Global Journal of Science Frontier Research
Agriculture & Biology
Volume 12 Issue 3 Version 1.0 March 2012
Type : Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4626 & Print ISSN: 0975-5896

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GJSFR-D Classification : FOR Code: 070399

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Strictly as per the compliance and regulations of :

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Abstract - Rotary solar dryer developed and evaluated for Kokam drying. Kokam fruits were selected as drying material. Time required reducing the moisture content upto 10 % as a safe storage for solar dryer was observed for ripen and unripe kokam fruits. Evaluation parameters were collection efficiency, system drying efficiency, pick-up efficiency, moisture ratio and drying rate. Maximum temperature inside the foldable solar dryer was 57^{0}C whereas maximum ambient temperature observed was 35.3^{0}C and solar irradiation was 600 W/m2.Humidity varies from 32.2% to 22.3% inside the solar dryer whereas outside humidity varies from 43.02% to 29.35%. Overall collection efficiency was found as 70.97 %. Maximum drying efficiency for salted ripen kokum was 9.88 per cent and unsalted salted ripen kokum was 7.66 percent.

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I. Introduction

The kokum is famous in Goa and Maharashtra for its cooling and anti-cholesterol properties (Mumtaz Khalid Ismail (2009)). The present area under kokum is 5000 hectares. It is proposed to increase this area up to 100000 hectares by the year 2025. It is further proposed to increase the productivity of these crops from the present level of 10 t/ha. to 15 t/ha. The pulp of the fruit is a very popular culinary ingredient in Maharashtra and in particular Konkan. (Lele, 2008) The fruits are beaten with sticks to separate the rind from seeds. The rind is repeatedly sun dried after soaking in the pulp juice. The dried purplish rinds, known as Kokum, are used for imparting flavour and taste to curries (Konkani cuisine (2009), much in the same way as tamarind fruit pulp is used in South India. The fruit is anthelmintic and cardiotonic and useful in piles, dysentery, fumours, pains and heart complaints. Kokam butter as sold in markets consists of eff shaped lumps or cakes, having a greasy feel and a bland oily taste. It is used mainly as edible fat. It is also used as an adulterant ghee. Kokum butter is considered nutritive, demulcent, astringent, suppositories and other pharmaceutical preparations.

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Solar energy in Konkan region was available for 8 to 9 months in a year with average sunshine hours ranged from 6.5 to 8 hours per day. The average solar energy ranged between 450-500 cal/cm2-day. The average lowest temperature for Konkan region was 15 ^{0}C and average highest temperature was 35^{0}C. At present these fruits are used for drying due to their availability and good market value at local level. It is a fruit dried and used as sour agent in cookery. Since anthocyanin is present, it is also used in making sherbet. The only alternative available is drying (Senadeera et al.,2003), which is most important techniques of food preservation (Menon and Muzumdar, 1987). To reduce the processing losses during the drying and to retain the quality of dried product, it is necessary to dry such fruit in the close chamber(Lambert, 1980) with preventing product from dust, insect, larva, birds and animal (Ong, 1999). By keeping importance of kokum drying in region, low cost rotary solar dryer was developed to carry out solar drying study.

II. Materials and Methods

a) Construction of low cost dryer

The low cost solar rotary dryer was design to dry commodities under hot and humid conditions prevailing in Konkan region of Maharashtra where most of the agricultural products need drying (Potdukhe and Thombre, 2002). This dryer can be rotated from all sides for easy to loading and unloading the material.

Dryer (Figure 1a & b) having a size 92cm x 75 cm was made by locally available bamboo, which consist of three main parts, collector, drying chamber and inlet and outlet openings (Koyuncu,2006). Drying chamber designed in such way that it consist 16 trays of 70cm x 50 cm size. Mosquito net was used for trays as it betters performance in humid region. Capacity of each tray is 0.6 kg. UV stabilized 200 micron plastic film was used for collection of solar energy (Best et.al., 1996). This film surrounded around the drying chamber and fixed by Velcro strip. Bottom and topside of the dryer was provided with openings for air circulation. Total cost of this dryer was Rs. 1700/-.

b) Measurements

The developed dryer was evaluated with standard procedure against the moisture removal and thermal analysis (Leon et.al, 2002). Total solar irradiation measured by using micro control based, liquid crystal solarimeter. The temperature and humidity at different location inside the drying chamber and outside environment was measured with thermocouple via a 8 channel dataloger (DataLog ver.v 81). In order to measure reading at a different point of air column through top and bottom of drying bed, temperature sensor were set at inlet and outlet as well as mid position of drying chamber. Airflow rate along the drying chamber was calculated by measuring the velocity of exist air at top opening through an anemometer.

