SENIOR PROJECT REPORT

# Controlled Atmosphere Miniature Chambers

by

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## ACKNOWLEDGEMENT

Many thanks to L. Berard (PhD post harvest physiologist), C. Vigneault (Agr. Eng.) and J.C. Desrosiers (Technician), who helped me start this project during my summer job at the Agriculture Canada Research Station in St-Jean-sur-Richelieu, and also throughout the semester. They were supportive, encouraging, and good friends.

Thank are also extended to Dr. Rajhavan and Yvan Gariepy for listening and helping me acquire and understand all the basics of this field of study, with their personal support and appreciated documentation.

## ABSTRACT

The design of a controlled atmosphere storage facility built for small scale research projects was improved. The final design was the concept of a possible statistical layout of eight control atmosphere units placed in a standard refrigeration room. They were accompanied by the same number of similar units, but functioning as refrigerated atmosphere storage facilities (RA), or as a control for the experience. The design of the RA unit was realized and two units (RA and CA) were tested together for a period of 65 days using cabbage as the biological material. The gas alteration on the CA was done with a lime $CO_2$-scrubber and with air injection, with the help of a programmable control unit and solenoid valves. The gas analysis was performed by a gas chromatograph.

The system maintained the desired levels of $CO_2$ and $O_2$ for short periods of time with a minimum surveillance. On the long run, lack of maintenance and problems from external parameters affected the experience. Both the CA and RA units showed a higher temperature inside the chambers that caused condensation on the lid, dropping on the cabbages and causing them to become rotten.

The system demonstrated good potential for low oxygen controlled atmosphere storage.

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# 1. INTRODUCTION

In the past 15 years the controlled atmosphere storage (CA)has been the best improvement in the storage of fruits and vegetables. However, even though the principles of this sytem are well understood, a lack of research and knowledge exists at the practical level resulting in ignorance of possible applications with respect to increasing storage life.

The size and cost of a standard CA facility does not make it practical for researchers to do experimental work in this field. They need a tool that will allow them to perform a minimum number of tests at different levels, whether it is with different commodities or different gas concentrations.

One solution in solving this kind of problem is to build a CA storage containers that can be fit inside a refrigerated room. Each storage facility will contain a sufficient number of commodity and should be controlled independently.

Control units should be provided to see whether the different results are caused by the storage conditions or by different external factors such as field conditions during the growing seasons, harvesting, etc. The control will be a normal atmosphere, high humidity refrigerated room; the same size as the CA storage unit. A $CO_2$ - lime scrubber system for CA storage with air injection was selected, since it provides any desired conditions.

Most of the design of the CA storage unit was available from the engineering department of Agriculture Canada. There was no air injection system or control of temperature. It has been tested only with apples. All the necessary adjustments were done and a discussion regarding the results will follow.

This project is divided in three parts:

1st part: Analysis of the temperature conditions occuring in the refrigerated room.

2nd part: Design modification and testing of small scale controlled atmosphere chamber (CA).

3rd part: Design and testings of small scale high relative humidity storage room (RA) to be used as control for the experience.

# 2. OBJECTIVES

Make the necessary technical installation for the realization of a research project in post harvest physiology where the controlled atmosphere is utilized.

Field: Agricultural engineering applied to research

## 2.1 Secondary objectives

Objective of the first part; the refrigerated room (RR)

Analyse the temperature conditions inside a refrigerated room and find the optimal disposition for biological material and the miniaturized chambers.

Objective of the second part; controlled atmosphere chambers

- The chambers will have to be able to maintain the conditions of the CA storage.
- The CA chambers will have to be controlled by a programmable control unit (PCU) and the gas composition will have to be analyzed individually without changing the proceedings of the experience.
- They will have to be airtight at atmospheric pressure + 2.54 cm of water of positive pressure.
- The gas distribution inside the chamber has to be homogeneous.
- They will have to maintain a temperature of 1°C ± 1°C.

Objective of the third part; regular atmosphere chambers

The chamber will have to be representative of a high humitidy regular atmosphere room (RA).

- They will provide a high relative humidity: ≈ 95%.
- Low temperature ≈ 1°C
- $O_2$ concentration: 21% ± 1%
- $CO_2$ concentration: 0.03% ± 1%

# 3. LITERATURE REVIEW

## 3.1 Introduction:

Long term CA storage of cabbage was found advantageous by many authors (van den Berg and Lentz (1966), Furny et al (1981), Isenberg (1979), Geeson et al (1980)). They are different kinds of CA storage systems and it is only recently that CA storage facilities for vegetables have been introduced on the Canadian market. So there is a need for research in CA to assess its commercial potential for the different fruits and vegetables.

The role of a fruit and vegetables storage facility is to maintain ideal conditions that will allow the conservation produce characteristics such as texture, humidity, tastiness, etc. The deteriorations are directly related to storage temperature, relative humidity, air circulation and gas composition.

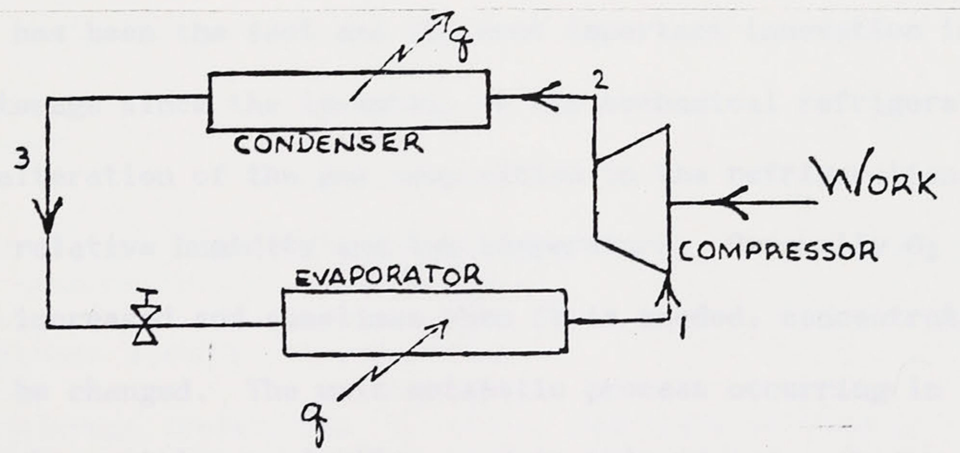
Temperature: The respiration rate will be at the minimum level for the lowest produce temperature, reducing the decomposition of the commodity. Each one will tolerate a specific minimum temperature below which it will be susceptible to chilling and freezing damage. The temperature should be as constant as possible. One aspect of the cold storage is to provide below freezing temperatures for precooling the commodity after harvest. In this process, the field heat from the commodity is removed. This aspect represents the greatest load that must be handled by the cooling system. There are various precooling methods: hydrocooling, vacuum cooling, high velocity cold air and contact icing.

Relative humidity: The freshness of a stored commodity depends largely on the retention of its initial water content. If the air is too dry, moisture losses will change the texture of the commodity. Therefore, to avoid desiccation of the produce, relative humidities should be kept close to saturation. But the growth of mold and other decay organisms can be caused by too much moisture, particularly if there is condensation formed at the surface of the products. There are different methods used commercially to provide high humidity storage; the Jacketed, the Filacell and the hypobaric systems are some examples (Raghavan, 1984).

## 3.2 Overview of Different Refrigerated Storage Systems

### 3.2.1 Mechanically refrigerated storage system

Most of the refrigerated rooms are cooled with vapor compression refrigerators. The refrigeration system consist of three basic components; the compressor, the condenser, (air cooled or water cooled) and the evaporator.




The vaporizing temperature depends on the pressure exerted on the fluid. Fans are required to circulate the storage air over the evaporator coils and through the stacked in order to achieve good cooling. However, it is difficult to maintain high relative humidity due to the inherent dehumidifying of the air occurring on the evaporator coils. Different high relative humidity storage systems with RA such as the Jacketed system and the Filacell system have been developed in America and they have shown excellent results.

In the Jacketed system, the product transpiration is producing the relative humidity. The refrigerated air is circulated through the air space surrounding the storage room instead of within the storage space itself. The main advantage of such a system is that the relative humidity can be held close to saturation and makes it independent from the cooling system. In the Filacell system, cold air near saturation is directed into the storage room. This saturated air is obtained by passing cold air through a web of polypropylene monofilaments on which cold water is sprayed.

### 3.2.2 Controlled atmosphere storage systems

CA storage has been the last and the most important innovation in fruit and vegetable storage since the invention of the mechanical refrigeration. It deals with the alteration of the gas composition in the refrigeration room along with high relative humidity and low temperature. Generally $O_2$ is reduced and $CO_2$ increased and sometimes when it is needed, concentrations of $C_2H_4$ and CO can be changed. The main metabolic process occurring in fruits and vegetables after harvest is respiration, and in this process, oxygen ($O_2$) is consumed and carbon dioxide ($CO_2$) produced. The rate of respiration of a commodity is a good indication of its storage life. While changing the composition of the gases in the storage room, the respiration rate is decreased. In the respiration, sugar is oxidized to produce carbon dioxide, water, and energy in form of heat.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + HEAT$$

The respiration rate is a function of the temperature of the storage facility, the harvest maturity of the fruit, the oxygen level in the storage room and fruit characteristics influenced by the growing conditions.

As well as decreasing the respiration rate, CA storage with high relative humidity has the advantages of preventing chlorophyll degradation, retardation of pectin changes and the reduction of bacterial infections (G.S.V. Raghavan et al.) One of the main advantages of CA storage is to reduce considerably the heat of respiration of the stored product. Toledo et al. (1969) estimated heat generation of a fresh product stored in CA to be 30% of its value in regular atmosphere.

There are three different groups of CA systems:

<u>$O_2$ Control Systems</u>*

A) External gas generators (external gas generators use open flame or catalytic burners to lower the $O_2$ level).

B) Liquid nitrogen atmospheric generators.

C) Hypobaric storage (reinforced, airtight, refrigerated room in which the air is continuously removed by a vacuum pump).

<u>$CO_2$ Control Systems</u>*

A) Water $CO_2$ scrubbers (they use water as the active absorber).

B) Lime $CO_2$ scrubbers.

With this system, outside air is introduced into the storage room to regulate $O_2$ concentrations.

C) Activated charcoal and molecular sieve.

D) Membrane systems

Since the latest Lime $CO_2$-scrubber will appear in a following section more explanations will be provided. The regulation of $CO_2$ concentrations is done by a simple hydrated lime $CO_2$- scrubber ($Ca(OH)_2$) . It can work by natural convection or the air can be forced by an adequate blower. Hydrated lime reacts with carbondioxide to produce another solid (calcium carbonate) and water. The basic chemical reaction is:

$$Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O + HEAT$$

*RAGHAVAN et. al. 1984

The use of electronic technology for automatic environmental control systems for fruit and vegetables storage is still relatively new. In the old days, the most sophisticated instruments were timers and ON/OFF switches. Although these traditional controls are still in use for many operations, they are labour intensive and require periodic recalibration and maintenance, and in many cases, they have a low level of accuracy. A rapid increase in the demand for electronic measurement and control systems as led to the introduction of monitoring and control systems for laboratory and commercial fruit and vegetable storage. The gas chromatograph can analyze the different gas concentrations in a sample within 5-8 minutes while it takes twice the time to find only $CO_2$ and $O_2$ concentrations manually with a lot less precision

(Raghavan et al. 1984).

### 3.3 Refrigeration properties of cabbages

Freezing of the cabbage in storage has to be avoided, the cabbage starts to freeze at -0.8°C. The winter cultivars of cabbage can be stored from three to seven months when kept at 0°C with high relative humidity. Cabbage is stored in CA at 5% $CO_2$ and 2.5% oxygen concentrations and between 0 and 1°C for up to 10 months. The CA preserves the color and maintain the tastiness of the cabbages. But the use of the catalytic burners for generation of CA gives a bad taste to the cabbages (Agr. Can., 1988).

In CA, the toxic effect of ethylene is neutralized by the high concentrations of carbon dioxide. Gariepy et al (1986) found that the best thermocouple location for optimum approximation of the cooling characteristics of cabbage with Newton's Law of cooling is at the mass-average temperature location.

