EXPERIMENTAL ANALYSIS OF SOLAR AIR DRYER FOR AGRICULTURAL PRODUCTS

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Abstract - *Agricultural and other products have been dried by the sun and wind in the open air for thousands of years. The purpose is either to preserve them for later use, as is the case with food; or as an integral part of the production process, as with timber, tobacco and laundering. In industrialized regions and sectors, open air-drying has now been largely replaced by mechanized dryers, with boilers to heat incoming air, and fans to force it through at a high rate. Mechanized drying is faster than open-air drying, uses much less land and usually gives a better quality product. But the equipment is expensive and requires substantial quantities of fuel or electricity to operate. 'Solar air drying' in the context of this technical brief, refers to methods of using the sun's energy for drying, but excludes open air 'sun drying'. The justification for solar dryers is that they may be more effective than sun drying, but have lower operating costs than mechanized dryers. Here, an indirect natural cum forced convection solar air dryer is fabricated to investigate its performance respectively under the hot and dry climatic condition of Hubli, Karnataka, India. Experimental analysis is conducted on the solar air dryer for both natural and forced convection. The performances of natural and forced convection are compared. The system consists of flat plate collector, drying chamber/cabinet and a chimney. There are six baffles attached to the absorber plate in zigzag manner so that it increases the turbulence in the flat plate collector which inturn helps in the rise of temperature of air and larger area of contact between air and the absorber plate.*

Key Words: *solar air dryer, Agricultural, forced convection, and natural convection.*

1. INTRODUCTION:

The use of solar energy in recent years had reached a remarkable edge. The continuous research for an alternative power source due to the perceived scarcity of fuel fossils is its driving force. It had become even more popular as the cost of fossil fuel continues to rise. Of all the renewable sources of energy available, solar energy is the most abundant one and is available in both direct as well as indirect forms. Solar energy applications were divided mainly into two categories: the first is the direct conversion to electricity using solar cells (electrical applications). The second is the thermal applications. The latter include solar heating, solar cooling, solar drying, solar cooking, solar ponds, solar distillation, solar furnaces, solar thermal power generation, solar water heating, solar air heating, etc. Detailed description, fundamentals and previous work performed on solar dryers and solar air heaters, as the vital element for the indirect and mixed modes of solar dryers. [1]

Solar air heater is a type of energy collector in which the energy from the sun, solar insolation, is captured by an absorbing medium and used to heat air. Solar air heating is a renewable energy heating technology used to dry the agricultural products effectively and efficiently. A simple solar air collector consists of an absorber material, sometimes having a selective surface, to capture radiation from the sun and transfers this thermal energy to air via conduction heat transfer. This heated air is then ducted to the agricultural products such as chilies, grapes etc.

Drying or dehydration of material means removal of moisture from the interior of the material to the surface and then to remove the moisture from the surface of drying material. Drying of seeds prevents germinations and growth and fungi and bacteria. The traditional age old practices of drying food crops in developing countries like India, Bangladesh etc. is spreading food products in open sun termed as open sun drying or natural sun drying .This natural sun drying is simple and economical but suffers from many drawbacks such as there is no control over the drying rate discoloration .

However, being unprotected from rain, wind-borne dirt and dust, infestation by insects, rodents and other animal, products may be seriously degraded to the extent that sometimes become inedible and the resulted loss of food quality in the dried Products may have adverse economic effects on domestics and international markets. Some of the problems associated with open-air sun drying can be solved through the use of a solar dryer which comprises of collector, a drying chamber and sometimes a chimney.[3] The use of solar technology has often been suggested for the dried fruit industry both to reduce energy costs and economically speed up drying which would be beneficial to final quality dried grapes, okra, tomato and onion using solar energy. They concluded that drying time reduced significantly resulting in a higher product quality in terms of colour and reconstitution properties. They also believe that as compared to oil or gas heated dryers, solar drying facilities are economical for small holders, especially under favourable meteorological conditions. [Solar dryers used in agriculture for food and crop drying ,for industrial drying process, dryers can be proved to be most useful device from energy conservation point of view. It not only save energy but also save lot of time, occupying less area, improves quality of the product, makes the process more efficient and protects environment also. Solar dryers circumvent some of the major disadvantages of classical drying. Solar drying can be used for the entire drying process or for supplementing artificial drying systems, thus reducing the total amount of fuel energy required. There are several advantages of controlled drying of grains such as product quality, storage capability and hygiene improvement, reduced wastage, time and space improved transportability.

