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Development of CA Storage Facilities for Vegetables

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Abstract
Although controlled atmosphere (CA) storage is used for apples, the technique has not been applied to the commercial storage of vegetables yet in Japan due to the high storage cost. Two types of modified air system CA (MASCA) storage facilities were developed which are economical and can be applied to vegetables. The construction and operation cost of MASCA storage facilities is low and the system consists of a simple structure with easy maintenance. MASCA facility is composed of a modified air generator, gas-tight CA room, O_2 and CO_2 monitors and sequence program. Two types of modified air generators, pressure swing adsorption (PSA) type and gas separation membrane (GSM) type, were developed. Both were designed to obtain the modified air (N_2-rich air which contains desired O_2 concentration) by improving the PSA-N_2 generator or GSM-N_2 generator. The O_2 concentration in modified air is regulated by controlling the pressure of the air compressor of PSA or GSM. The sequence programs were developed to operate these modified air generators for the rapid reduction of the O_2 concentration in the CA room and for the control of the atmosphere. As neither propane gas nor a CO_2 scrubber is required, fire hazard is reduced and the structure simplified, which is one of the features of MASCA storage facility. Storage tests of shiitake mushroom, broccoli, cabbage and mature-green Japanese apricot revealed that MASCA facility can be used widely for the storage of various fruits and vegetables.

Discipline: Postharvest
Additional key words: gas separation membrane, pressure swing adsorption, storage of fruits

Introduction

It is generally recognized that lower O_2 and higher CO_2 levels than those found in normal air influence the physiological activities of harvested vegetables. Among them, the most significant response of vegetables to the reduced O_2 and higher CO_2 atmosphere is the suppression of the respiration rate. Since respiration is the process whereby sugars and acids are converted into energy, the suppression of respiration leads to a high retention of these compounds, hence the better preservation of the vegetables.

Storage of fruits and vegetables in a mechanically controlled low O_2 and high CO_2 atmosphere is referred to as controlled atmosphere (CA) storage. Although CA storage is used for apples, commercial adoption of this method for vegetables has not made any significant progress in Japan due to the high construction and operation costs.

The author developed two types of modified air system CA (MASCA) storage facilities that are economical and can be applied to vegetables[2].

Conventional CA storage facilities

CA storage facilities used in the early stages are referred to as regular system. The reduction of the O_2 concentration in the CA room is achieved slowly by the respiration of vegetables (slow CA). However, a better preservation of the quality of vegetables can be obtained when a rapid reduction of the O_2 concentration in the CA room occurs. Thus, the regular system cannot be applied to vegetables which are highly perishable commodities.

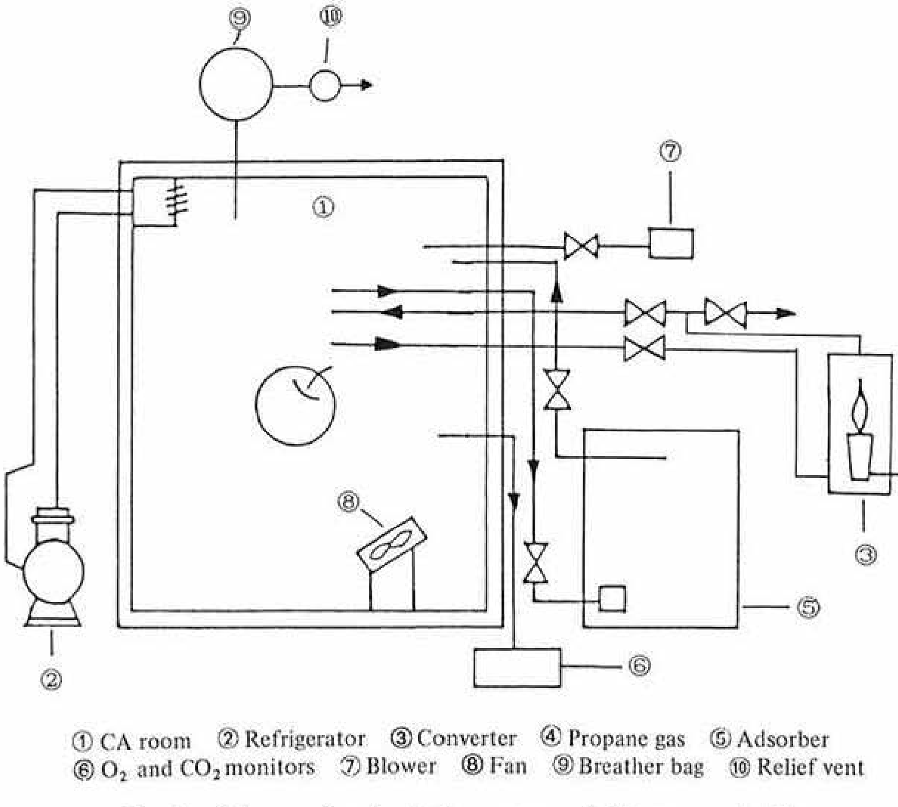
The most popular and well developed CA storage facility in Japan is the recirculation system (Fig. 1)[1]. Recirculation system provides a quick reduction of O_2 concentration by burning propane gas using a catalytic burner (referred to as rapid CA). Since a large amount of CO_2 is produced, an adsorber-desorber system is required to remove the excess of CO_2, and the air introduced into the CA room must be cooled. The disadvantages of this system are the high initial cost and operation expenses. Therefore, the recirculation system is not economically suitable for vegetables.

