

## Performance test of PSA-type O<sub>2</sub> separator for efficient O<sub>2</sub> supply to room ventilation system combined with CO<sub>2</sub> adsorption module

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**Abstract**—High purity O<sub>2</sub> concentrated by the PSA-type O<sub>2</sub> separator was applied to a room ventilation system combined with CO<sub>2</sub> adsorption module to remove the indoor CO<sub>2</sub> for the indoor air quality. And then the room was occupied by several persons to breathe for the O<sub>2</sub> consumption and CO<sub>2</sub> generation. As a result, the indoor air quality was improved by the ventilation system combined with the O<sub>2</sub> supply and the CO<sub>2</sub> adsorption module. It was due to the fact that the CO<sub>2</sub> concentration was not steeply increased, but also even decreased and then the increasing rate of the O<sub>2</sub> concentration with the O<sub>2</sub> supply was simultaneously increased by the CO<sub>2</sub> removal despite the CO<sub>2</sub> generation and O<sub>2</sub> consumption with the four persons' breathing. As a representative result, in the case of supplying the high purity O<sub>2</sub> of 30 L/min under using the CO<sub>2</sub> adsorption module, the best performance with the highest increasing rate of O<sub>2</sub> concentration and the lowest increasing rate of CO<sub>2</sub> concentration was obtained among the various cases, and then the increasing rates of CO<sub>2</sub> concentration and O<sub>2</sub> concentration were −2.3 ppm/min and 33.3%/min, respectively.

**Keywords:** Indoor Air Quality, Room Ventilation System, Zeolite-based Adsorbent, O<sub>2</sub> Separator, Supply, PSA-type, CO<sub>2</sub> Adsorption Module

### INTRODUCTION

CO<sub>2</sub> is a colorless, odorless, tasteless and global warming gas, comprising about 0.04% of the ambient air. Worldwide concern over the generation of CO<sub>2</sub> is increasing concomitant with the use of the fossil fuel, reduction of the energy cost and the improvement of the air quality. One thing is especially noteworthy in that indoor air quality and ventilation condition in terms of O<sub>2</sub> content is recently highlighted in connection with a sanitary criterion for indoor residents concerned with the harmful effect of CO<sub>2</sub> and CO [1]. The CO<sub>2</sub> concentration is used as a criterion of indoor air quality and ventilation condition as well as the amount of O<sub>2</sub> which gets insufficient for breathing, and CO<sub>2</sub> is treated as an important pollutant getting the dirty end of the stick together with CO when the CO<sub>2</sub> concentration is increased. CO<sub>2</sub> is generated by people breathing with the consumption and the fuel combustion, and then the CO<sub>2</sub> concentration is 1,000 ppm as a reference level in the indoor ventilation condition according to the indoor air quality with different countries [2-7]. When the CO<sub>2</sub> concentration is higher than 1,000 ppm as an acceptable standard in the indoor air quality, the breath and the inside ventilation of an alveolus highly increased. And then it leads to difficulty breathing and headaches. On the basis of these facts, there has been interest in CO<sub>2</sub> removal and its

related room ventilation system for the efficient O<sub>2</sub> supply [7]. CO<sub>2</sub> can be removed and treated with the various methods such as adsorption, membrane separation, and absorption. A CO<sub>2</sub> treatment method optimized for the reduction of the indoor CO<sub>2</sub> has been developed; however, its suggestion is very difficult due to the diversity and difficulty with the various treatment conditions [8,9]. Among the various CO<sub>2</sub> treatments, CO<sub>2</sub> adsorption via zeolite-based catalyst is regarded as economical and efficient for CO<sub>2</sub> removal with the low energy cost and reusability by the regeneration and then the activated carbon, alumina, zeolite-based molecular sieves, carbon molecular sieves, silica, and so on can be suggested as favorable candidates as an adsorption agent [10-16]. O<sub>2</sub> can be supplied using fresh air, but effective supply of O<sub>2</sub> is necessary using the pure O<sub>2</sub> concentrated after the separation by the effective method. The O<sub>2</sub> supply is influenced by the efficient concentration, separation, storage and production of O<sub>2</sub> content in air. PSA (pressure swing adsorption) can be used as an efficient O<sub>2</sub> separation/concentration via physical adsorption-desorption cycle with adsorbent.

In the present research, a PSA-type O<sub>2</sub> separator was suggested and investigated for the realization and applicability as an effective method to produce and supply pure O<sub>2</sub> for a room ventilation system to improve the indoor air quality. The CO<sub>2</sub> adsorption module was simultaneously combined with the room ventilation system for the treatment of CO<sub>2</sub> generated by people breathing. The operation conditions for the production and supply of O<sub>2</sub> was optimized under the various operation and environmental conditions, and performance tests were carried out. And then the effect of the supply with the O<sub>2</sub> separator and the CO<sub>2</sub> removal with the adsorption module on the indoor air quality was investigated.

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\*This article is dedicated to Prof. Seong Ihl Woo on the occasion of his retirement from KAIST.

