Separation Science and Technology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713708471

STUDY OF THE ADSORPTION/REMOVAL EFFICIENCY OF WOVEN AND NONWOVEN ACTIVATED CARBON FABRICS FOR MEK

W. T. Davis[a]; G. D. Kim[a]; T. C. Perry[b]
[a] Department of Civil and Environmental Engineering, The University of Tennessee, Knoxville, Tennessee, U.S.A. [b] U.S. Department of Energy, Office of Environmental Management, Oak Ridge, Tennessee, U.S.A.

Online publication date: 30 June 2001

To cite this Article Davis, W. T. , Kim, G. D. and Perry, T. C.(2001) 'STUDY OF THE ADSORPTION/REMOVAL EFFICIENCY OF WOVEN AND NONWOVEN ACTIVATED CARBON FABRICS FOR MEK', Separation Science and Technology, 36: 5, 931 — 940

To link to this Article: DOI: 10.1081/SS-100103629

URL: http://dx.doi.org/10.1081/SS-100103629

SEPARATION SCIENCE AND TECHNOLOGY, 36(5&6), 931–940 (2001)

STUDY OF THE ADSORPTION/REMOVAL EFFICIENCY OF WOVEN AND NONWOVEN ACTIVATED CARBON FABRICS FOR MEK

W. T. Davis,[1] G. D. Kim,[1] and T. C. Perry[2]

[1]Department of Civil and Environmental Engineering, The University of Tennessee Knoxville, Tennessee 37996
[2]U.S. Department of Energy, Office of Environmental Management, Oak Ridge, Tennessee 37831

ABSTRACT

The initial gaseous contaminant removal efficiency and adsorption characteristics for various commercially available activated carbon fabrics were determined at air flow rates, air temperature and pressure drop typical of an indoor air residential or small office environment. Methyl ethyl ketone (MEK) was used as the hazardous air pollutant for the laboratory tests. For the range of MEK concentrations tested, the initial fabric adsorption efficiency decreased as concentration increased, although the total adsorption capacity (g/g) increased. Initial fabric efficiencies were also higher at a lower air flow rate. The pure activated carbon nonwoven felt had higher adsorption capacity as well as higher initial adsorption efficiencies than the woven carbon fabrics tested. In all of the fabrics which were tested, the maximum adsorption efficiency was achieved initially, lasted only momentarily, then steadily decreased until adsorption capacity was reached. It was also observed that fabrics that had reached capacity, but were then subjected to the same air flow conditions as occurred during the adsorption process (except without the MEK present), immediately began to desorb the adsorbed MEK. This raises concern about the application of carbon adsorption systems for indoor environments, if concentrations are highly variable due to the potential of desorption from the fabric.

INTRODUCTION

Concentrations of hazardous air pollutants in the indoor air continue to be a source of concern for residential and office environments (1). The increasing use of man-made or modified building materials containing treated or synthetic materials, adhesives, and laminates provides a key source of odorous and potentially toxic vapors in the home and office. This presents a health concern to families, particularly those with small children, highly sensitive individuals, or family members who spend most hours at home indoors.

Filters containing activated carbon granules are common, inexpensive devices used to remove organic vapors from the indoor air environment and much research has been published on the adsorption capabilities of these filters. In recent years, additional activated carbon devices have become commercially available for removal of organic vapors from the indoor air. These devices include portable air cleaning units having filters with either activated carbon granules or carbon-impregnated fibers. Many units have a filter housing that holds multiple filter components, allowing each component to be purchased and replaced individually. Filter components designed to remove dust, pollen, mold, smoke, and odors are sold separately for many units. More recently available pure activated carbon fiber fabrics are growing in usage for both specialized and more general air cleaning applications (2,3,4,5).

In this study, the VOC removal efficiency and adsorption characteristics of various commercially available activated carbon woven and nonwoven fabrics are compared for use in an indoor air cleaning environment. Methyl ethyl ketone (MEK) is used as the organic air pollutant for the tests. This study examines the adsorption of MEK onto activated carbon fabrics (ACF) and compares experimental results with results obtained from a numerical model. Adsorption isotherms were calculated and modeled for woven and non-woven ACF using MEK concentrations between 10 ppmv and 1800 ppmv in a simulated indoor environment. While the OSHA PEL time weighted average is 200 ppm and the STEL is 300 ppm, additional research is being done to determine characteristics at much lower concentrations. The research presented here is based on preliminary data from an ongoing study of activated carbon fibers and fabrics.

