ABSORBABILITY OF CONTAMINANTS FROM AIR BY SNOW COOLING SYSTEM

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ABSTRACT

Snow has already been used effectively as a cold energy resource in some heavy snowfall areas in Japan. As the surface of snow is covered with cold melting water when snow is used as a cold energy resource, we can expect gas absorption on the surface. By this mechanism of the gas absorption, some airborne contaminants such as dust or harmful gases can be removed by the melting snow surface. In the snow cooling system, the air is cooled directly at the surface of a vertical snow hole drilled through the snow block, some contaminants are removed automatically and simultaneously with the heat transfer process. In this study, the authors measured the absorbability of tobacco smoke, formaldehyde, ammonia gas and some indoor air contaminants in a pilot plant of the snow cooling system. Experimental results showed that 40% formaldehyde and ammonia were removed when the inlet air temperature was cooled down from 30 degrees C to 13 degrees C. Also some contaminants included in tobacco smoke were removed by this system. This filter effect of the snow surface can be put to practical use in contamination control during air conditioning.

INTRODUCTION

Japan is situated in the same latitude as California in USA and in a temperate region. However most parts of Japan have snow in winter. Northwesterly seasonal winds off the Asian continent bring heavy snows mainly on the Japan Sea side from Hokkaido to the central part of Honshu. Some regions in this area have the greatest snowfalls in the world. In summer, however, temperatures climb above 30 degrees C in the same region and residents rely on an air conditioning system to stay comfortable in the sticky heat. Creative ways are therefor being sought to use this abundant snowfall as a source of clean and cold energy in the region where snow lies several meters in winter [1]. Snow is kept in a snow storage shed with adequately insulated walls until summer, when the air conditioning system is needed, and the snow can be used to cool air. We proposed one of the methods to cool air, that is, the direct heat exchange between hot air and the snow block through a vertical hole. The hot air is cooled through this heat transfer model known as the snow cooling system. This snow cooling system has been developed for practical application. Few parts are required for the construction of this system. Cooling capacity is virtually constant even when the volume of the snow block is reduced [2]. Another advantage of this system is concerned with contamination. Water-soluble airborne contaminants dissolve in the melting snow-water by direct contact, and contaminants are removed from the air [3]. In this experimental study, the authors investigated the removal effect of contaminants, such as tobacco smoke, ammonia, formaldehyde, toluene and ethanol, under the conditions close to actual use.

OUTLINE OF THE SNOW COOLING SYSTEM

An example of commercial plant of the snow cooling system is shown in Fig. 1 [4]. This system was constructed in Funagata, Yamagata prefecture Japan. This system consists of a snow storage shed, air ducts, a fan and air volume control equipment. It is very simple. The snow storage shed is filled with more than 60 tons of snow in winter. About 70% of the initial amount of the snow block remains by the beginning of summer. In summer, the remaining snows in the storage shed cools indoor air. Some vertical holes are drilled through this remaining snow block. Hot air is cooled through these snow holes. In this process, the wet surface of snow is expected to not only to have a cooling effect but also to dehumidify and decontaminate the air. Indoor air is supplied to the snow storage shed through an air duct for cooling air. The temperature of supply air into the living room is adjusted to the desired value by mixing (1) cooled air from the snow storage shed with (2) hot air from the bypass and with (3) the outside air.

