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Comparative Study of Experimental Investigation and Theoretical Verification of Modified Solar Dryer used to Produce Mango Pulp

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Abstract - *Looking at the statistics of the last few years, India is known as an agricultural country, which is contributing about 15 to 20% of the Indian economy. In India, we mainly lag behind other developing countries in the processing for preservation of such agricultural products. There is a lack of facilities in the agriculture sector in the developing countries of the world and there are many factors affecting agriculture. About 50% of the people in India are directly or indirectly associated with the agriculture sector through farming and related by-products manufacturing. Agricultural application of solar dryer is widely used in developed countries to preserve vegetables. Preservation of many agricultural products is possible with solar dryers. We get maximum sunlight in the world. The use of solar energy for product drying and other related purposes would be very economical. In their work the authors have presented the design modification of solar dryer for better utilization of solar energy. This is seen with the inclusion of spiral or helical type convection tube which inducts radiation from the Sun and emits radiant energy from the Earth to improve the heating rate by 22-27%.*

Key Words: Solar Dryer, DC Motor, Relays, Archimedean spiral, Heater, PV cells, PCM.

1. INTRODUCTION

With the use of solar energy for drying purpose, device used is solar dryers that are devices that control the drying process and protect agricultural produce from damage caused by insects, dust and rain. Besides it takes less time of drying and space per unit mass of product to be dried. Also, it is cheaper than other mechanical drying methods. Solar dryers are futuristic to the solutions to control the world's food and energy crisis. Using modifying technique of drying, most agricultural products can be preserved and processed more efficiently through the use of solar dryers [1–4].

Solar dried foods are quality products that can be stored for long periods of time, can be easily transported at minimum cost and at the same time provide excellent nutritive value. Therefore this paper presents the design and fabrication of solar food dryer for sun drying of agricultural produce, especially advanced mango juice (mango pulp or mango papad) [2,3–5].

Solar energy is available in almost all the regions of India. With the developing technology, solar energy has been released for many portable applications used in daily life. Applications of solar power in agriculture such as pumps and tractors are proposed by the researchers. Processing of the crop by solar drying technique is proposed by the authors. The design of a solar drying system for the Indian agriculture sector is presented in this paper. Crop protection has always been a challenge for farmers in India. Indian farmers are mainly owners of small land. The technology is very uneconomical to buy small land and many of them do not have the money to buy modern equipment. The quality of the product can also be improved in the conservation process as we can add or remove any substance from the crop in any quantity [4, 7].

Solar energy is converted into heat for further use or conversion into useful work. Heat is generated in drying products to preserve them for future use. To dry any product the air is heated to a predetermined temperature so that it can be used to absorb the moisture from the products. The solar power potential of India and its advantages over other energy generation methods make it important to effectively trap solar energy for as many applications as possible. Automation of control drying is very important to use it effectively along with new technological aids every day.

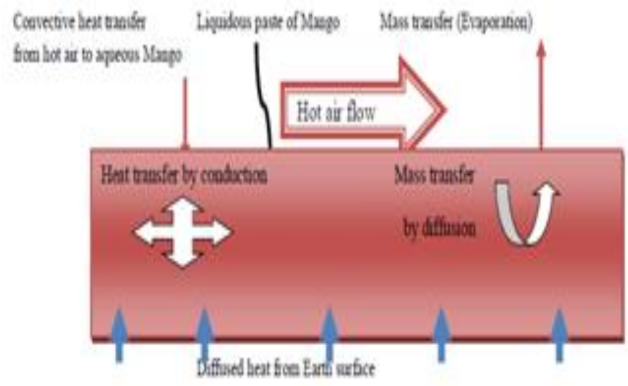

Fig.1: Mechanism of heat and mass transfer process through mango paste

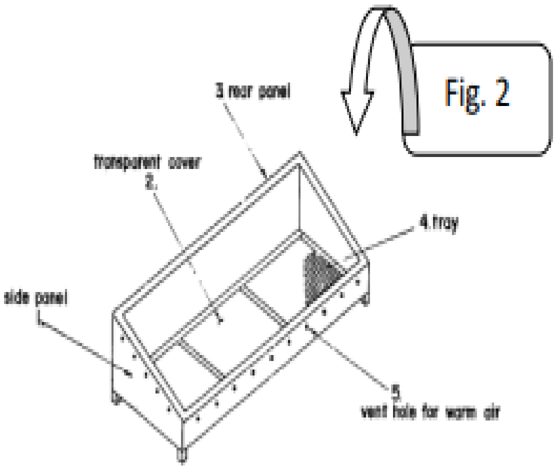

Fig. 2: Solar dryer (Box type)

