DEVELOPMENT OF A METHOD FOR CONTROLLING GAS CONCENTRATION FOR USE IN C.A EXPERIMENTS

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ABSTRACT

Based on the viscous flow characteristics of gas through capillary tube, a simple and low cost system was developed for controlling gas concentration for use in C.A experiments.

The gas flow rate through capillary tube had a linear relationship with pressure, $(length)^{-1}$ and $(radius)^4$ of capillary tube, which agreed well with Hagen-Poiseuille's law. The developed system could control the gas concentration in storage chamber within $\pm 0.3\%$ deviation compared to the preset concentration. The required time for producing target gas concentration in storage chamber was exactly predicted by the model used in this study, and it required much longer time than the calculated time which divided the volume of chamber by flow rate. Therefore, for producing target gas concentration as quickly as possible, it needs to supply higher flow rate of gas during the initial stage of experiment when gas concentration in storage chamber has not reached at target value.

It appeared that the developed system was very useful for C.A experiments. Because one could decide a desired flow rate by the prediction model, control flow rate freely and easily by changing pressure in the pressure-regulating chamber and the accuracy was high.

Key Words : Gas-mixing, Capillary tube, Gas flow, Gas concentration, C.A

INTRODUCTION

The controlled atmosphere storage or modified atmosphere storage, which controls O_2, CO_2 and N_2 concentration of the air in the storage room or packages, is used for preserving quality of agricultural products. For practical use of these storage methods, studies in post-harvest physiology have to be conducted, and this entail use of controlled atmosphere. Most of such experiments require O_2 levels between 0.1% and 10%, CO_2 levels between 1% and 30%, and with the remainder being N_2. More over, it needs many storage chambers, different level of gas concentration in each storage chamber and continuous flow of test atmosphere. However, the commercial gas mixing system is too expensive for use in the laboratory and so lower cost and simple system is needed.

Pratte(1960) suggested a method for controlling gas concentration using flow control

system which is composed of the Mariotte bottle, capillary tube and flow meter. This is considered as a low cost and accurate method, but it is very complicated for controlling gas concentration of each storage chambers in different levels.

Therefore, this study was carried out to develop a low cost and simple system for use in C.A experiments by improving the Pratte's method, which controls gas concentration of each storage chambers in different levels with continuous flow of gas. Also, the accuracy of developed system was discussed and technical suggestions are described for efficient design and proper use of the developed system.

MATERIALS AND METHODS

Theory of Fluid Flow in Capillary Tube

The laminar flow through a capillary tube can be described by the Hagen-Poiseuille law. It is stated that the flow rate is proportional to the pressure difference between the ends of the tube and the fourth power of its radius as equation (1).

$$Q = \pi r^4 \Delta P / 8\mu L \quad \text{----------} \quad (1)$$

where, Q : gas flow rate($m\ell$/s)
ΔP : pressure difference between the ends of tube(Pa)
R : radius of tube(mm)
L : length of tube(mm)
μ : viscosity of fluid(Pa·s)

Therefore, the flow rate of gas through capillary tube can be changed as pressure difference, length or radius of capillary tube. The developed system in this study was based on this principle.

Calibration of Gas Flow Rate

The gas flow rate through capillary tube was calibrated according to the gas pressure, the length and the diameter of capillary tube. The ranges of parameters used calibration were 490～4,000Pa of pressure, 100～600mm of length and 0.3048mm, 0.5588mm and 0.8128mm of diameter. Gas flow rate was measured by a digital bubble flow meter (Optiflow 570, Humonics Co.). Capillary tube was used (Cole-Parmer Co.'s) made of Teflon.

Test of the Precision of Developed System

To verify the precision of developed system, gas concentration of storage chamber was controlled within the range of 0～4% O_2, 2～10% CO_2, and the remainder being N_2.

Required pressure, length and diameter of capillary tube for producing a certain level of gas concentration were decided from calibration result. Measured gas concentration was compared to the preset concentration. Gas concentration was measured by a packaging atmosphere analyzer(Maptest 4000, Hitech Instruments Ltd).

