

NRC Publications Archive Archives des publications du CNRC

Effects of air velocity and temperature on VOC emissions from architectural coatings

Won, D. Y.; Shaw, C. Y.

This publication could be one of several versions: author's original, accepted manuscript or the publisher's version. /
La version de cette publication peut être l'une des suivantes : la version prépublication de l'auteur, la version acceptée du manuscrit ou la version de l'éditeur.

Publisher's version / Version de l'éditeur:

Indoor Air 2005, the 10th International Conference on Indoor Air Quality and Climate [Proceedings], 2, pp. 1822-1827, 2005-09-01

NRC Publications Archive Record / Notice des Archives des publications du CNRC :

<https://nrc-publications.canada.ca/eng/view/object/?id=c1aab74a-8996-48cb-bc94-730dd5fc8d6d>

<https://publications-cnrc.canada.ca/fra/voir/objet/?id=c1aab74a-8996-48cb-bc94-730dd5fc8d6d>

Access and use of this website and the material on it are subject to the Terms and Conditions set forth at

<https://nrc-publications.canada.ca/eng/copyright>

READ THESE TERMS AND CONDITIONS CAREFULLY BEFORE USING THIS WEBSITE.

L'accès à ce site Web et l'utilisation de son contenu sont assujettis aux conditions présentées dans le site

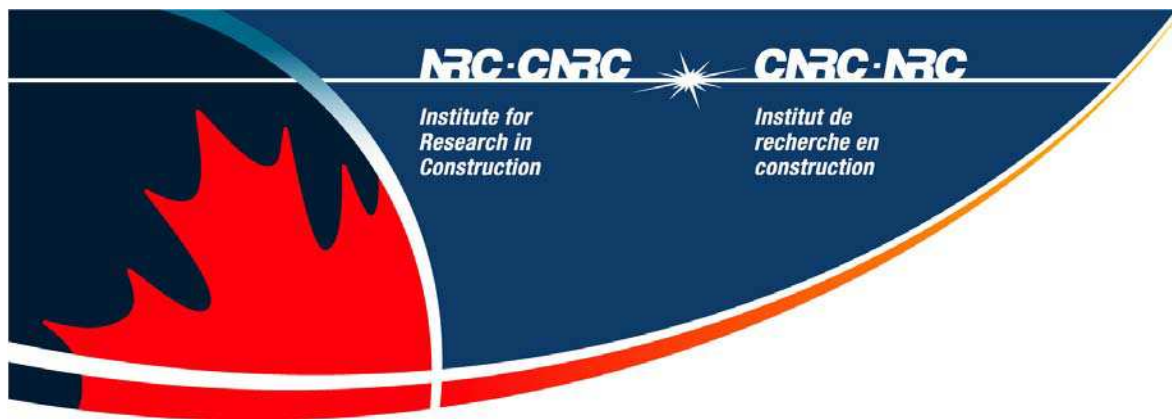
<https://publications-cnrc.canada.ca/fra/droits>

LISEZ CES CONDITIONS ATTENTIVEMENT AVANT D'UTILISER CE SITE WEB.

Questions? Contact the NRC Publications Archive team at

PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca. If you wish to email the authors directly, please see the first page of the publication for their contact information.

Vous avez des questions? Nous pouvons vous aider. Pour communiquer directement avec un auteur, consultez la première page de la revue dans laquelle son article a été publié afin de trouver ses coordonnées. Si vous n'arrivez pas à les repérer, communiquez avec nous à PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca.



<http://irc.nrc-cnrc.gc.ca>

National Research Council Canada

Effects of air velocity and temperature on VOC emissions from architectural coatings

NRCC-48140

Won, D.; Shaw, C.Y.

