J. Agric. Sci. Mansoura Univ., 33 (10): 7285 - 7297, 2008

SOME ENGINEERING PROPERTIES OF PEA SHELLS

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ABSTRACT

Drying of biomass is important to assure a year round supply of a certain feedstock and to minimize the loss of organic matter during storage. Egypt produces about 0.15 million ton of pea shells annually that can be used for the production of biofuel, compost and other valuable products. The main objective of this study was to study some physical properties (i.e., mass of an individual shell, bulk density, particle density and porosity) that affect the design of handling and processing equipment of this feedstock. Another objective was to determine the sun-drying time required to reach a moisture content at which it is possible to safely store pea shells without the loss of organic matter and without jeopardizing the feedstock to self ignition and spoilage by microorganisms or fungi. Sun-drying experiments were conducted during March 2008 under El-Mansoura weather conditions. The effects of drying tray type and the initial mass loading per unit exposed area on drying time were studied. Drying was carried out using galvanized screen and particleboard trays at three initial mass loadings of 2, 4 and 8 kg [shells]/m2. The results showed that the average weight of an individual shell was 2.11 (±1.11) g. High correlations were found between moisture content and each of the studied physical properties. The particleboard drying trays showed relatively higher drying rates than the screen trays. Drying curves were well described by an exponential function. Most of drying occurs in the falling rate period. Higher drying rates were observed under the lower initial mass loading than the higher mass loadings. It was possible to obtain a moisture content of about 20% (w. b.) after sun-drying the shells for 2.3 days at an initial mass loading of 2 kg/m2. To obtain a comparable moisture at the initial mass loadings of 4 and 8 kg/m2, shells should be dried for about 4 days.

INTRODUCTION

Biomass is a term for all biological-based feedstocks. It includes agro-industrial residues and wastes. Biomass supply chain starts with harvesting and collection and ends up with processing plant wherein biofuel and other valuable products (e.g., animal feed, compost, chemicals, ect.) are produced. Most of the biomass materials are produced seasonally, which means that storage is important to assure a year-round supply of such feedstocks.

Storage of biomass feedstocks with high moisture content could increase the chance for self ignition and growth of fungi and microorganisms that finally lead to loss of organic matter (Rupar-Gadd, 2006). Shinners et al (1996) studied the effect of different moisture contents on quality of alfalfa during storage. Results showed that the higher the moisture content the more spontaneous heat was produced. After 140 days of storage, the assessed losses of dry matter were 4.7, 4.0 and 12.0 %, respectively at moisture contents of 16.8%, 19.1% and 21.2%. During the storage of rice straw bales, Dobie and Haq (1980) found that bales with moisture contents of 20% and higher had a temperature rise from 15 °C to 30 °C. Fungi were noticed at the largest number of species at 30% moisture content. Moreover, during the thermo-chemical processing of biomass, the high moisture content decreases the calorific value and increases the emissions of hydrocarbons due to the incomplete combustion (Wimmerstedt, 1999). Besides, moisture content affects the physical properties of biological materials (McNeill et al., 2004). According to Gigler (2000), the combination of harvesting techniques and drying methods is a crucial factor in minimization the costs of biomass supply chain.

Many systems are being used for biomass drying. Bot et al. (2004) stated that hot-air drying is a relatively expensive process for the producer of feeding feedstocks.. These costs can be divided into costs for installation and costs for operation. Fuel represents 30-50% of the total costs. According to Ståhl et al. (2002), rotary drum dryers using combustion gases, as a heating medium, are the most common technique for drying sawdust in Sweden. Carsky (2008) designed and evaluated a fluidized bed dryer for lemon peels.

In arid and semiarid countries, like Egypt, sun drying could be used as a cheap alternative for drying of biomass feedstocks. Open sun drying is the oldest method that has been used for drying various crops. In this method, the material is spread in a thin layer on the ground or drying trays and exposed directly to solar radiation. Bot et al. (2004) revealed that sun drying is mainly applied to preserve a product and to make it transportable. The drying rates depend on external and internal parameters (Jain and Tiwari, 2003). External parameters include solar radiation, wind speed and relative humidity and temperature of ambient air. Internal parameters include initial moisture content, product type and absorptivity and mass of product per unit exposed area.