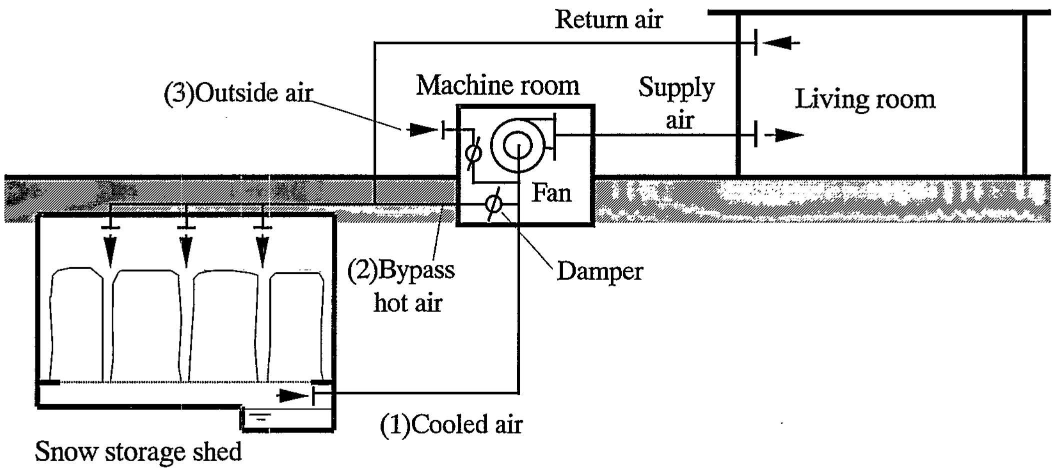

Fig. 1 Schematic diagram of the snow cooling system

METHODS

Experimental apparatus

Schematic diagram of experimental apparatus is shown in Fig. 2. Air is blown into the snow storage shed by the fan with an inverter. Temperature of air is controlled at 30 degree C as to cooling condition in summer by a heater with an automatically controller. Testing gases, such as tobacco smoke and ammonia gas, are added into air from each gas sources. The flow rate of the air is measured by an orifice flow meter. Tow sampling ports are branched at inlet and outlet lines of snow storage for measuring concentration of each gas. The snow storage shed has square cross-section of 1m each side, and can be filled with height of 2m of snow. Walls are insulated from heat by 100mm thick of heat insulator. The diameter of the inlet air duct is 100mm. Punching plates are installed in the upper part of snow storage shed to distribute air. Expanded metal is installed in the lower part of snow storage to separate water from snow, and to make a path for air.

Experimental method

Snow was filled into storage shed after its weight was measured, and was trodden down to make the density of snow constant. To make an air flow path, a vertical hole with a diameter of about

50mm was bored with dropping water at the center of snow bloke. For each testing contaminant, experiment was practiced until 80% of the snow block was melted. Ammonia, ethanol, formaldehyde, toluene, and tobacco smoke were selected as testing contaminants. Ammonia was measured with an ammonia gas analyzer (model-17, Thermo Electron). Ethanol was collected by silicagel cartridges and was measured with gas chromatography. Formaldehyde was collected by using impinger and was measured by spectrophotometry. Toluene was collected by using TENAX GR tubes and was measured with a gas chromatograp / mass spectrometer. Volatile organic compounds (VOCs) were included in tobacco smoke. Some compounds of VOCs were measured by the same method as toluene was measured. The commercial brand, Mild Seven, which was accounted for the largest market share of cigarettes sold in Japan in 1997, was selected in this study. A cigarette was sequentially smoked by a machine using a standard smoking cycle of one puff per minute of $35cm^3$-volume and 2 sec duration.

