International Journal of Advanced Research in Chemical Science (IJARCS)
Volume 1, Issue 3, May 2014, PP 38-43
ISSN 2349-039X (Print) & ISSN 2349-0403 (Online)
www.arcjournals.org

Volatile Organic Compounds Removal by Adsorption on Activated Carbon Filters

C. J.Nwali

School of Chemical Engineering and Advance Materials,
Newcastle University, NE1 7RU, United Kingdom
c.j.nwali@newcastle.ac.uk
engrnwalic@yahoo.com

Abstract: *In this study, BAX950 activated carbon;a wood-based activated carbon with particle size fraction 1-2 mmwas developed to investigate adsorption dynamics and isotherms of target volatile organic compounds. The adsorption of various volatile organic compound were analysed by intelligent gravimetric analyserto understand their barrier to diffusion on the activated carbon, which may affect the performance of the carbon filters in real situations.. These toxic organic compoundswas effectively removed by BAX950 activated carbon filters as both hydrophilic functionalities and hydrophobic graphene layers are present in the material acting as primary adsorption sites for hydroxyl groups and hydrocarbons respectively.The activation energies correspond to changes in surface coverage, which showed highest values at low relative pressure where molecular sieving occurs.*

Keywords: *Volatile organic compounds, Activated Carbon, Adsorption, Isotherm*

1. INTRODUCTION

The emissions of environmentally unfriendly volatile organic compoundsfrom industrial processes and combustion systems are ofmajor concern. [1]These compounds have been identified in urban areasusing gas chromatography to include alkanes, alkenes, alkynes, alkadienes and arenes. [1, 2]The environmental impacts of these toxic compounds are well established, in particular, the impacts on forests, aquatic life and corroded buildings.[1, 2]

Volatile organic compounds have several major sources, but are present in the atmosphere as a result of both biogenic and anthropogenic activities. The major sources of these compounds includes motor vehicle exhausts, petrol distribution and storage, evaporation of petrol vapours during vehicle refuelling, solvent use, chemical industry, oil refining and combustion sources as well as the minor sources of; land-filling, food and drink manufacture, agriculture, metal industry and straw and stubble burning. The compoundsare all organic compounds of anthropogenic nature, other than methane present in the atmosphere as gases or vapours but would be liquid or solid under standard conditions of pressure and temperature. The compounds are relatively unreactive, diffuse through the atmosphere and form a more uniform distribution globally irrespective of their source distribution making their removal difficult. The removal difficulty are due their low concentrations and the only method for their removal at such low levels of concentration is adsorption on a porous material such as activated carbon, for subsequent desorption and destruction via incineration methods. [3]

Abatement of volatile organic compoundsare focused to remove the species, which there levels of concentration are in pass per million (ppm). The possible methods of control of these emissions are dependent on the concentration of vapour in the gas phase. In the process industries, the recovery of volatile organic compoundsfrom gas streams are achieved from a number of processes, for example, adsorption, condensation, membranes and absorption. The choice of process for volatile organic compoundsrecovery in situation of very low concentrations in the gas phase pose a problem; therefore use of activated carbon adsorbents is required to concentrate thevolatile organic compoundswith active carbons being the preferred adsorbent. [4, 5]Filters have long been used for the removal of environmentally unfriendly species from effluent gas streams. Many filters are composed of carbon, usually activated carbon, which are highly micro porous making them such good adsorbents. Pollutants are concentrated by adsorption on the carbon until the filter bed is saturated followed by thermal desorption through a catalytic combustion system to convert the volatile organic compounds to carbon dioxide and water. The thermal desorption must be carried out in a controlled manner in order to operate efficiently and not overload the catalytic combustion system. The economics of the process are governed by the capacity of the filter bed under operational conditions and the ability to regenerate the carbon for further use on a repetitive basis. Toxic organic materials are effectively removed by such carbon filters as both hydrophilic functionalities and hydrophobic graphene layers are present in activated carbon acting as primary adsorption sites for hydroxyl groups and hydrocarbons respectively. The adsorption isotherm and kineticsof the carbon filters are critically important in the assessment of active carbon bed performance for adsorption of effluent species.The method of abatement of emissions of volatile organic compoundspresent in air at low concentrations is the adsorption of the organic species on active carbons to concentrate the species followed by desorption into catalytic combustion systems to convert the adsorbed organic materials to combustion products (CO_2 and H_2O).[4,5]

Activated carbon, a widely used adsorbent in industrial processes, composed of a microporous, homogenous structure with high surface area may be applied. BAX950 activated carbon, produced from a renewable, low-cost indigenous a wood-based product has gained attention worldwide because of its low cost and highly abundant characteristics.