The first solar dryer was developed at 'Brace Research Institute', Canada, in 1975 which is a hot box as shown in Fig 2 above where, fruits, vegetables and other materials can be dried on a medium scale.

The parameters considered can be classified as: (i) physical characteristics of the dryer; (ii) thermal performance; (iii) the quality of the dried product; (iv) Cost and payback period of the dryer [3, 4]. The main components of the equations describing the drying system were solar radiation, heat convection, heat gained or lost from the dryer container wall, and latent heat of moisture vaporization. The model was able to predict drying temperatures over a wide range of relative humidity values. It also has the ability to predict moisture loss from the product over a wide range of relative humidity values, temperature and wind velocity [2].

Indirect solar drying or convective solar drying is the new technology of product drying. It is a much more efficient method than the direct type of solar drying. In this method atmospheric air is heated in flat plate collector or concentrating type solar collector. Product moisture can be lost due to convection and diffusion. This method of drying is used to avoid direct exposure to solar radiation. This method mainly reduces drying products, but natural convection solar dryers have limitations [6].

The constraints under consideration are: (i) the availability of solar radiation intensity, (ii) the amount of raw product used for drying, (iii) the surface area of the absorber plate, (iv) the latitude and longitude angles of the solar dryer, (v) air circulation inside the drying chamber, (vi)heat transfer loss. Natural Convection Solar Dryer is suitable for drying purpose at domestic level. It can store 10-15 kg.

2. MATERIAL

The indirect hybrid type solar dryer is a combination of a pre-heater and dryer and a PV solar. The pre-heating unit in our work is using spiral path to circulate hot air to increase the contact time of hot air with the solidification of mango juice.

The most commonly seen design types are of cabinet form (wooden box with glass cover), some types are also modified using cardboard boxes and non-reflective nylon or polythene. The greenhouse effect and the thermo-siphon principle are the theoretical basis for the design under consideration. The solar collector has an air vent (or inlet) where air enters and is heated by the greenhouse effect, the hot air rises above the drying chamber passing around the trays and food, removing all moisture content vents and exits through the exhaust fan at the top of the cabinet. The solar food dryer has two major compartments or chambers integrated together:

1. Solar collector compartment, which can also be called the air heater of the system.
2. Drying chamber, designed to accommodate four layers of drying trays made of mesh (cheese cloth) on which the product (or food) is placed to be dried.

Table 1: Material required for dryer channel

Sr. No.	Component	Material
1	Solar collector	Glass
2	Absorber plate	Aluminium
3	Heating chamber	Wood
4	Drying chamber	Wood
5	Insulation	Glass wool
6	Tray	Aluminium
7	Roof	Wood

Table 2: Properties of aluminum (A6061) sheet

Properties	Values
Density (ρ)	2.70 g/cm^3
Young's modulus (E)	68 GPa
Tensile strength (σ_t)	124–290 MPa
Elongation (ε) at break	12–25%
Melting temperature (T_m)	585 °C
Thermal conductivity (k)	151–202 W/(m-K)
Linear thermal expansion coefficient (α)	2.32×10^{-5} K^{-1}
Specific heat capacity (c)	897 (kg-K)

2.1 Properties of Stainless steel (SS304)

Density = 7.93 g/cm^3, Melting point = 1400-1450 °C, Specific heat capacity = 500 J/kg·K at 20 °C, Electrical resistivity = 0.72 μΩ-m at 20 °C,Magnetic permeability = 1.02, Modulus of Elasticity = 193 GPa, Thermal diffusivity = 3.84 mm^2/s, Thermal conductivity = 16.2 W/m-K at 100 °C, Coefficient of thermal expansion (CTE) = 17.2×10^{-6}/K at 0-100 °C.