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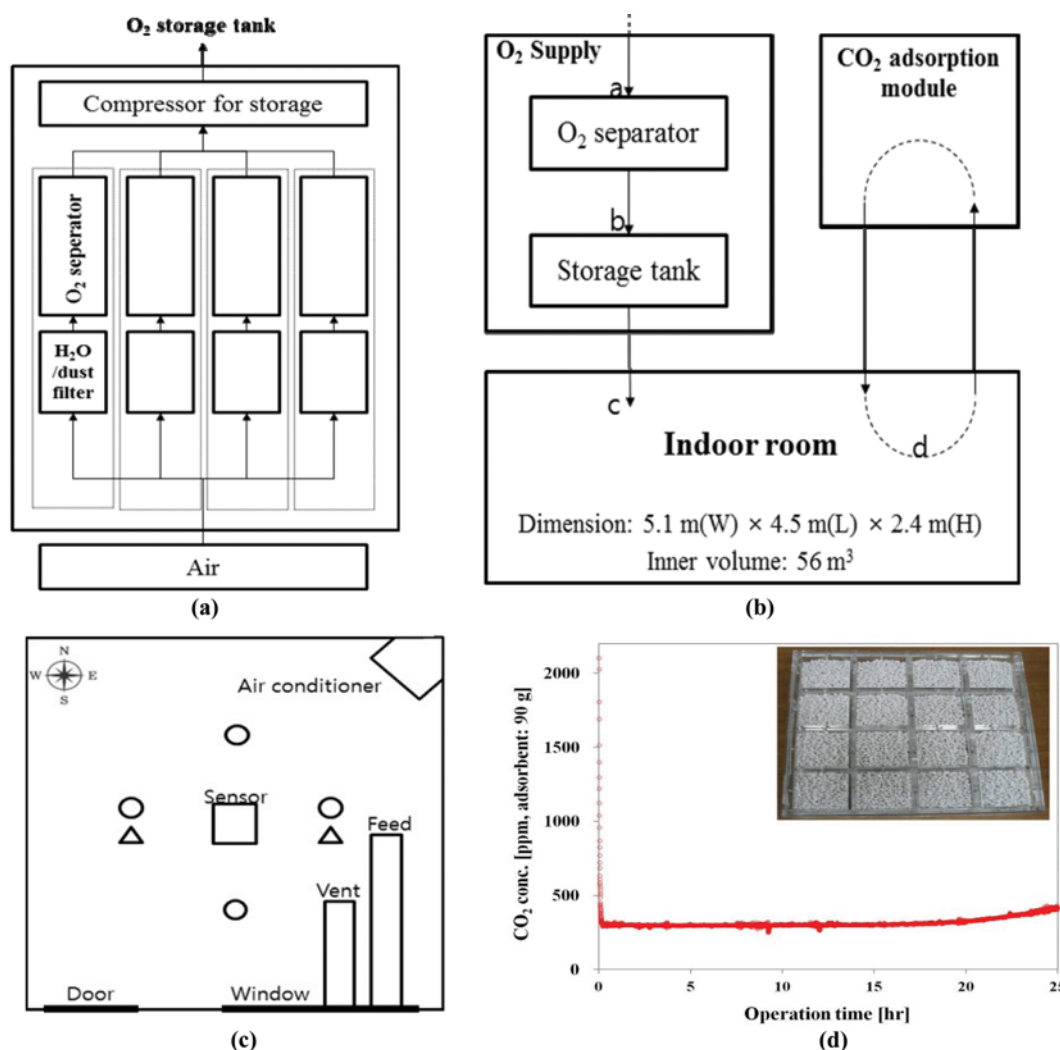


Fig. 1. Schematic diagram of the O<sub>2</sub> separator and ventilation system with CO<sub>2</sub> adsorption module for the improvement of the indoor air quality.

((a) O<sub>2</sub> separator, (b) ventilation system with O<sub>2</sub> separator and CO<sub>2</sub> adsorption module, (c) specification of indoor room for the ventilation system and the position of person (○: Position of 4 persons, △: Position of 2 persons), (d) picture of adsorption module and CO<sub>2</sub> break-through curve of adsorbent for CO<sub>2</sub> removal)

## EXPERIMENTAL

Fig. 1 shows a diagram of the O<sub>2</sub> separator (Dimension: 60 cm (W)×60 cm (L)×150 cm (H)) used in the room ventilation system combined with CO<sub>2</sub> adsorption module. The O<sub>2</sub> separator, which is in parallel composed of four adsorbent-packed beds, was operated by the inflow of air into the adsorbent-packed bed through the filter for moisture/dust removal. The O<sub>2</sub> thus separated and concentrated was discharged into the air-conditioned test room. In the O<sub>2</sub> separation/concentration process, the flow rate for the inflow into the bed packed by the adsorbent of 1.5 kg was about 60 L/min, and the internal pressure of the bed was automatically controlled by the discharged outflow in the range of 2–12 L/min.

A storage tank was constructed with quality aluminum in order to efficiently supply the flow rate and concentration of concentrated O<sub>2</sub> from the O<sub>2</sub> separator. The storage tank module consisted of four unit-tanks of 22 L individual capacity and the total volume

was about 88 L and could be individually operated by each unit tank in case of necessity. Concentrated O<sub>2</sub> by the O<sub>2</sub> separator was charged with the compressed pressure of 6–8 kg<sub>f</sub>/cm<sup>2</sup> into the storage tank installed with digital pressure gauge. After the storage step into the tank, the concentrated O<sub>2</sub> was discharged with the flow rate controlled by MFC (mass flow controller, Linetech Co. Ltd.) and was supplied to the indoor room.

The indoor room has dimensions of 5.1 m (W)×4.5 m (L)×2.4 m (H) and inner volume of 56 m<sup>3</sup> and its indoor temperature was controlled and maintained by an air conditioner. The feed and vent pipes for the circulation between the outdoor and indoor air were wall-mounted and located at a height of 1.8 m from the ground as shown in Fig. 1(c).