Development of modified air system CA (MASCA) storage

1) Principles of MASCA storage

MASCA was developed in considering the characteristics required for vegetable storage. The main advantages of MASCA storage are as follows:

(1) Reduction of O_2 concentration in the CA room does not depend on the respiration of vegetables (rapid CA).



① CA room ② Refrigerator ③ Converter ④ Propane gas ⑤ Adsorber
⑥ O_2 and CO_2 monitors ⑦ Blower ⑧ Fan ⑨ Breather bag ⑩ Relief vent

Fig. 1. Scheme of recirculation system of CA storage facility

(2) Accumulation of CO_2 in the CA room depends on the respiration of vegetables. Therefore, neither a CO_2 generator nor propane gas is needed for MASCA.

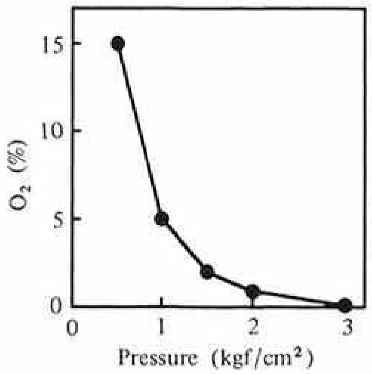


Fig. 2. Relation between pressure of air compressor of PSA-modified air generator and O_2 concentration in modified air

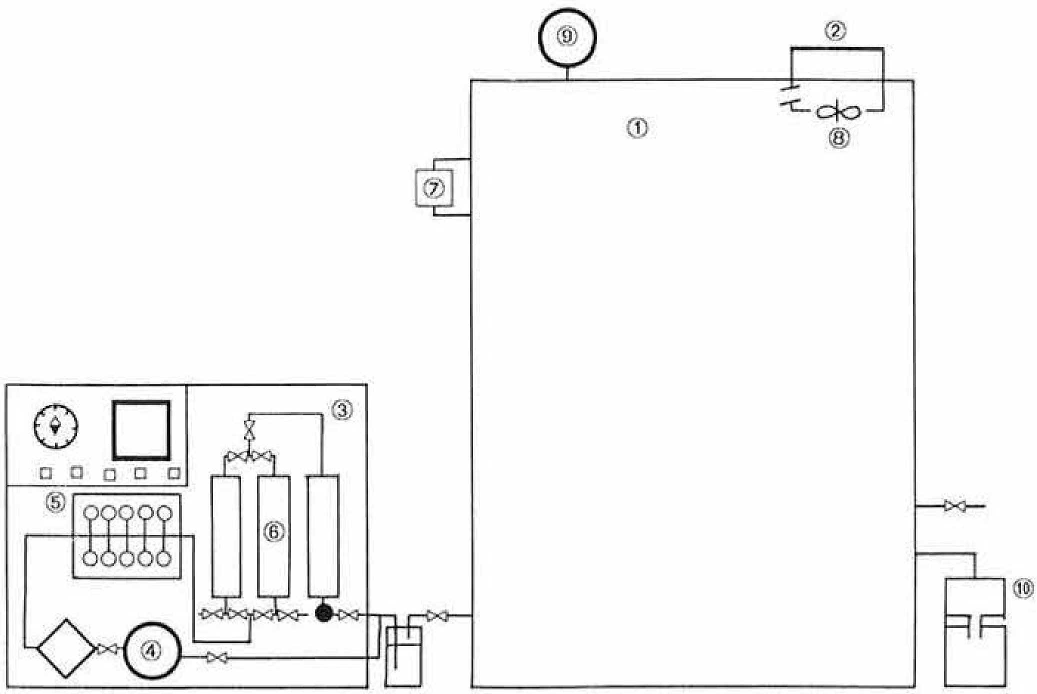
(3) The operation is fully automated, and no special expertise or skill is necessary.
(4) The atmosphere in the CA room is easily controlled as required for each commodity stored.
(5) Unless electricity is not available, there are no other limitations in the use of the system.

