# Solar Energy Conversion Technology

## Solar Air Heaters

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- ✓ **Testing of solar air heater**
- ✓ **Application of solar air heaters in drying and electricity generation**

# Testing of Solar Air Heater

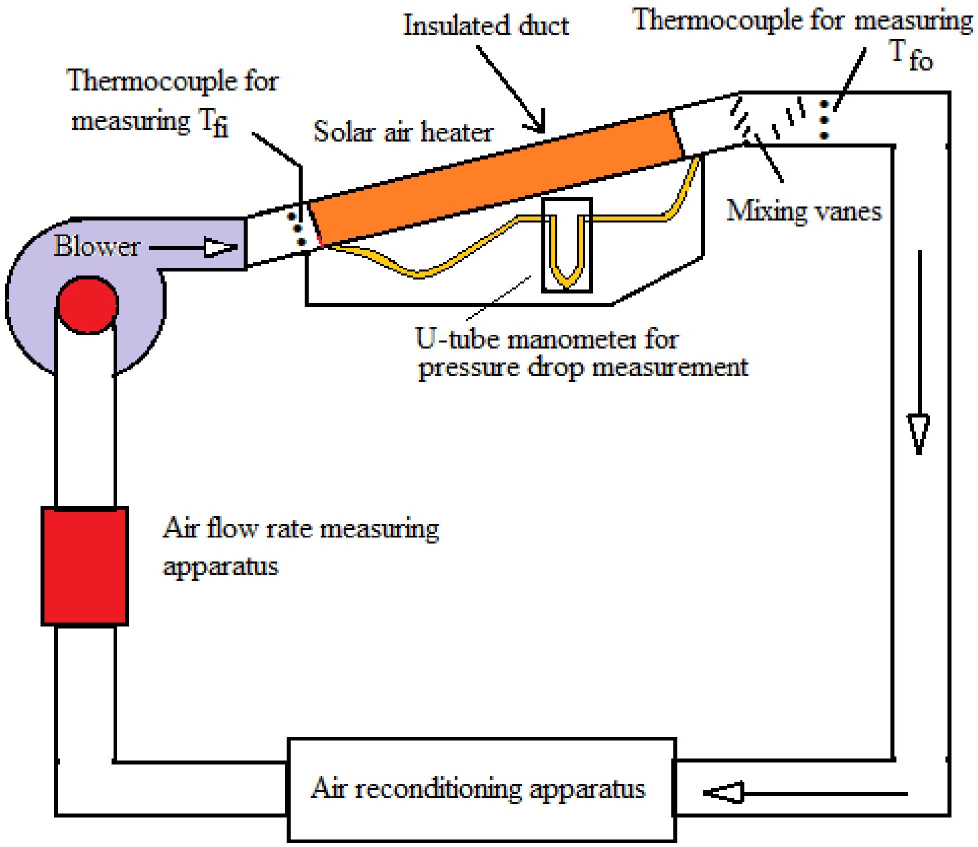
**Components:**

It is a closed loop consisting of

- ✓ A solar air heater to be tested
- ✓ A blower
- ✓ An apparatus for reconditioning the air which ensures that the air enters the air heater at the desired temperature

**Precautions:**

- ✓ Exit air has to be well mixed before the temperature is measured (Mixing is done with the help of vanes).
- ✓ Temperature need to be measured at different locations across the duct cross-section.

