Prediction Method of Weight Loss through Measurement of Controlled Atmosphere (CA) Storage Environment

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***Abstract*—Weight loss that influences the quality and farmer incomes is affected by storage environment of agricultural products. The interior of storage should be maintained at high humidity to prevent weight loss of products which contains a lot of moisture. The research had constantly proceeded with change of the heat exchanger surface areas, humidity systems to maintain high humidity within storage. And weight loss prediction carry out by vapor pressure deficit (VPD) and K-value. Relative humidity that exerts an effect weight loss of crop be influenced by storage temperature, leak state and volume of product. When weight loss predicts, different conditions of these factors derive the error. In case of CA storage, ways of forecasting the weight loss become easier than cold storage due to sealed storage with external environment during storage period. In this study, Apples were stored in purge-type CA storage and weight loss has been predicted by using operating characteristics of refrigerator system and environmental conditions. And it was compared with actual weight loss. As a result, humidity variation in the storage fluctuates with operation of unit-cooler. Furthermore unit-cooler operation factor is influenced by outside temperature and respiration heat. Prediction value of weight loss according to temperature and humidity has been most accurately predicted. Prediction value through measured defrosting water shows unit-cooler work quality. K-value needs verification to calculate of VPD method.**

***Index Terms*—controlled atmosphere storage, weight loss, transpiration, cold storage**

I. Introduction

Low temperature storage is the most commonly used method to extend the shelf life and to maintain the best quality after harvesting agricultural products. In particular, most agricultural products contain moisture reaching 80 to 95% [1], but losing market quality when the water loss is caused by increased production and breathing and the limit water loss is reached [2]. Reported that if water was lost by evaporation or breathing to reach a threshold water loss, The product was loses merchantability. The inside of the storage keeps low temperature and high humidity to maintain quality during the period of preserving agricultural products. At this time, when cooled for low temperature conditions, the moisture inside the storage is condensed and frosted on the surface of the unit cooler (evaporator), and then water is drained to the outside of the storage through the defrosting process. Repetition of the cooling process lowers the humidity inside the storage by guiding the discharge of the water in the storage to the outside. Increase of Vapor Pressure Deficit (VPD) due to repetition between agricultural products and atmosphere promotes transpiration. VPD between agricultural products and atmosphere was used to method of weight loss prediction [3]. Water loss of such agricultural products reduces the saleable weight and leads to decrease in farmer's income [4]. Yoon et al. reported on technology to maintain high humidity above 90%RH reducing the temperature difference between inside temperature of storage and surface temperature of evaporator through the expansion of heat exchange area [5]. Delelea *et al*. reported that application of humidification system on ULO (Ultra low oxygen) CA storage maintains high humidity and reduces weight loss [6]. In addition, a weight loss prediction model utilizing the measurement of internal temperature and humidity [7] of cold storage and transpiration coefficient [8]. However application of weight loss prediction model that Performed in a defined temperature and humidity range is difficult because of continuous change of temperature and humidity inside of cold storage due to unit cooler operation, opening and shutting of door. Moreover the transpiration coefficient of agricultural products is derived by experiment and coefficient which is not experimented is not available. Particularly, the evaporator is installed inside the cold storage and the discharge of water by the frosting and defrosting process is repeated continuously. For most studies on preservation properties, experiments are conducted under conditions without frosting and defrosting. Although, weight loss by transpiration is very important factor in preserving agricultural products, research is limited to specific works as weight loss inhibition of Chinese cabbage using film [9]. Especially, prediction of weight loss is very difficult Because of movement of moisture between inside and outside of storage through the door and leak. Supply of CA storage allows weight loss prediction for block between internal and external environment of cold storage.

In this study, apples were stored in CA storage, temperature and humidity in storage were measured and

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then operating characteristics were observed. We used this to calculate weight loss and compared with the actually measured weight loss.

II. METERIALS AND METHOD

A. Meterials

After selecting 200 to 250g of Fuji apples harvest ed in Jangsu-gun, Jeonbukdo, Korea in October 2015, 4.5 tons were stored in a CA container.