c) Moisture Content

The percentage moisture content was determined by using following formula, (A.O.A.C. 1980)

$$\text{M.C.(w.b.)\%} = \frac{(W_1 - W_2)}{W_1} \times 100$$

$$\text{M.C.(d.b.)\%} = \frac{(W_1 - W_2)}{W_2} \times 100$$

Where, W_1= weight of sample before drying, gram
W_2= weight of bone dried sample, gram

d) Drying Rate

The drying rate (g/h/100g of bone dry weight) of kokum sample during drying period was determined as follows,

$$\text{Drying rate (D.R.)} = \frac{\Delta W}{\Delta T}$$

Where, ΔW = weight loss in one hour interval (g/100g of bone dry wt)

ΔT= difference in time reading (h)

The drying was carried out by loading the weighted kokum fruits in dryer from morning 8:00 am to 17:00 pm. The kokam fruits were dried up to the final moisture content of (Malviya and Gupta 1985) 10 % (w.b.) (Siaka and Nkembo, 2004). The drying time required for drying the ripen and unripe kokum fruits from IMC to 10 % (wb) in solar dryer condition was critically observed.

e) Moisture Ratio

The Moisture ratio of prawns was computed by using the initial moisture content (IMC) and equilibrium moisture content (EMC)

$$MoistureRatio = \frac{(M - M_e)}{(M_o - M_e)}$$

where,

M = Moisture content (d.b.), %

M_e = EMC, (d.b), %

M_0 = IMC, (d.b), %

The EMC for kokum fruits was considered as 10 % (w.b.) Drying tests of kokum fruits sample under solar dryer conditions was carried out.

f) Weight measurement

Moisture removal rate was calculated by taking 1000 g samples among the commodities. These samples were measured using weight balance with accuracy up to ten milligram.

g) No load test and load test

Dryer was tested with no load test for the thermal profile, which could be suitable for drying of kokum fruits. As per the thermal ingredients, collection efficiency of dryer was calculated. The purpose of load test to calculate the time required drying the commodities as well as to find out the system drying efficiency and pick up efficiency of dryer.

III. Results and Discussion

a) No load test

i. *Analysis of Temperature profile inside the dryer*

Under no load condition of solar drying, radiation and temperature inside the collector were measured with time of day in the interval of 10 minute were plotted in Figure 2. Maximum temperature observed at tray no 4 at 13 pm was 57^{0}C while 38.7^{0}C at 10:54 am, 41.6^{0}C at 12:24 pm, 46.3^{0}C at 15:04 pm, and 55.1^{0}C at 11.14 am for tray number 1, 2, 3, and 5 respectively whereas maximum ambient temperature observed was 35.3^{0}C at 12:54 pm and solar irradiation was 600 W/m2 at 11:14 am. Minimum temperature was observed at the end of the day at 17:00 pm for all bottom trays. It implies in total five slots of trays inside the drying chamber, increasing profile temperature was observed from bottom tray to upper tray. Humidity inside dryer was minimum as compare to outside condition. Humidity varies from 32.2% to 22.3% inside the solar dryer whereas outside humidity varies from 43.02% to 29.35% shown in Fig.3.

In no load test temperature inside the dryer increases from bottom tray to upper tray due to decreasing air density as it passes through hottest zone. Lower tray of dryer contain minimum temperature because of just below the lower tray there is opening for fresh air entrance in dryer where the density of air is higher as compare to trays above lower trays. Top-most tray inside the dryer is not achieved maximum temperature as it just above upper tray, opening is provided to pass the hot air and hence maximum temperature was observed at tray number 4 which was hottest zone (T4) below the upper tray (T5). As the temperature increases humidity decreases, as per this phenomenon, humidity's inside the dryer was minimum as compare to outside condition of dryer. Optimum Collection efficiency was found inside rotary solar the dryer due to it exposes three sides of dryer to sun as well as it was perfectly airlock so as it gives better hot air draft.

ii. *Collection Efficiency*

Collection efficiency is defined as the ratio of heat received by the drying air to the insolation upon the absorber surface and is calculated from equation (i).

$$n_c = v \times \rho \times C_p x \times \Delta t \times C_p \div A_C \times I_C \qquad (i)$$

Where,

V= Volumetric flow rate of air (m^3S^{-1}), ρ = Air density (kgm^{-3}), ΔT= Air temperature elevation (K), Cp = Air specific heat ($Jkg^{-1}K^{-1}$), Ac= Collector area (m^2), Ic= Insolation on collector surface (Wm^{-2}).

