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Pigeonpea drying based on heat pipe principle utilizing agricultural waste as fuel

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■ ***Abstract*** **:** Pigeonpea (*i.e.* Toor seed) is the fourth most important pulse crop in the world with almost all production coming from the developing countries. There are several ways of preserving pigeonpea for later use. Drying is a traditional method for preserving pigeonpea. Drying of pigeonpea seeds prevents germination and growth of fungi and bacteria. The traditional age old practice of drying food crops in developing countries is by spreading food grains in open sun which may be termed as open sun drying. A heat pipe incorporated biomass dryer has been designed for small-scale commercial producers of agricultural products in non-electrified locations. Experiments have been conducted to test the performance of dryer and pigeonpea has been dried under natural and forced convection conditions. The rate of moisture removal from pigeonpea and efficiency of the dryer for various thicknesses of pigeonpea grain and at different air velocities have been estimated. The biomass based dryer was very much useful to dry grains more quickly without any damage for grains and the grains obtained after drying were good in quality as compared to open sum drying and natural convection conditions.

■ ***Key words*** **:** Agricultural waste (Biomass), Heat pipe, Pigeonpea, Drying, Moisture content

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Pigeonpea is the most versatile food legume with diversified uses as food, fodder and fuel. It has been recognized as a valuable source of protein particularly in the developing countries and its significance is comparatively more among Indians due to their reliance in vegetarian diets besides limited buying capacity of more than 27 per cent people living below the poverty line.

Drying is a thermo-physical and physico-chemical operation by which the excess moisture from a product is removed to a safe storage level of 10-14 per cent of moisture on wet basis. Drying of agricultural products is an important unit operation under post harvest phase. It has been found by several experiments that harvesting of crops at higher moisture content and subsequent drying to safe moisture levels leads towards saving of grains to the tune of 6-7 per cent. Therefore, in modern agriculture the importance of timely drying is an important operation.

The heat pipe is a device of very high thermal conductance. The idea of the heat pipe was suggested by Gaugler and Grover (1982). The heat pipe is similar in some respects to the thermal siphon system. A small quantity of water is placed in a tube from which the air is then evacuated and the tube sealed. The lower end of the tube is heated causing the liquid to vapourize and the vapour to move to the cold end of the tube where it is condensed. The condensate is returned to the hot end by gravity, since the latent heat of evaporation is large, considerable quantities of heat can be transported with a very small temperature difference from end to end. The thermal siphon has been used for many years and various working fluid have been employed, one limitation of the thermal siphon is that in order the condensate to be return to the evaporator region by gravitational force, the latter must be situated at the lower point.

In the heat pipe the evaporator position is not restricted and it may be used in any orientation. If the heat pipe evaporator happens to be in the lowest position gravitational forces will assist the capillary forces (Dunn and Reay, 1978).

The hypothesis entertained in this paper is that it is possible to produce high rate of drying of pigeonpea using agricultural waste (biomass) as fuel needed for heat and mass transfer with in the material by adopting heat pipe principle.

■ METHODOLOGY

Drying studies were conducted in an experimental dryer based on heat pipe principle and also under conventional open sun drying and these results were compared with the results of experimental dryer. Pigeonpea (variety TTB-7) with an initial moisture content of 25 per cent (w.b) was used for all the drying studies. Wet grains for drying studies were prepared by adding calculated amount of distilled water to pigeonpea and allowed to stabilize to reach uniform moisture in the grain. The studies were carried out in the Department of Agricultural Engineering, UAS, GKVK, Bangalore and M.S.Ramaiah Institute of Technology (MSRIT), Mechanical Engineering Department, Bangalore during the year 2006-2007.

Open sun drying:

In open sun drying known quantity of wet pigeonpea sample was spread over a known area so that the solar radiation is converted into thermal energy and thus making the evaporation of moisture from the pigeonpea. The schematics of open sun drying are depicted in the Fig. A. The grain temperature and the ambient temperature was measured with the help of K-type thermocouples. The dry bulb and wet bulb temperature of atmospheric air were measured with the help of psychrometer. The solar insolation was also recorded by using a pyranometer. These measurements were carried out on an hourly basis in the grain and for different layer thicknesses of pigeonpea. The weight of the pigeonpea on an hourly basis was also recorded by using a digital weight balance with an accuracy of 2g.

