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# Adsorption Capacity of Activated Carbon for n-Alkane VOCs

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## ABSTRACT

The volatile organic compounds (VOCs) in the indoor air come from many sources including building materials, furnishings, occupant activities and in some cases, the ventilation air. Granular activated carbons (GAC) have been increasingly used to remove these contaminants, particularly for small commercial buildings and those located in urban centers or near industrial plants where the quality of outdoor air may be worse than that of the indoor air. Tests were conducted to determine the efficiency of GAC in removing VOCs from the indoor air. Seven n-alkanes VOCs covering a wide range of molecular sizes were selected for these tests. They were pentane, hexane, heptane, octane, nonane, decane, and undecane. The breakthrough time and VOC mass adsorbed on GAC for these individual VOCs were obtained. It was found that the adsorption capacity of GAC decreases as the initial VOC concentration, $C_0$, decreases.

## 1. INTRODUCTION

Studies have indicated that indoor airs contain a large variety of volatile organic compounds,[1-2] which can have adverse effects on indoor air quality. Although the most frequently used strategy to remove these contaminants is ventilation. It depends on the contaminant concentrations in outdoor airs. The acceptable levels of indoor air quality in buildings cannot be effectively maintained by simply increasing ventilation alone, particularly for small commercial buildings, where the HVAC systems are not as nearly well designed and maintained as those in large office buildings. Because of the building height, the ventilation air of small commercial buildings may be more susceptible to contamination by vehicle exhaust and the exhaust of nearby buildings than that of tall buildings. Thus, in addition to ventilation air filtration may have to be used. This study addresses the issue of air filtration which is the use of adsorption technique to remove air contaminants from both the ventilation air and the indoor air. Granular activated carbon (GAC) was selected as the air filter media because it is less selective than other materials in absorbing volatile organic compounds (VOCs).[3-4] The purpose was to determine the effectiveness of activated carbons in removing VOCs under indoor conditions.

## 2. EXPERIMENTAL SECTION

Tests were conducted in both a small scale chamber and a full scale chamber. The adsorptive capacity of GAC was assessed in terms of two parameters: breakthrough time and adsorbed VOC mass.

## 2.1. Materials Used

The VOCs used for the tests were n-pentane (Lancaster, 99%), n-hexane (ALDRICH, 99%), n-heptane (Lancaster, 99%), n-octane (Lancaster, 99%), n-nonane (ALDRICH, 99+%), n-decane (Fisher, 99.8%), and n-undecane (ALDRICH, 99+%). The granular activated carbon (GAC) tested was obtained from HAYCARB Ltd.. It was irregular in size and shape with an average diameter of 4 mm.

## 2.2. Small Scale Chamber Test

The GAC was contained in a designed specimen holder, 2.5 cm in diameter and about 2.5 cm thick.[5] The thickness is similar to that of typical commercial filter products. The supply air was maintained at 296±1°C and 50±2% relative humidity with a flow rate of 6.58±0.02 l/min using a flow-temperature-humidity control system (Model HCS-301, Miller-Nelson Research Inc.). The challenge VOCs were injected into the supply air using a syringe pump (Model 341A, Sage Instruments) with speed ranging from 0.0101 to 0.0531 ml/h. The VOC concentrations in the supply air were calculated based on the amount injected, and were checked by the GC measured data. FID Hydrocarbon Analyzer (Model HC500-2C, MELOY LABORATORIES Inc.) was used to measure the total hydrocarbon concentrations (THC) continuously.

## 2.3. Full Scale Chamber Test

The GAC specimen was loaded into the charcoal holder (1’×2’×1’’) of the NRC full-scale chamber.[6] The supply air was controlled at 296±1 K, 50±2% relative humidity with a constant airflow rate of 3570±54 l/min. The challengeVOCs were generated by placing flasks or beakers of their liquid compounds on electronic balances inside the chamber. The electronic balances were used to measure the emission rate. The VOC concentrations at different locations were measured on site using a Multi-Gas monitor (Bruel&Kjær Type-1302).

## 2.4. Air Sampling and Chemical Analysis

Air samples were collected at locations both upstream and downstream of the GAC during both chamber tests with Supelo/Perkin-Elmer adsorption tubes at different time intervals, using a vacuum pump and mass flow controller (Matheson DYNA-Blender, Model 8280). The samples collected were analyzed using a gas-phase chemical analysis system consisting of an automatic thermal desorption (Perkin Elmer ATD 4000) and a gas chromatograph (Varain Star-3400cx) with a flame-ionization detector. The GC/FID was calibrated using sorbent tubes onto which liquid standards were loaded.[7]

# 3. RESULTS AND DISCUSSION

## 3.1. Breakthrough Curves

Figures 1 through 7 show the results of the small scale chamber tests. The breakthrough curves of n-alkanes for a filter media of 4.15 g granular activated carbons (GAC) at 296 K. The challenge VOC concentrations ranged between 5.39 and 28.36 ppm. The n-alkanes selected for the tests were pentane, hexane, heptane, octane, nonane, decane, and undecane. Figure 8 shows the results of the full scale chamber tests for pentane with a filter media of about 2600 g GAC. The challenge VOC concentrations ranged between 1.93-7.33 ppm.

