ENCH 630
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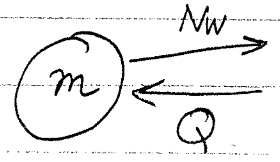
Drying Processes

Consider first evaporation from a droplet of pure liquid (e.g., a water droplet) or pure solid (e.g., ice crystal)



m = mass of droplet
N_W = flux of water vapor at droplet surface
Q = Conductive heat flux at droplet surface

Mass balance on droplet:

$$\frac{dm}{dt} = k'(H_{bulk} - H_S)\,a = N_W \cdot a$$

k' ← mass transfer coefficient based on humidity driving force

a ← area/unit volume

where H = humidity = $\frac{\text{mass of water}}{\text{mass of air}}$

S = droplet surface

Generally, heat transfer inside droplet is rapid so entire droplet is at T_S.

λ = heat of vaporation of liquid at T_S

Energy balance:

$$T_S C_{P,L} \frac{dm}{dt} = aQ + N_W(\lambda + C_{P,L} T_S)\,a$$

Q ← energy/area

$\lambda + C_{P,L} T_S = h_v$

aQ: conductive part of heat flux at droplet surface

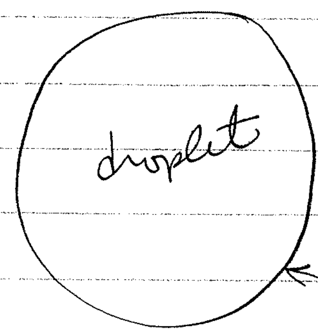
$N_W(\lambda + C_{P,L} T_S)\,a$: convective part of heat flux

Combining yields $Q = \frac{\lambda}{a}\frac{dm}{dt}$

Q is also given by the heat transfer coefficient:

$$Q = h(T_{bulk} - T_S)$$

h can be determined using standard correlations for heat transfer in the absence of mass transfer, although a correction factor for a mass flux (similar to the flux correction factors for mass transfer coefficients) may need to be applied. Example 18.5-1 of BSL gives a derivation for the film model. More specifically



energy flux at surface (since $v^* = 0$ due to no slip condition)

Eq. 18.4-6 of BSL $\rightarrow$ $e_s = \underbrace{-k(\nabla T)_s}_{\text{conductive part, i.e., } Q} + \underbrace{\Sigma(N_i \bar{H}_i)_s}_{\text{convective part}}$

Using the film model, we get for a single species diffusing

$$h = h^0 \frac{\Sigma N_A C_{pA}/h^0}{1 - \exp(N_A C_{pA}/h^0)}$$

h^0 ← heat transfer coefficient in the absence of mass transfer.

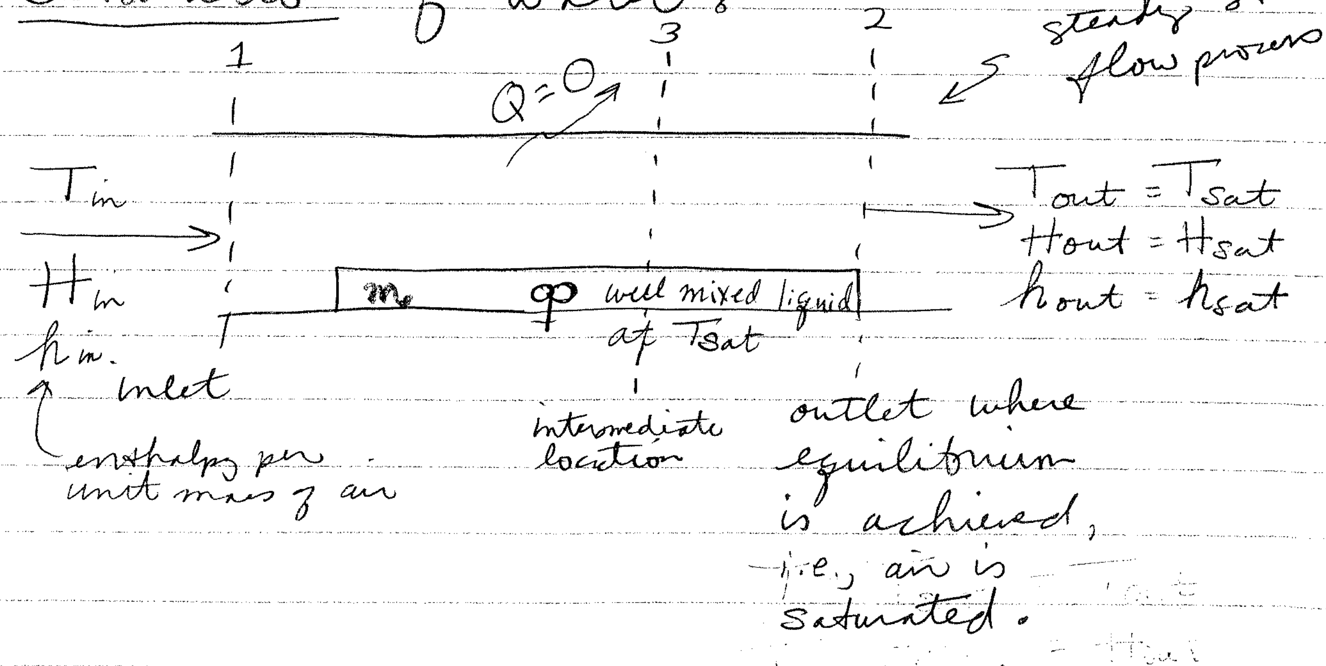
where $Q = -k(\nabla T)_s = h(T_{bulk} - T_s)$

