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LOW-TEMPERATURE DRYING OF WHEAT GRAIN IN-BIN UNDER LOCAL WEATHER CONDITIONS

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ABCTRACT

Two systems for drying high-moisture wheat grain (Giza 168) during 2002-harvest season were designed and tested under local weather conditions. The first system, the natural air-drying in which ambient air was forced directly through the test bin. The second system, the solar heated air-drying which a Gothic arch solar green house has internal volume of 32 m^3 was used to heat an air forced through test bin as a solar collector. Each bin having 0.7m diameter and 1.4m height perforated floor forming a plenum chamber of about 0.2m and connected to small centrifugal fan. The storage capacity of each bin was 320kg of wheat at moisture content of 18.6% (wet basis). The experiments were conducted to evaluate the effect of weather conditions, using natural and solar heated air in-bin drying systems with airflow rate of 2 m^3/min .t and grain depths of 0.35, 0.70 and 1.05m on grain temperature, grain moisture content, drying rate and final quality of wheat grain. Also, the change of grain moisture content during drying period and their effect on some physical properties of wheat grains, static pressure drop, grain shrinkage and required air quantity with ambient air drying system were evaluated.

The results indicated that the grain dimensions, thousand grain mass and porosity decreased but the bulk and particle densities increased by decreasing grain moisture content. Also, the drying potential of natural air under local climatic conditions could be used successfully for drying wheat grain during harvest season and using the solar collector increased the drying potential of natural air by 15.74%. The bulk temperature of dried grain during drying period from 15 to 22 June 2002 wheat harvest season was reduced due to the evaporative cooling resulted from moisture losses. Also, the drying rate of dried grain were 0.112% per hour with natural air, uniform grain moisture content and 0.187 percent per hour with solar heated air while, there were overdrying in the bottom layer. This means that with solar air drying system, the drying rate of wheat grains increased by 67% more than the drying rate with natural air drying system.

The static pressure drop through wheat grain increased by increasing grain depth and decreased by increasing drying time and at 1m grain depth, decreasing wheat grain moisture content by 1% (w.b.) tends to decreased the static pressure drop by 5.14%. Also, the wheat grain shrinkage was about 7% during drying period. Moreover, the air quantity required to dry wheat grain decreased by increasing drying time.It can be seen that, to minimize energy losses during drying system of grains in-bin when moisture content was reduced to 16%, the airflow rate was decrease or increase the grain depth by add wet grain above the dried grains.

1. INTRODUCTIN

Wheat in Egypt is the most important cereal crop and its production plays a significant role in the strategy to overcome food shortage and improve of self-sufficiency. Nowadays, the shortage in the wheat production in Egypt is often about 45% of the total consumption. The planted area of wheat crop was more than 2.75

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million Feddans annually (1.1 million Hectar), which produced 6.8 million tons of grain (*Tantawy, 2002).* Highest crop yields are obtained when grain is harvested after the kernel has reached physiological maturity stage, since natural and mechanical losses occur during the grain dried in the field. Also, wheat is usually harvested on June each year at relatively high level of moisture content, 17 –20% (wet basis), to minimize field losses and maximize the grain quality as well as to allow for the timely preparation of the land for multi-cropping. The harvesting has been mechanized by the use of combine harvesters, which enables large quantities of high moisture grains to be harvested in a short space of time. The almost universal use of the combine harvesters, coupled with increased yield has made it difficult to dry all the grain in a few weeks during and shortly after harvest. Drying capacity is still insufficient to cope with the drying demand for the large quantity of harvested grains during this short period. The delay in processing the high-moisture grain results in rapid qualitative and quantitative losses.

A real solution to avoid these losses will consists of either avoiding drying delay by using high capacity dryer or storage the high-moisture grain in bulk and dry it by using ambient air-drying or air heated by solar collector under local weather conditions. The designers of drying systems gave a considerable attention for ambient air and solar energy as infinite, natural, clean source and renewable energy, which can utilized efficiently and effectively for drying or heating the air inside the greenhouse and consequently utilizing it in drying process. This trend was due to the steadily increase in fossil fuel costs and uncertain availability.

Up to date ambient air-drying and air heated by solar collector have not been adapting in drying wheat grains in-bin under local weather conditions. Proper handling requires additional storage bins, solar collectors and well-trained staff as well as studies the feasibility of this system of grain drying in Egypt. The general objective of present study is to test an ambient air and air heated by solar collector system for drying high-moisture wheat grains stored in-bin during harvest season under local weather conditions.

The specific objectives included:

1-To evaluate the effect of weather conditions, using ambient and solar heated air in-bin drying systems and grain depth on grain temperature, grain moisture content, drying rate and final quality of wheat grain during harvest season.

2-To study the change of grain moisture content during drying period and their effect on some physical properties of wheat grains, static pressure drop of grain beds, grain shrinkage and required air quantity to dry grain with ambient air drying systems

2. REVIEW OF LITREATURE

Low-temperature in-bin drying as a typical on-farm method is commonly used in the United States of America for drying maize and Soybeans, ***Converse et al. (1974);*** in Europe for drying wheat, ***Muhlbauer et al. (1982);*** in Korea for drying rough rice, ***Muhlbauer et al. (1992);*** in Canada for drying barely, ***Arinze et al. (1994);*** in Brazil for drying coffee, ***Guimaraes et al.(1998)*** and in Egypt for drying rough rice, ***Shoughy (2001).*** They reported that, low-temperature drying system for grains consisting of a round or rectangular bins, an air distribution system such as a perforated false floor, air ducts and a small centrifugal fan. Ambient or slightly pre-heated air is forced vertically upwards through the 1 to 4 m thick bulk high moisture grain. Heat from the fan and fan motor is added to the ambient air stream providing a small increase in the temperature (1-2^{0}C) and an increase in ability of air to remove moisture.