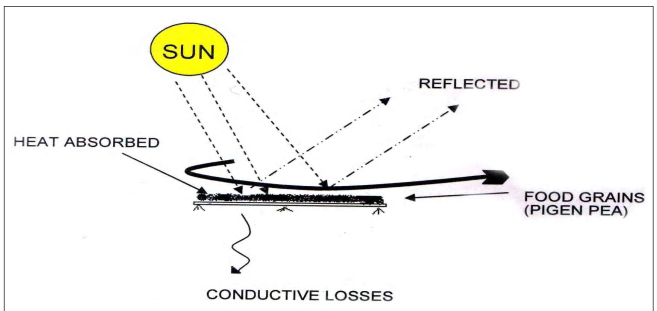

Fig. A : Schematics of open sun drying

Description of the experimental dryer on heat pipe principle with biomass burner:

The conceptual dryer also has solar heating devices in addition to biomass burner but are not deliberated in this work, the study was restricted only to biomass burner. The photograph and the schematic diagram of the dryer is shown in the Fig. B and C.

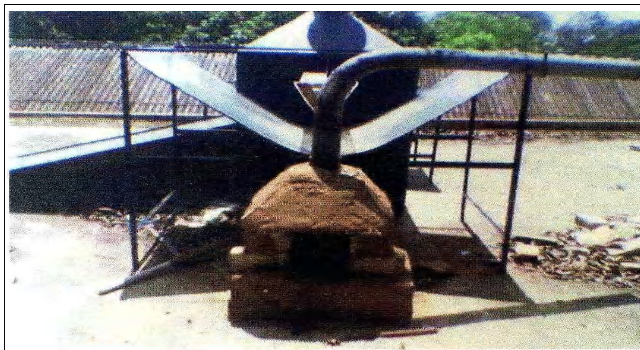

Fig. B : Schematic diagram of cabinet dryer with heat pipes

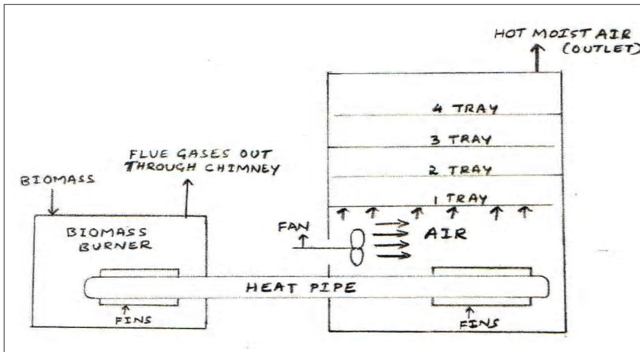

Fig. C : Schematics experimental dryer

Working of heat pipe for drying:

Heat pipe is a device of very high thermal conductance. The main section of the heat pipe are- an evaporator and a condenser as shown in Fig. D and E.

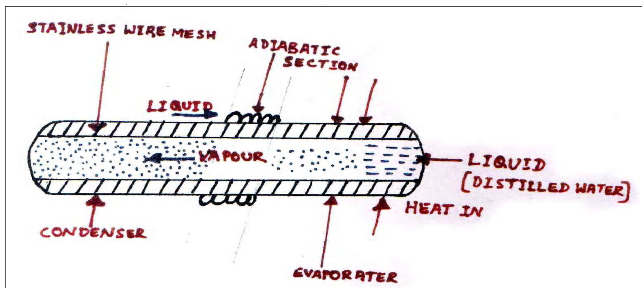

Fig. D : Diagram of heat pipe

Fig. E : Photograph of heat pipe showing fin details

Known quantity of saw dust was filled and loaded into the biomass burner. Few pieces of fuel wood of known quantity were also used for sustained burning process. Due to the burning of biomass the heat is liberated which is absorbed by the heat pipe. The liquid water acting as a working fluid inside the heat pipe gets transformed into a hot water vapour (at the evaporator end). Due to pressure difference, these hot vapours move towards the other end of the heat pipe, which acts like a condenser. At the condenser end the heat is released to the surroundings and air is heated up. This hot air is utilized for drying of wet pigeonpea. The thermal energy absorption by the wet pigeonpea results in the drying.

Drying experiments:

The drying studies of wet pigeonpea in the experimental dryer were conducted under the following two conditions.

Natural convection condition without a blower:

In natural convection conditions, a known quantity 12kg wet pigeonpea of known moisture content was equally placed on four trays (*i.e.* 3kg in each tray) and uniformly spread, known quantity of agricultural waste *i.e.* saw dust was filled and compacted inside the stove for burning and also known quantity of wood pieces were used for sustaining the burning process.