To dry materials a supply of heat energy is essential to evaporate the water and supply of air to carry away the water vapor produced. For control drying of food we use fuels like electricity, natural gas or coal etc. Due to scarcity of fossil fuels and many environmental problems associated with these uses energy engineers are searching of alternating sources of energy. Solar energy is best solution or appropriate alternative sources of energy. Solar energy is clean, safe and abruptly available. An improved technology in utilizing solar energy is the use of 'solar dryers' where the air heated in a flat plate solar collector and then heated air is pass through drying chamber/cabinet. [2]

1.1 Types of solar air dryer

- Direct solar
  In these dryers, the material to be dried is placed in a transparent enclosure of glass or transparent plastic. The sun heats the material to be dried, and heat also builds up within the enclosure due to the 'greenhouse effect.' The drier chamber is usually painted black to absorb the maximum amount of heat.

- Indirect solar dryers
  In these dryers, the sun does not act directly on the material to be dried thus making them useful in the preparation of those crops whose vitamin content can be destroyed by sunlight. The products are dried by hot air heated elsewhere by the sun.

- Mixed-mode dryers
  In these dryers, the combined action of the solar radiation incident on the material to be dried and the air preheated in solar collector provides the heat required for the drying operation.

- Hybrid solar dryers

In these dryers, although the sun is used to dry products, other technologies are also used to cause air movement in the dryers. For example fans powered by solar PV can be used in these types of dryers. [4]

1.2 Working principle:

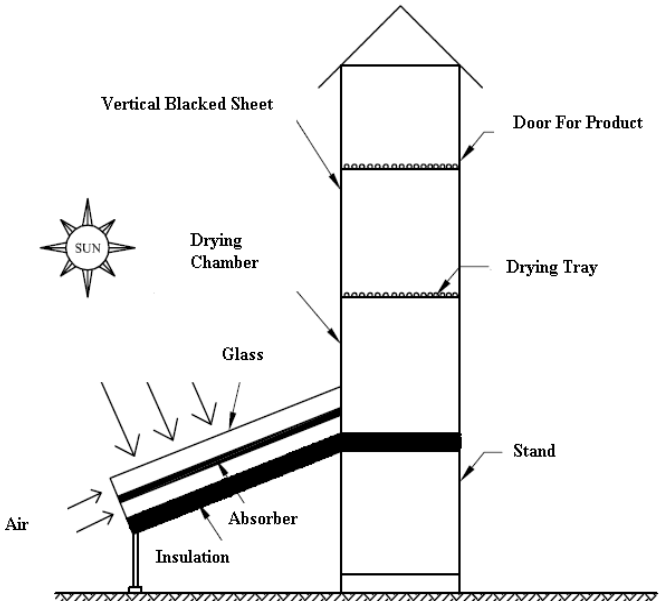

Fig -1: Natural convection solar dryer. [5]

The schematic of experimental set-up for a new type of solar dryer is shown in Fig-1. The absorber plate of the solar air heater consists of a thin box made of corrugated galvanized iron sheet on one side and plain galvanized iron sheet on the other.[5]

The solar dryer is a relatively simple concept. The basic principles employed in a solar dryer are:

- Converting light to heat: Black surface on the inside of a solar dryer will improve the effectiveness of turning light into heat.
- Trapping heat: Isolating the air inside the dryer from the air outside the dryer makes an important difference. Using a clear solid, like a glass cover, will allow light to enter, but once the light is absorbed and converted to heat, glass cover will trap the heat inside. This makes it possible to reach similar temperatures on cold and windy days as on hot days.

- Moving the heat to the food: Both the natural convection dryer and the forced convection dryer use the convection of the heated air to move the heat to the food.

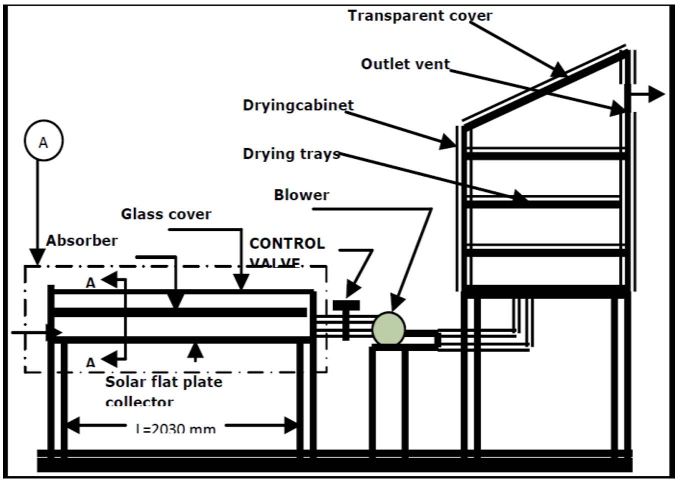

Fig -2: Forced convection solar dryer. [4]

The working remains the same as that of natural convection, here whereas a air blower is used to increase the velocity of the air which inturn increases the mass flow rate of the air and the moisture from the food is carried away by air faster.