The O<sub>2</sub> supplying part, which was composed of the O<sub>2</sub> separator and the storage tank, was constructed outdoors and then concentrated O<sub>2</sub> by O<sub>2</sub> separator from outdoor air was supplied into the indoor.

To remove the indoor CO<sub>2</sub> generated by people breathing, the CO<sub>2</sub> adsorption module packed with the commercial Li-based adsorbent (Anytech Co. Ltd., Model: ACE-04, CO<sub>2</sub> adsorption capacity = 0.896 mmol<sub>CO<sub>2</sub></sub>/g<sub>adsorbent</sub>) of 0.8 kg (volume: 1.5 L) was constructed outdoors. The picture and adsorption breakthrough curve of the adsorption module for indoor CO<sub>2</sub> removal are shown in Fig. 1(d). The indoor CO<sub>2</sub> was removed by the circulation of the indoor air of about 3.4 N/m<sup>3</sup> through the adsorbent bed of the outdoor CO<sub>2</sub> adsorption module.

In each step for the inflow and discharge of O<sub>2</sub>, the flow rate and concentration of O<sub>2</sub> were quantitatively controlled and monitored by MFC and O<sub>2</sub> analyzer (Omega Instruments, Model: s3520), respectively. The indoor concentration of CO<sub>2</sub> was analyzed by the CO<sub>2</sub> sensor calibrated with proofreading process.

We conducted the experimental process for the indoor air quality of the room in accordance with the operation conditions of O<sub>2</sub> separator combined with the storage tank of high purity O<sub>2</sub>. And then the effect of the CO<sub>2</sub> removal with the CO<sub>2</sub> adsorption module operated on the indoor air quality of the room was investigated. The indoor air quality, such as the concentration of indoor CO<sub>2</sub> and O<sub>2</sub>, was monitored with the flow rate of O<sub>2</sub> supplied, the operation of CO<sub>2</sub> adsorption module and the person number occupying the room. The monitoring time was different in accordance with the operation cases because the variation of the concentration of CO<sub>2</sub> and O<sub>2</sub> was limited by the originating condition and then was almost maintained after the monitoring time. In addition, the internal pressure of the storage tank was monitored because the supply of high purity concentrated O<sub>2</sub> from the storage tank into the room was confirmed by the variation of the internal pressure of the storage tank.

In the case of the persons' breathing, the number of individuals in the room varied from 2 to 4 in accordance with the experimental conditions. The results, such as the concentration of CO<sub>2</sub> and O<sub>2</sub>, were mainly influenced by the number of persons. However, we confirmed that the positions of persons in the room did not have an effect on the indoor air quality such as the concentration of CO<sub>2</sub> and O<sub>2</sub> because the inner space volume of the room (56 m<sup>3</sup>) might be simulated as a small space such as an office room to be occupied by 2-4 persons and cannot be influenced by their position. The persons were composed of two men (weight: 65-75 kg, age: 30-35) and two women (weight: 48-53 kg, age: 27-32); their positions are referentially presented in Fig. 1(c). In addition, the humidity of the room was varied in the range of 40-80%; however, its variation did not have an effect on the experimental results such as the concentration of CO<sub>2</sub> and O<sub>2</sub>.

## RESULTS AND DISCUSSION

Fig. 2 shows the indoor concentration of CO<sub>2</sub> and O<sub>2</sub> with and without supplying O<sub>2</sub> which was produced by the outdoor O<sub>2</sub> separator and filled in the storage tank. The room with the two persons' breathing was about 56 m<sup>3</sup> and the concentration and flow rate of O<sub>2</sub> supplied into the room were about 88% and 20 L/min, respectively. In the case of without O<sub>2</sub> supply, the indoor concentration of CO<sub>2</sub> was maintained until 10 min. However, the indoor concentration of CO<sub>2</sub> was raised from about 1,125 ppm after 10 min

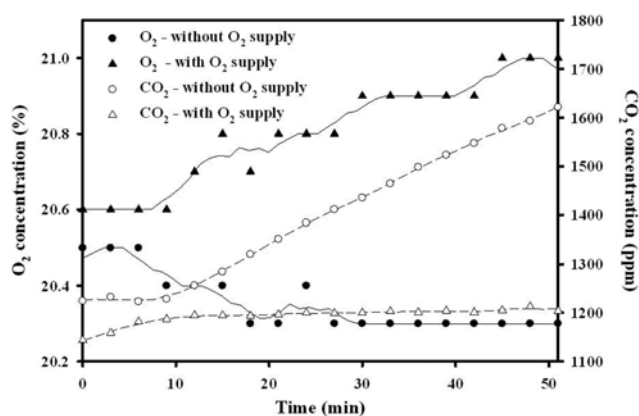


Fig. 2. Indoor concentration of CO<sub>2</sub> and O<sub>2</sub> with and without supplying O<sub>2</sub> into the room having two persons' breathing.

according to the time stream and reached at about 1,518 ppm after 52 min. Also, the indoor concentration of O<sub>2</sub> was decreased from about 20.5 to 20.28%. It was estimated that these results might be due to the fact that the O<sub>2</sub> consumption and the generation of CO<sub>2</sub> were simultaneously carried out in the room with the two persons' breathing. On the other hand, in the case of the supply of O<sub>2</sub> with the flow rate of 20 L/min and the concentration of about 88%, the CO<sub>2</sub> concentration was slightly increased until 12 min and was maintained after 12 min. Also, the O<sub>2</sub> concentration was maintained until about 6 min and was rapidly increased from about 20.6 up to 21.9%. From these results, it was due to the dramatic increase of the O<sub>2</sub> concentration with the O<sub>2</sub> with the sufficient supply of O<sub>2</sub> concentrated in spite of the O<sub>2</sub> consumption and CO<sub>2</sub> generation with two persons' breathing. As a result, it was known that the improvement of the O<sub>2</sub> concentration and the suppression of the CO<sub>2</sub> concentration could be caused by the supply of O<sub>2</sub> from the storage tank after the concentration by PSA-typed O<sub>2</sub> separator.