Prediction of Required Time for Producing Target Gas Concentration

It is assumed that gas is supplied with constant flow rate to storage chamber, then mixed fully with the remaining gas in the chamber, and then discharged outside. In this case, the required time that the gas concentration of storage chamber is reached at target concentration can be predicted by equation (2). The gas concentration according to elapsed time and gas flow rate were measured using 1,000 mℓ/min and 570.6 mℓ/min of N_2 gas and 29,850 mℓ of storage chamber.

$$C_{xt} = C_{xi} - \int (C_{xi} * Q / V)\, dt + \int (C_{xs} * Q / V)\, dt \quad \text{--------} \quad (2)$$

Where, C_{xt} : gas concentration in storage chamber at time t (%)
C_{xi} : gas concentration in storage chamber at time t-Δ t(%)
C_{xs} : supplied gas concentration(%)
Q : flow rate of supplied gas(mℓ/min)
V : volume of storage chamber(mℓ)
Δ t : time interval(min)

RESULTS AND DISCUSSION

Development of Gas Concentration Controlling System

Fig.1 shows the schematic diagram of developed system. It was composed of gas tanks, pressure-regulating chambers, digital pressure meters, needle valves, capillary tubes and storage chambers. Each gas tank has a pressure regulator for constant gas flow from gas tank to pressure-regulating chamber although quantity of gas in gas tank is decreased. Pressure in the pressure-regulating chamber is controlled and confirmed by the digital pressure meter and the needle valve which are installed on the pressure-regulating chamber, and then gas is supplied to capillary tubes with a certain pressure. Discharged gas from capillary tubes have different flow rate according to length, diameter of capillary tube and applied pressure. Among them, proper O_2, N_2, and CO_2 gas are selected and mixed for producing desired concentration. Mixed gas at a certain level of concentration is supplied into the storage chamber and discharged through the chamber.

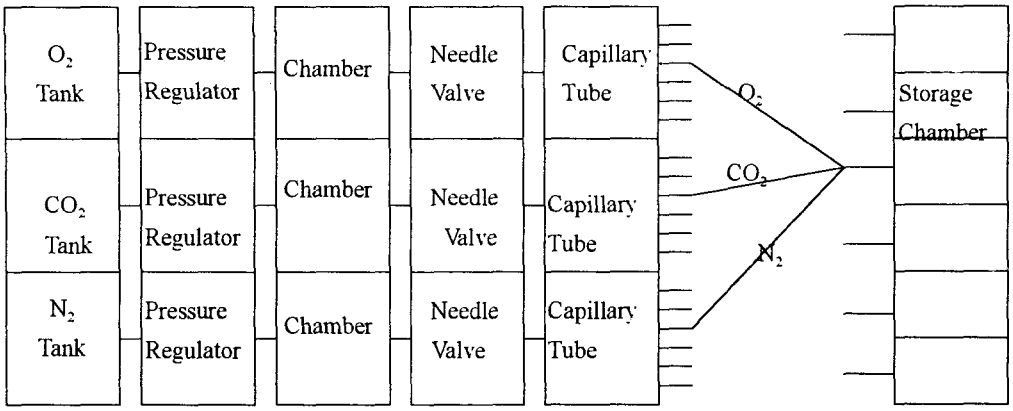

Fig.1. Schematic diagram of developed system.

Calibration of Gas Flow Rate through Capillary Tube

a. Relationship between flow rate and length

Fig.2 shows the relationship between flow rate and length of capillary tube. Letting all of the parameters except length remains at the constant value, the relationship between flow rate and $(\text{length})^{-1}$ is linear, and the graph of the function is a straight line.

