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SOME ENGINEERING FACTORS AFFECTING THE PERFORMANCE OF IN-BIN DRYING SYSTEM FOR SOYBEAN GRAIN

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ABSTRACT

The aim of this study was to investigate some engineering factors affecting the performance of in-bin drying systems for high-moisture grain. An ambient-air and solar heated-air drying systems with two airflow rates are used for drying soybean grain during 2002-harvest season. The change of grain moisture content and their effect on some physical properties of soybean grain and the static pressure drop during drying process was determined. Also, the effect of drying system, airflow rate and grain depth on the change of soybean moisture content, drying rate and energy consumption as well as final quality of dried grain were evaluated.

The results showed that the solar collector increased the air temperature by 7.2^{0}C and decreased the air relative humidity by 22% inside the greenhouse compared with ambient-air during drying process. The results also indicated that, linear dimensions and thousand grain mass of soybean are linearly related to its moisture content and increased with increasing moisture content within the range 11.9 to 29.2% (d.b.). While, bulk density, particle density and porosity of soybean decreased with the increase in grain moisture content. Also, increasing airflow from 1.2 to 2.4 m^3/min .t tends to decrease drying time by 33.33% and increasing energy consumption from 19.62 to 30.92 MJ/t with ambient-air drying while, with solar heated-air drying, the drying time decrease by 28.57% and energy consumption increased from 12.49 to 21.4 MJ/t. Moreover, the electrical energy consumption of the fan increased with natural-air drying due to the extension of drying time. Furthermore, decreasing soybean grain moisture content by 1% during drying process tends to increase the static pressure drop by 3.34%. On the other hand, using natural-air drying system with 2.4 m^3/min. t was found nearly equivalent to solar heated-air drying and gave the best quality of dried grain. While, using solar heated-air drying speeded up drying rate but increase energy required for drying and caused further over-drying of dried grain.

1-INTRODUCTION

Soybean (*Glycine Max*) is one of the important oil crops. It consumption ranks third among the world food oils after the cotton seed and sunflower. Up to date, the increase in soybean production are the following facts: a- the oil production is less than consumption by about 80%. b- the price increase is recently permitted, this will encourage the farmers to produce more soybeans. In Egypt, soybean crop is not only an oil crop but also a ready source of protein for people diet, chickens and animals. Drying of soybean grains are still done by traditional method (spread the grain on the floor under direct sunshine until moisture content changed from 20 to 12%, which considered safe for storage. The maximum moisture contents (wet basis) generally accepted for storage up to one year for soybean is 11 – 12%, for corn at 13% and wheat at 13 – 14%, *Carl*

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and Hall (1982). In order to overcome the existing shortage of farm labor during the harvesting period, the introduction of drying systems, which can be economically adopted on Egyptian farms, is an urgent necessity. Excessive drying rates or high temperature for drying may cause both physical, chemical damage and quality losses of the dried product. Excessive quality losses are avoided by using low temperature for drying.

Recently, 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. Up to date ambient air-drying and air heated by solar collector have not been adapting in drying soybean grains in-bin during harvest season. 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 evaluate the performance of an ambient-air and heated-air by solar collector for drying high-moisture soybean grains stored in-bin during 2002-harvest season.

The specific objective was to investigate:

1-The possibility of using ambient-air and solar heated-air drying systems for drying soybean grain in-bins during harvest season.

2-The changes of grain moisture content and their effect on some physical properties of soybean grains and static pressure drop of grain beds during drying in-bins with low temperature drying systems.

3-The effect of drying systems, airflow rates, and depth of dried grains during drying process on the change of grain moisture content, drying rate, specific energy consumption and final quality of soybean grains.

2. REVIEW OF LITREATURE

Soybeans occupy a premier position as a world crop because of their high and virtually unrivaled protein content and also a rich source of edible oil. They are legumes, and commercial varieties are usually spherical and yellow, although black, brown and green soybeans exist. Commercially, yellow soybeans are graded on weight, moisture, percent splits, heat damage, contamination by foreign material and discoloration. At harvest, the beans usually contain about 20-18 percent moisture (w.b.). They are dried to 13 percent moisture for storage of 6-12 months and 10-11 percent for longer storage, ***Barger (1981).***

Rodda (1985) indicated that, drying at relative humilities of 40 percent or higher is recommended to prevent the seed coat from cracking. Moreover, the airflow is kept at 0.05 m^3/min, a 27-kg bag of soybeans can be dried from 16 percent to 13 percent moisture in about 5 days at 2-3^{0}C above ambient temperature. Also, drying at 66 ^{0}C reduces the oil content and at 76^{0}C causes discoloration.

Muhlbauer et al. (1992) reported that utilizing 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.