Since η_c is a assessing of the performance of collector, it was calculated using the reading for no load tests shown in Figure 4 and overall collection efficiency was found as 70.97 % (Tiris, et.al., 1995).

b) Load test

i. *Moisture content, drying rate and moisture ratio variation*

Kokum fruits were selected for load test under rotary dryer. Initial moisture content was found to be 85-93 per cent in laboratory test for ripen and unripe kokum. These kokum fruits were dried upto 10 per cent moisture content inside the solar dryer. Time required to each condition for kokum drying was calculated. Salted ripen kokam inside the dryer required 15 hours to dry upto 9.62 per cent while unsalted ripen Kokum required 21 hours to reach moisture content upto 9.62 per cent. Unsalted unripe Kokum inside the dryer took 27 hours time to reach upto moisture content 9.67 per cent whereas salted kokam required 32 hours to dry upto 10.12 per cent shown in Figure 5. Trend observed during the kokum drying inside solar dryer for drying rate and moisture ratio was depicted in Figure 6.

In load test of dryer, kokum required more time in open condition due to minimum temperature and maximum humidity's and vice versa in solar drying conditions. Use of salt treatment to kokum before drying helpful to remove moisture rapidly as compare to unsalted kokum and it also gives better colour than dried unsalted kokum (Dubey and Pryor,1996). Drying efficiency and collection efficiency depends on the removal of moisture from kokum and hence maximum drying efficiency and collection efficiency was found in salt treatment method.

ii. *Drying Efficiency* (ηd)

Amount of heat required to evaporate the moisture inside the product is called as drying efficiency. Total heat in case of solar dryer is the availability of solar radiation on collector surface of the dryer. This drying efficiency was calculated by equation no. (ii)

$$n_d = w \times \Delta H_L / A_C \times I_C \qquad (ii)$$

Where,

W= moisture evaporated (kg)

ΔH= Latent heat of vaporization of water, 2320 (kJkg-1)

Id= Total hourly insolation upon collector, (Wm-2)

Ac= Area of collector (m2)

Maximum drying efficiency for salted ripen kokam was 9.88 per cent and unsalted salted ripen kokum was 7.66 per cent. For salted and unsalted unripe kokum, maximum efficiency was found as 4.72 per cent and 4.20 per cent respectively depicted in Fig. 7. Where as pickup efficiency (Balladin, et.al., 1997) for salted and unsalted kokam was found as 3 per cent cent respectively shown in Figure 8.

IV. Conclusions

1. Rotary solar dryer generate higher air temperature and consequential lower relative humilities, which are both conductive to improved drying rates and lower moisture content of the drying kokum fruit.
2. Solar rotary dryer is suitable for domestic drying of kokum fruit upto10 kg capacity.
3. Best results were found in salted ripen kokum compare to unsalted unripen kokum inside the dryer.
4. The dried kokum had good colour and appearance.
5. Comparative cost of solar dryer is low.

V. Acknowledgemnent

Authors are highly thankful to College of Agricultural Engineering and Technology, DBSKKV, Dapoli for providing all kind of facility to carry out the research work.

