自然對流型 乾燥機의 性能向上을 위한 模型實驗

I. 自然對流型 乾燥機의 分析

Improvement of Drying Performance of Natural Convection Drier Part I:Analysis of Natural Convection Drier

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摘 要

本硏究는 乾燥에 必要한 熱과 空氣를 熱源으로부터의 自然對流만에 의존하는 簡易火力乾燥機의 性能向上을 도모하기 위하여 실시되었으며 옥수수를 대상으로 模型實驗을 통하여 分析한 結果는 다음과 같이 要約된다.

1. 乾燥機 火口의 空氣流入口의 크기는 送風量에 영향을 미치며 空氣의 流入速度가 16m/min以下가 되도록 充分히 만들어야 한다.

2. 곡물층을 通過하는 送風量은 곡물층의 두께가 클수록 증가하며 송풍량과 곡물층 두께의 관계는 다음식으로 나타났다.

$$q=CD^{-k}$$

3. 送風量은 실험범위내에서는 열원으로부터 곡물층의 높이와 加熱空氣의 溫度上昇에따라 각각 直線的으로 증가하였다.

4. 송풍량은 곡물층의 두께, 열원으로부터의 곡물의 높이 및 가열공기의 온도상승에 의하여 옥수수층의 경우 다음과 같이 추정될 수 있다.

$$q=0.00265H(\Delta T)D^{-0.76}$$

5. 바람이 송풍량에 미치는 영향은 매우 커서 8 km/hr의 풍속을 가진 바람이 流入口側으로 불때 송풍량은 바람이 없을 때보다 무려 5배나 증가하였다.

6. 乾燥室의 前後方間의 가열공기의 온도차이는 열원으로부터 곡물층의 높이가 낮을수록 증가하였으며 이 현상은 바람이 불때 더욱 현저하게 나타났다.

7. 乾燥機의 壁面을 통한 熱損失은 열원으로부터 곡물층의 높이와 가열공기의 온도상승에 따라 각각 直線的으로 증가하였다.

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Introduction

The problem of grain drying is becoming increasingly important in developing countries, especially in tropical areas. Effective grain drying is necessary not only to minimize post-harvest losses but also to preserve grain quality. Furthermore, it makes possible increased production through multiple cropping where the off-season crop is harvested in humid weather.

Under humid conditions, it is necessary that some source of added heat energy be provided to supply the heat of vaporization. In developed countries, driers for that purpose have been studied and developed thoroughly. These driers, however, have not been introduced successfully to the developing countries because of small land holdings of farmers, their low income and poor technical knowledge, and lack of road facilities.

Brook(1964) developed a natural convection drier, which is originated from a Samoan cocoa drier. It has a flue as a heat source and utilizes buoyancy force of natural convection as a drying force to move heated air through the grain without any mechanical device. Since this type of drier can be built by farmers themselves by making use of primarily native materials and it is fairly simple to operate, it is being used in some tropical countries such as Nigeria and Dahomey.

Webb(1969) gave a design of a natural convection drier for Nigerian farmers and stated that the drying floor should be 0.61 to 0.76m above the firebox to prevent the crop in the center from getting scorched. Lindblad and associates(1974) gave a design of this type of drier to introduce it to the farmers in Dahomey, Africa. They recommended the floor height of 1.28m for a 2.44 m×2.23m drying floor. Thorshaug (1974) suggested that the layer of shelled maize should not be more than 0.1m thick and the layer of maize cobs not exceed 0.3 to 0.43m when drying with this type of drier. Unfortunately, however, there has been no systematic study about the design criteria and performances of this type of drier.

The objective of this study was to analyze a natural convection drier in order to find the effects of airflow rate, temperature rise, drying floor height, grain depth and air inlet size on its performance.

Materials and Methods

Grain used for this study was yellow dent shelled corn at about 18% moisture content (wet basis).

For analyzing a natural convection drier, two model driers were constructed. As shown in Figure 1, the material to be dried, A, is contained in a removable perforated metal sheet, B, mounted on a plenum chamber, C. The box was constructed of plywood and has a cross-sectional area of 0.84m²; the grain rests on a perforated galvanized steel sheet secured on the angle bar, D, attached to the wall, E. The heating unit, F, consisted of 22.9cm dia. galvanized-plate vent pipe and three 1 Kw heating elements which were placed inside the enclosed cylinder. Air is supplied into the plenum chamber through the air inlet, G, which is made of steel plate and changeable to other sizes. The wall, E, was constructed of two 0.64 cm thick plywood sheets, 1.91cm apart in which the air space was filled up with glass wool. To make the plenum chamber air tight an adhesive type was used on the inside and outside edges. The model driers were simulated basically from a natural convection drier recommended by Lindblad and associates(1974).