Utilizing mainly the drying potential of the ambient air or air heated by solar collector and extremely low airflow rates of 1.8 to 5.6m^3/min.tonne equivalent to an air velocity of 0.1 to 0.15 m/s leads to the low power requirement and low thermal energy consumption. Since the bin can be used for drying as well as for later storage. This form of drying offers advantages of modest investment, simplify the drying equipment, minimum labor requirement and energy consumption as well as uniform drying and high quality of products as compared to high temperature drying, ***(Muhlbauer et al., 1992).*** Also, ambient air-drying and solar heated air requires careful analysis of the weather before introduction in order to reduce the risk of spoilage and some judgement and operator skill. In these systems, the drying front progress through the bin from bottom to top and drying may continue for several hours or even days. The grain in the top of the bin remains at high moisture and near ambient wet bulb temperature through most of the drying period. Therefore, drying should be completed before mold growth occurs in the top layer ***(Stroshine and Yang, 1990).*** The airflow rate required for successful bin drying must be adequate to reduce the moisture content of grain in all parts of the bin to 12-14.0% within a relatively short time after harvesting to prevent quality loss from mold activity. So, ambient air in-bin drying system or air heated by solar collectors may be better adapted than systems which use fossil fuels because of high costs, cracking losses and causes high environment pollution. Also, traditional method requires large surface area and labor for spreading, stirring and collecting farm crops.

Brooker et al. (1974) indicated that, the rate of grain drying in bins depends on the temperature and humidity of air while drying, the rate of airflow through the grain, and the moisture content. The recommended airflow for small grains is ranged from 1.1 to 5.6 m^3/min. tonne, although lower airflow will suffice low moisture grain. They also reported that, increasing wheat grain moisture content from 16 to 20%(w.b.) tends to increase airflow rate from 1.0 to 3.3 m^3/min. tonne, while decreases grain depth from 2.4 to 1.2 m.

Calderwood (1977) studied the effect of both solar heated air and stirring auger for rice drying in-bin under Texas weather conditions. He concluded that the use of solar heated air reduced the elapsed time for drying and reduced the electrical energy required for fan operation compared with unheated air-drying. Also, *Morey and Cloud (1977)* found that energy requirements were reduced approximately 25 % by using supplemental solar heat in the low temperature phase compared to the ambient-air drying.

Kunze and Calderwood (1978) mentioned that most storage bins could be adapted to forced air-drying. However, there are certain limitations regarding the use of storage bins. The maximum economical depth of storage for drying of small grains is 1.8 m, for shelled corn and for pea beans 2.4 m, and for ear corn 6 m. They also found that, horsepower required to operate the fan becomes quite large for greater depths and is generally considered uneconomical for drying. The capacity of the fan required depends on the depth of grain and the rate of airflow. While, the rate of airflow depends upon the crop and it's moisture content.

Kim et al. (1989) developed and tested a small-scale ambient air in-storage dryer for Korean farms. The standard version of rectangular is 2.4 m length, 1.8 m width and loaded up to a depth of 1.2 m. The capacity of dryer ranges from 1.4 to 3.0 ton. A 0.4 kW motor fan is used to force 3.1 to 6.0 m^3/min.m^3 of ambient air for drying the grain to safe storage moisture content. Their results showed that, under Korean weather conditions, a layer of paddy 0.9 to 1.2 m thick can be dried during 7 to 15 days from an initial moisture content without supplemental heating of up to 25% to safe storage conditions by continuous ventilation with ambient air. Low airflow rates of 3.1 to 6.6 m^3/min. m^3 resulted in a power requirement of approximately 400 W for driving the fan. Also, they found that compared with traditional sun drying methods, the product quality was significantly better.

Kamel and Abdel-Rahman (1999) studied the air thermal behavior inside a greenhouse (Gothic arch type) as a solar dryer during the period of March up through June 1999 under Kafr El-Sheikh weather conditions. They found that the solar greenhouse gave around 7 ^{0}C higher than the outside air temperature and a reduction range of 5 – 6 % of air relative humidity compared with the outside air relative humidity.

Shoughy (2001) developed and tested an ambient air in-storage drying system for laboratory scale during 1998 rough rice harvest season. He indicated that ambient air-drying potential under local weather condition was high and can be used successfully for drying high moisture rough rice with high quality during harvest season without supplementary heating. Also, ambient air drying with continuous fan operation and airflow rate 3.6 m^3/min. tonne was dried rough rice from 22.6 to 14% moisture content (w.b.) through 8 day with uniform moisture and no negative effect on milling quality, germination rate, cracking ratio, reduce fungi growth and considering the most suitable method in seed production.

3. MATERIAL AND METHODS

3.1. Test Bins and Solar Collector:

Two identical prototype cylindrical bins were constructed of galvanized steel sheets. Each bin having 0.7 m diameter and 1.4 m height, perforated floor forming a plenum chamber of about 0.2 m high as shown in Fig. (1). The storage volume of each bin was 0.46 m^3 . Thus, the storage capacity of each bin was 320 kg of wheat, with bulk density of about 695 kg/m^3 . Each bin was connected to small centrifugal fan,which has a power of 0.25 kW. Air supplied by the fan passed through PVC pipes of 0.075 m of inner diameter . The airflow rate supplied to the bins was controlled by ball valves located on the entrance of the plenum chamber. A gothic arch greenhouse has a floor area of 16.4 m^2 (4.56 m x 3.60 m) and total height of 2.3 m with internal volume of 32m^3 was constructed and installed at Rice Mechanization Center (R.M.C.) and used as a solar collector. More details are found in ***Kamel and Abdel-Rahman (1999).***

3.3. Experimental Procedures

Two different drying systems for drying wheat grains were used as shown in Fig.(1). The first was natural air-drying system in which ambient air was forced directly through the grain bulk by using centrifugal fan. The second was solar heated air drying system in which a gothic arch solar greenhouse heated an air. The daily operation period continued 10 hours per day from 9 a.m. to 7 p. m. to take the weather data inside and outside the greenhouse such as air temperature and relative humidity. The wheat grains (Giza 168) was harvested and pre-cleaned by the combine at an average moisture content of 18.6% and filled in the two bins immediately on 14 May 2002. The top surface of the grain was leveled and air in the two drying systems was forced through the grain bins by the fans. The airflow to grain mass was set to 2 m^3/min. tonne , referring to ***Brooker et al. (1974).***

The drying process was finished at moisture content of 13% (w.b.) in the top layer of each bin. The static pressure drops in the plenum and three levels of the test bin were measured during experiment every day until the drying period was finished. The changes in moisture content of the grain in relation to bulk depth and drying time was determined every day. After drying period was finished, the mean sample was taken to evaluate the fungal growth and germination rates. To investigate the influence of drying system on the quality characteristics of wheat grain, a reference sample was spread out in a thin layer of 0.02 m at room temperature, 27^{0}C, under shade until moisture content reached 13.0% (w.b.) which ensured that no change of quality can occur. Also, some physical properties of grains were measured because these are very important to design equipment for handling, aeration, drying, storing, and processing of cereal grains.