Marcel Dekker, Inc.
270 Madison Avenue, New York, New York 10016

EXPERIMENTAL METHOD

A laboratory test stand was built to simulate a contaminated indoor air environment. The filter test stand (Figure 1) provided for air flow rate control, ambient temperature, a pollutant gas mass flow regulator, a filter housing assembly, a gas analyzer, and a computerized data logger and analog/digital converter. A constant concentration of MEK in air was created by passing a small slipstream of the inlet air through a rotameter to a small fritted bubbler containing MEK (liquid). Adequate mixing and residence time were provided to ensure that the MEK was volatilized and mixed into the gas upstream of the filter holder. The inlet and outlet MEK concentrations were measured using a Miran 1A portable gas analyzer, which uses a single-beam spectrometer with variable wavelength. The filter housing accepts a 5-inch diameter filter sample. Once the filter specimen is clamped into position, a 2-inch diameter area in the center is exposed to gas flow. Inlet concentrations were established without a filter in place. Once the inlet concentration was determined, the filter was then placed in the filter housing, testing was initiated, and the outlet concentration was continuously measured until termination of the test. The concentrations were recorded using an InstruNet electronic data logger and analog/digital converter feeding into a pentium computer. Pressure drop and temperature were also measured during each test.

The activated carbon fiber fabrics were supplied by different manufacturers. The fabrics are essentially 100% carbon, typically made by a staged high-temperature heat treatment process in which polyacrylonitrile or other suitable precursor material is carbonized and activated, yielding a soft, pliable activated carbon fab-

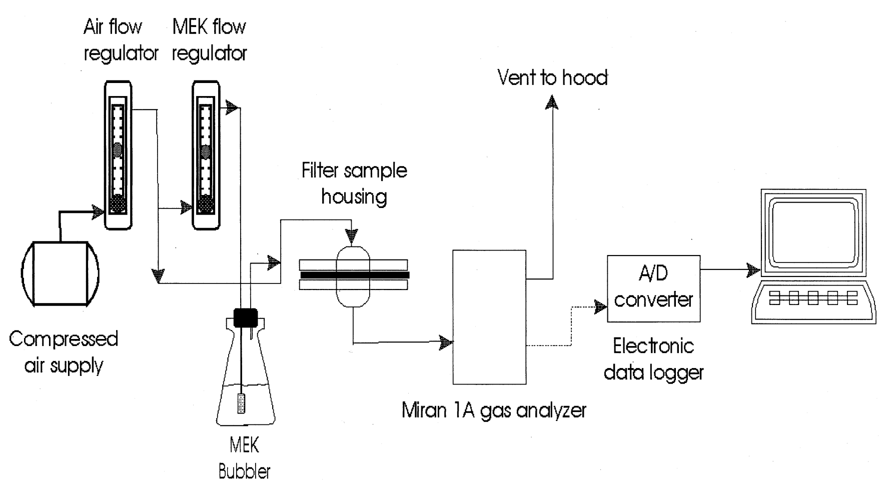

Figure 1. Filter test stand.

MARCEL DEKKER, INC.
270 Madison Avenue, New York, New York 10016

Table 1. Characteristics of the Activated Carbon Fabrics Used in This Study

Fabric	Dry Weight g/m^2	Surface Area (BET) m^2/g	Thickness mm
W1 (woven 1)	210	1000-1200	1.2-1.4
W2 (woven 2)	110	1000-1200	0.4-0.6
N (nonwoven)	120	1500	1.2

ric. The carbon fabric can be regenerated a number of ways after saturation. The method used for this research was heating for several hours in a laboratory oven at 400 °F. Filter samples were regenerated prior to each test. After testing, filter samples could be regenerated and reused in subsequent tests. Between tests, filter samples were stored in dessicators to minimize moisture adsorption. Three filters (fabrics) are the focus for this study. They are designated as W1 (woven 1), W2 (woven 2), and N (nonwoven). The N fabric is a needled carbon felt. Table 1 provides the characteristics of these three fabrics.