Table 1. Experimental design.

Classification	Treatments	Remark
I	Inlet size : 110cm²	Floor height : 70 cm
	220 〃	Temperature rise : 22°C
	330 〃	No wind
	Grain depth : 5cm	
	10 〃	
	15 〃	
II	Floor height : 40cm	Inlet size : 220cm²
	55 〃	Grain depth : 10 cm
	70 〃	Temperature rise : 33°C
		Wind : 0.8km/hr
III	Temperature rise : 11°C	Inlet size : 220 cm²
	22 〃	Floor height : 70 cm

33 〃 Grain depth : 10 cm
No wind

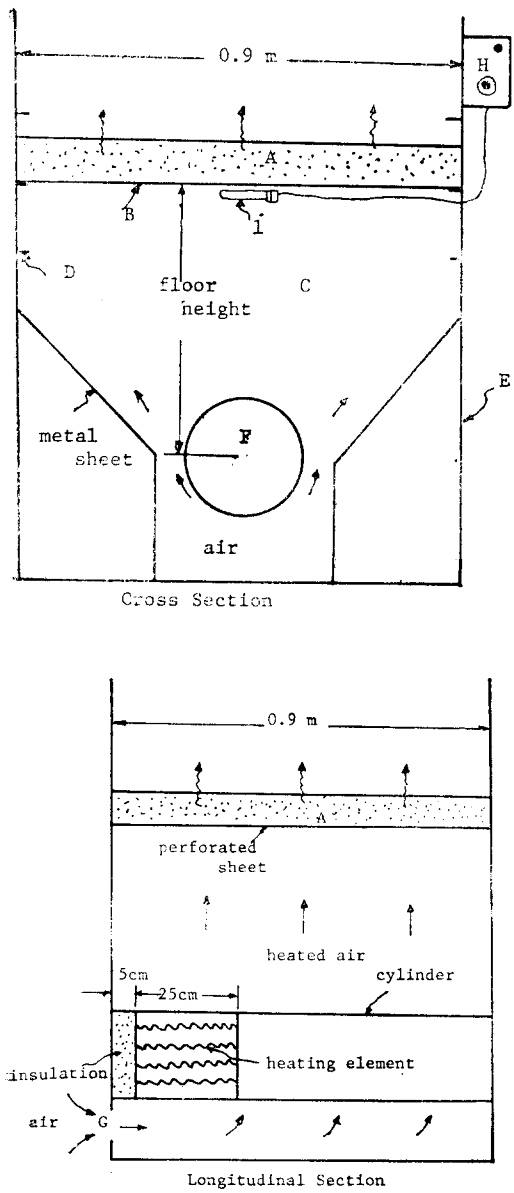

Fig. 1. Schematic diagram of a model drier.

The drying air temperatures in the plennm chamber were controlled by a temperature controller. Thermocouples were used to measure drying air temperatures at 6 different locations just below the drying floor, the inlet air temperature an air temperature leaving at the surface of grain. The heat input was measured by the use of a watt-hour meter after about 2 hours which are required to stabilize the grain temperature.

The experiments were divided into three categories, as shown in Table 1; air-inlet size and grain depth test, drying floor height test and temperature rise test. In the first test the air inlet size and grain depth were varied to find their effects on airflow rate. In the second test, the drying floor height was varied to study its effect on airflow rate. In this test, a room fan was used to simulate natural wind at a velocity of 8km/hr in order to find the effect of wind on airflow rate. The last test was to study the effect of temperature rise on airflow rate.

Airflow rate was caculated from the energy input using the relationship given by:

$$Q = Ca \times \frac{q \times 60}{v} \times \Delta T$$

where Q : energy consumption(KJ/hr)

Ca : specific heat of air(KJ/kg °K)

q : air flow rate(m^3/min, or cmm)

ΔT : temperature rise(°K)

V : specific volume of air(m^3/kg)

To measure the heat loss through the walls and grains the air inlet was tightly closed and the grain surface was covered with a galvanized sheet and the clearance between the walls and the sheet was sealed by an adhesive type. In calculating airflow rate the specific heat of air was assumed to be 1.004 KJ/kg. °K throughout the tests. The energy required to increase the sensible heat of water vapor in the air and the variance of the specific weight of the ambient air was neglected. Environmental conditions throught the tests were maintained at 23.61±0.56°C and 72±7% R.H. with a room air conditioner.

Results and Discussion

Figure 2 and 3 show the effect of the air inlet sizes on airflow rate with different grain depths for the given temperature rises, 4.4°C and 15.6°C, respectively. At the sizes of air inlet above which the airflow rate did not increase significantly, the highest air velocity through the air inlet was 16.15 m/min. Assuming the resistance of the air through the air inlet to be a function of air velocity, the allowable air velocity through the inlet should be less than 16.15 m/min.