3. DESIGN CONSIDERATIONS AND CALCULATIONS

1. Temperature - The range of drying temperature is 35°C-65°C. The normal temperature for drying the seeds etc. of the crop of advanced mango juice (mango pulp or mango papad) is considered to be 50°C.

2. This design was made for the optimum temperature for the dryer is 65-70°C and the air inlet temperature or the ambient temperature of the dryer is assumed to be 35-38°C (approx. outdoor temperature).

3. Efficiency – It is defined as the ratio of the useful output rating in terms of energy used to the energy input rating per unit product per unit thickness of mango pulp [8, 9].

4. Air gap - It is suggested that for passive solar dryers in hot climates, a gap of 10 cm should be made as air vent (inlet) and air passage [5,6]. The air gap can be reduced accordingly by using forced convection.

5. Glass and Flat Plate Solar Collector - For effective use of solar in Bhopal (M.P.), the glass covering should be 4-5 mm thick. 5 mm thick transparent glass was used in our design calculations. An aluminum sheet of 1.5 mm thickness was used.

6. Dimensions - It is recommended that a continuous exchange of air and a spacious drying chamber should be achieved in the solar food dryer design, for effective use the drying chamber should be 50 × 50 × 50 with air passage (air vent) 40 cm is considered the dimension out of the cabinet of 50 × 5 cm^2.

7. Dryer Tray - The metal (steel) mesh was treated as a dryer screen or tray to aid air circulation within the drying chamber. Two layers of metal mesh trays were considered in the design calculations. The dimensions of the tray are taken to be 50×40 cm.

8. An 18V exhaust fan is used to exhaust the air from the drying chamber.

The design of the dry chamber protects the food placed on the trays from direct sunlight by using wooden wall sides and top as this is undesirable and bleaches the color, removes flavor and causes uneven appearance of pulp causes drying.

4. OUR PROPOSAL

In our proposal the images of modified solar dryer are as follows:

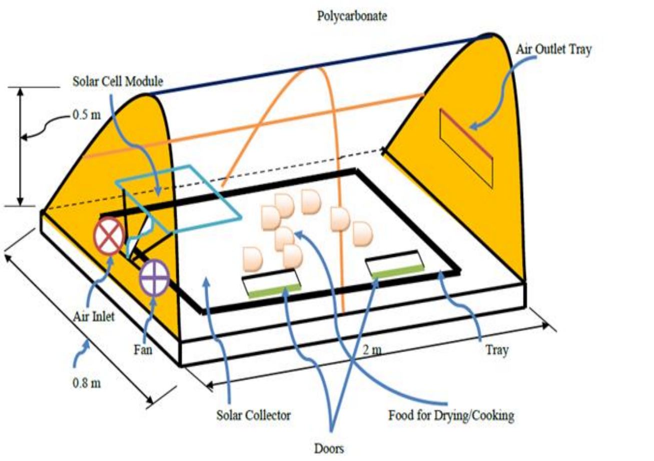

Fig.3: Pictorial Views of Solar Dryer System

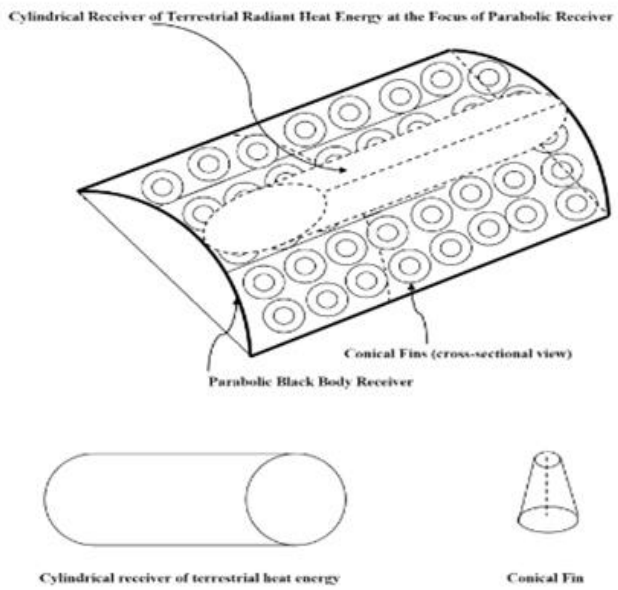

Fig.4: Bottom side of solar dryer

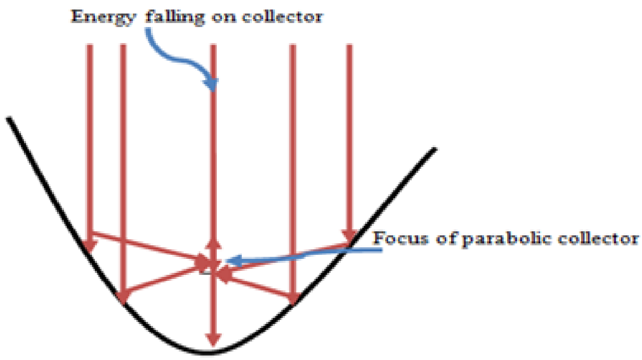

Fig.5: Focusing mechanism of parabolic receiver

The design procedure flow chart is as follows:

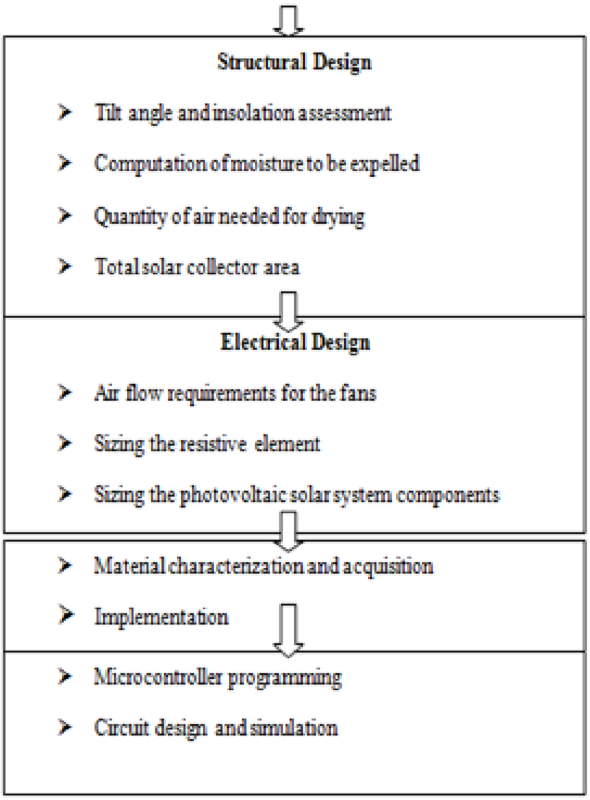

Fig.6: Design procedure flow chart

4.1 Curved tube design

Types of curved tubes tube under design consideration are:

4.1.1 Helical coil tube geometry

The schematic diagram and specifications of helical coil profile is shown in figure 7.

4.1.2 Archimedean coil tube geometry

The schematic diagram and specifications of tube is given in figure 8.