In Egypt, most of food processing wastes are either used as animal feeds or transported to landfills wherein they are biologically decomposed causing environmental pollution problems. One of the important wastes is pea shells. According to FAO (2005) Egypt is the sixths country in the world for green pea. It produces 0.29 million ton that produces about 0.15 million ton of shells. To effectively transport and store these feedstocks, a simple and cost effective drying method should be applied. Besides, some physical properties such as bulk density, true density and porosity should be known for designing different processes for the production of biofuel, animal feed and compost. Therefore, the main objectives of this study were: (1) to determine some physical properties such as bulk density, real density and porosity of pea shells and; (2) to study the effect of tray type and initial mass loading per unit area on the time required to reduce the moisture content of shells to a safe moisture content for storage.

MATERIALS AND METHODS

1. Peas shells

Most of pea processing plants in Egypt separate the shells manually. To conduct the experiments, two different amounts of peas were purchased from a local market, then shells were removed manually. The amount of shells was weighted and found to be 50.5 (±3.9) % of the total mass of purchased peas.

2. Sun-drying Experiments

Two experiments were conducted. The main objective of the first experiment was to determine some physical properties of pea shells at different moisture contents. The main objective of the second experiment was to determine the sun-drying time required to achieve a moisture content at which it is possible to safely store the shells without deterioration and losses of the organic matter. Different sizes of drying trays were used: 50×50, 25×50, and 25×25 cm. These dimensions could accommodate different initial mass loadings of 2, 4 and 8 kg [shells]/m^2. Each of these initial mass loadings was examined in two kinds of trays. The first was made of screen with openings of 5 mm and the second was made of particleboard with a thickness of 4 mm. The frame of both tray kinds was made of wood with a height of 10 cm. Two trays were used for each studied initial mass loading. The trays were fixed horizontally on a wooden frame at 20 cm height on the roof of the Department of Agricultural Engineering, Mansoura University, El-Mansoura, Egypt. A plastic cover was used to cover the experimental units during nights. Cover was removed at about 8:30 AM and spread at about 5:30 PM. Shells were stirred manually twice daily. A small sample of about 10 g was randomly withdrawn periodically from each experimental unit to measure the reduction of moisture content.

2.1 Experimental site and weather conditions

The first and second experiments were conducted during February and March 2008, respectively. Whether conditions (wind speed, high and low temperatures of air) in El-Mansoura (latitude 31.2 °N; longitude 31 °E), during the second experiment were obtained from Guardian (2008). The chance of rain was 0% during that period. Solar radiation flux on a horizontal surface was calculated from the equations presented by Duffie and Beckman (2006) using the proper clearness index for the Egyptian conditions (Omran, 2000). Table (1) shows average wind speed, and high and low temperatures of air.

Table (1): Wind speed and air temperature during the experiments time

Date (days of March)	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th
Average wind speed (km/h)	---	5.5	7.0	4.5	6.0	7.0	5	10	12	8.5	8.0	10.5
High temperature (°C)	--	22	23	26	30	33	31	30	24	24	25	22
Low temperature (°C)	---	13	14	18	20	23	21	17	14	13	11	12

2.2. Measurements

During the second experiment, air temperature and relative humidity above the drying trays and the temperature of shells were measured at least three times every day at 9:0 AM, 1:0 PM and 3:0PM. Hygro- Infrared Thermometer (EXTeCh instruments, MA, USA) was used for these measurements. The ranges for humidity, infrared temperature and air temperature were 10% to 95%, -50 to 500°C and -20 to 60°C, respectively. The accuracies of humidity, air temperature and infrared temperatures were ± 3.5%; ± 2°C and ± 2 °C, respectively.

