EXPERIMENTAL STUDY OF VOCS ADSORPTION ONTO FIXED BED ACTIVATED CARBON

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Abstract
The paper presents a study of benzene and toluene vapours adsorption onto fixed bed activated carbon using the gaseous stream method. An experimental investigation of influence of process variables, namely species molecular mass, gas superficial velocity and operation temperature, on adsorption dynamics, was performed.

Key words: activated carbon; adsorption; aromatic hydrocarbons

INTRODUCTION

Volatile organic compounds (VOCs) are among the most common pollutants emitted by the chemical and electronic material industries. They are present in gas or liquid streams and are very harmful for both human health and environment, even at very low concentration (Lillo-Ródenas, 2005; Mohan et al. 2009). There are various methods to treat VOCs gaseous streams, e.g. absorption, adsorption, condensation, thermal oxidation, catalytic oxidation, photocatalytic oxidation (Mo et al. 2009; Benkhedda et al. 2000; Chiang et al. 1999; Chiang et al. 2001; Chiang et al. 2002; Dimotukis et al. 1995; Dolidovich et al. 1999; Huang et al. 2002, Kawasaky et al. 2004).

The separation technique based on adsorption is a promising method because it is non-denaturing, highly selective, energy efficient and relatively inexpensive. Adsorbents are natural or synthetic materials of amorphous or microcrystalline structure, which are available as granules, extruded pellets, fibers etc. Activated carbons (AC) remain the most used adsorbents, mainly due to their superior physical and chemical properties, such as highly developed porous structure, large specific surface area, good mechanical properties, biocompatibility and chemical stability, as well as their low cost and great accessibility. They are produced from a wide variety of carbonaceous precursors such as lignite, coal, wood and also various agricultural and forest by-products (Baquero et al. 2003; Girgis et al. 2002; El-Hendawy 2003; Philip and Girgis, 1996; Aggarwal and Dollimore, 1997; Ahmadpour and Do, 1997; El-Hendawy, 2005; Guo and Lua, 1999; Müler-Hagedorn et al. 2003; Qasem at al. 2004, Aygun et al. 2003; Legrouri et al. 2005).

Activated carbon is an efficient adsorbent employed to retain a wide variety of contaminants from gaseous mixtures. Important applications are the air purifying in homes and buildings, shallow fixed beds of activated carbon being used in ventilation systems, air conditioning devices, air-purifying respirators, cooker or industrial hoods (Mo et al. 2009; Dimotukis et al. 1995; Kawasaky, 2004). Fixed beds of activated carbon are also used to remove VOCs from air flows. Process variables influencing fixed bed adsorption dynamics are nature, porosity and specific surface area of adsorbent, bed length, adsorbate molecular mass, concentration and flow rate of feed stream, operation temperature etc (Lillo-Ródens et al. 2005; Moham et al. 2009; Chiang al. 2001; Kawasaky et al. 2004). It is well known that aromatic hydrocarbons, especially benzene, toluene and xylene, can produce allergies and Goodpasture's syndrome (Kawasaky et al. 2004). The adsorption behavior of benzene and toluene onto a large variety of activated carbon (granular, pellets, fibers) was reported in the related literature (Lillo-Ródens et al. 2005; Mohan et al. 2009; Kawasaky et al. 2004). These studies proved adsorption capacities of 0.13-0.34 g benzene/g AC and 0.12-0.64 g toluene/g AC.

The aim of this paper is to present an experimental study of benzene and toluene adsorption onto fixed bed activated carbon using the gaseous stream method. The influence of process variables, namely species molecular mass, gas superficial velocity and operation temperature, on adsorption dynamics was studied.

MATERIAL AND METHODS

Chemicals and reagents

Cylindrical extruded pellets of granular activated carbon, ENVIROCARB^{TM} AP4-60, supplied by Chemviron Carbon Company, were produced by high temperature steam activation of coal.

The characteristics of the solid phase used for aromatic hydrocarbons removal study are listed in Table 1.