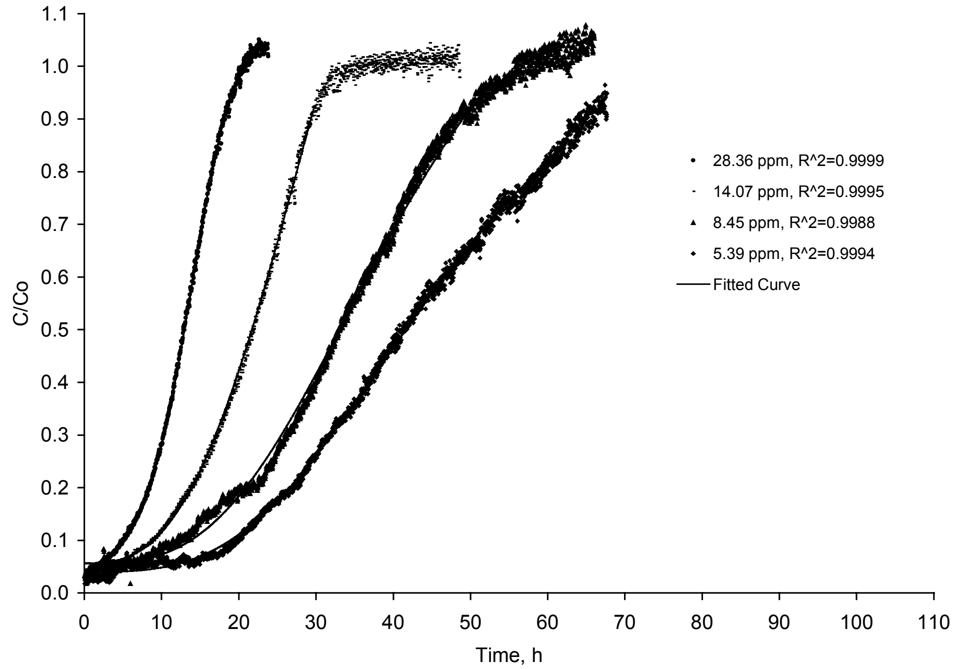


**Figure 1.** Breakthrough curves of small-scale test for pentane.

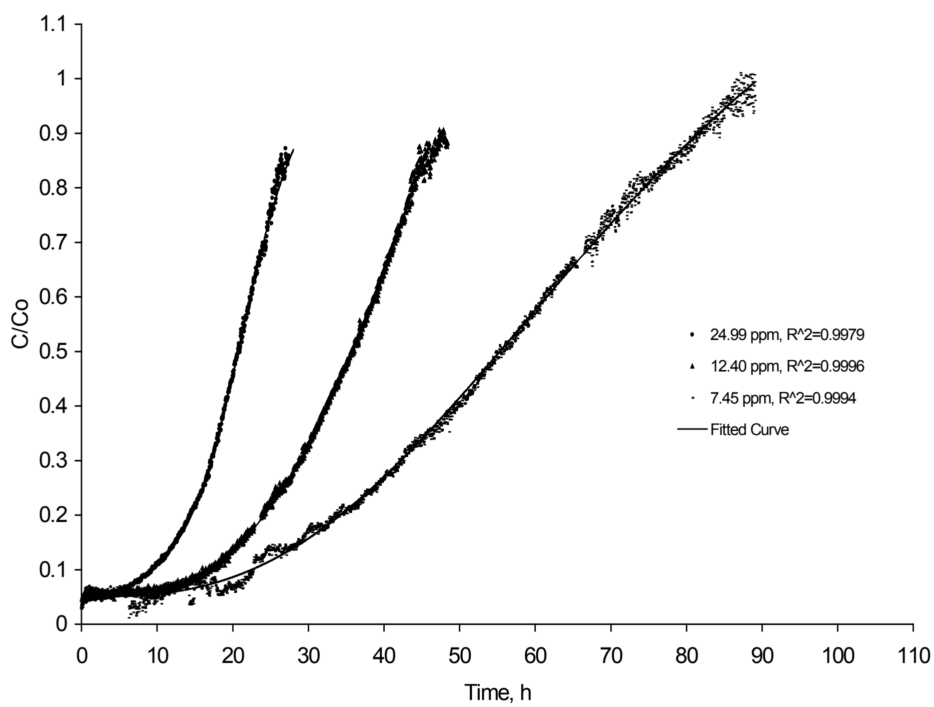


**Figure 2.** Breakthrough curves of small scale test for hexane.

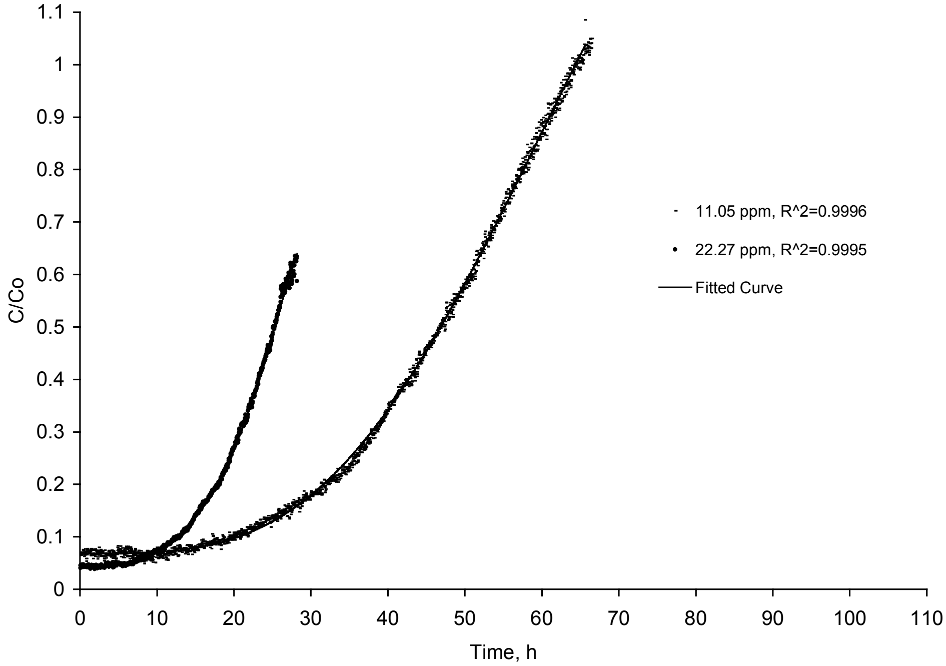


**Figure 3.** Breakthrough curves of small-scale test fro heptane.

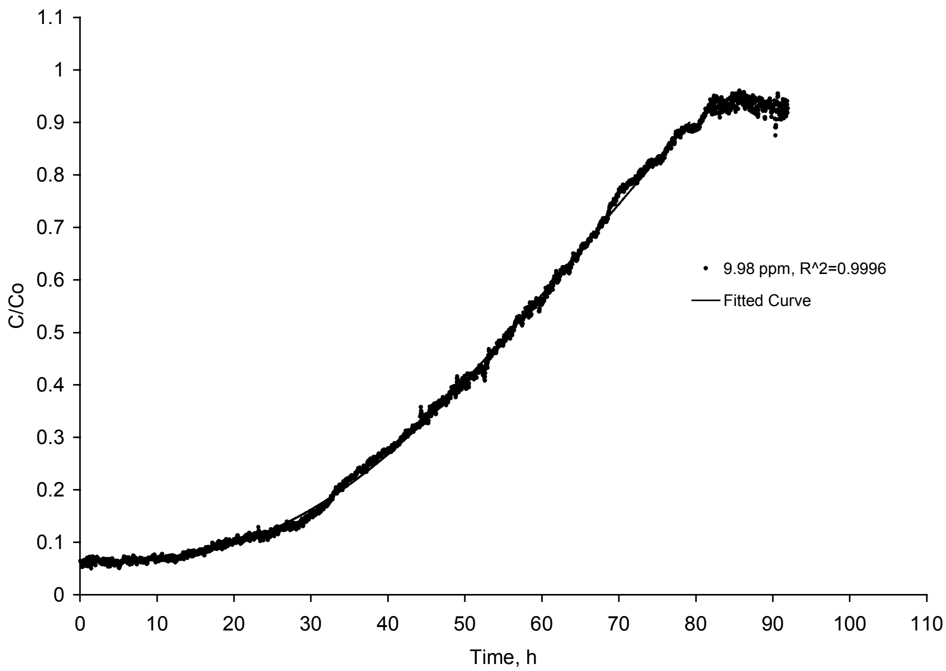


**Figure 4.** Breakthrough curve of small-scale test for octane.

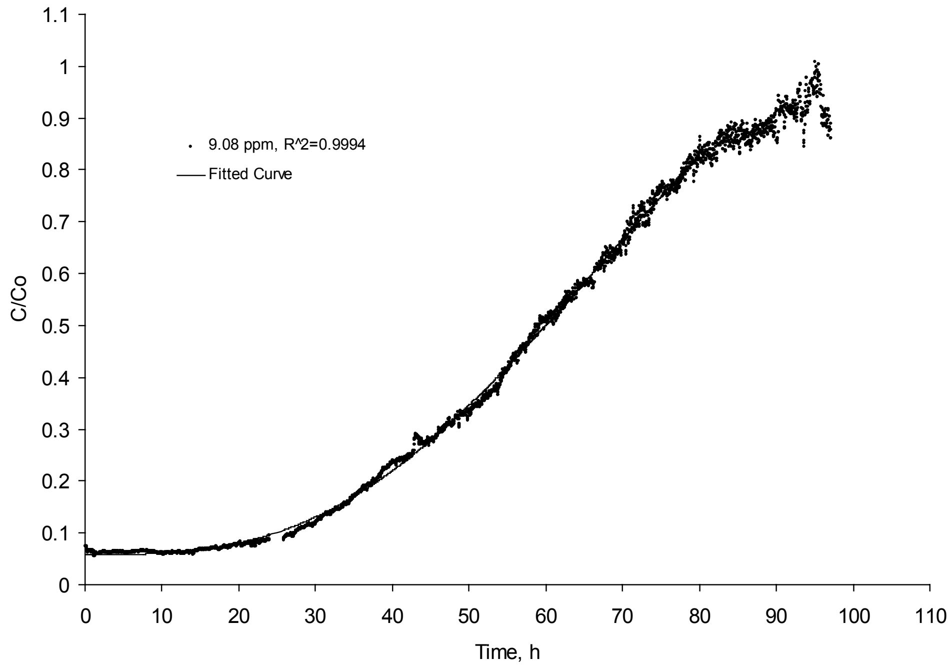


Figure 5. **Breakthrough curve of small-scale test for nonane.**

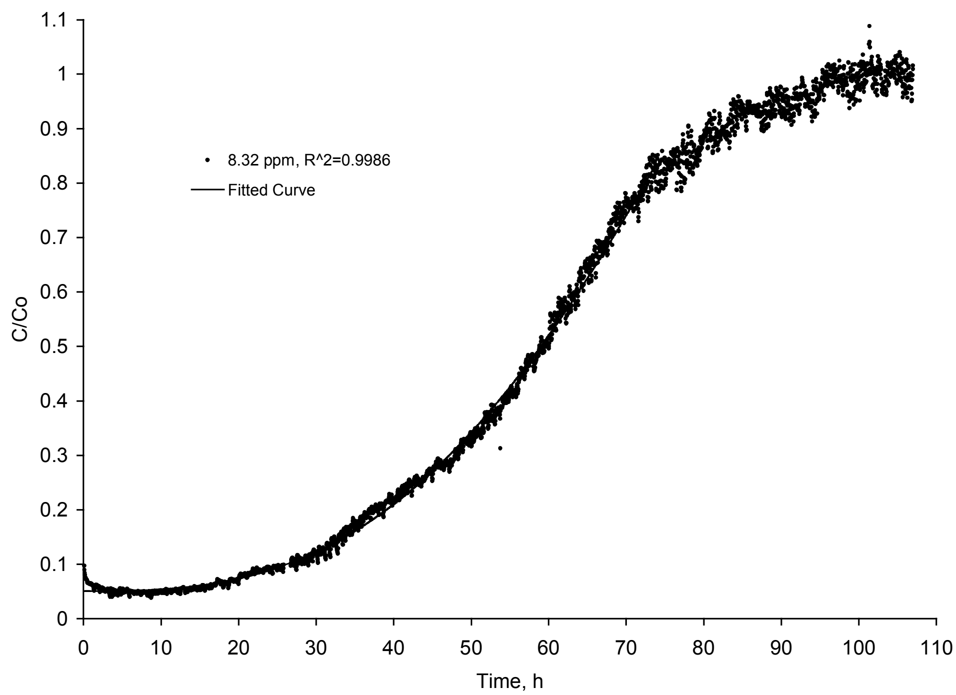


Figure 6. **Breakthrough curve of small-scale test for decane.**

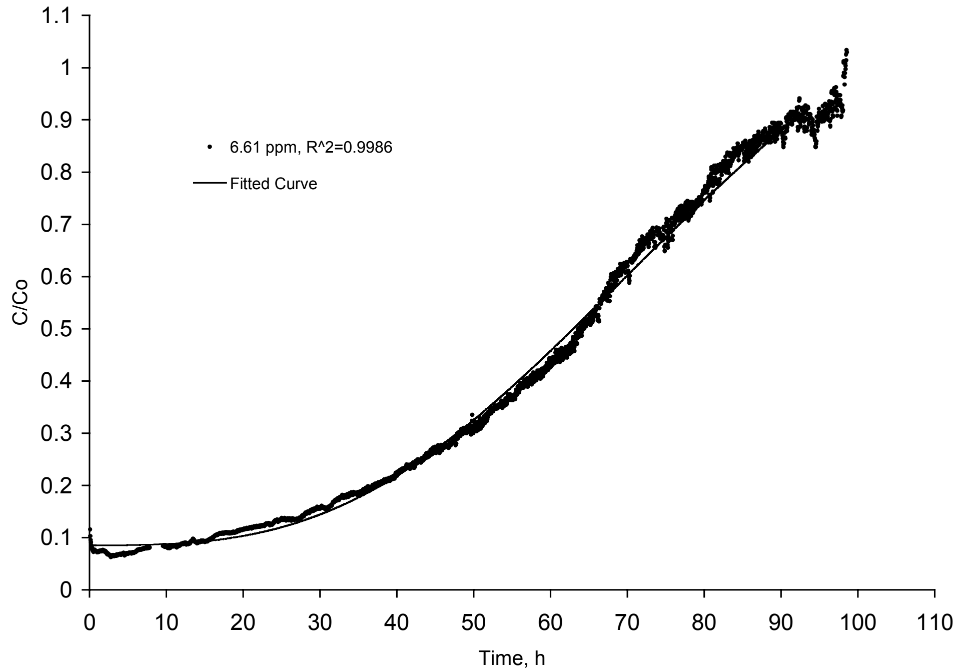