2) Structure of MASCA facility

MASCA facility consists of a modified air generator, gas-tight CA room, O_2 and CO_2 monitors and sequence program.

(1) PSA-modified air generator

Pressure swing adsorption (PSA)-N_2 generator produces N_2-rich air from compressed air after O_2 adsorption onto molecular sieve. Programmed by a time sequencer, the molecular



① CA room ② Refrigerator ③ PSA-modified air generator
④ Air compressor ⑤ Pressure control unit ⑥ Molecular sieve
⑦ O_2 and CO_2 monitors ⑧ Fan ⑨ Breather bag ⑩ Relief vent

Fig. 3. Scheme of PSA-MASCA storage facility

sieve releases the adsorbed O_2, then recovers a normal pressure and is reactivated.

The O_2 concentration in the N_2-rich air generated from the molecular sieve can be controlled by adjusting the pressure of the compressor (Fig. 2)[3]. As shown in Fig. 3, ten pressure regulators were installed in the PSA-N_2 generator. The improved generator was designated as a PSA-modified air generator, and the CA that uses this type of generator is designated as PSA-MASCA[4].

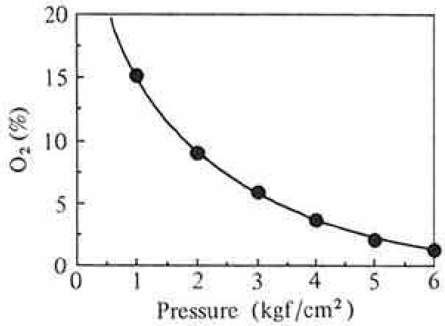
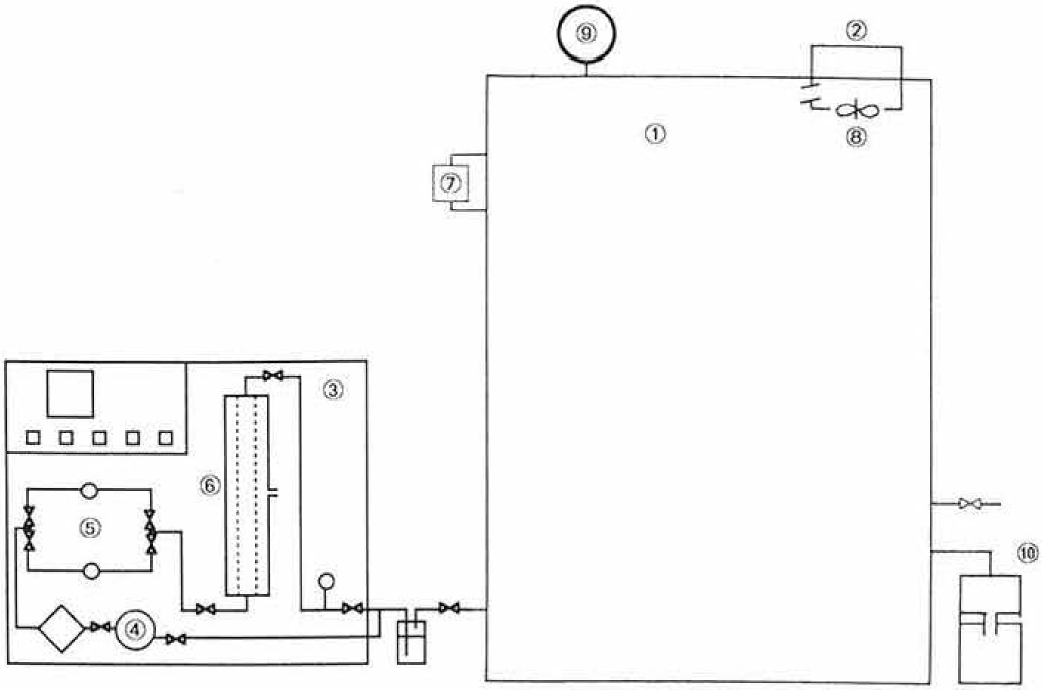