3. Measurements of physical properties

3.1. Mass of one shell

The mass of an individual shell was determined in 100 observations using a digital balance with an accuracy of 0.1 g.

3.2. Bulk density determination

Wet bulk density was determined under different moisture contents. It was determined, in five replicates, according to Matouk et al. (2004) and Mohamed (2007). The wet bulk density (ρ_w) is the ratio of the wet or as-received shell mass (M_w) to total volume occupied (V_w) (Mohee and Mudhoo, 2005):

$$\rho_w = \frac{M_w}{V_w}$$

3.3. Total and air filled porosities

Total porosity (TP) is sum of both air and water porosities. It can be expressed as follows (Bohnhoff and Converse, 1987):

$$TP = \frac{V_v}{V_t} = \frac{V_w + V_a}{V_w + V_a + V_s}$$

Where:
V_t = total volume of sample (m^3);
V_v = volume occupied by both water and air (m^3);
V_w= volume occupied by water (m^3);
V_a= air filled volume (m^3).
V_s = volume of solids in sample (m^3).

Another important characteristic is the air filled porosity. Air filled porosity influences the rate at which air can be mechanically moved through a system. It is important when designing forced aerated composting and drying (Bohnhoff and Converse, 1987). AFP is defined as the ratio of gas filled pore to total volume of sample:

$$AFP = \frac{V_a}{V_t}$$

Bohnhoff and Converse (1987) presented an equation to calculate the AFP as a function of bulk density (ρ_b, kg/m^3), particle density (ρ_p, kg/m^3), water density (ρ_w, kg/m^3) and wet basis moisture content (MC, decimal) as follows:

$$AFP = 1 - \rho_b \left[\frac{MC}{\rho_w} + \frac{(1 - MC)}{\rho_p} \right]$$

4. Determination of particle (i.e., true) density

Particle density was determined at different moisture contents according to the method described by Mohee and Mudhoo (2005). In this method, about 5-10 g of the sample was placed in a dry and clean 100-mL graduated cylinder and accurately weighed. The cylinder was brought to the final volume with hexane, and completely submersing the sample. While tilted at an angle, the flask was gently swirled until no further air bubbles were seen to emerge. After mixing, the cylinder was again brought to the final volume. The weight of the shell–hexane mixture was recorded. Based on the density of hexane (656 kg/m^3), that was determined under the laboratory conditions, the volume of hexane was determined. Then particle density was calculated as the ratio of the mass of pea shells (m_p) to the shells volume (Vp) that was measured by the hexane displacement as follows (Matouk *et al.*, 2007; Fasina, 2008):

$$\rho_h = \frac{m_p}{V_p}$$

5. Analyses

5.1 Proximate analysis

Moisture content was measured in an oven at 105 °C for 24 hours. The volatile solids (VS) were measured after burning the samples at 550 °C for 2 hours according to APHA (1992).

5.2. Carbon and hydrogen analyses

Carbon and hydrogen were determined in the Department of Chemistry, Faculty of Science, Mansoura University. A manual Herarous apparatus was used. During the determination samples were burned at high temperature in the presence of oxygen and a catalyst.

RESULTS AND DISCUSSION

1. Proximate analysis and potential use of pea shells

Moisture content, organic matter contents and elemental composition of pea shells are shown in Table (1). As can be seen, the moisture content of fresh shells is about 86% and VS/TS is about 96%. Similar values were reported by Madhukara et al. (1997).The calculated C/N ratio is 24.7. These characteristics make pea shells as a good substrate for bioconversion process (e.g., biogas and compost production). According to Madhukara et al. (1997) the physical and chemical characteristics of pea shells are similar to those of water hyacinth that is used successfully as a feedstock for biogas production. On the other hand, the high moisture content reduces the conversion efficiency and increases the emissions when using these wastes for thermo-chemical processes such as gasification and incineration (Wimmerstedt, 1999). Therefore drying is important to increase the efficiency of these processes.