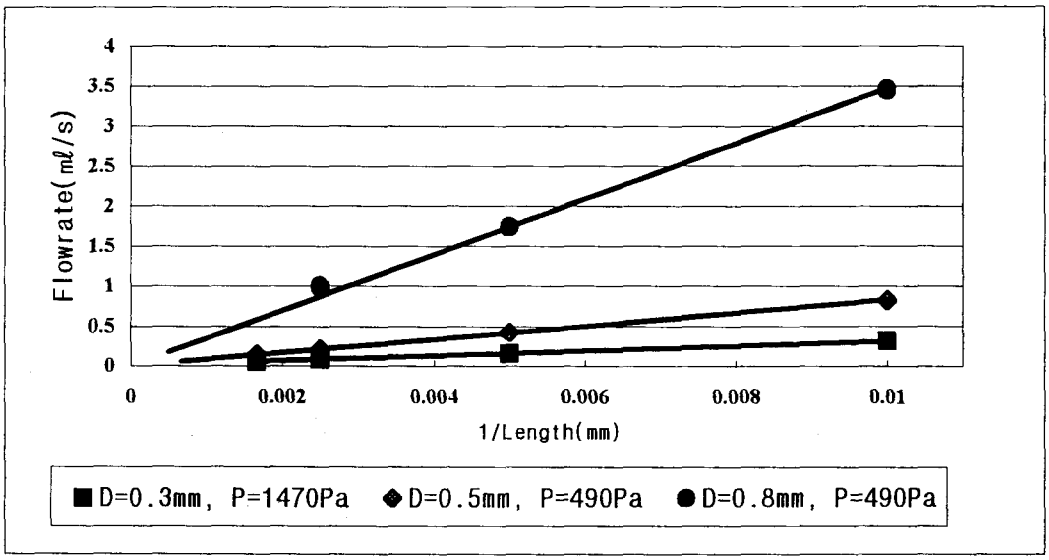

Fig.2. Relationship between flow rate and length.

b. Relationship between flow rate and pressure

Fig.3 shows the relationship between flow rate and pressure. Keeping all of the parameters except pressure at a constant value, the relationship between flow rate and pressure is linear and the graph of the function is a straight line.

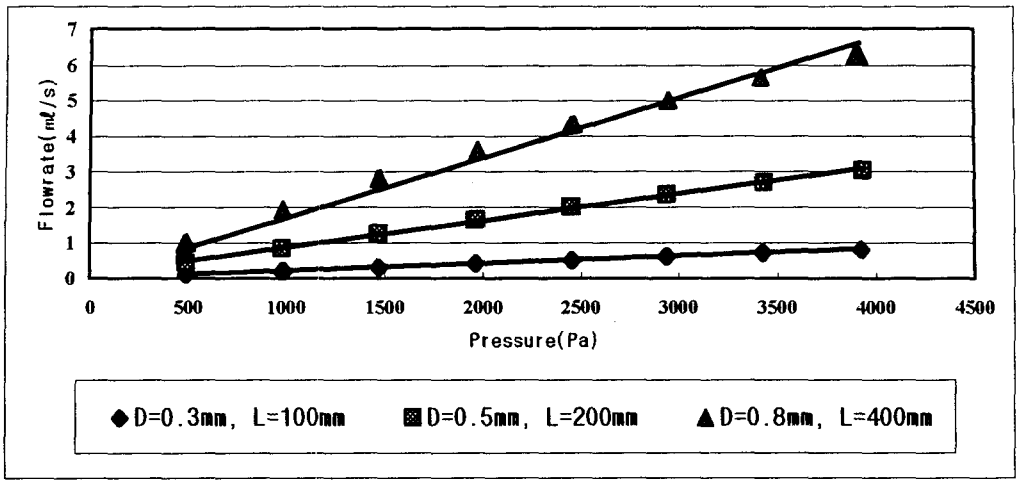

Fig.3. Relationship between flow rate and pressure.

c. Relationship between flow rate and radius

Fig.4 shows the relationship between flow rate and radius of capillary tube. Keeping all of the parameters except radius at a constant value, the function between flow rate and $(\text{radius})^4$ is linear and the graph of the function is a straight line.

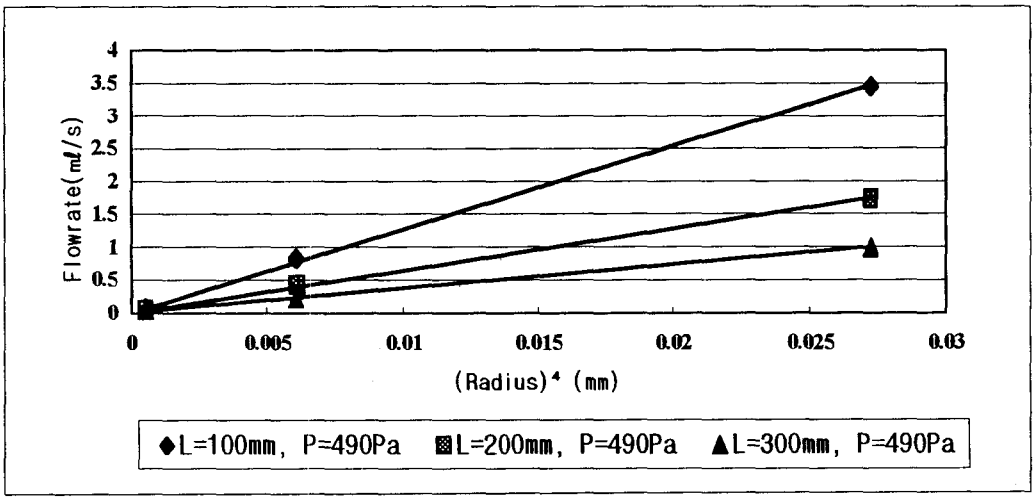

Fig.4. Relationship between flow rate and radius.