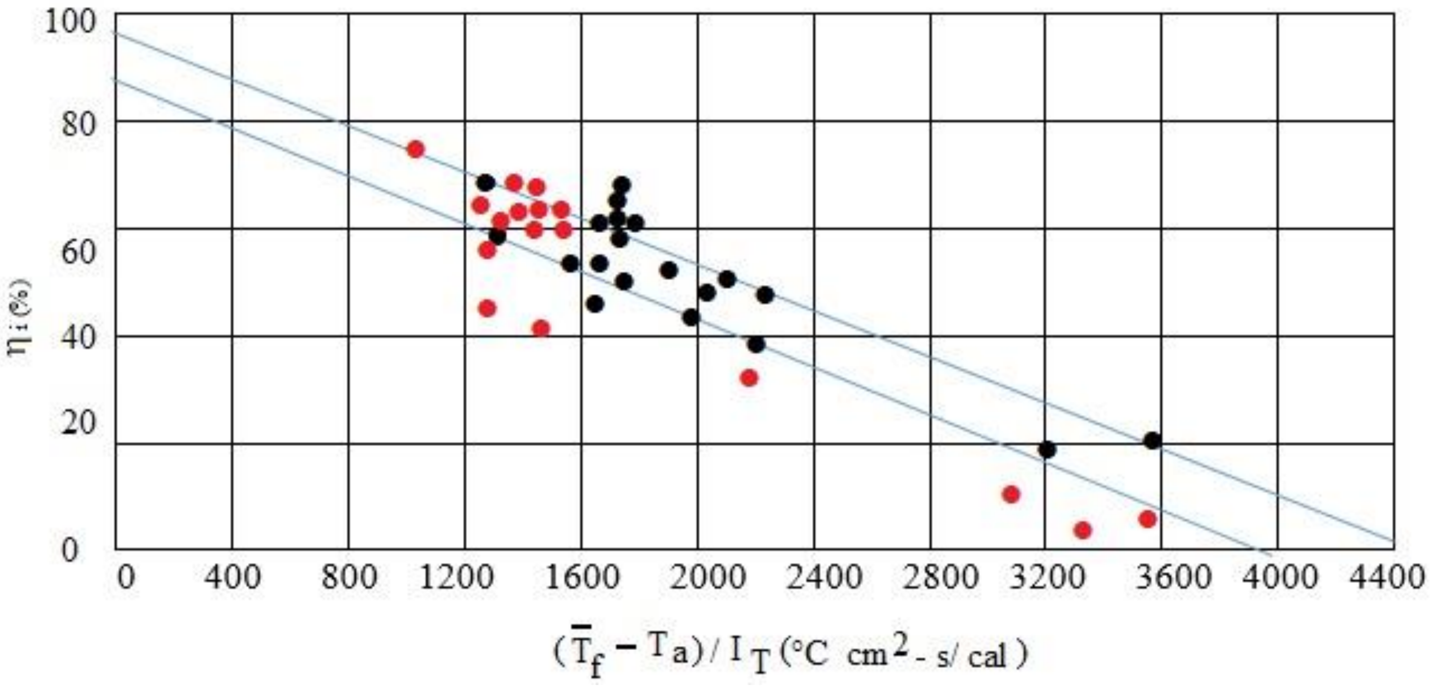



Testing Configuration for SAH

# Testing of Solar Air heater

Experimental results of Gupta and Grag

**Scatter of data is large**




Typical performance curves

# Comparison of testing of LFPC and SAH

- ✓ For LFPCs, changes in the value of mass flow rate do not appreciably affects the performance because of high values of the liquid side heat transfer coefficient.
- ✓ A single test curve is therefore, generally adequate for predicting the behavior of such collectors.

- ❖ In the case of SAHs, changes in the value of mass flow rate appreciably affects the performance because the value of the air side heat transfer coefficient is relatively low.
- ❖ In order to obtain complete information on a solar air heater, it becomes necessary to conduct tests over a range of mass flow rates with each flow rate yielding its own efficiency curve.

**Ex.1** The efficiency curves shown in Fig.1 are obtained for a solar air heater ($L_1$=1.2 m, $L_2$=0.9 m) which is tested over a range of flow rates varying from 25 to 200 kg/h. Find the efficiency which would be obtained and the corresponding mass flow rate if the air heater is used under the following conditions:

- ✓ Air inlet temperature: 54 $^oC$
- ✓ Air outlet temperature: 74 $^oC$
- ✓ Ambient temperature: 26 $^oC$
- ✓ Solar flux incident on collector face: 950 W/$m^2$

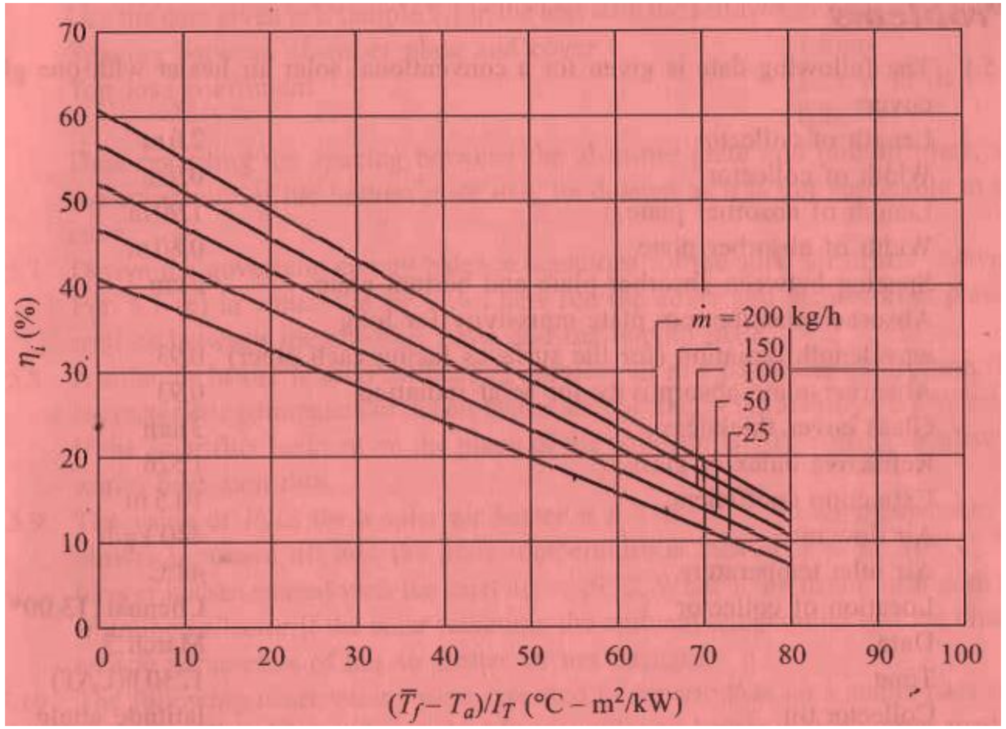


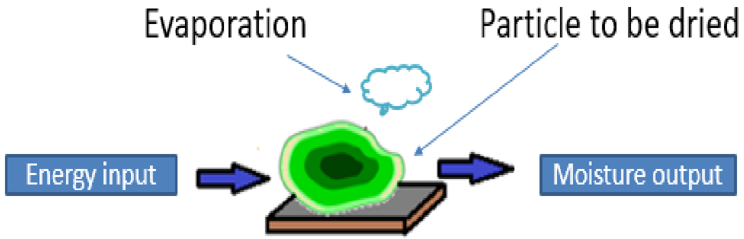

Fig.1: Efficiency curves

# Solar Drying of Agricultural Products

- Use of solar radiation  for drying is one of the oldest applications of solar energy
- Solar drying has not yet been widely commercialized
- Solar dryers are generally of small capacity
- Design of solar dryers are based  on empirical and semi-empirical data than in theoretical designs
- The majority of the solar dryer designs are used mainly for drying of various crops either for family use or for small-scale industrial production

# Drying principle

- The large portion of energy consumed during drying is for transforming liquid water into its vapour (L =2258 kJ/kg at 101.3 kPa)
- Water may be contained in various forms (free water, bound water etc.) – directly related to the drying rate.
- Free water is regarded as unbound and the product is non hygroscopic.
- Bound moisture is trapped in closed capillaries and the material is called hygroscopic.