# 4. MATERIALS AND METHODS

## 4.1 Analysis of the temperature conditions inside the RR

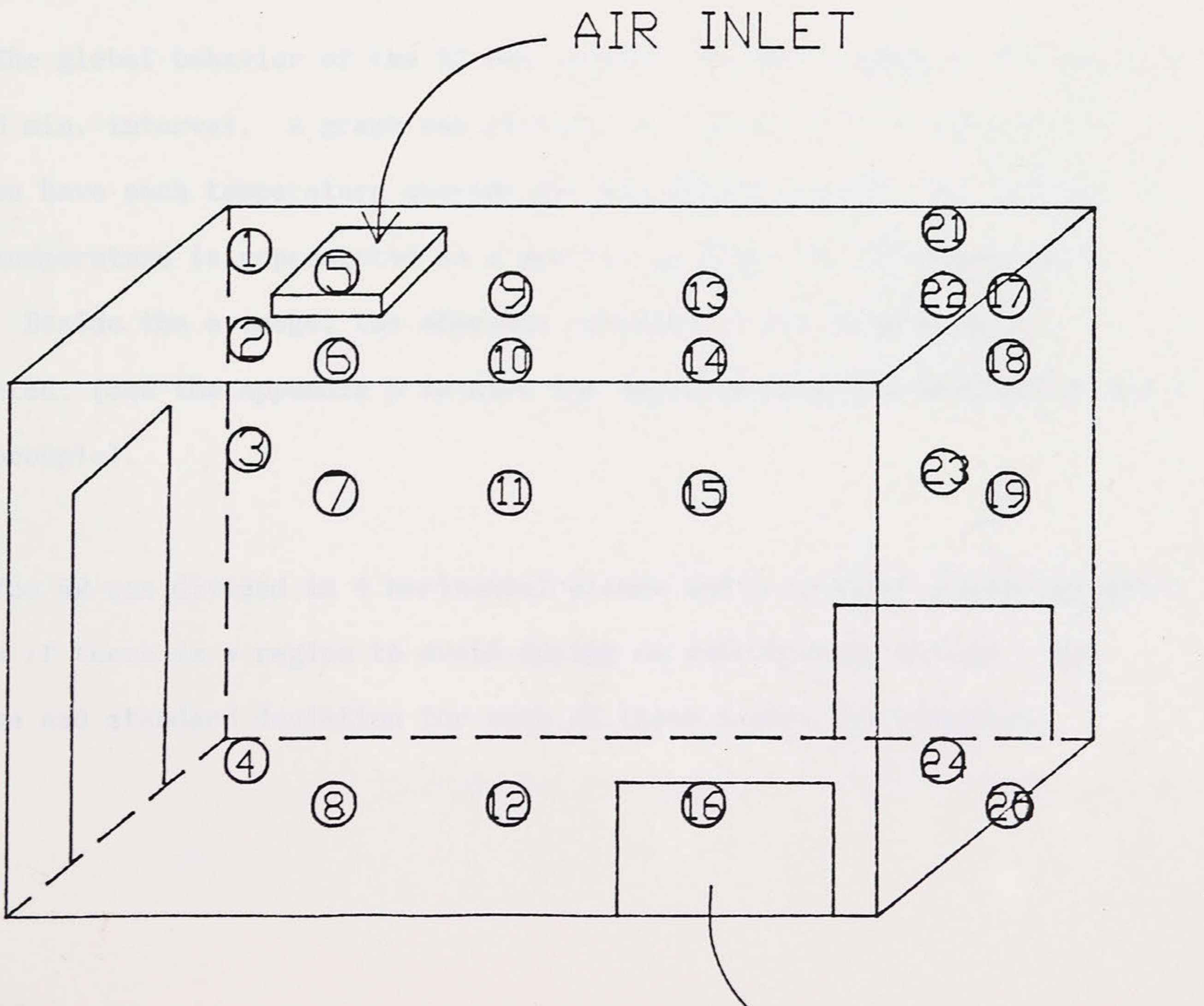
The dimensions of the regrigerated room was 3 m x 2.1 m of floor area and 2.4 m in height. 24 type "T" thermocouples were placed in the refrigerated room (Fig. 1). They were grouped 6 series of 4 thermocouples. Each thermocouple of the same series were on one vertical axis. The thermocouples were at corresponding heights between the series.

1st thermocouple: at the ceiling (except no. 5 which is in the inlet)

2nd thermocouple: 20 cm under the ceiling

3rd thermocouple: 0.9 m from the floor (approximate height of the chamber)

4th thermocouple: on the floor




GURE 1. DIAGRAM OF THE REFRIGERATION

Thermocouples on the same horizontal plan: # 5 (inlet)
# 1-9-3-13-21-17 (ceiling)
# 2-6-10-14-22-18
# 3-7-11-15-23-19
# 4-8-12-16-20-24 (floor)

Monitoring and recording of the temperatures was done every five minutes by the data logger (Doric Minitrend 205 datta logger and Dorig Diditrack 360, precision ± 1°C) for the following situations.

- empty room;
- room filled with plastic boxes for storage;
- room filled with plastic boxes filled with cabbages and covered by a plastic sheet to avoid water drifting onto the cabbages;
- room filled with 8 barrels.

The global behavior of the RR was assessed by the average of the 24 TC at each 5 min. interval. A graph was plotted to visualized the relationship. Then we have each temperature average for the entire period. The average of each temperature is represented in a drawing in space of the refrigerated room. Beside the average, the absolute variance of the temperature is indicated. (See the Appendix B to have the detailed behavior on graph of each thermocouple).

The RR was divided in 4 horizontal planes and 5 vertical planes in space to see if there is a region to avoid during an experimental design. The average and standard deviation for each of these planes was computed.

## 4.2 CA chambers

The chambers were primarily composed of a 110 l barrel made of polyethylen plastic. The top was closed by a circular lid made of acrylic 12.7 mm thick. A rubber seal, held in place by a galvanized steel ring provided good airtightness. Everything was fixed on the barrel by 6 to 8 C-clamps. Vacuum grease on each side of the rubber completed the seal, see Fig. 3.

### 4.2.1 $CO_2$ scrubber

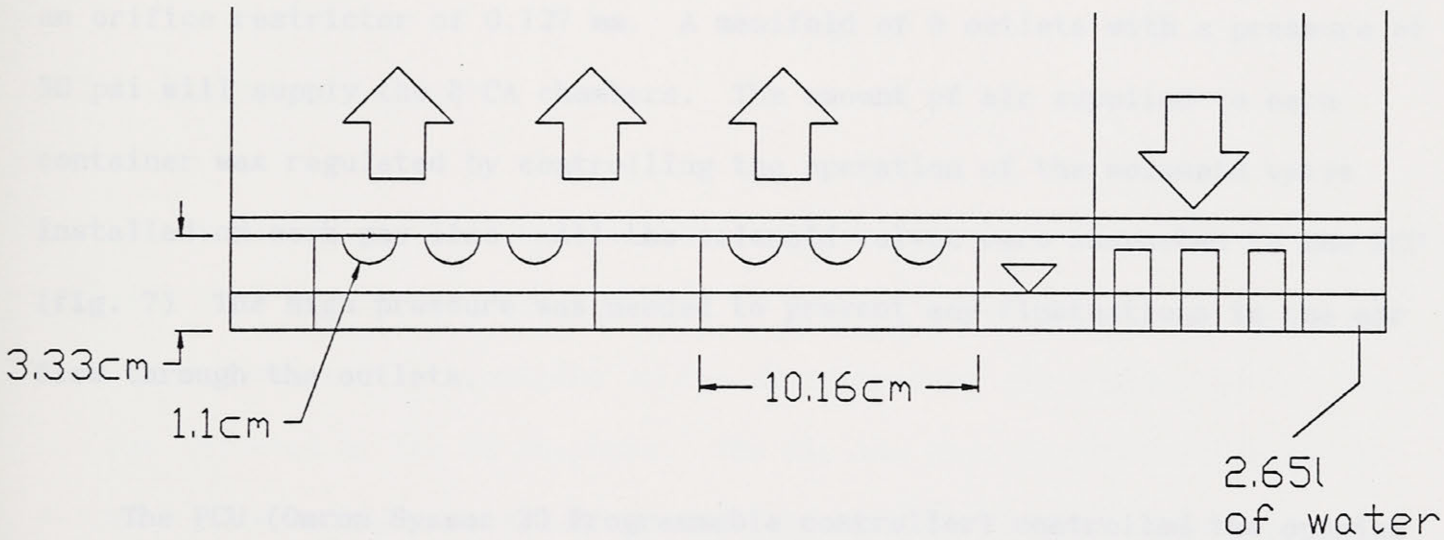
The $CO_2$ scrubber (Figure 4) was attached to the acrylic plate by a 12.7 mm NPT brass pipe. The scrubber was made with 100 mm ABS pipe filled with hydrated lime (2000 g). Two solenoid valves and two hand valves were placed before and after the $CO_2$ scrubber. The hand valves were used to close the circuit if we need to change parts or refill the scrubber with lime. The solenoid valves were connected to the PCU.

### 4.2.2 Blower or air circulation

A blower (Figure 5) was placed inside the chambers. This blower had 3 functions:

1) it mixes the gases inside the chambers to prevent the $CO_2$ to accumulate at the bottom ($CO_2$ is heavier than air).
2) it provides the humidity needed.
3) Circulating the air through the $CO_2$-scrubber when the solenoid valves were opened.

The blower was ran by a 24V electric motor. It was placed inside a 76 mm diameter ABS pipe. This pipe was placed vertically inside the chamber and it was made of two sections fitting together, so that when the acrylic lid was fixed it stays in place and took the whole height of the barrel. Spacers a the top of the pipe produce the inlet of the blower, and at the same time a small vacuum to suck the air through the $CO_2$ scrubber when the solenoid valves opened. The outlet was located at the bottom of the pipe. A film of water was placed at the bottom of the barrel to provide a high level of relative humidity. The air passed over this film of water and is diffused upward uniformly through a polypropylene plate (6mm) perforated with small holes (Figure 2). Spacers were listed to maintain the polypropylene plate above the film of water.




GURE 2 : AIR DIFFUSER SET-UP

The outlet of the $CO_2$ scrubber, fixed onto the acrylic plate, right above the inlet of the blower to provide good air circulation. One inlet and outlet were installed on the acrylic lid to provide a possible installation of an ethylene scrubber. The scrubber will be activated by a diaphragm pump and it will be portable.

A pressure regulator was installed on the acrylic lid to maintain a maximum pressure of 25 mm of water in the barrel. A 20 litres plastic bag connected to the barrel was inflated before starting the experience. The main purposes of this bag was to absorb the fluctuations in atmospheric pressure and prevent the formation of any vacuum inside the chamber. One thermocouple was placed inside the chamber. Monitoring and recording of the air temperature in each CA chamber was performed by the datta acquisition system (Doric Minitrend 205 datta logger and a Doric Digitrack 360).

### 4.2.3 $O_2$ Injection

The $O_2$ level in the barrel was maintained by flushing with air (21% $O_2$ + 79% $N_2$) from a compressed-air line calibrated to deliver 0.5 litres/min through an orifice restrictor of 0.127 mm. A manifold of 8 outlets with a pressure of 50 psi will supply the 8 CA chambers. The amount of air supplied to each container was regulated by controlling the operation of the solenoid valve installed on each gas line. All the solenoid valves were connected to the PCU (fig. 7) The high pressure was needed to prevent any fluctuations in the air flow through the outlets.

The PCU (Omron Sysmac 20 Programmable controller) controlled the opening time of the solenoid valves and the opening time interval. All the valves opened at the same time but they were closed at their respective time according to their different needs. The CA composition ($CO_2$, $O_2$ and $N_2$) in each container was sampled manually and analyzed using a gas chromatograph. (HP 5890 Gas chromatograph, HP3393A Integrator, precision of ± 0.2%). Results from the analysis indicated if the time of operation of the CA control units needed to be adjusted in order to maintain $CO_2$ and $O_2$ concentrations within 0.2% of the design levels of 5% and 2.5% respectively. Sampling of the gas inside the barrels was done near the surface through a septum. Sampling tests were done at the bottom of the barrel to identify any $CO_2$ accumulations.