Fig. 3 shows the variation of the O<sub>2</sub> concentration with the flow rate of O<sub>2</sub> supplied into the room having the two persons' breath-

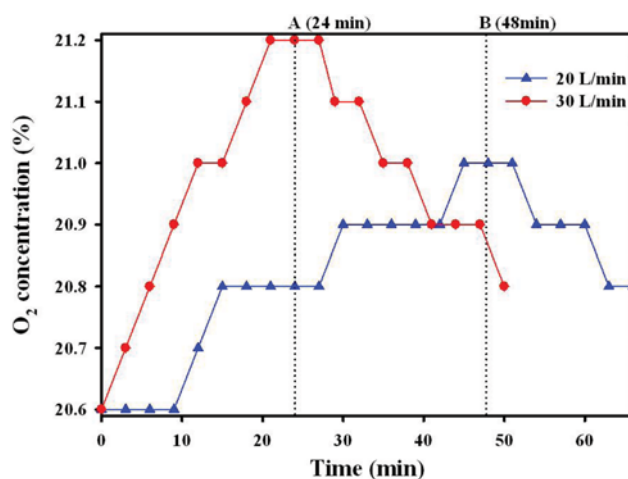


Fig. 3. The variation of the O<sub>2</sub> concentration with the flow rate of the high purity O<sub>2</sub> supplied into the room having the two persons' breathing from the storage tank.

ing from the storage tank. The flow rate of  $O_2$  was varied from 20 to 30 L/min and the  $O_2$  concentration was about 88%. The inner volume of the room was about  $56 \text{ m}^3$ . Regardless of the flow rate variation of  $O_2$  supplied, the monitoring time section was separated and then the points of A and B of Fig. 3 were retention time separated according to before and after interruption of the  $O_2$  supply. In the case of supplying the  $O_2$  flow rate of 20 L/min, the  $O_2$  concentration was maintained until about 9 min and increased from about 20.6% up to 21% after 48 min. However, after 66 min, the  $O_2$  concentration was reduced to about 20.8% during about 18 min of the  $O_2$  supply interruption. In the case of supplying the  $O_2$  flow rate of 30 L/min, the  $O_2$  concentration was rapidly increased up to about 21.2% until 24 min and dramatically decreased to about 20.8% during 26 min with the interruption of  $O_2$  supply after 24 min. As compared with the case of supplying  $O_2$  of 20 L/min, the increasing rate and decreasing rate of the  $O_2$  concentration were increased with the increase of the  $O_2$  flow rate, and this result was caused by the sufficient supply of  $O_2$  concentrated. It was known that the flow rate of  $O_2$  concentrated and supplied into the room from the storage tank has an influence on the indoor air quality such as the concentration of  $O_2$ .

In this section, to investigate the relationship between the indoor air quality and the supply of  $O_2$  from room the outside of the room more carefully, the number of the person presented in the room was more than about four. Fig. 4 shows the concentration of  $O_2$  and  $CO_2$  without the  $O_2$  supply in the room of the four persons' breathing. The  $CO_2$  concentration proportionally increased with the time stream and reached from about 1,380 up to 1,820 ppm after 20 min. On the other hand, the  $O_2$  concentration was maintained at about 20.2% until 9 min, but gradually decreased to about 20.0% after 20 min. As compared with the case of the room having the two persons' breathing in Fig. 4, with the number of the persons present in the room, the increasing rate of the  $CO_2$  concentration and the decreasing rate of the  $O_2$  concentration were increased with the increase of the  $O_2$  consumption and the  $CO_2$  generation.

On the basis of these results, the effect of the  $O_2$  supply and the  $CO_2$  adsorption module on the indoor air quality like the concentration of  $O_2$  and  $CO_2$  monitored will be investigated under the

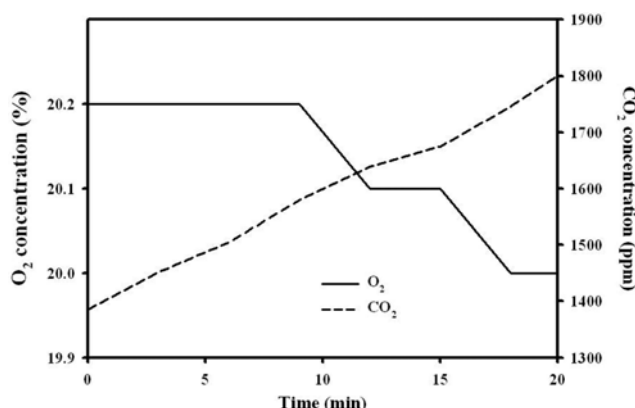


Fig. 4. The concentration of  $O_2$  and  $CO_2$  without the  $O_2$  supply in the room of the four persons' breathing.