B. Experimental Apparatus

TABLE I. CHARACTERISTIC OF CA STORAGE AND SENSOR

Item	Specification	
CAstorage	Size	6.0 ×2.4 ×2.7 m
	Condensing unit	3hp
	Unit-cooler	5hp
	Airbag size	5.0 ×2.0 ×0.3 m
N_2Generator	Amount of supply	6 (N㎥/hr)
Sensor	Temperature	-20~60℃ (±0.1℃)
	Humidity	0~99%RH (±4.5%RH)
	Oxygen	0~25% (±0.22%)
	Carbon dioxide	0~5% (±0.01%)

The experimental equipment consists of the storage of 5 ton scale, a nitrogen generator, a condensing unit, a controller, and an integrated sensor. The integrated sensor measures temperature, humidity, concentration of O_2 and CO_2, and uses the measured values to control the nitrogen generator and the condensation unit. At this time, the nitrogen generator of the PSA (Pressure Swing Adsorption) system supplies high concentration N_2 to the inside of the storage to replace N_2 - O_2 and adjust the O_2 concentration. Air bag is used to minimize the pressure fluctuation of the storage accordingly because the volume of the air changes according to the internal temperature change of the storage. Fig. 1 shows a schematic diagram of the CA reservoir used in the experiment and Table I shows the performance characteristics of CA storage and integrated sensors.

C. Weight Loss Measurement and Prediction Method

The reference weight loss value is the weight measurement value of the apple stored in the storage. The weight loss prediction method used vapor weight calculation by temperature and humidity, defrosting water by defrosting cycle and vapor pressure deficit (VDP). Relative humidity in the CA storage varies with moisture production by agricultural products and emissions by operation of condensing unit. Moisture is produced by respiration and transpiration and discharged to outside of storage through condensation, frost and defrost processes.

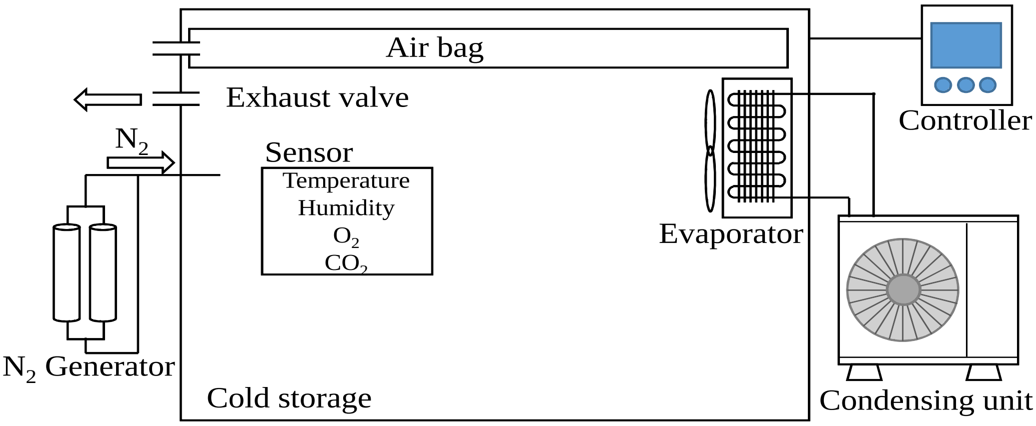

Figure 1. Schematic diagram of CA storage

Therefore, the weight loss of agricultural products stored in hermetically sealed storage is predictable through changes in temperature and humidity. The weight loss predicted using temperature and humidity are shown in equation (1) and calculated using weight difference between saturated vapor and vapor.

$$\text{Weight loss} = \sum_{d=1}^{n} (m_{sat} - m_{RH}) \tag{1}$$

As described above, if the discharge of moisture is limited to the defrosting water, it is possible to predict weight loss using the defrosting water. The weight loss predicted using defrosting water are shown in equation (2).

$$\text{Weight loss} = \left(\frac{W_{tot} - W_{dw}}{W_{tot}}\right) \times 100 \tag{2}$$

Finally, the weight loss using VPD is the same as equation (3), at this time K-value is reported as Jonathan = 35, Golden Delicious = 58, Bramley's seedling = 42, and other varieties are on average 42 (ASHRAE Handbook, 2006).