**Figure 7.** Breakthrough curve of small-scale test for undecane.

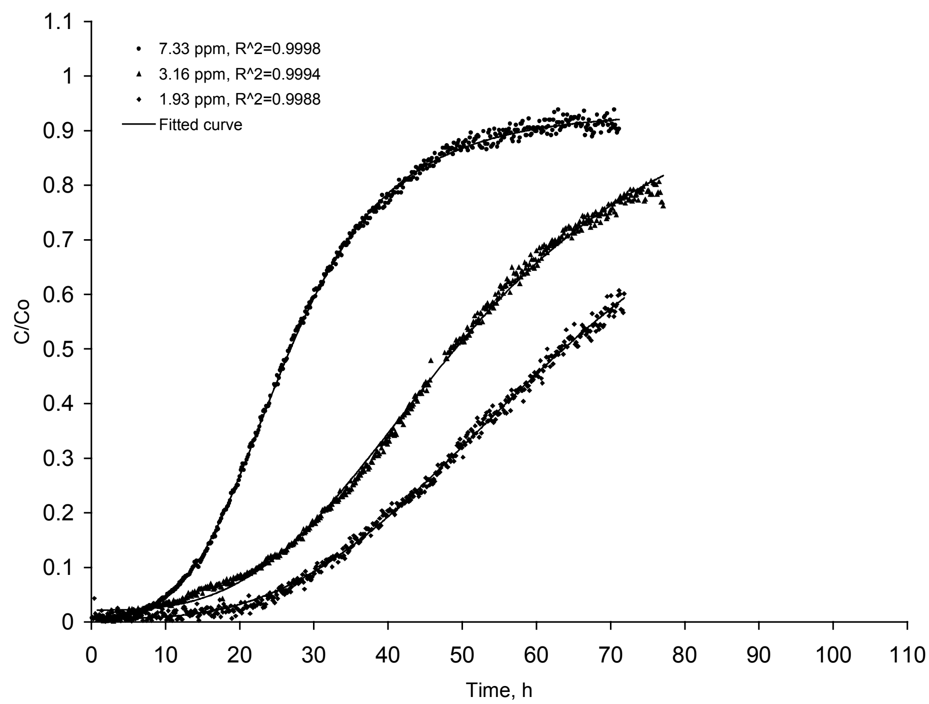


**Figure 8.** Breakthrough curves of full-scale chamber test for pentane.

## 3.2. Characterization of the Air Filter

In order to assess the effectiveness of air filter media in adsorbing chemical contaminants, both the breakthrough time and adsorbed VOC mass were derived from the breakthrough curves. The breakthrough time was obtained directly from the fitted curves. The VOC mass adsorbed on GAC can also be determined from Eqs. 1 and 2.[8]

$$M_{VOC} = C_0 Q \int_0^{t_b} [1 - P(t)] dt \quad (1)$$

$$M = \frac{M_{VOC}}{M_C} \times 100\% \quad (2)$$

where, P(t) is a function of fractional penetration, which varies from 0 to 1 for all challenge VOCs. The results of breakthrough capacity for VOCs on GAC are shown in Table 1.