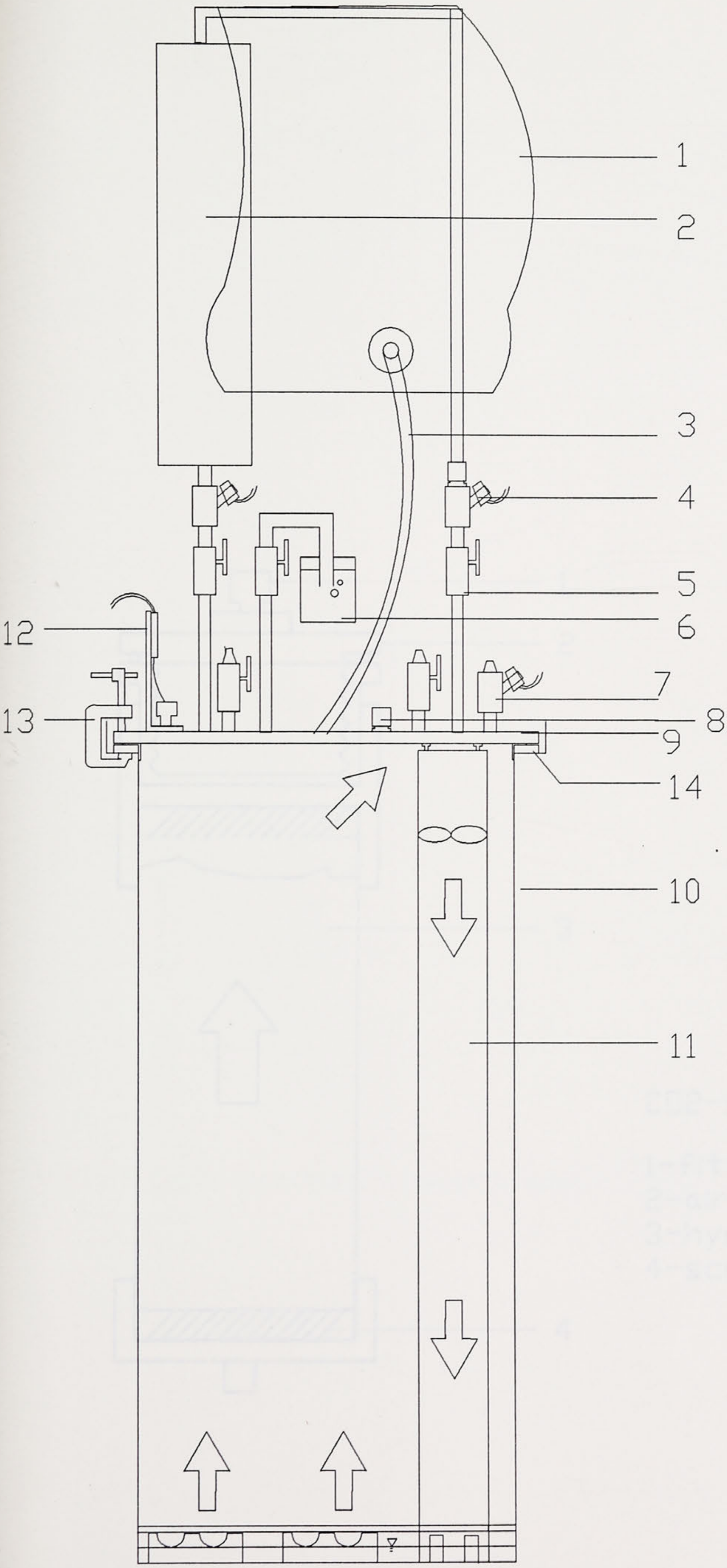
## 4.3 RA chambers (control)

The RA chambers were made with the same barrel and acrylic lid as the CA chambers. Attached to the lid was one thermocouple, one air inlet and one outlet. The same blower was installed inside the chamber. High relative humidity air was injected continuously in the chambers at a rate of two to three air-change/day to maintain the $O_2$ level close to 21% and a high relative humidity.

### 4.3.1 Humidifying column

The humidifying water column was placed inside the refrigerated room supplied four RA chambers (Figure 6). It was activated by a diaphragm pump that sucked the air from outside of the RR to prevent any contamination from the gas rejected by the CA chambers. The air was then pumped through an air diffuser immersed in a water column and delivered to the RA chambers by 4 orifices of 0.127 mm.

The humidifying water column was placed inside the RR to prevent condensation. The outside air was cooled inside the cold water column. A typical amount of water added to the air by the water column was 1.28 g/day. The water column with the air diffuser did also act as an air filter. The pump was operating at 10 psi which was 83% of its maximum capacity. The flow of humid air entering each chamber was 3.4 ml/sec which equalled 2.7 air change per day (representative of a normal humid RR).




1-20l plastic bag

2-$CO_2$-scrubber(see fig4)

3-PVC tubing 635mm(1/4")

4-Solenoid valve

5-Hand ball valve

6-Pressure regulator
(2,5cm or 1" water)

7-Air injection solenoid valve

8-Septum

9-Acrylic lid (127mm,1/2")

10-Polypropylen barrel

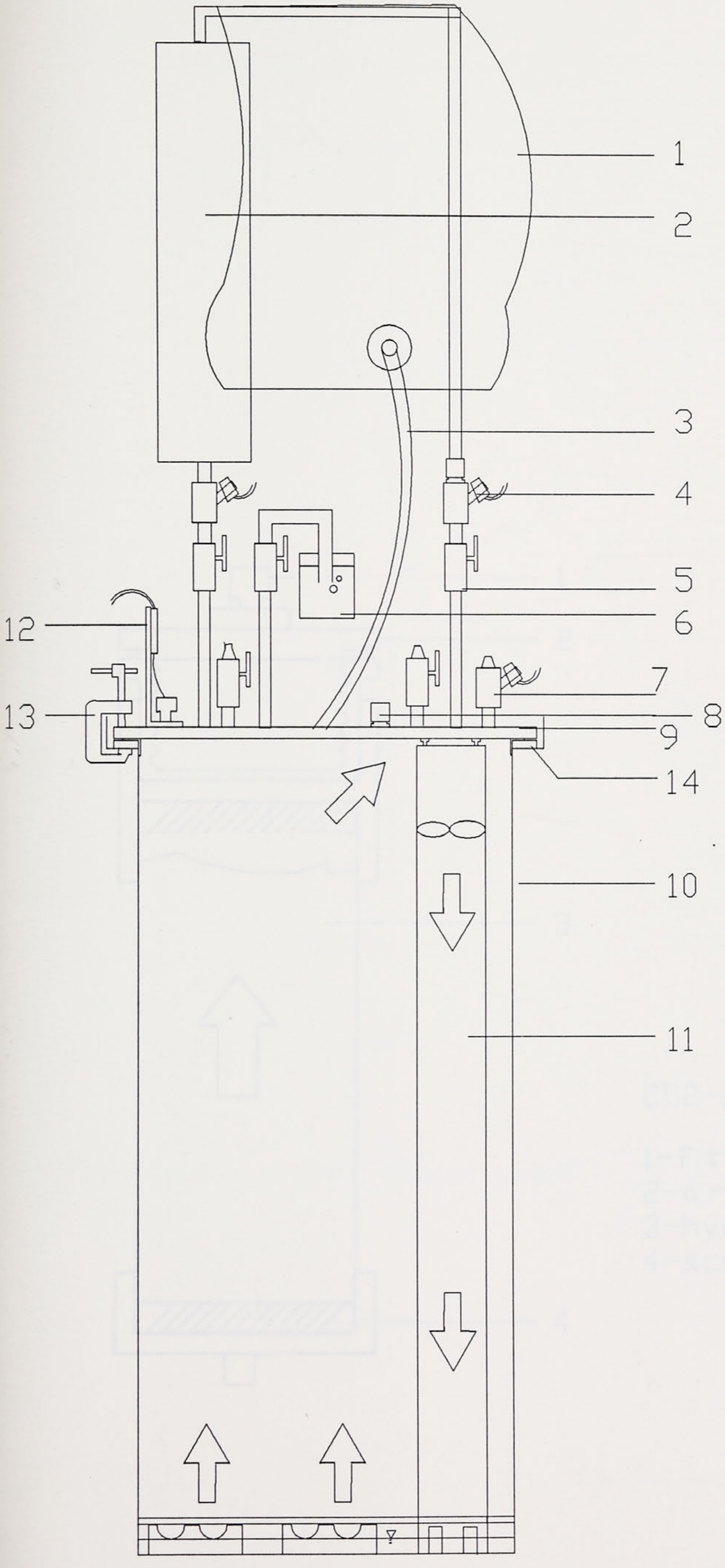
11-Blower (see fig5)

12-Airtight quick-release thermocouple

13-C-clamp 508mm(2")

14-Rubber sceal 635mm(1/4")

Fig.3 : CA chamber




1-20l plastic bag

2-CO2-scrubber(see fig4)

3-PVC tubing 635mm(1/4")

4-Solenoid valve

5-Hand ball valve

6-Pressure regulator
(2.5cm or 1" water)

7-Air injection solenoid valve

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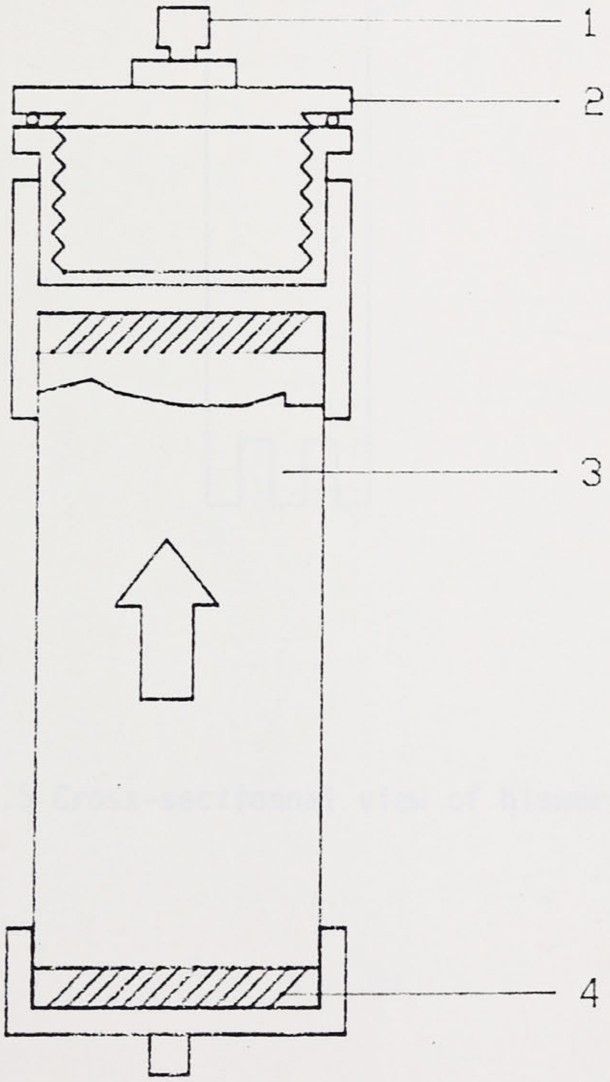
Fig.3 : CA chamber