$$\text{Weight loss} = \text{Kvalue} \times \text{VPD} \tag{3}$$

III. RESULTS AND DISCUSSION

A. Change in Environment of CA Storage

Fig. 2 shows the temperature and humidity and the concentration change of O_2 and CO_2 for 200 to 210 days after apologizing inside the CA storage. The humidity in the CA storage is maintained at 93 to 95%RH and decreases to 80 to 85%RH when the unit cooler operates. Especially when the unit cooler operates and the temperature rises due to defrost, the humidity decrease to at least 67%RH. High humidity air in storage is easily condensed and frozen on surface of unit cooler and defrosting water is discharged to the outside via the defrosting process. On the other hand, the humidity change is not displayed while the nitrogen generator is operating. N_2 produced using the nitrogen generator is supplied to the interior of the storage and cooled. If the absolute humidity is the same, if the temperature decreases, the relative humidity will increase. That is, N_2 having a low relative humidity is supplied to the interior

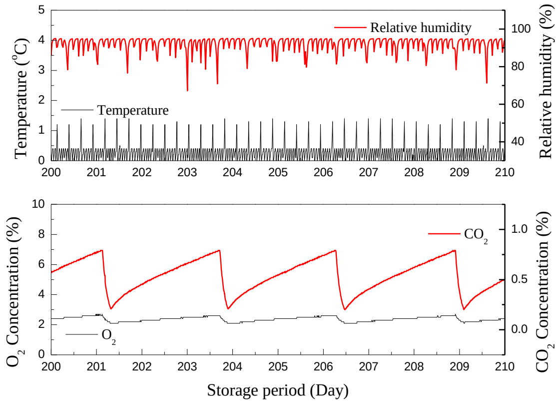

Figure 2. Change in environment conditions (temperature, humidity, O_2, CO_2) inside CA container. Of the storage and cooled, the relative humidity is increased. Accordingly supply of N_2 is not greatly affected to change of humidity in storage.

B. Operating Ratio and Defrosting Water

Fig. 3 shows the average temperature of the seasonal outside of Jangsu-kun and the operation rate of the unit cooler. The outside temperature is distributed from -12.8 to 23.6℃ depending on the season, and the operation rate varies in proportion to the ambient temperature from1.4 to 23.8%. On the other hand, the process of lowering preserved initial product temperature maintains a high operating rate of 20% or more regardless of outside air. In general, the operation rate of the unit cooler is determined by the cooling load, and the cooling load of the CA storage is heat of respiration and temperature difference between storage inside and outside. Respiration heat of apple depends on storage temperature and it is 86.9 W when considering storage temperature and weight of apples in this experiment. According to the formula for calculating the cooling load of the cold [1], a cooling load of 11 W per 1℃of the temperature difference occurs. Considering the stored respiration heat of apple, The storage requires a heating load of 0.8W from the outside air temperature of 8℃, unit air conditioner operation is not necessary.

Fig. 4 shows operating ratio of unit cooler according to outside temperature by actual operation rate of .storage installed in field and calculated value using cooling capacity and cooling load. The operating ratio of the unit cooler increases in proportion to the outside temperature. However, the outside temperature is the highest at the operating rate of 23.75% at -6.3℃ because of operation of unit cooler for process of lowering the product temperature. Also, at -8 °C. or less, the cooling load no longer acts, but the operation rate of 2 to 3% is shown. The unit cooler is operated by the cooling load generated in the defrosting process and the outside maximum temperature at -8℃ or more in the day.

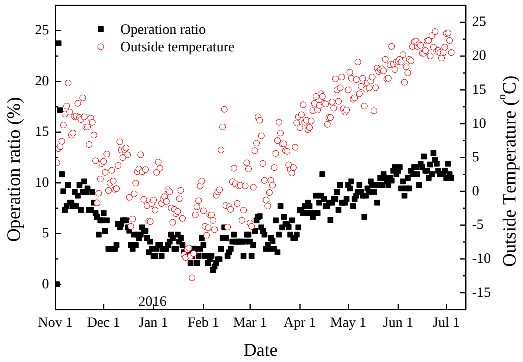

Figure 3. The average temperature and the unit-cooler operation ratio according to season of Jangsu-gun.

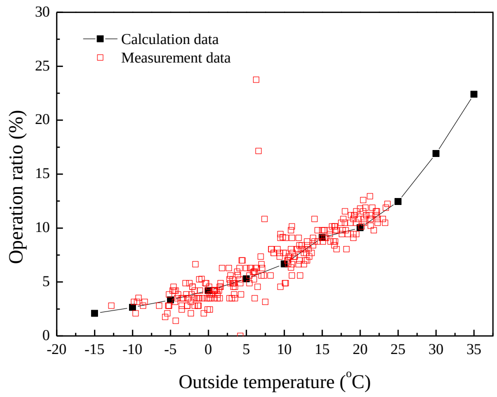

Figure. 4. Operating ratio of unit-cooler according to outside temperature.