Deshpande et al. (1993) determined the dependence of physical properties of soybean on moisture content. They indicated that, when moisture content changed from 8.7 to 25% (d.b.), the length of grain ranged from 6.32 to 6.75mm , the width from 5.23 to 5.55 mm, the thickness from 3.99 to 4.45 mm, the geometric mean diameter from 5.09 to 5.51mm, the sphericity from 0.806 to 0.816, the surface area from 0.813 to 0.952 cm^2 , the volume of grain from 0.091 to 0.113 cm^3 and thousand grain mass from 0.110 to 0.127 kg. While, kernel density decreased from 1216 to 1124 kg/m^3, bulk density from 735 to 708 kg/m^3 and porosity from 0.40 to 0.37 decmail.

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 climatic 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.

Weiss (2000) reported that hot-air dryers of soybeans require close supervision to prevent seed damage, generally the highest drying temperature 60 ^{0}C reduces germination and affects seed quality. Also, with properly supervised artificial drying there is little difference in seed viability, quality, oil content or characteristics between hot and cold air blasts, although hot air dried seed may require more careful storage. If the seed is harvested at high moisture content, above 20% and dried to 14%, the higher the initial moisture content the lower is viability.

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 used to dry rough rice from 22.6 to 14% moisture content (w.b.), through 8 day with uniform moisture and there are no negative effect on milling quality, germination rate, cracking ratio, reduced fungi growth and considering the most suitable method for seed production.

3- MATERIAL AND METHODS

3.1. Test Bins:

Fig. (1) shows the ambient-air and solar heated-air drying systems used in the experiments. Four the same prototype cylindrical bins were constructed of galvanized steel sheets. Each bin was 0.7m in diameter and had an effective height of 1.4m, a free volume of 0.46m^3, perforated floor forming a plenum chamber of about 0.2m height, for distribution of drying-air and was capable of holding approximately 280kg of soybeans at 20.8%,(w. b.), moisture content. The surface of system bed was open to the atmosphere but shielded from direct sunshine by a roof erected over the bins and supported on a metal frame. The temperatures and sampling ports were measured at three levels in each bin (0.35, 0.70 and 1.05m from the perforated floor). Each two bins were connected to small centrifugal fan (0.25 kW). Air supplied by the fan passed through PVC pipes of inner diameter of 0.075m. The airflow rate supplied to each bin was controlled by ball valve located on the entrance of the plenum chamber of the bin. Two bins dried by using ambient air and the other two bins were dried by solar heated-air, which heated by using a solar collector.

3.2. Solar Collector:

A gothic arch greenhouse has a floor area of 16.4 m^2 (4.56m ×3.6m) and total height of 2.3m with internal volume 32m^2 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 and Instrumentation:

Soybean variety (Giza 21) was harvested and pre-cleaned by combine at moisture content of about 20.8% (w.b.) in September 10, 2002. Four bins were filled immediately with fresh soybean grains at the same level of moisture content. Two different drying systems for drying soybean grains are used as shown in Fig. (1). The first was natural air-drying system in which ambient-air was forced directly through the grain bulk. 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 9a.m. to 6 p.m. to take the weather data inside and outside the greenhouse such as air temperature and relative humidity. The changes of grain moisture content in relation to bulk depth and drying time were determined every day taking samples by using a double concentric tube-sampling probe. Grain temperature and moisture content were measured at three level (0.35, 0.70 and 1.05m) measured from the floor of test bins. Thermocouple probes are connected to an interface analog digital converter *model, (LE 1000)* and the temperatures reading from thermocouple probes are recorded at intervals of 4 hours. Airflow rates were measured by a thermal anemometer manually inserted in the airflow pipe at the entrance of each bin. The solarimeter with a portable recorder, *model (Y 3057-11)* was employed to measure the solar radiation flux incident on a horizontal surface outside the solar collector.

The moisture meter, *model (PC 100)* was used to measure the grain moisture content. An electrical meter, *model (GG 150E)* which connected at the source of power was used to measure the energy required for forcing air through grain bulk. Also, at the end of drying process, random soybean samples were taken to measure and evaluate the quality of dried grains. Moreover, physical properties included size of the grain, thousand grain mass, bulk density, particle density and porosity were determined at different moisture content ranged from 11.9 to 29.2 % (d.b.). Bulk density was determined by weighing the amount of grain needed to fill a 500ml graduated cylinder by using a digital balance. For particle density, hand-counted samples of 500 grains were poured in 250ml container filled partially with Paraffin oil and the net volume of the sample was obtained. Triplicate determinations were made in all cases. The porosity of bulk grain was computed from the values of bulk density and kernel density using the relationship given by ***Mohsenin (1970)*** as follows:

$$\varepsilon = \frac{\rho_p - \rho_B}{\rho_p} \times 100, \% \qquad (1)$$

Where:

ε = Porosity of bulk grain, % ρ_B = bulk density, kg/m,^{3} and ρ_p = particle density, kg/m^3.