Experimental set-up

The laboratory set-up employed for experimental investigation of gas adsorption is shown in figure 1. A sample of 28.0 g of granular activated carbon (1) was packed into a glass column (2) with an internal diameter d=1.5 cm and a height H=29 cm, set into a plastic support (3) and fitted with an insulating layer (4). Activated carbon fixed bed was heated by a spiral wound electric resistance (5) which was fed by a direct current source (6). Bed temperature was measured by a digital thermometer consisting of a prove (7) and a display (8). Atmospheric air, whose flow was adjusted by a valve (10) and measured by a flow-meter (11), was introduced by means of a compressor (9) into a bubble flask (12), wherein it was bubbled into a liquid aromatic hydrocarbon (benzene or toluene). The bubble flask was put on a heating plate (13) to heat the liquid phase. The mixture of air and hydrocarbon vapour was fed into the bottom of adsorption column, up-flowed through the adsorbent fixed bed and exited on the column top. Gaseous mixture temperature entering in the column was measured by a digital assembly (14) and (15).

Tabel 1

Solid phase characteristics

No	Property		
	Name	Value	Unit
PELLET			
1	Diameter	0.43	cm
2	Average length	0.83	cm
3	Volume equivalent diameter, d_P	0.60	cm
4	Density, ρ_P	1	g/cm^3
5	Porosity, ε_P	0.63	-
6	Specific surface area, σ	10^7	cm^2/g
FIXED BED			
1	Mass, m_b	28	g
2	Volume, V_b	51.22	cm^3
3	Density, ρ_b	0.55	g/cm^3
4	Porosity, ε_b	0.45	-

Aromatic hydrocarbon vapour was adsorbed onto the activated carbon until the fixed bed was saturated. The amount of adsorbed hydrocarbon was determined based on the increase of glass column weight, which was measured on-line by an electronic balance (16) and was indicated on the display of a computer (17). It was considered that the saturation state was achieved when the mass did not vary in time for half an hour.

Experimental investigation was performed using two values of air superficial (fictive) velocity (1 cm/s and 1.5 cm/s) and two values of operation temperature (20^0C and 30^0C). All experiments were carried out at atmospheric pressure.

RESULTS AND DISCUSSION

Characteristic saturation curves of adsorbent fixed bed

Benzene and toluene concentrations in adsorbent fixed bed, expressed as adsorbed hydrocarbon masses divided by activated carbon mass, versus time, at various values of air superficial velocity and operation temperature, are illustrated in Fig. 2. Concentration in solid phase increases almost linearly in time until a saturation (equilibrium) value is attained. Larger values of concentration are obtained at high value of air superficial velocity. In case of benzene adsorption, the slope of concentration curve does not depend on operation temperature for an air superficial velocity of 1 cm/s, while for a superficial velocity of 1.5 cm/s the concentration in fixed bed at 30^0C is slightly higher than that at 20^0C.

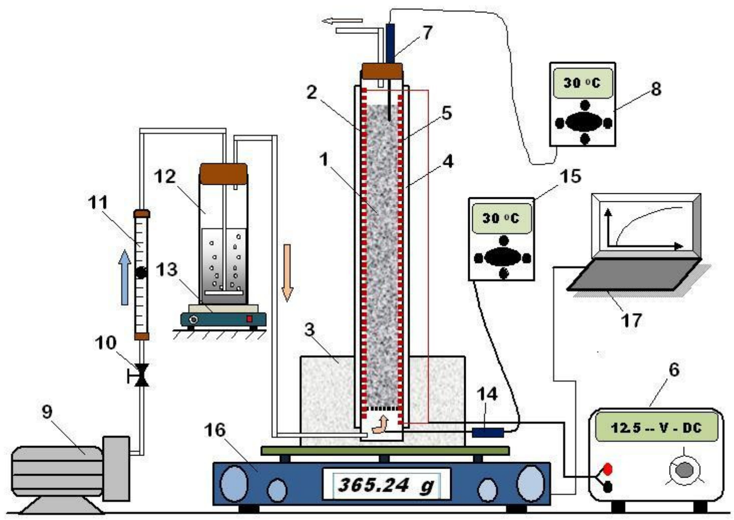

Fig. 1 Experimental set-up: 1 - activated carbon; 2 - glass column; 3 - plastic support; 4 - insulating layer; 5 - electric resistance; 6 - direct current source; 7,14 - digital thermometer prove; 8,15 - digital thermometer display; 9 - compressor; 10 - valve; 11 - flow-meter; 12 - bubble flask; 13 - heating plate; 16 - electronic balance; 17 - computer.