CO2-scrubber

1-fitting
2-airtight cap
3-hydrated lime
4-screen

Fig.4 : CO2-scrubber

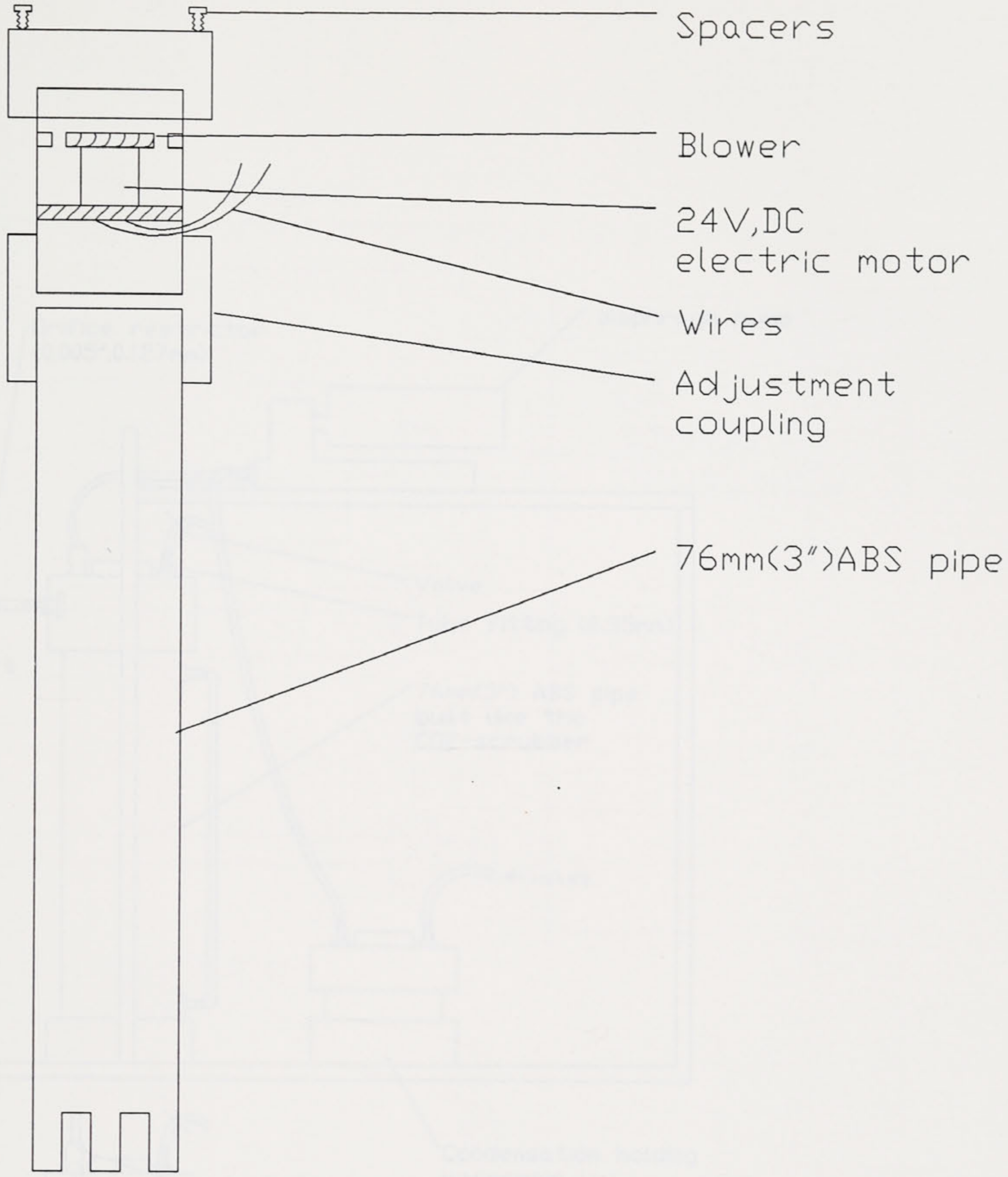



Fig.5 Cross-sectionnal view of blower

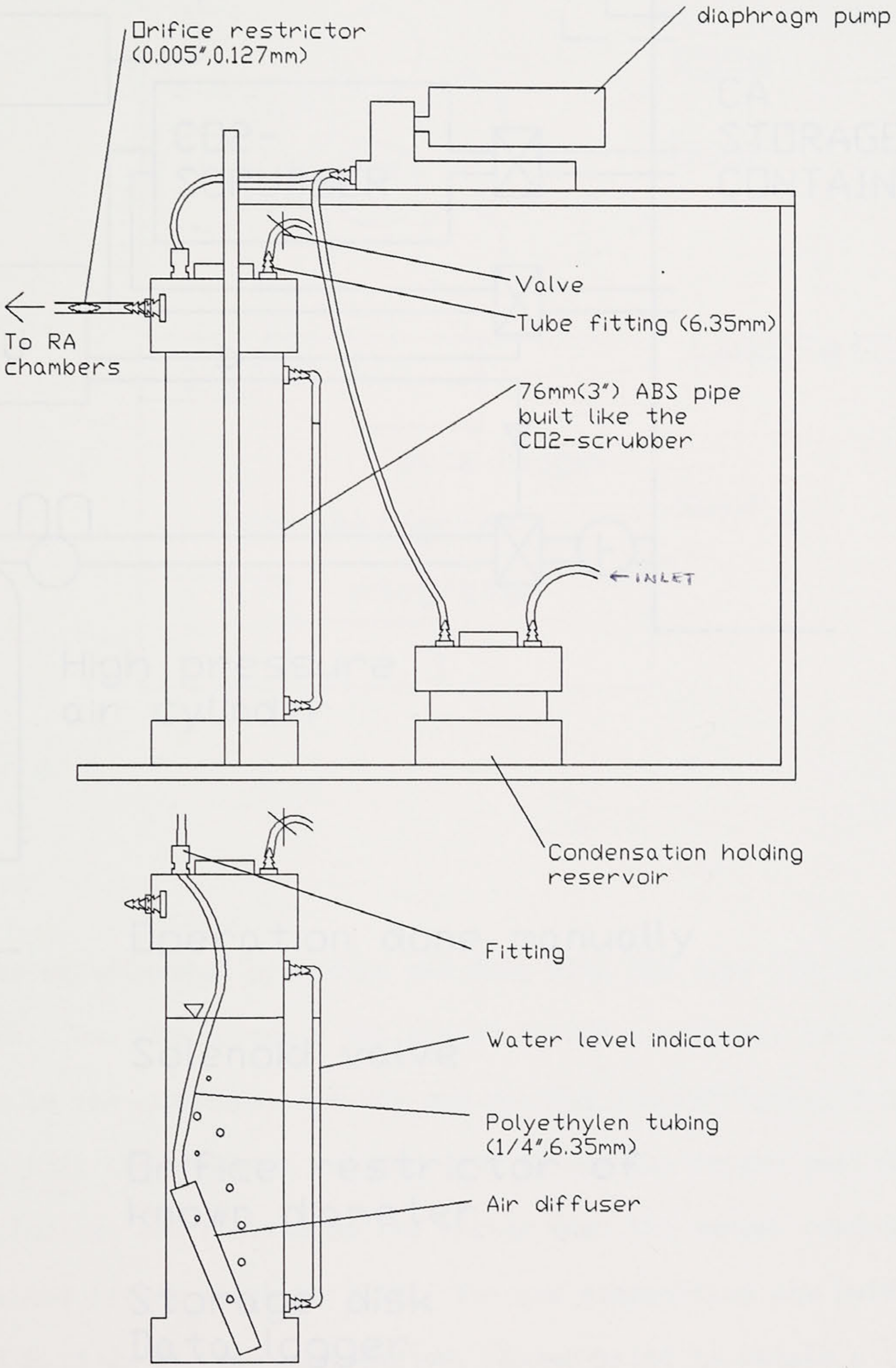
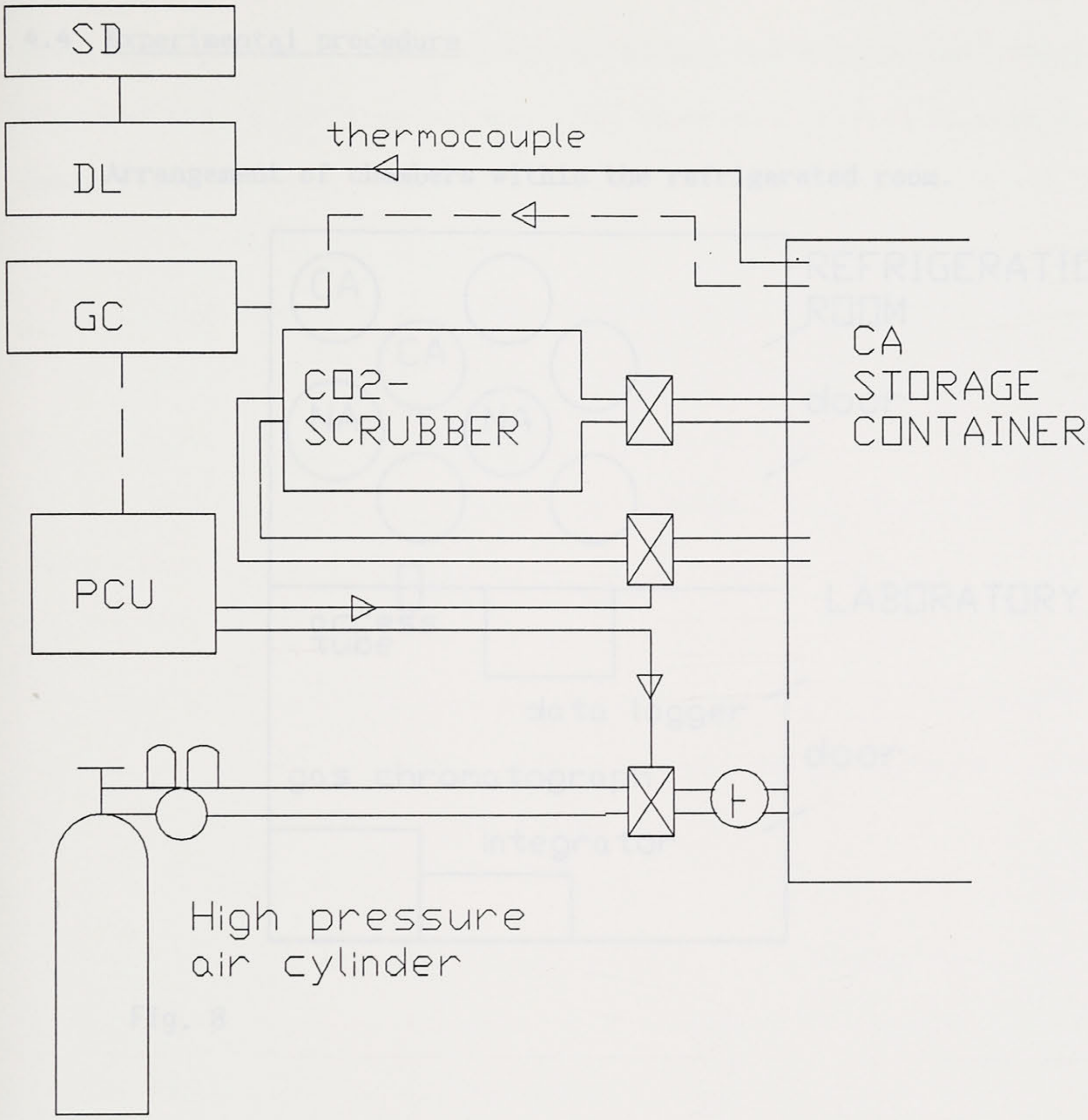



Fig. 6 : Humidifying water column for RA chambers




— — Operation done manually

Solenoid valve

Orifice restrictor of known diameter

SD Storage disk
DL Data logger
GC Gas chromatograph
PCU Programmable control unit

Fig. 7 : Diagram of CA set-up.

## 4.4 Experimental procedure

Arrangement of chambers within the refrigerated room.

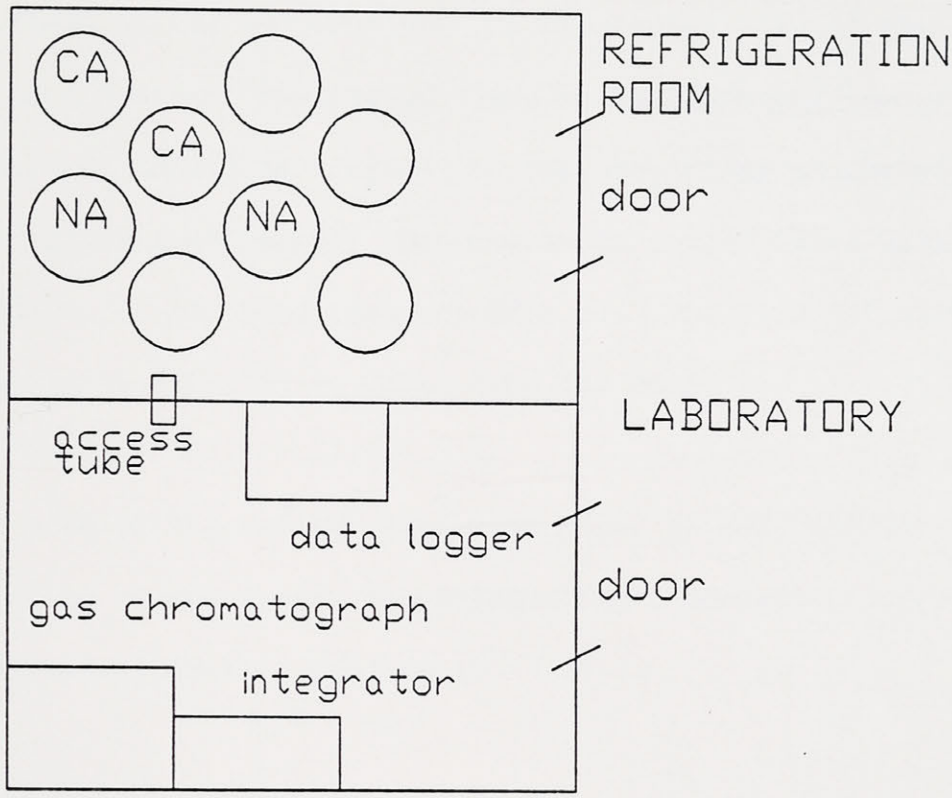



Fig. 8

The experimental procedure was done with 300 days old Winter Cultivar Cabbages. One thermocouple was placed inside a cabbage, the others were hanging in the chambers, and one was reading the refrigerated room temperature. We have left the chambers on their own to see the oxygen pull down period at the beginning, and reacted on the system when the oxygen concentration reached the desired level, which is 2.5%. The gas composition was held as close to 5% $CO_2$ and 2.5% $O_2$ for the next period. Later tried to obtain a low $O_2$ condition (1%) and created some fermentation in the cabbages and tried to relate it to the inside cabbage temperature. Also to see the behavior of the chamber itself, we put one of each chambers (RA and CA) without any cabbages, and recorded the inside temperature. The experiment lasted 65 days at a RR temperature of 1°C.

# 5. RESULTS AND DISCUSSION

5.1 RR temperature analysis: The results showed that there was no temperature gradient on the vertical nor the horizontal axis of the refrigerated room. However, the region close to the door was warmer than the rest of the room, and should be avoided for the proceeding of the experiment. The overall averaged temperature of the room tends to stabilize when it is filled with products of any kind (See appendix A). The commodities therefore should be stored in the area 65 to 75 cm from the door.

The entire area of the refrigerated room might be safe for the of the experience regarding of our needs, but eliminating a probable source of error adds a factor of safety to this procedure.

5.2 Airtighness results of the chambers: All chambers have held a pressure differential of 2.5 cm of water for a period of 30 minutes, which is representative of a CA storage room.

5.3 Temperature: The temperature inside the chambers filled with cabbages stabilized at 2°C while the RR temperature fluctuated between 2 and 0°C (Graph no. 3). The high temperature in the chambers filled with commodities was caused by the heat of respiration, and therefore the RR temperature should be lowered to obtain the desired 1°C in the chambers. the chambers filled with commodities have the advantageous properties of attenuating the fluctuations in temperature of the RR.

## 5.4 CA: Carbon dioxide and oxygen fluctuations

The $O_2$ decreased to 2.5% in the CA chamber within 9 days (Graph no. 1). The volume of the empty barrel was 110 l and the volume taken by the cabbages was around 37.5 l which equals to 34% of the space, which is not enough to explain this fast $O_2$ pull down. (We will see that the 20 l bag doesn't participate in the gas exchange).