2. COMPONENTS OF SAH

2.1 Absorber Plate

The primary function of the absorber plate is to absorb as much as possible of the radiation reaching to plate, loose as little heat as possible upward to the atmosphere and downward through the back of the container.. In general, absorption of solar energy impinging on an absorber plate should be as high as possible, but re-emission (loss) outward from the collector should be minimized. Absorber plates are usually given a surface coating (which may be a black paint) that increases the fraction of available solar radiation absorbed by the plate (its absorptance α). These surfaces must be able to withstand repeated and prolonged exposure to high temperatures without appreciable deterioration or out gassing. As a absorber plate we can use various material sheet on the basis of their Solar absorptance, Infrared emittance and Reflectance. The emittance of a surface varies with its temperature and its roughness. If it is a metal, it depends also on its degree of oxidation. Highly polished metals have low emittance but more reflectivity. Selective absorbers often consist of a very thin black metallic sheet metal base. The sheet is thick enough to act as a good absorber, with $\alpha = 0.95$. Table gives values of absorptance and infrared (IR) emittance for various Materials; it also gives values of reflectance. It is noteworthy that many common building materials have excellent emitting surfaces for long wave radiation.

2.2 Baffles:

A flat board or plate, deflector, guide, or similar device constructed or placed in flowing air systems to cause more uniform flow velocities to absorb more energy and to divert, guide the air. These baffles provide more area of contact by diverting or deflecting the air flow. Due to this reason heat transfer takes place more and air take more heat. Main purpose of baffles in solar dryer is to provide more contact area to get more heat. Main applications of baffles are Solar Dryer, Heat Exchangers, Flow Channels etc.

2.3 Solar toughened glass:

One of the essential components of the collector is the glass cover. Glass easily transmits short-wave radiation, which means that it poses little interference to incoming solar energy. Once the sun's energy has passed through the glass windows and has absorbed by some material inside, the heat will not be reradiated back outside. Glass therefore acts like heat trap. Solar collectors usually called flat plate collectors, almost have one or more glass covers. The figure shows the solar toughened glass of 4mm thickness and of 0.95 transmittance. The area of the glass is about 2sq.mtrs.

2.4 Air blower

Air blower is used to increase the velocity of the air. The air blower sucks the air from suction pipe and blows it to other side through pipe. The specification of blower is 220-240v, 50-60Hz, 500W, Speed 0-16000/minute.

2.5 Drying Chamber:

Design of solar drying chamber is most important part of the solar drying system because air flow through chamber also depends on design. Most common designs are cylindrical chamber with a cone of 40-60º, drying chambers with a flat bottom, horizontal box type drying chambers. Drying Systems should be designed to be the most efficient and economical. It is square shaped drying chamber with dimension of 5ocmX50cmX50cm. Drying chamber take hot air from the Solar Air Heater through a pipe and remove the humidity or moisture content from the product and dry the product. Hot air leaves in atmosphere through solar chimney. [2]

3. RESULTS AND DISCUSSIONS

The experiments were performed on red chilies and grapes. The drying time is 9 hours. Collector is inclined at 25° with horizontal and oriented in the South - North direction. During experimentation 6 temperatures and solar intensity were measured hourly in the month of February to May, for drying of red chilies, grapes, banana chips. Solar intensity varied between 402-509 W/m^2 and maximum temperature rise was 15-20^{o}C. Hot air at 45-61^{o}C from the collector is supplied through 40 mm diameter PVC pipe at the bottom of the drying cabinet. The moisture content of chilies was reduced from 90% to 13% . Result of the present study shows that the drying time is reduced and quality of the final products are superior. The results have been shown graphically. The graphs which is bar chart shows relation between time of day vs. temperature for natural convection. The two temperatures shown are ambient temperature and collector outlet temperature and from the bar chart it is clear that the difference of the temperature is between 15°C to 20°C. The graphs are plotted between solar intensity and time of day and data taken from the above tables. The graph shows hourly variation of solar intensity of the solar air heater, as the day progresses solar intensity increases with maximum at noon. It is observed that the drying time taken to dry same quantity of product in forced convection is less than the natural convection. The red chilies were dried by natural convection in three days reducing the weight from 610 grams to 243 grams. Whereas the same quantity of red chilies were dried by forced convection with the use of air blower in two days reducing the weight from 610 grams to 230 grams. The grapes were dried by natural convection in seven days reducing the weight from 1000 grams to 224 grams. Whereas the same quantity of grapes were dried by forced convection with the use of air blower in four days reducing the weight from 1000 grams to 234 grams. The agricultural products are dried from 90% moisture content to 15-20% moisture content. It is observed that the drying time is less in forced convection than the natural convection.