This article presents new andprocess of removal of volatile organic compounds through adsorption of several organic vapours independently on BAX950 activated carbon.

2. EXPERIMENTAL

2.1 Materials and Adsorptive Used

BAX950, a wood-based activated carbon with a particle size fraction of 1-2mm were obtained from Westvaco Corporation, Virginia USA.

The adsorbates used were methanol of 99.8% purity, ethanol (99.5%), propan-1-ol (99.7%) and butan-1-ol (99.8%), n-octane (99%) and n-nonane (99%) supplied by B.O.C., Surrey.

3. STATIC VAPOURADSORPTION MEASUREMENTS

The apparatus used for this studywas an Intelligent Gravimetric Analyser (IGA) model 003, which is designed for use with gas and vapour systems, both static and flowing, supplied by Hiden Analytical Ltd. This apparatus allows isotherms and the corresponding kinetics of adsorption and desorption, for set pressure steps, to be determined. [6]

The balance and pressure control system were fully thermostatted to 0.1 K to eliminate changes due to the external environment. The microbalance had a long term stability of ±1μg with a weighing resolution of 0.2μg. The sample (100 mg) was outgassed until it reached a constant weight, at a pressure of < 10-6 Pa at 473 K.

The liquid used to generate the vapour was degassed fully by repeated evacuation and vapour equilibration cycles of the liquid supply side of the vapour reservoir. The vapour pressure was gradually increased, over a time-scale of ~30 s to prevent disruption of the microbalance, until the desired value was achieved. Pressure control was via the use of two pressure transducers with ranges 0 to 0.2 and 0-10 kPa, each with an accuracy of 0.02% of the specified range. The pressure was maintained at the set point by active computer control of the inlet/outlet valves throughout the duration of the experiment.

Pressure steps in the range of p/po values 0 to 0.973 were used to obtain the isotherm. The mass uptake was measured as a function of time and the approach to equilibrium monitored in real time with a computer algorithm. After equilibrium was established, the vapour pressure was increased to the next set pressure value and the subsequent uptake was measured until equilibrium was re-established.

The increase in weight versus time profile, due to adsorbate uptake for each pressure step, was used to calculate the kinetic parameters for adsorption. The errors in the calculated rate constants were typically better than 2% of the value.

The sample temperature, maintained by a thermostirrer and sample chamber jacket, was constantly monitored throughout the duration of the experiment and the variation in temperature was minimal (< 0.1 K). In the case of desorption the reverse procedure was carried out.

The saturated vapour pressures were calculated using the Antoine equation:[7]

$$\log_{10} p = A - \frac{B}{T + C}$$

Where A, B and C are constants, p is the pressure in Torr (mm of mercury and T is the temperature in degrees Celsius. The constants for the adsorbates used, as well as the temperature ranges over which they are valid, are given in Table 1. Values calculated using this method is known to have good correlation with experimental results. [7]

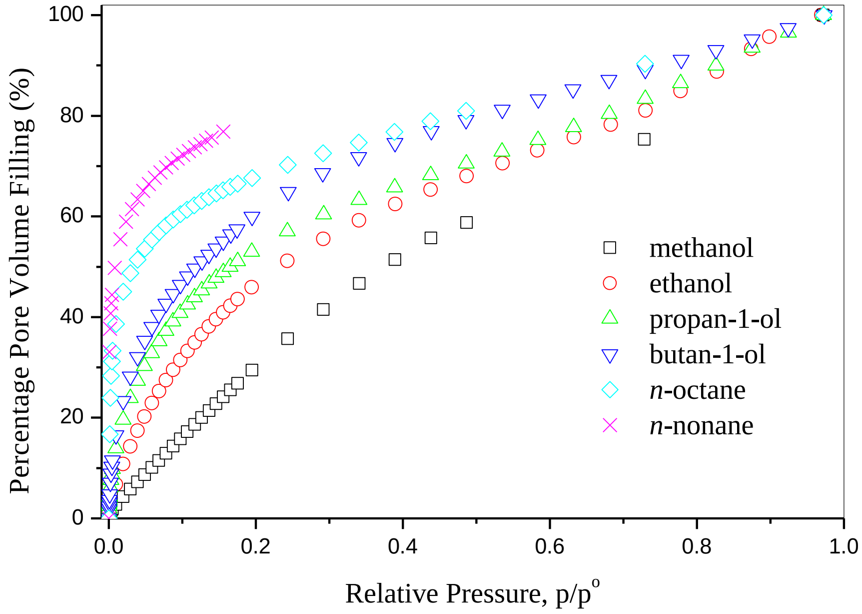
Table 1. *Vapour Pressure Constants for Adsorbatesused[7]*