Fig. 4. Relation between pressure of air compressor of GSM-modified air generator and O_2 concentration in modified air

PSA-MASCA enables to control the O_2 concentration in the CA room from 1 to 10% at increments of 1% in addition to its function of N_2 generator. This system provides wide applications for the storage of commodities.

(2) GSM-modified air generator

A gas separation membrane (GSM) made of polyimide hollow fiber separates N_2 from O_2 in the air depending on the permeability. Like PSA, the O_2 concentration in generated air (modified air) can be regulated by adjusting the pressure of the air compressor (Fig. 4). The



① CA room ② Refrigerator ③ GSM-modified air generator
④ Air compressor ⑤ Pressure control unit ⑥ Gas separation membrane
⑦ O_2 and CO_2 monitors ⑧ Fan ⑨ Breather bag ⑩ Relief vent

Fig. 5. Scheme of GSM-MASCA storage facility

structure of GSM-MASCA is shown in Fig. 5.

Either the PSA-type or GSM-type is used for MASCA. The efficiency of PSA as a generator is higher than that of GSM. However, GSM offers some advantages in terms of structure, weight and initial cost.

(3) CA room

A commercial prefabricated refrigerator 6 m^3 in capacity was used as a CA room for MASCA storage. To make the room gas-tight, seams of wall panel were calked with a silicone liquid gasket, and a stainless steel sub-door was fixed inside of the insulation board. A polyethylene/nylon breather bag was attached to a pipe leading into the CA room to allow fluctuations in volume caused by the changes in the temperature of the air in the room.

Conventional prefabricated refrigerators which are available can be modified at a low cost.

(4) O_2 and CO_2 monitors

The O_2 monitor MC-7000GA (Iijima Products M.F.G. Co., LTD., Tokyo) and CO_2 monitor CGIC-4 (Toa Electronics LTD., Tokyo) were used without any modification.

(5) Sequence program

A sequence program for PSA-MASCA was developed to control the atmosphere in the CA room by the modified air generator (Fig. 6)[7]. The program for GSM-MASCA is almost the same as that for PSA-MASCA except for the step of generator idling. The response of the GSM generator to the pressure of the air compressor is so quick that the idling step can be omitted in the program for GSM-MASCA (Fig. 7).

Atmosphere control

A rapid reduction of the O_2 concentration in the CA room (rapid CA) can be achieved with the modified air generator by using its function of N_2-generator. The N_2-rich modified air with a concentration of less than 0.5% of O_2 is introduced into the CA room until the O_2 level in the CA room is reduced to the desired concentration, then the generator is brought to a standstill by the signal from the O_2 monitor.

When O_2 in the CA room decreases to the critical concentration by respiration, air is introduced from the air compressor of the modified air generator until the O_2 concentration reaches the desired level. Consequently, the O_2 concentration in the CA room is regulated in the range of desired and critical concentrations.

MASCA builds up the CO_2 level in the CA room with the CO_2 evolved from vegetables by respiration. When the CO_2 level reaches the critical concentration, the CA room is ventilated with modified air to prevent further build-up of CO_2. As the modified air contains the desired level of O_2, the O_2 concentration in the atmosphere is not affected by ventilation. The modified air generator is brought to a standstill when the CO_2 concentration in the CA room is reduced to the desired level. Thus, the CO_2 concentration in the CA room is regulated in the range of desired and critical concentrations.

As the switch on and off operations of the modified air generator are performed automatically by the signals from O_2 and CO_2 monitors, the operation of MASCA is very simple and no special expertise is required. Since all the processes required for CA, i.e., reduction of O_2 concentration, air supply and maintenance of CO_2 level, are performed by the modified air generator, the construction of the MASCA facility is very simple, and no inflammable gas like propane gas is used. These characteristics result in reduced fire hazard and low running cost. Furthermore, the MASCA facility can be used in any area where electricity is available.