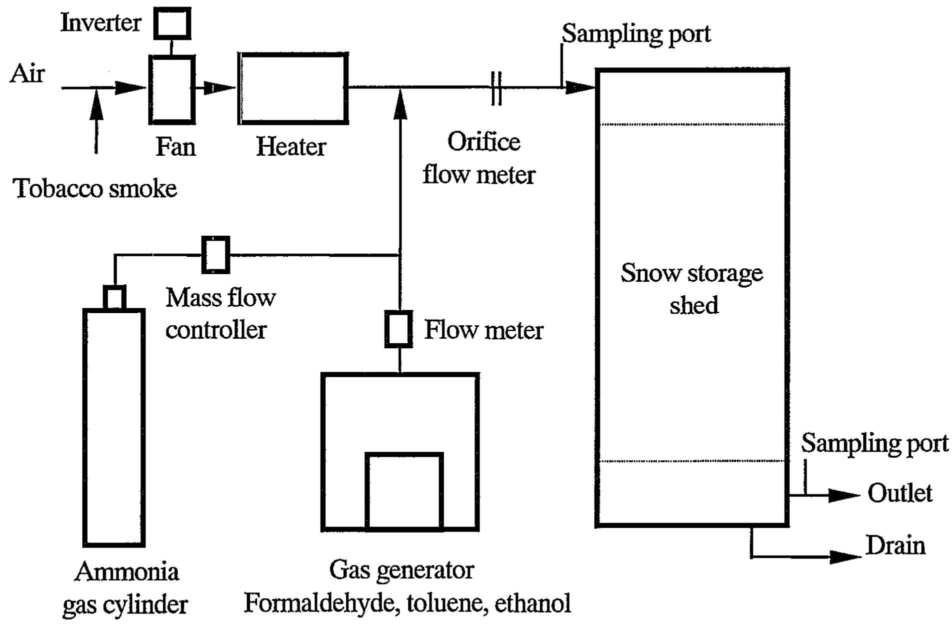

Fig.2 Schematic diagram of experimental apparatus

RESULTS AND DISCUSSION

Experimental results are expressed by removal rate η defined with following equation.

$$\eta=(1-C_{out}/C_{in})\times100 \qquad (1)$$

Where C_{out} is contaminant concentration in outlet air, C_{in} is in inlet air.

Ammonia

Effect of remaining fraction of snow

In this snow cooling system, snow block melts in process of cooling the air and changes its volume and shape. Remaining fraction Z is defined as remaining snow volume divide by initial snow volume. The experimental results on the effect of remaining fraction of snow Z on removal rate η

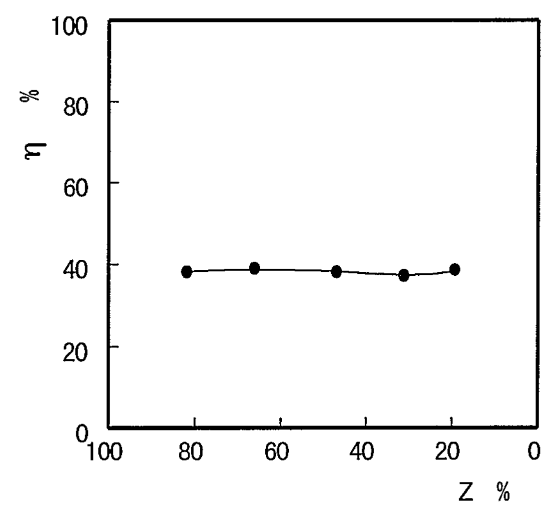

Fig. 3 Effect of remaining fraction of snow Z on removal rate η of ammonia

of ammonia are shown in Fig. 3. This experiment was performed under the following conditions; inlet concentration of ammonia was 3ppm, air flow rate was 0.0255m^3/s, inlet air temperature was 30 degrees C and outlet air temperature was about 13 degrees C. Removal rate of ammonia was almost constant even when remaining fraction of snow was reduced. The algebraic mean value shown in Fig.3 was 39%. From these experimental results, it is cleared that this snow cooling system can be used easily to remove ammonia gas in the practical field with constant absorbability.