Adsorbate	RMM gmol^{-1}	Temperature Range K	A	B	C
Water	18	263 - 383	8.09553	1747.32	235.07
Methanol	32	223 - 338	7.89750	1474.08	229.13
Ethanol	46	224 - 329	6.95206	1084.53	231.39
Propan-1-ol	60	275 - 393	7.84767	1499.21	204.64
Butan-1-ol	74	288 - 404	7.47680	1362.39	178.77
n-Octane	114	292 - 425	6.91868	1351.99	209.15
n-Nonane	128	312 - 452	6.93893	1431.82	202.01

4. RESULTS AND DISCUSSION

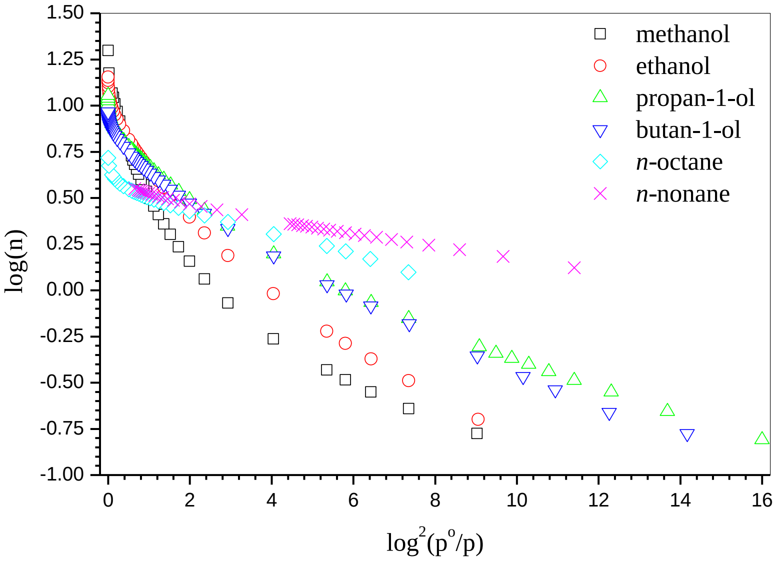
The isotherms showed a progressive change from Type I to Type III character, in the IUPAC classification scheme (figure 1). Isosteric enthalpies of adsorption, calculated using the van't Hoff isochore, showed a decrease with increasing surface coverage and good correlation with literature values for methanol, ethanol, butan-1-ol, n-octane and n-nonane.

Figure 1: Isotherms for methanol, ethanol, propan-1-ol, butan-1-ol, *n*-octane and *n*-nonane adsorption on BAX950



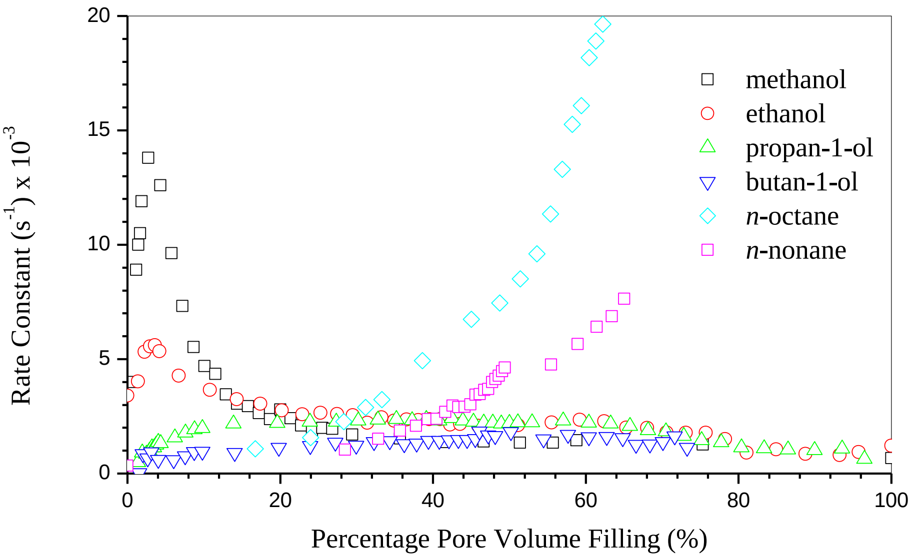
The D-R analysis (figure 2) showed a curve in the plot at the same relative pressure describingmaximum rates observed in the alcohol series. It is reasonable to conclude a barrier exists, which causes the rate to decrease and the associated curvature in the D-R plot.