The fabrics were tested at face velocities of 19, 39, and 78 cm/s. Only single layers of the fabrics have been tested to date for this study. Future research will include testing of multiple layers. MEK concentrations tested in this initial phase of the test program ranged from 10 to 1800 ppm. It is recognized that indoor air concentrations of VOCs typically average less than 10 ppm. (6). The initial phase of the test program was conducted across a wide range of pollutant concentrations to simulate an unusual occurrence of high VOC concentrations, and to facilitate the ease of measurement using the Miran 1A analyzer. Testing at concentrations below about 5 ppm will require use of a different analyzer with greater sensitivity. In addition, the tests reported in this study were conducted at a relative humidity of less than 20%. Testing at higher humidities has not yet been conducted, but it is anticipated that adsorption capacities at high humidities will be reduced as has been reported in other studies (7). Each fabric was tested through complete adsorption and desorption. A constant flow rate and concentration were used throughout the adsorption test until fabric capacity was reached. Once saturation was reached, the MEK mass flow regulator was closed, allowing only clean air to pass through the fabric. Desorption continued until no MEK was detectable in the outlet air.

RESULTS AND DISCUSSION

The initial VOC removal efficiency, η, can be expressed as $(1\text{-}C_e/C)\text{x}100\%$, where C is the inlet vapor concentration and C_e is the outlet concentration (8). Typical MEK adsorption and desorption curves obtained for the woven and nonwoven fabrics are shown in Figure 2. A curve is also provided for a commercially available activated carbon granule (ACG) filter. The time and concentrations scales have been normalized for comparison of the woven and nonwoven curves. The woven fabric had a test time of about 350 seconds and an inlet concentration of 1560 ppm, whereas the nonwoven fabric had a test time of about 3500 sec and an inlet concentration of 167 ppm. Although most deep bed activated carbon systems have a finite period of complete removal followed by breakthrough, many of the tests conducted in this study on the relatively thin fabrics exhibited only a partial removal even at the beginning of the test. As shown in Figure 2, the woven fabric exhibited about 47% efficiency at the beginning of the adsorption test followed by a gradual decrease in efficiency to zero as the fabric approached adsorption capacity. On the other hand, the nonwoven fabric exhibited a finite period of operation at near 100% efficiency before breakthrough occurred.

Figure 3 provides a comparison of the initial removal efficiency for the W1 fabric at velocities of 19 cm/s and 78 cm/s. As indicated in the figure, lower initial efficiencies were observed at the higher velocity. As the MEK concentration increased, the data indicate a decreased initial efficiency. Using the above equation for η, initial VOC removal efficiencies were also computed for each type of fabric tested. As shown in Figure 4, the nonwoven fabric, N, exhibited the highest initial efficiency at 100%. The 100% removal efficiency lasted several seconds

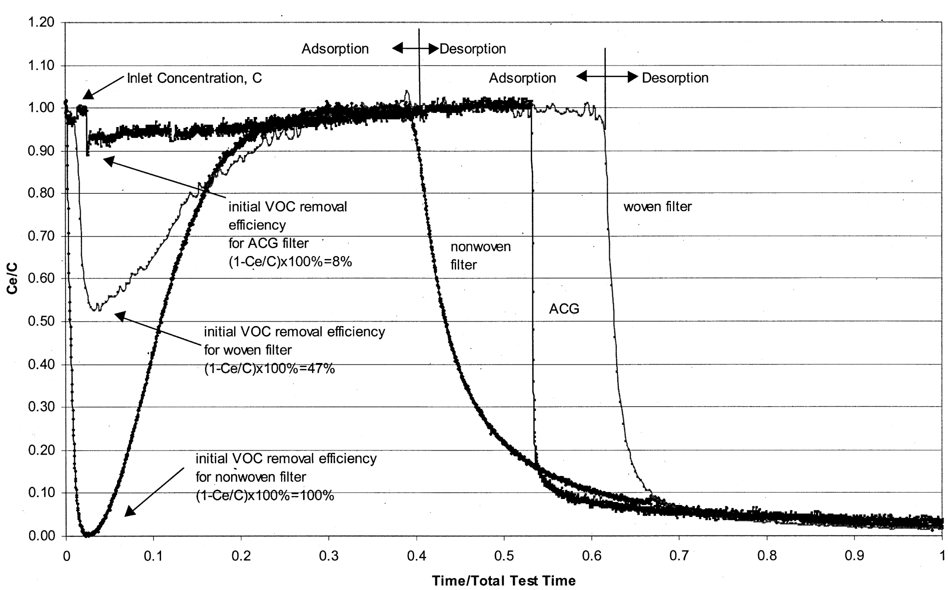

Figure 2. Typical MEK adsorption/desorption curves for woven, nonwoven, and ACG filters.

