Tropical Agricultural Research Vol. 26 (4): 714 – 720 (2015)
Short Communication

The Effect of Thermal Conditions on CO_2 Distribution in a Greenhouse

Hee Tae Kim, Chi Ho Kim, Eun Gyu Choi, Byung Ok Jin
Yong Cheol Yoon[1], and Hyeon Tae Kim[*]

Department of Bio-Industrial Machinery Engineering
Gyeongsang National University
(Institute of Agriculture & Life Science), Jinju, Korea

ABSTRAC: *An experiment was conducted to determine the extent to which the distribution of CO_2 depended on the thermal conditions within a greenhouse. The CO_2 levels and the change in the horizontal temperature gradient were measured throughout the greenhouse. The appropriate level of CO_2 and the concentrated mass of CO_2 were analyzed at predetermined points to verify the relation between CO_2 and temperature to establish whether a constant distribution existed throughout the facility. As a result, when using the membrane system, the CO_2 concentrations external and internal to the greenhouse were measured to be 380~440 ppm and 1020 ppm, respectively. The efficiency of the membrane system was shown to be about 268%. The highest CO_2 concentration was about 1000 ppm near the floor, where the temperature was the lowest. In contrast, at a height of 2.50 m, where the temperature was the highest, the CO_2 concentration was the lowest at about 400~500 ppm.*

Keyword: *Carbon dioxide concentration, efficiency, greenhouse, membrane system, temperature*

INTRODUCTION

The cultivation of crops is a focused effort intended to overcome problems currently associated with agriculture. Unlike the outdoor growth environment, cultivation in green house creates an environment that is conducive for the mass production of high quality products in a controlled environment. Application of high concentration of CO_2 has been reported to promote effective germination and yield growth, to promote the rapid transplantation survival of roots, to improve flower or fruit size, to increase the shelf life, and to maintain the uniform quality of the crop. In fact, this gas, together with water is a major component not only with regard to the process of photosynthesis, but also for achieving an increase in the productivity (in dry-weight) and quantity of greenhouse crops within facilities (Nederhoff and Vegter, 1994). Efficiency is a key factor in the use of CO_2, because its use may cause considerable expenses to be incurred (Kläring *et al.*, 1997). The efficiency of photosynthesis and productivity was found to increase when high CO_2 levels were maintained in facilities where crops such as paprika and tomatoes are cultivated. This was also the case with peppers, where CO_2 levels as high as 700~1,000 ppm were utilized under low intensity or at a low temperature in the winter or spring seasons to increase the CO_2

[1] Dept. of Agricultural Engineering, Gyeongsang National Univ. (Institute of Agriculture & Life Science), Jinju, Korea
[*]. Corresponding author: bioani@gnu.ac.kr

absorption of the crops and thus the productivity (Sanchez-Guerrero *el al.*, 2005). Although maintaining a high CO_2 concentration within a facility may have a positive effect on paprika production, high levels of CO_2 would at the same time reduce the efficiency with which the CO_2 is utilized. This indicates the importance of considering the most economical CO_2 levels. When the temperature is taken into consideration, CO_2 fertilization within a greenhouse is known to improve the crop yield (as mentioned above), although the excessive use of CO_2 has given rise to concern. Thus, an experiment was conducted to check the extent to which the distribution of CO_2 depends on the thermal conditions within the greenhouse. This involved measuring the CO_2 content and the change in temperature across different areas within the greenhouse. In addition, appropriate CO_2 levels and the mass of CO_2 that is concentrated in specific areas were analyzed to verify the relation between CO_2 and temperature to ensure a constant distribution over the facility.

METHODOLOGY

This experiment was conducted for 18 weeks from June 1, 2012 to October 10, 2012, within a greenhouse made of glass with a size of 300 m^3. The greenhouse was completely sealed with the exception of the entrance. A high-efficiency membrane system was used to infuse and maintain a proper level of CO_2 in the experiment (Figure 1). The membrane system is based on a technology designed to separate gases by means of a membrane. In the case of air, when a mass of compressed air is supplied into one of the membrane chambers at a certain pressure, and the pressure in the opposing chamber is lower, specific gases, such as CO_2, that have a higher permeation rate than N_2, will permeate the membrane fast, while gases, such as N_2, with a low permeation rate remain within the hollow fibre membrane, which produces a high concentration of N_2 and CO_2 (Figure 2).