Table (2): Proximate and ultimate analysis of pea shells. Standard deviations are between brackets

Parameter	Value
Moisture content (% w.b.)	86.2 (0.3)
TS (% w.b.)	13.8 (0.3)
VS (% w.b.)	13.2 (0.4)
Ash (% w.b.)	0.6 (0.1)
VS/TS (%)	95.7
C (%TS)	52.0 (1.6)
H (%TS)	7.7 (0.1)
N(% TS)	2.1*

***Madhukara *et al.* (1997)**

2. Physical properties of shells

2.1. Mass of individual shell

The normal distribution curve for the mass of an individual shell at different moisture contents (MC) is shown in Fig. (1). Knowing the mass of an individual shell (M_1) at a specific moisture content (MC_1), the following equation can be used to calculate the mass of that shell (M_2) at a different moisture content (MC_2) as follows:

$$M_2 = \frac{MC_2 . M_1 . (1 - MC_1)}{(1 - MC_2)} + M_1 . (1 - MC_1)$$

It should be mentioned that measurements were carried out for the fresh shells (MC = 86%). Then the pervious equation was used to calculate the mass of an individual shell at the moisture contents of 75 and 20%. The mass of fresh individual shell ranged from 0.6 to 5.8 g. About 71% of shells have mass between 1 and 3 g. The average mass of an individual shell was calculated to be 2.09 (±1.11); 1.01 (±0.53) and 0.31 (±0.17)g at moisture contents of 86, 75, and 20% (w.b.), respectively.

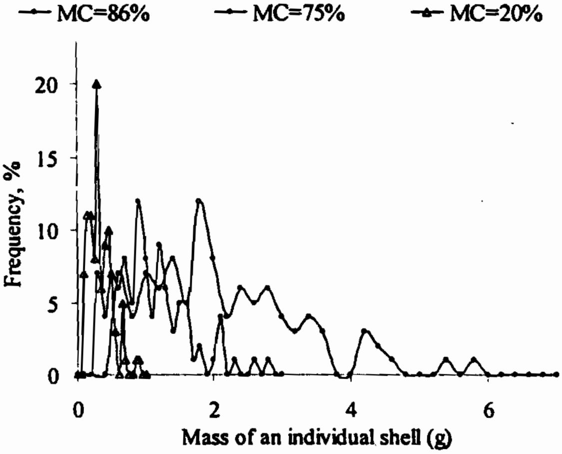

Fig. (1). Normal distribution curve of the mass of an individual shell

2.2. Bulk and particle densities and porosity

Wet and dry bulk densities of shells as functions of moisture contents are shown in Fig. (2). As can be seen, while the wet bulk density increased from 39 to 195 kg/m^3, the dry bulk density decreased from 32 to 23 kg/m^3 as the moisture increase from 16% to 88% (w.b.). The values of bulk density are very low. Therefore, a densification processes should be used for a cost effective transportation and storage of pea shells. According to Fasina (2008) most agro-processing byproducts are lightly-dense (<150 kg/m^3) and therefore can not be efficiently and economically transported over long distances where they can be utilized. The increase in bulk density with increase in moisture content indicates that the increase in mass, owing to the presence of moisture in sample, is greater than the accompanying volumetric expansion of the bulk (Suthar and Das, 1996).

The wet bulk density (WBD, kg/m^3) and moisture content (MC, % w.b.) could be correlated as follows:

$$WBD = 0.03MC^2 - 0.9757MC + 48.232 \quad (R^2 = 0.998).$$

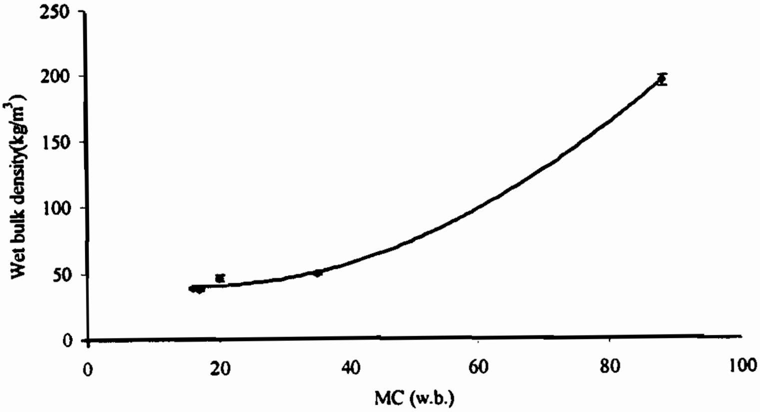

Fig. (2). Relationship between wet density and moisture contents of pea shells. Y Error bars are the standard deviations between measurements replicates

Particle density and total and air filled porosities of shells as functions of moisture contents are shown in Fig. (3). As can be seen, particle density increased from 1075 to 1206 kg/m^3 as the moisture content decreased from 88% to 16% (w.b.). This may indicate that higher rates of volume reduction during the drying as compared with the rate of mass reduction (e.g., Matouk et al., 2004 and Mohamed 2007).

The best fit for particle density (PD, kg/m^3) as a function of moisture content (MC, %) was in the form:

$$PD = 0.0403\ MC^2 - 5.714\ MC + 1266.5 \quad (R^2 = 0.624).$$

It can also be seen from Fig. (3) that while total porosity increases, air filled porosity decreases with moisture content. Two linear equations were obtained to describe total porosity (TP, decimal) and air filled porosity (AFP, decimal) as functions of moisture content (MC, % w.b.) as follows:

$$TP = 0.0002\ MC + 0.9673 \quad (R^2 = 0.814)$$

$$AFP = -0.0022MC + 1.0094 \quad (R^2 = 0.965)$$

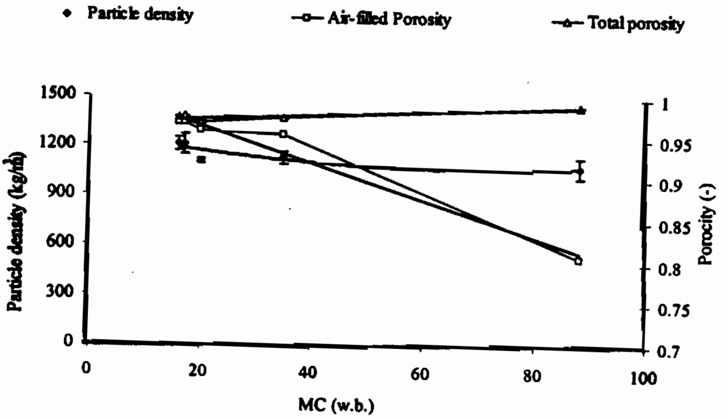

Fig. (3). Particle density and shells porosity as functions of moisture contents. Y Error bars are the standard deviations between measurements replicates

3. Results of drying experiments

3.1. Drying curves

Figures (4) and (5) show the relation between moisture content and drying times for the experiments conducted with screen and particleboard trays, respectively. As can be seen from these figures that, most of the drying process occurred in the falling rate period. As expected, drying rate increases with the decrease of initial mass loading. For both drying trays, at an initial mass loading of 2 kg/m^2, moisture contents (MC) decreased rapidly, from the beginning till 1.3 day, then slowly after that. While at the initial mass loadings of 4 and 8 kg/m^2, a rapid reduction of MC was noticed till 3.3 day then MC decreased slowly till reaching the final moisture content. At the initial mass loading of 2 kg/m^2, it was possible to obtain a moisture content of 19% and 23% (w.b.) after 2.3 days on the particleboard and screen trays, respectively. At the same drying time, it was only possible to obtain a moisture content of about 41% and 45% (w.b.), respectively when using particleboard and screen trays at the other two studied initial mass loadings (4 and 8 kg/m^2). For the latter two initial mass loadings, it was possible to obtain a moisture content of about 22% after 3.3 days using both drying trays. The inverse relation between the drying rate and the initial mass loadings may be due to one or two reasons. The first is that the decreased exposed area per unit mass of the shells when using larger initial amounts of shells. The second reason is that air can only carry a certain amount of water from the shells, depending on the psychometric properties of air, and thus with increasing the initial mass loading the air can not carry more moisture to attain the increased amount of water present in the shells loaded (Nijmeh *et al.*, 1998).

