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# Multifunctional solar wall for dehumidification, heating and removal of formaldehyde: Part 1. System description, preparation and performance of $SiO_2/TiO_2$ adsorbent

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ABSTRACT

This article proposes a novel multifunctional solar wall that can realize heating and removal of formaldehyde in winter and dehumidification and removal of formaldehyde in summer. Multifunctional materials focusing on the dehumidification and the removal of low-concentration indoor gaseous contaminant simultaneously are of great interest for the improvement of building environment and energy conservation in building. $SiO_2/TiO_2$ composite adsorbents with different $TiO_2$ content for the adsorption of formaldehyde and dehumidification were prepared by the sol–gel method. The porous properties of the composite adsorbents were investigated by ASAP2010 volumetric adsorption analyzer. The water vapour adsorption isotherms at 25 °C and breakthrough curves of formaldehyde at typical indoor pollutant concentrations i.e. 0.7 ppm and 1.4 ppm, respectively were measured. The kinetic adsorption curves of water vapour and formaldehyde on composite adsorbents were measured and linear driving force (LDF) model was applied. Also the kinetic adsorption rate constants obtained by the fittings of the kinetic adsorption curves based on LDF model were analyzed. Results showed that composite adsorbents had excellent water vapour adsorption capacity under the low and medium humidity compared with commercial silica gel. The introduction of $TiO_2$ increased the polarity of composite adsorbents. And composite adsorbent with a certain amount of $TiO_2$ ($SiO_2$: $TiO_2$ = 90: 10, mole ratio) possessed high kinetic adsorption rate constant under the low relative humidity. Furthermore, the introduction of $TiO_2$ improved formaldehyde adsorption capacity under typical indoor concentration levels, which suggested that composite adsorbents were efficient in capturing the trace amount of indoor formaldehyde.

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## 1. Introduction

With the rapid development of economy and improvement of living standards, residential buildings consume a large amount of energy for heating and air conditioning. At the same time, two serious threats that human beings confront are the depletion of fossil fuels and global warming. The application of solar energy in architecture is one of the most effective measures for energy conservation in building. Solar-collected wall heating technology has been widely used in the past few decades due to its numerous advantages such as simple configuration, high efficiency and zero running cost [1]. Nowadays, citizens spend a lot of time in residential building so that it is necessary to guarantee the high Indoor Air Quality (IAQ) and thermal comfort. Providing enough fresh air by opening window may improve IAQ to some extent, but this is dependent on the outdoor IAQ because more serious outdoor air pollution problems exist in developing cities [2]. Moreover, this leads to the increase of the cooling load in summer and the heating load in winter. In fact, latent load mainly comes from the fresh air, especially in humid areas. While considering the thermal comfort, keeping room closed for a long time causes the accumulation of pollutants such as volatile organic compounds (VOCs) that are emitted from furniture, decorative materials, cooking and other

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**Nomenclature**

| | |
|---|---|
| $m$ | mass, Kg |
| $k$ | adsorption rate constant, $min^{-1}$ |
| $w$ | weight of adsorbent in the formaldehyde breakthrough experiments, Kg |
| $L$ | length of the bed, m |
| $Q$ | volumetric flow rate of gas, slpm |
| $q$ | formaldehyde adsorption capacity of adsorbent, mg/g |
| $C$ | concentration of formaldehyde, ppm |

*Subscripts*

| | |
|---|---|
| $0$ | original |
| $t$ | time |
| $s$ | saturation |

*Abbreviation*

| | |
|---|---|
| LDF | linear driving force |
| IAQ | Indoor Air Quality |
| VOCs | volatile organic compounds |
| ppm | parts per million |
| ACF | actived carbon fiber |
| CS | commercial silica gel |
| SG | Silica gel |
| ST1-3 | composite adsorbents with different molar ratios of between $SiO_2$ and $TiO_2$ that were 100: 0, 90:10, 80:20 and 70:30, respectively |
| STs | samples with $TiO_2$ |
| Slpm | standard liter per minute |
| TEOS | tetraethyl silicate, $Si(OC_2H_5)_4$ |
| TBOT | tetrabutyl titanate, $C_{16}H_{36}O_4Ti$ |
| HVAC | Heating, Ventilation and Air Conditioning |

indoor goods. There is a general agreement that the concentration of indoor VOCs is 2–10 times than that of current legal limiting concentration [3]. Therefore, it is very necessary to design and investigate a novel multifunctional system applied in residential buildings that can achieve the most possibility of building efficiency and high indoor environment quality.