Combining equations from above:

$$H_s - H_{bulk} = \frac{h}{\lambda k'} \left(T_{bulk} - T_s \right)$$

Given H_{bulk}, T_{bulk}, and the function $H_s(T_s)$ (i.e., the saturation humidity as a function of temperature), T_s and H_s can be solved for. T_s is termed the "wet bulb" temperature.

Consider next the adiabatic saturation of water:



mass balance: mass flow of air

$$\frac{dm}{dt} = G \left(H_{in} - H_{sat} \right)$$

(mass of liquid; H_{sat} = mass of vapor / mass of air)

enthalpy balance:

$$T_s C_{P,L} \frac{dm}{dt} = G \left(h_{in} - h_{sat} \right)$$

This leads to

$$\frac{h_{in} - h_{sat}}{H_{in} - H_{sat}} = C_{p_L} T_{sat}$$

This can be rewritten as follows:

$$C_{p\,air} T_{in} + H_{in} \overbrace{(\lambda_1^0 + C_{p,v} T_{in})}^{h_{v,in}}$$

heat of vaporization at reference temperature, assumed to be $T=0$. Thus temperatures in above equation can be considered to be $T - T_{ref}$ with T in °C.

$$- \{ C_{p\,air} T_{sat} + H_{sat} \underbrace{(\lambda_1^0 + C_{p,v} T_{sat})}_{h_{v,out}}$$

$$= C_{p_L} T_{sat} (H_{in} - H_{sat})$$

rearranging:

$$(C_{p\,air} + H_{in} C_{p,v})(T_{in} - T_{sat}) = \underbrace{(\lambda_v^0 - (C_{p,L} - C_{p,v}) T_{sat})}_{\lambda}(H_{sat} - H_{in})$$

λ ← heat of vaporization at T_{sat}

also $C_{p,\,humid\ air,\,inlet} = C_{p\,air} + H_{in} C_{p,v}$ = "humid heat"

$$\therefore \quad T_{inlet} - T_{sat} = \frac{\lambda}{C_{p,\,humid\ air,\,inlet}} (H_{sat} - H_{in}$$

Generally $\frac{h}{k' C_{p,\text{humid air}}}$ is termed the psychometric ratio (P). Employing the Chilton-Colburn j factors for heat and mass transfer ($j_H = j_D$), we set

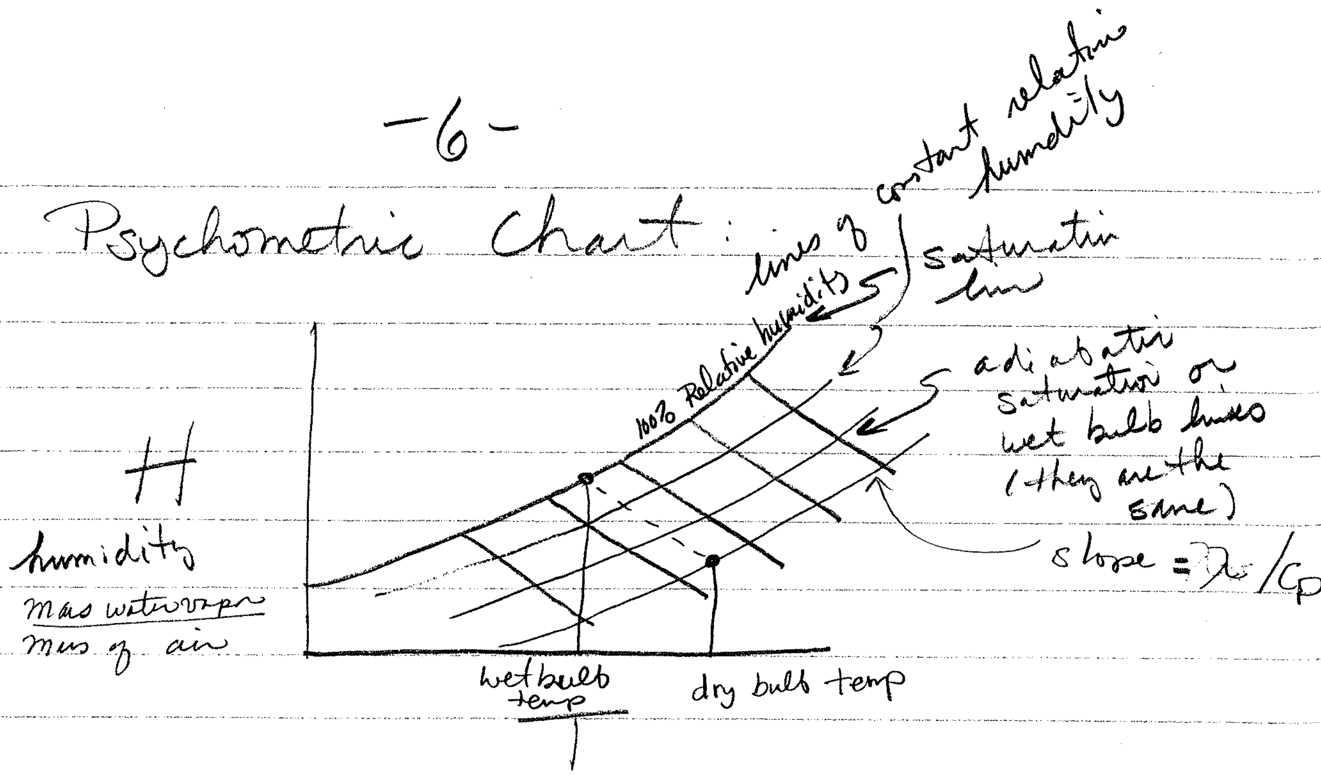
$$P = \frac{j_H}{j_D} \cdot \left({}^{Pr}/_{Sc} \right)^{2/3}$$