Figure 2: Dubinin-Radushkevich plots for the adsorption of methanol, ethanol, propan-1-ol, butan-1-ol, *n*-octane and *n*-nonane on BAX950



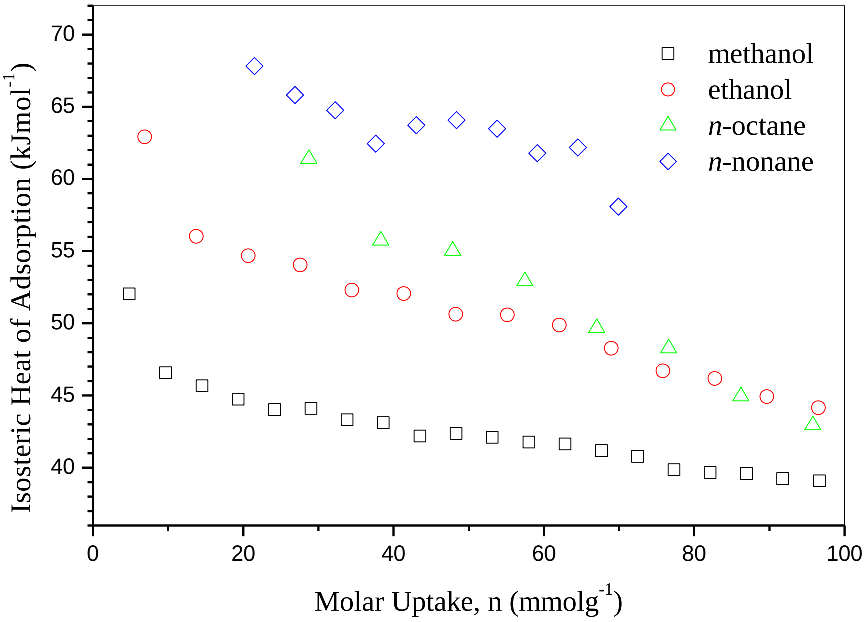
The rate constants with liquid volume (figure 3) showeda change in rate constant with respect to the hydrophilicity/ hydrophobicity of the adsorbate.

Figure 3: Variation in rate constant for adsorption of methanol, ethanol, propan-1-ol, butan-1-ol, *n*-octane and *n*-nonane on BAX950



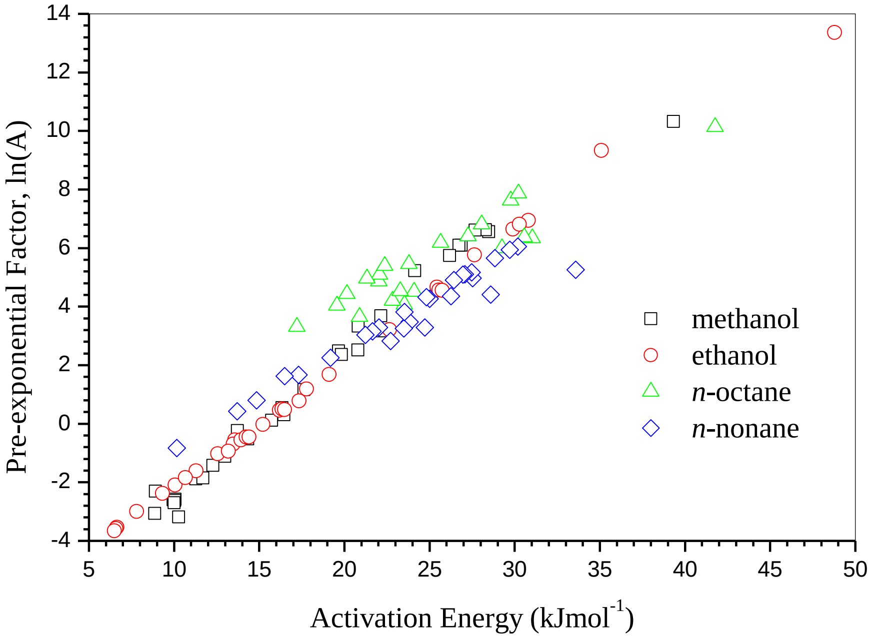
Activation energies were calculated to investigate the diffusional barriers to adsorption, and imply that as the isotherms were carried out in relative pressure terms the activation energies correspond to changes in surface coverage (figure 4). The values obtained are in the range 6 – 49 kJmol^{-1}, and show highest values at low relative pressure where molecular sieving occurs. Peaks are observed for water, due to agglomeration and clustering of adorbed molecules, at ~8% pore volume filling, as well as both aliphatics (~58% for *n*-octane and ~62% for *n*-nonane), where a barrier causes a maximum in the activation energy at the relative pressure corresponding to a deviation in the D-R plot