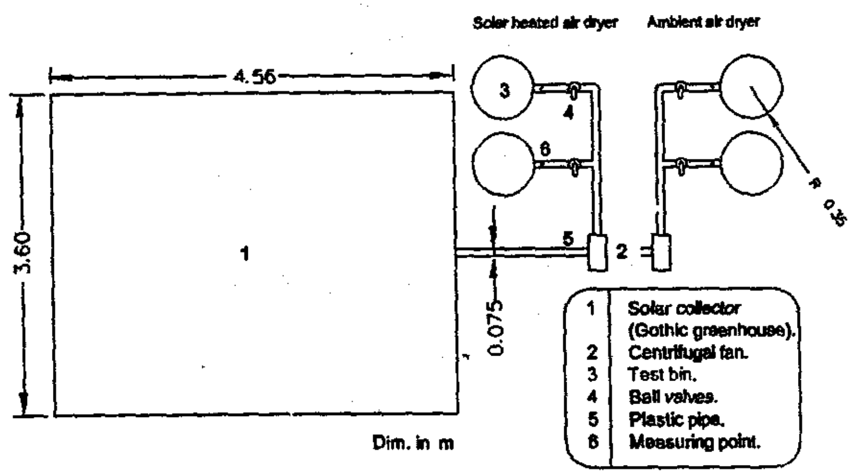

Figure (1): Schematic diagram of ambient and solar heated air dryers.

3.4. Quality Evaluation Tests:

The quality evaluation parameters for this study were limited to the percentages of split, heat damage, discolored and germination percent of soybean grains. These tests were conducted only at the end of experiment in the top layer grains of test bins. The percentage of splits as the percentage of beans with grain coats of two colors was evaluated. The percentage of discolored and heat damaged grains was separated from a sample of 50 grams of soybean grains manually by visual inspection and then expressed as a percentage (***Shoughy, 2001***). Also, germination test was conducted for three replicates of each sample. Each replicate used 100 seeds, was growing in patry dishes containing moistened filter paper for a week in an incubator adjusted at 25 ^{0}C according to ***Anon (1981).***

3.5. Miscellaneous Equations:

3.5.1. Thermal performance of the greenhouse as a solar collector:

To measure the thermal performance of the greenhouse as a solar collector, a series of equations according to ***Abdel-Latif and Helmy, 1992*** were employed as follows:

$$Q_c = RA_dT \quad \text{.........(2)}$$

$$Q_s = mc_p(t_{at} - t_{ao}) \quad \text{.........(3)}$$

$$m = vA_{pw}\rho \quad \text{.........(4)}$$

$$\eta = (Qs)/(Qc)\times 100 \quad \text{.........(5)}$$

Where:

Q_c = available solar radiation, watt; R = solar radiation flux incident, w/m^2;
A_d = area of solar green dryer, 16.4m^2 ; T = transimttance of greenhouse cover, %;
Q_s = useful heat gain rate in heating air, Watt; m = mass flow rate of drying air, kg/s;
c_p = specific heat of drying air, 1006 J/kg/^{0}C; t_{at} = drying air temperature, ^{0}C;
t_{ao} = air temperature outside the collector, ^{0}C; v = air speed, m/s;
A_{pw} = cross sectional area of the plastic pipe, m^2 ; ρ = density of drying air, 1.175kg/m^2
η = effectiveness of greenhouse collector in heating air, %.

3.5.2. Energy consumption:

The energy consumption for forcing an air through the grain bins by using centrifugal fan, which has three phase electric motor, was estimated according to ***Uppal (1984)*** by using the following equation:

$$P = \sqrt{3}.\, N_L \,.\, I_L \cos\varphi \,.\, \rho \quad \text{.........}(6)$$

Where:

P = fan power, Watt; N_L = electric potential, Volt; ρ = efficiency, %
I_L = electric current, ampere; and $\cos\varphi$ = power factor equal 0.8.

3.5.3. Static pressure:

The static pressure was measured inside grain beds every day at 10 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***):

$$P = \rho \, . g \, . h \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad ..(7)$$

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.

3.6. Statistical Analysis of Data:

Data was analyzed by using Excel Statistical Package Programs Form on the Rice Mech. Center. The analysis of variance was employed in this experimental work to study, examine and assess the effect of drying method and airflow rates on the drying time, the quality of dried soybeans and energy consumption during drying process under local weather conditions.

4. RESULTS AND DISCUSSION

4.1. Air Temperature and Air Relative Humidity:

The difference between the outlet and inlet air temperature and air relative humidity is a measure heating capacity of two drying systems. The hourly average air temperature and relative humidity outside the solar collector were 29.9 ^{0}C and 54.3% and the corresponded values inside the solar dryer were 37.1 ^{0}C and 32.3%, respectively. This means that, the greenhouse increased the air temperature inside the collector by 7.2 ^{0}C and decreased the air relative humidity by 22%. These difference in air temperature and relative humidity were strongly affect the drying rate of solar heated-air drying method compared with natural-air drying of soybean grains.

4.2. Solar Radiation:

The hourly variation in solar radiation available during drying process affects the collector effectiveness for heating the drying air and decreasing the air relative humidity inside the collector. Fig. (2) shows that, solar radiation gradually increases from sunrise till it reaches the maximum average value of 862.5 W.h /m^2 at noon, it then decreases gradually until it reaches 242.6 W.h /m^2 at 6p.m. Generally, the hourly average solar radiation during the soybean harvest season (September 2002) was about 542.5 W.h /m^2.

