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Ultrafast screening of commercial sorbent materials for VOC adsorption using real-time FTIR spectroscopy

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ABSTRACT

Recovery of valuable volatile organic compounds (VOCs) from waste streams is of great industrial importance. Adsorption on zeolites offers an economically and environmentally friendly alternative to conventional activated carbon. When evaluating the suitability of a given zeolite for a particular adsorption application, its adsorption capacity has to be determined. This is traditionally achieved using gas chromatography as an analysis tool, yielding only a few discrete sampling points that constitute the adsorption profile. Meanwhile, only low flow rates and low concentrations of volatile organics can be used, rendering the procedure troublesome and time consuming. Herein, we propose a tool for the fast screening of a large amount of zeolites using on-line and *quasi* real-time Fourier Transform Infrared Spectroscopy (FTIR). The technique was used to determine the adsorption capacity of three different commercial zeolites and two silica gels, for five industrially relevant VOCs: acetone; methanol; isohexane; isopentane; and toluene. A series of rapid measurements of the individual adsorption capacities were carried out to obtain a detailed overview of the versatility of the proposed method for the characterization of multi-component and multi-sorption bed systems.

1. Introduction

Volatile organic compounds (VOCs) are an important class of air pollutants, especially in industrial environments [1–3]. The removal of these VOCs is crucial in view of air pollution control. Some important destructive methods that are commonly used are incineration [4,5], biofiltration [6–8], and advanced oxidation processes (AOPs) such as photocatalysis [9–13]. As an alternative, recuperative, non-destructive methods, such as condensation [4], scrubbing [14] or adsorption [15] are gaining in popularity due to a wealth of potential applications that these recovered compounds offer. For instance, recovered VOCs with low vapor pressure can be used as an alternative fuel source. The adsorption of VOCs on highly porous solids is an economically interesting technology since large amounts of organic molecules can be stored in small volumes of solid material, without high pressure requirements. Activated carbon (AC) is one of the most extensively used VOC adsorbents due to its relatively low-cost production [16–18]. 25 years ago, zeolites were identified as potential adsorbent materials for the removal of VOCs as abatement systems [19]. At present, extensive reports on zeolite adsorption technology are readily available [20–23]. Zeolites offer some important advantages over common AC. Their greatest advantage is the improved safety of zeolites as compared to AC. When heated above 120 °C, there is a potential risk of fire ignition in the AC beds. In contrast, zeolites are capable of withstanding very high temperatures due to their inorganic nature. Furthermore, polymerization or oxidation of some compounds can be catalyzed due to the presence of inherent impurities in AC leading to the formation of potentially hazardous by-products. Regeneration is also much more difficult for AC. Once the surface of AC is saturated, the material is commonly discarded and replaced [24]. The final major advantage of zeolites is the fact that the adsorption capacity remains high even at high relative humidity, whereas in the case of AC, the adsorption capacity drops rapidly at a relative humidity of 50–60% [19,25–28]. In summary, an ideal adsorbent for VOC removal should have (1) high thermal stability, (2) high adsorption and regeneration capacity, (3) limited catalytic activity, and (4) low cost.

The selective adsorption of VOCs is of high industrial relevance for a variety of applications. For instance, concentrated VOCs can be used as an alternative source of fuel. To select the best suited zeolite for selective VOC adsorption, screening the adsorption capacity is required.

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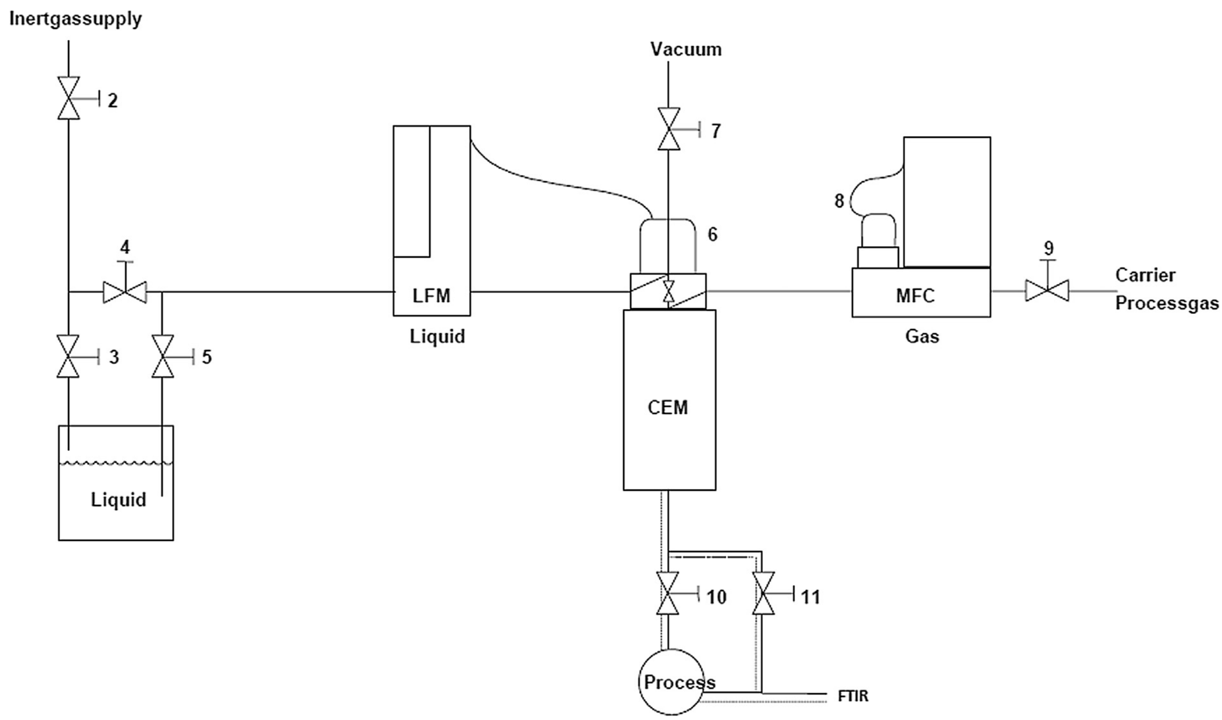

