Experimental Investigation of Hybrid Food Dryer Using Solar and Exhaust Gas

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Abstract -- In many countries of the world, the use of solar thermal systems in the agricultural area to conserve vegetables, fruits, coffee and other crops has shown to be practical, economical and the responsible approach environmentally. Solar heating systems to dry food and other crops can improve the quality of the product, while reducing wasted produce and traditional fuels - thus improving the quality of life. Drying means moisture removal from the product. Drying is helpful in preserving food product for long time, it prevent product from contamination. Basically, there are three types of solar dryers; direct solar dryers, indirect solar dryers and mixed-mode dryers. Primarily open to the sun or direct sun drying technique is used. However, it has some disadvantages. These disadvantages can be overcome by indirect type of dryer which is used for drying products as application of solar energy. This project is focused on hybrid solar dryers.

Based on preliminary investigations under controlled condition of drying experiments, a mixed-mode solar dryer with natural convection using solar collector was constructed. The present work describes the development of dryer considerations followed by the results of experiments to compare the performance of the natural convection with exhaust gases from the diesel engines. This hybrid solar dryer had been used in experimental drying tests under various loading conditions.

Keywords: Direct Solar Dryer, Indirect Solar Dryers mixed-mode dryers, Natural Solar Dryer, Hybrid Solar Dryer.

INTRODUCTION

Drying, is a simple, low-cost way to preserve food that might otherwise spoil. Drying removes water and thus prevents fermentation or the growth of molds. It also slows the chemical changes that take place naturally in foods, as when fruit ripens. Surplus grain, vegetables, and fruit preserved by drying can be stored for future use.

People have been drying food for thousands of years by placing the food on mats in the sun. This simple method, however, allows the food to be contaminated by dust, airborne molds and fungi, insects, rodents, and other animals. Furthermore, open air drying is often not possible in humid climates.

To overcome the above mentioned problems indirect mode solar dryers are used. In an indirect mode solar dryer, the crop is not directly exposed to solar radiation. The incident solar radiation is absorbed by some other surface - usually a solar collector where it is converted into heat. The air for drying flows over this absorber and is heated. The warmed air is then used to transfer the heat to the crop located within an opaque structure. The hybrid dryer produces a better quality product and can, depending on the heat source, reduce the drying time by up to 50 percent compared to traditional drying.

Classification of solar dryers

According to Baker & Christopher G.J, 1997 there are three types of solar dryers and they are classified according to the type of energy used.

1. Open air
2. Direct Sun
3. Indirect Sun
4. Mixed Mode
5. Hybrid

DESIGN ASPECTS OF HYBRID SOLAR DRYER

Design Features

The Hybrid solar dryer has the shape of a home cabinet with tilted transparent top. The angle of the slope of the dryer cover is 15° for the latitude of location. The dryer is set on casters to make it mobile. Copper tube heat exchanger rods are placed at the bottom of the cabin. The diesel engine is arranged such that the exhaust gases released from the engine are passed through the inlet of the...
heat exchanger and released to the atmosphere through outlet. The dryer is provided with air inlet and outlet holes at the front and back, respectively. The outlet vent is at higher level. The vents have sliding covers which control air inflow and outflow. The movement of air through the vents, when the dryer is placed in the path of airflow, brings about a thermosyphon effect which creates an updraft of solar heated air laden with moisture out of the drying chamber. The source of air is natural flow. In hybrid system the exhaust gases from the diesel engine are passed through the inlet of heat exchanger and the air passing through the cabin is heated up which in turns removes the moisture from the products placed on trays. The gases from the outlet of heat exchanger are allowed to atmosphere.

Hybrid Solar Dryer Design Considerations

The size of the dryer was determined based on preliminary investigation which was found to be 2.6kg per m² (tray loading). The sample thickness is 3mm for solar drying of vegetables.

The following points were considered in the design of the natural convection hybrid solar dryer system:

- The amount of moisture to be removed from a given quantity of products.
- Harvesting period during which the drying is needed.
- The daily sunshine hours for the selection of the total drying time
- The quantity of air needed for drying.
- Daily solar radiation to determine energy received by the dryer per day.
- Wind speed for the calculation of air vent dimensions.

Design procedure

The size of the dryer was determined as a function of the drying area needed per kilogram of Product to be dried. The drying temperature was established as a function of the maximum limit of temperature the fruit might support. From the result of preliminary experiments on the crop, the optimal drying temperature was 55°C and final moisture content of carrots for storage is 18% w.b. the corresponding relative humidity is 16%.