**Table 1.** Test results of breakthrough capacity in both chamber tests.

| **Compounds** | **GAC mass, g** | **VOCs $C_0$, ppm** | **Breakthrough time, h** | | | **Capacity at Breakthrough, % of GAC mass** | | |
|---|---|---|---|---|---|---|---|---|
| | | | 10% | 30% | 50% | 10% | 30% | 50% |
| Pentane | 4.148 | 28.45 | 5.13 | 10.33 | 12.96 | 3.85 | 7.26 | 8.54 |
| | 4.152 | 14.04 | 8.99 | 16.99 | 21.72 | 3.36 | 6.25 | 7.49 |
| | 4.148 | 8.45 | 13.79 | 25.52 | 33.09 | 3.07 | 5.36 | 6.45 |
| | 4.148 | 5.40 | 18.94 | 32.07 | 41.64 | 2.73 | 4.36 | 5.23 |
| Hexane | 4.148 | 24.71 | 9.29 | 17.15 | 20.72 | 7.34 | 12.81 | 14.62 |
| | 4.151 | 12.38 | 16.59 | 28.85 | 35.75 | 6.48 | 10.68 | 12.42 |
| | 4.146 | 7.77 | 22.51 | 42.21 | 55.34 | 5.29 | 9.29 | 11.23 |
| Heptane | 4.150 | 22.28 | 10.72 | 19.02 | 23.42 | 8.74 | 14.68 | 17.00 |
| | 4.151 | 11.03 | 20.55 | 37.85 | 46.85 | 8.24 | 14.40 | 16.76 |
| Octane | 4.151 | 9.96 | 20.66 | 42.53 | 55.76 | 8.55 | 16.52 | 20.08 |
| Nonane | 4.148 | 9.06 | 25.80 | 46.67 | 60.00 | 10.95 | 18.67 | 22.35 |
| Decane | 4.149 | 8.30 | 26.74 | 47.17 | 59.00 | 11.74 | 19.76 | 23.46 |
| Undecane | 4.151 | 6.61* | 18.67 | 47.87 | 62.97 | 8.12 | 19.80 | 24.53 |
| Pentane** | 2480.6 | 1.93 | 30.98 | 48.45 | 63.74 | 1.47 | 2.16 | 2.61 |
| | 2608.2 | 3.16 | 23.15 | 37.34 | 49.17 | 1.86 | 2.95 | 4.10 |
| | 2604.1 | 7.33 | 13.91 | 21.07 | 26.88 | 2.57 | 3.89 | 4.97 |