4.3. Thermal Performance of the Solar Heated-air Collector:

The thermal performance of solar heated-air as a collector was calculated by using equations 2 through 5, indicated before, in terms of effectiveness for heating. As shown in Fig. 3, the greenhouse effectiveness for heating air decreased gradually from 9a.m.till it reached the minimum value (27.5%) at noon, then, it increased gradually until it reached the maximum value (75.6%) at 6 p.m. The effectiveness of collector for heating air was affected by the difference between ambient air temperature inside and outside the greenhouse collector. When this difference is increased, the useful heat drying the grains is increased and the removed moisture from the dried grains in addition to the drying rate were thus increased, making the drying process in the case of solar heated-air system more efficient than the ambient-air drying system. This result was agreed with the results obtained by *Radwan (2002).*

4.4. Physical Properties of Soybean Grain:

Average values of some physical properties of soybean grain variety (Giza 21) such as the three dimensions (length, width and thickness), thousand grain mass , bulk density, particle density, and porosity at different moisture contents are presented in Table (1). The results indicated that dimensions and thousand grain mass of soybean appeared to be linearly dependent on the moisture content. The soybean grain expands in length (from 6.45 to 7.25mm), width (from 5.52 to 6.1mm), thickness (from 4.05 to 4.96mm) and thousand grains mass increased (from 122 to 163 gram) within the moisture content range of 11.9 to 29.2% (d.b.). It can be seen that, the grain expands more along its thickness in comparison to its other two axes. This may be due to the arrangements of the cells in the kernel and to the increase in the cavity between the two halves of the cotyledons with the increase in moisture content. This result was agreed with the results obtained by ***Deshpande et al. (1993).*** The effect of moisture content on bulk and particle densities of soybean grain showed a linear decrease with an increase in moisture content in the specified moisture range. The bulk density decreased from 780.95 to 712.42 kg/m^3 and the particle density from 1298.56 to 1100.8 kg/m^3. Since the porosity depends on the bulk as well as particle densities, the magnitude of variation in porosity depends on these factors only. The porosity of soybean grain was found to decrease (from 40.4 to 35.2%) with the increase in moisture content from 11.9 to 29.2%. This result is very important because the resistance of bulk grain to airflow is, in part, a function of the porosity and kernel size.

4.5. Bulk Grain Moisture Content:

The change of soybean moisture content at different layers during drying period by using two airflow rates with natural and solar heated-air drying systems is shown in Fig.(4). The results indicated that, drying zones were established immediately at the bottom layers of grain bulks and moved upward as the drying process proceeded. The drying zone with 2.4 m^3/min. tonne airflow rate and solar heated-air drying system was faster than with 1.2m^3/min. tonne airflow rate and natural-air drying system. The decrease of soybean grain moisture content from 20.8 to 12 % (w.b) at top layer of test bins needed 30h with higher airflow rate for solar heated-air drying system and 42h with lower airflow rate. While, with natural-air drying system, the drying process continues 40h with higher airflow rate and 60h with lower airflow rate. It can be seen that, increasing airflow rate from 1.2 to 2.4 m^3/min. tonne tended to decrease the drying time by 33.33 and 28.36% with natural-air and solar heated-air drying systems, respectively. This is due to the change of grain moisture for solar heated-air dryer was higher than that with natural-air dryer. The results also showed that the average moisture content of dried grain by using natural-air drying system was nearly uniform at 12% that allowed safe for storage of soybean at the end of drying period. While, with solar heated-air drying system, there are over-drying of dried grain in the bottom layer (10.5%), especially with higher airflow rate. This result was agreed with the results abtained by ***Muhlbauer, 1992.***

Table (1): Average values of some physical properties of soybean grain (Giza 21 variety) at different moisture content.

Moisture content, % (d.b.)	Dimensions, mm			Thousand grain mass, gram	Bulk density, kg/m³	Particle density, kg/m³	Porosity, %
	Length	Width	Thickness				
11.9	6.45	5.52	4.05	122	780.95	1298.56	40.4
14.2	6.53	5.60	4.18	129	772.25	1263.20	39.1
18.5	6.65	5.69	4.35	137	755.30	1215.26	38.2
23.3	6.80	5.80	4.53	145	734.65	1164.42	37.1
27.9	7.02	5.95	4.75	152	720.65	1128.75	36.3
29.2	7.25	6.10	4.96	163	712.42	1100.80	35.2