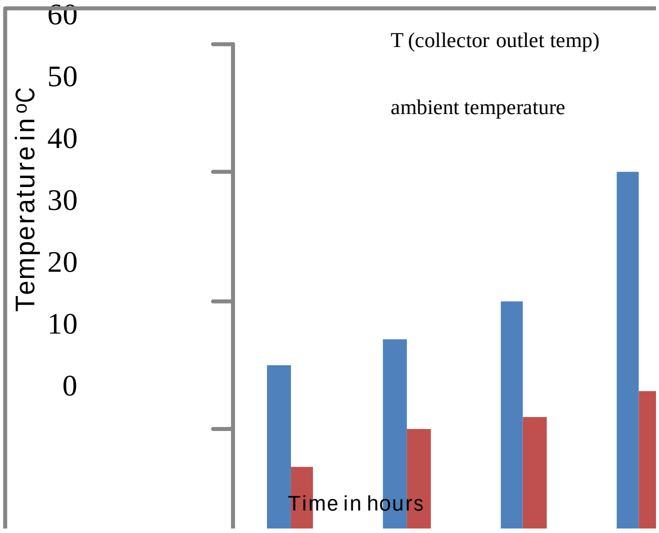

Chart -1: Temperature vs time in hours (natural convection)

The above graph which is bar chart shows relation between time of day vs. temperature for natural convection. The two temperatures shown are ambient temperature and collector outlet temperature and from the bar chart it is clear that the difference of the temperature is between 15°c to 20°c.

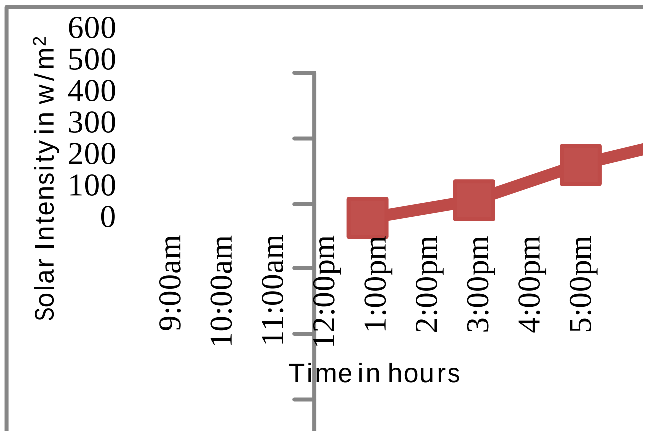

Chart -2: Average intensity vs time (natural convection)

The graphs are plotted between solar intensity and time of day and data taken from the above tables. The graph shows hourly variation of average solar intensity and efficiency of the solar air heater, as the day progresses solar intensity increases with maximum at noon.

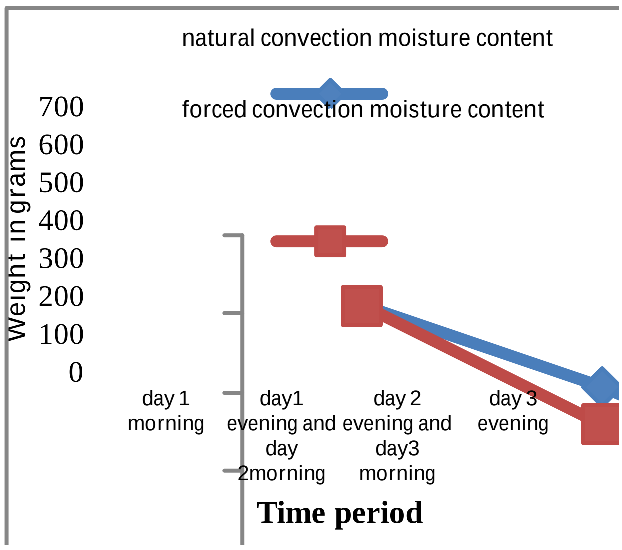

Chart -3: Moisture content vs time period

The graph above is plotted between moisture content vs time period. This plot represents the comparison of moisture content of natural and forced convection solar dryer vs time period taken. The graph indicates that moisture content reduction in forced convection is faster than natural convection. From graph chilies dried in 2 days in case of forced convection while same weight of chilies taken 3 days to dry. Hence forced convection is best suited for mass production.