Process of moisture removal from a solid by using thermal energy input.

- Hot air drying involves the simultaneous action of heat and mass transfer.

- Moisture content is expressed either on dry or wet basis
- Wet basis: expressed as the ratio of weight of moisture content per unit of wet material.

$$W = \frac{m_w}{m_w + m_d} \text{ kg per kg of mixture}$$

$m_w$ = mass of water

$m_d$ = mass of dry solid

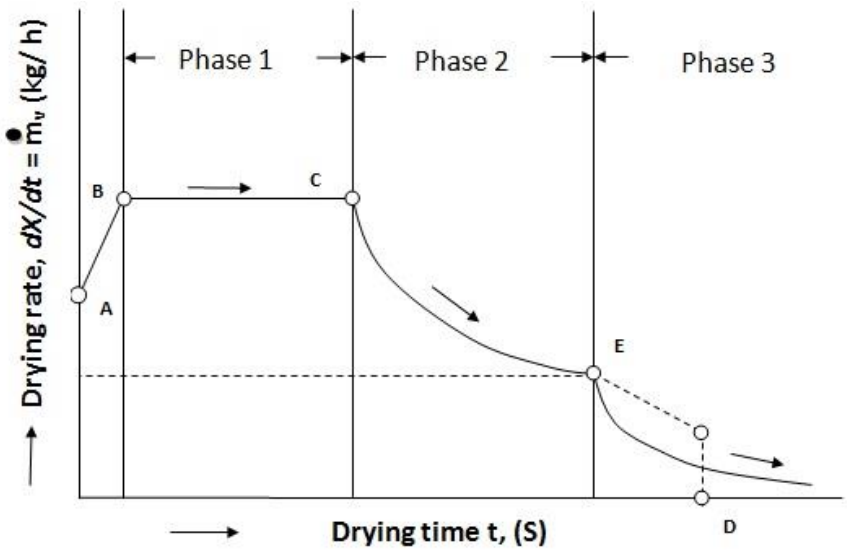
- Dry basis: expressed as the ratio of water content to the weight of dry material.

$$X = \frac{m_w}{m_d} \text{ kg of water per kg of dry material}$$

# Drying Rate

**Determined by the temperature and moisture content of the product as well as the temperature, relative humidity and velocity of the drying air.**

- ✓ AB is the time spent to heat up the material until the drying temperature is achieved.
- ✓ BC is the constant-rate drying
- ✓ CE the falling rate drying where flow of moisture from mass interior is decreased continuously.
- ✓ E there is still moisture inside the product, moisture removal takes place slowly by diffusion and drying can stop at point D.




**The drying period of these regimes, for hygroscopic products depends on the initial moisture content and the prescribed, moisture content, for safe storage**

# The water activity

- Water activity, is of great importance for food preservation as it is a measure and a criterion of microorganisms growth and probably toxin release, of enzymatic and non enzymatic browning development.
- For every food or agricultural product there exists an activity limit below which microorganisms stop growing.

$$\boxed{\begin{aligned}&\alpha_w = \left(p_w / p_w^*\right)_T \approx \varphi\\&p_w = \text{partial pressure of water solution}\\&p_w^* = \text{partial pressure of pure water, at the same temperature}\end{aligned}}$$

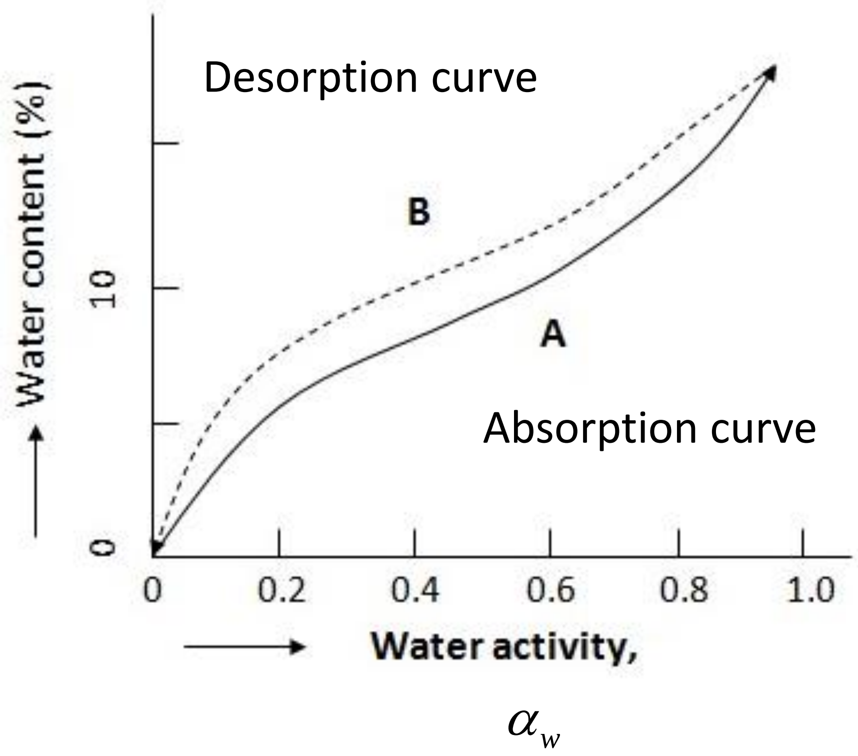
- ❖ Majority of the bacteria grows at $\boxed{\alpha_w = 0.85}$
- ❖ Mold and yeast grows at about $\boxed{\alpha_w = 0.61}$
- ❖ Fungi grows at about $\boxed{\alpha_w < 0.7}$