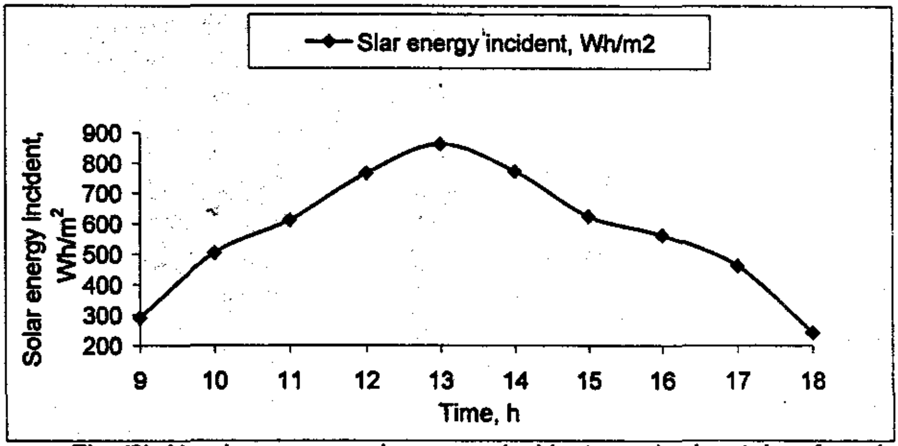

Fig. (2): Hourly average solar energy incident on a horizontal surface during September 2002-soybean harvest season.

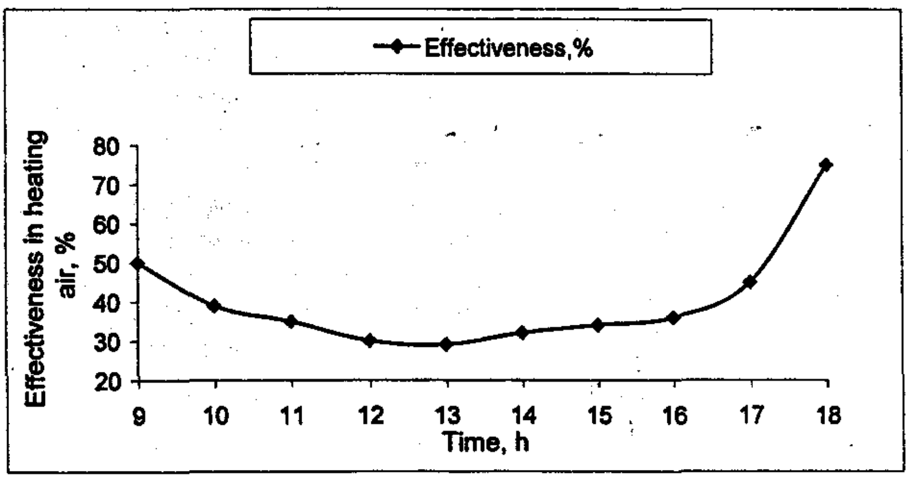

Fig.(3):Relation between time and the effectiveness of solar collector for heating air during the experiment.

4.6. Drying Rate:

The results in Fig.(4) showed that the drying rate (the precentage of moisture content removed per hour) increased significently by increasing the airflow rate for both drying systems and drying rate of soybean grains at the first drying time was higher than that at the entire drying time of drying. This was attributed to the fact that, the grain, which had high moisture content, dried faster than that at low moisture content at constant airflow rate and at the same conditions of drying air. However, the tendency of decrease of grain moisture content responded faster for high airflow rate than for low airflow. The drying rate was changed from 0.163 to 0.245 percent/h with natural-air and from 0.233 to 0.327 percent/h with solar heated-air drying when airflow rate changed from 1.2 to 2.4 m^3/min.tonne. Inspection of these results showed that, increasing airflow rate from 1.2 to 2.4 m^3/min. tonne with natural-air give nearly the same drying rate when using 1.2 m^3/min .tonne airflow rate with solar heated-air drying system. Also, the rate of drying in lower grain layers is greater than that of the upper grain layers at the same drying system and airflow rate.

4.7. Energy Consumption for Soybean Grain Drying:

Table (2) indicated the effects of drying systems and airflow rates on the energy consumption for fan operation during the drying process of soybean grain. The results showed that, increasing airflow rate from 1.2 to 2.4 m^3/min. tonne tends to increase the fan electrical power consumption from 56.5 to 209.05 Watts. This is due to the increase of static pressure drop through soybean grains from 107.91 to 255.06 Pa with the specific airflow rate. The results also showed that increasing airflow rate tends to decrease drying time by 33.33% and increasing energy consumption from 19.62 to 30.92 MJ/tonne for natural-air drying system. While, for solar heated-air drying system the drying time decreased by 28.57% and the energy consumption increased from 12.49 to 21.4 MJ/tonne. The results showed that the solar heated-air drying system consumed less values of energy than that of an ambient-air drying system for two airflow rates. This trend was due to the decrease of the drying time in case of using solar heated-air drying system. It can be seen that, increasing airflow rate from 1.2 to 2.4 m^3/min. tonne with natural-air dying was found nearly equivalent to solar supplemental heat drying. While, at the same airflow rate (2.4 m^3/min. tonne), the use of supplemental heat in the airstream speeded up drying rate from 0.245 to 0.327 percent/h but increase energy required for drying and caused further over-drying of grains. The use of higher airflow rates with natural-air drying to reduce drying time may be economical if the electrical power is feasible in the farms and the total cost of drying is reasonable.