* Obtained from GC data
** Determined in NRC full-scale chamber

## 3.3. Prediction of Filter Performance under Indoor Conditions

It is not practical to test GAC against VOCs at concentrations normally existed in indoor environments, because such a test would require more than 1000 h.[3] To reduce the test time, VOCs at high concentrations are routinely used. An extrapolated method is then used to predict the performance of GAC under indoor conditions.

The relationship of the breakthrough time between two different VOC concentrations has been developed by Nelson and Harder:

$$\frac{t_{b1}}{t_{b2}} = \left(\frac{C_{01}}{C_{02}}\right)^{\beta} \tag{3}$$

where, β is about -0.67, which is the average value of the slopes of breakthrough time versus contaminant concentration curve plotted on logarithmic scales for various VOCs.[9] Examples of such curves for both pentane and hexane are shown in Figure 9.

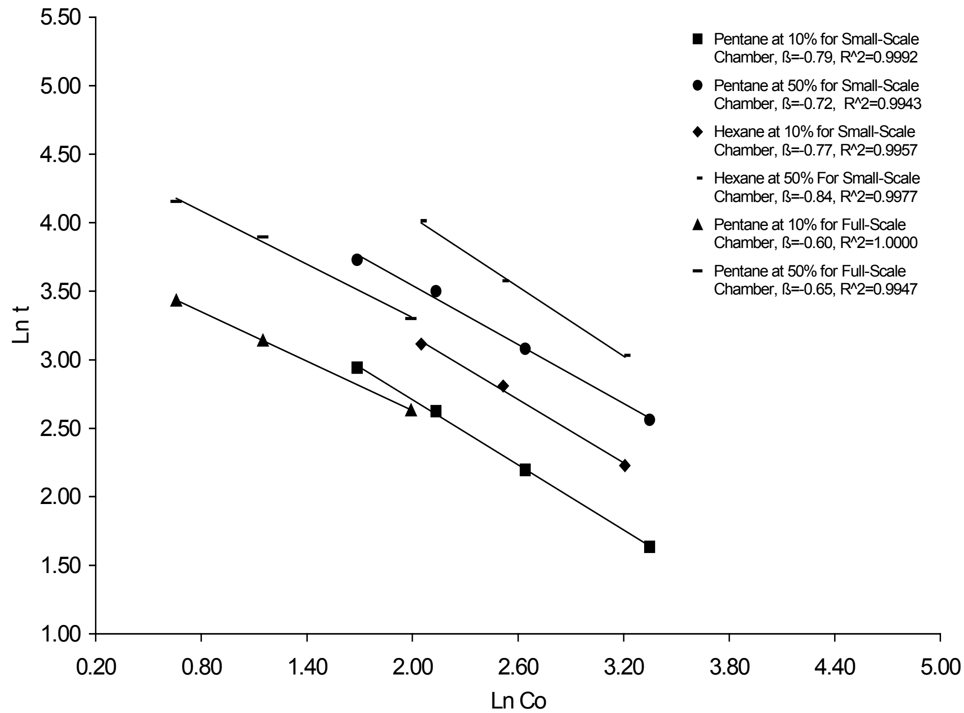


**Figure 9.** Effect of initial concentration on breakthrough time.

Figure 10 shows the relationship between adsorbed VOC mass (M) and the initial VOC concentration ($C_0$) for pentane and hexane. The measured data were fitted to an equation of the following form:

$$M = \sigma(1 - e^{-\alpha C_0}) \tag{4}$$

where, σ represents a maximum adsorption mass under given conditions, α is a constant which is a function of individual adsorbate/adsorbent species and experimental conditions. σ and α were obtained from the measured data using the least square analysis. It is obvious that M equals zero or σ as $C_0$ reaches zero or infinite.

Figure 10 shows that the VOC mass adsorbed by GAC decreased as $C_0$ decrease, particularly sharp $C_0 < \sim 5$ ppm. As the indoor VOC concentrations are usually very much less than 5 ppm, in ppb ranges, the results suggest that GAC is not an effective filter for normal indoor use. Figure 10 also shows that the measured data from both small and full scale chambers agree closely with the fitted curves for pentane at 10% and 50% breakthrough.