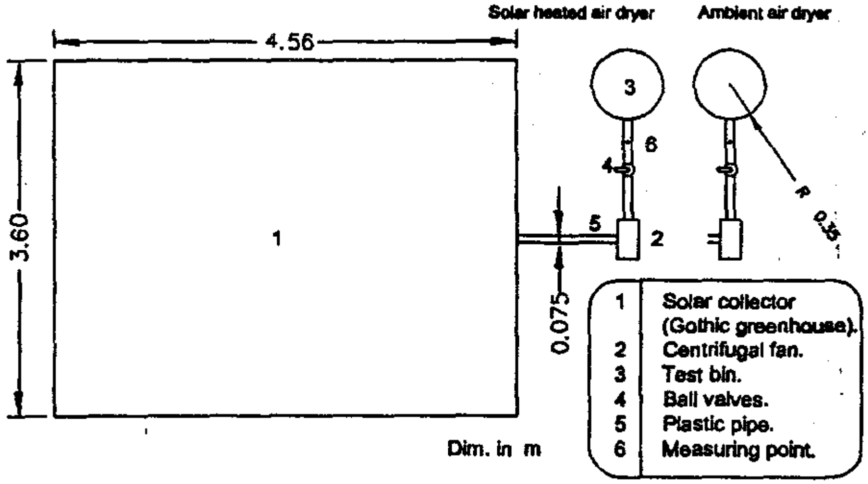


Figure (1): Schematic diagram of ambient and solar heated air dryers.

3.4. Instrumentation:

The thermocouple sensors were installed to measure temperature of the grains and drying air. Grain temperatures were measured at three levels at the center of bin (0.35, 0.70 and 1.05 m) from bin floor. Also, ambient dry- and wet-bulb temperatures were measured at inlet and outlet air of the bins. Thermocouple probes are connected to an interface analog digital converter (LE1000, Model) and the temperatures reading from thermocouple probes are recorded for 4 hours intervals. The changes of moisture content of wheat grain in relation to bulk depth and drying time was determined every day by taking samples by using a double concentric tube-sampling device from the center of the test bins. To measure the grain moisture content, the moisture meter, model (SP-1D) which calibrated with oven method (at 130 ^{0}C for 18 hours) with accuracy of about $\pm 0.1\%$ was used. A thermal anemometer, model (Sato SK-73D) was used to measure airflow rate. To measure the static pressure drop in grain beds, a declined manometer was used.The grain germination and fungal growth rates were evaluated after drying was finished (more details are found in ***Shoughy, 2001***).

3.5. Miscellaneous Equations:

3.5.1. Static pressure:

The static pressure was measured inside grain beds every day at 11 a.m. by insert right coppers tube with 6 mm inside diameter and connected with a declined manometer and by using the following equation (***Shoughy, 2001***):

$$P = \rho \cdot g \cdot h \quad \ldots (1)$$

Where: P = static pressure, Pa; ρ = density of the water, kg/m^3 ;
g= gravitational acceleration, m/s^2 ; and h= head of water, m.

3.5.2. Equilibrium moisture content:

During drying, the equilibrium moisture content and relative humidity relationship is adequately described by the modified Henderson equation, ***ASAE (1998)***:

$$M_e = \frac{1}{100}\left[\frac{Ln(1-RH)}{-C_1(T_g+C_2)}\right]^{1/N} \quad \text{.........(2)}$$

Where: M_e = equilibrium moisture content, dry basis, decimal;
T_g = grain temperature, ^{0}C;
RH = air relative humidity, decimal;
C_1,C_2 and N are empirical constants which depend on the material (for wheat C_1= 0.00043295, C_2= 2.1119 and N= 41.565).

3.5.3. Anzlyzing drying process by using psychrometric chart:

1- To calculate water removed from bulk grain mass (***Shoughy, 2001***):

$$Water\ removed,\ kg = M_g(\frac{M_i\text{-}M_f}{100-M_f}) \quad \text{.........(3)}$$

Where: M_g = mass of dried grain, kg; M_i = initial mass of dried garin, kg;
M_f= final mass of dried grain, kg.

2-To determine how much water is taken out for each kg of air moving through the grain ,ΔW (***Shoughy, 2001***):

$$\Delta W = W_{in} - W_{out} \quad \text{.........(4)}$$

where: W_{in}= moisture ratio in inlet air, kg $_{water}$/kg $_{dry\ air}$
W_{out} = moisture ratio in outlet air, kg $_{water}$/kg $_{dry\ air}$

3-To determine the weight of air (M_a) passing through the grain in kg/h:

Mass of air (M_a) = Airflow rate (m^3/min)/Volume of inlet air (m^3/kg).....(5)

4- To determine the drying rate, or rate of water removed per hour, kg $_{water}$/h:

$$Drying\ rate,\ kg_{water}/h = M_a(W_{in}-W_{out}) \quad \text{.........(6)}$$

Where: M_a = mass of drying air, kg.

5- To find the time needed to dry wheat grains (***Shoughy, 2001***):

$$Drying\ time,\ h = \frac{water\ removed\ (kg)}{Drying\ rate(kg_{water}/h)} \quad \text{.........(7)}$$

4. RESULTS AND DISCCSION

4.1. Some Physical Properties of Wheat Grains:

Table (1) shows some physical properities of wheat grains Giza (168) such as kernel dimensions, thousamd grain mass, porosity, bulk and particle densities of wheat grain at various moisture contents (w.b.). The results indicated that the grain dimensions, thousand grain mass and porosity decreased by decreasing grain moisture contents. While, the bulk and particle grain densities increased with decreasing grain moisture contents. The variations in grain bulk, particle densities and porosity of wheat grain occurred because the fact that increasing of the moisture content of grains led to a reduction in grain mass required to fill the same volume of the bin. Also, the rate of increasing the required grain volume was higher than that of the grain mass. This fact is very important and was affected by the degree of packing for the grain bed, which influenced by the filling method of stored bins.