# Equilibrium moisture content

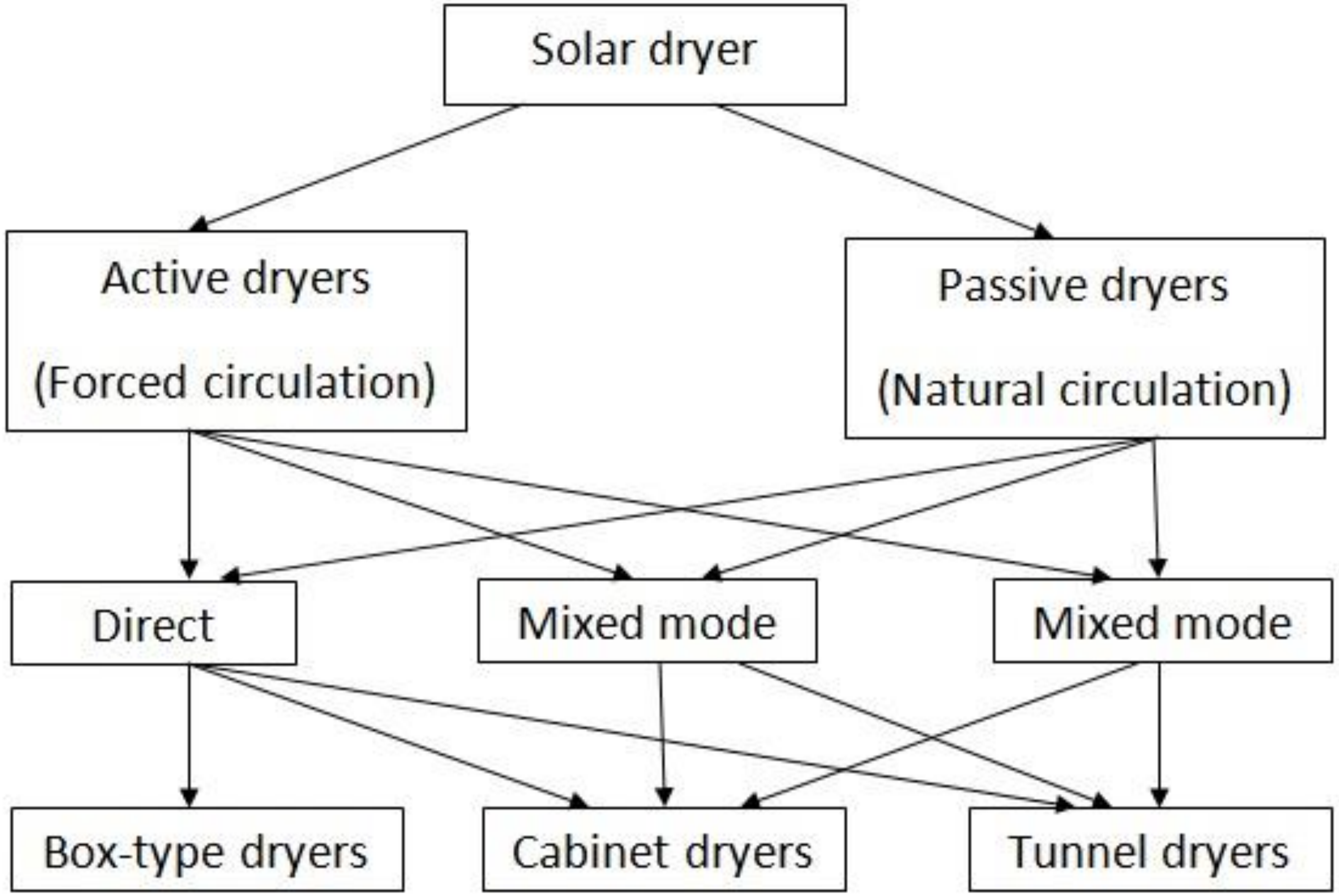
The equilibrium moisture content refers to the moisture content when the vapor pressure exerted by the moisture of product equals vapor pressure of the nearby ambient air.