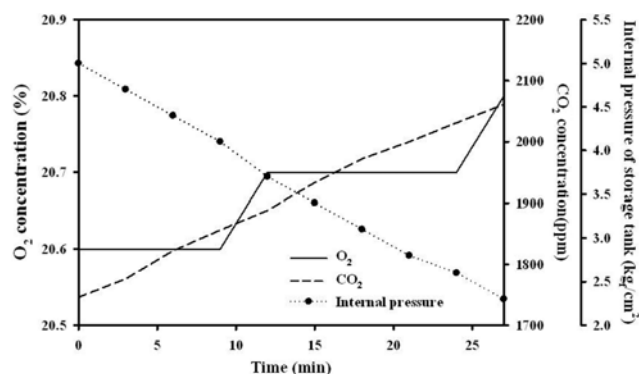


Fig. 5. The indoor concentration of  $O_2$  and  $CO_2$  and the internal pressure of the storage tank varied with the supply of 10 L/min  $O_2$  concentrated from the  $O_2$  storage tank after the  $O_2$  separation without the  $CO_2$  adsorption module.

various conditions.

Fig. 5 shows the indoor concentration of  $O_2$  and  $CO_2$  and the internal pressure of the storage tank varied with the supply of 10 L/min  $O_2$  concentrated from the  $O_2$  storage tank after the  $O_2$  separation without the  $CO_2$  adsorption module. The initial concentration of  $O_2$  and  $CO_2$  was about 20.6% and 1,746 ppm, respectively. The number of the persons present in the room was four and the concentration of  $O_2$  supplied to the room was about 88%. Also, the initial internal pressure of the  $O_2$  storage tank was about  $5 \text{ kg}_f/\text{cm}^2$ . With supplying 10 L/min  $O_2$  concentrated from the storage tank to the room having three persons' breathing, the internal pressure of the storage tank was proportionally decreased and reached to about  $2.3 \text{ kg}_f/\text{cm}^2$  after 27 min. In addition, the concentration of  $O_2$  and  $CO_2$  was gradually increased up to about 20.8% and 2,080 ppm, respectively. Unlike the case of two persons' breathing with the supply of 20 L/min  $O_2$  concentrated to 88% shown in Fig. 5, the  $CO_2$  concentration was increased despite the  $O_2$  supply, because the  $CO_2$  generation may be dramatically increased by the increase of the number of persons present in the room and an insufficient  $O_2$  supply. As compared to the decrease of the  $O_2$  concentration in the case without the supply of  $O_2$  shown in Fig. 5, the  $O_2$  concentration was increased and the increasing rate of  $CO_2$

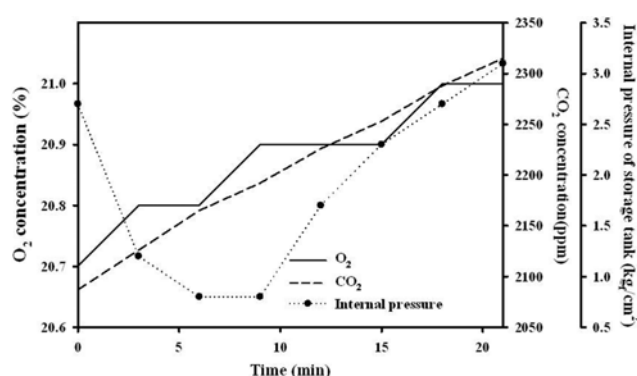


Fig. 6. The indoor concentration of  $O_2$  and  $CO_2$  and the internal pressure of the storage tank varied with the supply of 20 L/min  $O_2$  concentrated without  $CO_2$  adsorption module.

concentration was decreased because the increase of CO<sub>2</sub> concentration was suppressed with the O<sub>2</sub> supply of 10 L/min.

Fig. 6 shows the indoor concentration of O<sub>2</sub> and CO<sub>2</sub> and the internal pressure of the storage tank varied with the supply of 20 L/min O<sub>2</sub> concentrated without CO<sub>2</sub> adsorption module. The initial concentration of O<sub>2</sub> and CO<sub>2</sub> was about 20.7% and 2,080 ppm, respectively. The number of persons present in the room was four and the concentration of O<sub>2</sub> supplied was about 88%. Also, the initial internal pressure of the O<sub>2</sub> storage tank was about 2.8 kg<sub>f</sub>/cm<sup>2</sup>. The internal pressure of the tank was decreased and reached to 0.8 kg<sub>f</sub>/cm<sup>2</sup> until 9 min with supplying O<sub>2</sub> to the room. However, the internal pressure of the tank rapidly increased after 9 min and reached 3.1 kg<sub>f</sub>/cm<sup>2</sup> after 21 min because the O<sub>2</sub> separator was operated by an insufficient storage amount of O<sub>2</sub> as compared with the O<sub>2</sub> amount required for the O<sub>2</sub> supply, and O<sub>2</sub> was generated and stored in the tank. Under this internal pressure variation with the operation of the O<sub>2</sub> separator, the O<sub>2</sub> concentration rapidly increased with higher increasing rate due to the higher amount of O<sub>2</sub> than that of the case of the O<sub>2</sub> supply of 10 L/min and arrived at about 21.0% after 21 min. In addition, the CO<sub>2</sub> concentration increased with lower increasing rate than that of case of the 10 L/min because the increase of CO<sub>2</sub> was suppressed by the high amount of O<sub>2</sub> supplied despite the CO<sub>2</sub> generation with four persons' breathing. From these results, with increasing the O<sub>2</sub> supply, the increasing rate of the O<sub>2</sub> concentration was raised and that of CO<sub>2</sub> concentration was suppressed in the indoor air quality.