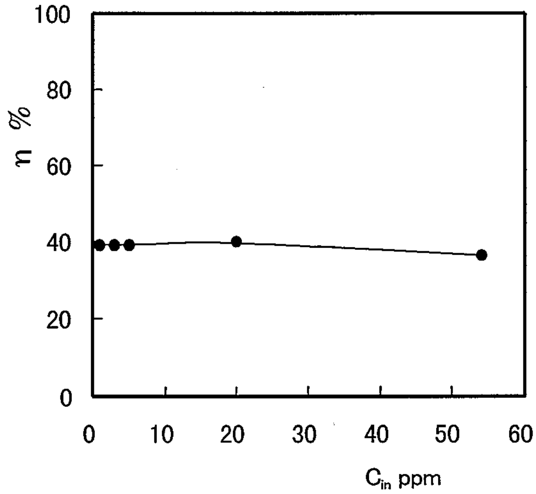

Fig. 4 Effect of inlet gas concentration C_{in} on removal rate η of ammonia

Effect of inlet gas concentration

Removal rates for several inlet gas concentration of ammonia are shown in Fig. 4. They are the mean values of removal rates measured for remaining fraction of snow being 85% to 20%. Fig.4 showed that removal rates were almost constant until 50ppm which was comparatively high concentration condition indoor air. It seems that removal rate is not affected by the inlet gas concentration.

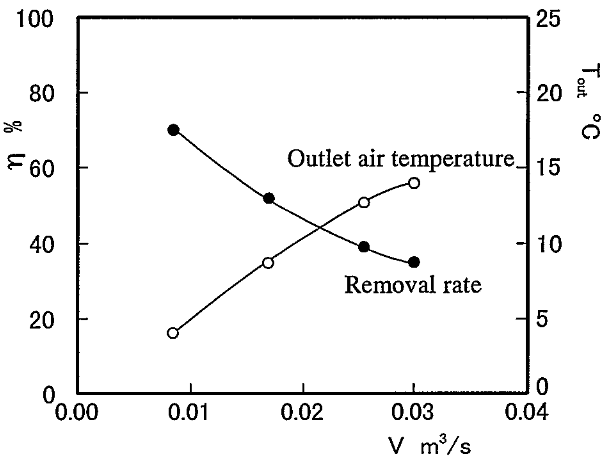

Fig. 5 Effect of air flow rate on removal rate of ammonia

Effect of air flow rate

Mean removal rates as to Z of ammonia at several air flow conditions are shown Fig. 5. In the same figure, air temperatures at the outlet of the snow storage shed are plotted. It was observed that removal rate increased and outlet air temperature decreased with the decrease of air flow rate. Under the condition of air flow rate was 0.0085m^3/s, the removal rate of ammonia exceeded over 70%. However the air temperature dropped to 4 degrees C which was too cold for the air of living room. Under the condition of air flow rate was 0.0255m^3/s, air temperature at the outlet of snow storage was 13 degrees C, which was a conventional temperature for air conditioning systems, and the removal rate was about 40%. As air is circulated in an air conditioning system, it is clear that the removal rate can be raised by many times. For example, when the air is circulated through snow cooling system twice and the removal rate is 40% for one path, the removal rate becomes to 64%. If the air is circulated five times, the removal rate become over 90%, which would be a practical regime for air-conditioning.

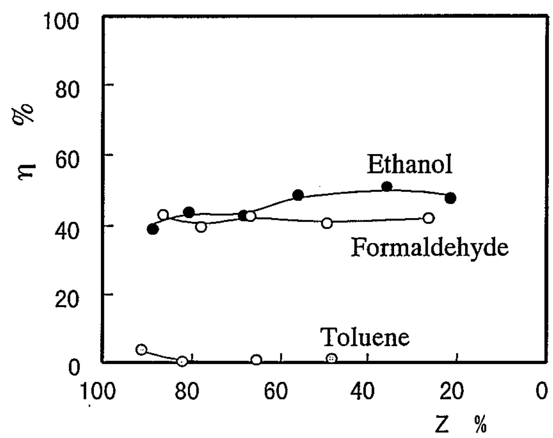

Fig. 6 Removal rate of ethanol, formaldehyde and toluene

Ethanol, formaldehyde and toluene

Ethanol is widely used as a hospital disinfectant, and is included in exhaust gas from alcohol factories. It is desirable to remove ethanol from air because it causes black mold. Ethanol is seemed to be absorbed by melting snow water in this system, because it is highly water-soluble. Experimental results are shown Fig.6. The removal rates of ethanol varied little with Z. The average value was 45% , and was a little higher than the value of ammonia.
Formaldehyde is taking concern as an indoor air contaminant, and is released in the air by fabrics, plywood, and other building materials. Its mean removal rate was observed 39% same as ammonia.
The concentration of toluene is usually the highest in the chemical contaminants in the office [5]. Experimental results showed that toluene could not be removed from air because toluene was not water-soluble.

