DESIGN AND FABRICATION OF SOLAR DRYER WITH REFRIGERATION

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Abstract - Solar energy is the most promising of the renewable energy sources. ‘Sun Drying’ is the most widespread method of food preservation in tropical and subtropical countries. It reduces the moisture content of the product and retain more of their nutritional value with less risk of spoilage by microorganisms. However being unprotected from rain, wind, dust and insects. Some of the problems associated with open air sun drying can be solved through the use of a solar dryer which comprises of a drying chamber and solar panels. The solar drying and refrigeration system utilizes solar energy to heat/cool air and to dry/cool any food substance loaded, which is beneficial in reducing wastage of agricultural products.

I. INTRODUCTION
Drying is one of the methods used to preserve food products for longer periods. Drying is a simple process of moisture removal from a product in order to reach the desired moisture content. The heat from the sun coupled with the wind has been used to dry food for preservation from several thousand years. The removal of moisture prevents the growth and reproduction of microorganisms like bacteria, yeasts and molds causing decay and minimizes many of the moisture-mediated deteriorative reactions. Drying materials at optimum temperatures and in a shorter amount of time enables them to retain more of their nutritional value such as vitamin C.

Most of the problems relating to the marketing of fruits and vegetables can be traced to their perishability. Perishability is responsible for high marketing costs, market gluts, price fluctuations and other similar problems. Deterioration of fruits and vegetables during storage depends largely on temperature. One way to slow down this change and so increase the length of time fruits and vegetables can be stored, is by lowering the temperature to an appropriate level. Considering cooling demand increases with intensity of solar radiation, solar refrigeration has been considered as a logical solution.

II. NEED FOR DRYER AND REFRIGERATION
The purpose of drying is to remove moisture from the agricultural produce so that it can be processed safely and stored for increased periods of time. Crops are also dried before storage or, during storage, by forced circulation of air, to prevent spontaneous combustion by inhibiting fermentation. It is estimated that 20% of the world’s grain production is lost after harvest because of inefficient handling and poor implementation of post-harvest technology. Grains and seeds are normally harvested at a moisture level between 18% and 40% depending on the nature of crop. These must be dried to a level of 7% to 11% depending on application and market need. Once a cereal crop is harvested, it may have to be stored for a period of time before it can be marketed or used as feed. The length of time a cereal can be safely stored will depend on the condition it was harvested and the type of storage facility being utilized. Grains stored at low temperature and moisture contents can be kept in storage for longer period of time before its quality will deteriorate. Some of the cereals which are normally stored include maize, rice, beans.
India is the largest producer of fruits and second largest producer of vegetables in the world. In spite of that per capita availability of fruits and vegetables is quite low because of post-harvest losses which account for about 25% to 30% of production. Besides, quality of a sizable quantity of produce also deteriorates by the time it reaches the consumer. The need for such solutions is huge. In India alone, 10 million tons of cold storage capacity is required to prevent the over 30% wastage of perishable produce. The current facilities are accessible only to the big farmers/middlemen who hoard when supplies peak, leading to huge price fluctuations. The bottom of the pyramid (BOP) i.e. the small farmer loses out, as they have to sell their produce at very low prices right after harvest. This design is ideal for the rural segment, as it does not depend on grid electricity and after a 2-year breakeven, leads to over 40% increase in their profits. The estimated annual production of fruits and vegetables in the country is about 130 million tones. This accounts for 18% of our agricultural output. Due to diverse agro climatic conditions and better availability of package of practices, the production is gradually rising. Although, there is a vast scope for increasing the production, the lack of cold storage and cold chain facilities are becoming major bottlenecks in tapping the potential. The cold storage facilities now available are mostly for a single commodity like potato, orange, apple, grapes, pomegranates, flowers, etc. which results in poor capacity utilization.