A version of this document is published in / Une version de ce document se trouve dans:

Indoor Air 2005, The 10th International Conference on Indoor Air Quality and Climate, Beijing, China, Sept. 4-9, 2005, pp. 1-6



National Research
Council Canada

Conseil national
de recherches Canada

Canada

EFFECTS OF AIR VELOCITY AND TEMPERATURE ON VOC EMISSIONS FROM ARCHITECTURAL COATINGS

D Won^{*}, and CY Shaw

Institute for Research in Construction, National Research Council Canada,
1200 Montreal Road, Ottawa, Ontario K1A 0R6, Canada

ABSTRACT

Volatile organic compound (VOC) emissions from building materials are typically tested under standardized conditions (i.e., at ~23 °C and 50% RH). While a standardized testing condition is desirable to produce comparable and compatible emission data, it is also necessary to understand the effects of various environmental conditions on material emissions. Experiments were designed to quantify the effects of environmental factors including air velocity and temperature on the VOC emissions from solvent-based paint. To report the effects in a quantitative format, the varied levels of environmental factors were correlated with coefficients of a mass-transfer model accounting for internal diffusion and surface evaporation. It was observed that diffusion coefficient is a function of air temperature, while evaporation coefficient is a function of air velocity.

INDEX TERMS

Volatile organic compounds, Diffusion, Evaporation, Indoor air quality, Environmental factors

INTRODUCTION

Environmental factors including surface air movements and temperature can influence VOC emissions from building materials. While there has been a large amount of research on the topic, there are limitations in several ways. The most frequently used approach is to compare concentrations or emission rates obtained from dynamic chamber tests for different environmental conditions. The approach can lead to different conclusions depending on which data are compared since they change over time partly due to depletion of sources. Additionally, the results in most previous research were reported in a qualitative format such that it is difficult to utilize them in indoor air quality simulation.

This suggests that a new systematic approach is necessary to quantify the effects of environmental factors on VOC emissions from building materials. This paper presents the results of quantifying the environmental effects on coefficients of a mass-transfer based emission model.

RESEARCH METHODS

Model Selection: A mass-transfer model, which is a theory-based model as opposed to an empirical model, was selected to predict chamber air concentration with a wet building material specimen. The model accounts for two mass-transfer mechanisms: diffusion inside the material specimen and evaporation at the surface of the specimen. The chamber air concentration can be expressed with diffusion (D) and evaporation (α) coefficient:

^{*} Corresponding author email: doyun.won@nrc-cnrc.gc.ca

$$\frac{C - C_o}{C^* - C_o} = 1 - \sum_{n=1}^{\infty} \frac{2\gamma \exp\left(-\beta_n^2 D t / l^2\right) \cos(\beta_n x / l)}{(\beta_n^2 + \gamma^2 + \gamma) \cos(\beta_n)} \quad (1)$$

where β s are positive roots of $\beta \tan \beta = \gamma$ and $\gamma = l\alpha/D$, C is the concentration of a chemical in the specimen (mg/m^3), C_o is the initial concentration of a chemical in the specimen (mg/m^3), C^* is the concentration that would be in equilibrium with the vapor pressure in the atmosphere remote from the surface (mg/m^3), D is the diffusion coefficient of a chemical in the specimen (m^2/s), α is the evaporation coefficient (m/h); and l is the specimen thickness (m), x is the distance upwards from the substrate, and t is the time.

Based on Equation 1, the total amount of a chemical left the chamber system at time t (M_t) can be expressed as Equation 2 for a large time t .

$$\ln\left(1 - \frac{M_t}{M_\infty}\right) = \ln\left[\frac{2\gamma^2}{\beta_1^2(\beta_1^2 + \gamma^2 + \gamma)}\right] - \frac{\beta_1^2 D}{l^2} t \quad (2)$$

where β_1 is the smallest positive root among β s, M_∞ is M_t for an infinite t , which is the product of A , l and C_o ; and A is the area of the specimen (m^2).

Plotting the logarithmic term on the left hand side of Equation 2 versus time can lead to the diffusion coefficient. The evaporation coefficient can be obtained using the first data set after the specimen is introduced into the chamber. More detailed information on the model and the methodology to calculate model coefficients can be found in Won and Shaw (2003).