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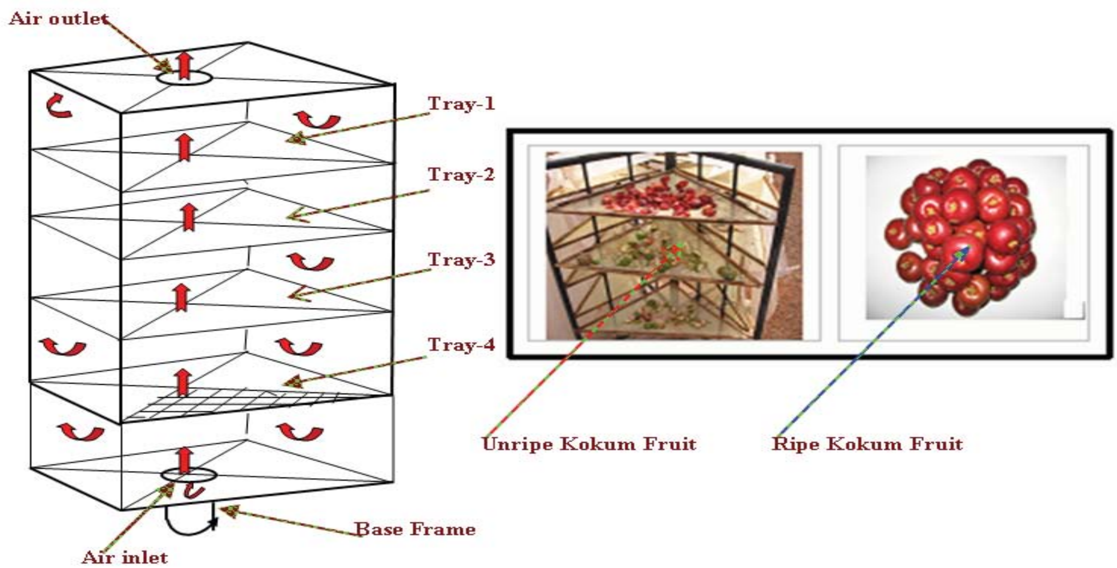


Fig.1 : Inside View of Rotary Solar Dryer.

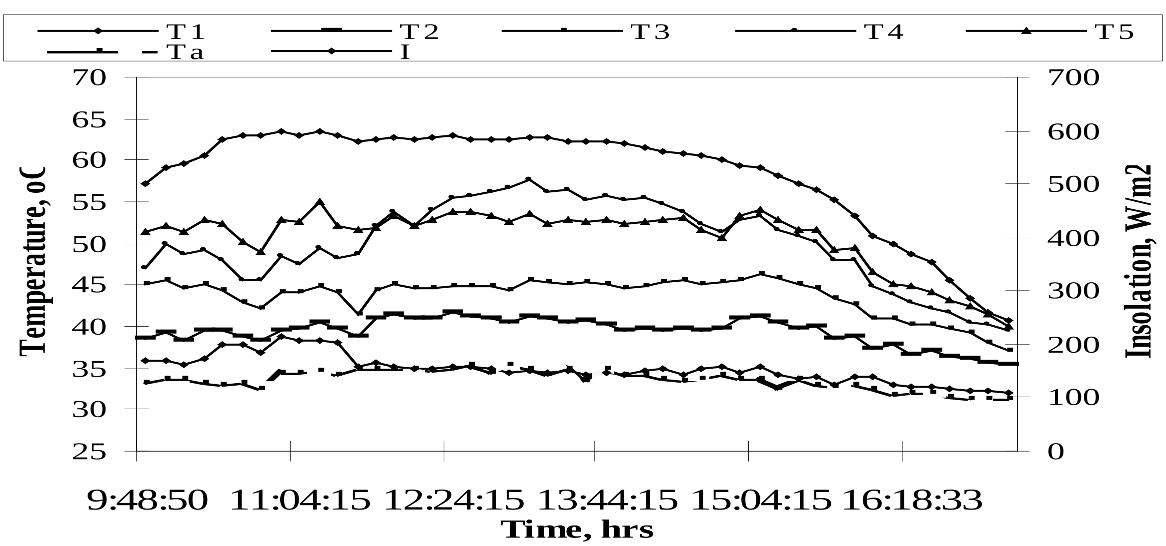


Figure 2 : Thermal profile inside the solar dryer.