Thus there is great need for large capacity cold storage and drying facilities in our country

III. CONSTRUCTION DETAILS

3.1 DRYER UNIT
The solar dryer consists of the solar collector (air heater), the drying cabinet and drying trays:

**DRYING CABINET:** Direct solar dryers use only the natural movement of heated air. A part of incidence solar radiation on the glass cover is reflected back to atmosphere and remaining is transmitted inside cabin dryer. Further, a part of transmitted radiation is reflected back from the surface of the product. The remaining part is absorbed by the surface of the material. Due to the absorption of solar radiation, product temperature increase and the material starts emitting long wave length radiation which is not allowed to escape to atmosphere due to presence of glass cover unlike open sun drying

**DRYING TRAYS:** The drying trays are contained inside the drying chamber and were constructed from a double layer of fine chicken wire mesh with a fairly open structure to allow drying air to pass through the food items.

3.2 REFRIGERATION UNIT
The Vapour absorption refrigeration systems use a heat source instead of electricity to provide the energy needed to produce cooling. The most basic components of a vapour absorption cycle are the evaporator, absorber, pumps, generator, condenser and throttle valves. In this system the NH3 is used as a refrigerant and the water is used as an absorbent.

**EVAPORATOR:** The low pressure and low temperature liquid refrigerant enters the evaporator section where it absorbs the heat from the substance kept in the evaporator and make the substance cool and refrigerant converted into low pressure and high temperature vapour refrigerant. Hence this process is constant pressure process.

**ABSORBER:** The absorber is a sort of vessel consisting of water that acts as the absorbent, and the previous absorbed refrigerant. Thus the absorber consists of the weak solution of the refrigerant
(ammonia in this case) and absorbent (water in this case). When ammonia from the evaporator enters the absorber, it is absorbed by the absorbent due to which the pressure inside the absorber reduces further leading to more flow of the refrigerant from the evaporator to the absorber. At high temperature water absorbs lesser ammonia, hence it is cooled by the external coolant to increase it ammonia absorption capacity.

**PUMP:** When the absorbent absorbs the refrigerant strong solution of refrigerant-absorbent (ammonia-water) is formed. This solution is pumped by the pump at high pressure to the generator. Thus pump increases the pressure of the solution.

**GENERATOR OR HEAT EXCHANGER:** The refrigerant-ammonia solution in the generator is heated by the external source of heat. This is can be steam, hot water or any other suitable source. Due to heating the temperature of the solution increases. The refrigerant in the solution gets vaporized and it leaves the solution at high pressure. The high pressure and the high temperature refrigerant then enters the condenser, where it is cooled.

**CONDENSER:** The vapour refrigerant at high pressure and temperature enters the condenser where it is condensed to low temperature refrigerant.

**EXPANSION VALVE:** Now this low temperature vapour refrigerant enters into expansion valve where it expand adiabatically, to low pressure and low temperature refrigerant.

**IV. WORKING PRINCIPLE:**

![Diagram of the refrigeration system](image)

The liquid refrigerant present in the evaporator gets vaporized by absorbing heat from the substances present in that section into low pressure vapour refrigerant. The vapour refrigerant then enters into the absorber section where absorbent (water) is present. The existence of absorbent in the absorber, it changes into a strong hot water –ammonia solution. This strong solution of low pressure is pumped into the generator (heat exchanger) at high pressure. The strong solution in the generator is heated up by using a heater separating solution and vapour. This weak absorbent solution left in the generator is returned to the absorber and the high pressure vapour refrigerant is passed into the condenser. The vapour refrigerant at high pressure and temperature enters the condenser where it is condensed to low temperature refrigerant.
The waste heat from the condenser is utilized in the drying unit. Now the high pressure refrigerant passes through expansion valve where it is reduced to low pressure and low temperature liquid refrigerant. And this liquid refrigerant again enters the evaporator section and the cycle repeats.