Fig. 1. Composition of membrane system

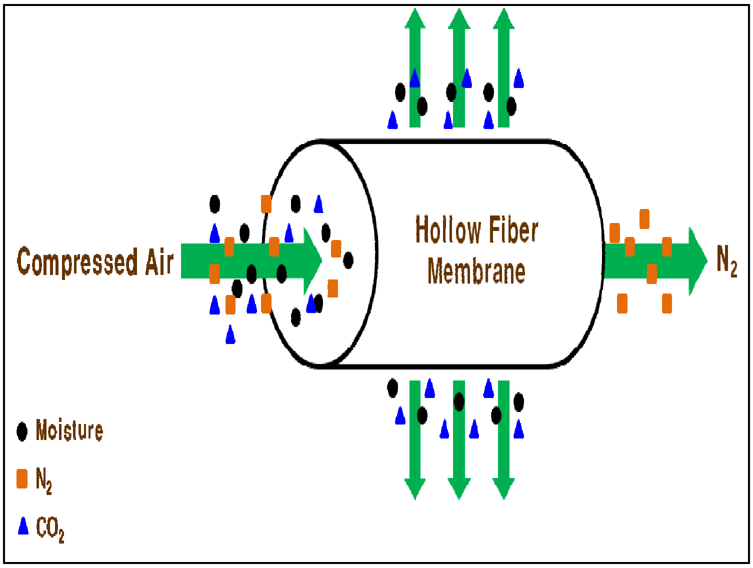

Fig. 2. Principle of membrane system

The membrane has several advantages, such as low energy consumption, simplicity of the technique and equipment, selectivity, ease of processing, and low investment and operating costs. Therefore, compared to other methods, gas separation technique has gained considerable interest, because of its simplicity. Inside the greenhouse in which the experiment was conducted, the average initial CO_2 concentration was 389.5 ppm. The CO_2 that was used in the experiment was concentrated due to having permeated the membrane. With the concentration maintained at approximately 1004.5 ppm, the CO_2 was transferred to the greenhouse at a rate of 160 L/min through an inlet that is located 2.6 m above the entrance. The temperature and CO_2 concentration were measured using Testo 535 and Testo 905-T1 measuring equipment that were placed together for the duration of the experiment (Table 1.). Measuring was conducted at the 125 points designated within the greenhouse, from a point 0.3 m above the floor upward at intervals of 0.55 m, and from a point 30 cm from the outer wall horizontally at intervals of 1.3 m. On October 7, 2012, at 2 pm the temperature was 20^{o}C and the outdoor CO_2 concentration was 385 ppm. Next, concentrated CO_2 (1015 ppm) was separated and transferred into the greenhouse, inside which the average temperature was 40^{o}C. The general distribution of temperature within the greenhouse was measured and presented by means of Sigma Plot Ver.10.0 just as CO_2.

RESULTS AND DISCUSSION

This experiment was conducted for 18 weeks from June 1, 2012 to October 10, 2012. The results showed that the use of the membrane system made it possible to increase the internal CO_2 concentration of the greenhouse to 1020 ppm from its usual level of 380 ~ 440 ppm as measured outside of the greenhouse. The efficiency of the membrane system is shown to be about 268% (Table 1).