← Lewis number

Since, for air-water system, the Lewis number ≈ 1, and $j_H \approx j_D$, we have P = 1 so the adiabatic saturation temperature and wet bulb temperature are the same.

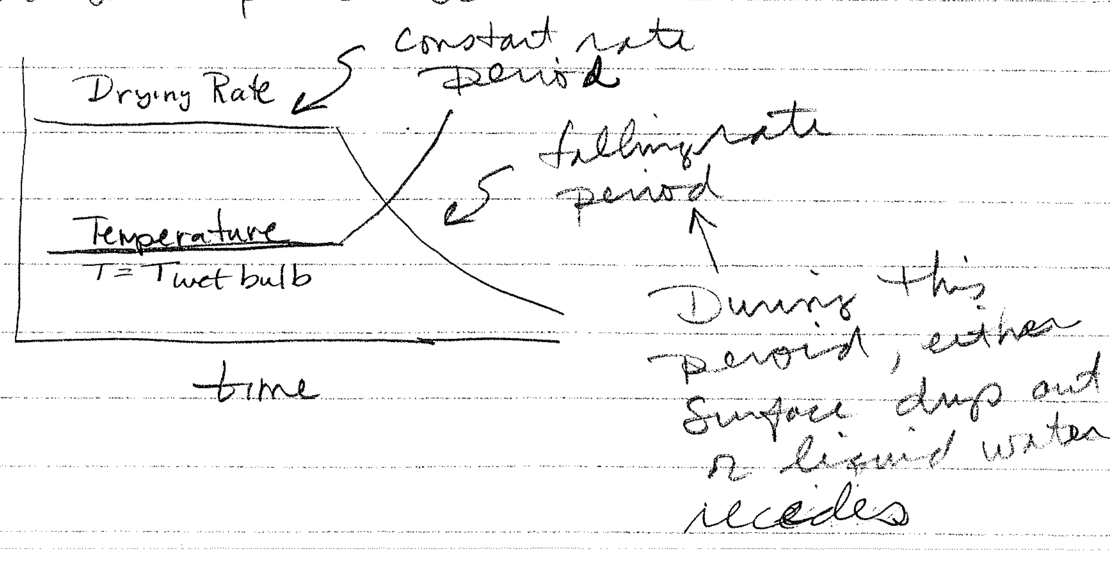
Note that the above energy and mass balances ~~apply~~ for adiabatic saturation also apply if the outlet is located at plane "3", where the air is only partially saturated, in which case we replace H_{sat} and T_{sat} with H_{out} and T_{out}. This defines the adiabatic saturation curve $H_{out}(T_{out})$.

Psychometric Chart:

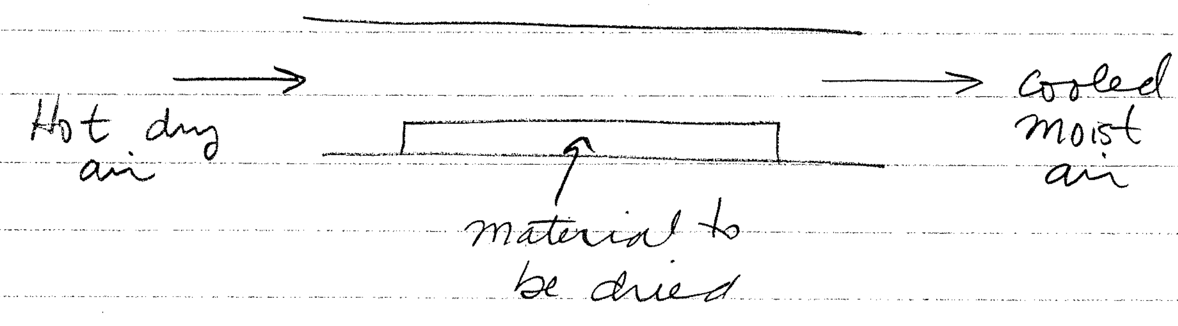


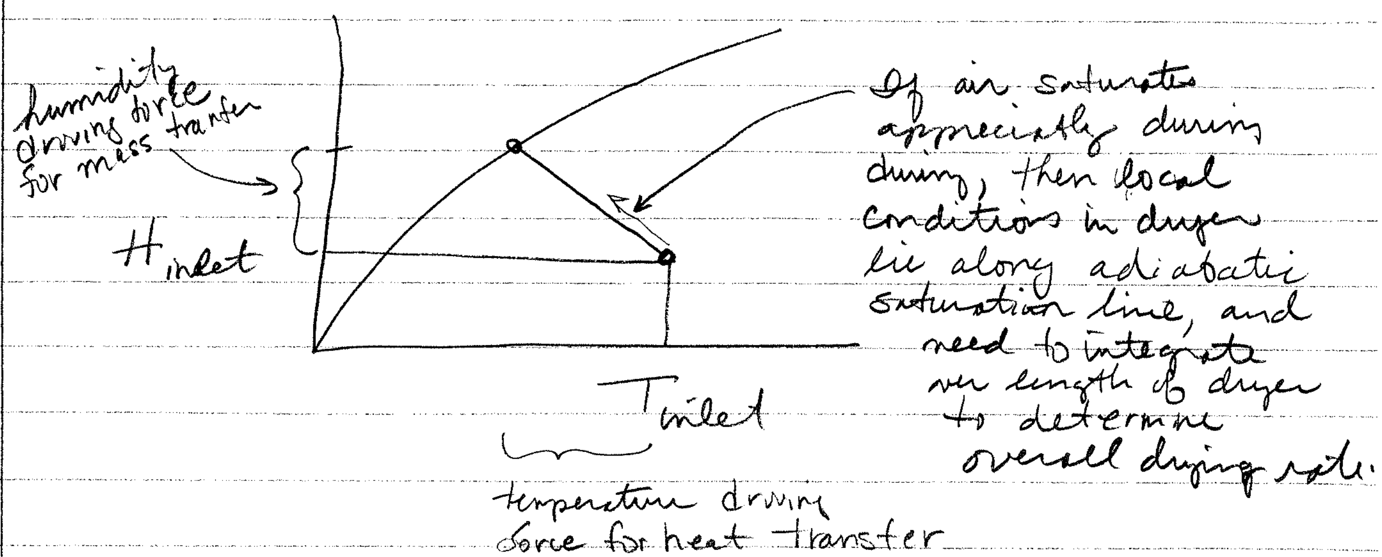
Drying Rates

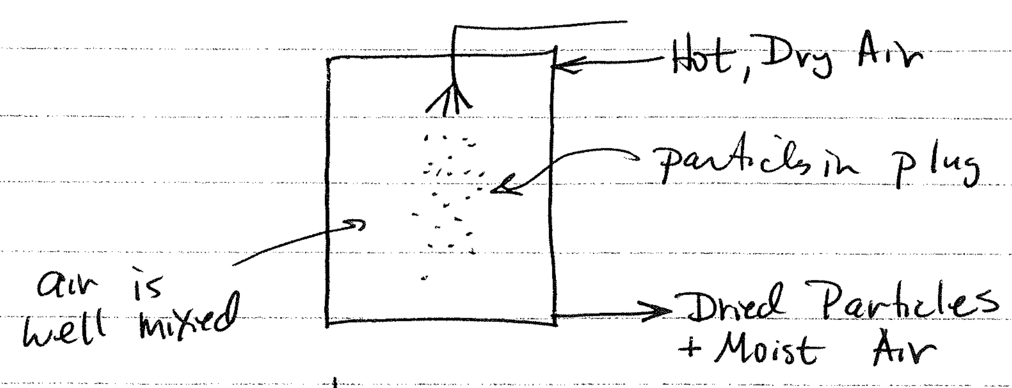
When drying porous solids or liquid solution of high molecular weight solute (e.g., wood or milk solution) then capillarity or the fact that the mole fraction of water remains near unity even if a large fraction of water is evaporated, means that for a significant period the material drys as if it was pure water