V. CALCULATIONS

5.1 Mathematical Calculations For Each Component

Operating temperatures and pressures:
The most favourable working temperatures for ammonia and water refrigeration system are:
Generator Temperature, \( T_g = 60-99 \) °C
Condenser Temperature, \( T_c = 28-60 \) °C
Absorber Temperature, \( T_a = 16-32 \) °C
Evaporator Temperature, \( T_e = 10-20 \) °C

The operating temperatures chosen are:
Generator Temperature, \( T_g = 65 \) °C
Condenser Temperature, \( T_c = 30 \) °C
Absorber Temperature, \( T_a = 30 \) °C
Evaporator Temperature, \( T_e = 10 \) °C

The temperature which is lowest in the condenser is theoretically chosen for the calculations.

Operating pressures:
The temperature is directly proportional to the pressure that is the reason for the operating pressures to correspond to the temperatures of the system. Taking a theoretical example for the system, the saturation pressure for condensation in the Condenser at 300°C can be obtained from steam tables and is equal to 0.0425bar. Also 1bar = 750.06mm of Hg. Therefore 0.0425bar = 32mm of Hg which is also equal to Generator pressure because Condenser and Generator operate at same pressure. Now the saturation pressure for saturated vapours formed in the Evaporator at a temperature of 10°C can again be obtained from steam table which comes to be 0.0081bar or 6.1mm of Hg which will also be equal to the Absorber pressure as both operate under same pressure.

Capacity of the system or Refrigerating Effect (\( Q_e \)) = 3.788kW (Theoretical value)

Calculation of enthalpy (\( h \)) at every designated point of the system:

Obtaining heat transfers for each component:

**Evaporator**
Applying the Energy balance
\[ Q_e = \text{Refrigerating effect} = 3.788kW = m (h_{10} - h_9) \]
\[ m = 3.788 / (2508.70 - 125.70) \]
\[ m = 1.58 \times 10^{-3} \text{ kg/s} \]
Or \( m = 1.58 \times 10^{-3} \text{ kg/s} \) = mass flow rate of refrigerant.
Now, Circulation Ratio, \( \lambda = \xi_{WS} / (\xi_{SS} - \xi_{WS}) \)
\[ \lambda = 0.48 / (0.56 - 0.48) = 6 \]
Therefore, \( m_{SS} = \lambda m = 13.22 \times 10^{-3} \text{ kg/s} \)
and \( m_{WS} = (1 + \lambda) m = (1 + 6) \times 2.203 \times 10^{-3} = 15.42 \times 10^{-3} \text{ kg/s} \)

**Absorber**
Applying the Energy balance
\[ Q_a = m (h_{10} + m_{SS}x_{h5} - m_{WS}x_{h1}) \]
\[ = (2.203 \times 10^{-3} \times 2508.70) + (13.22 \times 10^{-3} \times 195) - (15.42 \times 10^{-3} \times 180) \]
\[ = 5724W \]
\[ = 5.724kW \]
Solution Heat Exchanger (HX)

Writing the Energy balance for Heat Exchanger,

\[ m_{ws}(h_3-h_2)=m_{ss}(h_4-h_5) \]

\[ 15.42 \times (h_3+180) = 13.22 \times (-120+195) \]

\[ h_3 = -115.70 \text{ kJ/kg} \]

**Generator**

\[ Q_g = m_7h_7 + m_8h_4 - m_9h_3 \]

\[ = (2.203 \times 10^{-3} \times 2621.32) + (13.22 \times 10^{-3} \times -120) - (15.42 \times 10^{-3} \times -115.70) \]

\[ = 6330 \text{ W} \]

\[ = 6.33 \text{ kW} \]

**Condenser**

\[ Q_c = m_8(h_7-h_8) = 2.203 \times 10^{-3} \times (2616.50-125.70) \]

\[ = 5487 \text{ W} = 5.487 \text{ kW} \]

\[ \text{COP} = \frac{Q_c}{Q_g} = \frac{3788}{6330} = 0.598 \]

**Coefficient of Performance of the refrigeration system = 0.598**

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