d. Relationship between flow rate and combined parameters

Fig.5 shows the relationship between flow resistance(R) and combined parameters. Letting $R = P/Q = C(8\mu L/\pi r^4)$, the function between R and $8\mu L/\pi r^4$ is linear, the graph of the function is straight line. From the regression analysis C=596.0224 and the coefficient of determination was 0.9984. Therefore, the relationship between flow rate and combined parameter was described as equation (3).

$$Q = 0.000209724\ \pi r^4 P / \mu L \quad \text{--------} \quad (3)$$

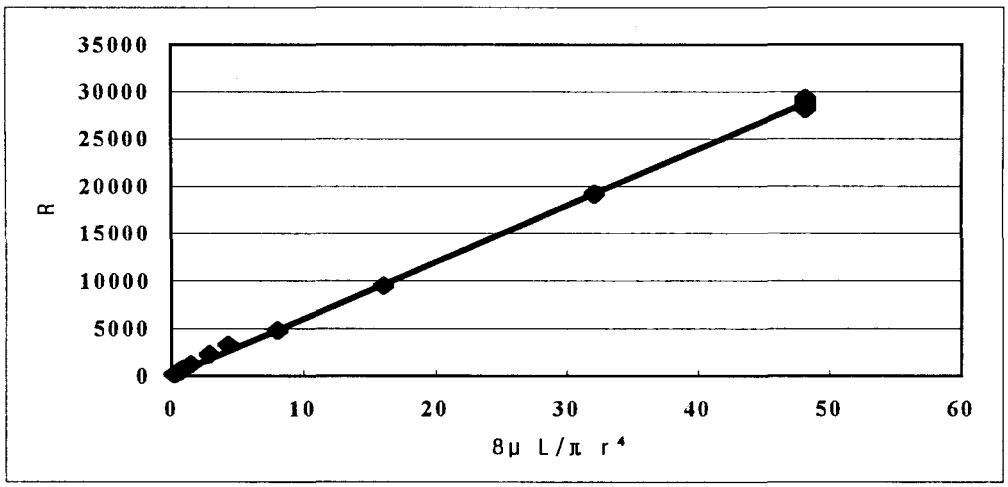

Fig.5. Relationship between flow rate and combined parameters.

The Precision of Gas Concentration Controlling

The preset and measured gas concentrations are compared on Table 1. The gas concentration in the storage chamber was controlled within ±0.3% deviation compared to the preset concentration. Therefore, it was concluded that the developed system could be used for C.A experiments.

Required Time for Producing Target Gas Concentration

Fig.6 shows change of gas concentration in a storage chamber as elapsed time and gas flow rate. The predicted and measured concentration was not agreed exactly, however the required time for producing target concentration was exactly agreed. In general, when volume of chamber is 29,850 mℓ and gas flow rate is 1,000 mℓ/min, we usually calculate required time for producing target concentration as 29,850 ÷ 1,000 = 29.85 min but it is not correct. The required time is much longer than calculated time by the above method and the exact required time is about 200min from Fig.7. This is very important for post-harvest physiological experiments using C.A condition. If flow rate is too low, it takes longer time to have a certain C.A condition. In this case, experimental results may have serious errors. Therefore, it is necessary to produce and target gas concentration in storage chamber as quickly as possible. For this purpose, we must use higher flow rate of gas during the initial stage of experiment when gas concentration in storage chamber has not reached the target value. Then, decrease the flow rate when gas concentration has reached at target value. The developed prediction model can be used to decide desired flow rate and the developed system can control flow rate easily and freely by changing pressure in the pressure-regulating chamber. Therefore, it was concluded that the developed system is very useful for C.A experiments.