Table 1. Greenhouse external and internal CO_2 concentrations (ppm)

External CO_2 concentrations

Date / Time	6/15	8//16	8/17	8/18	9/19	9/20	10/8
8	376.5	380.1	396.2	387.8	385.8	376.5	385.7
12	388.3	397.2	400.3	387.2	395.4	408.3	384.8
18	383.1	386.3	396.6	379.9	393.0	395.3	395.2

External CO_2 concentrations

Date / Time	6/15	8//16	8/17	8/18	9/19	9/20	10/8
8	973.6	989.1	983.6	1010.2	1015.3	985.2	990.9
12	986.4	1009.1	1056.8	997.4	1017.6	987.3	988.4
18	995.2	1101.0	999.7	985.8	1023.5	1001.3	997.3

The analysis refers to data that was obtained on October 7, 2012. Figures 3-5 show the vertical distribution of CO_2 within the greenhouse. The lowest level at which CO_2 measurements were taken was 0.3 m above the floor of the greenhouse. The CO_2 was found to be concentrated in the corners of the greenhouse farthest away from the CO_2 inlet and on the opposite side in relation to the centre of the y-axis. The flow rate of the CO_2 entering the greenhouse decreased gradually beyond a distance of 4 m, and was concentrated from that point downwards. Above that point, the level of CO_2 was only concentrated in certain areas. Its dispersion in the opposite direction was thought to have been caused by the interference of objects when the CO_2 was transferred into the facility. The horizontal and vertical temperature gradients were also likely to affect the concentration.

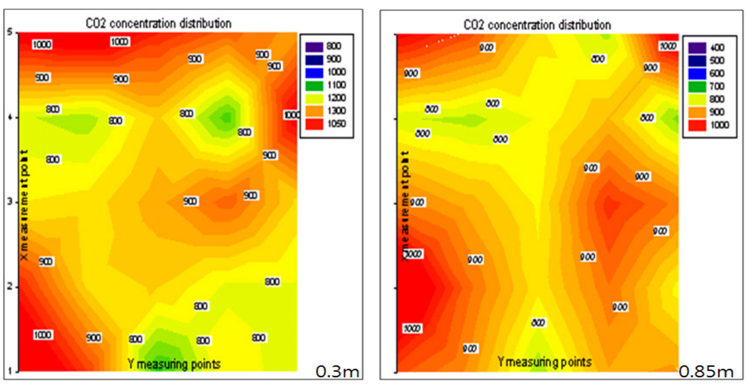

Fig. 3. Location-specific CO_2 distribution in the greenhouse (at heights between 0.3 m and 0.85 m)

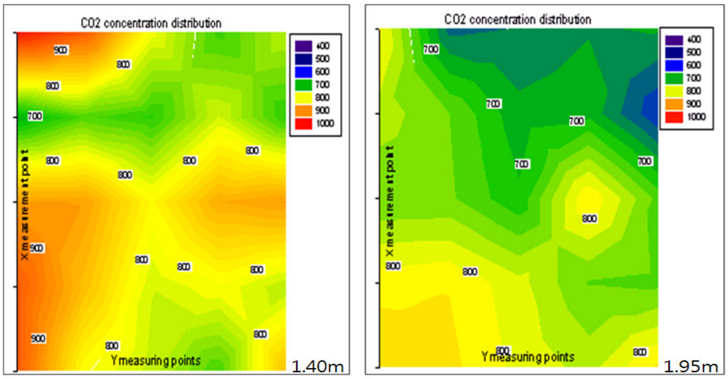

Fig. 4. Location-specific CO_2 distribution in the greenhouse (at heights between 1.40 m and 1.95 m)

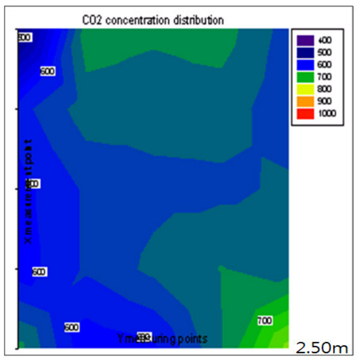

Fig.5. Location-specific CO_2 distribution in the greenhouse (at a height of 2.50 m)