Table (1): Some physical properties of wheat grain (Giza 168) at various moisture contents.

Grain moisture content,% (w.b.)	Grain dimensions, mm			Thousand grain mass, gram	Bulk density, kg/m^3	Particle density, kg/m^3	Porosity, %
	Length	Width	Thickness				
18.6	6.92	3.52	2.90	32.43	681	1170	43.5
15.5	6.75	3.46	2.82	31.66	695	1198	42.3
13.0	6.61	3.35	2.74	30.34	720	1216	40.8
11.2	6.50	3.22	2.62	29.56	732	1215	39.5

4.2. Weather Conditions:

The wheat crop was harvested in Egypt through May month every year. The drying experiment was conducted from 15 to 22 May during 2002-wheat harvest season. The averages of ambient air temperature during harvest season ranged between 24.6 to 31.3 ^{0}C and relative humidity ranged between 32 to 56.2%. The drying potential of the ambient air ranged between 0.0108 to 0.0092 kg $_{water}$/ kg$_{dry\ air}$ and indicated high drying potential of ambient air during that period. Also, by using greenhouse solar collector, the average of solar heated air during wheat harvest season 2002 was ranged between 32.6 to 39.3 ^{0}C and average relative humidity ranged between 21 to 40 %. It can be seen that the average solar heated-air temperature increased by 7^{0}C and the average relative humidity reduced by 8%. Also, the drying potential of solar heated air ranged between 0.0125 to 0.0098 kg $_{water}$/ kg$_{dry\ air}$. This means that, using solar collector under local weather conditions increased the drying potential by 15.74%. Moreover, from an equilibrium moisture content and relative humidity equations (*ASAE, 1998*). It was found that with local weather condition during that period, the averages of ambient air temperatures and relative humidities were nearly at equilibrium with 10.5 % with natural air and 8.5% equilibrium moisture content of wheat grains with solar heated air. This mean that, the drying potential of ambient air under local weather conditions was high and enough to dry the high-moisture wheat grain during harvest season 2002 from the initial moisture content ranged between 17 to 20% (w.b.) to the safe moisture content of storage. Also, solar heated air was used to increase the drying capacity of the drying air, which can have a positive influence on the income under weather conditions.

4.3. Analyzing Grain Drying with Natural and Solar Heated Air by using Psychrometric Chart:

The weather data during this period of drying was analyzed by using psychometric chart as indicated in Fig. (2). The natural air during drying period (15-22 May during 2002 harvest season) at 32.5^{0}C dry-bulb temperature, 25.6 ^{0}C wet-bulb temperature and solar heated air with 39.8 ^{0}C dry-bulb temperature , 31.2^{0}C wet-bulb temperature were used to dry high-moisture wheat grain in-bin from initial moisture content (M_i) 18.6 % (w.b.) by using airflow rate of 2 m^3/min. t with 10 hour fan operation (from 9 a.m. to 7 p.m. each day). To estimate the final moisture content and drying time, the following steps were carried out:

1-The air characteristics of natural and solar heated-air which used in drying wheat grains during 2002 harvest season are shown in Table (2).These weather data represented the averages of dry- and wet-bulb temperatures during harvest season of wheat grains under local conditions.

2-The equilibrium moisture content of dried grain (M_f) in this case by using modified Henderson equation 2 is nearly 10.5 %, (w.b.) with natural air condition and 8.5% with solar heated air condition. Suppose the fan was shut down when the average grain in the top layer of test bin was 13%, which considered safe moisture for wheat grain storage in bins.

3-To calculate water removed from bulk mass(M_g) for 320 kg wheat grains which was dried from 18.6 to 13.0% moisture content

$$Water\ removed = 320(\frac{18.6-13.0}{100-13.0}) = 20.6kg$$

4-To determine how much water is removed from each kg (ΔW) of air moving through the grain:

ΔW *(with natural air-drying)* $= 0.0178 - 0.019 = -0.0012\ kg_{water}/kg_{dry\ air}$

ΔW *(with solar heated air drying)* $= 0.025 - 0.0278 = -0.0028\ kg_{water}/kg_{dry\ air}$

5-To determine the mass of air (M_a) passing through the grain in kg/h:

M_a *(With natural air drying)* $= (4.6/0.89) \times 60$ min/hour $= 310.11$ kg/h

M_a *(With solar heated air drying)* $= (4.6/0.92) \times 60$ min/hour $= 300$ kg/h

6-To determine the drying rate (DR), or rate of water removed per hour, kg_{water}/h:

DR *(with natural air drying)* $= 310.11\ (0.0178 - 0.019) = 0.372\ kg_{water}/h$.

DR *(with solar heated air drying)* $= 300(0.025 - 0.0278) = 0.84\ kg_{water}/h$

7-To find the time (Dt) needed to dry wheat grains:

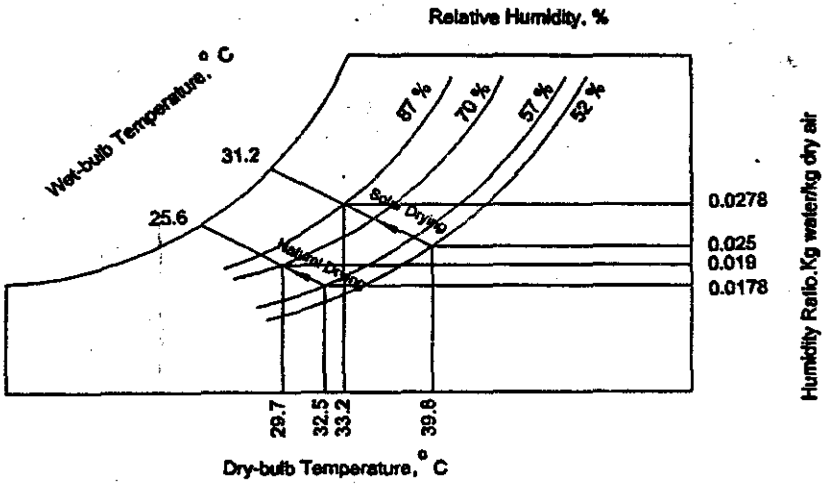
$$Dt\ (with\ natural\ air) = \frac{20.6}{0.372} = 55.4\ hours \approx 6\ days\ \ (10\ h/day).$$

$$Dt\ (with\ solar\ heated\ air) = \frac{20.6}{0.84} = 24.5\ hours \approx 3\ days\ \ (10\ h/day)$$

There are many assumptions required to analyze the drying process by using the psychrometric theory such as:

1-The air leaves the grain in equilibrium with the wettest grain,

2-The incoming air conditions are constant with each system over the drying period, and 3- No heat is lost to the surroundings.