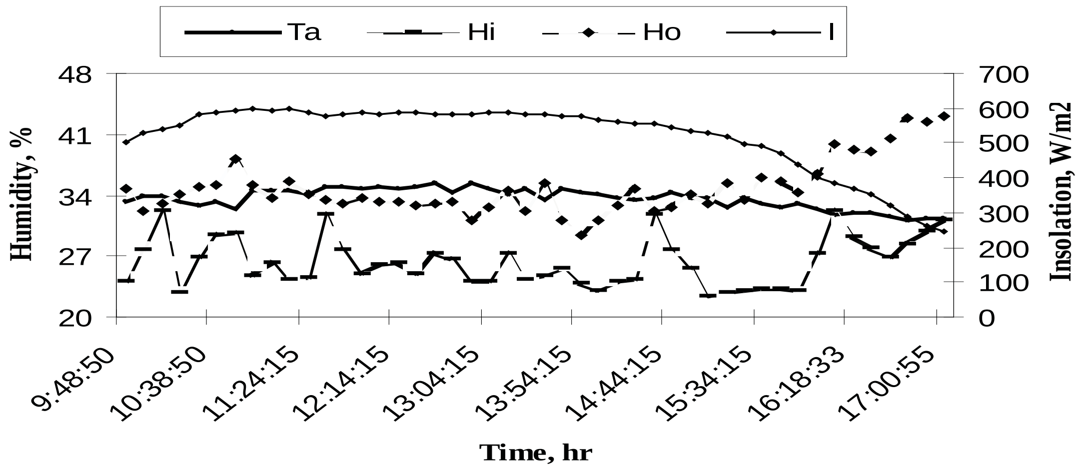


Figure 3 : Variation of humidity inside the solar dryer.

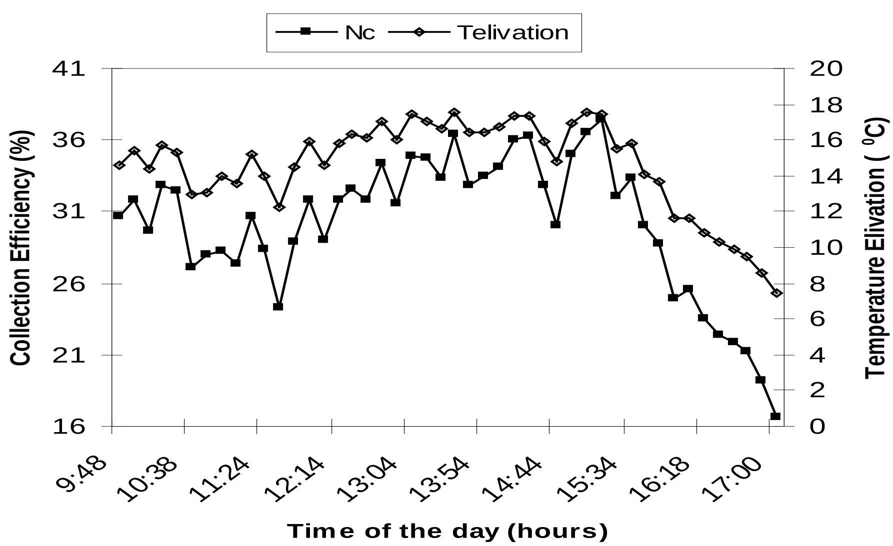


Fig. 4 : Variation of collection efficiency with time.

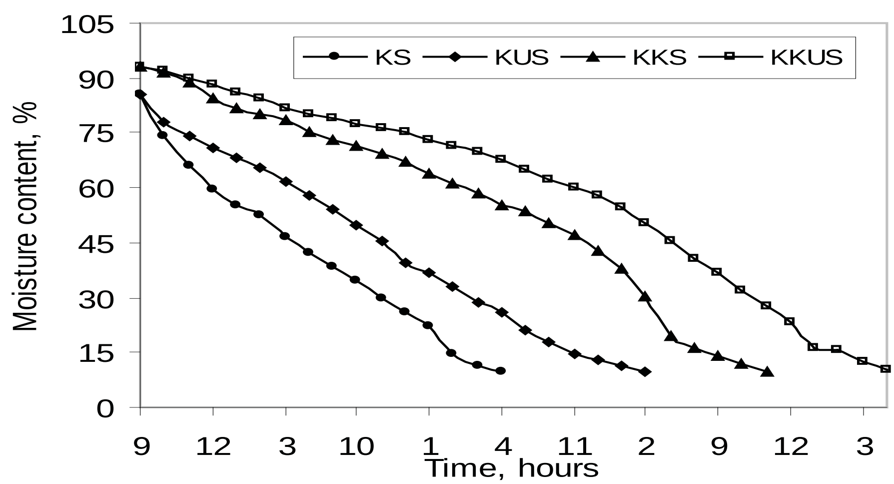


Fig. 5 : Variation of moisture content with time.