Fig. 1. Schematic illustration of the experimental set-up for gas phase VOC adsorption measurements. Numbers 2–5, 7 and 9–11 indicate valves; number 6 indicates the CEM unit and number 8 indicates a gas MFC (reprinted with permission of Gefran/Bronkhorst).

Table 1
Mass of adsorbent bed (g) for each adsorption experiment.

VOC	
Adsorbent	Mass of adsorbent bed (g)
Acetone	
ZEOflair® 100	1.191
ZEOflair® 110	1.085
ZEOflair® 300	0.891
SYLOBEAD® SG 127	1.216
SYLOBEAD® SGH 127	1.281
Activated carbon	1.329
Methanol	
ZEOflair® 100	1.203
ZEOflair® 110	1.275
ZEOflair® 300	0.881
SYLOBEAD® SG 127	1.326
SYLOBEAD® SGH 127	1.212
Activated carbon	1.202
Isopentane	
ZEOflair® 100	1.166
ZEOflair® 110	1.003
ZEOflair® 300	1.081
SYLOBEAD® SG 127	1.377
SYLOBEAD® SGH 127	0.743
Activated carbon	1.236
Toluene	
ZEOflair® 100	1.121
ZEOflair® 110	1.001
ZEOflair® 300	1.094
SYLOBEAD® SG 127	1.547
SYLOBEAD® SGH 127	1.747
Activated carbon	1.064
Isohexane	
ZEOflair® 100	0.984
ZEOflair® 110	1.193
ZEOflair® 300	1.196
SYLOBEAD® SG 127	1.546
SYLOBEAD® SGH 127	1.327
Activated carbon	1.055

The most common technique for analysis of VOC adsorption profiles of materials is gas chromatography (GC) [7,15–17,19,29–32]. Some important advantages of GC for the detection of VOCs are its ability to measure extremely low concentrations down to ppb levels and its effective high resolution separation of different compounds. A major limitation of GC is that it is highly time consuming. The time between two sampling points is at least 30 s and can be as long as a few minutes, depending on the length of the column and the temperature program. As a result, the obtained adsorption profile relies on a few discrete sampling points, taken over a prolonged period of time.

In this work an alternative technique is proposed based on Fourier Transform Infrared Spectroscopy (FTIR). This, too, is shown to be a viable tool to perform adsorption measurements since VOCs can be easily detected by FTIR, commonly at higher concentrations than for GC (ppm levels). In contrast to GC detection, FTIR enables on-line and *quasi* real-time detection of gaseous components, making it suitable for ultrafast screening studies. In this work, this is demonstrated by screening the adsorption capacities of three commercial zeolites and two silica gels for five relevant VOCs including acetone, methanol, isohexane, isopentane and toluene. It is, however, not the intention of this work to study adsorption/desorption kinetic mechanisms, nor to select the most suitable adsorbent material or process conditions for a given industrial application. Our aim is only to show that from a practical point of view, FTIR as detection tool provides a much faster yet still very accurate screening of adsorbent materials for VOCs in comparison with conventional GC detection.

In view of practical applications of recovered VOCs, desorption of these compounds and reusability of the sorbent are equally important [33,34]. Therefore, as a final proof of concept of the proposed methodology, a complete set of adsorption-desorption cycles has been performed on a multi-component gas flow and a multi-adsorbent bed system, showing the potential of this technique for full characterizeation in terms of the adsorption and regeneration capacities of the adsorbent materials.