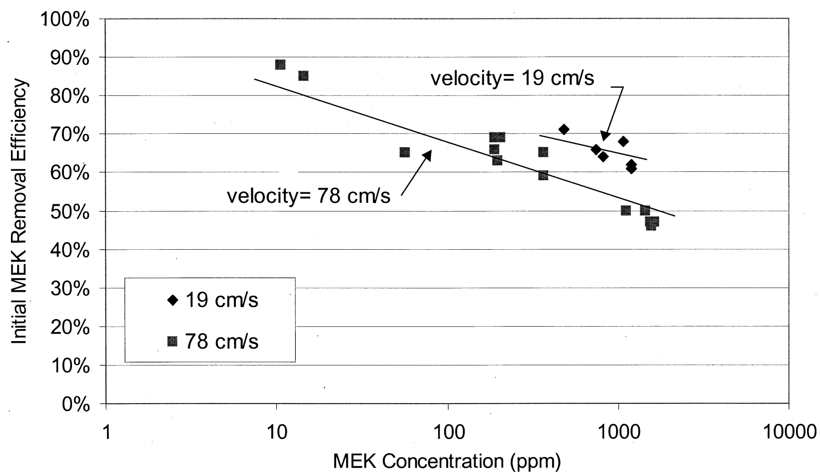

Figure 3. MEK concentration versus initial removal efficiency for W1 filter.

before any MEK breakthrough was measured. The W1 fabric, which has twice the carbon of the W2 fabric, exhibited the second highest initial removal efficiency. The W2 fabric had the lowest overall initial removal efficiency. None of the woven fabrics achieved 100% removal efficiency for the conditions tested. The su-

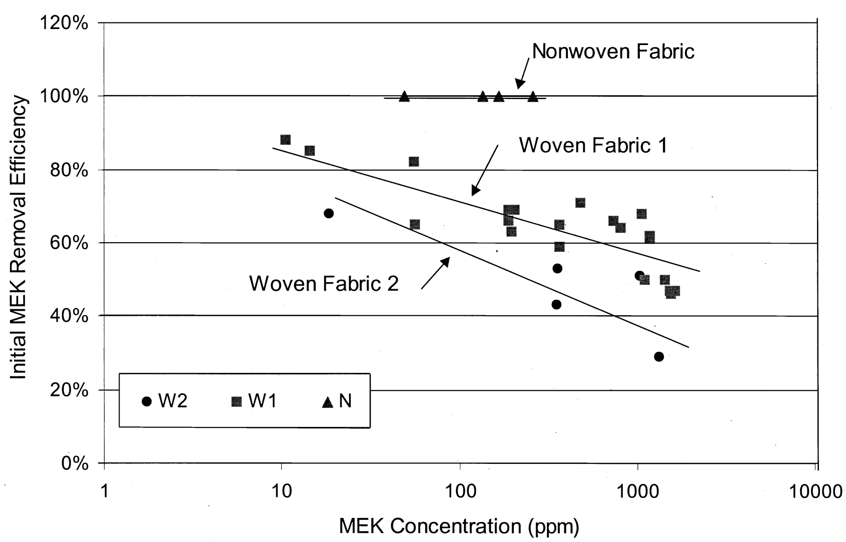

Figure 4. Initial VOC removal for activated carbon fabrics.

Marcel Dekker, Inc.
270 Madison Avenue, New York, New York 10016

perior initial performance of the nonwoven fabric was attributed to the random packing and non-uniform spacing between fibers. In comparison, the woven media had distinct pore openings between the woven yarns with little coverage in the interstitial spaces between the yarns. Additional testing is to be conducted to determine if the initial efficiency of the woven fabrics will continue to increase when tested at concentrations that are lower than 10 ppm. The data shown in Figure 3 suggest that the initial efficiency may continue to increase for lower concentrations.

Spurney (9) provides another method of comparing fabric efficiencies that also takes into account the pressure drop, an important consideration for indoor filter designs. A quality factor, Q, is computed by the equation E / ΔP, where E is the removal efficiency of the filter and ΔP is the pressure drop across the filter. Q is a measure of filter quality or performance. The higher the ratio of efficiency to pressure drop, the higher the relative quality of the filter. The same velocity and gaseous pollutant (or same particle size) must be used in order to compare filter performance. The Spurney equation was applied to the filter test data to compute a Q factor based on an initial removal efficiency percentage divided by pressure drop in inches of water. The resulting Q values are given in Figure 5. When pressure drop is also considered, the woven fabrics outperformed the nonwoven fabric even though the nonwoven fabric had a higher initial removal efficiency. Additional testing is needed to determine how the nonwoven fabric compares at higher velocities, as well as how performance is affected when multiple layers of fabric are used.