From Figs. (4) and (5), it appears that, in all of the experiments, the shells reached a final moisture content of less than 20% (w.b.) after 4 days.

This would be the equilibrium moisture content (EMC) with the ambient air. The final moisture content obtained in these experiments would be enough for safe storage of the pea shells. No data could be found in the literature for safe moisture content for the storage of pea shells. However, Egg et al (1993) revealed that moisture content should be 20% or less before baling and storage of hay.

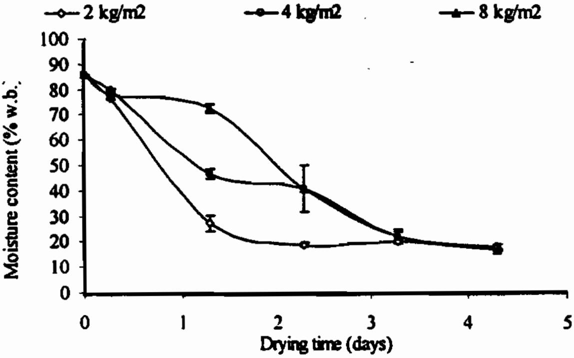

Fig. (4). Moisture content profile over drying time using a drying tray with a particleboard bottom. Y error bars are the standard deviations between duplicate experimental units

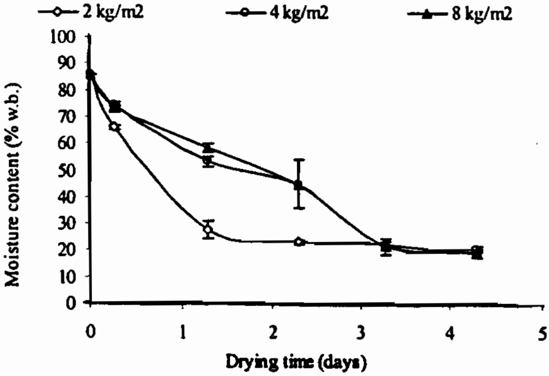

Fig. (5). Moisture content profile over drying time using a drying tray with a screen bottom. Y error bars are the standard deviations between duplicate experimental units

3.2 Mathematical modeling

The model of Jasinskas *et al.* (2008) who modeled the changes of moisture contents of energy crops during the natural drying was used to describe the drying of pea shells as follows:

$$M = a\exp(bt)$$

Where:

M is the moisture content (kg [water]/kg [dry matter]); t drying time (day); and *a* and *b* are constants.

The experimental data were used to calculate the model parameters. The calculated values of *a* and *b* together with the determination coefficient (R^2) are shown in Table (3). As can be seen, the model could well describe the drying process at the studied initial mass loadings for both tray types. As can be seen that while the values of *a* increase with increasing the initial mass loadings the values of *b* decrease for both drying trays. The particleboard tray had higher values of *a* and *b* than the screen tray.