Experimental Set-up: Emission tests were conducted with a solvent-based paint sample contained in a Petri dish in a 400 L chamber with an air change rate of 0.5 per hour and a RH level of 50%. The paint was purchased in a local retail store and was spiked with six aliphatic hydrocarbons (heptane, octane, nonane, decane, undecane, and dodecane) and one aromatic compound (toluene) to have more diverse compounds. The density of the paint mixture was estimated to be 1.266 g/L after the addition of chemicals. One test lasted 72 hours during which the exhaust from the chamber was regularly collected on sorbent tubes, which were thermally desorbed and analyzed with GC/MS. The varied environmental conditions include air velocity (v) and air temperature (T). More detailed information on the chamber test can be found in Won and Shaw (2003) and Won et al. (2004)

RESULTS

Effects of Air Velocity: The air velocity over a paint sample was varied by changing the voltage delivered to the DC motor that controls the axial fan in the chamber (Won et al., 2004). The varied DC motor voltages are 5, 10, 15, 20, and 25 volts. The air velocity was measured with a flow analyzer equipped with a hot-wire probe. Figure 1 summarizes the vertical air velocity profiles from the surface ($h/H = 0$) of a specimen to the middle ($h/H = 0.5$) of the chamber. The velocity levels inside the Petri dish were below or close to 0.05 m/s, which is the minimum velocity the system can measure. To minimize the uncertainties in the velocity levels, the velocity levels at $h/H = 0.5$ were used as the representative for further data analyses.

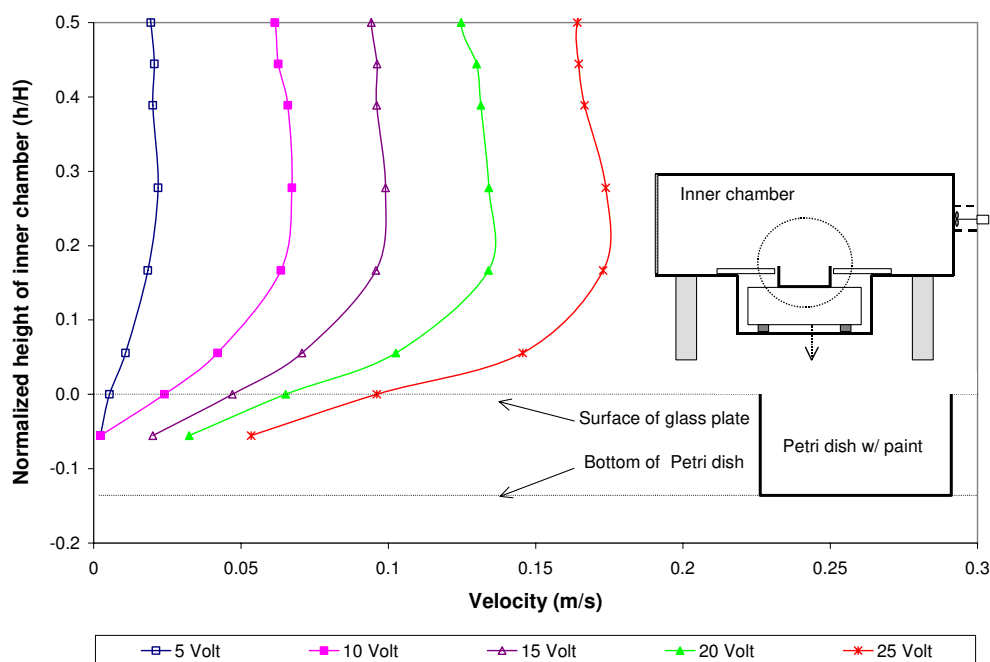


Figure 1. Vertical air velocity profile in the inner chamber

Figure 2 presents example concentration profiles of 1,4-dimethylbenzene as a function of air velocity at the mid-height of the inner chamber. Similar profiles were also obtained for other chemicals. In general, it appears that there is a positive relationship between air velocity and VOC emissions. The concentration data were used to determine D and α .