Tobacco smoke

Mean removal rates of formaldehyde and nicotine included in tobacco smoke vs. air flow rate are shown Fig. 7. Removal rates were increased with a decrease of air flow rate. Under the condition of air flow rate $0.0048 m^3/s$, the removal rate of nicotine became over 90%. Under the air flow rate $0.0255 m^3/s$, it observed that formaldehyde was removed 20%, which was lower than the results of individual experiment shown Fig. 6. It seems to caused this result that a parts of formaldehyde is included in tobacco smoke particles, which are more difficult to be adsorbed than gases.
Analytical results of some volatile organic compounds in tobacco smoke are shown in Table 1. The air flow rate was low value and was $0.0085 m^3/s$. It is very difficult to determine individual quantities, because there are too many compounds in tobacco smoke. This table showed that some compounds which we were able to determine because of their large quantities. The removal rate of benzene and toluene were 60% and 63% respectively as shown in Table 1. However toluene was not removed in individual experiment as shown in Fig.6. This difference may be because toluene is included in tobacco smoke particles, and some of these particles are adsorbed on the snow surface. Other compounds are removed to some degree as shown in Table 1.

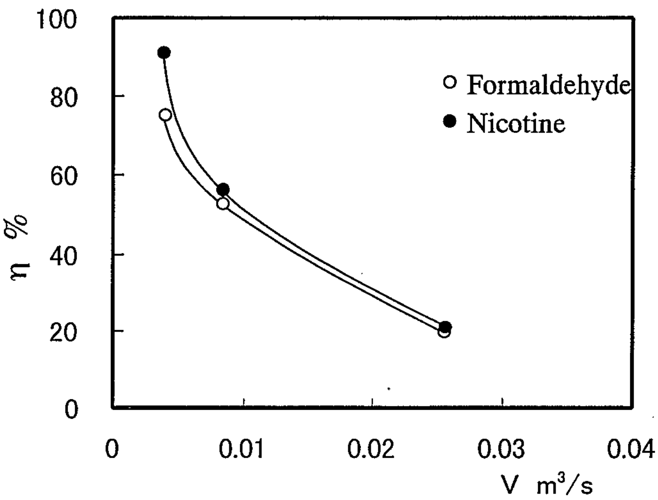

Fig. 7 Removal rate of formaldehyde and nicotine in tobacco smoke

Table 1 Removal rate of some compounds in tobacco smoke by snow cooling system.

Compound	Removal rate	Compound	Removal rate
Benzene	60%	Styrene	42%
Toluene	63%	Tridecane	41%
Etylbenzene	43%	Tetradecane	50%
p-Xylene	27%	D-Limonene	57%

CONCLUSION

A snow cooling system has been investigated from the point of view of the good use of natural energy. In this paper, the authors investigated the removal effect of some contaminants from air by the snow cooling system. From the results of this experiment, it is clear that water-soluble airborne contaminants, such as ammonia, ethanol and formaldehyde, are removed effectively by the melting snow water. Water-insoluble airborne contaminants, such as toluene and so on, are not removed. However toluene and benzene, which are included in tobacco smoke, can be removed. From the experimental results described above, the authors conclude that the snow cooling system has worth to remove some contaminants from air. The authors will make effort to apply this system to actual contamination control and will investigate this system from the point of view of contamination control of indoor air. As thermal storage system is recommended in Japan to peak cut the demand for electric power during daytime in summer, ice has been used as storage material in some office buildings. Even in regions without snow the removal effect could be used in an ice storage system, in which the direct heat exchanged between ice and air, just as in the snow cooling system. Therefor, the authors believe that this snow cooling system will be used widely in the future.

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