Figure(2): A schematic of psychrometric chart representation of the drying process by using natural and solar heated air.

Table (2): Air characteristics of natural and solar heated-air.

Conditions of air	Natural air drying		Solar heated-air drying	
	Inlet air	Outlet air	Inlet air	Outlet air
Dry-bulb temperatures, °C	32.5	29.7	39.8	33.2
Wet-bulb temperatures, °C	25.6	25.6	31.2	31.2
Relative humidities,%	57	70	52	87
Moisture ratio(W), kg $_{water}$/kg $_{dry\ air}$	0.0178	0.019	0.025	0.0278
Specific volume, m^3/kg	0.89	0.85	0.921	0.906
Density, kg/m^3	1.124	1.176	1.086	1.104
Specific Enthalpy, kJ/kg	77	77	108	108

4.4. Bulk Grain Temperature:

Fig. (3) shows the maximum, minimum ambient air, solar heated air temperature and average grain temperature at three levels of grain depths(0.35, 0.70, 1.05m) in the two test bins during drying period. The averages grain temperatures values in the bin dried by solar heated air was higher than that with the grain dried by natural air.

Also, the cooling zone was established immediately at the bottom layer of the two test bins and moved upward, based on the changes of grain temperature, air relative humidity at each layer and wet-bulb temperature of drying air. While, the cooling zone with natural air drying system was faster than that with solar heated air drying system. The bulk temperature values in test bins reduced from 33.8 to 27.8 ^{0}C in the bin dried by natural air and from 33.8 to 32.1 ^{0}C in the bin dried by solar heated air during the drying period. This is due to the evaporative cooling resulted from moisture losses. The grain temperature values in the test bins lay between the range of maximum and minimum ambient air temperatures because of the fluctuation of ambient air temperature during the day and the night. The temperature distribution in the test bins gave an idea about the speed of the drying zones in the wheat grain beds.

4.5. Bulk Grain Moisture Content:

Fig. (4) shows the changes in wheat grain moisture content with different grain depths and drying systems during drying period. The drying process continued until the grain moisture content reduced from 18.6 to 13 % (w.b.) at the top layer. The results showed that the drying zones established immediately at the bottom layers of grain bulk and moved upward through the bins based on the changes of grain moisture content and air relative humidity at each layer. Also, the speed of drying zone in the bin dried by solar heated air was faster than that with the grain dried by natural air drying system. This is due to the higher temperature of solar heated air drying system. The reduction of grain moisture content needed 30 hours (3 day) with solar heated air drying system and 50 hour (5 days) with natural air drying system by using airflow rate of 2 m^3/ min.tonne of wheat grain.

The drying rate during the first 10 hours was higher than that in the entire drying period.The drying rate during the test indicated 0.112 percent /hour with natural air drying system and 0.187 percent /hour with solar heated air drying system. This means that with solar air drying system, the drying rate of wheat grains increased by 67% more than the drying rate with natural air drying system. The grain at the bottom layer in bin dried by natural air did not show over-drying or rewetting cycles caused by changing ambient air conditions of grain, while in grain dried by solar heated air there was overdrying grain in the bottom layer (11.5%). Also, the grain in the test bin dried by natural air when drying period was completed were nearly uniform of moisture content at about 13 %, (w.b.) that allowed safe storage of wheat more than that in grain dried by using solar heated air drying system.

4.6. Grain Quality Tests:

Table (3) summarizes the results of grain quality tests with two drying systems compared to shade drying sample at the end of drying period. The germination and fungal growth rates can be used as an index for the grain deterioration during drying and storage periods. The germination rate with grain dried by natural air increased more

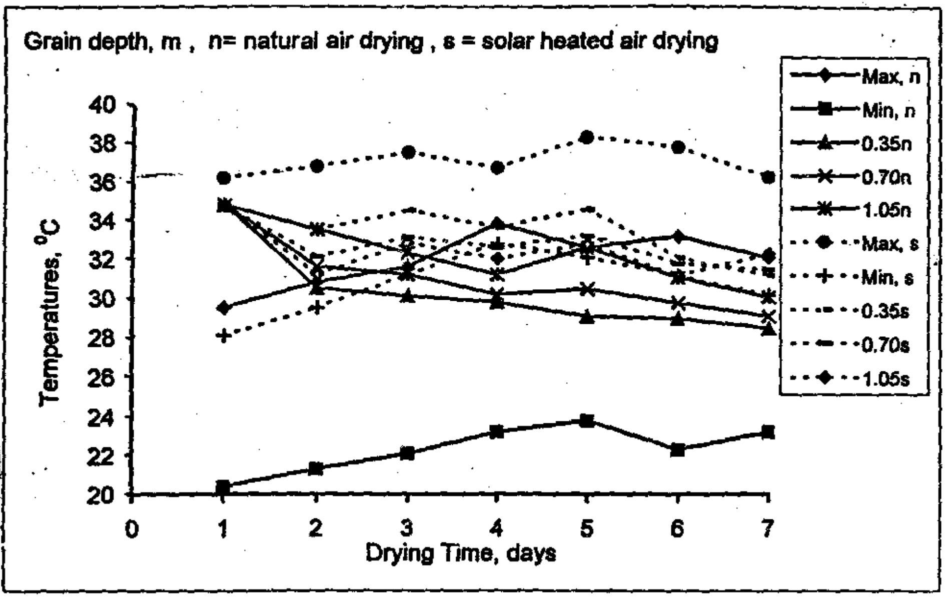


Fig.(3): Maximum and minimum natural and solar heated air temperatures and average grain layers temperature with two drying systems during drying process.