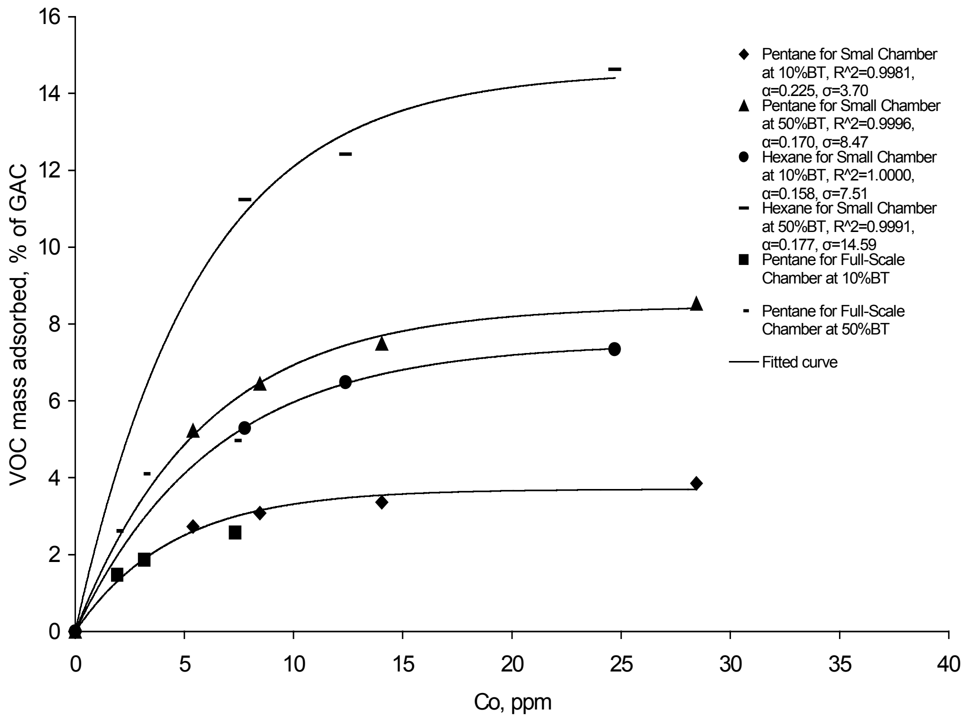


**Figure 10.** Relationship between initial concentration and VOC mass adsorbed.

## 3.4. Breakthrough Characteristics and Molecular Size

The vapor pressure and the radius of gyration for VOCs were obtained from VOCBASE.[10] For comparison, the breakthrough times (50%) of all measured n-alkanes at concentration 10 $mg/m^3$ were calculated. The results are shown in Figure 11. It indicates that the breakthrough time of GAC is inversely proportional to the logarithm of vapor pressure.