Table (3): Values of the model parameters

Type of drying tray	Initial mass loading (kg/m²)	a	b	R^2
Screen	2	2.36	-0.66	0.72
	4	3.96	-0.71	0.93
	8	4.18	-0.73	0.95
Particleboard	2	2.81	-0.75	0.74
	4	4.20	-0.76	0.93
	8	5.39	-0.82	0.97

3.3. Temperature of shells

The measured temperatures of shells are shown in Figs. (6) and (7). As can be seen from these figures, there is no noticeable differences between the initial mass loadings on the shells temperatures. It can be noticed that, directly after removing the cover in the morning, the temperature of ambient air was relatively higher than the temperatures of shells. After exposing the shells to solar radiation, shells absorbed solar energy and their temperatures rose. The calculated solar flux incident of a horizontal surface is shown in Fig. (8). A maximum flux incident of about 600 W/m^2 could be calculated at around noon time. Comparing both drying trays, it can be seen that the temperature of shells on the particleboard trays had relatively higher temperatures than those on screen trays. This might be due to the heat storage in shells and particleboard as compared with the higher convective heat loss from the bottom of drying tray in the case of screen trays. This might explain the little difference that was noticed in the drying rates between both drying trays.

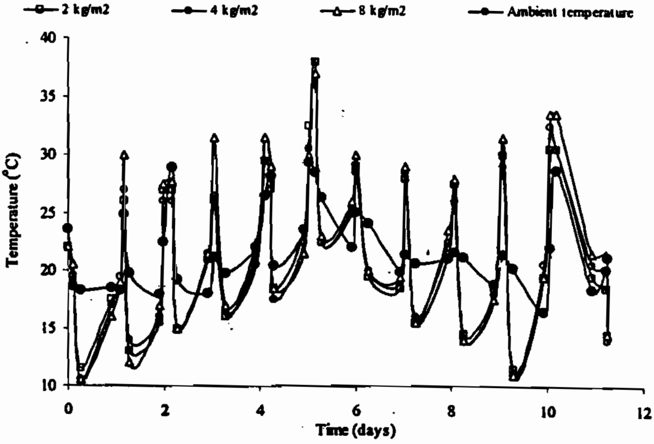

Fig. (6). Temperature of shells dried on screen trays

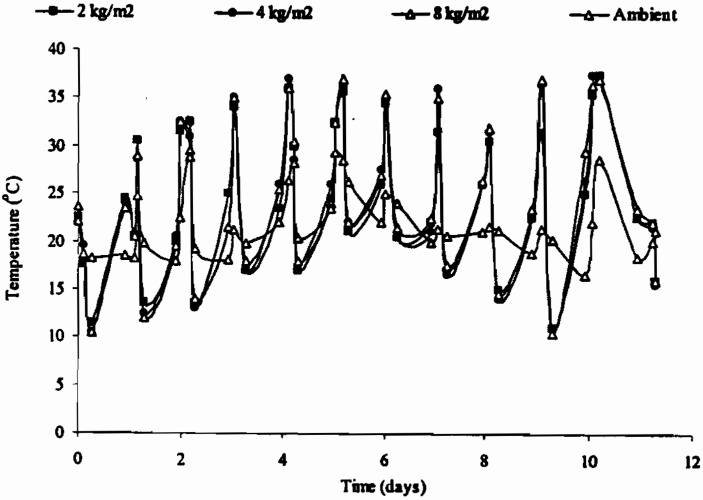

Fig. (7). Temperature of shells dried on particleboard trays

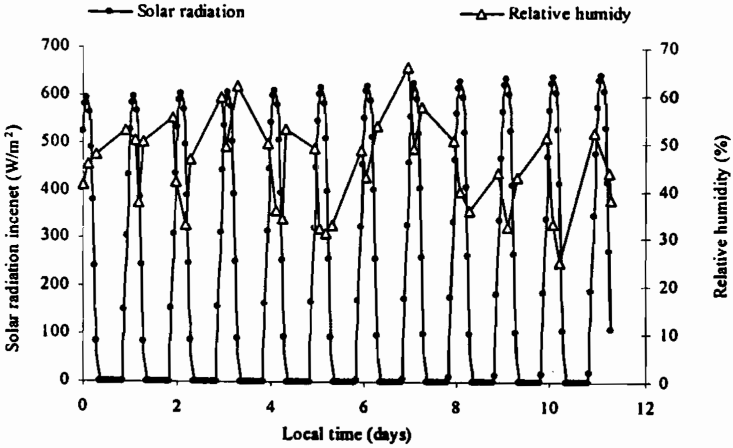

Fig. (8). Calculated solar radiation incident and measured relative humidity of air

Conclusions

1- Bulk density of pea shells is very low. Therefore densification process should be used for cost effective transportation and storage of pea shells.