Characteristic curves of toluene adsorption show lower values of concentration in solid phase for an air superficial velocity of 1 cm/s and an operation temperature of 30^0C, while for a superficial velocity of 1.5 cm/s the concentration at 30^0C is higher than that at 20^0C.

Characteristic saturation data of aromatic hydrocarbons adsorption summarized in table 2 emphasize the following aspects:

- saturation time decreases with superficial velocity and operation temperature and increases with species molecular mass;
- saturation concentration of benzene and toluene in solid phase increases with air superficial velocity and decreases with temperature and molecular mass;
- saturation concentration of benzene and toluene in gaseous phase increases with air superficial velocity and decreases with temperature and molecular mass.

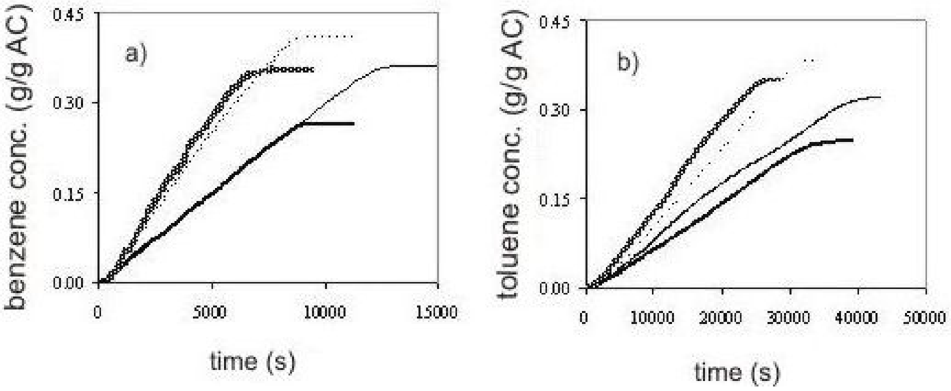

Fig. 2 Experimental saturation curves of fixed bed in case of benzene (a) and toluene (b) adsorption: — w=1 cm/s, t=20^{0}C; w=1.5 cm/s, t=20^{0}C; ▬ w=1 cm/s, t=30^{0}C; □□□□ w=1.5 cm/s, t=30^{0}C.

Table 2

Saturation data of aromatic hydrocarbons adsorption onto activated carbon

Exp.	Aromatic hydrocarbon	Air superficial velocity	Temp.	Saturation time	Hydrocarbon saturation concentration in solid phase	Hydrocarbon saturation concentration in gaseous phase
		w	t	τ_∞	$c_{si\infty}$	$c_{i\infty}=c_{i0}$
		[cm/s]	[^{0}C]	[s]	[g/g AC]	x10^3 [g/cm^3]
1	benzene	1.0	20	13 200	0.363	0.346
2		1.5		9 660	0.414	0.360
3		1.0	30	9 420	0.266	0.356
4		1.5		7 620	0.358	0.394
5	toluene	1.0	20	41 520	0.319	0.097
6		1.5		32 040	0.384	0.101
7		1.0	30	37 440	0.248	0.083
8		1.5		26 400	0.352	0.112

CONCLUSION

For the characterization of air vapours aromatic hydrocarbons adsorption onto activated carbon the following were achieved:

- a laboratory set-up was conceived and built;
- benzene and toluene adsorption onto fixed bed activated carbon using the gaseous stream method was experimented;
- an experimental investigation to evidence the influence of aromatic hydrocarbon species, gas superficial velocity and operation temperature on fixed bed adsorption dynamics was performed.

The results obtained with the laboratory set-up show the possibility to study VOCs adsorption on activated carbon and even to enhance adsorption changing process parameters.

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