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The contaminant removal efficiency of an air cleaner using the adsorption/desorption effect

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ABSTRACT

The adsorption and desorption of volatile organic compounds (VOCs) in relation to material surfaces were conducted to control indoor air quality. The VOC removal performance of building materials using sorption effects was validated in cases related to poor indoor air quality that occurred during non-ventilation periods during intermittent-ventilation situations. The objective of this investigation is to present the contaminant removal efficiency and practicality of a prototype air cleaner which uses sorption effects. Toluene and formaldehyde were used as pollutant sources and were continuously emitted into the test chamber. Effects due to the number of sorption units, operation time and mode of contaminant removal performance were examined. The sorption materials evaluated in this investigation were a porous material, zeolite, pumice stone and hydro-corn. As a result of the experiments, zeolite exhibited relatively high contaminant removal efficiency with toluene, and zeolite and the porous material exhibited high removal efficiency with formaldehyde for both one-cycle and two-cycle sorption modes. Moreover, significant removal performances were observed in the numerical analysis of the continuous-operation mode.

1. Introduction

Major strategies for the control of indoor pollutant sources are source control, enclosure and ventilation at the source, as well as dilution and displacement ventilation [1]. The source control method restricts potentially harmful pollutant emissions, such as VOCs and formaldehyde, emissions from furnishings, and furthermore discourages tobacco smoking. Enclosure and ventilation at the source control pollutants generated by the activity of building occupants using local extractors and cooker or range hoods to remove these pollutants at the source. Dilution and displacement ventilation are used for diluting and removing residual pollution from unavoidable contaminant sources, like odor and CO_2 emissions generated by building occupants. In addition to these methods, filtration methods have been developed to remove chemical pollutants using gas adsorption and chemical gas filters.

Consequently, air cleaners with the aforementioned gas adsorption and chemical gas filters have been recognized as some of the most effective strategies for the removal of indoor air contaminants and reduction in ventilation loads for saving energy in buildings. Most of the filters remove airborne particulates from indoor air, except for special filters with chemical additives. These do not have a high enough removal performance for gaseous contaminants such as VOC. Howard-Reed et al. focused on experiments to measure the removal of decane with sorption-based in-duct gaseous air cleaners and sorption-based portable air cleaners in a single-zone test house [2]. It was demonstrated that gaseous air cleaners can be highly effective at removing certain indoor air contaminants. Moreover, there are several installation and operation conditions that can alter their performances in the field. Nozaki et al. investigated the VOC removal efficiency of domestic air cleaners that had been widely used as pollution mitigation measures in Japan, and then presented the 22 VOCs removal rates of the air cleaners [3].

It is difficult to control indoor air quality at a stable concentration level using sorption materials passively in the form of sheet and board products. Generally active systems like air cleaners are better than passive systems for the control of indoor air quality. There are few researches about air cleaners with sorption materials. The authors concentrated on materials with reversible sorption effects which would adsorb chemical contaminants, instead of specific materials with nonreversible adsorption like cultivated carbon. Moreover, the authors have developed a theoretical basis based on the theory developed by Tichenor et al. [4] for the

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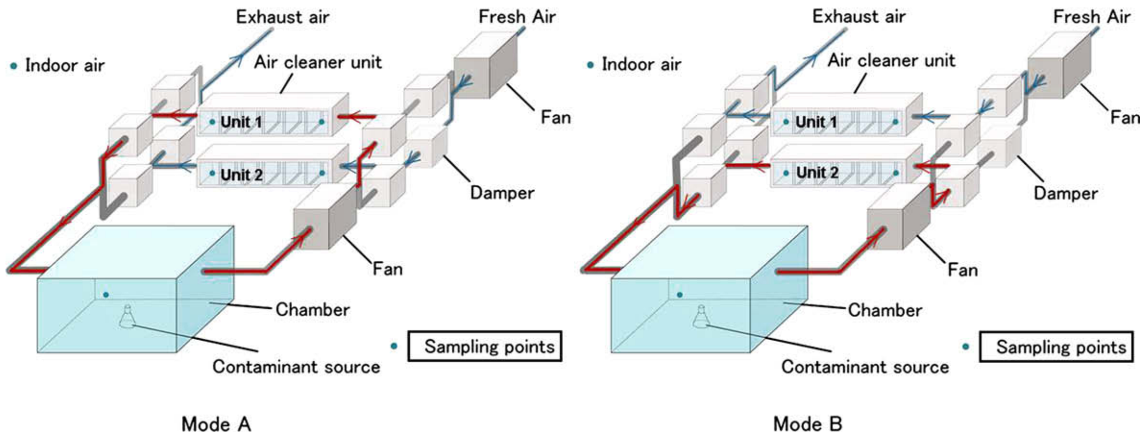

