In-bin 乾燥 및 貯藏體系에 관한 實驗的 硏究

Experimental Study on In-bin Drying and Storage System

高 學 均* 鄭 昌 柱*
Koh, Hak Kyun, Chung, Chang Joo

摘 要

本 硏究는 現在 國內 農村에서 問題視되고 있는 벼의 乾燥와 貯藏方法을 改善하기 爲한 한가지 方法으로써 Grain bin의 利用에 따른 技術的인 適用可能性을 究明하는데 있었으며 乾燥熱源으로서는 常温空氣와 Solar Collector에 依한 補充加熱空氣를 使用하였다.

乾燥試驗에서는 벼의 乾燥速度, 層別含水率의 變化, 動力消耗量, 搗精收率 等을 測定 比較하였으며 乾燥가 完了된 後에는 貯藏試驗도 아울러 實施하였다. 本 試驗을 通하여 얻은 結果는 다음과 같다.

1. 本試驗에 使用된 Solar Collector는 集熱面積이 27.7m²의 Flat-plate型式이며 內部에 太陽熱의 貯藏媒體로서 約 7m³의 검은 돌을 使用하였다. Collector의 效率은 35%이었으며 Collector를 通過하여 Bin으로 들어가는 空氣의 温度는 外氣温에 比하여 晝間에는 約 4℃, 夜間에는 約 8°C 程度 上昇된 것으로 나타났다.

2. 常温空氣와 Collector를 利用한 乾燥試驗結果 安全貯藏含水率에 到達하는데 各己 約 7日과 約 5日이 所要되었다.

3. 太陽熱 乾燥는 常温通風乾燥에 比하여 穀物層間의 含水率差異가 약간 크게 나타났으나 乾燥速度가 빠를뿐만 아니라 動力消耗量도 적은 것으로 分析되었다.

4. 乾燥試驗이 完了된 直後 二次에 걸처 Bin內에서 貯藏試驗을 實施한 結果 貯藏期間中 벼의 安全保全이 可能했으며 平均含水率이 12.0～14.5%범위에서 유지되었다.

* 서울大學校 農科大學 農工學科

Introduction

In the traditional paddy harvesting system in Korea, there are in general two stages of drying operation. The first stage of drying operation is performed by use of natural solar energy while the paddy is laid down on ground, bound in small bundles and lined up for shocking operation. The paddy grains during this stage are dried down to the moisture content of about 17%(w.b.). The second stage of drying, which is done only when a further drying is necessary for marketing and storage, is carried out by placing a thin layer of the threshed paddy on straw-mats or on a paved ground.

There are many strong reasons why these conventional drying practices should be improved. First of all, a large portion of grain losses is incurred due to shattering when relatively dried paddy through the process of sun-drying is handled. This shattering loss is a serious problem, especially for the most HYV, and unavoidable in the conventional drying system. Secondly, both the quantitative and qualitative grain losses of the milled-rice become greater due to degrading premilling factors of paddy grains when the unthreshed paddy under the process of sun-drying is rewetted because of frequent raining. Thirdly, an adaptation of a modern technology of any mechanical drying is a necessary step toward improvement of not only drying operation itself but also the traditional harvesting system as a whole. For instance, the use of combine to overcome the shortage of farm labor, which is becoming one of the serious problems in the Korean agriculture, may not be possible without adaptation of an effective mechanical grain-drying system.

In spite of such an importance, a limited number of grain dryers is being used on farms at present. Two types of mechanical dryers are available commercially now in Korea; a batch-type with 3.3m² of floor area and a continuous-flow type with the loading capacities of 1,200, 1,700, and 3,200kgs. However, these mechanical dryers have not gained popularity by farmers at the present stage, probably because of their high purchase price and operating cost.

As an alternative method for solving the immediate need for an improved drying operation, a possibility of using the in-bin grain drying and storage system has been considered. The reason is that natural air during the harvesting period has a fairly good drying potential, with the average daytime temperature and relative humidity, in October, of about 20°C and 65%, respectively. The air having these conditions is sufficient to dry paddy down to about 14%, which is the equilibrium moisture content at the condition. In addition, if the system is technically feasible for use of farm-level drying, it would have an additional advantage in view of its extended use as an improved storage system. The traditional storage system on farms, such as the straw-bag or bulk storage in a small room-type warehouse, is one of the major sources of grain loss.