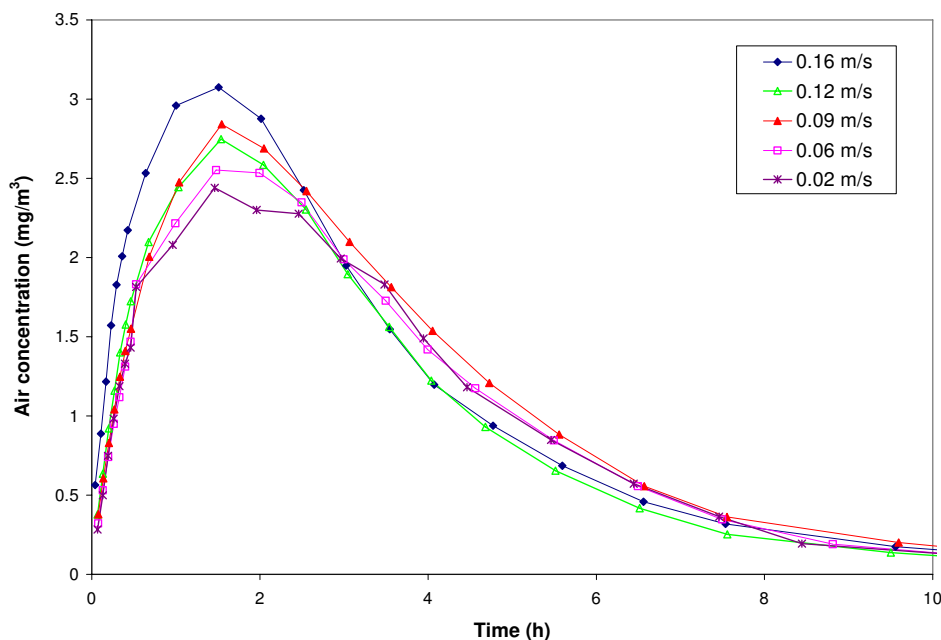


Figure 2. Example concentration profiles as a function of air velocity at $h/H=0.5$

Figures 3 and 4 present α and D as a function of air velocity (v) at the mid-height of the chamber for alkanes. It can be seen that D is not a strong function of v . The increase of α is negligible from 0.02 to 0.09 m/s of air velocity and starts to become significant after 0.09 m/s. While it is not shown in this paper, a similar effect was shown for alkyl benzenes including

toluene, ethyl benzene, 1,2-dimethylbenzene, 1,2,4-trimethylbenzene, and 1,2,4,5-tetramethylbenzene.