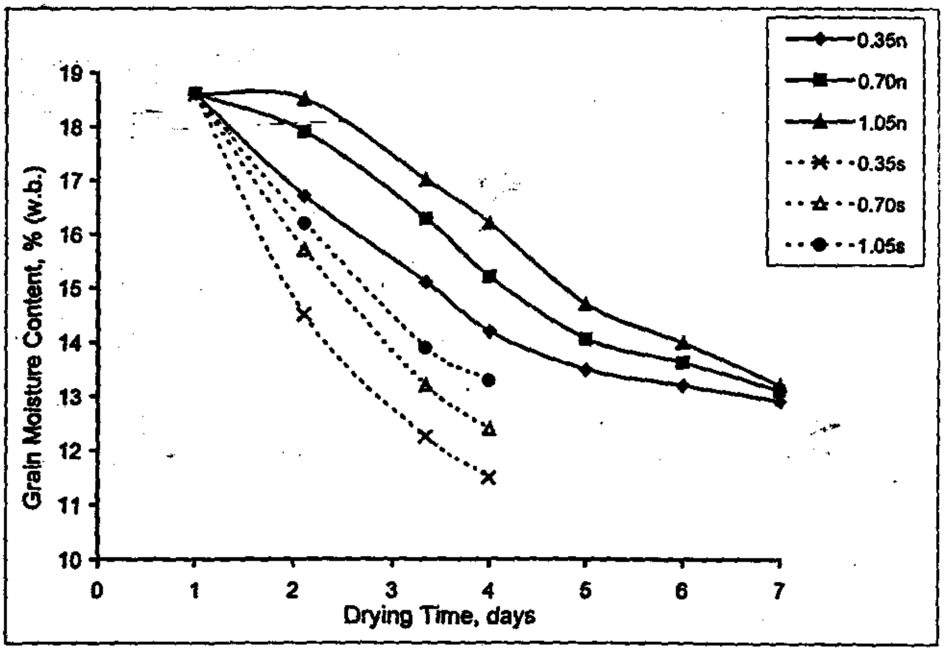


Fig. (4): The changes in grain moisture content with two drying systems at different grain layers during drying process.

than that with grain dried by solar heated air by 4% and there was no significant difference with shade drying sample (reference sample). Also, the fungal growth rate in grain dried by natural air was lower than the grain dried by solar heated air. The fungal growth rates after drying period was1.4 % with grain dried by natural air, while in grain dried by solar heated air it was 3.2 % compared to the initial growth. Therefore, these results indicated that the natural air-drying under local conditions is suitable method for seed production and good control of molds during drying process.

Table (3): Effect of drying system on wheat grain quality (germination rate and fungal growth rate).

Grain quality indicator	Drying system		
	Natural air drying	Solar heated air drying	Reference sample (shade drying)
Germination rate, %	96	92	96
Initial fungal growth, %	2.5	2.5	2.5
Final fungal growth, %	1.4	3.2	1.3

4.7. Static Pressure Drop of Wheat Grains during Drying Period:

Fig. (5) shows the changes of static pressure drop at the plenum chamber of the drying test bin and at various grain depths during drying period of wheat grain (Giza168) by using natural air at airflow rate of 2 m^3/min. tonne. The results indicated that the static pressure drop through the grain increased by increasing grain depth and decreased with increasing drying time. Also, the decrease of static pressure during the first period of drying wheat grain was higher than that in the entire drying period. It decreased from 73.58 to 49.05Pa in the top layer and from 206.01 to 176.58 Pa in the bottom layer when moisture content of dried wheat changed from 18.6 to 13.0 % (w.b.) This decrease in the static pressure in grain bed is probably due to the reduction of grain size accompanied by a reduction in bed depth and porosity as the moisture content was progressively reduced. It can be seen that, at the same grain depth, decreasing wheat grain moisture content by 1% (w.b.) tends to decrease the static pressure drop by 5.14%. Also, grain shrinkage during the drying periods caused the height of grain bed to decrease continually. The total volumetric shrinkage was about 7 % of the initial volume when wheat grain was dried from 18.6 to 13.0 % (w.b.) moisture content.These results agreed with the result obtained by ***Guimaraes et al., (1998).***

4.8. Required Air Quantity to Dry Wheat Grains:

Fig. (6) shows the air quantity, which passes through the dried grain mass and accumulated air quantity (m^3/tonne) every day during drying period by using natural air at initial airflow rate of 2 m^3/min .tonne of high-moisture wheat grain. It can be seen that, at the beginning of drying experiments, the air quantity of 2880 m^3/tonne are needed to dry the high moisture wheat grain was higher that of 2160 m^3/tonne during entire

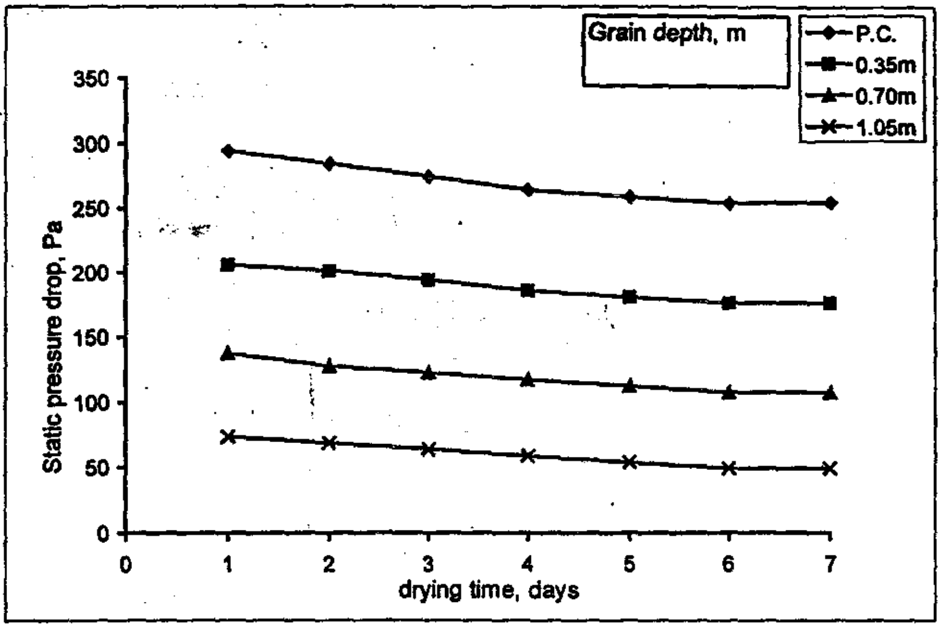


Fig.(5): The changes of static pressure drop at different wheat grain depth during drying process by using riatral air.