MASCA storage of fruits and vegetables

(1) Shiitake-mushroom

The respiration rate of shiitake-mushroom (*Lentinus edodes* (Bark) Sing.) was markedly

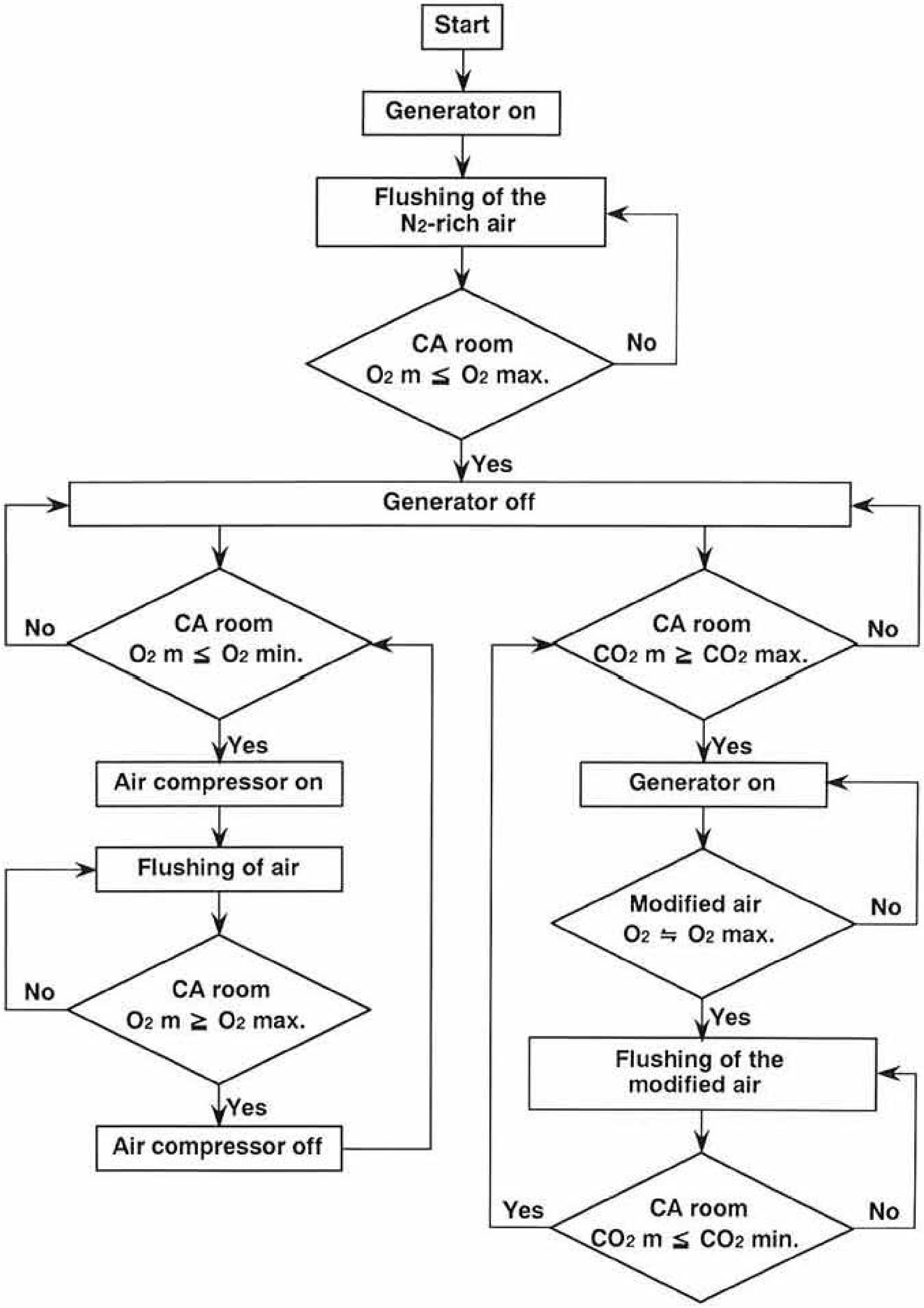


Fig. 6. Flow diagram of automatic operation of PSA-MASCA
O_2 m: O_2 concentration in the CA room, O_2 min.: Critical O_2 concentration, O_2 max.: Desired O_2 concentration, CO_2 m: CO_2 concentration in the CA room, CO_2 min.: Desired CO_2 concentration, CO_2 max.: Critical CO_2 concentration.