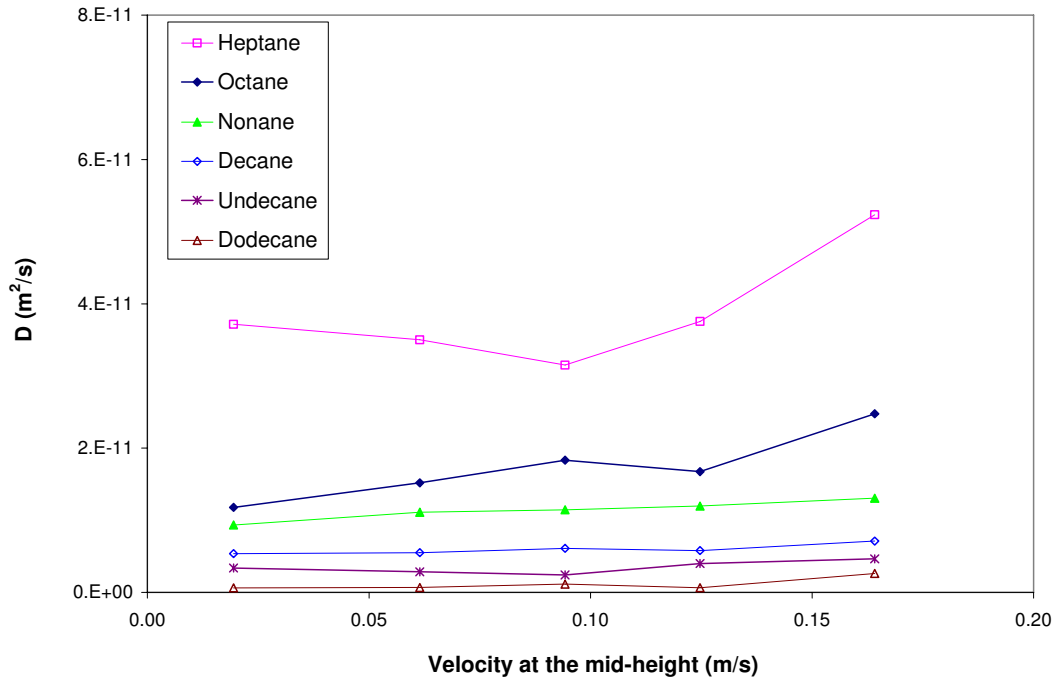


Figure 3. D as a function of v at the mid-height for alkanes

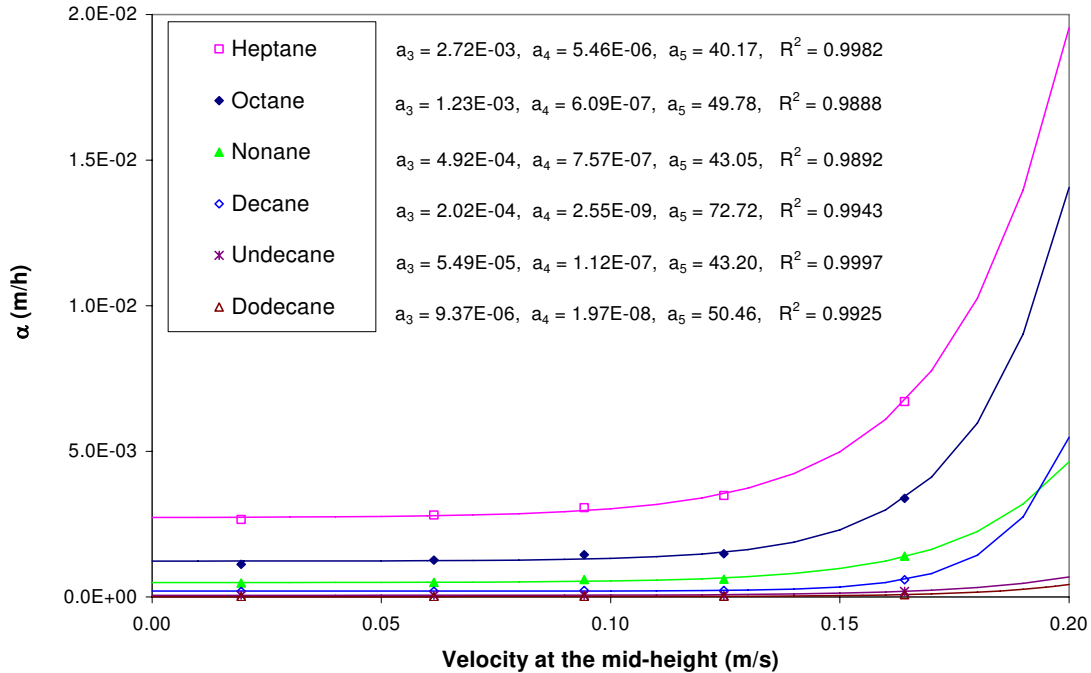


Figure 4. D as a function of v at the mid-height for alkanes

To quantify the effects of air velocity on emissions, a correlation equation was obtained between v and α . In literature, it was shown that there is a power-law relationship (Sparks et al., 1986) or a linear relationship (Topp et al., 2001; Won et al., 2004) between air velocity

and evaporation (mass-transfer) coefficient. Neither the power-law model nor the linear model explained the relationship between α and v for the experiments in this research. Equation 3 was suggested for the correlation between v and α .

$$\alpha = a_1 + a_2 \text{EXP}(a_3 v) \quad (3)$$

where α is evaporation coefficient (m/h), v is air velocity at the mid-height of the inner chamber (m/s), and a_1 , a_2 and a_3 are correlation constants, which are reported in Figure 4 for alkanes.