Fig. 7 shows the indoor concentration of O<sub>2</sub> and CO<sub>2</sub> and the internal pressure of the storage tank varied with the supply of 30 L/min O<sub>2</sub> concentrated without CO<sub>2</sub> adsorption module. The initial concentration of O<sub>2</sub> and CO<sub>2</sub> was about 21.1% and 2,350 ppm, respectively. The number of persons present in the room was four and the concentration of O<sub>2</sub> supplied was about 88%. Also, the initial internal pressure of the O<sub>2</sub> storage tank was about 3.4 kg<sub>f</sub>/cm<sup>2</sup>. The internal pressure of the tank decreased and reached 1.4 kg<sub>f</sub>/cm<sup>2</sup> until 3 min with supplying O<sub>2</sub> to the room. However, the internal pressure of the tank rapidly increased after 3 min and reached 3.5 kg<sub>f</sub>/cm<sup>2</sup> after 6 min because the O<sub>2</sub> separator combined with the tank pressure was automatically operated by an insufficient storage amount of O<sub>2</sub> as compared with the O<sub>2</sub> amount required

for the O<sub>2</sub> supply, and O<sub>2</sub> was generated and stored in the tank. As compared with the case of the supply of 20 L/min O<sub>2</sub>, the decreasing rate with the O<sub>2</sub> supply and the increasing rate with the operation of the O<sub>2</sub> separator were increased by the supply and generation of the O<sub>2</sub> amount increased from the viewpoint of the internal pressure of the tank. The O<sub>2</sub> concentration was more rapidly increased and the CO<sub>2</sub> concentration was more slightly increased than those of the cases of 10 and 20 L/min due to the sufficient amount of O<sub>2</sub> supply as compared to the cases of 10 and 20 L/min.

From these results without CO<sub>2</sub> adsorption module, it was concluded that the indoor air quality with the improvement of the O<sub>2</sub> concentration and the suppression of CO<sub>2</sub> concentration could be improved by the increase of the O<sub>2</sub> supply.

In this section, the CO<sub>2</sub> adsorption module was applied in order to improve the indoor air quality more than the case of only O<sub>2</sub> supply. To investigate the effect of the O<sub>2</sub> supply system combined with CO<sub>2</sub> adsorption module on the indoor air quality of the room, the concentration of O<sub>2</sub> and CO<sub>2</sub> was monitored with the amount variation of the O<sub>2</sub> supplied with the operation of the CO<sub>2</sub> adsorption module. The amount of CO<sub>2</sub> adsorbent packed in the module having the inner volume of 1.5 L was about 0.8 kg. Also, the flow rate of the indoor air circulated for the CO<sub>2</sub> removal was about 3.3 Nm<sup>3</sup>/min.

Fig. 8 shows the indoor concentration of O<sub>2</sub> and CO<sub>2</sub> and the internal pressure of the storage tank varied with the supply of 10 L/min O<sub>2</sub> under the operation of the CO<sub>2</sub> adsorption module. The initial concentration of O<sub>2</sub> and CO<sub>2</sub> was about 20.7% and 1,700 ppm, respectively. The number of persons present in the room was four and the concentration of O<sub>2</sub> supplied to the room was about 88%. Also, the initial internal pressure of the O<sub>2</sub> storage tank was about 5.0 kg<sub>f</sub>/cm<sup>2</sup>. With the O<sub>2</sub> supply to the room, the internal pressure of tank was continuously decreased and reached to about 1.6 kg<sub>f</sub>/cm<sup>2</sup>. The O<sub>2</sub> concentration was increased after 15 min and arrived at about 20.9% with the O<sub>2</sub> supply, and then its increasing rate was higher than that of the case without CO<sub>2</sub> adsorption module. This result may be due to the sufficient O<sub>2</sub> supply as compared to the amount of O<sub>2</sub> required despite the O<sub>2</sub> consumption and CO<sub>2</sub> generation with four persons' breathing. The CO<sub>2</sub> concentration increased by CO<sub>2</sub> generated with the four persons; however, its rate

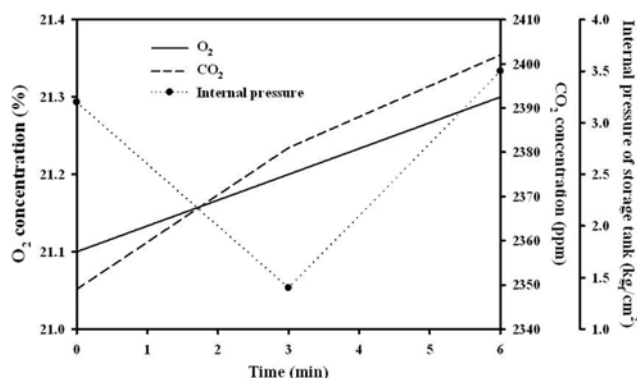


Fig. 7. The indoor concentration of O<sub>2</sub> and CO<sub>2</sub> and the internal pressure of the storage tank varied with the supply of 30 L/min O<sub>2</sub> concentrated without CO<sub>2</sub> adsorption module.

