THERMAL WAVES INDUCED BY VOLATILE ORGANIC COMPOUND (VOC) ADSORPTION ONTO ACTIVATED CARBON FILTER

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Introduction

Adsorption of organic vapors onto granular activated carbon (GAC) is an exothermic phenomenon capable of liberating enough heat to raise the temperature of the system [1]. If the vapor contains high concentrations of organic compounds or if the adsorbed molecules undergo oxidation reaction, the adsorption efficiency of the carbon bed can be reduced and combustion can occasionally occurs [2]. An experimental design was carried out to study the influence of several factors (water content of the GAC, RH of the air, gas concentration) on the warming of the bed). The nature of the solvent and type of carbon employed were also investigated. Adsorption energies are also determined so as to foresee these thermal effects.

Experimental

Four commercial GAC were used : PICA NC 60, CECA AC 40, CHEMVIRON WS 4A and NORIT RB2.

The experimental setup consists of a humidity and volatile organic compound (VOC) vapor generation and an insulated GAC column. The VOC vapor generation was achieved by dividing a dry air flow in two parts. One is connected to a VOC tank held at a constant temperature and the other dilutes the VOC saturated air. VOC concentration (C_0) is adjusted by varying the relative flow rates of the two streams. The desired RH of the air is obtained in the same way. The temperature and gas concentration were measured along the central axis of the column.

Adsorption energies were obtained at 20°C using a thermobalance coupled to a calorimeter (model TG DSC 111). Differential scanning calorimetry is an effective technique for determining interaction energies [3].

Results and Discussion

The experimental design emphasizes that the VOC concentration (C_0) is the most influencial factor on the temperature rise (ΔT) in a GAC bed. The adsorption rate is controlled by intraparticule mass transport which is higher when C_0 increases. As adsorption kinetics accelerate, the energy flux released in the system increases and so ΔT is greater. The GAC bed becomes very hot with a methylethylketone (MEK) concentration of 100 $g.m^{-3}$ (Figure 1). Higher level of MEK (150 $g.m^{-3}$) creates a bed ignition. This combustion may be initiated by the high carbon oxidative activity with MEK [2]. The thermal waves precede the adsorption front so the adsorption does not take place at the initial bed temperature. As adsorption equilibrium and diffusion coefficient are temperature dependent, an excessive warming creates a slight decrease of the adsorption capacity at the breakthrough time (Figure 2).

Thermal effects due to VOC adsorption are also strongly dependent on the initial water content of the GAC as shown in Figure 3. Acetone adsorption on dry GAC produces high temperature rise (ΔT) but with a wet GAC there is moderate ΔT. In the latest case, a heat balance of the adsorber proved that the released adsorption heat of acetone is balanced by the desorption heat of the water being displaced.

High relative humidity of the air (RH=95%) is not detrimental to the performance of the GAC bed in the presence of high C_0 and the overheating of a dry GAC bed is not affected (Figure 3).

Adsorption energies (E_{ads}) of the fifteen VOC studied prove to be between 44.6 $kJ.mol^{-1}$ and 81.9 $kJ.mol^{-1}$ (Figure 4).

The temperature rise could then be correlated with this adsorption heat and the VOC concentration (Figure 5). This relation is established for fifteen VOC and four GAC within the concentration range 20-100 $g.m^{-3}$ and the superficial gas velocity range 0.14-0.56 $m.s^{-1}$.

Conclusion

The warming of a GAC adsorber can be well predicted from the knowledge of the carbon-solvent interaction and the VOC concentration when no oxidizing reaction occurs. Attention should be paid to the operating conditions of an activated carbon system for adsorbing organic vapors because of the highly exothermic reactions that may create a fire hazard.

References

[1] Le Cloirec P., Delage F. Temperature variation in VOC adsorption in activated carbon filters. Extended

abstracts, 2nd Asia Pacific Conference on Sustainable energy and environmental technology. Milton (Australia). June 1998.
[2] Akubuiro E.C. Potential mechanistic routes for the oxidative disintegration of ketones on carbon adsorbents. Ind. Eng. Chem. Res., 1993; 32(12) : 2960-2968.
[3] Baudu M., Le Cloirec P., Martin G. First approach of desorption energies of water and organic molecules onto activated carbon by differential scanning calorimetry studies. Wat. Res., 1993; 27(1) : 69-76.