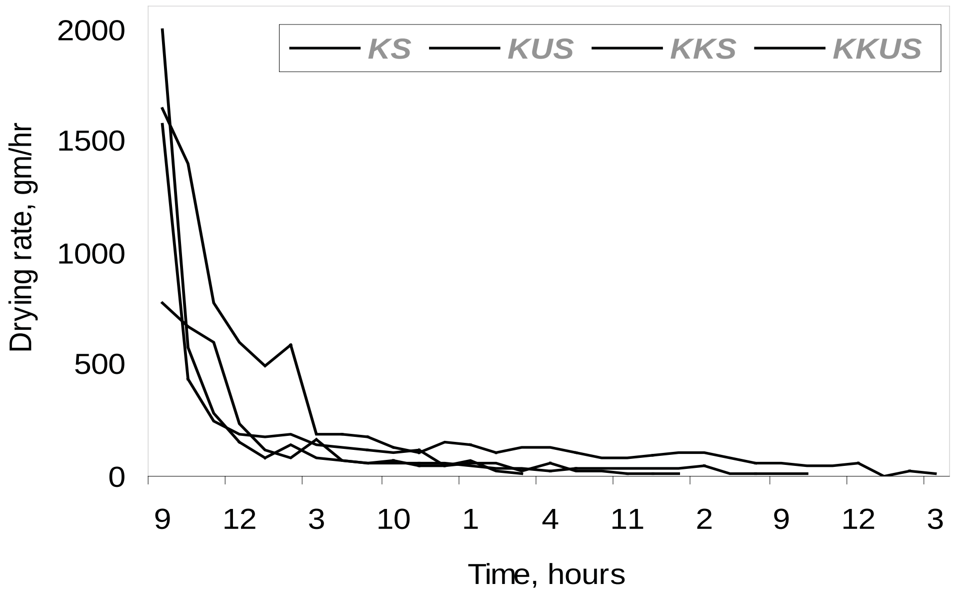
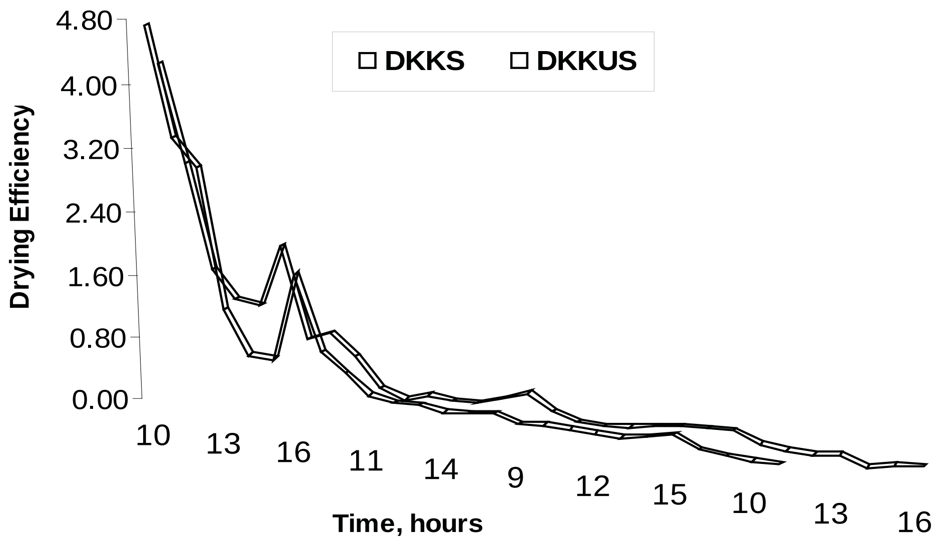
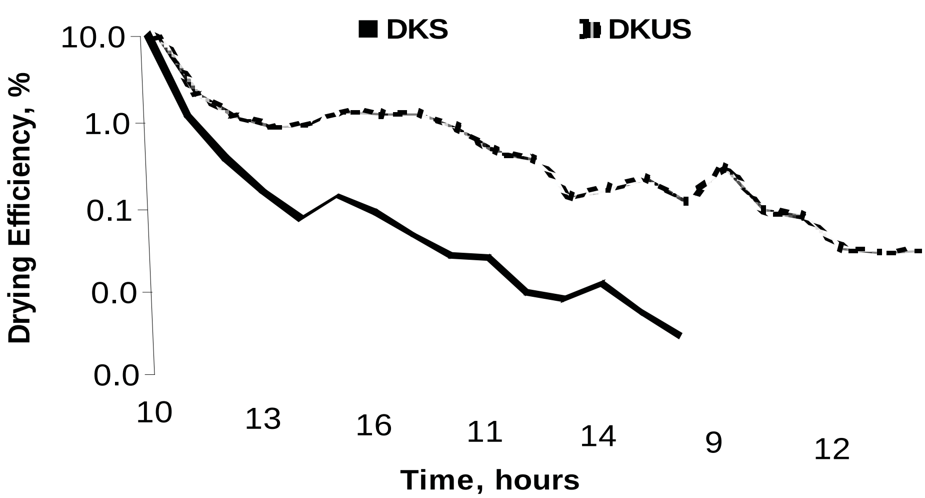


Fig. 6 : Variation of drying rate with time.