The paper discussed here is one of the papers in series to be published in connection with the investigation of a new improved method of farm-level paddy drying and storage in Korea.

As a first part of the study, this paper is concerned with the investigation of the technical feasibility of the in-bin grain drying and storage system for use on farms. The specific objectives of the study are:

1. To find out the drying characteristics of the paddy in the in-bin drying system by use of natural air and of supplementary heated air supplied by a solar energy collector.
2. To find out the suitability of the above system for use of grain storage as the environmental and operational conditions are varied.

Experimental Equipment and Procedure

1. Experimental Equipment

Two round steel bins both having the same size with the diameter of 2.0m and the height of 1.8m were constructed for experimental use of the in-bin drying and storage system. The bins were installed with a perforated floor at the bottom and equipped with a 1/2 horsepower motor to operate the vane-axial fan for aeration. A loading gate was provided at the upper part of the bin and an unloading gate at its lower position.

To measure the temperatures at specified positions within the grain bins, a 24-point thermocouple recording system was installed. To evaluate the grain quality including the moisture content, sampling holes having about

5 cm diameter were provided in the radial direction of the bin wall.

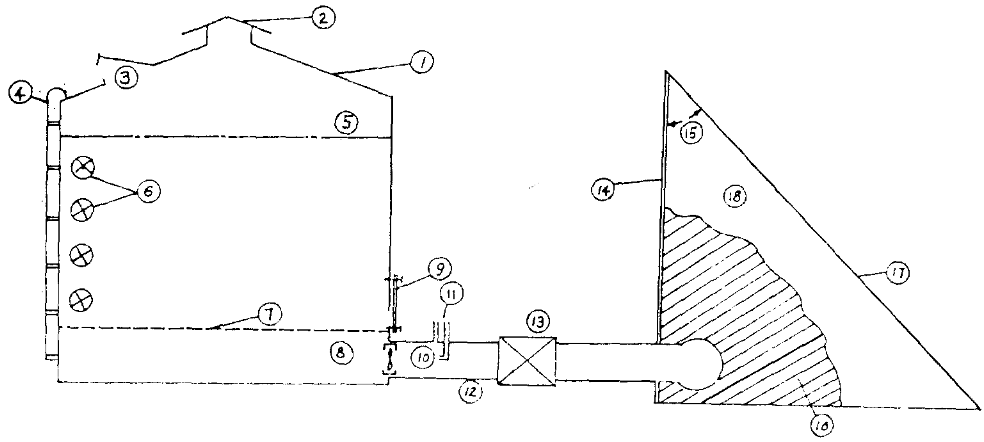
One of the bins installed was used for natural air drying and the other for supplementary heated air drying. The supplementary heating system, as shown in Figure 1, is composed of a flat-plate solar energy collector and heat-storage. The area of the collector plate, which was covered with polyethylene film, was 27.7m². The collector was inclined toward the south with the angle of 48° from the horizontal plane. Black rocks with the volume of 7.2m³ were used both as a heat absorber and storage medium. The rocks were piled over a perforated metal-duct with the diameter of 45cm and length of 8m. A centrifugal fan was installed between the grain bin and the solar collector in order to force the heated air through the grain mass.

The identical bin with the fan and temperature monitoring system used for the drying experiment was also used for conducting the storage experiment.

2. Experimental Procedure

Drying experiment: Drying experiments with and without the supplementary heated air were conducted with the paddy harvested in the rice harvesting season of 1979. The variety selected was MILYANG-23, which was grown at a private farm located at nearby the College of Agriculture, Seoul National University. Information about the variety and the conditions of grains at the time of loading the bins are summarized in Table 1.

