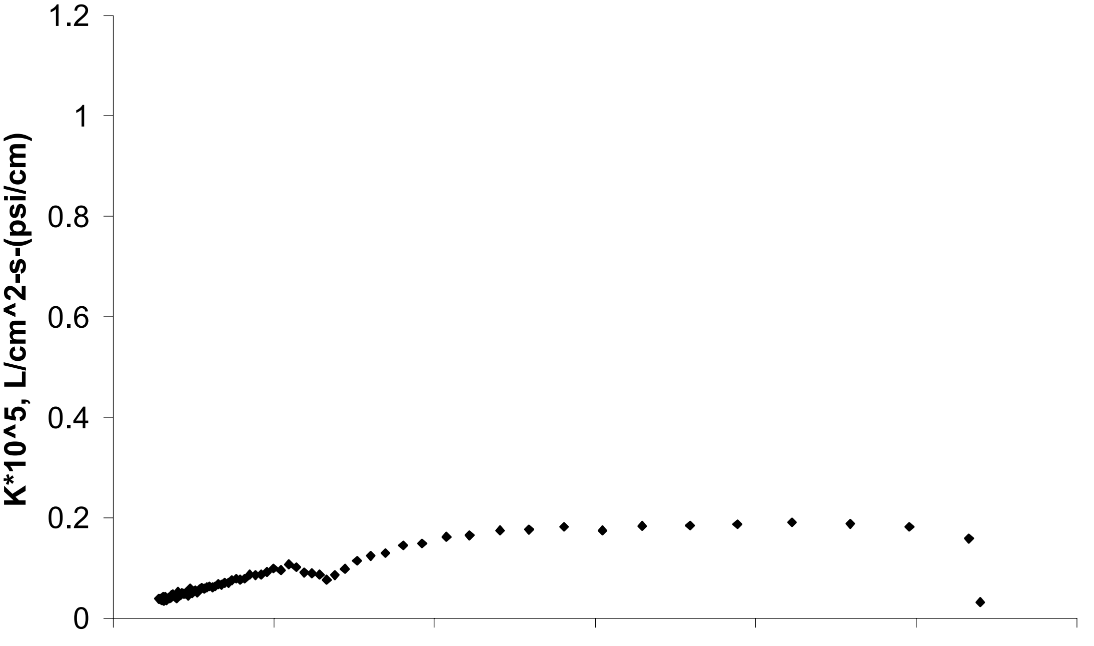
The permeability is obtainable from the variation of ln(po-pi) with time. From Equation 5:

$$K = -(V_0 l_0 / RTA)\, [d \ln (p_o - p_i) / dt] \qquad (6)$$

The vapor transmission rate computed after Equation 6 is plotted in Figure 7 as a function of differential pressure.



(a) Textile # 1



(b) Textile # 2

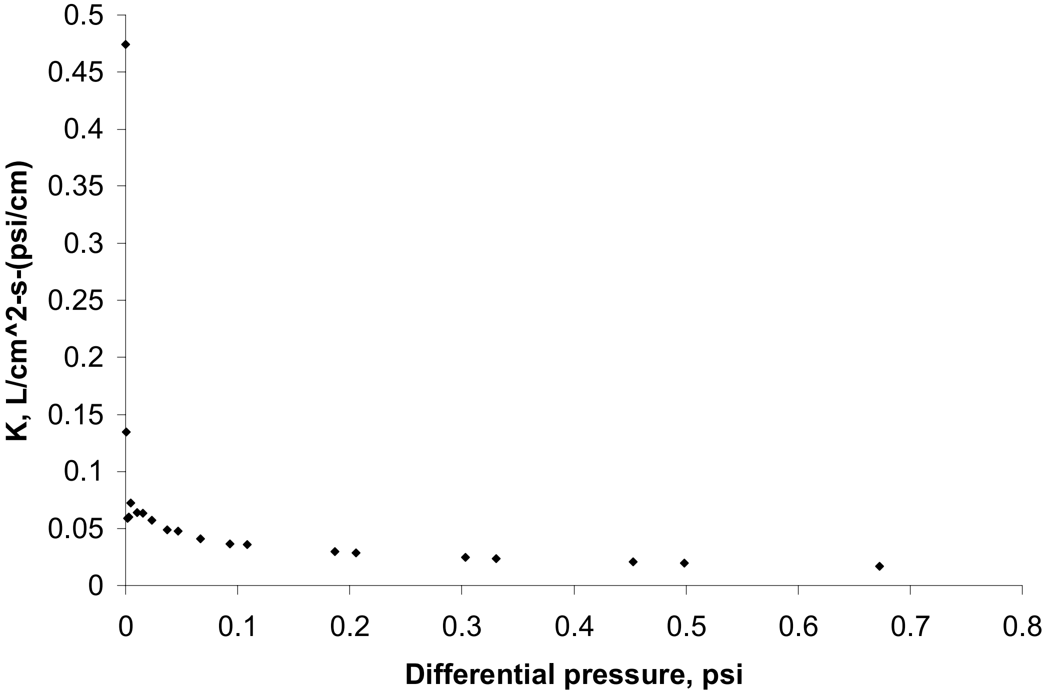
Figure 7. Water vapor transmission rate.