Acknowledgements

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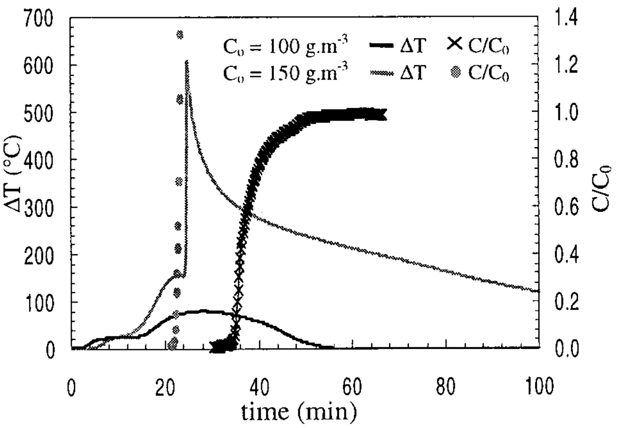

Figure 1. Effect of the MEK concentration on combustion hazard of the GAC bed (U_0=0.14 m.s^{-1} - axial position = 24 cm)

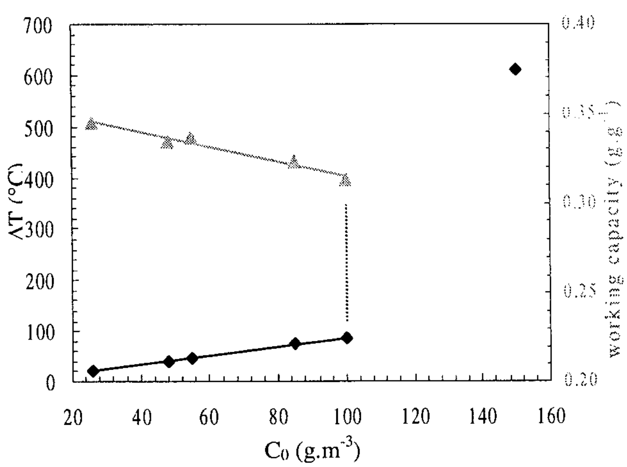

Figure 2. Temperature rise and working adsorption capacity of a dry carbon bed (Pica NC 60) for different inlet MEK concentrations (U_0=0.14 m.s^{-1}).

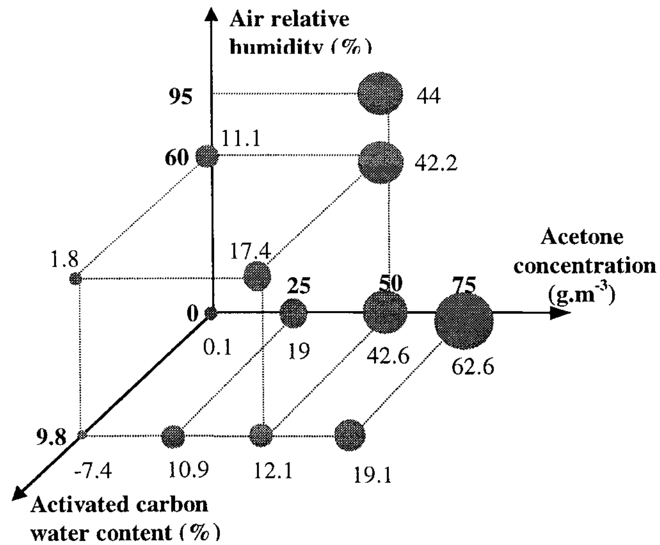

Figure 3. ΔT values (°C) on Pica NC 60 for several operating conditions (U_0=0.14 m.s^{-1})

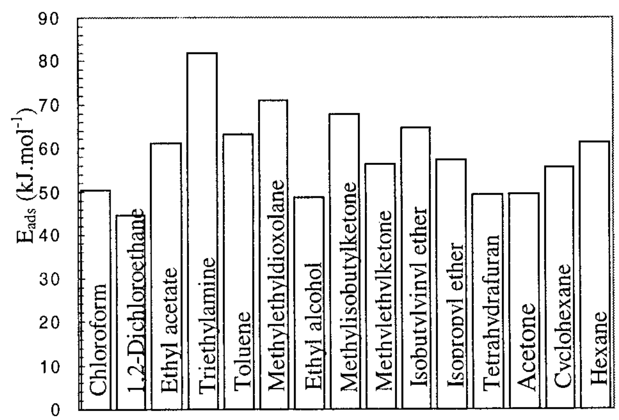

Figure 4. Adsorption energies at 20°C on Pica NC60 for various VOC.

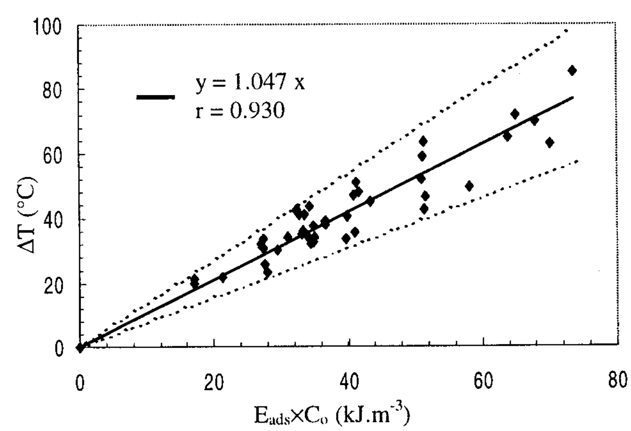

Figure 5. Prediction of the temperature rise inside the GAC bed from the adsorption energy and the VOC concentration.