This high respiration rate could only be explained by the fact that the 300 days old cabbages were in a stage of dormancy breakdown. After harvesting, cabbages are in a dormant period. At approximately 300 days of storage life, they start producing buds which increases the metabolism and the respiration rate.

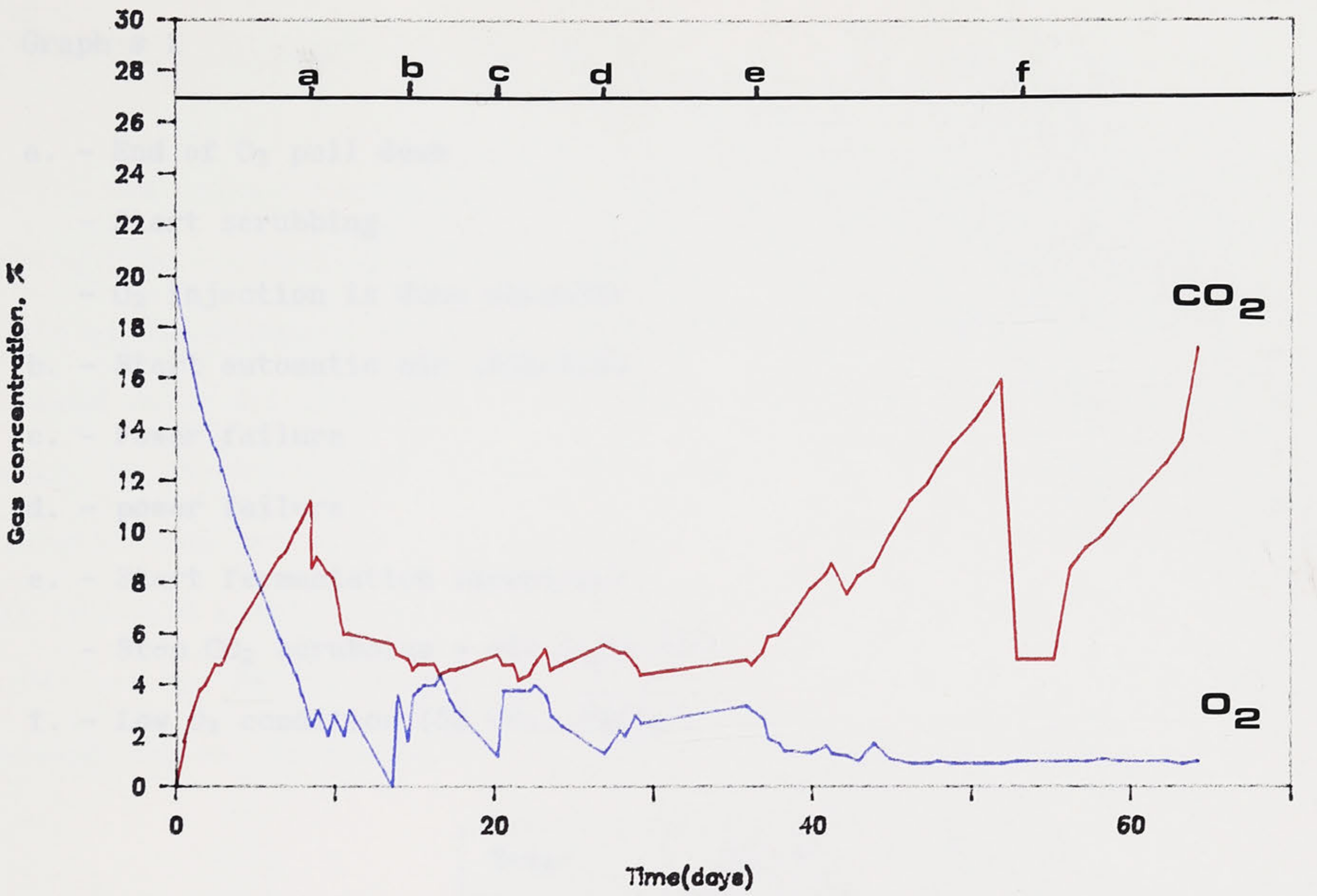
The scrubbing of the $CO_2$ should started after 3 days and the air injection after 9 days. The cabbages did consumed around 0.4% of $O_2$ per day. The familiarization to the different apparatus and the reactions of the cabbages to the gas alterations were the main causes, as well as some power failures. The difficulty arised when considering the relationship between the precision of the apparatus, the minimum control that we wanted, and the response of the commodities to the different actions done on the system.

When no external problems disturbed the experience, satisfactory results were obtained. An automatic sampling and analyzing system that would be programmed to changed the gas concentrations almost continuously should provide better control of the gas composition in the CA chambers.

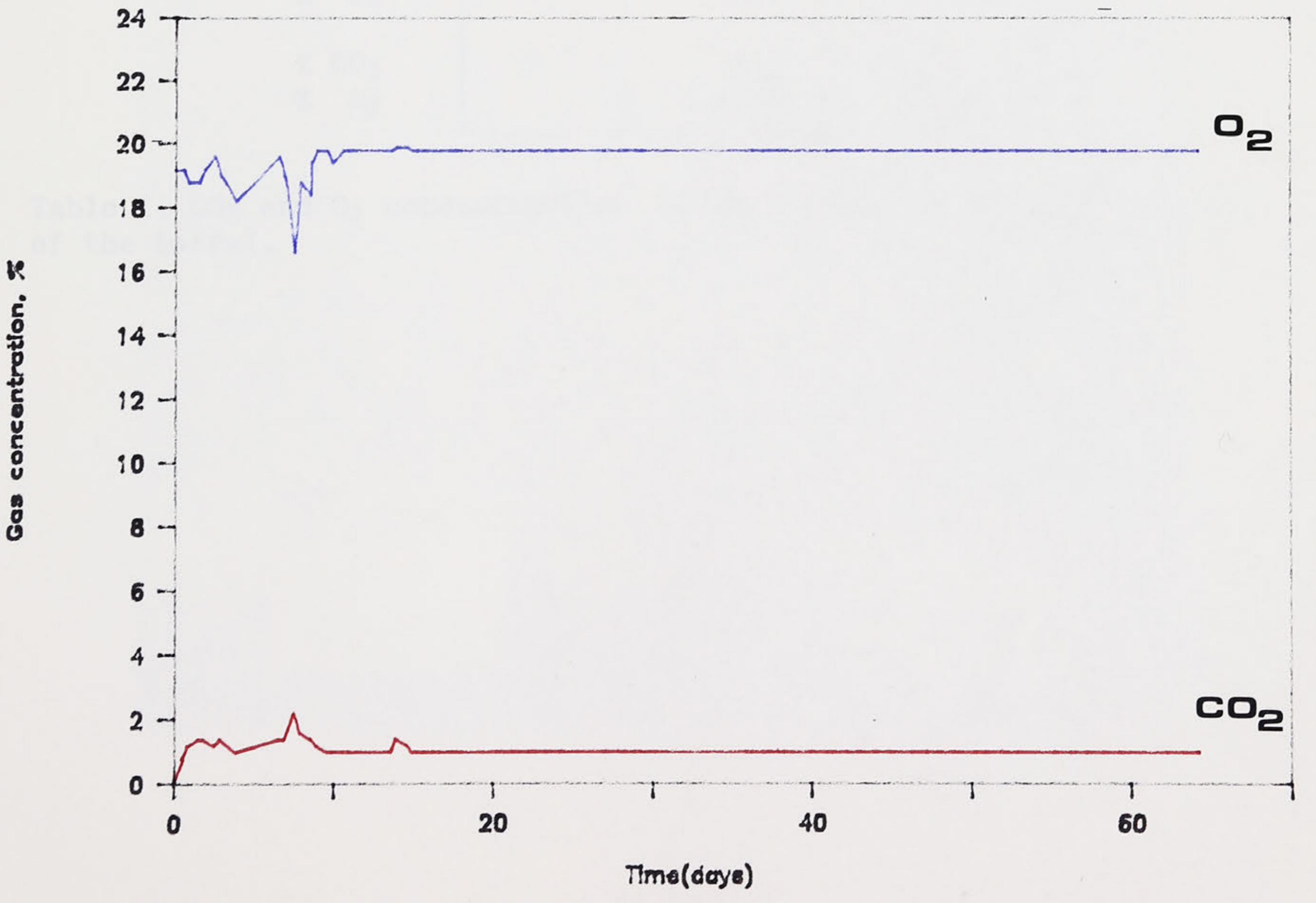
The gas concentration in the 20 l balloon was different from the inside of the barrel. The $O_2$ concentrations measured were high, close to the normal air. There is two possible explanations for this situation. First, the diffusion of the gases through the PVC ¼" dia. tubing connecting the chamber and the balloon was practically nonexistent. Second, the material of the balloon may have been highly permeable to $O_2$.

After 36 days the chamber left on its own to simulate a failure had 1% $O_2$ and 5% $CO_2$. Most of the time, the fermentation process in the cabbages start at the tip of the apex but it is hard to put a thermocouple right at this location since it changes with different cabbages (Bérard, 1988). After 53 days the $CO_2$ concentration was brought to 5% and the $O_2$ was at 1% at equilibrium, so this system should work properly for conditions of low $O_2$,

5.5 RA (Graph # 2) . During the experience, the NA chambers maintained a $CO_2$ and $O_2$ concentration of 1% and 20%, respectively, which was close to the normal refrigerated room conditions. 93% RH was measured inside the chamber.




Graph no1 : CO2 and O2 concentrations fluctuations for the CA storage unit




Graph no2 : CO2 and O2 concentrations fluctuations for the RA storage unit.

Graph # 1

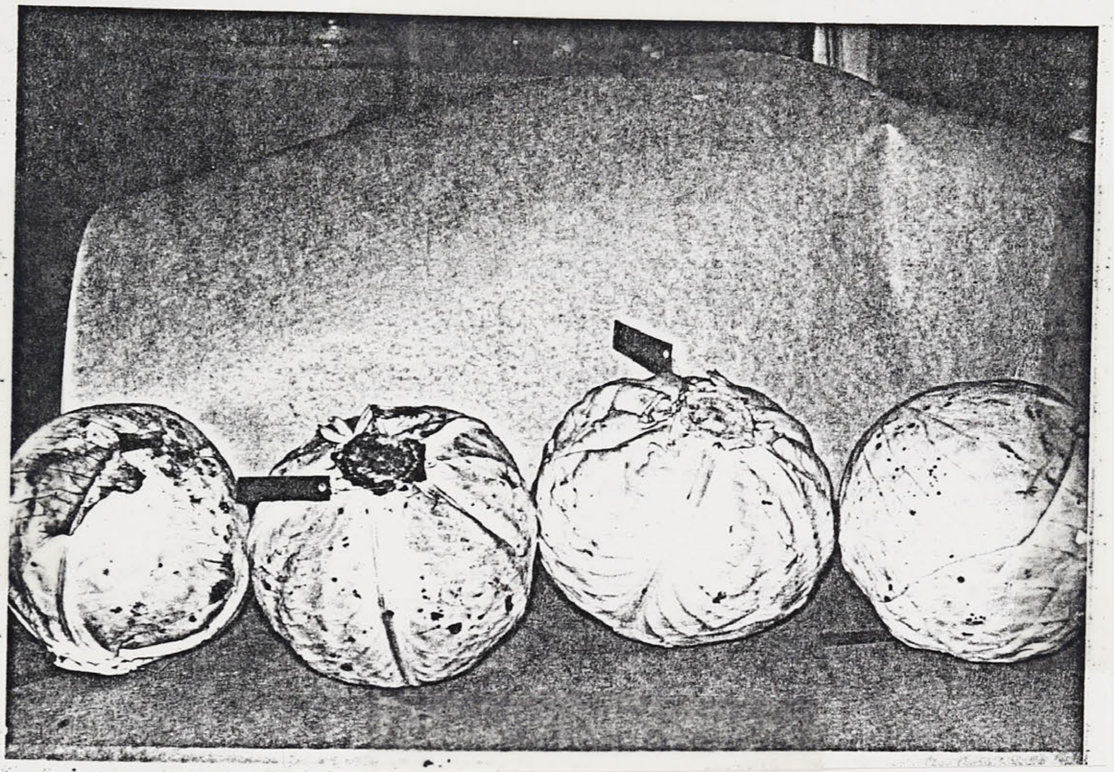
a. - End of $O_2$ pull down
   - Start scrubbing
   - $O_2$ injection is done manually
b. - Start automatic air injection
c. - Power failure
d. - power failure
e. - Start fermentation experience
   - Stop $CO_2$ scrubbing + air injection
f. - Low $O_2$ condition (5% $CO_2$, 1% $O_2$)

| | Trial | Bottom | Top |
|---|---|---|---|
| % $CO_2$ | 1 | 4.8 | 4.8 |
| % $O_2$ | | 3.8 | 3.8 |
| % $CO_2$ | 2 | 4.8 | 4.8 |
| % $O_2$ | | 3.8 | 3.8 |
| % $CO_2$ | 3 | 4.2 | 4.2 |
| % $O_2$ | | 3.8 | 3.8 |

Table 1: $CO_2$ and $O_2$ concentrations in the CA unit at the top and bottom of the barrel.