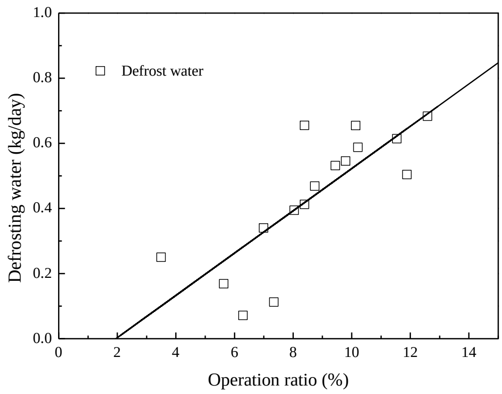

Figure 5. Weight of defrosting water according to operating ratio.

Fig. 5 shows weight of defrosting water according to operation ratio. The weight of defrosting water was measured once a week and divided by the measurement cycle to indicate the weight of defrosting water per day. The defrosting was done four times a day, and the defrosting water was discharged to 0.07kg/day at 6% of operation ratio up to 0.68kg/day at 12.8% of operation ratio. The increase of discharging water to outside of storage increases the probability of occurrence of condensation and frost by low temperature surface of unit cooler and high humidity of air.

C. *Analysis of Weight Loss*

Fig. 6 shows comparing the weight loss predicted value using temperature and Humidity, defrosting water, VPD and K-value with actual measured weight loss. Actual measured weight loss was 3.34%, the predict value of weight loss using the temperature and humidity was 3.34%, the predict value of weight loss using the defrosting water was 3.08%, the predict value of weight loss applying VPD and K-value (30, 42) was 3.31% and 4.65% respectively. When predicting weight loss using temperature and humidity, gradient appeared gently irrespective of the season and did not show the influence of change in unit cooler operation rate. On the other hand, the prediction value of weight loss using the defrosting water remarkably appeared depending on the season. The condensation amount of moisture decreases at low operating ratio of unit cooler, and the progression of depletion becomes slow when the outside air is low in winter A high operating rate by cooling load increases condensation and amount of discharged water. At this time, the relative humidity in the storage is lowered and transpiration becomes active, so that the progress of depletion is accelerated. Moreover, the predicted weight loss by using the defrosting water is displayed lower than the actually measured gum moil. The defrosting water is measured only for those discharged to the outside of the storage and Moisture condensed inside the storage is not considered. In case of predicting the weight loss using VPD and K-value “42”, prediction error is 1.3%p. When decreasing the K-value to "30", it shows a very close approximation to 0.02% p, and it can be confirmed that the weight loss is predicted with the similar pattern as the actual measured weight loss. In order to use the VPD prediction method which is greatly affected by the transpiration coefficient, it is required to experimental.

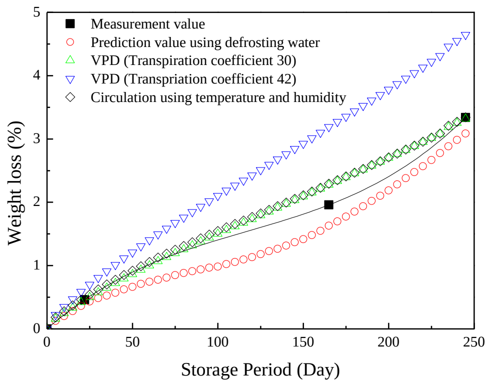

Figure 6. Weight loss according to analysis method

IV. Summary

The factors influencing the weight loss were identified and the weight loss was predicted using change of temperature and humidity in the storage, the defrosting water and the VPD method. Unit cooler operation can have effect on decrease of humidity in storage. Also, the predict method of weight loss using temperature and humidity showed the closest value to the actual weight loss. The amount of weight loss by defrosting water was proportional to the operation rate of unit cooler. The operation rate of the unit cooler is influenced by the change of the outside air temperature and moisture condensed in the reservoir causes a weight loss rate error. The effect of the transpiration coefficient (K-value) is predominant in predicting the weight loss using VPD, and it is necessary to verify the value of the evaporation coefficient of Fuji apple (42). In this study, we could calculate the closest predicted value when the K-value of Fuji apple was changed to 30.

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