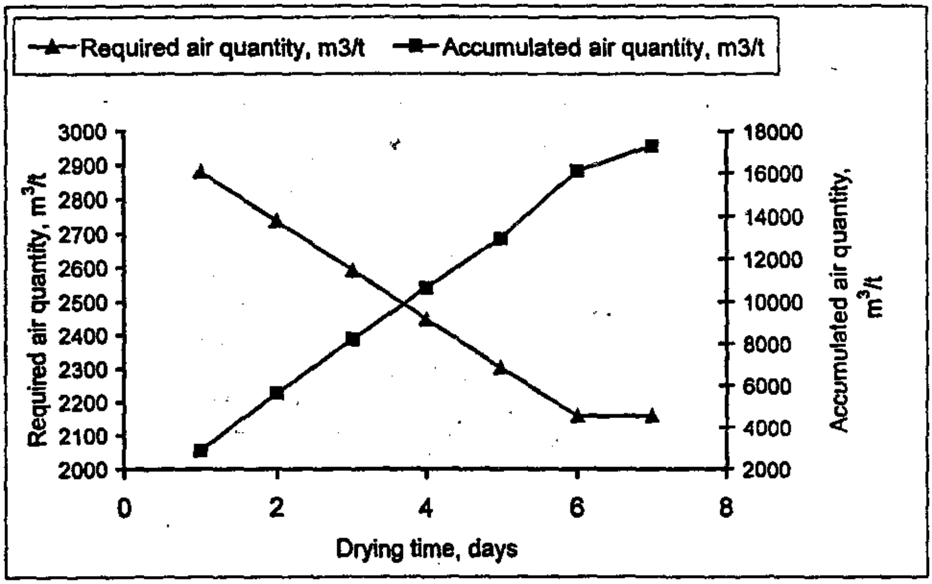


Fig. (6): Effect of drying time on the changes of required air quantity and accumulated air quantity during drying wheat grains by using natural air.

drying period. This means that the air quantity to dry the grain decreased by increasing drying time. Also, low airflow is needed to dry grain at lower moisture content. These results may be due to grain shrinkage and changes of bulk density and porosity of dried grain. The results also showed that accumulated airquantity with dried grain increased from 2880 to 17280 m^3/tonne by decreasing rate with drying time as a result of the same reasons. The experimental data also showed that the airflow supplied to the drying beds decreased rather than increased during drying. The combined effect of the reduced grain depth and plenum pressure was the increase of the pressure gradient across the grain bin. Also, the grain mass was packed denser at the end of drying than at the start of drying, which caused by the grain shrinkage. Denser packing of grain mass means the reduction in bulk porosity and the increase of the resistance of grain to airflow. The increase of resistance due to moisture reduction of the grain was even larger than the decrease of the resistance due to reduction of grain bed depth. This result was agreed with the results obtained by *Gu et al. (1996)*. The net effect of the increase of the pressure gradient and the denser packing of grain mass was the lower airflow rates supplied to the drying bed. This mean that to minimize energy losses when moisture content of dried grain reduced to 16%, the airflow rate decreased or increased the grain depth by add wet grain above the dried grain.

CONCLUSIONS

From the present study it can be concluded that:

1-The grain dimensions, thousand grain mass and porosity decreased and the bulk and particle densities increased significently by decreasing grain moisture contents.

2-The drying potential of natural air under local weather conditions ranged between 0.0108 to 0.0092 $kg_{water}/kg_{dry\ air}$ with natural air and with solar heated air ranged between 0.0125 to 0.0098 $kg_{water}/kg_{dry\ air}$. and could be used successfully for drying wheat grain during harvest season.

3-Using solar collector increased the drying potential of natural air by 15.74%. The bulk temperature of dried grain during drying period from 15 to 22 June 2002 wheat harvest season was reduced due to the evaporative cooling resulted from moisture losses.

4-The drying rate of dried grain was 0.112% per hour with natural air, uniform grain moisture content and 0.187 % per hour with solar heated air while there were overdrying in the bottom layer. This means that with solar air drying system, the drying rate of wheat grains increased by 67% more than the drying rate with natural air drying system.

5-The static pressure drop through wheat grain increased significently by increasing grain depth and decreased by increasing drying time and at the same grain depth, decreasing wheat grain moisture content by 1% (w.b.) tends to decreased the static pressure drop by 5.14%. Also, the wheat grain shrinkage was about 7% during drying period.

6-The air quantity required to dry wheat grain was decreased significently from 2880 to 2160 m^3/tonne during drying period by using natural-air drying and to minimize energy losses during drying grains in-bin when moisture content was reduced to 16%, the airflow rate was decreased or increased the grain depth by add wet grain above the dried grains.