Fig. 1. Measurement apparatus and the operation modes.

adsorption/desorption effects of material surfaces on contaminant removal in rooms, and conducted performance evaluations of a prototype air cleaner with a single sorption unit, by numerical simulation [5]. This air cleaner showed significant efficiency in the removal of contaminants inside a house installed with a hybrid ventilation system. We presented the development of an indoor air cleaner using the adsorption/desorption effect during the experiment and its impact assessment on the global environment by the life cycle inventory (LCI) analysis [6]. The LCI analysis of air cleaners with a removal efficiency of 50% was equivalent to conventional mechanical ventilation systems with heat-exchange efficiency of 70%. Consequently the aim of the present air cleaner with sorption effects is not only to remove chemical contaminants from indoor air, but also to reduce the ventilation load required for controlling indoor air quality as well as the environmental load such as wastes from spent filters used for general air cleaners.

The main objective of this paper is to investigate the removal performance of a prototype air cleaner using adsorption/desorption effects for different adsorptive materials and including operation time and mode of laboratory experiments. In this paper, fundamental parameters related to system performance such as sorption characteristics of the materials, operation mode and time, and so on, were investigated for the proto-type system with two cleaner units.

2. Methods

A proto-type measurement system for the investigation of fundamental characteristics in VOC removal efficiency consists of sorption units, ducts, fans, controllers, and dampers to control air flow. The experimental installation of an air cleaner with the following components: two sorption units, two duct fans, eight dampers and ducts made of stainless steel to avoid the adsorption of chemical contaminants on the surface of the measurement system, is shown in Fig. 1. The opening and closing of the dampers to change the flow pattern according to the operation mode are controlled by controllers connected to a computer. The computer can send a signal to control the dampers based on any mode which has been programmed in advance. The sorption capacity of materials used in this system is not considered to be sufficient for small buildings or houses in a single mode, therefore two modes at the least are required to obtain a stable performance of VOC removal by operating one mode after the other mode. It operates in two modes – Mode A: the process of adsorption to circulate indoor air and adsorb chemical contaminants on the surface of the Sorption Unit 1 and the process of desorption to emit or remove the contaminants from the surface of Sorption Unit 2 to the outdoors, and Mode B: the process of desorption for Unit 1 and that of adsorption for Unit 2.

In this experiment, the adsorptive materials evaluated are natural zeolite, pumice stone, hydro-cone, artificial zeolite and a type of porous material as shown in Fig. 2. The diameter of each material including the porous material, which was broken into small pieces, is about 3–10 mm. Zeolites are hydrated aluminosilicate minerals that have a micro-porous structure. Zeolites are used widely as ion-exchange beds in domestic and commercial water purification, catalysts in the petrochemical industry, a type of soil treatment, and so on [7]. Also zeolites have been used as an interior building material to control indoor air humidity in the construction sector. In addition zeolites are noted as some of the most efficient adsorptive materials to remove VOC from indoor air. Both types of natural and artificial zeolites were measured. Hydro-corn is made from soil and used as artificial soil to cultivate plants, and has a lot of small pores to keep water required for foliage plants. Pumice stone also has a high number of small pores inside and is widely used to make lightweight concrete. It is also used as an abrasive, especially in polishes, pencil erasers, cosmetic exfoliants, and so on [7]. Ceramic tile was developed to adsorb moisture and chemical contaminants from indoor air.

The air cleaner we used required a wide surface area of adsorptive material in order to obtain high removable efficiency of pollutants [5]. Therefore the form of the materials was granulated to increase the surface area which in turn can increase contact with

Fig. 2. Adsorptive materials investigated.