5.6 Physiological control of quality

All the cabbages showed serious traces of decay caused by the water dripping from the acrylic lid where there was a lot of condensation. The quality of the cabbages was better preserved by the CA treatment. The condensed water dripping from the top had resulted less severe damages to the cabbages in CA than in RA. In the CA treatment since there wasn't any trace of lateral buds caused by a dormancy breakdown, contrarily to the RA treatment where we could easily identify some. The external leaves were less yellow in the CA than the RA and the cut section of the cabbage was oxidized in the RA treatment and not in the CA.



RA CA

The mass loss for the cabbages inside the RA storage unit was higher than for the CA unit. Two reasons can explain this. First, the relative humidity in the RA unit was less and the cabbages lost some water in the atmosphere. During power failures, the water column providing humidity stopped and might have increased the possibility of weight loss. Secondly, the cabbages under high oxygen concentration (≈21%) had high rate of metabolism and consumed the carbohydrates and sugars which is responsible for part of the mass loss. The brown color of the leaves on the cabbages of the RA unit at the control of quality showed that the respiration and metabolism rate were high and consumed some of the cells of the vegetables (Berard, 1988).

CONTROL OF QUALITY

Weight of cabbages in grams

CA

| | #no | before | after | weight loss(-) |
|---|---|---|---|---|
| top | 19 | 2246 | 2248 | +2 |
| | 12 | 2533 | 2540 | +7 |
| | 17 | 4433 | 4435 | +2 |
| | 2 | 4519 | 4515 | -4 |
| | 13 | 3928 | 3919 | -9 |
| | 1 | 2857 | 2065 | +8 |
| | 3 | 2630 | 2620 | -10 |
| | 10 | 4057 | 4070 | +13 |
| | 18 | 4583 | 4567 | -16 |
| bottom | 7 | 1962 | 1957 | -5 |
| | | | | -1.2g |

NA

| | #no | before | after | |
|---|---|---|---|---|
| top | 16 | 3390 | 3378 | -12 |
| | 20 | 2368 | 2356 | -12 |
| | 14 | 3111 | 3105 | -6 |
| | 15 | 3721 | 3684 | -37 |
| | 4 | 3823 | 3809 | -14 |
| | 5 | 2188 | 2178 | -10 |
| | 11 | 2905 | 2871 | -34 |
| | 6 | 4088 | 4061 | -27 |
| | 8 | 5041 | 5003 | -38 |
| bottom | 9 | 1525 | 1512 | -13 |
| | | | | -203g |

TABLE 2

AIR FLOW AT THE FOUR OUTLETS OF THE WATER COLUMN

| Outlet | Flow (ml/sec) | Air change per day |
|---|---|---|
| 1 | 3.59 | 2.82 |
| 2 | 3.24 | 2.54 |
| 3 | 3.48 | 2.73 |
| 4 | 3.4 | 2.67 |

TABLE 3

# 6. CONCLUSION

The heat of respiration and transpiration of cabbages caused the condensation of water under the lid and rotting of the cabbages.

The level of humidity in the RA unit was too low, causing a higher mass loss of the cabbages.

$CO_2$ and $O_2$ levels were maintained for short period of time close to the desired levels. Low oxygen concentration are attainable and can be maintained.

The system appeared to be versatile, easy to work with, and easily modified, and showed great potential with a minimum of final readjustments and modifications.

## 7. RECOMMENDATIONS

- Adjust RR temperature so that the inside chambers temperature is maintained at around 1°C instead of 2°C.

- Check the behavior of the $CO_2$ scrubber to obtain the relationship of the absorbing capacity as a function of time, or the amount of air filtered. It will then be possible to know when to change the hydrated lime inside the scrubber.

- Install a reset switch to restart the cycle when there are power failures.

- Never deflate the balloon during an experience since the gas that will be introduced in the barrel will be at a different concentrations of $CO_2$ and $O_2$ than the one inside the barrel. This is because there is practically no diffusion of the gases in the PCV tubing between the barrel and the balloon. Also, there may be diffusion of gases through the material of the balloon, caused by a possible semi-permeability. Still, the test should be done at a larger scale to verify this statement. A balloon two orifices, with one over the vacuum of the blower, could solve the problem entirely.

- To prevent any condensed water from dripping on the cabbages, the chambers should be inclined at a sufficient angle to allow the water to glide on the sides of the barrel and accumulate at the bottom. The blower speed can be adjusted by changing the voltage (DC motor), decreasing the rpm to provide air circulation and increasing it for precooling, or to obtain a higher rate of $CO_2$ scrubbing.

There is no need to put any water at the bottom of the barrel to provide a high relative humidity in the chambers. The chamber can act as a simple Jacketed system, the product transpiration is producing the relative humidity, the refrigerated air circulating around it.

The source of air for the NA chamber should not be taken from the room containing the gas chromatograph since it can be contaminated by it or by the people working in this small room. Depending on the latitude where the experiment is taking place, the source of air can be taken from the outside or from inside the building where there is good ventilation (in Quebec, the outside air during the winter will freeze the water in the column). The amount of water that has to be added to the air must be adjusted for specific conditions of humidity and the temperature of the air used.

A fungal spore and bacterial filter should be used since high reproduction rates are encountered in high humidity.

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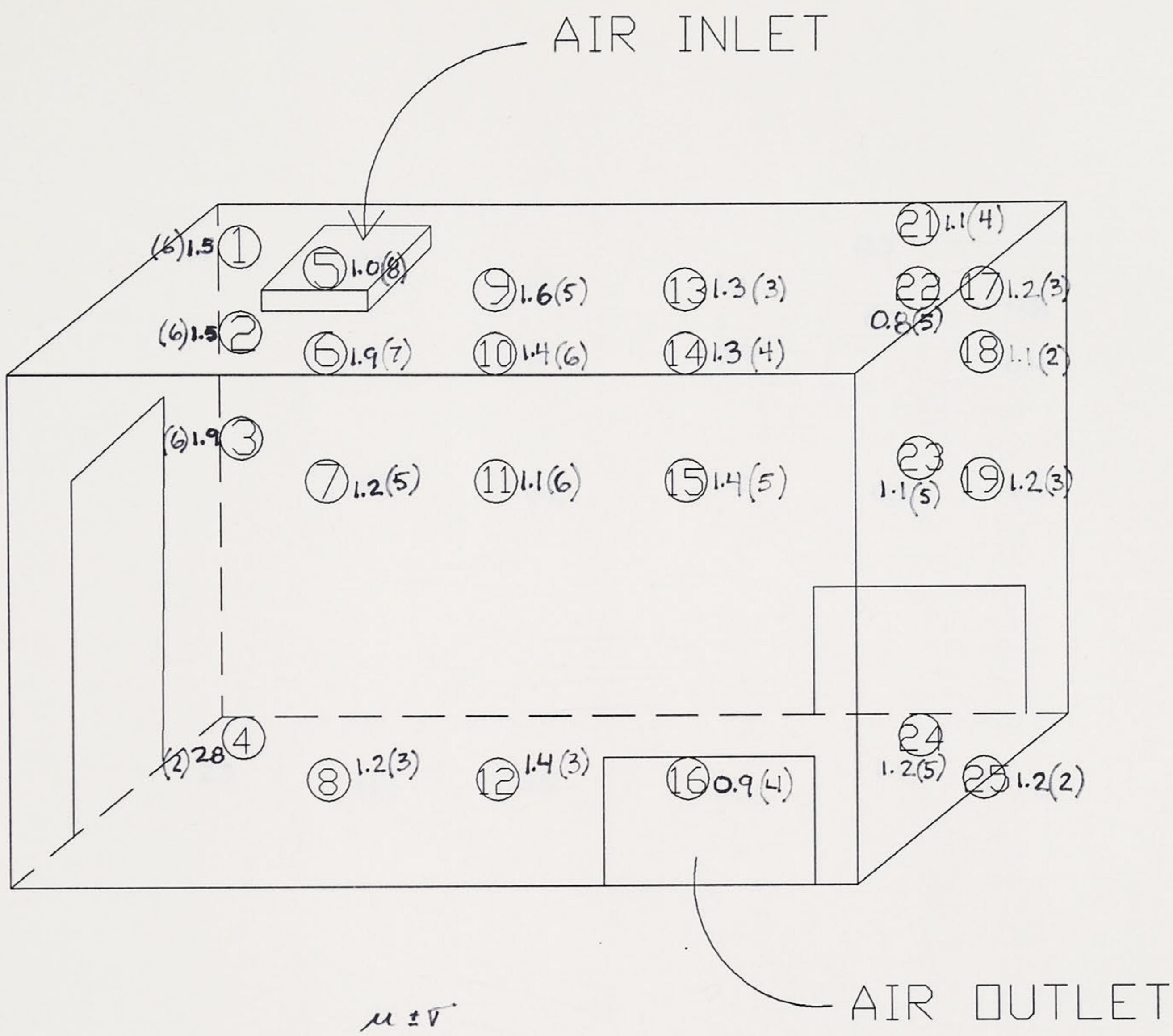
# 9. APPENDIX A



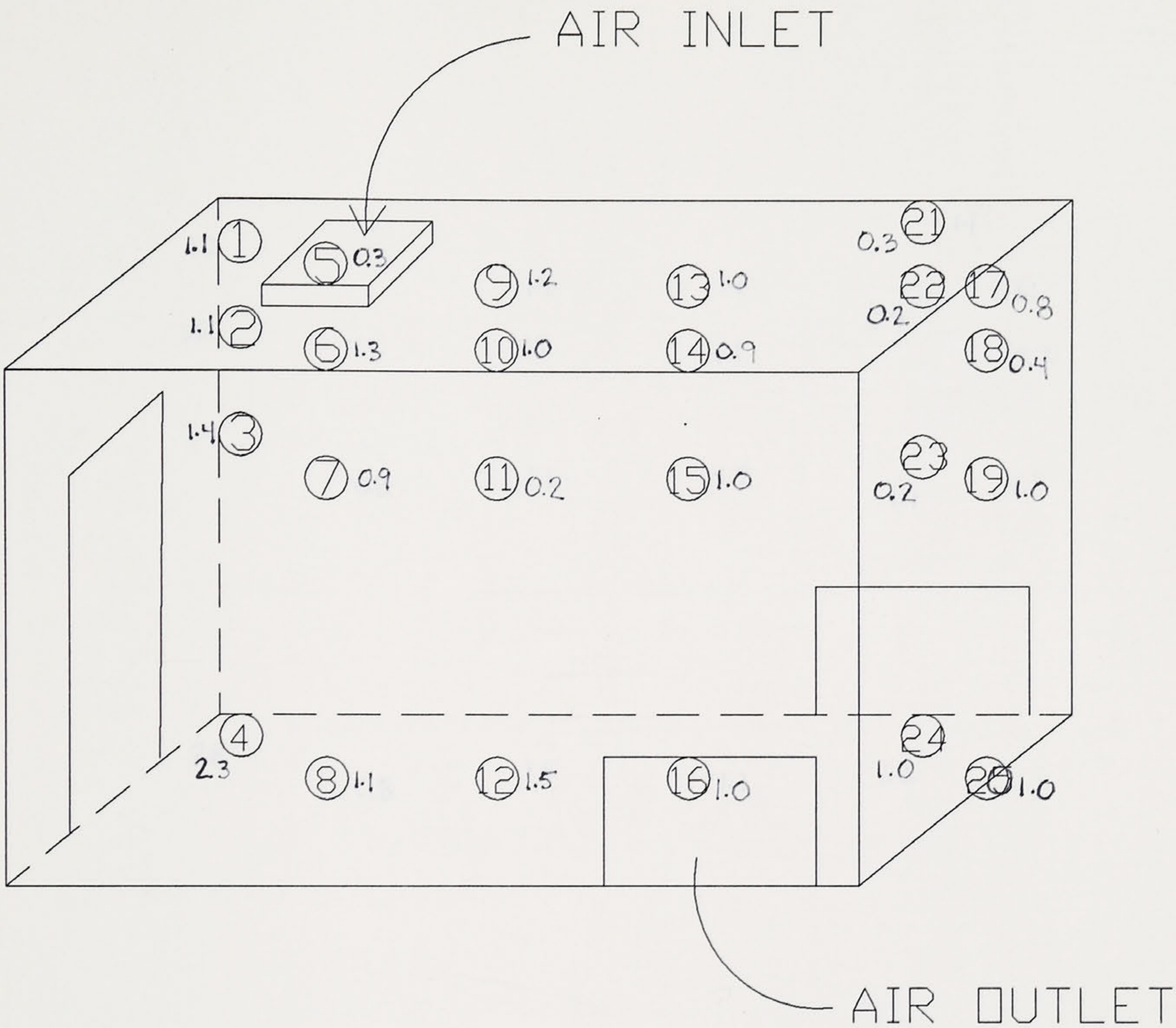

$\mu \pm \nu$

Vertical plane 1:2.0±0.6 °C
2:1.3±0.4 °C
3:1.4±0.2 °C
4:1.1±0.2 °C
5:1.2±0.1 °C

$\mu \pm \nu$

Horizontal plane 1:1.3±0.2 °C
2:1.3±0.4 °C
3:1.3±0.3 °C
4:1.4±0.7 °C
TOTAL AVERAGE: 1.3±0.4°c
AVERAGE TEMPERATURE OF MODIFIED AREA:1.2±0.2°C