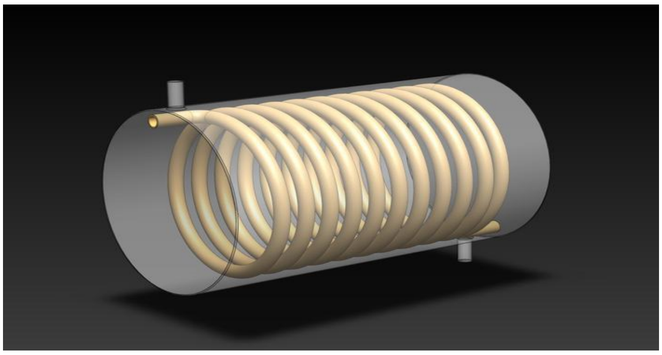

Fig.7 : Schematic of helical coil tube

Fig.8 : Schematic of Archemedian spiral coil tube

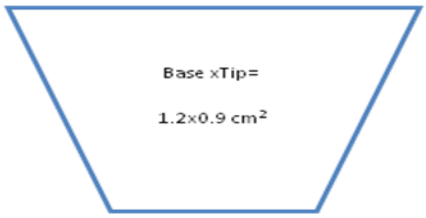

Fig.9 : Trapezoidal fin fitted on outer body of dyer system

5. PRINCIPLE OF OPERATION

Principle of Operation The system consists of a controller, heating system, solar power source, fan and sensor. The system can be adjusted according to the required temperature, humidity and drying conditions. The parameters during control can be as per requirement. The harvested mango juice is extracted either mechanically or manually and spread on cotton sheets which are covered over plywood strips of different surface areas. Layers of different thicknesses with different surface areas of mango juice are spread on sheets and placed in a conventional solar dryer. The required time, temperature, heat etc. are measured and the obtained values are compared with the theoretically obtained values assumed in the modified solar dryer.

Fig.10: Mango juice of 3 mm thickness for drying in conventional sun's energy

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Fig.11: Dried Mango pulp of 3 mm thickness

Fig.12: Mango juice of 5 mm thickness for drying in conventional sun's energy

Fig.13: Dried Mango pulp of 5 mm thickness

6. RESULTS AND DISCUSSION

6.1 Effect of surface temperature on wetting/ solidification time of mango pulp produced

It is evident from the Figure 14 with increase in surface temperature or the temperature of air pre-heater time of solidification of mango juice reduces.

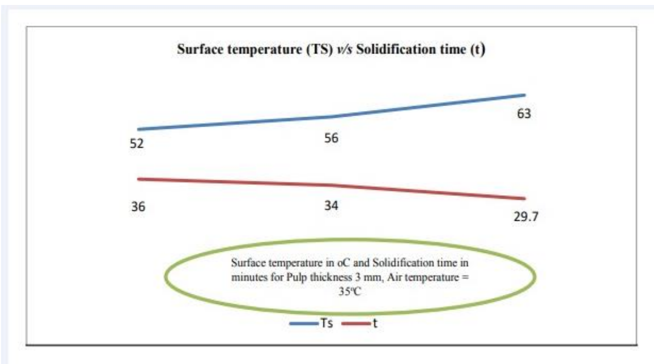

Fig.14: Surface temperature *v/s* Solidification time

6.2 Effects of solidification time with respect to surface area

It is seen from the Figure 15-16 that at constant temperature of atmospheric air and constant thickness of pulp produced solidification temperature increases appreciably with increase in surface area of pulp produced.

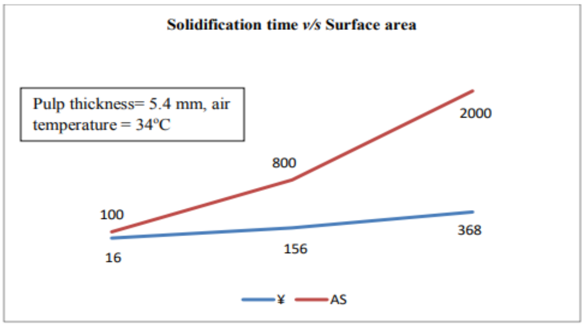

Fig.15: Solidification time *v/s* Surface area

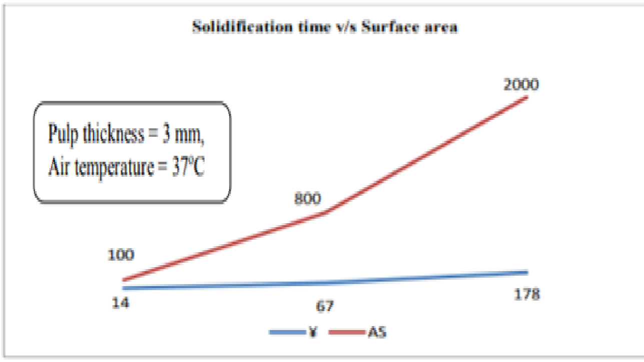

Fig.16: Solidification time *v/s* Surface area

6.3 Effects of hot air flow rate and convection heat transfer

It is seen that with increase in circulation of air effectiveness of heat transfer is more thus the rate of drying increases.