Indoor humidity is an important factor that influences the thermal comfort and human health. High humidity environment may aggravate the hot feeling in summer and induce the activation of mould leading to various diseases. Desiccant wheel dry technology has been widely investigated because it can easily realize the independent control of temperature and humidity and has superior ability to utilize the low-grade heat sources, such as solar energy, waste heat, etc. The application method of solar energy on dehumidification systems at present is the combination with large heat collection devices that adsorb solar energy to heat the air in regenerator [4]. However, some problems exist such as low efficiency of energy use, complexity of system and large volume.

Several strategies, such as condensation, adsorption, photocatalytic oxidation (PCO), thermal oxidation and catalytic oxidation, are commonly investigated for the removal of indoor VOCs [5–8]. However, for VOCs at low concentration levels such as in the range of parts per million (ppm) i.e. typical indoor levels, adsorption technology and photocatalytic oxidation technology (PCO) or the combination of these two advanced technologies are found to be innovative and efficient methods to gaseous VOCs abatement [9].

The most commonly used photocatalysts is nano-titania ($TiO_2$). Fig. 1 shows the basic reaction mechanisms of the PCO on catalyst

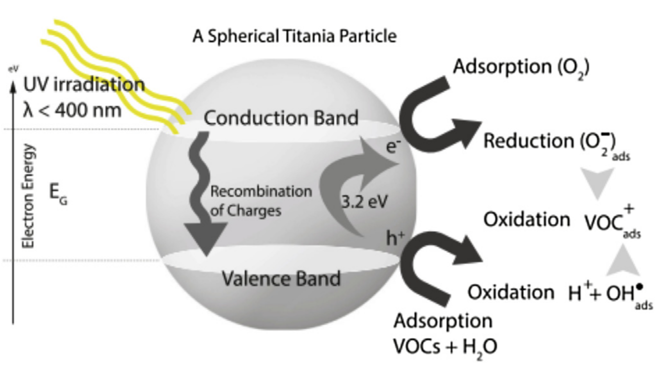


**Fig. 1.** Reaction mechanisms of the PCO on catalyst particle [11].

particle. When the ultra-violet (UV) lights that have enough energy to overcome the band gap between valence band (VB) and conduction band (CB) irradiate semiconductor $TiO_2$, the hole–electron pairs form. And $h^+$ and $e^-$ are powerful oxidizing and reductive agents, respectively, which can drive reduction and oxidation, respectively, of compounds adsorbed on the surface of a photocatalyst. And the hydroxyl radical ($OH\cdot$), which comes from the oxidation of adsorbed water or adsorbed $OH^-$, is the dominant strong oxidant. A series of chemical reactions are as follows [7,10].

$$\text{Activation}: TiO_2 + h\nu \rightarrow h^+ + e^-, \tag{1}$$

$$\text{Oxidizing reaction}: OH^- + h^+ \rightarrow OH^\bullet, \tag{2}$$

$$\text{Reduction reaction}: O_2 + e^+ \rightarrow {O_2}^-, \tag{3}$$

$$\text{VOCs degradation}: OH^\bullet + VOCs \rightarrow CO_2 + H_2O. \tag{4}$$

The keyword is obviously the adsorbent whether for the adsorption of gaseous VOCs or dehumidification. Properties of sorbent play an important role in an adsorption process, which determine system the coefficient of performance (COP). The commonly used adsorbents include activated carbon, silica gel, molecular sieve and zeolite. And desiccant includes lithium chloride and calcium chloride as well. Activated carbon has advantages such as high adsorption capacity and low cost. They are widely used as VOCs adsorbent. However, it presents the drawbacks of combustible risk and high regeneration temperature. Lithium chloride behaves good hygroscopic capacity and low regeneration temperature in dehumidification process [12], but its corrosion to the system limits its application. Silica gel, a type of porous material with great microporous structure of internal interlocking cavities, is widely used for desiccation because of its large adsorption amount, non-corrosive and low regeneration temperature [13]. Some studies showed that oxygenated VOCs, mostly polar ones, are normally adsorbed on adsorbent surface via hydrogen bonding with O-containing groups on the surface of adsorbents [14]. Porosity and surface oxygen group content have the major influence on the adsorption of low-concentration VOCs [15]. The oxidative treatment on active carbon fibers (ACFs) leaded to a higher adsorption capacity on acetaldehyde but lower one on toluene due to the increase of the surface concentration of O-groups [16], which gave a good evidence of the adsorption mechanism of oxygenated VOCs on adsorbents. From this point of view, a

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