4.8. Static Pressure Drop of Soybean Grain 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 soybean grain (Giza 21) by using ambient-air at airflow rate of 2.4 m^3/min. tonne.

Table (2): Effect of drying systems and airflow rates on the pressure drop, electrical power consumption, drying time and specific energy consumption for drying soybean grain.

Drying system	Airflow rate, m^3/min. tonne	Static pressure drop ,Pa	Electrical power, Watt	Drying time, h	Specific energy consumption*, MJ/tonne
Natural-air drying	1.2	107.91	56.5	60	19.62
	2.4	255.06	209.05	40	30.92
Solar heated-air drying	1.2	98.1	56.6	42	12.49
	2.4	235.44	209.05	30	21.40

*Specific energy consumption (MJ/t): includes the energy consumption for drying and fan operation.

The results indicated that the static pressure drop through the grain increased significantely by increasing grain depth and decreased with increasing drying time. Also, the decrease of static pressure drop during the first period of drying soybean grain was higher than that in the entire drying period. It decreased from 49.05 to 34.34Pa in the top layer and from 117.72 to 88.29Pa in the bottom layer when moisture content of dried soybean changed from 20.8 to 12.0 % (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 1m grain depth, decreasing soybean grain moisture content by 1 % (w.b.) during drying process tends to increasing the static pressure drop by 3.34%.

4.9. Soybean Grain Quality After Drying Process:

Table (3) shows the quality of dried soybean grains by using natural-air and solar heated-air drying systems with two airflow rates in the top layers in the test bins at the end of drying process as compared to shade drying sample. The average percentage of spilt grain was increased by 6.5% with natural-air and increased by 7.5% with solar heated-air compared to 5% with shade drying sample. Also, the average percentage of heat damaged kernel was increased by 0.15% with natural-air and increased by 0.25% with solar heated-air drying systems compared to 0.1% for shade drying sample. Moreover, the average percentage of discolored grain was increased by 1% with natural-air and increased by 2.5% with solar heated-air drying systems compared to 0% for shade drying sample. While, the average percentage of germination rate was decreased by 3.5% with natural-air and decreased by 4.5% with solar heated-air drying systems compared to 3% for shade drying sample. The results also showed that, the moderate treatment which is one of the characteristics of ambient-air or low temperature drying minimize the percentage of split, heat damage and discolored grains as well as the germination rate of soybean grains. This result may be due to the increase of bulk temperature during drying with solar heated-air system also the grain at the top layer of bin remained at high moisture content through most drying period.

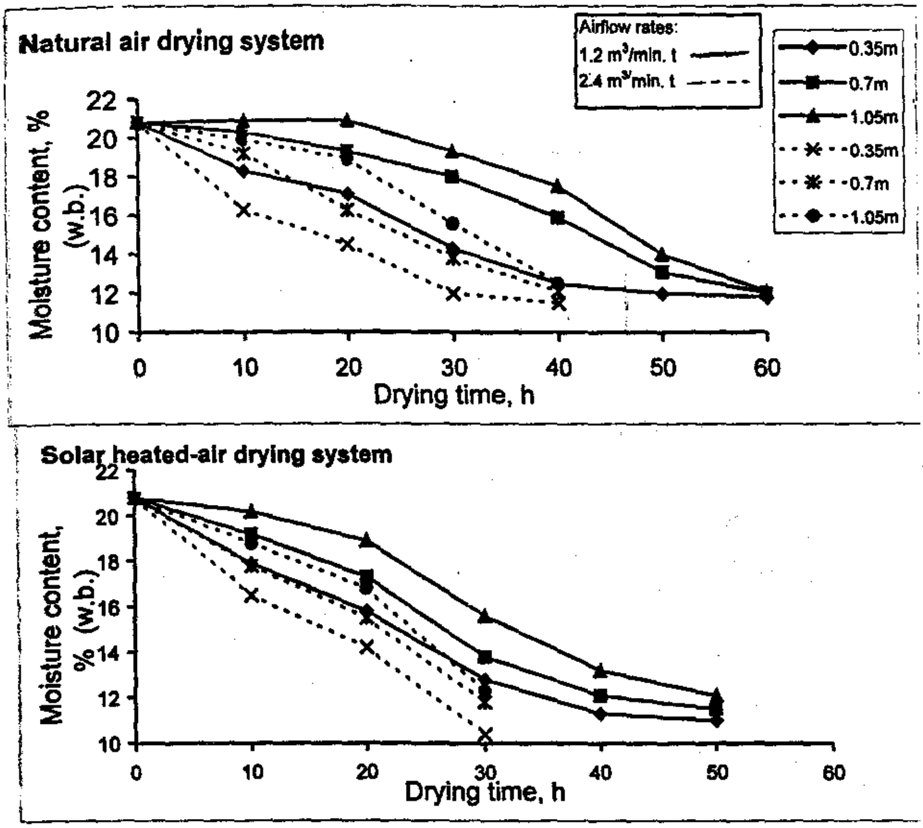

Fig. (4): The changes in grain moisture content with two drying systems and airflow rates at different grain layers during drying period.