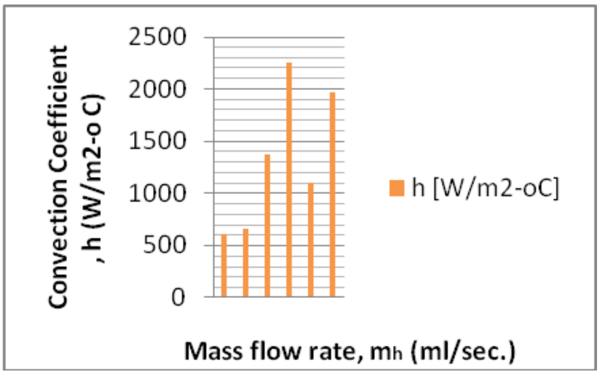

Fig.17 : Mass flow rate of hot air *v/s* convection heat transfer coefficient

6.4 Effect of input energies

It is seen that with modified dryer the energy trapped in molten mango is increased up to 18 % or more if we use combined spiral pathway and trap the emission of earths geothermal energy Figure18.

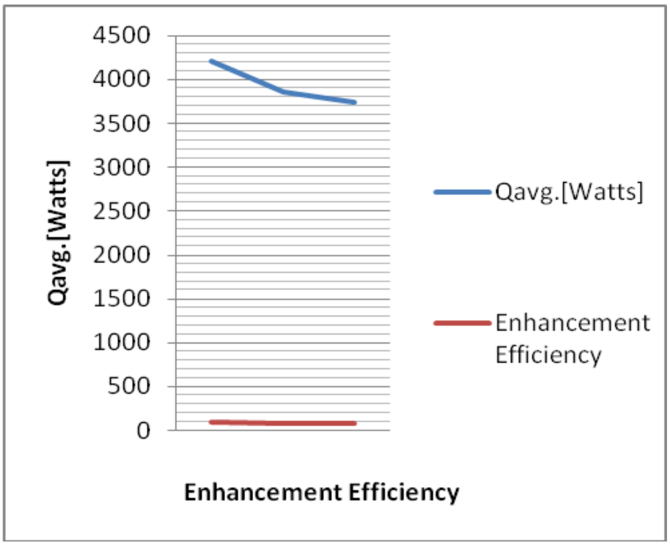

Fig.18: Average heat transfer rate *v/s* enhancement efficiency

7. CONCLUSIONS

Agriculture is one of the major sectors in India. With a population of over 135 crores, many people depend on agriculture for their earnings. The problem with current farming is preserving the farmed crop as many products have a very short shelf life without processing. Many factors such as environmental impact, production and hence the return on investment made for farming are not clear to the farmers. We get maximum sunlight in India and have to use it in India as per requirement. The application of the modified solar dryer system for Indian farms is designed by the authors, which is compared with the conventional simple solar dryer. A comparison between the modified and simple solar dryer [2] is presented in this paper with the aim of increasing the effectiveness of solar utilization. Cheaper materials can be used in the construction of the modified solar dryer. It is the best way to use clean energy and protect the environment as efficiently as possible but, the initial cost increases significantly. Also, in this way wastage of mangoes, storage cost, handling cost and loss of moisture or solidification of mango juice are reduced. Meteorological data should be readily available to users of solar products to ensure maximum efficiency and effectiveness of the solar dryer. Drying methods and temperature were found to have a significant effect on the moisture loss rate of the samples. Drying of mango juice in modified solar drying system will take less time as compared to other drying conditions. The modified solar drying system generated the highest diffusion values which were approximately 50 times higher than those of sun and oven (50°C) drying.

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