Grain bins were loaded with paddy in the depth of 1.1m, giving the total holding capacity of 2,500kgs. The fan installed in the bin was operated continuously for the first week, and thereafter intermittently from 9 : 00 am



1) Grain bin
2) Ventilator
3) Manhole
4) Outside ladder
5) Grain surface
6) Sampling hole
7) Perforated floor
8) Anemometer
9) Outlet
10) Pitot-static tube
11) Manometer
12) Aeration duct
13) Fan & motor
14) Insulation wall
15) Tilted angle, 48°
16) Rock-pile
17) Plate covered with vinyle sheet
18) Solar collector

Fig. 1. Schematic diagram of solar-collector connected to the grain bin system.

to 9 : 00 pm until the grain moisture of about 14% was attained. The air flow rate was kept at $4m^3$/min per m^3 of grain throughout the testing period. Grain temperatures at specified positions were continuously recorded by the thermocouple system installed.

The grain sample for the measurement of its moisture content was taken once a day at all specified locations by use of sampling probes and measured by use of the standard air-oven method. Grain quality after the completion of drying experiment was evaluated in terms of laboratory milling test. Other information related to the drying experiments is shown in Table 1.

Table 1. Conditions of drying experiments

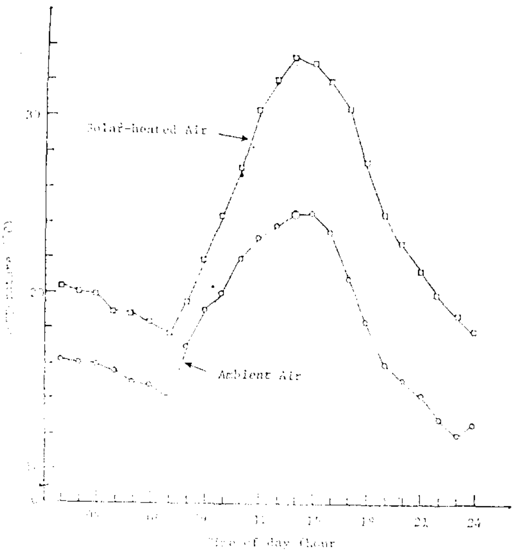
Descriptions	Natural-air drying	Supplementary heated-air drying
Paddy variety	MILYANG-23	MILYANG-23
Transplant dates	April 17	April 17
Harvest dates	Sept. 29	Sept. 30
Initial properties:		
Moisture content (w.b.)	20.2%	19.8%
Grain temperature	18°C	18°C
Bulk density	589kg/m^3	572kg/m^3
Foreign matter	1.13%	1.35%
Grain quantity	2,000kg	2,000kg
Grain depth	1.1m	1.1m
Test date	Sept. 30-Oct. 13	Oct. 1-Oct. 12
Continuous fan operation time	210 hrs	170 hrs

Storage experiment: Grain storage experiment was conducted twice by use of the grain bins used for natural air drying tests. The first experiment was started on February 12, 1979 and terminated on August 2, 1979. The grains loaded for the experiment was Suweon -264 rice variety that produced in 1978. The rough rice at the time of the experiment initiation had the moisture content of 13.4% (w.b.) and temperature of 5°C. The bin was filled to a depth of 1.3m and held 2.2M/T of grain. The airflow rate used for aeration was 0.36m^3/min per m^3 of grain. The aeration was performed whenever the ambient air temperature was about 5°C lower than the grain temperature and when the relative humidity of the ambient air was below 70 percent. Ambient air temperature and relative humidity readings measured at the three-hour basis were taken from nearby Suweon Weather Station. Moisture content of the stored grains was measured occasionally throughout the experimental period. The milled-rice and head-rice recoveries of the rough rice sample taken after the completion of the experiment was evaluated with the laboratory mill.

The second storage experiment was initiated immediately after the drying, which was Mid-October of 1979, and terminated on May 14, 1980. Since the storage experiment was conducted by use of the finishing product of the drying experiment, variety of the rough rice stored, quality of the grains and the loading conditions of the former were practically the same as those of the latter as shown in Table 1. In addition, experimental procedures used in the second year were basically the same as those in the first year.