Effects of Air Temperature: Emission tests were conducted with four levels of air temperature (19, 24, 28, and 34 °C). The resulting α and D are shown in Figures 4 and 5 for alkanes. It appears that only D is a strong function T . A similar observation was made for alkyl benzenes.

The dependence of diffusion coefficient in air (D_a) was reported to be proportional to air temperature raised to the power of 1.5 and 2 (Lyman et al. 1982). In other cases, an Arrhenius-type equation, in which the natural logarithm of the diffusion coefficient is proportional to $-1/T$, was used to express the dependence of D on T (Yang et al., 2001). In this research, it was shown that a power-law equation is more suitable for more volatile compounds such as heptane, octane and nonane, while a linear equation is better for less volatile compounds such as decane and undecane. In overall, a linear model (Equation 4) provided slightly better R^2 values.

$$D = b_1 + b_2 T \quad (4)$$

where D is diffusion coefficient (m^2/s), T is temperature ($^{\circ}\text{C}$), and b_1 and b_2 are correlation constants, which are reported in Figure 6 for alkanes.

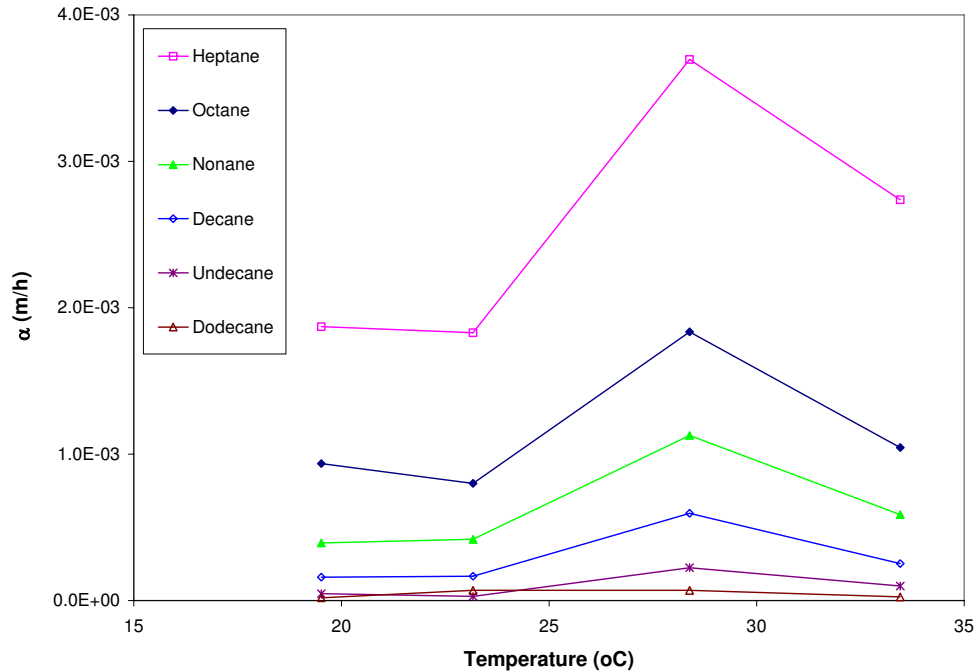


Figure 5. α as a function of temperature (T) for alkanes

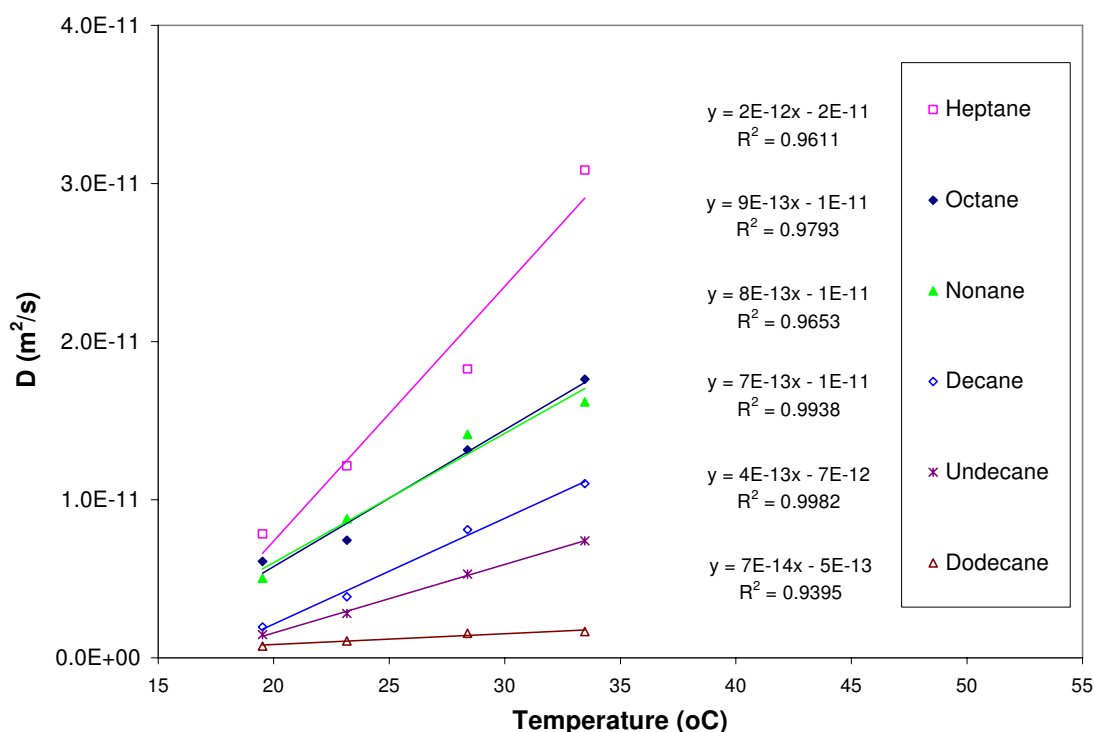


Figure 6. D as a function of temperature (T) for alkyl benzenes

CONCLUSION AND IMPLICATIONS

It was shown that emissions of alkanes from a solvent-based paint were affected by air velocity (v) and temperature (T). The environmental effects were quantified through a correlation equation obtained for α as a function of v and that for D as a function of T for each chemical. The correlation equation can be used in predicting air concentrations of VOCs from architectural coating indoors for various levels of air velocity and temperature.