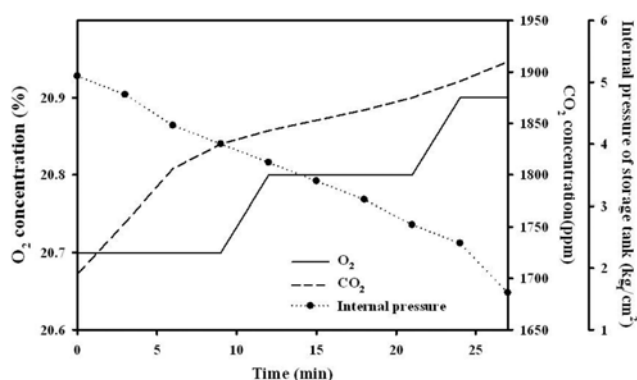


Fig. 8. The indoor concentration of O<sub>2</sub> and CO<sub>2</sub> and the internal pressure of the storage tank varied with the supply of 10 L/min O<sub>2</sub> under the operation of the CO<sub>2</sub> adsorption module.

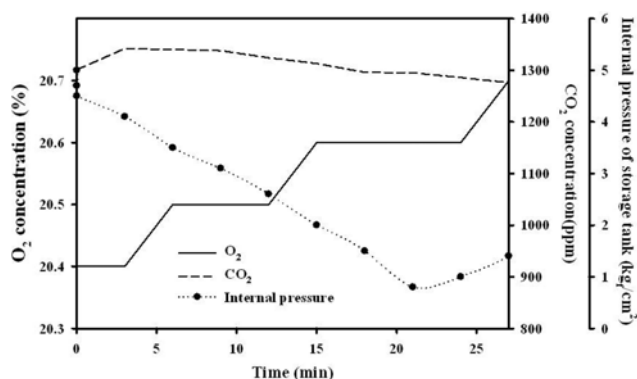


Fig. 9. The indoor concentration of O<sub>2</sub> and CO<sub>2</sub> and the internal pressure of the storage tank varied with the supply of 20 L/min O<sub>2</sub> under the operation of the CO<sub>2</sub> adsorption module.

of increase was lower than that of the case without the CO<sub>2</sub> adsorption module. Consequently, it was concluded that the indoor air quality was improved by the CO<sub>2</sub> removal with the CO<sub>2</sub> adsorption module as compared with the O<sub>2</sub> supply without the CO<sub>2</sub> adsorption module.

Fig. 9 shows the indoor concentration of O<sub>2</sub> and CO<sub>2</sub> and the internal pressure of the storage tank varied with the supply of 20 L/min O<sub>2</sub> under the operation of the CO<sub>2</sub> adsorption module. The initial concentration of O<sub>2</sub> and CO<sub>2</sub> was about 20.4% and 1,300 ppm, respectively. The number of persons present in the room was four and the concentration of O<sub>2</sub> supplied was about 88%. Also, the initial internal pressure of the O<sub>2</sub> storage tank was about 4.5 kg<sub>f</sub>/cm<sup>2</sup> and the amount of the indoor air circulated for the CO<sub>2</sub> removal was about 3.3 Nm<sup>3</sup>/min. The internal pressure of the tank was decreased and reached 0.8 kg<sub>f</sub>/cm<sup>2</sup> until 21 min with supplying O<sub>2</sub> to the room. However, the internal pressure of the tank was increased after 9 min and reached 1.4 kg<sub>f</sub>/cm<sup>2</sup> after 21 min because the O<sub>2</sub> separator was operated by an insufficient storage amount of O<sub>2</sub> as compared with the O<sub>2</sub> amount required for the O<sub>2</sub> supply, and then concentrated O<sub>2</sub> was generated and stored in the tank. With the O<sub>2</sub> supply of 20 L/min combined with the CO<sub>2</sub> adsorption module, the O<sub>2</sub> concentration was increased to about 20.7% after 27 min and then its increasing rate was higher than that of the case of the supply of 10 L/min. However, the CO<sub>2</sub> concentration was slightly increased in the initial time and was maintained in the short range

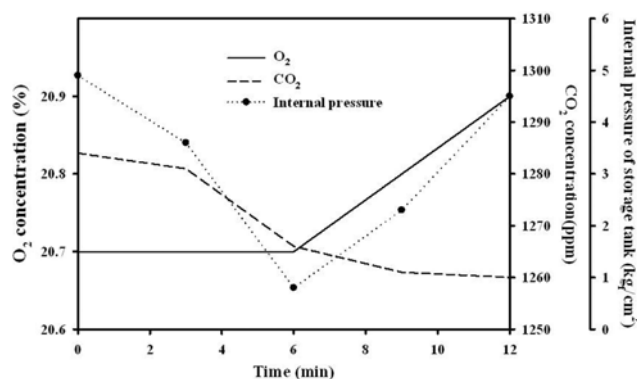


Fig. 10. The indoor concentration of O<sub>2</sub> and CO<sub>2</sub> and the internal pressure of the storage tank varied with the supply of 30 L/min O<sub>2</sub> under the operation of the CO<sub>2</sub> adsorption module.

of 1,280 and 1,340 ppm after 3 min. These results may be due to the fact that the CO<sub>2</sub> concentration was not increased by the CO<sub>2</sub> removal with the adsorption module despite the CO<sub>2</sub> generation with four persons' breathing as compared to the case without the CO<sub>2</sub> adsorption module.