# Sorption Isotherms

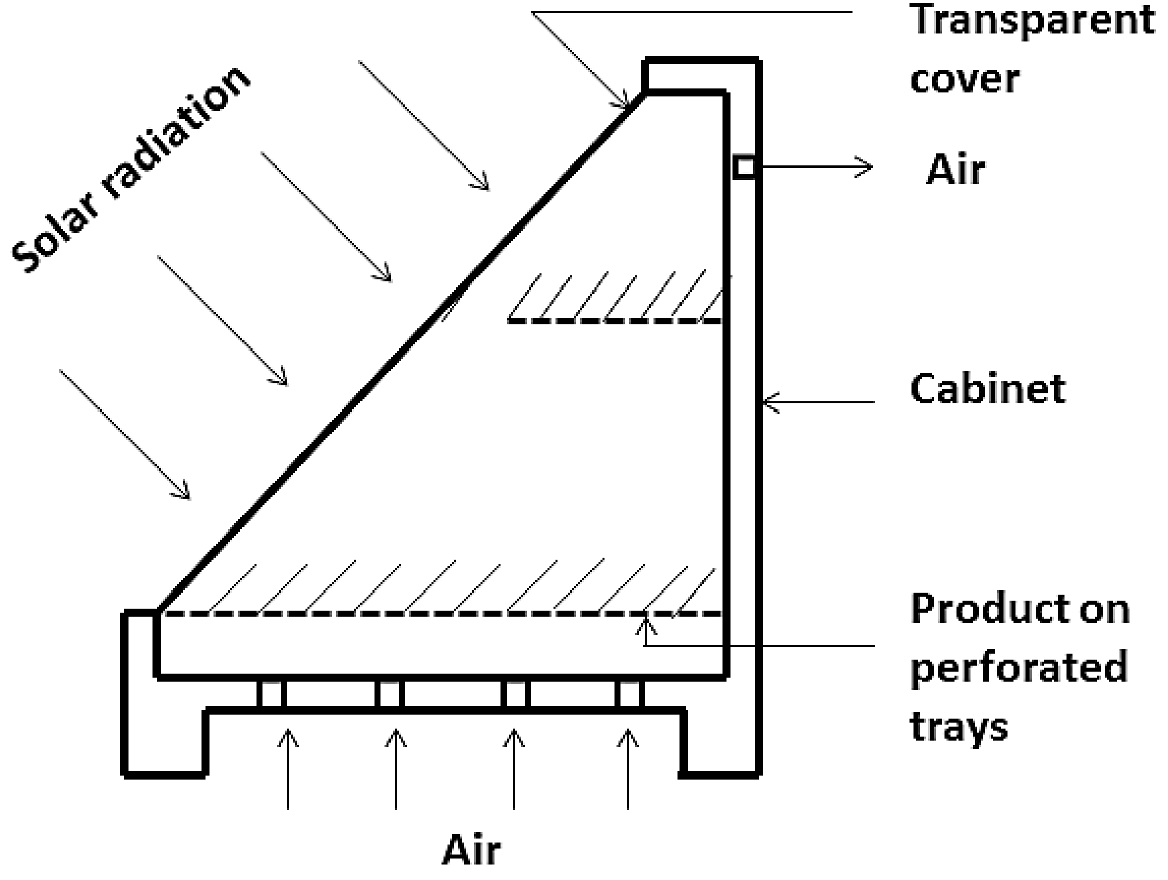
- Sorption isotherms are graphical representations of the relationship between moisture content at the corresponding water activity $\alpha_w$, over a range of values at constant temperature.
- It has slight hysteresis in re-absorbing water when the product has been dried.