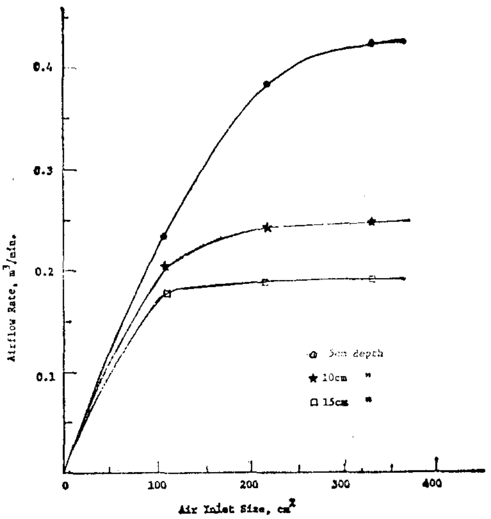

Fig. 2. Airflow rate versus air inlet size at different depths of grain with a temperature rise of 22°C and a floor height of 70cm.

The effects of the grain depth on airflow rate were plotted on log-log paper as shown in Figure 4, yielding the straight lines. The

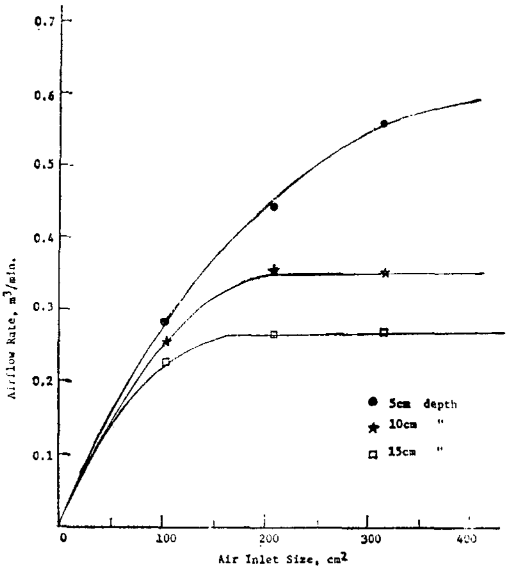

Fig. 3. Airflow rate versus air inlet size at different depths of grain with a temperature rise of 33°C and a floor height of 70cm.

following equations were obtained for airflow rate:

$q=6.042\times10^{-2}D^{-078}$: for temperature rise of 15.6°C

$q=4.536\times10^{-2}D^{-074}$: for temperature rise of 4.4°C

where q : airflow rate(cmm)

D : grain depth(m)

As shown in Table 2, there was a tremendous effect of wind on airflow rate. A statistical analysis of the airflow data with 8km/hr wind showed that there was no significant effect of the height of drying floor on airflow rate. However, it appeared that the airfl ow rate under natural convection with no wind had a linear relationship with the height of drying floor. The resulting equation with the temperature rise of 15.6°C and the grain depth of 0.1m is given by:

$q=0.494H+0.0107$

where H: the height of drying floor from the center of flue(m)

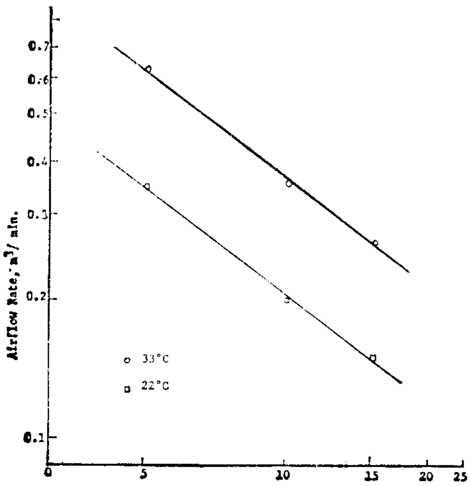

Fig. 4. Airflow rate versus grain depth at different temperature rises with a floor height of 70cm on log-log paper.