Fig. 10 shows the indoor concentration of O<sub>2</sub> and CO<sub>2</sub> and the internal pressure of the storage tank varied with the supply of 30 L/min O<sub>2</sub> under the operation of the CO<sub>2</sub> adsorption module. The initial concentration of O<sub>2</sub> and CO<sub>2</sub> was about 20.7% and 1,280 ppm, respectively. The number of the persons in the room was four and the concentration of O<sub>2</sub> supplied was about 88%. Also, the initial internal pressure of the O<sub>2</sub> storage tank was about 4.5 kg<sub>f</sub>/cm<sup>2</sup> and the amount of the indoor air circulated for the CO<sub>2</sub> removal was about 3.3 Nm<sup>3</sup>/min. The internal pressure of the tank was decreased and reached 0.8 kg<sub>f</sub>/cm<sup>2</sup> until 6 min with supplying O<sub>2</sub> to the room. However, the internal pressure of the tank was increased after 6 min and reached 4.5 kg<sub>f</sub>/cm<sup>2</sup> after 12 min because the O<sub>2</sub> separator was operated by an insufficient storage amount of O<sub>2</sub> as compared with the O<sub>2</sub> amount required for the O<sub>2</sub> supply and then concentrated O<sub>2</sub> was generated and stored in the tank. The O<sub>2</sub> concentration was maintained until 6 min and rapidly increased after 6 min. And then its increasing rate was higher than that of the case without the CO<sub>2</sub> adsorption module and with the O<sub>2</sub> supply of 10 and 20 L/min. Also, the CO<sub>2</sub> concentration was slightly decreased to about 1,260 ppm after 12 min. In this case, the increasing rate of

Table 1. Effect of the CO<sub>2</sub> adsorption and O<sub>2</sub> flow rate on the variation of the indoor air quality

Usage of CO <sub>2</sub> adsorption (--)	w/			w/o		
Flow rate of O <sub>2</sub> supplied (L/min)	10	20	30	10	20	30
ΔCO <sub>2</sub> concentration (ppm)	341	228	53	206	-37	-21
ΔO <sub>2</sub> concentration (%)	0.1	0.3	0.2	0.2	0.2	0.3
Increasing rate of CO <sub>2</sub> concentration (ppm/min)	11.4	10.9	8.8	7.6	-2.1	-2.3
Increasing rate of O <sub>2</sub> concentration (ppm/min, ×10 <sup>-3</sup> )	3.3	14.3	33.3	7.4	16.7	33.3

\*ΔCO<sub>2</sub> concentration (ppm)=CO<sub>2</sub> concentration<sub>after ventilation</sub>-CO<sub>2</sub> concentration<sub>before ventilation</sub>

\*ΔO<sub>2</sub> concentration(ppm) = O<sub>2</sub> concentration<sub>after ventilation</sub>-O<sub>2</sub> concentration<sub>before ventilation</sub>

\*Increasing rate of CO<sub>2</sub> concentration (ppm/min)=ΔCO<sub>2</sub> concentration/Duration time for ventilation

\*Increasing rate of O<sub>2</sub> concentration (ppm/min)=ΔO<sub>2</sub> concentration/Duration time for ventilation

the O<sub>2</sub> concentration and the decreasing rate of the CO<sub>2</sub> concentration were increased by the simultaneous O<sub>2</sub> supply and CO<sub>2</sub> removal as compared to the case without the CO<sub>2</sub> adsorption module and with O<sub>2</sub> supply of 10 and 20 L/min. As a result, it was concluded that the indoor air quality could be improved by the increase of the O<sub>2</sub> supply and the CO<sub>2</sub> removal with the CO<sub>2</sub> adsorption module.

To discuss synthetically about the various results above mentioned, the effect of CO<sub>2</sub> adsorption and O<sub>2</sub> flow rate on the variation of the indoor air quality was listed in Table 1. Regardless of the usage of CO<sub>2</sub> adsorption, the concentration increasing rate of CO<sub>2</sub> and O<sub>2</sub> was respectively and simultaneously decreased and increased with the increase of the amount of O<sub>2</sub> supplied into the room, and then it was known that the indoor air quality was improved by the supply of high purity concentrated O<sub>2</sub> from outside. In addition, without reference to the amount of O<sub>2</sub> supplied, the CO<sub>2</sub> concentration was not steeply increased but also slightly decreased and then the increasing rate of O<sub>2</sub> concentration was increased in accordance with using the CO<sub>2</sub> adsorption module despite four persons' breathing under the supply of the identical O<sub>2</sub> amount. As a result, it was concluded that the indoor air quality was improved by both the artificial CO<sub>2</sub> removal with the CO<sub>2</sub> adsorption module and the supply of high purity O<sub>2</sub> concentrated from outside.

### CONCLUSIONS

In a room ventilation system with CO<sub>2</sub> adsorption module to improve the indoor air quality, a PSA-type O<sub>2</sub> separator combined with the storage tank was used to control the concentration of O<sub>2</sub> and CO<sub>2</sub>. The O<sub>2</sub> separator, which was combined with the storage tank to supply O<sub>2</sub> efficiently through the preservation, was used for the production of O<sub>2</sub>. Also, the CO<sub>2</sub> adsorption module was used for the removal of CO<sub>2</sub> generated by the people breathing. O<sub>2</sub> consumed by the people breathing was replenished by the supply of the concentrated O<sub>2</sub> which was produced by the O<sub>2</sub> separator outside of the room. And then CO<sub>2</sub> generated by the people breathing was removed by the CO<sub>2</sub> adsorption module. Therefore, these processes lead to the improvement of the concentration of O<sub>2</sub> and CO<sub>2</sub>. It was concluded that the indoor air quality of the room deteriorated by O<sub>2</sub> consumed and CO<sub>2</sub> generated by the people breathing could be improved by the artificial O<sub>2</sub> supply and CO<sub>2</sub> removal, and then these process can be realized through a room ventilation

system composed of the O<sub>2</sub> separator with the storage tank and CO<sub>2</sub> adsorption module.

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