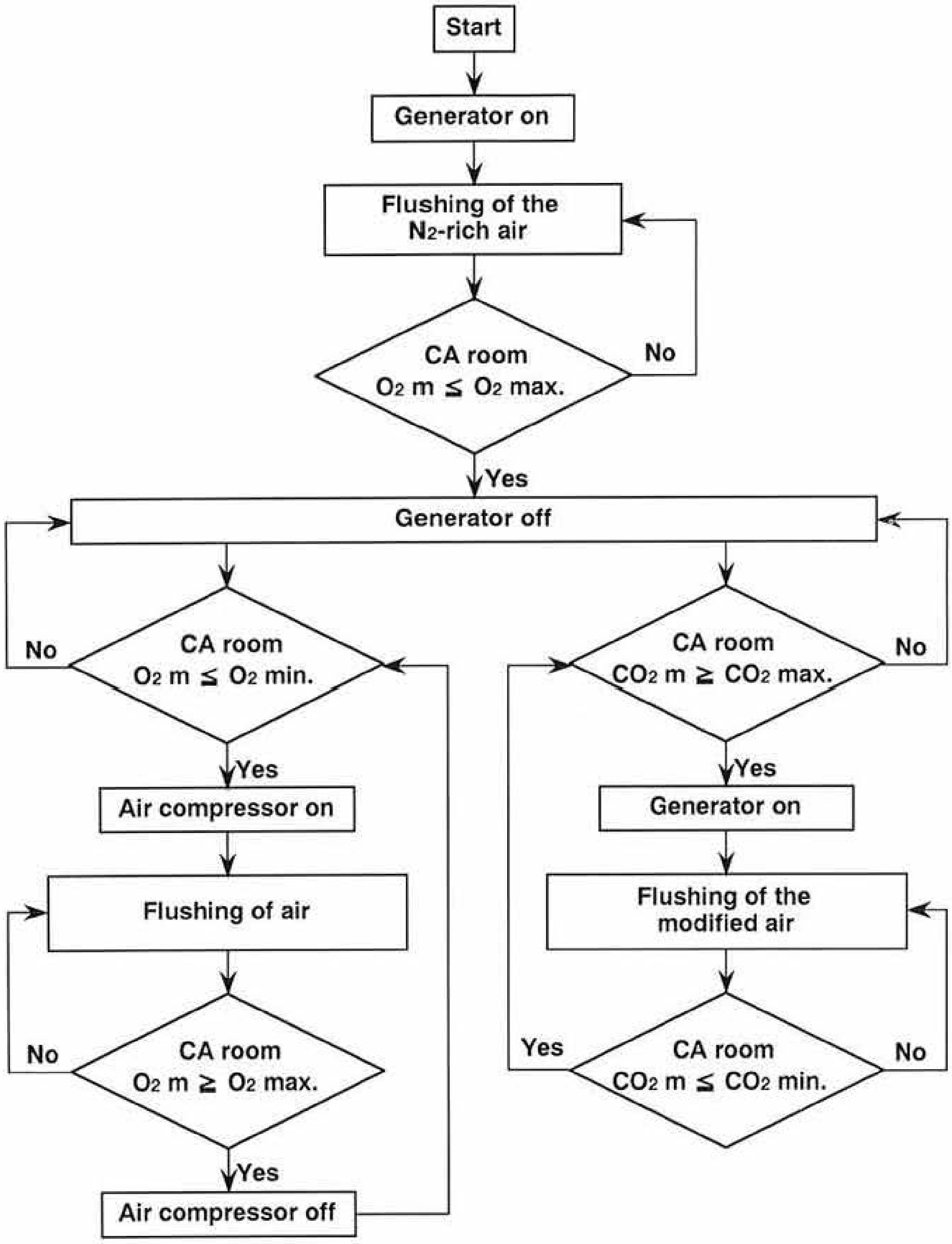


Fig. 7. Flow diagram of automatic operation of GSM-MASCA
O_2 m: O_2 concentration in the CA room, O_2 min.: Critical O_2 concentration, O_2 max.: Desired O_2 concentration, CO_2 m: CO_2 concentration in the CA room, CO_2 min.: Desired CO_2 concentration, CO_2 max.: Critical CO_2 concentration.