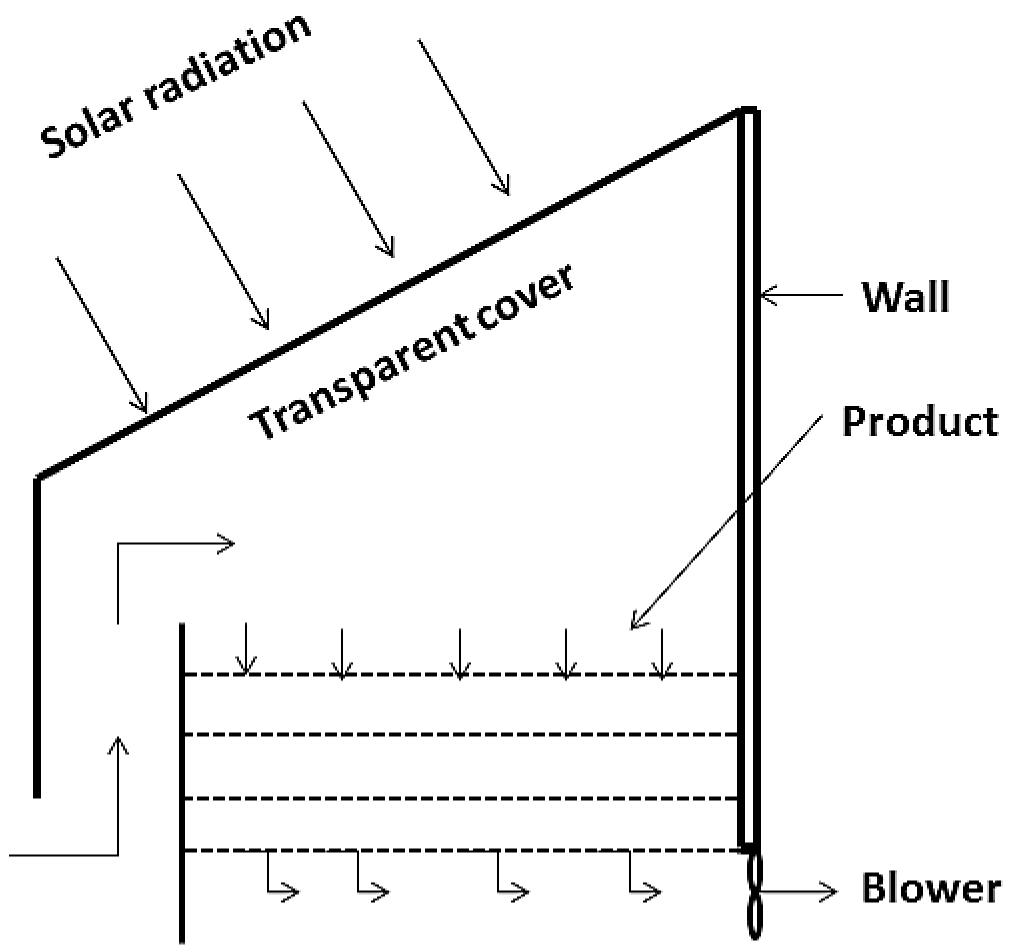
# Methods of Drying



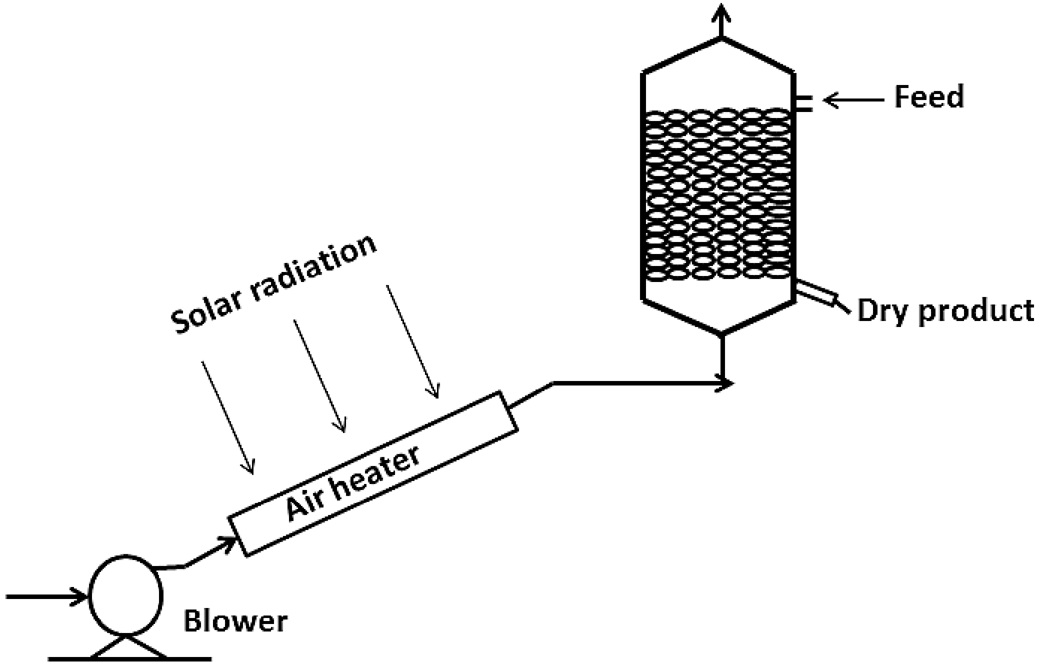
# Cabinet Dryer



# Forced circulation dryer (direct gain)



# Forced circulation dryer (indirect gain)




- ✓ Capacity: 10 t/day
- ✓ Initial moisture:11-14%
- ✓ Final moisture after drying: about 5%

# Drying Calculations

**Ex.2 Considering:**

- Total Mass, m= 100 kg
- Initial Moisture Content, $m_i$= 75 %
- Final Moisture Content, $m_f$= 14 %
- Drying Time, t= 2.8 hours
- Maximum allowed temperature, 70 °C
- Ambient temperature, $T_a$= 25 °C

**Water that has to be removed (based on wet material moisture content)**

$$\Rightarrow W = \frac{W_{in} - W_{out}}{100 - W_{out}} = \frac{74-14}{100-14} \approx 0.71 \text{ kg per kg of material}$$

- ✓ For 100 kg of product, water that has to be removed, 0.71 X 100 = 71 kg
- ✓ Amount of material dry in 2.8 hours = 100/2.8 = 35.71 kg/h
- ✓ Drying rate, $\dot{m}_v = 35.7 \times 0.71 = 25.35 \text{ kg/h}$

From the enthalpy–humidity diagram

- ❖ For air temperature 25 $^o$C and relative humidity 60%, the absolute humidity is 12.0 g/kg and enthalpy 56 kJ/kg .
- ❖ For air 70 $^o$C relative humidity is 6.5% and enthalpy is 100 kJ/kg .

$$\varphi_m = (100+57)/2 = 78.5\%$$

- ❖ For mean air humidity 78.5%, the air humidity at the exit of the dryer is 28 g/kg and the corresponding temperature is 35 $^o$C

**✓ Air needed for drying of 100 kg of raw material**

$$V_{air} = 100 \times \frac{\dot{m}_w}{\rho_{air}(x_m - x_a)} = 100 \times \frac{25.35}{1.227 \times (28-12)} = 129.13 \text{m}^3/\text{h}$$

✓ Heat needed to increase drying air temperature from 25 to 70 $^o$C

$$Q = \rho_{air}(h_2 - h_1) = 1.227 \times (100-56) \times 129.13$$
$$\Rightarrow Q = 6971.47 \text{kJ/h}$$