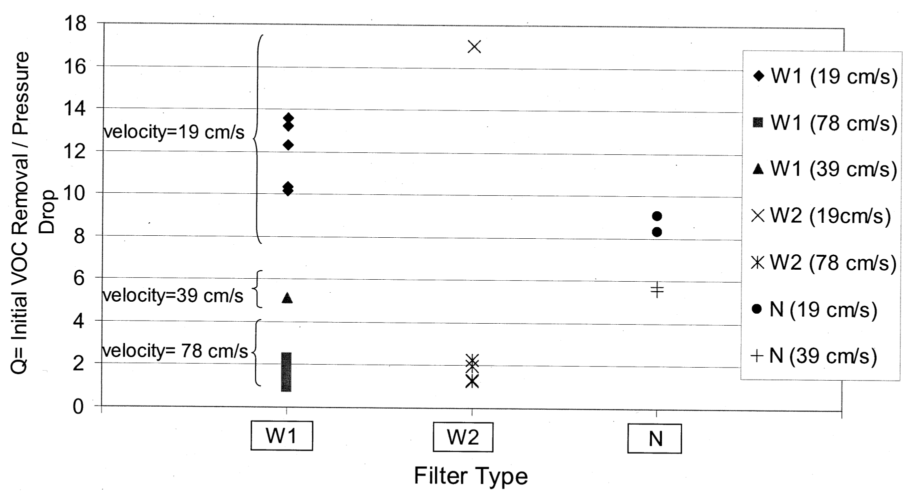

Figure 5. Comparison of quality factor, Q, for woven and nonwoven fabrics.

Marcel Dekker, Inc.
270 Madison Avenue, New York, New York 10016

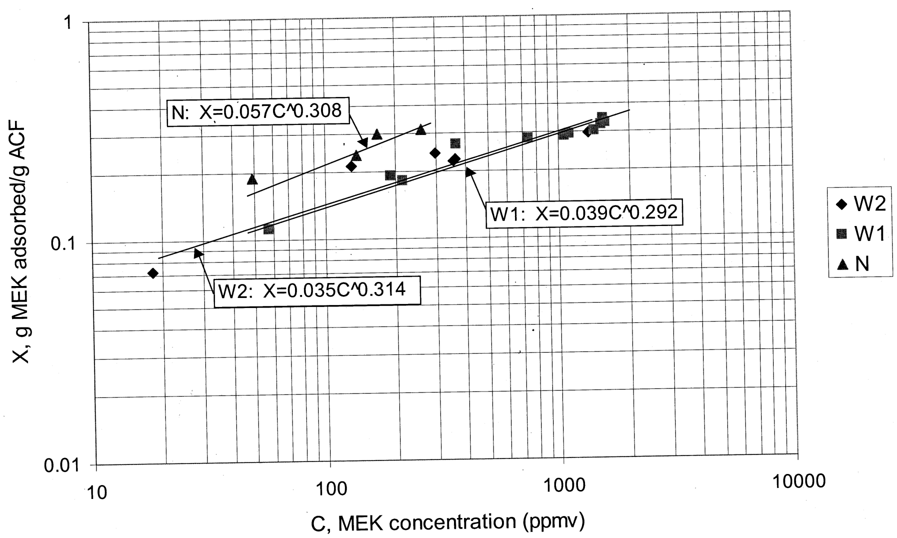

Figure 6. Isotherms for woven and nonwoven ACF.

Isotherms were developed for each type of fabric tested. The isotherms are typical Type I isotherms characteristic of carbon.(10, 11) Figure 6 shows isotherms for both the woven and nonwoven fabrics. The Freundlich equation (12) was used to model the experimental MEK adsorption data and describe adsorption isotherm data. The Freundlich equation is represented as:

$$X = aC^b$$

where X is the mass of adsorbate adsorbed divided by the mass of adsorbent (g/g); a and b are empirical constants; and C is the concentration of the adsorbate in the bulk gas phase in ppm. The experimental adsorption isotherm data for MEK were plotted on a log-log scale with the Freundlich equations. The two woven ACFs, as shown in Figure 6, did not show a significant difference in the adsorption capac-

Table 2. Adsorption Isotherm Constants for the Fabrics Used in This Study

$X = aC^b$			
Fabric	Constant a	Constant b	R
W1	0.039	0.292	0.97
W2	0.035	0.314	0.94
N	0.057	0.308	0.96

ity. However, the non-woven fabric had a higher adsorption capacity in the tested concentrations from 10 ppmv to 1800 ppmv than the woven fabrics. The lines through the data in Figure 6 are results from fitting the Freundlich equation with constants presented in Table 2. The correlation coefficients (R) for the best fit equations using the Freundlich equation ranged from 0.94 to 0.97.