reduced in response to the decrease in the O_2 concentration and increase in the CO_2 levels. The respiration rate at the atmosphere of 1% O_2/10% CO_2 was 40% of that in air (Fig. 8). The appearance of shiitake-mushroom stored in air at 10°C was no longer acceptable after 4 days of storage due to browning, while no quality deterioration was observed for samples stored for 3 days after 9 days of MASCA storage at the same temperature[5]. The slight off flavor due to anaerobic respiration which was detected was entirely removed by exposure of shiitake-mushroom to air.

(2) Broccoli

The respiration rate of broccoli (*Brassica oleracea* L., Italica group) was reduced by 50–70% under MASCA storage conditions of 3% O_2/5% CO_2. The chlorophyll losses were delayed to a greater extent in MASCA storage than in air where the content decreased to 1/10 within 6 days (Table 1). The ascorbic acid content in air-stored control samples was reduced by 60–70% at the time of development of a yellow color, while MASCA storage delayed the loss of ascorbic acid (Fig. 9). Undesirable odors and taste did not develop in MASCA-stored broccoli[8].

(3) Cabbage

MASCA (3% O_2/4.5% CO_2 storage) enabled to preserve the visual quality of cabbage for

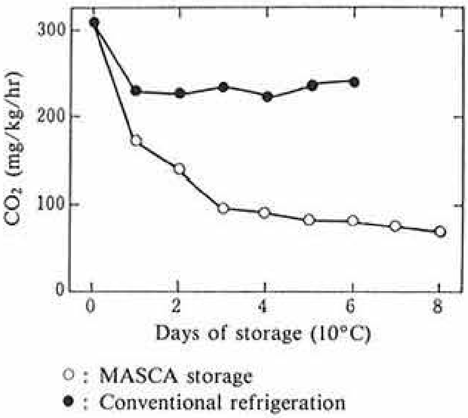


Fig. 8. Changes in respiration rate of Shiitake during storage

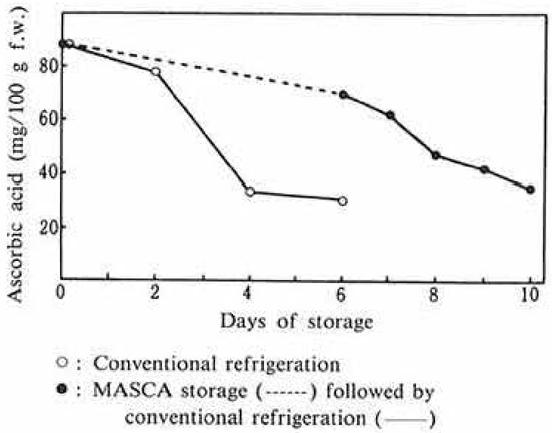


Fig. 9. Changes in ascorbic acid content during storage of broccoli at 10°C

Table 1. Changes in chlorophyll content during storage of broccoli at 10°C

(mg/100 g f.w.)

Days of storage	Conventional refrigeration			MASCA storage			Conventional refrigeration after MASCA storage		
	a	b	Total	a	b	Total	a	b	Total
0	48.5	17.4	65.9	48.5	17.4	65.9			
2	39.9	13.0	52.9						
4	12.2	3.8	16.0						
6	4.7	1.9	6.6	37.5	11.4	48.9	37.5	11.4	48.9
7							32.0	8.6	40.6
8							24.8	6.9	31.7
9							14.7	4.1	18.8
10							13.2	3.9	17.1

27 days at 3°C whereas in air storage visual acceptability was lost due to yellowing and mold. MASCA storage enabled to delay the loss of chlorophyll and decay. Ascorbic acid was preserved during MASCA storage, while 50% of ascorbic acid was lost in air storage.