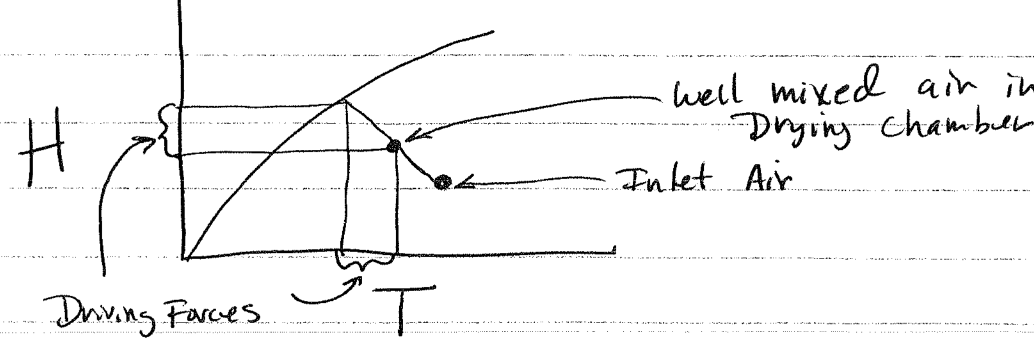


In general, for a tunnel dryer.



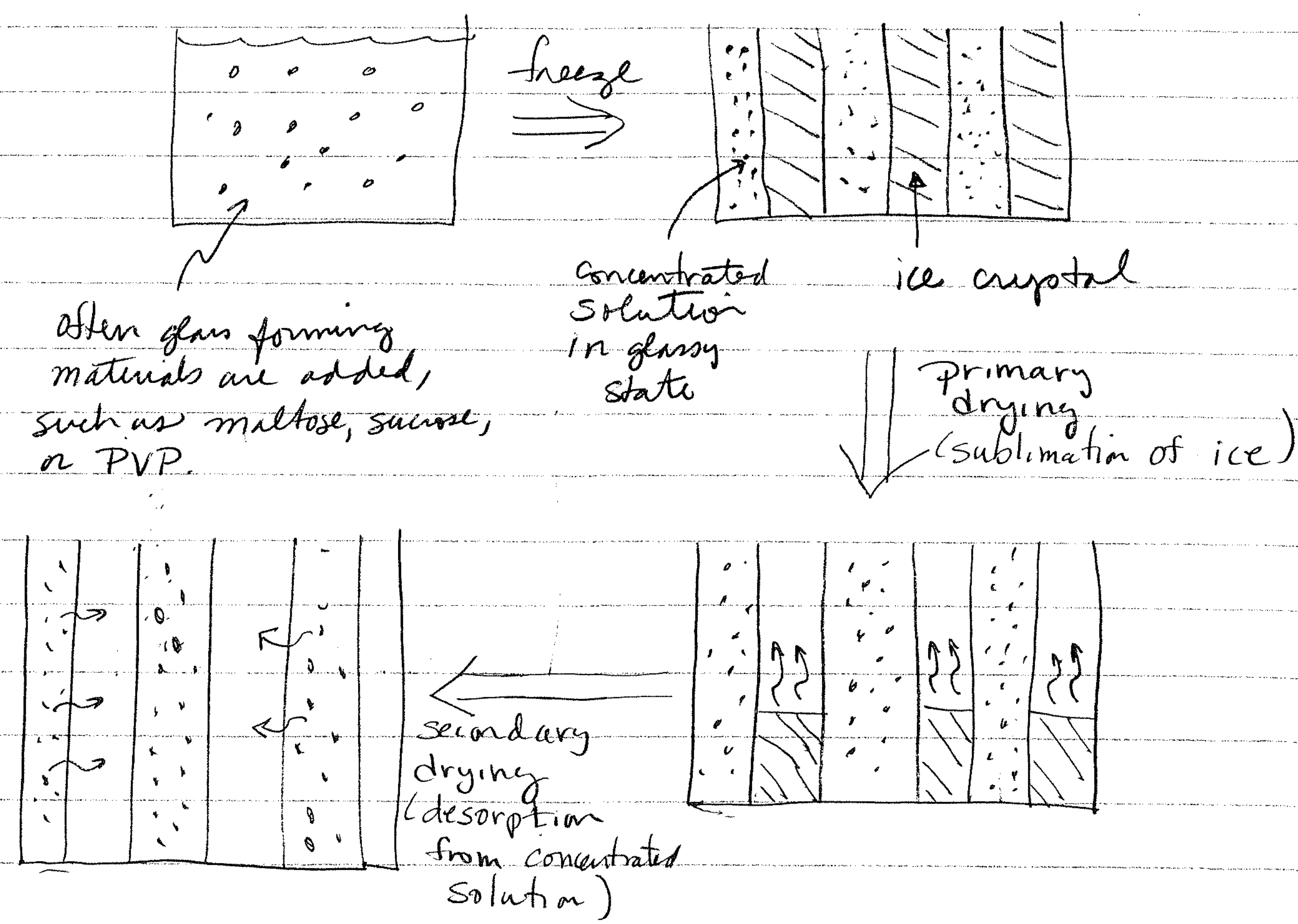




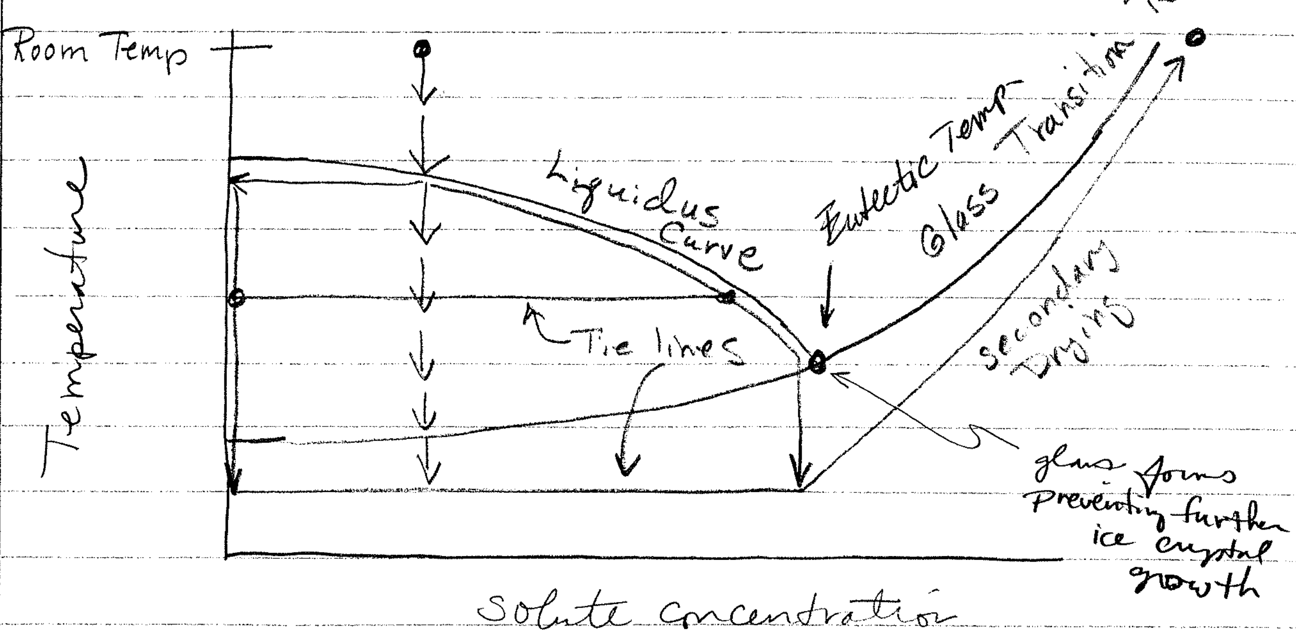


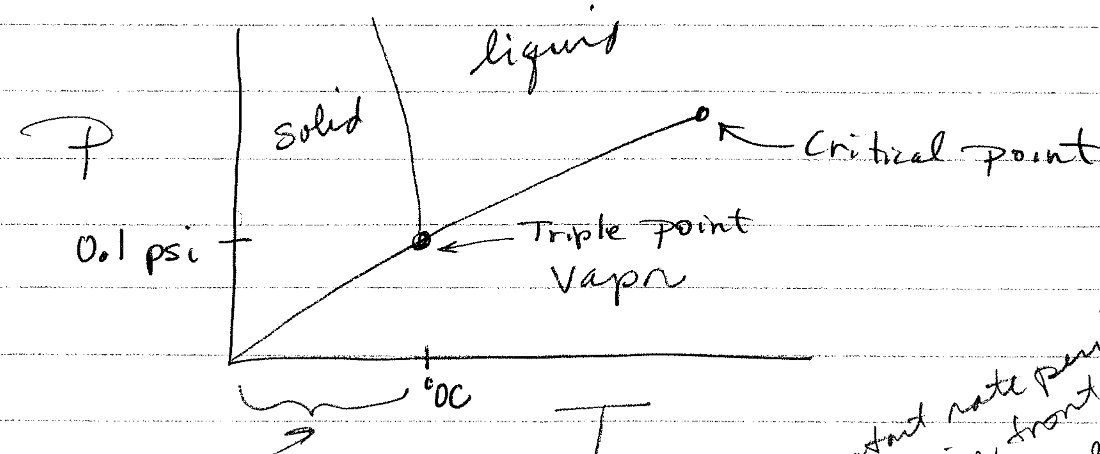
Freeze Drying (also termed "lyophilization" from the Greek "solvent loving" due to the fact that freeze dried material is highly porous and easy to re dissolve in a solvent) generally consists of two steps: freezing and sublimation