It also appeared that the rate of airflow increased linerarly with the temperature rise. The resulting equation with the floor height of 0.84m and the grain depth of is given by:

$q=1.02\times10^{-2}\Delta T+1.08\times10^{-2}$

Table 2. Airflow rate data for testing the effects of drying floor height with and without wind. (Grain depth, 10cm)

Unit : cmm

		Drying floor height(cm) 40	55	70
Wind	0	0.206	0.289	0.367
		0.199	0.281	0.355
	8km/hr	1.528	1.567	1.659
		1.641	1.635	1.616

where T : the difference between the temperature of inlet air and the drying air temperature(°C)

Three equations described previously were combined to give the following equation for approximating the airflow rate:

$q=0.00265H(\Delta T)D^{-076}$

The general equation to determine the airflow rate per unit bed area can be expressed by dividing the above equation by the bed area 0.84m³. The resulting equation is given by:

$q=0.00315H\Delta T\ D^{-0.76}$

where q : m³/min/m²

In Table 3 the values of airflow rate obtained from the experiment and those calculated by the above equation are given. The results show that there is a little difference, about 3.6% in average, between the experimental and calculated values.

Table 3. The comparison of the values of airflow rate obtained from the experiments with those calculated by the predictive equation.

Grain depth (cm)	Floor height (cm)	Temperature rise (°C)	Airflow rate(cmm) Experimental	Calculated*	Difference(%)
5	70	22	0.416	0.399	4.23
10	40	33	0.203	0.198	2.10
10	55	33	0.285	0.275	3.48
10	70	11	0.126	0.117	6.97
10	70	22	0.240	0.235	2.24
10	70	33	0.355	0.352	0.88
15	70	22	0.183	0.172	5.74
15	70	33	0.266	0.258	2.78
Average					3.55

* : Calculated by the energy input.

A stati stical analysis for testing the temperature difference in the plenum chamber just below the drying floor is given in Table 4. The results showed that there was no significant difference in drying air temperature between the left and right side of the plenum chamber throughout the tests. However, there was a significant difference in drying temperature between the front and back side due to the higher temperature of the front part of heating unit. The mean temperature difference between the front and back side increased as the floor height decreased, more remarkably with 8km/hr wind. In natural convection the increase of the temperature difference was relatively small above the floor height of 55cm (i.e., with the ratio of the floor height to the width of drying floor, 60%). The temperature difference with 8km/hr wind results mostly from the higher static pressure of the back side of air duct below the flue.

The heat loss through the walls and grain increased linearly with the height of drying floor and the temperature rise.

Table 4. Analysis of the drying temperature data for testing the temperature difference(°C) in the plenum chamber.

wind	Height	Direction	D	SD	t
0	40cm	Lift-Right	0.6111	1.1184	0.5464
		Front-Back	2.2129	0.2651	8.3489*
	55	Left-Right	0.3333	0.9103	0.3662
		Front-Back	1.6204	0.4698	3.4493*
	70	Left-Right	0.0417	0.7933	0.0525
		Front-Back	1.3982	0.4076	3.4301*
8km/hr	40	Left-Right	0.1944	3.9015	0.0498
		Front-Back	10.1296	0.8106	12.4971*
	55	Left-Right	0.1389	2.3797	0.0584
		Front-Back	6.3426	0.6939	9.1399*
	70	Left-Right	0.0417	1.6039	0.0260
		Front-Back	4.4074	0.6280	7.0181*

* : Significant at 0.05 level(one-tailed test)
D : Mean difference
SD : Standard deviation
t : t-test value

Conclusions

(1) The size of air inlet has a significant effect on airflow rate. The air inlet should have the size so that the air velocity becomes less than 16m/min.

(2) The rate of airflow increased as the grain depth decreased following the relationship given by:

$$q = CD^{-k}$$

(3) The rate of airflow increased linearly with the height of drying floor and the temperature rise from the inlet air to the drying air at the range tested.

(4) The rate of airflow can be predicted approximately in terms of the grain depth, the height of drying floor and the temperature rise following the equation given by:

$$q=0.00265H(\Delta T)D^{-0.76}$$

(5) Wind has a tremendous effect on airflow rate. Even a 8km/hr wind increased airflow rate as much as 5 times over the natural convection without wind.

(6) The temperature difference between the front and back side of the plenum chamber increased as the floor height decreased, more remarkably with a 8km/hr wind.

(7) The heat loss through the walls increased linearly with the height of drying floor and the temperature rise.

References

1. Brook, J.A. 1964. A cheap crop drier for the farmer. Tropical Stored Products Information. (7) : 257—268.
2. Kutateladze, S.S. 1963. Fundamentals of heat transfer. Academic Press Inc., New York : 21—22
3. Lindblad, C., M. Newman and R. Vinita. 1974. Construction manual for the mud-walled grain drier. Contonou, Dahomey.
4. Thorshaug, H. Construction and utilization of various farm and village level grain storage facilities. Working paper no. 2 for West African Seminar on the Volunteer Role in Farm and Village-Level Grain Storage, Contonou, Dahomey.
5. Webb, E.R. 1969. A crop drier and grain storage silo for the small farm. Ministry of Agriculture and Natural Resources, Ibadan, Nigeria.