Figure 4: Isosteric enthalpies of adsorption for methanol, ethanol, *n*-octane and *n*-nonane adsorption on BAX950



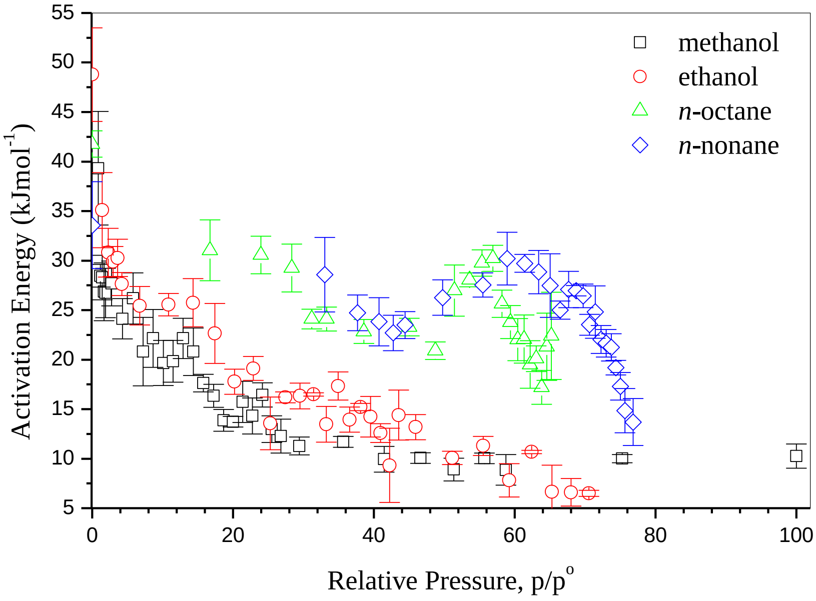
There is good correlation between ln (A) and the activation energy, E_A, as shown in figure 5; indicative of a compensation effect.

Figure 5: Activation energy against pre-exponential term for methanol, ethanol, *n*-octane and *n*-nonane adsorption on BAX950



Therefore, from the results obtained,BAX950 activated carbon for the removal of volatile organic compounds at the ppm level as the final stage of effluent stream clean-up have shown to be an economic technology.

Figure 6: Activation energies for the adsorption of methanol, ethanol, *n*-octane and *n*-nonane on BAX950



5. CONCLUSIONS

The reduction of volatile organic compounds at low concentrations in air is a generic problem with a wide range of applications. The low concentration of these volatile organic compounds has motivated the use of adsorbents to concentrate them before either recovery or destruction through a catalytic combustion system. Adsorption onto BAX950 activated carbon adsorbents appears to be the major area for development in recovery technology; for a complete understanding of the removal processes from the environment.The adsorption dynamics and isotherms of target volatile organic compounds on BAX950 activated carbon wasstudied to understand thebarrier to diffusion on the activated carbon, which may affect the performance of the carbon filters in real situations.

ACKNOWLEDGEMENTS

The authors would like to thank Petroleum Development Trust Fund (PTDF), Nigeria for providing financial support. Also acknowledged Wolfson Northern Carbon Reduction Laboratories Newcastle University, UK.

REFERENCES

[1] Loughlin, K.F.; Hassan, M.M.; Fatehi, A.I.; Zahur, M. Gas Sep. Purif.1993, 7, 264.

[2] Benham, M.J.; Ross, D.K. Z. Phys. Chem.1989, 163, 25.

[3] Harding, A.W.; Foley, N.J.; Norman, P.R.; Francis, D.C.; Thomas, K.M. Langmuir 1998, 14, 3858.

[4] Fletcher, A.J.; Thomas, K.M. Langmuir1999, 15, 6908.

[5] Agrawal, R.K. J. Therm. Anal.1986, 31, 73

[6] Benham, M.J.; Ross, D.K. Z. Phys. Chem. NeueFolge1989, 163, 25.

[7] Lange's Handbook of Chemistry; 15th ed.; McGraw-Hill: New York, 1999.