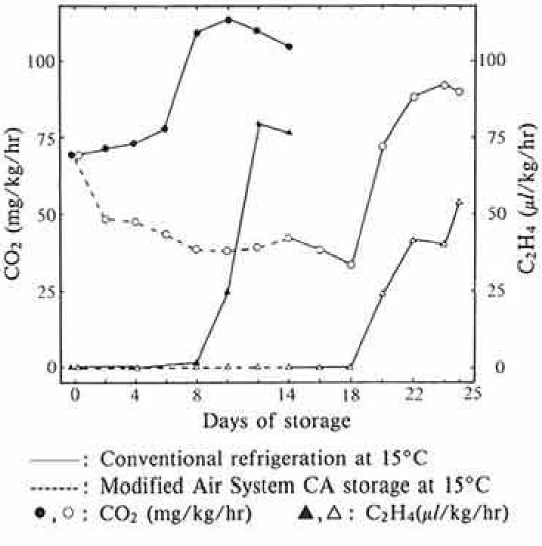


Fig. 10. Changes in respiration rate and evolution of ethylene in mume fruits during storage at 15°C

(4) Japanese apricot

A storage test with mature-green Japanese apricot (Mume, *Prunus mume* Sieb. et Zucc.) revealed the significant advantage of MASCA storage over air storage at 15°C. The respiration rate increased gradually in the initial days of air storage and then dramatically when ethylene evolution was detected with loss of the green color (Figs. 10, 11). On the other hand, the respiration rate decreased during MASCA storage, and ethylene evolution was suppressed

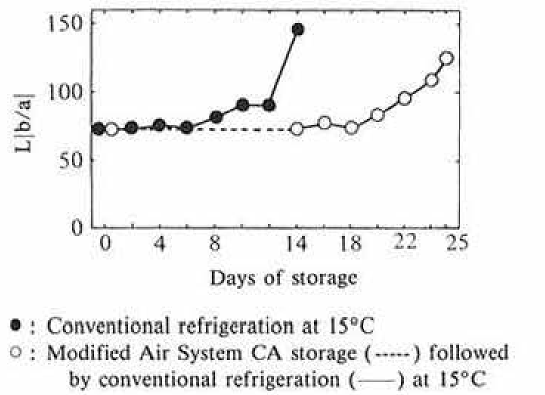


Fig. 11 Changes in surface color of mume fruits during storage at 15°C

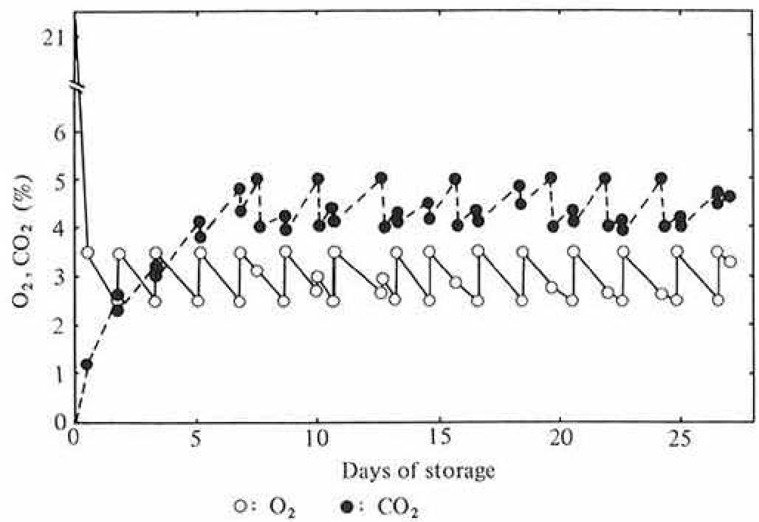


Fig. 12. Changes in O_2 and CO_2 concentration in CA room during PSA-MASCA storage of cabbage at 3°C

entirely in a 2.5% O_2/4% CO_2 atmosphere. Neither yellowing nor chilling injury was observed in MASCA-stored fruits. Four days after the removal of fruits from MASCA storage, however, increase in the respiration rate, evolution of ethylene and loss of green color occurred. These results show that MASCA storage enables to delay the ripening of mature-green Japanese apricot[6].

Cost of MASCA storage

A batch of cabbage (600 kg) was stored under MASCA conditions of 3% O_2 and 4.5% CO_2 for 27 days at 3°C (Fig. 12). The cost for the control of the atmosphere by PSA-MASCA and GSM-MASCA (excluding the cost for refrigeration and depreciation) was estimated at 0.05 yen and 0.08 yen/kg of cabbage, respectively.

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