Results and Discussion

Analysis of Solar Collector Efficinecy: In the solar collector-heat storage system, the rocks were heated during the daytime and the heat stored in the rocks was transferred to the drying air during the night. In general, the maximum temperature of the air drawn through the rocks occurred about 2 : 00 pm and the minimum temperature about 7 : 00 am as shown in Figure 2. The data points shown in Figure 2 were obtained from temperature measurements made on one day during the drying experiment. Similar patterns of temperature variation appeared throughout the testing period. For the given system, the temperature of the air passing through the perforated duct was observed to increase about 4°C on the average above the ambient air temperature during the night and about 8°C during the daytime.



Fg. 2. Temperature variations of ambient air and solar-heated air on a typical day (Oct. 4, 1979)

The collector efficiency on a typical day was calculated from the ratio of the energy collected to the radiation available. The amount of energy collected by the system was based on measurements of the quantity of air and the temperature rise in the air. The formula used for the calculation is:

$$Q=C\cdot G\cdot \triangle T$$

where Q=amount of energy collected, Kcal/hr
C=specific heat of air, 0.24 Kcal/kg°C
G=mass flow rate of air, kg/hr
$\triangle T$=temperature rise,°C

The radiation available on the tilted surface was calculated as follows:

$$Q_s=A\cdot I_p$$

and $I_p=I_h\cdot\frac{\cos\alpha}{\sin\beta}\{\cos(\phi-\beta)\}$

where Q_s=total solar energy received on tilted surface, Kcal/day
A=collector surface area, m^2
I_p=solar energy received on tilted surface per unit area, Kcal/m^2 day
I_h=solar energy received on horizontal surface per unit area. Kcal/m^2 day
α=azimuth angle, degrees
β=altitude angle, degrees
ϕ=tilted angle of collector surface, degrees

With Q_s calculated, the radiation available on the tilted surface can be obtained from the following equations.

$$Q_a=Q_s\cdot F(1-d)(1-s)$$

and $f=1.008T\cdot a$

where Q_a=radiation available on tilted surface, Kcal/day
f=collecting efficiency, decimal
(1-d)=dirt-loss factor
(1-s)=shading-loss factor
T=transmittance of the collector surface
a=absorptivity of the rocks

In the above equations, the following assumptions were made for the calculation of the radiation available.

$(1\text{-}d) = 0.92$

$(1\text{-}s) = 0.97$

$T = 0.8$

$a = 0.8$

Thus, the collector efficiency, $\eta = Q_f/Q_a$ was calculated to be approximately 35.0%.

Drying Experiment: Figure 3 shows the drying curves of grains located at top, middle, and bottom layers of the grains when the natural air was forced into the grain bin. Throughout the drying period, there maintained some moisture gradients of the grain between the top and bottom layers. However, the gradient was getting narrower as drying proceeded, and was leas than 1% when the grain moisture content reached about 14% after 7 days of drying.

The drying with supplementary heated air supplied by the solar collector indicated basically the same drying curves as those of the natural air, as shown in Figure 4. However, the drying with the supplementary heated air gave comparatively a much higher rate of

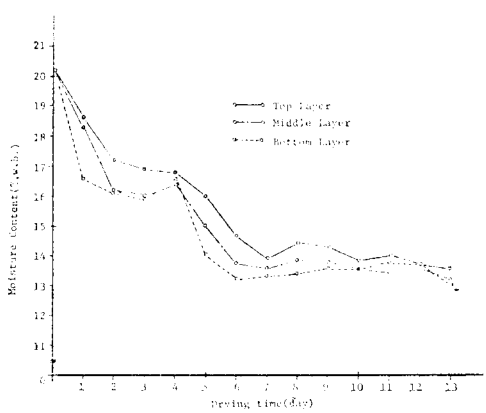


Fig. 3. Drying curves of grains located at different layers when the bin was supplied with natural air.