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. Wenping Yang for the help with the GC/MS operation and Mr. Gang Nong for the assistance with the operation of the 400 L chamber.

REFERENCES

- Lyman WJ, Reehl WF, and Rosenblatt DH. 1982. *Handbook of chemical property estimation methods: Environmental behavior of organic compounds*, McGraw-Hill Book Company.
- Sparks LE, Tichenor BA, Chang J and Guo Z. 1996. "Gas-phase mass-transfer model for predicting volatile organic compound (VOC) emission rates from indoor pollutant sources," *Indoor Air*. 6: 31-40.
- Topp C, Nielsen PV, and Heiselberg P. 2001. "Influence of local airflow on the pollutant emission from indoor building surfaces," *Indoor Air*. 11: 162-170.
- Won D. and Shaw CY. 2003. "Determining coefficients for mass-transfer models for volatile organic compound emissions from architectural coatings," *Proceedings of the 7th International Conference of Healthy Buildings*, Singapore, Vol 1, pp 198-203.
- Won D, Nong G, and Shaw CY. 2004. "Quantification of effects of air velocity on VOC emissions from building materials," *Proceedings of CIB World Building Congress 2004*, Toronto, Vol 1, pp 253-258.
- Yang X, Chen Q, Zeng J, Zhang JS, Shaw CY. 2001. "A mass transfer model for simulating volatile organic compound emissions from 'wet' coating materials applied to absorptive substrates," *International Journal of Heat and Mass Transfer*, 44, 1803-1815.