The transmission rate reaches its highest value during the incubation period and then slowly decreases with decrease in differential pressure. Such behavior may be attributed to the strong interaction of the vapor with the textile. Initially, absorption of the vapor by the textile gives rise to the incubation period. Transmission occurs due to the pressure gradient as well as the concentration gradient of vapor. With decrease in pressure gradient, contribution to flow due to concentration gradient of the vapor is reduced. Therefore, effective permeability is reduced.

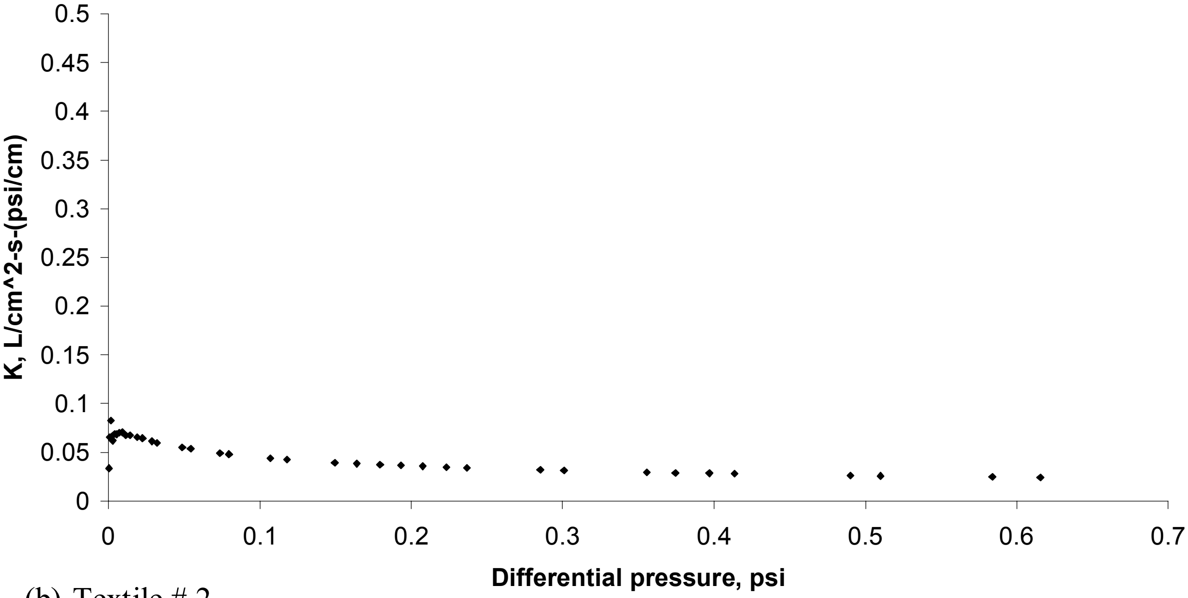
The behavior of the two investigated textiles is almost identical. However, the transmission rate through textile #1 is almost four times that through textile #2.These data may be compared with the transmission rate of air, which is not expected to interact with the textiles.

Air Transmission Rate

Air transmission rates through textile samples are computed from the air flow rates through textile samples measured in the capillary flow porometer as functions of differential pressure. The flow rate K expressed in L/cm^2-s-(psi/cm) is presented in Figure 8 for both textiles as functions of differential pressure.



(a) Textile # 1.



(b) Textile # 2.

Figure 8. Air permeability through the textiles.

Comparison of results in Figure 8 with those in Figure 7 shows that water vapor permeability is almost five orders of magnitude lower than air permeability, although the viscosity of vapor is close to that of air. The vapor permeability goes up with increasing differential pressure while the air permeability goes down with increased differential pressure. These observations are consistent with strong interaction of vapor with textiles. Water vapor might be condensing on textiles and partially blocking the pores of the textile. However, more work needs to done to clarify the mechanism of interaction and transmission of water vapor in textiles.

In terms of air permeability the two textiles do not show much difference. The mdifference in the air permeability of the two textiles is very small. However, vapor transmission rate through textile # 1 is almost four times that of textile # 2.

Comparison with Other Methods

A number of other methods including the ASTM cup method can be used to measure water vapor transmission rate. These techniques are based on vapor transmission due to a concentration gradient. The results can be unreliable because of the difficulty in maintaining a constant concentration [4]. The technique used in this investigation is based on transmission due to a pressure gradient, which can be accurately controlled. More work needs to be done for obtaining results, which can be compared.

Summary and Conclusion

1. An instrument for water vapor transmission analysis has been described.
2. The water vapor analyzer and capillary flow porometer were used to investigate two commercial technical textiles.

3. Water vapor transmission rates and air permeability of the two textiles were measured.
4. Water vapor transmission rate was almost five orders of magnitude lower than he air transmission rate. Water vapor transmission rate increased with increase in differential pressure whereas air transmission rate decreased with increase in differential pressure.
5. The two textiles showed considerable difference in their vapor transmission rates. However, difference in their air transmission rates was insignificant.

References

1. V. Gupta and A. K. Jena, Advances in Filtration and Separation Technology, American Filtration and Separation society, vol. 13b, (1999), 833.
2. Akshaya Jena and Krishna Gupta, Journal of Industrial Textiles, vol. 29, No. 4, (2000), 317.
3. A. E. Scheidegger, The Physics of Flow through Porous Media, Macmillan, 1957.
4. Y. Hu, V. Topolkaraev, A. Hiltner and E. Baer, Journal of Applied Polymer Science, vol. 81, (2001),1624.