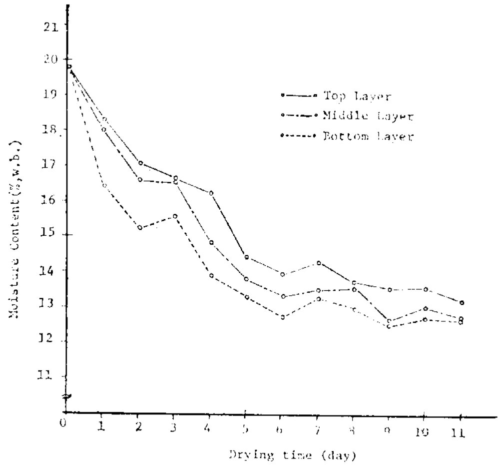


Fig. 4. Drying curves of grains located at different layers when the bin was supplied with supplementary heated-air.

drying, a little greater moisture gradient between upper and bottom layers throughout the test period, and a shorter period of drying to arrive at the desired final moisture content (refer to Table 2). These trends are clearly indicated by the comparison of the average drying curves of natural air drying with and without supplementary heat, as shown in Figure 5. It is noteworthy that, under the operational and ambient air conditions examined in the experiment, no much advantage could be attained by the addition of supplementary heating system. However, we should not underestimate the need for the solar collector system for use of grain drying in an unfavorable weather condition.

The electric energy input for fan operation is compared in Table 2. From this analysis, it is evident that the drying system with supplementary heat had no much saving in electric energy input compared to the natural air drying system. However, it is apparent that saving in fan energy would be greater if weather conditions during the test period would be unfavorable for drying grains with natural air.

It suggests that further research is needed to compare the grain drying with and without solar collector-heat storage system when the weather conditions during drying period may be unfavorable for natural air drying.

Grain quality evaluated in terms of brown-rice, head-rice and milled-rice recoveries, and germination rate is shown in Table 3.

In this analysis, it is specially noticed that

Table 2. Comparison of electric energy input for fan operation

Drying method	Operation time(hrs.)	Energy input(Kwh)	Average final grain MC(%, w.b.)
Natural air	130	59	13.9
drying	150	64	13.6
Solar	120	41	13.8
drying	140	50	13.3

Table 3. Results of milling tests for natural and solar-heated air drying

Items	Natural drying	Solar drying
Brown-rice recovery	78.3%	79.4%
Milled-rice recovery	72.5	73.1
Head-rice recovery	70.5	70.9
Germination rate	94.0	94.0

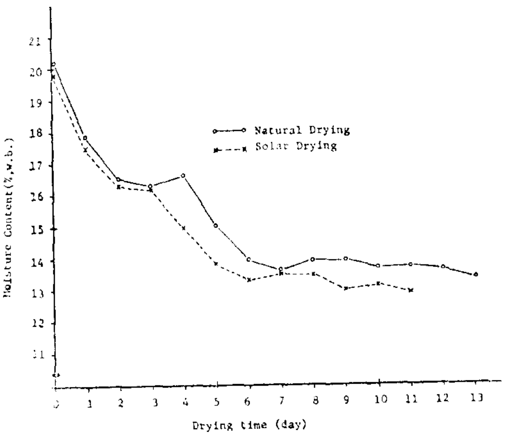


Fig. 5. Comparison of drying curves between the natural air and solar heated air drying systems.

head-rice recoveries of 70.9% and 70.5% for drying with and without supplementary heat, respectively, are extremely high compared to that of the paddy harvested by means of the traditional method. Furthermore, the high quality of the grains dried by both systems could be observed by the closeness of the head-rice and milled-rice recoveries, which is usually more than 10% for the paddy harvested by traditional method. It was found that no grains were discolored.

Storage Experiment:

(1) Temperature variation: Daily and monthly temperature variations throughout the storage period were analyzed in this paper. Figure 6 shows an example of typical daily temperature variation in the grain mass at three different locations due to the temperature variation of the ambient air. The temperature of the grain mass adjacent to the bin wall changed closely with the ambient air temperature. It was also noticed that the grain temperature near the wall facing south was affected more apparently by the outdoor temperature than that near the wall facing north.