(a)



(b)

Figure 7 : Variation of drying efficiency with time

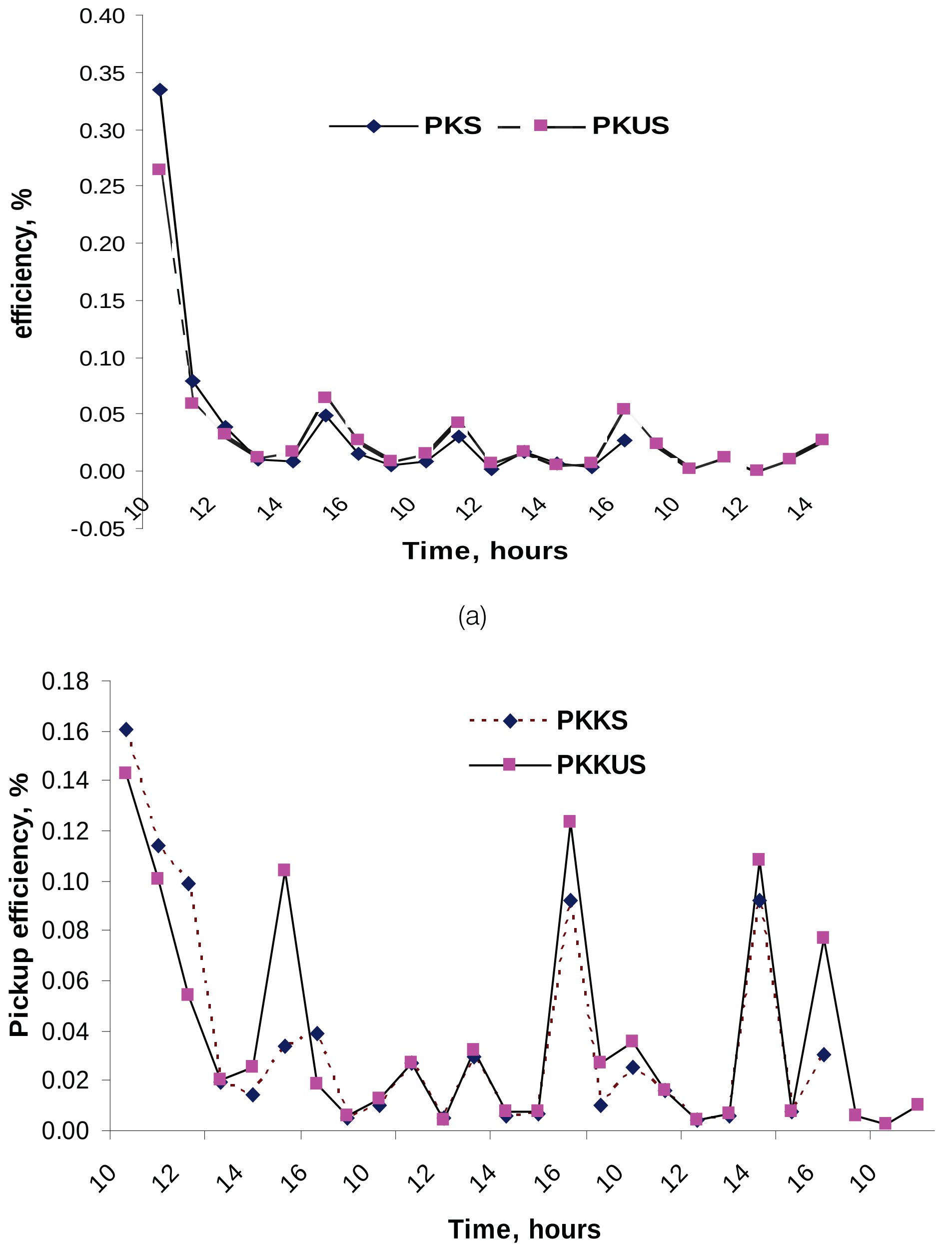


Fig. 8 : Variation of pickup efficiency with time.