**❖ For 2.8 hrs of drying period the energy consumption is**

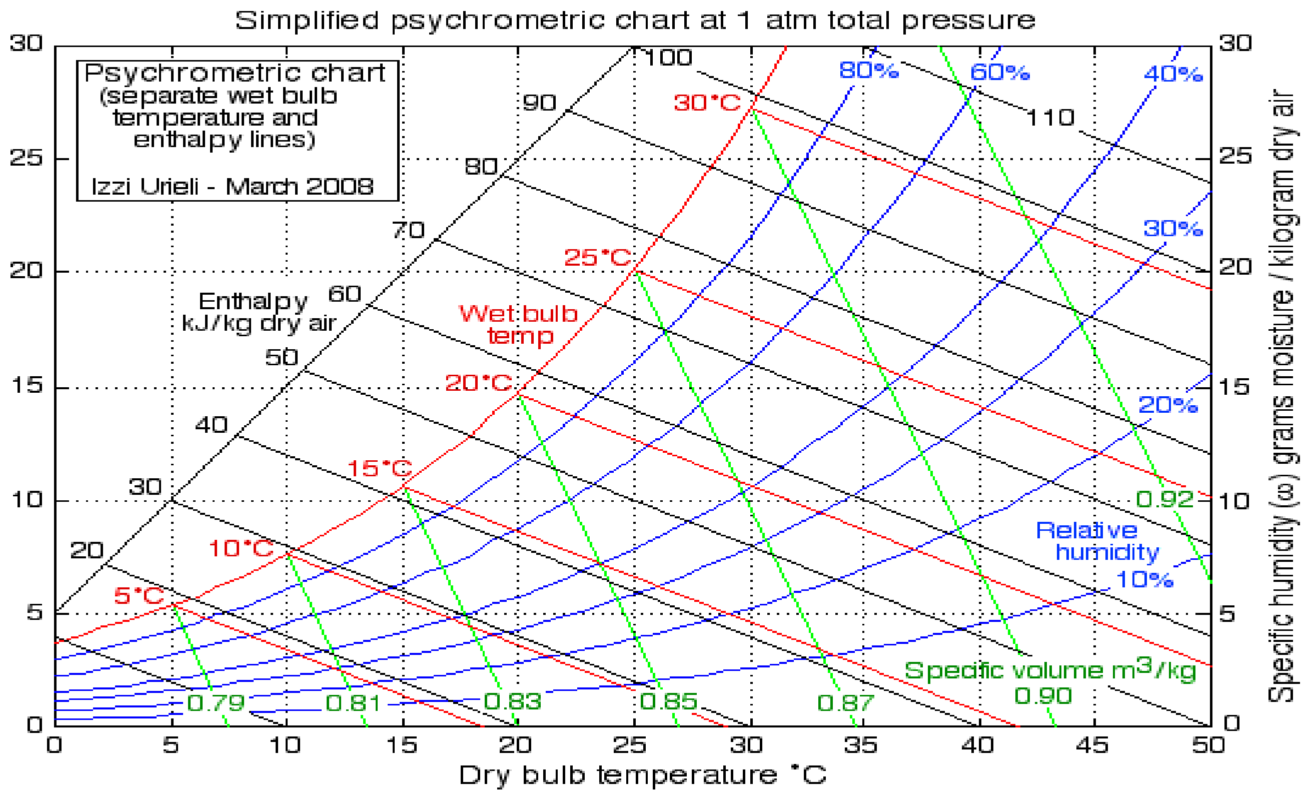
$$Q = 6971.47 \times 2.8 \text{kJ} = 19.52 \text{MJ}$$

**Energy Consumption:** $\boxed{Q = 6971.47 \times 2.8\text{kJ} = 19.52\text{MJ}}$

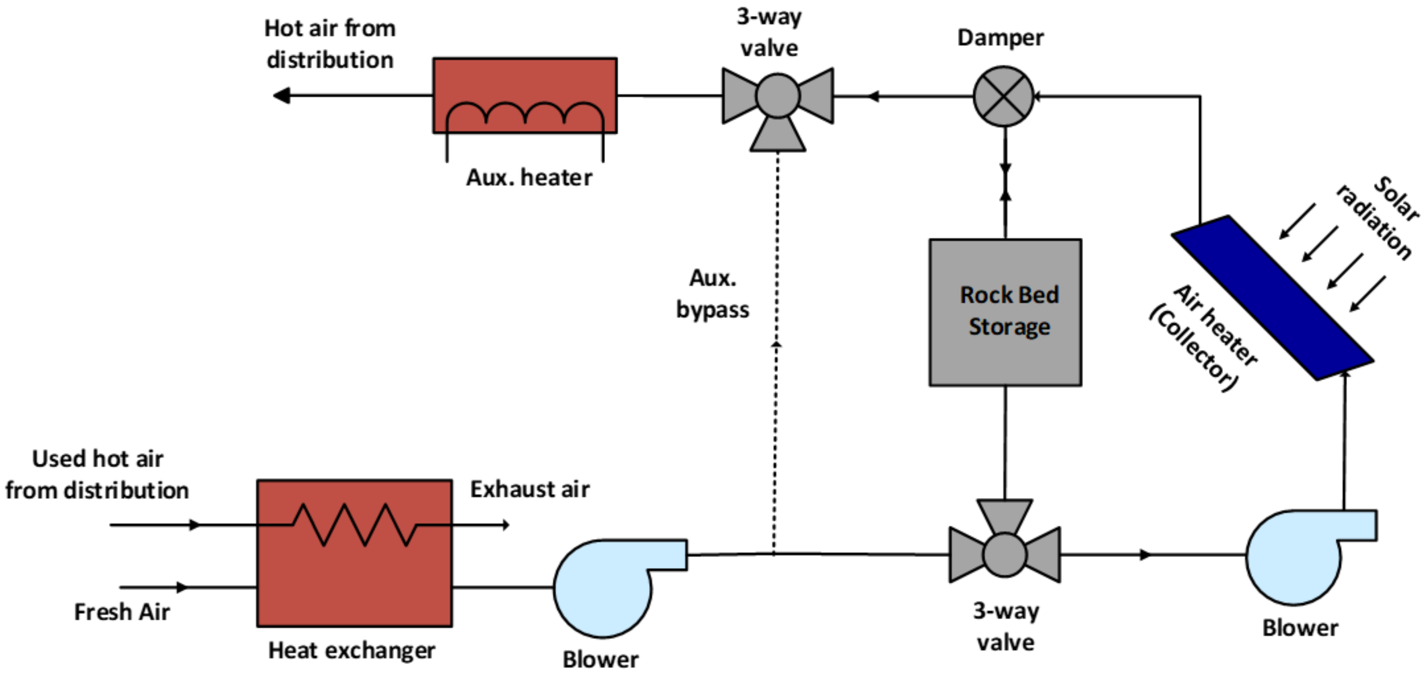
The collector area required may be calculated from the heat required value by taking into consideration the solar collector efficiency and the corresponding heat loss.