However, the grain temperature inside the grain mass appeared to be almost constant throughout the day even without aeration. Almost similar patterns were observed throughout the storage period. Figure 7 shows the observed outdoor temperature and average grain temperatures during the test period from March to July. During the period, the average grain temperature increased gradually from 3°C in March to 30°C in July. Figure 8 also shows the change of ambient air temperature and average grain temperatures in the second storage experiment which was performed during the period from October, 1979 to May 1980. During the storage period, the grain temperature changed with the ambient temperature, showing less fluctuation in the grain temperature. The temperatures decreased from about 20°C in October to -10°C in February and increased gradually to about 25°C, thereafter.

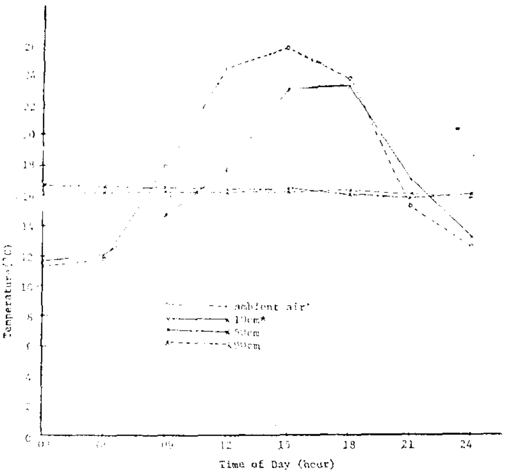


Fig. 6. Daily variation in grain temperature in the radial direction of the bin (May 19, 1979)(*:the distance from the bin wall to the center)

However, it was observed from the storage tests that the average temperature of the grain mass in the bins was in general slightly higher than the ambient temperature because of the heating effect which resulted from the respiration of the grain stored.

(2) **Moisture variation:** Figure 9 shows the results of the first storage experiment in which rough rice with the moisture content of 13.4% was stored during the test period. During the storage period, the average moisture content changed with the range of 13.5% to 15.3%.

The moisture content of the grains measured at three different locations of the bin was kept constant for about two and a half months after the intiation of storage experiment. However, the moisture content gradually increased due to the change of environmental condition except for those measured on June 21. Because of a heavy rain on that day, the moisture content of the grain mass located at the center portion of the grain bin gained about 1.5% higher than the average at that time.

In the second experiment, the average moisture content changed with the range of 11.5% to 14.5% throughout the storage period as shown in Figure 10. On the whole, the average moisture content of the grain stored was kept constant for about two months. The moisture content increased by about 1% on the average from the middle of December to that of March of the next year, and again decreased to about 12.5%, thereafter.

However, it may be concluded that the moisture content at all levels in the two bins maintained at safe storage levels (below 14.0%) during each storage period.

(3) **Grain quality:** During the storage period, no mold activity was found. The

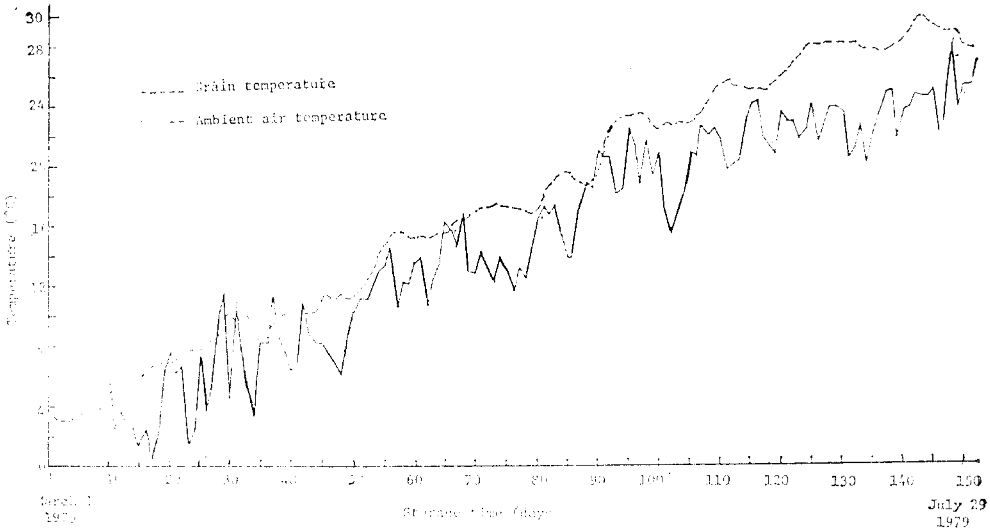


Fig. 7. **Variarion in average ambient air temperature and grain temperature during the storage period.**