Figures 6 and 7 show the relation between the temperature and the CO_2 concentration within the greenhouse, and this was the point of reference for comparing the measurements at different locations. The temperature distribution within the greenhouse is shown in Figure 6, the difference was distinguished with increasing height above the floor. Except for one or two points, the distribution was constant at all points. The difference in temperature was about 25°C between the highest and the lowest points. The distribution of CO_2, shown in Figure 7, was inversely proportional to the temperature. The highest CO_2 concentration was about 1000 ppm at the bottom, at the level at which the temperature was the lowest, while, at a height of 2.50 m, where the temperature was the highest, the CO_2 concentration was at its lowest at about 400~500 ppm. The horizontal temperature variation across the middle layer indicates that in certain areas the temperature remained unchanged with increasing height above the floor. The distribution of the CO_2 concentration exhibited a similar tendency. The distribution of CO_2 in the facility and its variation according to temperature was measured by determining the distribution of CO_2 in the greenhouse at each temperature point, and the relation between CO_2 and the temperature was analyzed with regard to the constancy of CO_2 distribution and what is considered to be an appropriate level of CO_2 within the greenhouse.

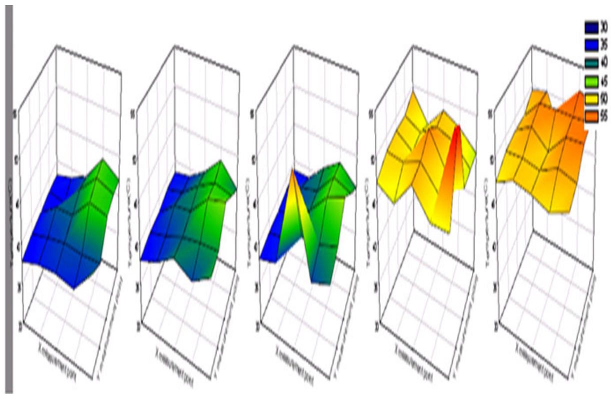

Fig. 6. **Temperature distribution as a function of height in the greenhouse**

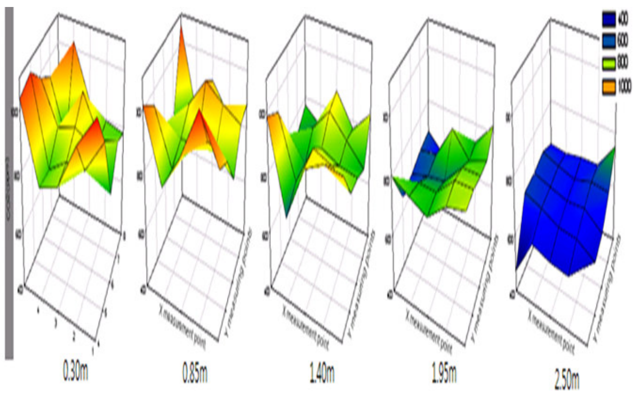

Fig. 7. **CO_2 distribution as a function of height in the greenhouse**

CONCLUSIONS

The distribution of CO_2 within the facility was measured as a function of the temperature and location to analyze the actual levels of CO_2 within the facility and the unequal distribution of CO_2 with the aim of verifying the relation between the CO_2 concentration and temperature. As a result, the temperature and the distribution of CO_2 were measured a predefined points. The comparison established that the temperature was inversely proportional to the CO_2 concentration. However, increase in the accuracy and number of measurements would enable a large volume of data to be accumulated and contribute to the clarification of the relation between CO_2 and thermal conditions which are considered to be the best environmental enablers to help crops grow.

ACKNOWLEDGEMENT

This study was performed with the support from the Rural Development Administration Research Project (PJ010000).

REFERENCES

Klaring, H.P., Schwarz, D. and HeiBer, A. (1997). Control of nutrient solution concentration in tomato crop using models of photosynthesis and transpiration. Acta Hortic.*, 450,* 329 - 334.

Nederhoff, E.M. and Vegter, J.G. (1994). Photosynthesis of stands of tomato, cucumber and sweet pepper measured in greenhouses under various CO_2 concentrations. Ann. Preprints of the 2013 IFAC Bio-Robotics Conference Sakai, Japan, March 27 - 29, 2013 Copyright @2013 IFAC Bot. *73,* 353 - 361.

Sanchez-Guerrero, M.C., Lorenzo, P., Medrano, E., Castilla, N., Soriano, T. and Baille, A. (2005). Effect of variable CO2 enrichment on greenhouse production in mild winter climates. Agric. For. Meteorol. *132,* 244 - 252.