Due to burning the heat is liberated which is used by the heat pipe for transferring liquid water into water vapour. These vapours due to capillary pressure difference moved towards condenser and where heat is released to wet pigeonpea. The thermal energy absorption by the wet pigeonpea results in the drying of pigeonpea. The grain temperature, ambient temperature and wet bulb temperature of air were recorded for every hour interval by using copper constantan thermocouples and a psychrometer. The weight of pigeonpea sample on an hourly basis was also recorded using a digital weighing balance with an accuracy of 2g. The same procedure was repeated for different layer thicknesses of pigeonpea in the trays and the different layer thicknesses were 1cm, 3cm and 5cm, respectively.

Forced convection condition using the blower:

In Forced convection condition, an artificial flow of air over the heat pipe and pigeonpea was maintained by using a blower. The same quantity of wet pigeonpea of known initial moisture content weighing 3kg in each tray and was spread in four trays of the dryer. A known quantity of saw dust and wood pieces were used for burning inside the stove. The thermal energy released by the condenser end of the heat pipe increases the temperature of the air, which is flowing over it. This high temperature air flow through the wet pigeonpea resulted in the moisture loss in pigeonpea samples because of both heat and mass transfer processes. The grain temperature, ambient temperature and wet bulb temperature of air were recorded for every hour interval by using copper constantan thermocouples and a psychrometer. The weight of pigeonpea sample on an hourly basis was also recorded using a digital weighing balance with an accuracy of 2g. The drying experiments were conducted with different grain layer thicknesses in the trays for 1cm, 3cm and 5cm, respectively and for different air velocities in the drying chamber by varying the speed of the blower *i.e.* 0.1, 0.2 and 0.3m/s, respectively.

Overall efficiency of the dryer:

The overall efficiency of the dryer was calculated by using the readings of moisture evaporation for different thicknesses of pigeonpea for every 1hr interval under both natural and forced convection conditions. The thermal efficiency of the dryer was calculated by considering the calorific value of saw dust and wood as 10200kcal/kg. The overall efficiency was calculated by using the formulae given below.

$$\text{Overall efficiency of the dryer} = \frac{\text{Mev X L}}{\text{Mbiomass X C.V}}$$

where,

Mev = mass of evaporation moisture from the grain/h

L = latent heat of evaporation of water at atmospheric pressure, kj/kg

Mbiomass = mass of biomass fuel, kg/h

C.V = calorific value, kcal/kg

■ RESULTS AND DISCUSSION

The variation of percentage of moisture loss (w.b) with drying time is shown in Fig. 1. The layer thickness was found to have a profound effect on drying rate; lower thickness resulted in lesser final moisture content. The final moisture reached in layer thicknesses of 1cm, 3cm and 5cm, respectively after the end of 6h of drying.

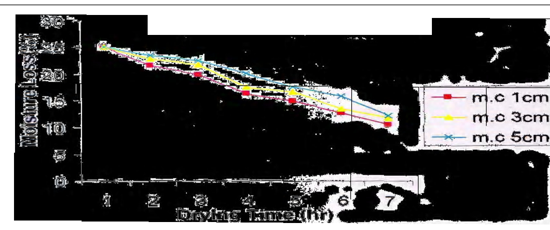

Fig. 1 : Variation of moisture loss (%) with time for different thicknesses of pigeonpea under open sun drying

Due to convective mass transfer co-efficient, the moisture evaporation from the pigeonpea grain is more in forced convection compared to natural convection and open sun drying. Fig. 2 indicates the variation of overall efficiency of the drying with time. From the experimental study, in forced convection condition in 1cm layer of thickness, the moisture removal rate was less as compared to natural and open sun drying and the average drying rates were obviously higher in case of forced convection drying compared to natural and open sun drying.

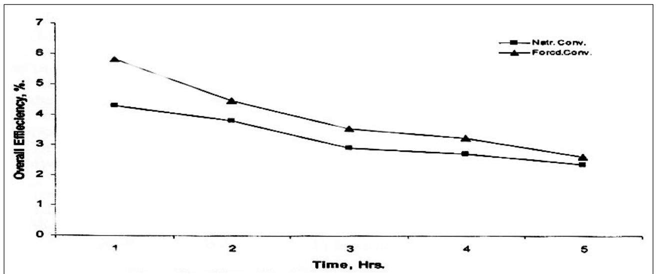

Fig. 2 : Variation of overall efficiency of drying with time

In forced convection drying, the overall efficiency of the dryer was higher as compared to natural convection drying. This is due to more moisture evaporation in forced convection than natural convection condition and also the overall efficiency decreases to less moisture evaporation for both forced and natural convection drying as thickness of the grain increases.