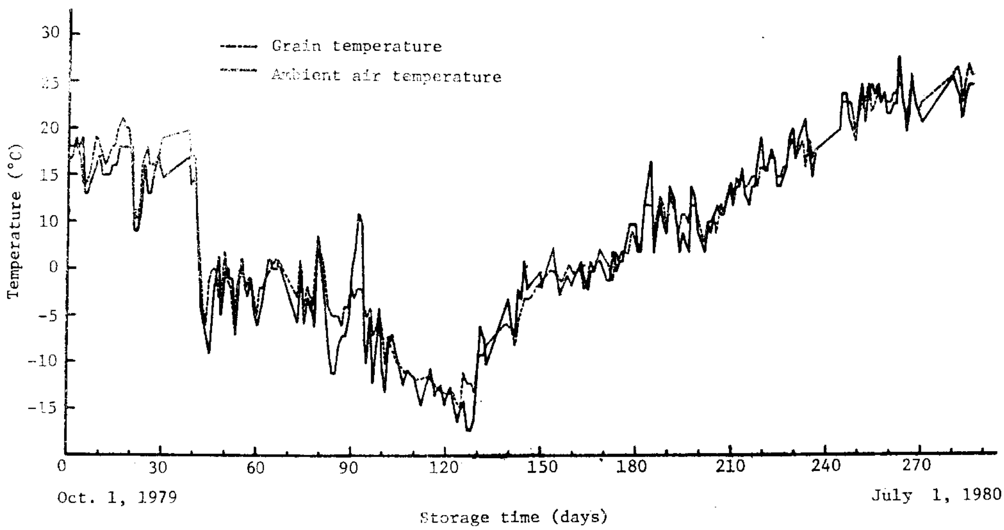


Fig. 8. **Variation in average ambient air temperature and grain temperature during the storage period.**

quality of the grain used in each test was maintained without deterioration. The laboratory milling test with the paddy samples at the end of the first and second storage periods showed that brown rice recoveries were 79.90% and 80.51%, milled rice recoveries 72.80% and 70.76%, and head-rice recoveries 63.63% and 66.82%, respectively.

Summary and Conclusions

In this study, an attempt was made to improve the current method of on-farm paddy drying and storage in Korea. For this purpose,

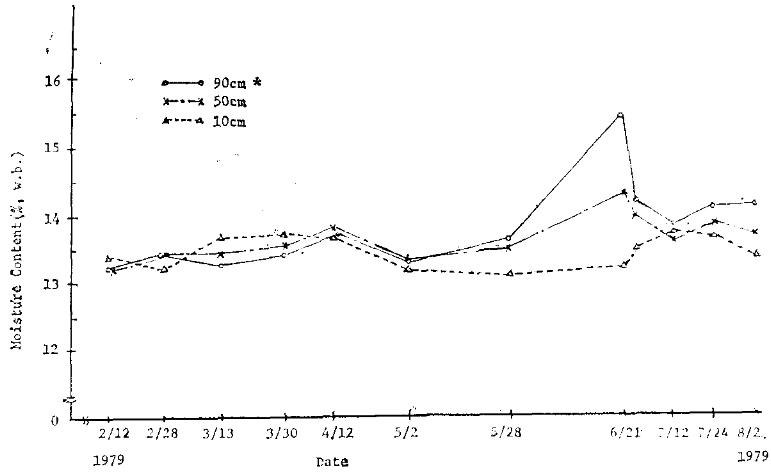


Fig. 9. **Moisture content variation in the radial direction of the bin.**
(*:the distance from the bin wall to the center)