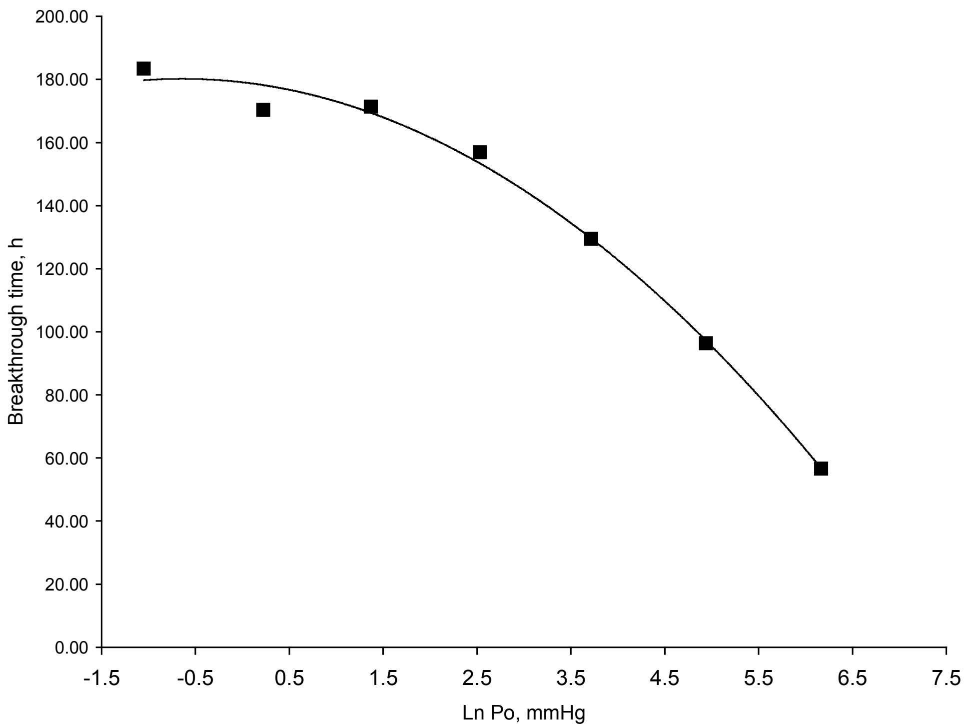


**Figure 11.** 50 % breakthrough time and vapor pressure for the alkanes at concentration 10 $mg/m^3$

The relationship between VOC adsorbed mass (50% breakthrough) and molecular size is shown in Figure 12. It shows that the VOCs mass adsorbed increases with the amount of carbon in the n-alkane molecules. The rate of increase appears to slow down when the molecular size as represented by the radius of gyration exceeds 5 Å. Generally, the adsorbed mass on GAC is proportional to the size of these molecules. However, large molecules are also easier to desorb from GAC than smaller ones. As the size of VOC molecule increases, the VOC molecules desorbed increases. Thus, the rate of adsorbed VOC mass increases first with the size of VOC molecules and then starts to slow down when the radius of gyration exceeds 5 Å.

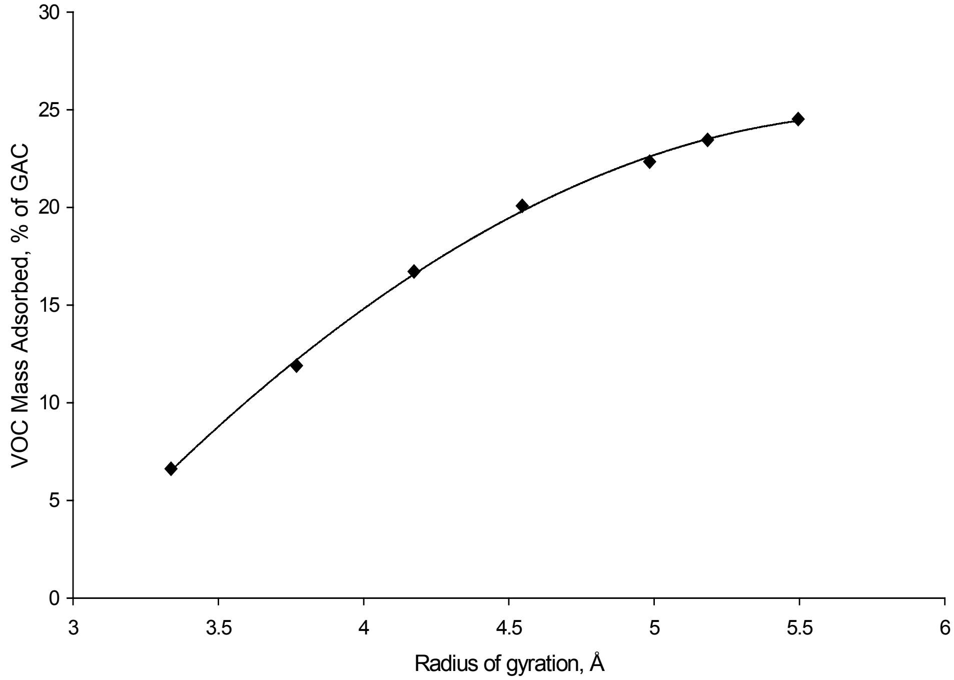


**Figure 12.** Adsorbed mass and molecular size for the alkanes at 50% breakthrough

# 4. CONCLUSION

A method was developed to determine the effectiveness of GAC in removing indoor VOCs. Test were conducted on a commercial grade GAC to assess its effectiveness in removing seven n-alkanes. The results indicate that GAC may not be effective in adsorbing VOCs at concentrations in ppb ranges which are normally found indoors. Further studies are needed to search appropriate filter media materials for indoor applications.

# 5. ACKNOWLEDGEMENT

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# 6. REFERENCES

1. Jones, A.P. *Atmospheric Environment*, 1999, 33, 4535-4564.
2. ASHRAE, *ASHRAE Handbook on HVAC Applications*, Atlanta, GA, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.,1999, Chapter 44
3. Graham, J.; Bayati, M. *Proceedings of Indoor Air 90*, Toronto, Canada, 1990,.p133.
4. Graham, J.R. and Ramaratnam, M. Chemical Engrg. 1993, (Feb) 6.
5. Zhang, Z., Nong, G., Shaw, C.Y. NRC Final Report, Mar. 2000.

6. Zhang, J.S.; Nong, G.; Shaw, C.Y.; Zhu, J.P.; Mason, M.; Howard, B. and Brown, St. NRC Final Report 2.1, Sept. 1999.
7. Zhu, J.P.; Zhang, J.S.; Kanabus-Kaminska, M.; Lusztyk, E. and Shaw, C.Y. Internal Report, No. IRC-IR-753. 1997.
8. VanOsdell, Douglas W. and Sparks, Leslie E. ASHRAE Journal, Feb., 1995.
9. Nelson, G.; Harder, C. Am. Ind. Hyg. Assoc. J. 1976, Vol. 37(4), 205-216.
10. Jensen, B.; Wolkff, P. VOCBASE, version 2.1, Nat. Inst. Occup. Health, Denmark 1996.