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تجفيف حبوب القمح في المخزن بدرجات الحرارة المنخفضة تحت ظروف الطقس المحلية

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يعتبر القمح من أهم محاصيل الغذاء في العالم وفي مصر حيث يزرع منه ما يزيد عن ٢,٧٥ مليون فدان تنتج ٦,٨ مليون طن حبوب سنويا. وبالرغم من ذلك يستورد حوالي ٤٥% من الاستهلاك السنوي المحلي. ويتم حصاد القمح في السنوات الأخيرة بالكومباين عند محتوى رطوبي مرتفع بعد مرحلة النضج الفسيولوجي بكميات كبيرة في فترة وجيزة بغرض تقليل الفقد في الحقل والحفاظ على الجودة. لذلك يلزم تجفيف الحبوب مباشرة إلى المحتوى الرطوبي الآمن للتخزين لمنع أكسدها، ويعتبر نقص عدد المجففات الصناعية من أهم مشكلات صناعة الحبوب في مصر بالإضافة إلى أن المجففات الصناعية التي تستخدم هواء ذو درجات حرارة عالية تنتج حبوب جودتها منخفضة وتسبب تلوث البيئة. لذلك يلزم تجفيف الحبوب باستخدام درجات الحرارة المنخفضة من المصادر الطبيعية لانتاج حبوب جودتها مرتفعة وتوفير استهلاك الطاقة ومنع تلوث البيئة. أجريت هذه التجارب بغرض دراسة إمكانية استخدام الهواء الطبيعي وكذا الهواء الطبيعي المسخن بالطاقة الشمسية في تجفيف حبوب القمح مرتفعة الرطوبة التي تم تخزينها في الصوامع مباشرة أثناء موسم الحصاد (مايو ٢٠٠٢). وكذلك دراسة التغير في الصفات الطبيعية لحبوب القمح وبعض العوامل التصميمية المؤثرة على تشغيل نظام التجفيف في المخزن تحت ظروف الطقس المحلية.

تم تصنيع نموذجين معمليين لصوامع التخزين والمجمع الشمسي من الخامات المحلية وأجريت التجارب في مركز ميكنة الأرز بميت الديبة – معهد بحوث الهندسة الزراعية في موسم حصاد القمح صنف سخا ١٦٨ في الفترة من ١٥- ٢٢ مايو ٢٠٠٢ حيث تم حصاد القمح (صنف جيزة ١٦٨) بآلة الحصاد الجامعة عند محتوى رطوبي ١٨,٦% على أساس رطب وتم تنظيفه وتخزينه مباشرة في المخازن. وتم استخدام نظامين للتجفيف: الأول دفع الهواء الطبيعي داخل المخزن والآخر دفع الهواء المسخن باستخدام مجمع شمسي (صوبة بلاستيكية مساحة أرضيتها ١٦,٤ م^{2} وحجمها الداخلي ٣٢ م^{3}) بمعدل سريان للهواء مقداره ٢ م^{3}/دقيقة . لكل طن من حبوب القمح باستخدام مروحتين قدرة كل منها ٠,٢٥ كيلووات. وذلك لدراسة تأثير نظامي التجفيف بالهواء الطبيعي وكذا الهواء الطبيعي المسخن بالمجمع الشمسي وعمق طبقة الحبوب على التغير في كل من درجة الحرارة والمحتوى الرطوبي للحبوب أثناء فترة التجفيف وكذلك تأثير الانخفاض في المحتوى الرطوبي أثناء عملية التجفيف على التغير في الضغط الاستاتيكي وانكماش الحبوب وكمية الهواء اللازمة لتجفيف حبوب القمح في المخزن.

ومن أهم النتائج التي تم التوصل اليها ما يلي:

١- عند انخفاض المحتوى الرطوبي لحبوب القمح قلت أبعاد الحبوب و وزن الألف حبة والمسامية معنويا بينما زادت قيمة الكثافتين الظاهرية والحقيقية.

٢- القوى الدافعة للتجفيف للهواء الطبيعي وكذا المسخن بالطاقة الشمسية تحت ظروف الطقس المحلية أثناء حصاد القمح موسم ٢٠٠٢م عالية وتكفي لتجفيف القمح مرتفع الرطوبة في المخزن وكانت نسبة إنبات الحبوب المجففة عالية وتم القضاء على الفطريات في نهاية مرحلة التجفيف مما يجعلها من أفضل طرق التجفيف لانتاج التقاوي.

٣- انخفضت درجة حرارة الحبوب أثناء التجفيف باستخدام الهواء الطبيعي بمقدار ٦ °م بينما مع الهواء المسخن بالمجمع الشمسي انخفضت درجة الحرارة بمقدار ١,٧ °م بسبب التبريد التبخيري الناتج عن انخفاض المحتوى الرطوبي للحبوب من ١٨,٦ الى ١٣%.

٤- كان معدل التجفيف في المخزن الذي تم تجفيفه بالهواء الطبيعي ٠,١١٢% في الساعة مع انتظام المحتوى الرطوبي في الطبقات المختلفة بينما مع استخدام الهواء المسخن بالطاقة الشمسية كان معدل التجفيف ٠,١٨٧% في الساعة وبالتالي زاد معدل التجفيف بنسبة ٦٧% ولكن حدث تجفيف زائد في الطبقة السفلي للمخزن (١١,٥%) في نهاية مرحلة التجفيف.

٥- بزيادة عمق الحبوب زاد الانخفاض في الضغط الاستاتيكي خلال الحبوب معنويا بينما قل مع زيادة زمن التجفيف وكذلك حدث انكماش في الحبوب بنسبة ٧% أثناء عملية التجفيف بسبب الانخفاض في المحتوى الرطوبي. فقد انخفض الضغط الاستاتيكي من ٢٠٦,٠١ الى ١٧٦,٥٨ باسكال في الطبقة السفلي بينما انخفض في الطبقة العليا من ٧٣,٥٨ الى ٤٩,٠٥ باسكال عند انخفاض المحتوى الرطوبي للحبوب أثناء عملية التجفيف. أي أنه عندما ينخفض المحتوى الرطوبي لحبوب القمح بنسبة ١% يزداد الانخفاض في الضغط الاستاتيكي بمقدار ٥,١٤%.

٦- انخفضت كمية الهواء اللازمة لعملية التجفيف معنويا من ٢٨٨٠ الى ٢١٦٠م^{3}/طن بسبب زيادة الانخفاض في الضغط الاستاتيكي نتيجة زيادة الكثافتين الظاهرية والحقيقية وكذا نقص المسافات البينية بين الحبوب نتيجة الانخفاض في المحتوى الرطوبي للحبوب المجففة وكذلك انكماش الحبوب بعد التجفيف بنسبة ٧%. مما سبق يتضح انه لزيادة كفاءة استخدام الطاقة في عملية التجفيف في المخزن يجب خفض معدل سريان الهواء قرب نهاية مرحلة التجفيف أو زيادة عمق الحبوب وذلك باضافة حبوب رطبة فوق الحبوب المجففة في المخزن.

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