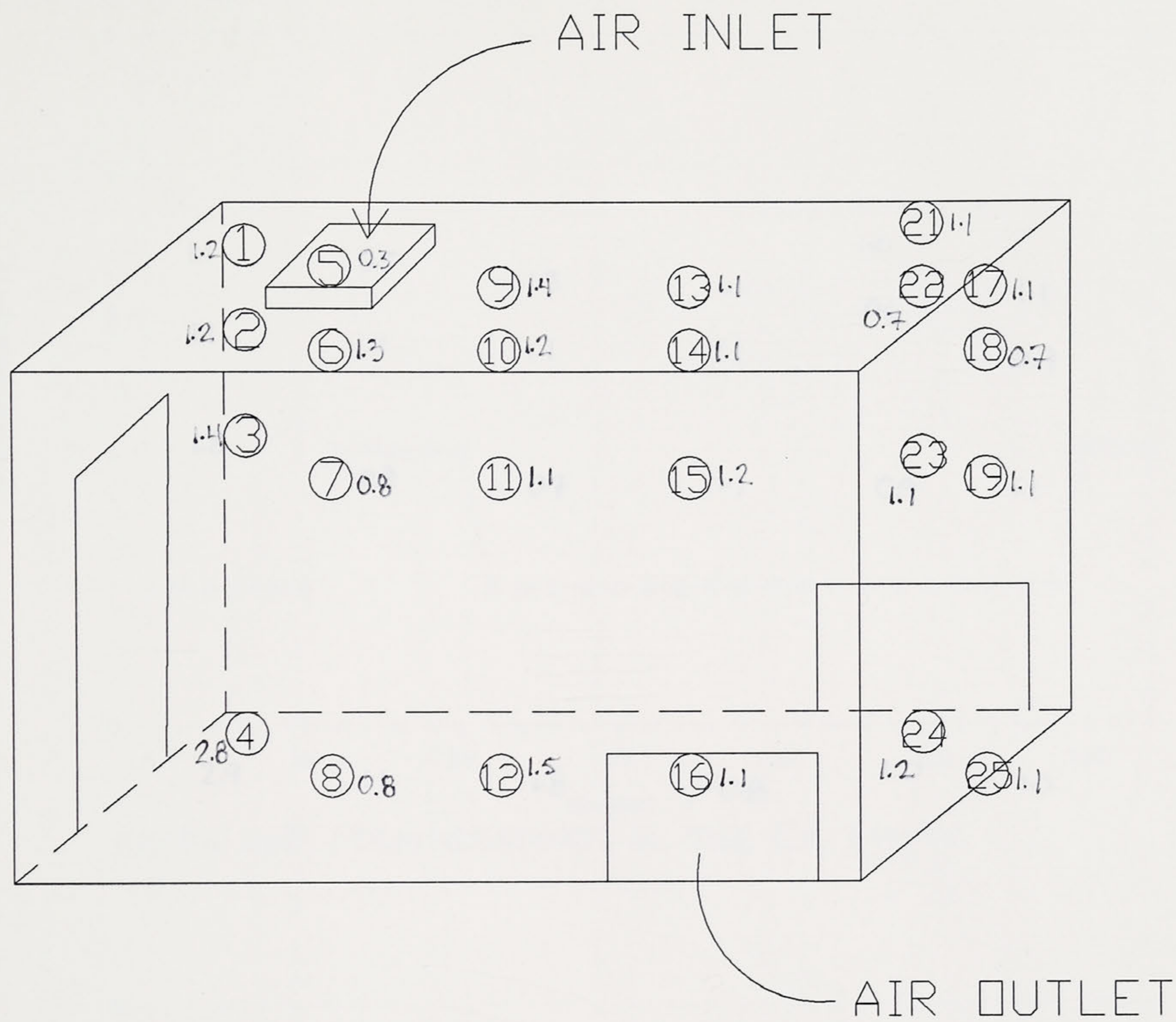
Fig 9. Temperature analysis: empty RR




Vertical plane 1:1.4±0.6 °C
2:0.9±0.4 °C
3:1.0±0.5 °C
4:0.7±0.4 °C
5:0.8±0.3 °C

Horizontal plane 1:0.8±0.4 C
2:0.8±0.4 C
3:0.8±0.5 C
4:1.3±0.5 C
TOTAL AVERAGE: 0.9 0.5 c
AVERAGE TEMPERATURE OF MODIFIED AREA:0.8±0.4°C

Fig 9b. RR with plastic boxes for storage

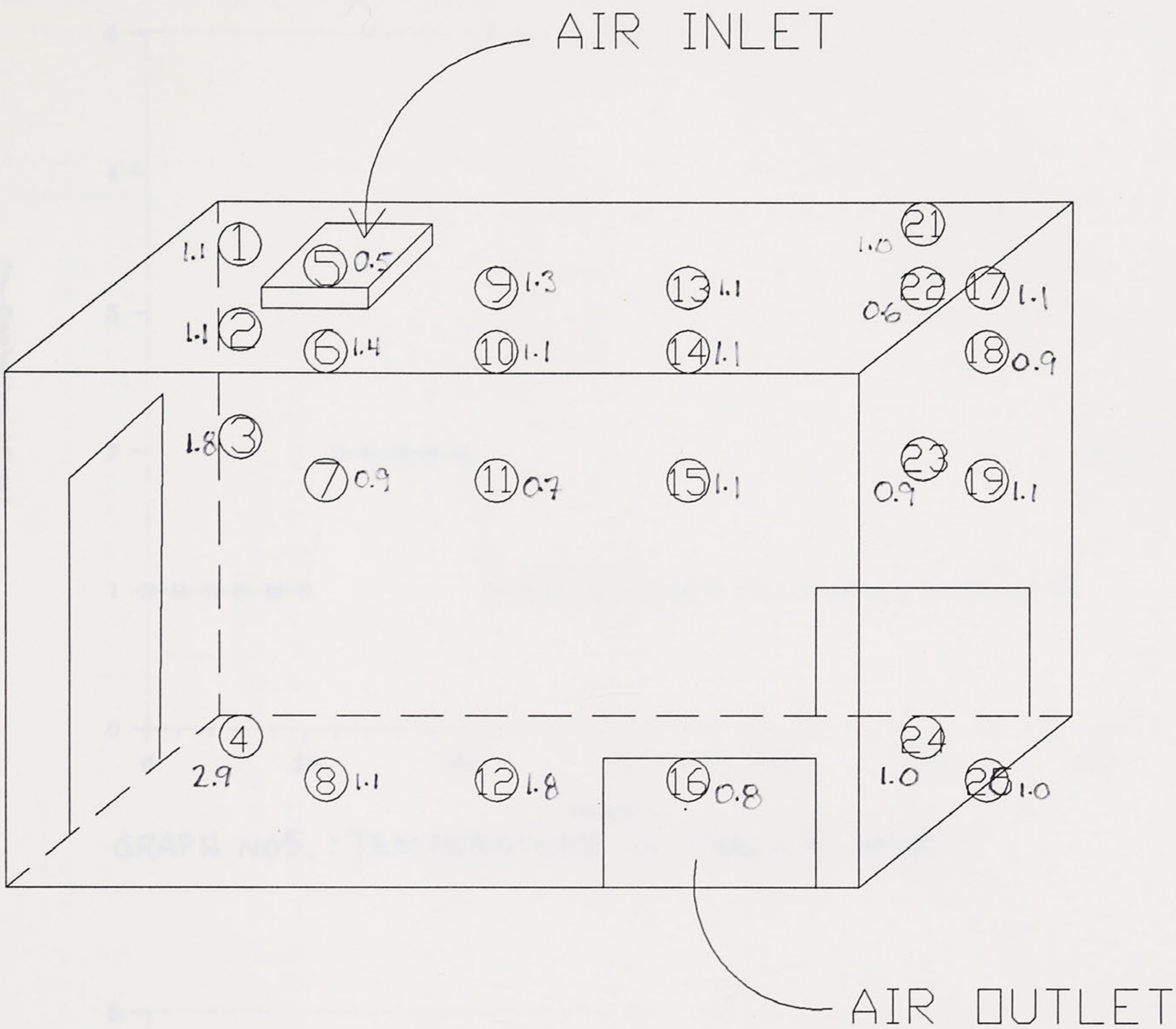



Vertical plane 1:1.7±0.8 °C
2:0.9±0.3 °C
3:1.3±0.2 °C
4:1.1±0.2 °C
5:1.0±0.2 °C

Horizontal plane 1:1.1±0.2 °C
2:1.0±0.3 °C
3:1.2±0.3 °C
4:1.4±0.7 °C

TOTAL AVERAGE: 1.2± 0.4°C
AVERAGE TEMPERATURE OF MODIFIED AREA: 1.1 ± 0.2 °C

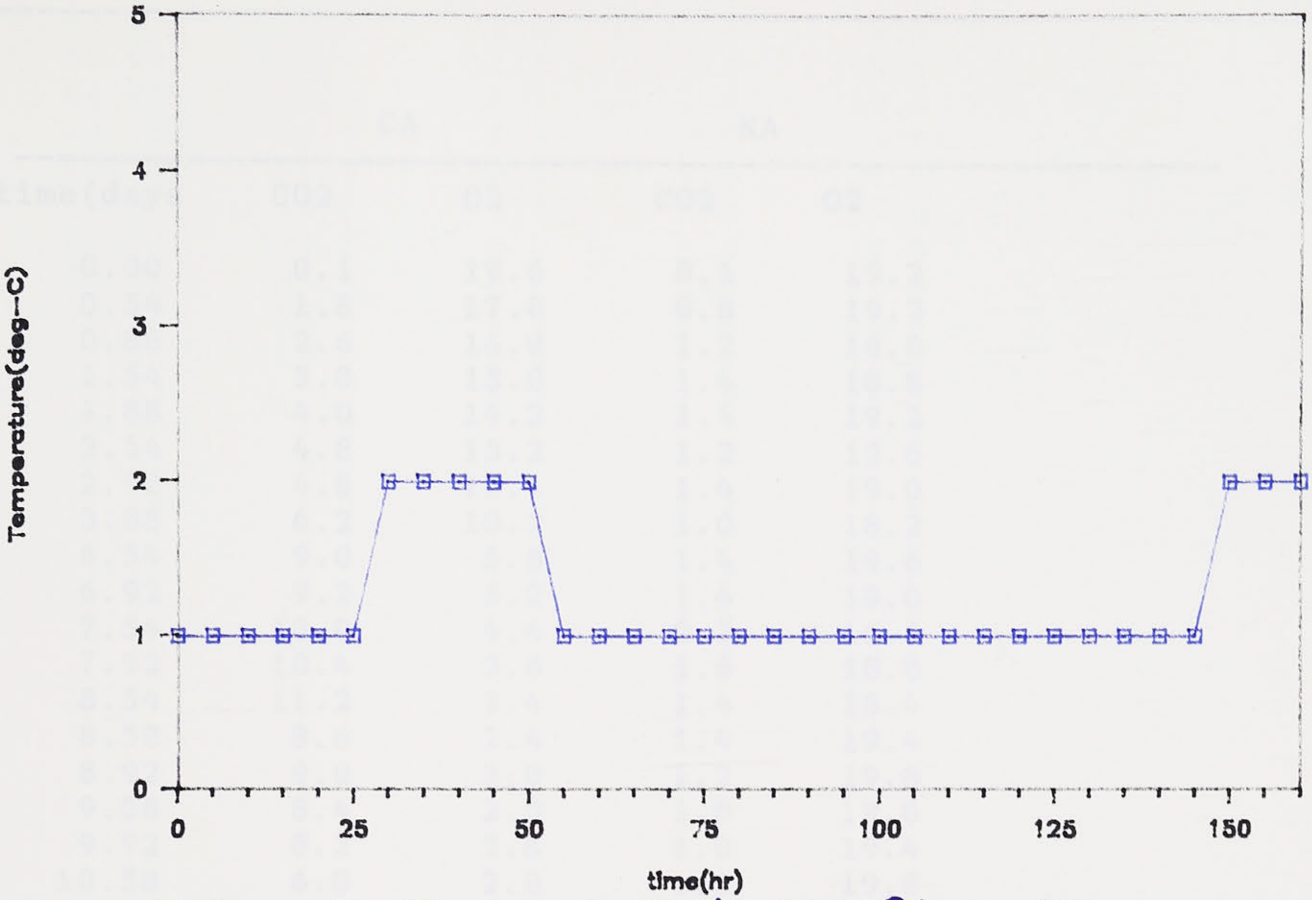
Fig 9c. RRwith plastic boxes filled
with cabbages