CONCLUSION

For the range of MEK concentrations tested, the initial fabric adsorption efficiency decreased as concentration increased, although the total adsorption capacity (g/g) increased. Additional testing is currently being conducted at concentrations below 10 ppm to determine if concentrations more typical of indoor air quality would result in higher initial efficiencies than those shown in Figures 3 and 4 of this study. Initial fabric efficiencies for the woven fabrics were also higher at a lower air flow rate. The pure activated carbon nonwoven felt had higher initial adsorption efficiencies than the woven carbon fabrics tested. In all of the fabrics, which were tested, the maximum adsorption efficiency was achieved initially, lasted only momentarily, then steadily decreased until adsorption capacity was reached. It was also observed that fabrics that had reached capacity, but were then subjected to the same air flow conditions as occurred during the adsorption process (except without the MEK present), immediately began to desorb the adsorbed MEK. Manufacturer's information and some articles have referred to desorption in ambient air as a positive characteristic of the activated carbon fibers that results in leveling the concentration peaks. While elimination of concentration spikes may be a positive aspect, the release of the adsorbed chemical raises concern about the application of carbon adsorption systems in indoor environments where air is being recirculated, due to the potential of desorption from the carbon into the recirculated air. Further investigation of the desorption performance is also planned to be conducted as a part of this research at a later date.

ACKNOWLEDGMENTS

The authors would like to thank Joseph Hayes, Jr. (American Kynol), and Calgon Carbon for providing the carbon fabrics for this research.

REFERENCES

1. Hodgson, A.T., Daisey, J.M., and Grot, R.A., *Sources and Source Strengths of Volatile Organic Compounds in a New Office Building*, J. Air Waste Manage. Assoc. 41: 1461-1468, 1991.

2. Joseph S. Hayes, JR., In *American Kynol*, Reprinted *from Kirk-Othmer: Encyclopedia of Chemical Technology*, Vol. 16, Third Edition, pp. 125-138.
3. Economy, J. and Lin, R.Y., *Adsorption characteristics of Activated Carbon Fibers*, Applied Polymer Symposium No. 29, 199-211, 1976.
4. Fuerman, R.G., Cal, M.P., Larson, S.M., Rood, M., *Removal of Gaseous Organic Contaminants from Indoor air with Activated Carbon Fibers*, Air & Waste Manage. Assoc., 84th Annual Meeting, June 16-21, 1991, 91-62.5.
5. Rood, M.J., Foster K., Cal, M., Graf, O., Larson, S., and Economy, J., *Adsorption Properties of Activated Carbon Fibers: Applications to Indoor Air Quality*, Proceedings of Indoor Air ‘93, Vol. 6, pp. 429-434.
6. U.S. Environmental Protection Agency, *A Comparison of Indoor and Outdoor Concentrations of Hazardous Air Pollutants*, EPA/600/N-98/002, Inside IAQ, Research Triangle Park, NC 27711, Spring/Summer 1998.
7. Cal, M.P., Rood, M.J., and Larson, S.M., *Removal of VOCs from humidified gas streams using activated carbon cloth,* Gas. Sep. Purif., Vol. 10, No. 2, pp. 117-121, 1996.
8. Wadden, R.A. and Scheff, P.A., *Indoor Air Pollution*, NY: John Wiley & Sons, 1983.
9. Maini, S.M., Hersh, S.P., and Tucker, P.A., *Barrier fabrics for Protection against Aerosols*, Textile Progress, Volume 26, No. 1, 1995, pp.1-41.
10. Wark, K., Warner, C.F., Davis, W.T., *Air Pollution- Its Origin and Control*, Third Ed., Menlo Park: Addison Wesley Longman, 1998.
11. Cooper, C.D., & Alley, F.C., *Air Pollution Control A Design Approach*, Chicago: Waveland Press, 2nd Edition, 1994.
12. Treybal, R.E., Mass-Transfer Operations, McGraw-Hill, New York, p. 581 (1980).

Marcel Dekker, Inc.
270 Madison Avenue, New York, New York 10016