Fig -3: Experimental setup

It is the assembled view of all three parts (Solar Air Heater, drying chamber/cabinet, solar chimney) of solar dryer.

Table -1 Variation of absorber plate temperatures and solar intensity with respect time (Day 1) (24/4/2015)

Sl. No	Time	T1 ºC	T2 ºC	T3 ºC	T4 ºC	T5 ºC	T6 ºC	Amb. Temp ºC	Solar Int in w/m²
1	9 am	28	78	76	35	31	27	28	378
2	10 am	30	82	79	39	35	30	30	405
3	11 am	32	93	89	44	40	36	31	459
4	12 pm	33	102	97	52	47	41	33	499
5	1 pm	33	105	104	54	51	42	34	507
6	2 pm	30	94	97	45	42	36	30	432
7	3 pm	31	87	90	40	36	31	31	374
8	4 pm	29	82	86	38	35	30	29	403
9	5 pm	29	70	73	37	33	28	29	302

Thermal efficiency of solar collector: [2]

Formula:

$\eta = mC_P\Delta T/IA_c$

Where $m=\rho A_o V$

Velocity of air at outlet duct (v)=18.5m/s

Diameter of outlet duct=40mm

Area of outlet duct (A_o) $=\pi/4(d)^2$

$=\pi/4(.04)^2$

$=1.25\times10^{-3}m^2$

Density of air = 1.2kg/m³

$m=1.2\times1.25\times10^{-3}\times18.5$

m=0.02775 kg/sec

Specific heat of air at 55°C is calculated by interpolation

At 0°C specific heat=1.00123 Kj/Kg°C

At 100°C specific heat=1.0096Kj/Kg°C

Specific heat = [(55-0) (1.0096-1.00123)/100]+1.00123

=1.0058KJ/Kg °C

$\eta = mC_P\Delta T/IA$

Where solar intensity (I) =506W/m²

$\Delta T=20°C \quad A=2m^2$

$\eta=[(0.02775\times1.0058\times10^3\times20)/(506\times2)]\times100$

$\eta=55.15\%$

Where,
η- Thermal efficiency in %
m- Mass flow rate in Kg/sec
C_P- Specific heat in KJ/Kg °C
ΔT- Difference of inlet and outlet temperature in °C
I- Solar intensity in W/m²
A_c- Area of collector in m²
A_o- Area of outlet duct in m²
V- Velocity of air at outlet duct m/s
ρ- Density of air in Kg/m³

Table-2 Specifications of solar air dryer

SL no.	Component	Specifications	Material	Quantity
01	Solar collector	Length=2000mm Width=1000mm Height =150mm	Plywood of 8'*4'*3/4" size	01
02	Drying chamber	Length =400mm Width =500mm Height =500mm	Plywood of 8'*4'*.24' size	01
03	Absorber plate	Length=2000mm Width=1000mm Thickness =1mm	GI sheet 18 gauge with black painting	01
04	Toughened Glass	Length=2000mm Width =1000mm Thickness=5mm	Solar toughened glass(0.9 transmittance)	01
05	Air blower	600 watts, 2.3m³/sec, 0-16000rpm	Fiber body	01
06	K-type thermocouple	5000mm(5m)		01
07	Temperature indicator			01
08	Drying net	Length =400mm Width =500mm	Stainless steel net	04

4. CONCLUSIONS

Solar air dryer is best suited for the drying process one of the most important potential applications of solar energy is the solar drying of agricultural products. The post harvest losses of agricultural products can be reduced drastically by using well designed solar drying systems. Among the different types of solar dryers, the indirect mode forced convection solar dryer has good speed and quality of drying. The designed solar air dryer with a collector area of $2m^2$ dries agricultural products from 89.6% to 13% moisture content under ambient conditions during harvesting period from February to April. Experiments were performed on solar air heater, the maximum temperature rise is 20°C and the solar intensity was found to be in the range of 402-509 w/m^2. Maximum collector efficiency of 55.15% is obtained for forced convection. Drying time is less in forced convection than the natural convection. So forced convection is preferred than natural convection for drying of agricultural products.

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