Heat exchanger

The exhaust gases of diesel engine containing pollutants and contaminants that is toxic, so it is not safe when used directly as the drying air in foodstuffs. The use of heat exchangers is one of the technologies to separate heat and pollutants contained in exhaust gases, which can generate hot air that is clean, free of smoke, dust and ash that food protected from contamination. Based on the construction and characteristics, heat exchangers differentiated into several types, i.e. shell and tube, double pipe and compact heat exchangers.

![Fig.1 Copper tube heat exchanger](image)

Heat exchangers of compact type have several advantages, among others large heat transfer surface per unit volume of the core, small dimensions, material is easy to obtain, high effectiveness, suitable for gas fluid on both sides and no possibility of contamination between the two fluids.

Diesel engine

In a diesel engine combustion cycle, there is the energy balance of fuel combustion, 35% of energy used as the work, 20% of the energy is lost as the engine coolant, 10% is lost by radiation and 35% is lost with the exhaust gas. Quality waste heat from the flue gas are high temperature, and the greater potential value for heat recovery. Heat lost with the exhaust gas of 35% is a potential that can be utilized for various purposes such as for steam power plants, foodstuffs and agricultural products dryers, heating, or for other purposes. There are two main criteria to utilize exhaust gas as a heating are exhaust gas temperature and exhaust gas mass flow rate. Diesel engine exhaust gas temperature can reach 200 °C depending on the power and load variations. Exhaust gas mass flow rate correlated with the amount of engine power, the volume of a cylinder, engine rpm, as well as the fuel air ratio.

Arrangement of Heat exchanger

The copper tubes are arranged at the bottom of the trays. The copper tubes get heated due to the flow of exhaust gases from the engine. The natural air entering through the duct passes through the copper tubes and the temperature of the air increases. Then the hot air passes through the trays and removes the moisture from the product which is kept on the trays and the cabin temperature also increases significantly.
Arrangement of thermocouples

The thermocouples are used to indicate the temperature of the air. The three thermocouples are arranged at where temperatures are needed. The first thermocouple is placed at the inlet of the air, second one placed at the entry of the hot air in to the chamber; third one is placed at the exit of the hot air at the vents. The thermocouple ire’s are connected to the digital thermometer for taking the temperatures as follows.

ADVANTAGES

- Dryer will work efficiently even in cloudy days.
- Higher drying temperature in shorter time.
- Protect from insects, dust, and animals.
- Better control of the drying process.
- Reduces land required.
- Dryers protect food from sunlight (UV rays), better preserving nutrition & colour.
- May reduce labour required.
- Faster drying time reduces chances of spoilage.
- More complete drying allows longer storage.
- Allows more control.

DISADVANTAGES

- Quality of products is not obtained in some cases.
- Adequate solar radiation is required.
- It is more expensive

RESULTS

Temperature variation in the dryer
(Natural convection, carrot)

Temperature variation in the dryer
(Exhaust gas Drying, Carrot)
Temperature variation in the dryer
(Exhaust gas and Solar Drying, Carrot)

**Temperature variation**

<table>
<thead>
<tr>
<th>Time in Hours</th>
<th>Temperature °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>150</td>
</tr>
</tbody>
</table>

**Weight Comparison**

<table>
<thead>
<tr>
<th>Time</th>
<th>Open drying in gms</th>
<th>Natural convection drying in gms</th>
<th>Exhaust gas Drying</th>
<th>Combine Exhaust and solar Drying</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 mins</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>1 hr</td>
<td>156.4</td>
<td>180</td>
<td>185.5</td>
<td>163.2</td>
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<tr>
<td>2 hr</td>
<td>124.4</td>
<td>144</td>
<td>161.1</td>
<td>129.2</td>
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</tbody>
</table>

**CONCLUSION**

Present work is focused on hybrid solar dryers. An experimental study of how hybrid solar dryers fare compared to other dryers, various design modifications and enhancement techniques applied to them is done. The Hybrid dryers are cost effective type of dryers and are easy to fabricate and use. Hybrid solar dryers do not use any auxiliary equipment and protects the products from external contamination and it can use in unfavorable weather condition and also it is used in night time. These are the simplest form of dryers and are easy to fabricate, use and cost-effective.

From the measurement, calculation, design and testing of heat exchanger for drying vegetables several conclusions are obtained.

[1] Diesel engine which emits the exhaust gases which has the potential to dry the vegetables is used.

[2] The design of heat exchanger made in accordance with the characteristics of the exhaust gas of diesel engines is a compact heat exchanger measuring length and diameter of each 0.56m, 0.13 m, using hallow shaped surfaces made of copper material with a thickness of 0.6 mm.

[3] Using the exhaust gas and solar energy in hybrid for drying besides more economical, it is also more environmentally friendly.

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