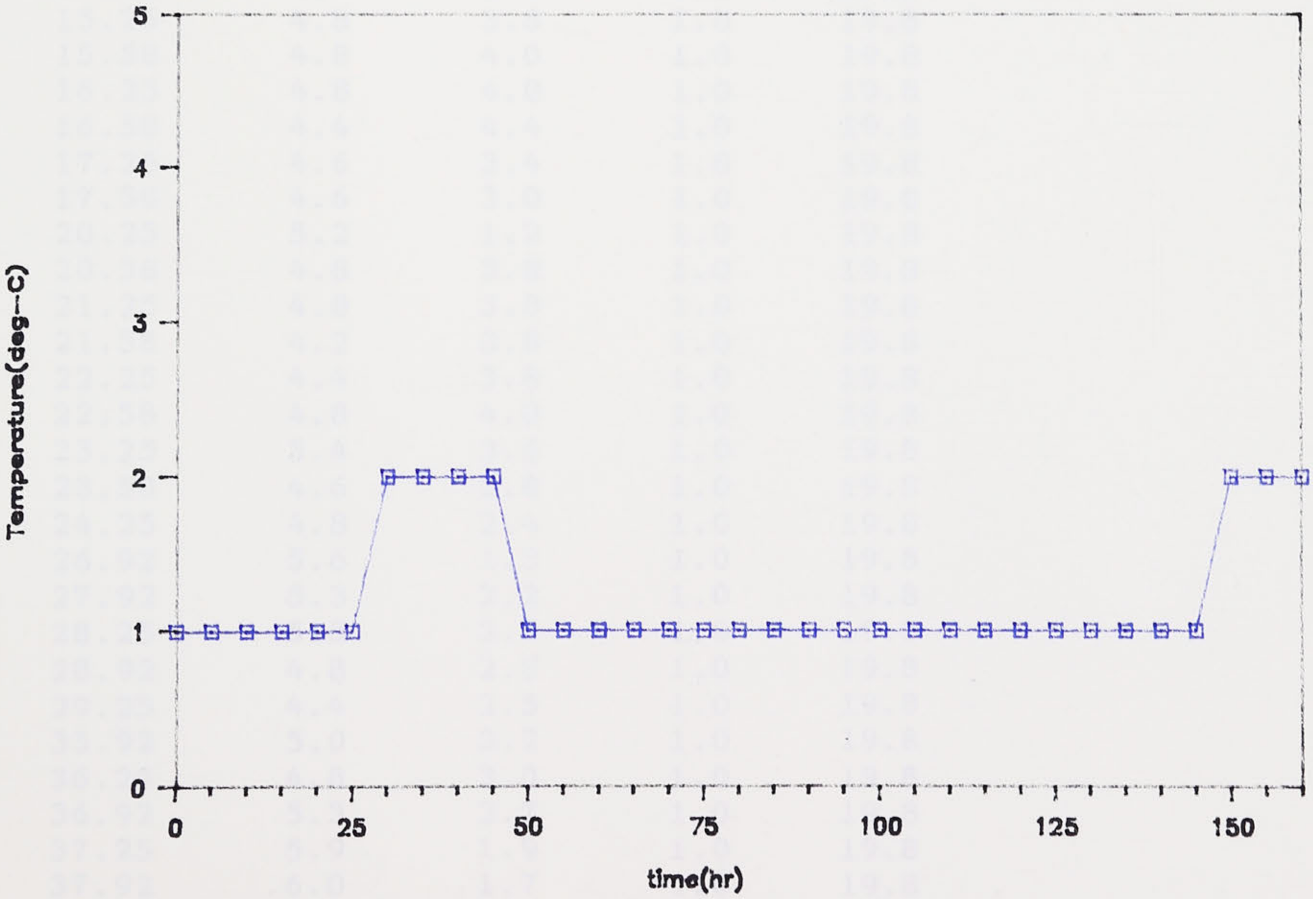

Vertical plane
1:1.7±0.9 °C
2:1.0±0.4 °C
3:1.2±0.5 °C
4:1.0±0.2 °C
5:1.0±0.1 °C

Horizontal plane
1: 1.0±0.3 °C
2:1.0±0.3 °C
3:1.1±0.4 °C
4:1.4±0.8 °C
TOTAL AVERAGE: 1.1 0.5 c
AVERAGE TEMPERATURE OF MODIFIED AREA: 1.0±0.3 °C

Fig 9d. RR with 8 barrels
with cabbages




GRAPH NO5. : TEMPERATURE IN THE CA EMPTY.




GRAPH NO.6. : TEMPERATURE IN THE RA EMPTY.

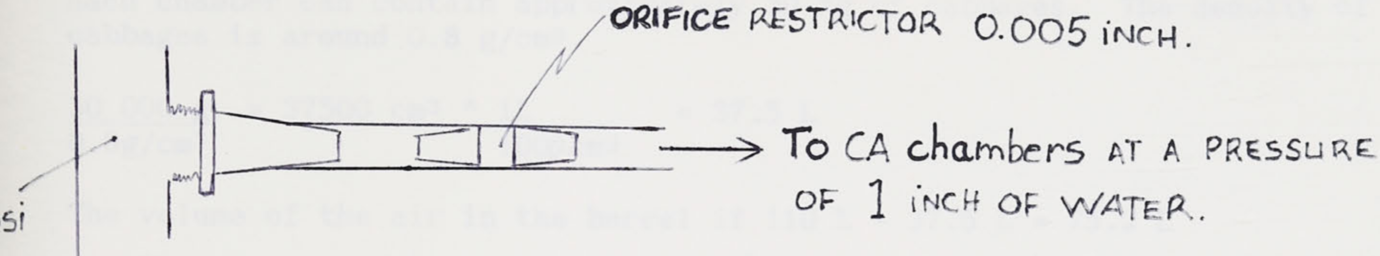
BLE 4

Gas concentration in the CA and NA storage unit during the experiment

| | CA | | NA | |
|---|---|---|---|---|
| time(days | CO2 | O2 | CO2 | O2 |
| 0.00 | 0.1 | 19.6 | 0.1 | 19.2 |
| 0.54 | 1.8 | 17.8 | 0.8 | 19.2 |
| 0.88 | 2.6 | 16.8 | 1.2 | 18.8 |
| 1.54 | 3.8 | 15.0 | 1.4 | 18.8 |
| 1.88 | 4.0 | 14.2 | 1.4 | 19.2 |
| 2.54 | 4.8 | 13.2 | 1.2 | 19.6 |
| 2.92 | 4.8 | 12.4 | 1.4 | 19.0 |
| 3.88 | 6.2 | 10.2 | 1.0 | 18.2 |
| 6.54 | 9.0 | 5.8 | 1.4 | 19.6 |
| 6.92 | 9.2 | 5.2 | 1.4 | 19.0 |
| 7.54 | 10.0 | 4.4 | 2.2 | 16.6 |
| 7.92 | 10.4 | 3.6 | 1.6 | 18.8 |
| 8.54 | 11.2 | 2.4 | 1.4 | 18.4 |
| 8.58 | 8.6 | 2.4 | 1.4 | 19.4 |
| 8.92 | 9.0 | 3.0 | 1.2 | 19.8 |
| 9.58 | 8.4 | 2.0 | 1.0 | 19.8 |
| 9.92 | 8.2 | 2.8 | 1.0 | 19.4 |
| 10.58 | 6.0 | 2.0 | 1.0 | 19.8 |
| 10.92 | 6.0 | 3.0 | 1.0 | 19.8 |
| 13.58 | 5.6 | 0.0 | 1.0 | 19.8 |
| 13.92 | 5.2 | 3.6 | 1.4 | 19.9 |
| 14.58 | 5.0 | 1.8 | 1.2 | 19.9 |
| 14.92 | 4.6 | 3.6 | 1.0 | 19.8 |
| 15.25 | 4.8 | 3.8 | 1.0 | 19.8 |
| 15.58 | 4.8 | 4.0 | 1.0 | 19.8 |
| 16.25 | 4.8 | 4.0 | 1.0 | 19.8 |
| 16.58 | 4.4 | 4.4 | 1.0 | 19.8 |
| 17.25 | 4.6 | 3.4 | 1.0 | 19.8 |
| 17.58 | 4.6 | 3.0 | 1.0 | 19.8 |
| 20.25 | 5.2 | 1.2 | 1.0 | 19.8 |
| 20.58 | 4.8 | 3.8 | 1.0 | 19.8 |
| 21.25 | 4.8 | 3.8 | 1.0 | 19.8 |
| 21.58 | 4.2 | 3.8 | 1.0 | 19.8 |
| 22.25 | 4.4 | 3.8 | 1.0 | 19.8 |
| 22.58 | 4.8 | 4.0 | 1.0 | 19.8 |
| 23.25 | 5.4 | 3.6 | 1.0 | 19.8 |
| 23.58 | 4.6 | 2.8 | 1.0 | 19.8 |
| 24.25 | 4.8 | 2.4 | 1.0 | 19.8 |
| 26.92 | 5.6 | 1.3 | 1.0 | 19.8 |
| 27.92 | 5.3 | 2.2 | 1.0 | 19.8 |
| 28.25 | 5.3 | 2.0 | 1.0 | 19.8 |
| 28.92 | 4.8 | 2.8 | 1.0 | 19.8 |
| 29.25 | 4.4 | 2.5 | 1.0 | 19.8 |
| 35.92 | 5.0 | 3.2 | 1.0 | 19.8 |
| 36.25 | 4.8 | 3.0 | 1.0 | 19.8 |
| 36.92 | 5.3 | 2.7 | 1.0 | 19.8 |
| 37.25 | 5.9 | 1.9 | 1.0 | 19.8 |
| 37.92 | 6.0 | 1.7 | 1.0 | 19.8 |
| 38.25 | 6.3 | 1.4 | 1.0 | 19.8 |
| 39.92 | 7.8 | 1.3 | 1.0 | 19.8 |
| 40.92 | 8.4 | 1.6 | 1.0 | 19.8 |

**Samples calculations**

**Air injection**




$$\frac{V_1^2}{2g} + \frac{p_1}{\rho} + Z_1 = \frac{V_2^2}{2g} + \frac{p_2}{\rho} + Z_2$$

$p_1$ = pressure inside manifold
$\rho$ = air density
$g$ = gravity
$Z_{1,2}$ = potential energy

$Y_1 = 0$, $Z$ and $Z_2 = 0$

$$\frac{p_1 - p_2}{\rho} = \frac{V_2^2}{2g} ; \quad p_1 - p_2 = \sqrt{\frac{V_2^2}{2g}\rho}$$

since in the unit of "psi" the gravity is already considered, in this case,

$$p_1 - p_2 = \sqrt{\frac{V_2^2}{2}\rho}$$

1" of $H_2o$ = 0.0361 psi

$$50 - 0.0361 = \sqrt{\frac{V_2^2}{2} (2.377 \times 10^{-3})}$$

$\rho$ of air = $2.377 \times 10^{-3} \frac{pi^2}{lb.sec^2}$

$V_2$ = 2460 ft/sec

$V_2$ measured = 2157 ft/sec

The losses are $\frac{2460 - 2157}{2460} \times 100 = 12\%$

Area of the orifice with d = 0.005"

$$A = \frac{\pi d^2}{4} = 1.963 \times 10^{-5} \text{ in}^2$$

$$\text{Flow} = 2157 \frac{\text{ft}}{\text{Sec}} \times \frac{12\text{in}}{\text{ft}} \times 1.963 \times 10^{-5} \text{ in}^2 = \frac{0.508 \text{ in}^3}{\text{sec}}$$

$$\frac{0.508 \text{ in}^3}{\text{sec}} * \frac{60\text{sec}}{\text{min}} * \frac{(2.54)^3\text{cm}^3}{\text{in}^3} \times \frac{\text{L}}{1000 \text{ cm}^3} = \frac{0.5 \text{ L}}{\text{min}}$$

Flow entering the chamber through the orifice restrictor is 0.5 L/min.

The volume of the chamber is 110L*

Each chamber can contain approximately 30 kg of cabbages. The density of the cabbages is around 0.8 $g/cm^3$.

$$\frac{30\ 000\ g}{0.8 g/cm^3} = 37500\ cm^3 * \frac{1L}{1000\ cm^3} = 37.5\ L$$

The volume of the air in the barrel if 110 L - 37.5 L = 75.2 L

To increase the $O_2$ concentration in the barrel by 1%, we must inject:

$$75.5\ L \times 1\% = 0.725L \text{ of } O_2$$

or

$$\frac{0.725\ L}{21\%} = 3.45\ L \text{ of air}$$

at a rate of 0.5 litres/min (under a pressure of 50 lbs) the solenoid valves must be opened $\frac{3.45\ L}{0.5\ L/min} = 6.9$ min.

* The volume of the 20 L balloon is not participatingh in the gas alterations (see discusion)