Table.1. Comparison of preset and measured gas concentration in storage chamber

Preset Concentration(A)		Measured Concentration(B)		Deviation(|A-B|)	
O2(%)	CO2(%)	O2(%)	CO2(%)	O2(%)	CO2(%)
0.0	6.0	0.18	5.9	0.18	0.1
		0.18	5.9	0.18	0.1
		0.18	5.9	0.18	0.1
1.0	4.0	0.79	4.3	0.21	0.3
		0.75	4.5	0.25	0.5
		0.76	4.5	0.24	0.4
1.0	8.0	0.80	8.4	0.20	0.4
		0.81	8.0	0.19	0.0
		0.79	7.9	0.21	0.1
2.0	2.0	1.69	2.4	0.31	0.4
		1.67	2.4	0.32	0.4
		1.71	2.3	0.29	0.3
2.0	6.0	2.11	6.2	0.11	0.2
		2.05	6.4	0.05	0.4
		1.98	6.5	0.02	0.5
2.0	10.0	1.77	9.5	0.23	0.5
		1.81	9.5	0.19	0.5
		1.81	9.9	0.19	0.1
3.0	4.0	2.71	4.4	0.29	0.4
		2.62	4.6	0.38	0.6
		2.73	4.6	0.27	0.6
3.0	8.0	2.70	7.8	0.3	0.2
		2.56	7.8	0.44	0.2
		2.63	7.7	0.37	0.3
4.0	6.0	3.54	6.2	0.46	0.2
		3.58	6.2	0.42	0.2
		3.60	6.2	0.40	0.2
Average				0.25	0.3

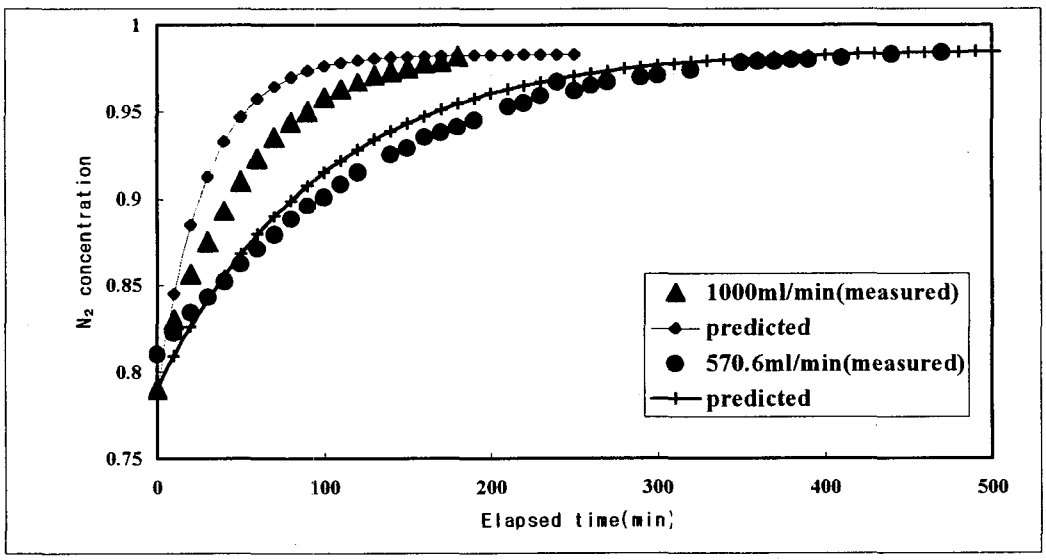

Fig.6. Change of gas concentration in storage chambers.

CONCLUSIONS

Based on the viscous flow characteristics of gas through a capillary tube, a simple and low cost system was developed for controlling gas concentration for use in C.A experiments. To evaluate the performance of the developed system, the gas flow rate through capillary tube, the required time for producing target gas concentration and the controlling accuracy of the gas concentration were measured.

The obtained results can be summarized and concluded as follows.

1. The flow rate of gas through capillary tube had a linear relationship with pressure, $(length)^{-1}$ and $(radius)^4$ of capillary tube, which agreed well with Hagen-Poseuille's law. The relationship between flow rate and combined parameters was described as $Q = 0.000209724\ \pi\ r^4P\ /\ \mu\ L$ and the coefficient of determination was 0.9984.

2. The developed system could control the gas concentration in the storage chamber within $\pm 0.3\%$ deviation compared to the target concentration.

3. The required time for producing target gas concentration in storage chamber was exactly predicted by a model used in this study, and it required much longer time than the calculated time which divided the volume of chamber by flow rate.

4. For C.A experiments using continuous flow of gas, it needed to use higher gas flow rate during the initial stage of experiment when gas concentration in storage chamber has not reached at target value.

5. It was concluded that the developed system was very useful for C.A experiments. Because one could decide a desired flow rate by prediction model, control flow rate freely and easily by changing pressure in the pressure-regulating chamber and accuracy was high.

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