# Psychrometry & Drying

- Psychrometry is the study of the properties of mixtures of air and water vapor. The psychrometric chart is a graphical representation of the physical and thermal properties of atmospheric air.

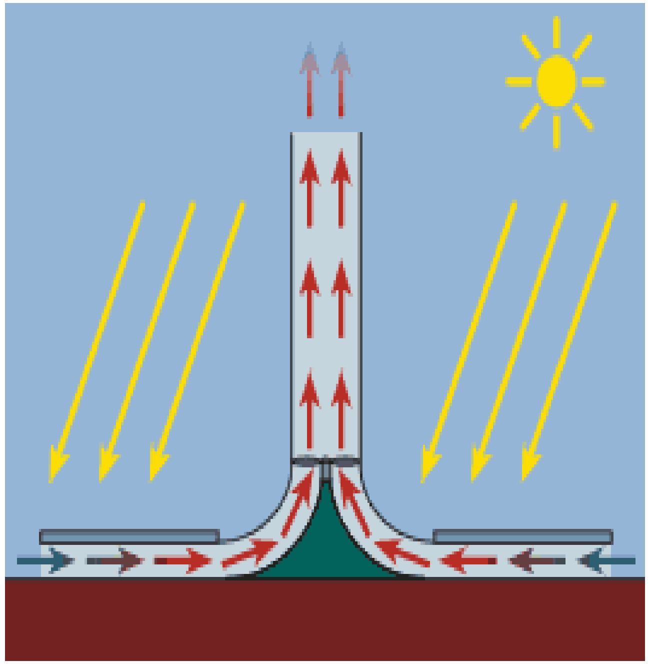


# Drying with storage



# Solar chimney power plant

Suggested in 1970s
(solar updraft tower power plant)



Consists of a
- ✓ tall central chimney
- ✓ circular greenhouse with transparent cover
- ✓ a metal frame to hold the green house.
- ✓ A fan and generator unit

- ✓ **Sunlight passing through the transparent cover causes the air trapped in the greenhouse to heat up to 10 to 20 °C.**
- ✓ **A convection system is set up in which hot air is drawn up- continuously replaced by fresh air drawn in the periphery of the greenhouse.**
- ✓ **The energy contained in the updraft air is converted into mechanical energy by a turbine located at the base of the chimney and then into electrical energy by conventional electrical generators.**

Pilot plant in Manzanares, Spain

- ✓ 195 m tall chimney, dia: 10.3 m.
- ✓ The solar collector area extended to a radius of 122 m from the chimney with glazing being 1.85 m above the ground.
- ✓ Total area of the glazing: 46000 m$^2$.
- ✓ Turbine: 4 nos of 5 m long blades and rotated at 1500 rpm to produce a peak output of 50 kW.

- The energy conversion efficiency of a solar chimney is low.
- Maximum conversion efficiency is given by

$$\boxed{\eta_{\max} = \frac{gH}{C_p T_a}}$$

$H$ = Height of the chimney tower

$T_a$= Temperature of the ambient air

**Ex:3** With following assumptions and given data, calculate the maximum possible conversion efficiency obtainable with the chimney. Also estimate the efficiency of the plant as a whole and the daily electrical output in a typical summer month (6.5 $kWh/m^2$).

*Given data:* height of the chimney, H=300 m, Solar collection area of the greenhouse : 50000 $m^2$, $C_p$ = 1005 J/kg-K, Ta = 305 K, **Assumptions:** (1) The turbine-generator set converts only 50% out of the maximum available energy into electrical energy, (2) the collection efficiency of the greenhouse: 25%

$$\eta_{\max} = \frac{gH}{C_p T_a} = \frac{9.81 \times 300}{1005 \times 305} = 0.0096 \times 100 = 0.96\%$$

$$\eta_{overall} = 0.25 \times 0.00960 \times 0.50 = 0.0012 \times 100 = 0.12\%$$

**Daily electrical output of the plant: 6.5 ($kWh/m^2$) x 50000 x 0.0012 = 390 kWh**

**200 MWe plant in Australia: 1 Km high and greenhouse collector of 7 km in diameter at base**

# Summary

- Testing of Solar Air Heater
- Applications of SAH
  - Drying of agricultural products
    - Drying characteristic curve
    - Drying calculation
  - Process heat in industry
  - SAH for power generation