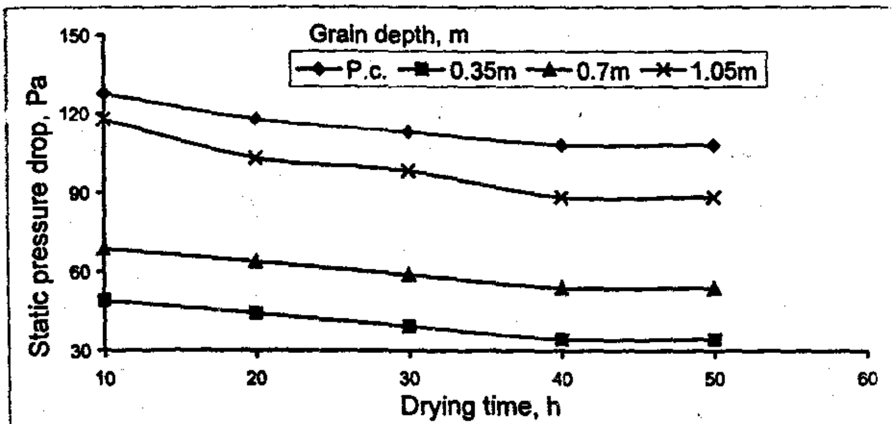

Fig.(5): The changes of static pressure drop at different soybean grain dep during drying period by using natural air drying system.

It can be seen that, drying soybean grain by using natural-air gave the best quality of dried grain and uniform moisture content as the same with shade drying samples as compared with solar heated-air drying system.

Table (3): The quality of dried soybean grain by using two airflow rates with two drying systems.

Grain quality indicator	Natural-air drying		Solar heated-air drying		Shade drying sample
	1.2m^3/min. .tonne	2.4m^3/min.tonne	1.2m^3/min.tonne	2.4m^3/min.tonne	
Splits, %	6	7	7	8	5
Heat damage, %	0.2	0.1	0.3	0.2	0.1
Discolored grain, %	1	1	3	2	0
Germination rate, %	96	97	95	96	97

5. CONCLUSIONS

Nowadays, it is very important to avoid drying delay by using adequate drying methods after harvest by using clean energy to prevent grain deterioration and to keep the grain with high quality in order to increase the international trade from agricultural production. The foregoing study can lead to the following conclusions:

1- The hourly average solar energy during the drying experiment through September 2002 was about 542.5 W.h/m^2.

2- The dimensions and thousand grain mass of soybean were increased significantly with increasing grain moisture content. While, the bulk density, particle density and porosity of soybean grain were decreased with increase the grain moisture content.

3- Increasing airflow rate from 1.2 to 2.4 m^3/min. tonne tends to decrease drying time by 33.33% and increasing energy consumption from 19.62 to 30.92 MJ/tonne for natural-air drying system. While, for solar heated-air drying system the drying time decreased by 28.57% and the energy consumption increased from 12.49 to 21.4 MJ/tonne.

4- Decreasing soybean grain moisture content by 1% (w.b.) during drying process tends to increase the static pressure drop at 1m depth by 3.34%.

5- Using natural-air drying system with increasing airflow rate from 1.2 to 2.4 m^3/min. tonne was found nearly equivalent to using the solar heated-air drying and gave the best quality of dried grain. While, using solar heated-air drying speeded up drying rate but increase energy required for drying and causes further over-drying of dried grain.

6- Using higher airflow rates with natural-air drying to reduce drying time and produce good production may be economical if the electrical power is feasible in the farms and the total cost of drying is reasonable.