2- Bulk density, true density and porosity depend strongly on moisture content.

3- To achieve a moisture content that is safe for pea shells storage, shells should be sun-dried, under El-Mansoura weather conditions in March, for 2.3 days at an initial mass loading of 2 kg/m^2 and for 3.5 days at initial mass loadings of 4 and 8 kg/m^2 using particleboard trays.

4- An exponential model could adequately describe the drying curves of pea shells.
5- Although many mathematical models have been developed and applied for solar and sun drying of different foods, little has been done to model the solar and sun drying of biomass feedstocks. A comprehensive modeling study is needed to optimize the drying parameters of different biomass feedstocks.

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بعض الخواص الهندسية لقشور البسلة

حامد الموافى المشد

قسم الهندسة الزراعية- جامعة المنصورة

يعد تجفيف الكتلة الحيوية أمرا هاما لضمان استمرارية وجود هذه المواد طوال العام مما يؤثر على اقتصاديات استخدام تلك المواد فى انتاج الطاقة الحيوية و بعض المنتجات الأخرى الهامة كالكمبوست و أعلاف الحيوان. كما يعمل التجفيف على تقليل الفقد فى المادة العضوية و الذى قد ينشأ عن الاحتراق الذاتى و نمو الكائنات الدقيقة و الفطريات اذا تم التخزين على محتويات رطوبية عالية. و تنتج مصر كمية كبيرة من قشور البسلة تقدر بحوالى ٠,١٥ مليون طن سنويا و التى يمكن استخدامها لانتاج الوقود الحيوى و بعض المنتجات الأخرى الهامة. و كان الهدف الأساسي للبحث هو دراسة بعض الخواص الطبيعية مثل كتلة القشرة و الكثافة الظاهرية و الحقيقية و كذلك المسامية و التى تؤثر على تصميم معدات تداول و تصنيع تلك االقشور. و كان هناك هدف أخر للدراسة و هو حساب زمن التجفيف الشمسى اللازم للوصول الى محتوى رطوبى أمن لتخزين تلك القشور. وقد أجريت تجارب التجفيف الشمسى المفتوح فى شهر مارس ٢٠٠٨ وذلك تحت الظروف الجوية لمدينة المنصورة. و قد تم دراسة تأثير نوعين من صوانى التجفيف : الاولى على هيئة شبكة والأخرى مصنوعة من الخشب المصنع (أبلاكاج) .كما تم أيضا دراسة تاثير ثلاث كثافات تحميل ٢ و ٤و ٨ كجم/م٢ على زمن التجفيف. أوضحت النتائج أن متوسط كتلة القشرة الطازجة ٢,١١(±٠,٠١) جم. و قد وجد أن هناك ارتباط كبير بين الخصائص الطبيعية المقدرة والمحتوى الرطوبى. و قد تم معظم التجفيف فى مرحلة التجفيف المتناقص. و قد وجد أيضا ان التجفيف يمكن وصفه باستخدام نموذج رياضى لدالة اسية . أوضحت صوانى التجفيف المصنوعة من الخشب معدلات تجفيف و درجات حرارة للقشرة أعلى نسبيا من الصوانى المصنعة من الشبكة. وقد حقق معدل التحميل ٢كجم /م٢ أسرع تجفيف بالمقارنة بمعدلات التحميل الأخرى. من هذه التجارب فانه يمكن الحصول على محتوى رطوبى امن للتخزين (٢٠%) و ذلك بعد ٢,٣ يوم وذلك على معدل التحميل ٢كجم /م٢. أما عند معدلات التحميل الأعلى فانه يلزم التجفيف لمدة ٤ أيام.