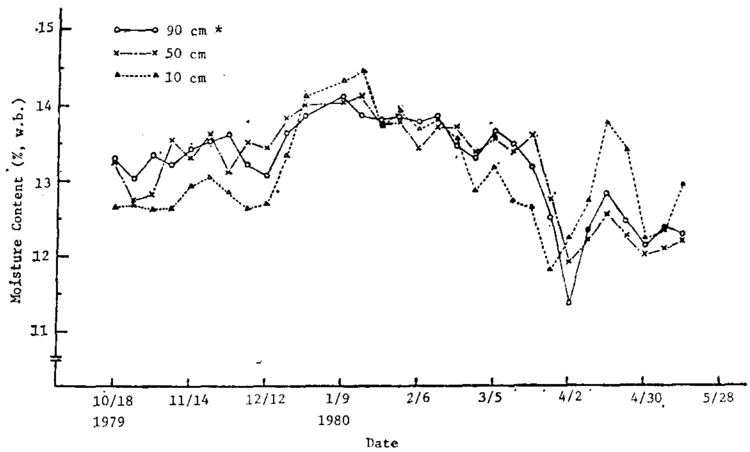


Fig. 10. **Moisture content variation in the radial direction of the bin.**
(*:the distance from the bin wall to the center)

an in-bin drying and storage system was developed, and two natural air drying methods with and without supplementary heat were compared in terms of drying rate, period for arriving at the desired final moisture content, moisture gradient between upper and bottom layers, and electrical energy input for fan operation during the drying period. In addition, the storeability of paddy in the bin was investigated.

The results of the study are summarized as follows:

1. The solar collector installed for this study was a flat-plate collector with the area of 27.7m² and rock-piled heat storage medium having the volume of 7m³. The estimated efficiency of the solar collector was found to be about 35%. The system was capable of supplying the supplementary heated air which is 4°C higher than the ambient air temperature during the daytime and 8°C higher during the night.

2. The natural-air drying both with and without supplementary heat was proved to be technically very feasible. Under the favorable weather condition in October and the air flow rate of $4m^3/min/m^3$ of grain, it took only about 7 days for the grain in the natural air system to dry from about 20 to 14%. Under the identical conditions, the drying period of about 5 days were necessary for the supplementary heat-air drying system.

3. A shorter operational period for the completion of grain drying and lower input of electrical energy for fan operation were proved to be the advantages of the drying system with the solar collector. However, the system also showed adverse effects such as a slightly greater moisture gradient between the upper and bottom layers and a possibility of overdrying paddy below 14%.

4. Storage experiments of the paddy in the grain bin were conducted with the paddy grains harvested in 1978. During the storage period, the average moisture content of the grain at each level of the bins changed with the range of 12.0% to 14.0%, and no deterioration of the grain was found in the storage tests.

5. The results of laboratory milling tests showed an overall increase in milled-rice and head-rice recoveries of paddy grains after completion of the drying and storage tests as compared with those obtained from the traditional method.

References

1. Converse, H.H. and D.B. Sauer: 1976. Low Temperature Grain Drying with Solar Heat. ASAE Paper No. 76-3018.
2. Converse, H.H., A.H. Gràves and D.S. Chung: 1973. Transient Heat Transfer within Wheat Stored in a Cylindrical Bin. Trans. ASAE, Vol. 16, No. 1.
3. Whiller, A.: 1967. Design Factors Influencing Solar Collector. Low Temperature Engineering Application of Solar Energy, Prepared by ASHRAE.
4. Foster, G.H. and R.M. Peart: 1976. Solar Grain Drying Progress and Potential. USDA Agricultural Research Service, Agriculture Information Bull. 401.
5. Hottel, H.C. and B.B. Woertz:1942. The Performance of Flat Plate Solar-heat Collectors. Trans. ASME, Vol. 64.
6. Kim, S.R.: 1974. Study on the Small Grain Bin for the Improvement of Grain Drying and Storage. J. Korean Society of Agricultural Engineering. Vol. 16, No. 1.
7. Koh, H.K.: 1978. Determination of Equilibrium Moisture Content of Rough Rice. J. Korean Society of Agricultural Machinery. Vol. 3, No. 2.
8. Thompson, T.L.: 1972. Temporary Storage of High-moisture Shelled Corn Using Continuous Aeration. Trans. ASAE, Vol. 15, No. 2.