The variation of moisture loss (%) with time for different thicknesses of pigeonpea under natural and forced convection conditions as shown in the following Fig. 3, 4, 5 and 6,

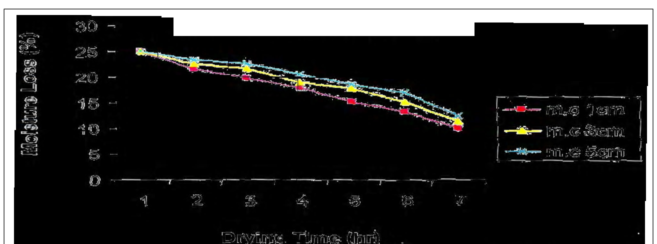

Fig. 3 : Variation of moisture loss (%) with time for different thicknesses of pigeonpea under natural convection condition

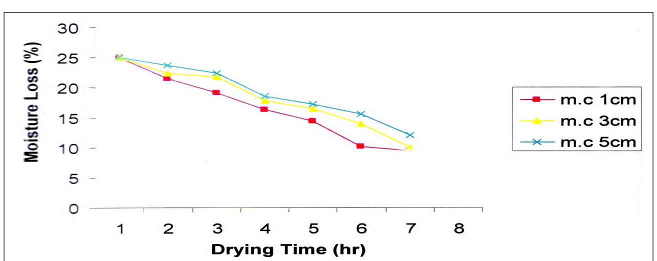

Fig. 4 : Variation of moisture loss (%) with time for different thicknesses of pigeonpea under forced convection (v=0.1 m/s) condition

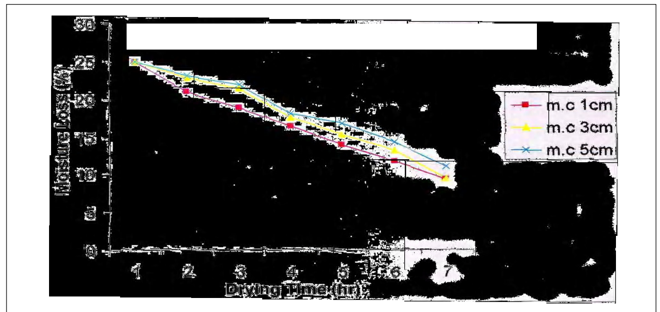

Fig. 5 : Variation of moisture loss (%) with time for different thicknesses of pigeonpea under forced convection (v=0.2 m/s) condition

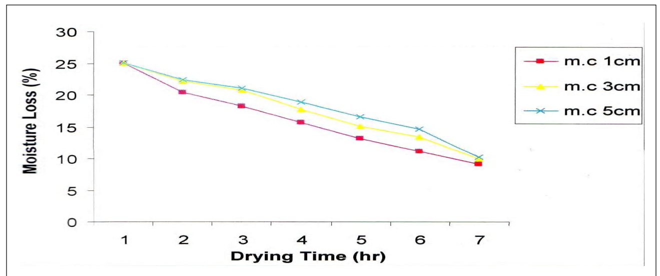

Fig. 6 : Variation of moisture loss (%) with time for different thicknesses of pigeonpea under forced convection (v=0.3 m/s) condition

respectively.

Summary:

A heat pipe is a device that can quickly transfers heat from one point to another. The drying system fuelled by biomass appears to be suitable for rural areas where it is locally available and is often the cheapest source of energy. A biomass-fuelled dryer also offers the advantage that it can operate continuously and it can be used during rainy season, cloudy days and night time also. For these reasons a biomass-fuelled dryer for small-scale applications has been investigated.

Considerable reduction in drying time is the major advantage reported with this biomass dryer. The facilitating of continuous year round operation of the biomass dryer and the 60-80 per cent reduction in drying time in comparision with open sun drying and solar drying. Increase the utilization of the biomass dryer incorporated with heat pipes and the farmers can get fair price for their produce and thus making them economically prosperous.

Finally, from the experimental study, the biomass based dryer was very much useful to dry the grains more quickly without any damage for grains and the grains obtained after drying were good in quality as compared to open sun drying and natural convection conditions.

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