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الملخص العربي

بعض العوامل التصميمية المؤثرة في أداء نظام التجفيف في المخزن لمحصول فول الصويا

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يعتبر محصول فول الصويا من أهم محاصيل الزيوت في العالم بعد القطن وعباد الشمس. وفي السنوات الأخيرة زاد إنتاجه لاستخدامه في إنتاج الزيت حيث نستورد ٨٠ % من الاستهلاك المحلي بالأضافه إلى استخدامه كمصدر للبروتين وتغذية الدواجن والحيوانات وزيادة سعره مما شجع على زراعته. ويتم حصاد محصول فول الصويا بالكومباين عند محتوى رطوبة عالي يتراوح بين ١٨ - ٢٠ % (على أساس رطب) بهدف تقليل الفاقد في الحقل والحفاظ على جودة المنتج. لذلك يلزم تجفيفه بعد الحصاد مباشرة لان ارتفاع نسبة الزيت به (٢٠ %) تساعد على سرعة فساده بسبب تزنخها. وتجفيف الحبوب بالطريقة التقليدية في الشمس يسبب فقد كبير في جودتها. والهدف من هذا البحث هو دراسة إمكانية استخدام الهواء الطبيعي وكذلك الهواء المسخن بالطاقة الشمسية كطاقة متجددة نظيفة في تجفيف محصول فول الصويا في المخزن بهدف تقليل عمليات التداول للمحصول وتقليل التكاليف وكذلك منع تلوث البيئة. ولتشغيل هذا النظام يلزم دراسة بعض العوامل التصميمية المؤثرة في تشغيله ومدى الاستفادة من ظروف الطقس المحلية في تجفيف محصول فول الصويا أثناء موسم حصاده وكذلك تقدير مقدار الزيادة في معدل سريان الهواء الذي يجب استخدامه في المجفف في حالة عدم توفر الطاقة الشمسية. أجريت التجارب في مركز ميكنة الأرز بميت الديبة حيث تم حصاد وتنظيف محصول فول الصويا بالكومباين عند محتوى رطوبة ٢٠,٨ % (على أساس رطب) وتم تخزينه مباشرة في الصوامع في موسم حصاد سبتمبر ٢٠٠٢ م . وتم استخدام نظامين للتجفيف: الأول باستخدام نظام دفع الهواء الطبيعي داخل الحبوب، والثاني هو دفع الهواء المسخن بالطاقة الشمسية بمعدلين سريان للهواء ١,٢ ، ٢,٤ م³/ دقيقة لكل طن حبوب المخزنة في صوامع. أيضا تم تجفيف عينه في الظل كطريقة قياسية للتجفيف. تم تقدير كفاءة الأداء للمجمع الشمسي أثناء موسم حصاد محصول فول الصويا و التغير في الخواص الطبيعية للحبوب والضغط الاستاتيكي نتيجة التغير في المحتوى الرطوبي أثناء مرحلة التجفيف لحبوب فول الصويا وكذلك تأثير كل من نظامي التجفيف ومعدلي سريان الهواء وعمق الحبوب على المحتوى الرطوبي ومعدل التجفيف والطاقة المستهلكة في التجفيف وتأثير ذلك على جودة الحبوب المجففة في نهاية مرحلة التجفيف.

<u>وكانت أهم النتائج التي تم التوصل اليها ما يلي:</u>

١- أوضحت النتائج أن كفاءة التجميع للمجمع الشمسي تبدأ عالية عند بداية اليوم ثم تتناقص تدريجيا حتى تصل إلى الحد الأدنى لها (٢٧,٥ %) عند الظهيرة ثم تزداد تدريجيا بعد ذلك حتى الغروب وذلك بسبب الفرق في درجات الحرارة والرطوبة النسبية للهواء داخل وخارج الصوبة والتي تعتمد عليها كفاءة عملية التجفيف.

٢- زادت أبعاد الحبوب ووزن الألف حبة لحبوب فول الصويا معنويا بزيادة محتوى الرطوبة من ١١,٩ إلى ٢٩,٢ % (على أساس جاف) بينما أنخفض كل من الكثافة الظاهرية والحقيقية للحبوب والمسافات البينية بين الحبوب مع زيادة محتوى الرطوبة.

٣- بزيادة معدل سريان الهواء من ١,٢ إلى ٢,٤ م³/ دقيقة لكل طن حبوب أدي إلى انخفاض زمن التجفيف بمعدل ٣٣,٣ % وزاد معدل الطاقة المستهلكة من ١٩,٦٢ إلى ٣٠,٩٢ ميجاجول/ طن باستخدام الهواء الطبيعي بينما مع الهواء المسخن بالطاقة الشمسية انخفض زمن التجفيف بمعدل ٢٨,٥٧% ولكن زاد معدل استهلاك الطاقة من ١٢,٤٩ إلى ٢١,٤٠ ميجاجول/ طن.

٤- أدى انخفاض المحتوي الرطوبي لحبوب فول الصويا بمقدار ١ % أثناء مرحلة التجفيف إلى زيادة الانخفاض في الضغط الاستاتيكي داخل كتلة الحبوب المجففة عند عمق ١متر بمقدار ٣,٣٤ %.

٥- استخدام الهواء الطبيعي أعطى حبوب ذو جودة عالية ومحتوى رطوبة منتظم في كل الطبقات في المخزن في نهاية مرحلة التجفيف مع تقليل التلوث وزيادة نسبة الإنبات. بينما الحبوب المجففة باستخدام الهواء المسخن بالطاقة الشمسية حدث فيه تجفيف زائد في الطبقة السفلي في المخزن(١٠,٥ %) وكانت أقل جودة مقارنة بالحبوب المجففة في الظل. وأيضا استخدام معدل سريان هواء مقداره ٢,٤ م³ /دقيقة لكل طن حبوب مع الهواء الطبيعي يعادل تقريبا معدل سريان مقداره ١,٢ م³/دقيقة لكل طن حبوب مع الهواء المسخن بالطاقة الشمسية لذلك يوصى بزيادة معدل السريان للهواء بدلا من استخدام الهواء المسخن بالطاقة الشمسية للحصول على حبوب ذو جودة عالية و متجانسة في محتوى الرطوبة في نهاية مرحلة التجفيف و كذلك توفير استهلاك الطاقة.

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