Freezing

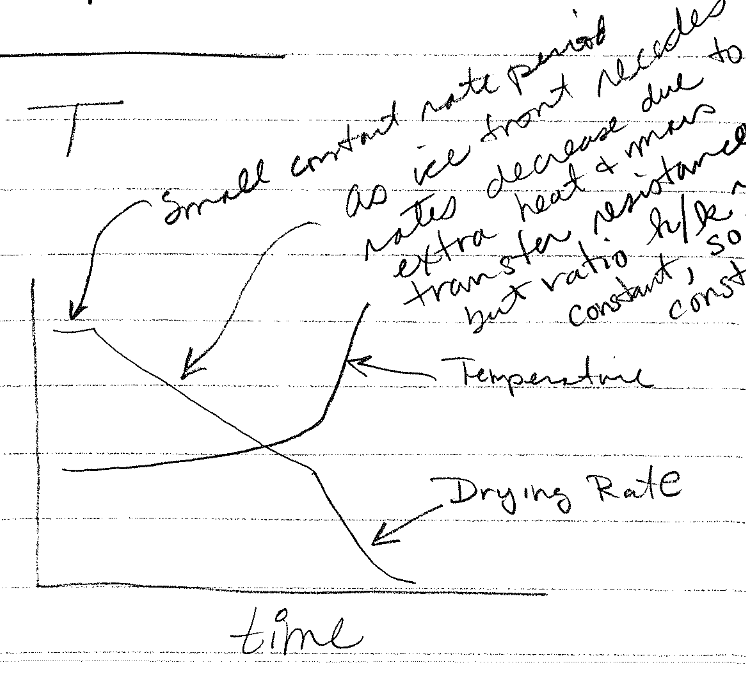


Freezing and Drying Processes

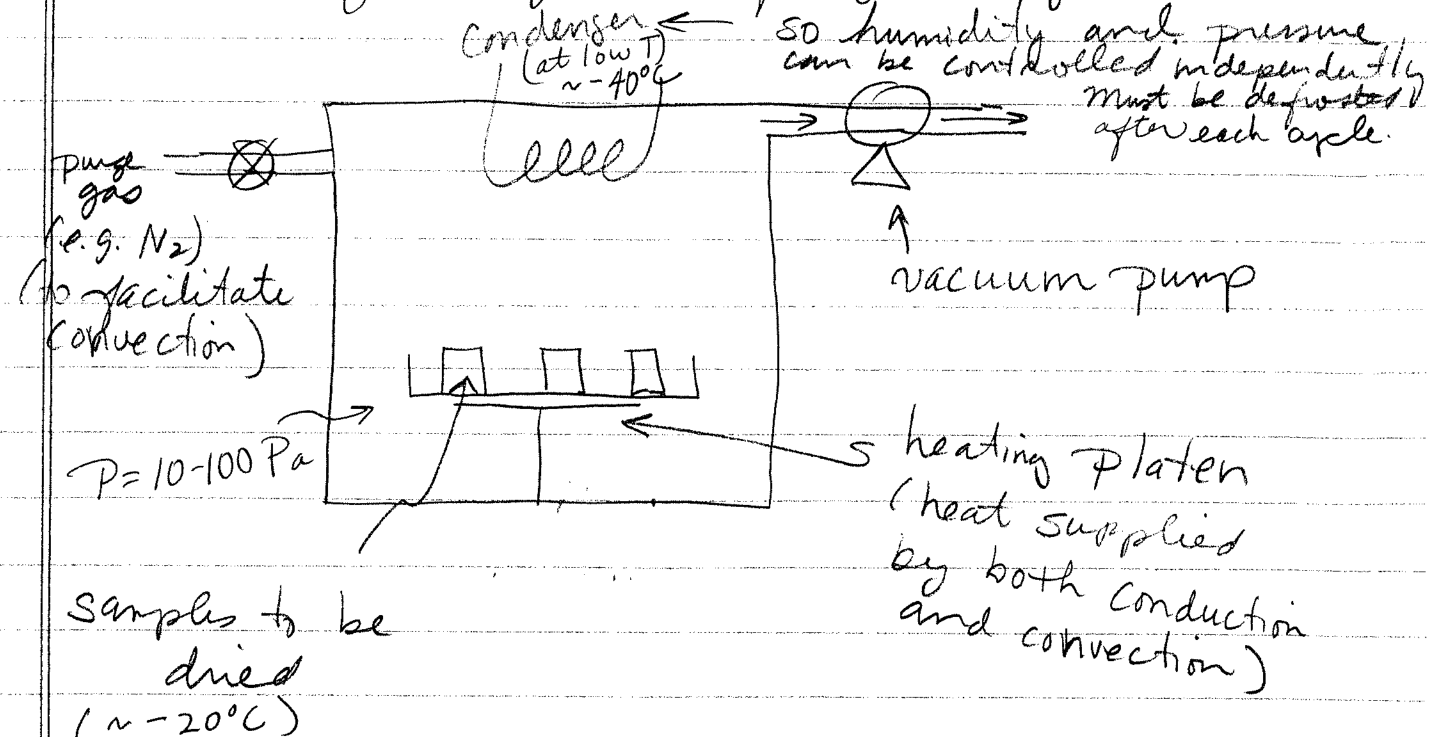




T&P are in this range so that ice sublimes



Design of a typical freeze dryer



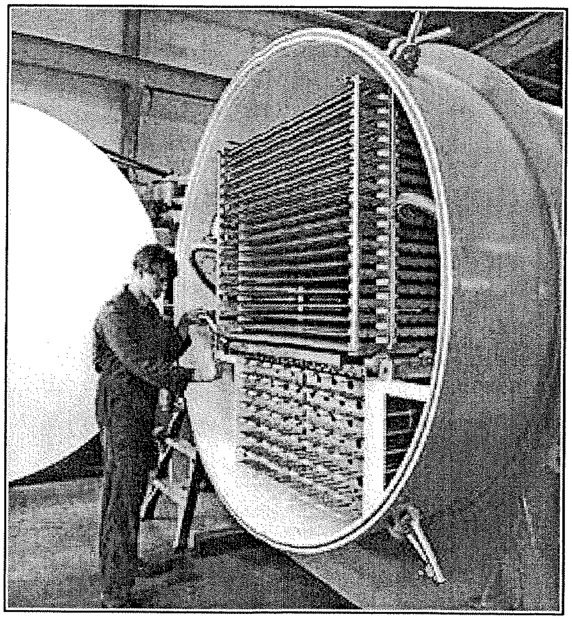
References:

"Freeze Drying: A Practical overview" by L.A. Gatlin and S.L. Nail, in Protein purification process engineering, vol 18 of Bioprocess Technology, Dekker, NY, 1994.

"CRC Freeze Drying of Foods" C. Judson King, Cleveland, CRC Press, 1971.

"Downstream Processes: Equipment and Techniques" John W. Snowman, pp. 315-351, Alan R. Liss, publisher, 1988.

MODEL FD600 - FD1000 STANDARD COMMERCIAL DRYERS



The Cuddon Freeze Dryer was designed after consideration of the factors necessary for pharmaceutical and health food freeze-drying techniques.

METHOD

Four steps are used to carry out the basic principle of drying biologicals by sublimation of ice in vacuum. Although each product may demand different handling techniques, the four conditions are necessary and must be met in the following order.

1. The product must be solidly frozen below its eutectic point.
2. A condensing surface of low temperature must be provided.
3. The system must be capable of evacuation to low pressures in a reasonable time.
4. A controlled source of heat input to the product must be employed to drive the water from the solid to the vapour state.

From beginning to end, a constantly changing state of difference must exist between the product ice temperature and the system pressure/temperature. The migration of water vapour from the product ice occurs only if this differential exists. This is achieved by controlling the energy absorbed by the product during sublimation.

Freeze drying equipment is designed to create a controlled set of conditions which maintain the optimum temperature pressure difference for a given product and thereby allowing the transfer of moisture in an efficient manner.

DESCRIPTION

CHAMBER:

Chamber construction can be offered in stainless steel or mild steel. The standard mild steel model interior is shot blasted and primed, then coated with four coats of epoxy chemical resistant paint. This specification is similar for the chamber doors that are double hinged for correct alignment. Two viewing ports each 200mm in diameter are provided in the doors, one each, for observation of the ice vapour condenser, and the other at shelf level. Cuddon Freeze Dryers are approved by the New Zealand Ministry of Agriculture and Fisheries. The chamber is fitted with stainless steel pneumatically operated valves that isolate the vacuum line connection, drain, water defrost and vacuum release.
The exterior can be painted in your choice of colour.

MODULAR SHELF HEATING PLATES:

The plates are fabricated from type 304 stainless steel, with flat upper sides and embossed lower sides to provide a heating fluid passage. The shelves are assembled in banks for ease of manufacture and to reduce weight when handling. Each bank is fitted with wheels that run in a stainless steel track located directly above the vapour condenser. Two sets of type 316 stainless steel product trays are provided. These trays feature rounded corners for easy cleaning.

SHELF REMOVAL:
The heating system is connected to each shelf module by two type 316 stainless steel flexible hoses and quick release couplings. Each shelf module is removable from the drying chamber by rolling onto a trolley.

TROLLEYS:
Two trolleys are provided that have self centring and locking pins so that they may be positioned in front of the chamber. Each module trolley has a continuation of the chamber rail and allows the complete assembly to be rolled out onto this trolley for maintenance or cleaning.

HEATING SYSTEMS:
A thyristor controlled electric boiler that is connected in series with the plates provides heating. A centrifugal pump circulates the heat medium. The temperature of the plates is electronically controlled as required by the drying pattern selected at the control panel.
A cooling heat exchanger is provided in the circuit for reducing the temperature of the plates when necessary either by water, or refrigerant if the shelf freezing option is desired. Safety devices are provided in the event of the circulating pump failing or if the fluid in the plates reaches critical low temperatures. A balance tank is fitted to a high point of the system to contain the thermal expansion when heating the fluid from low temperature.

VACUUM SYSTEMS:
The rotary piston vacuum pump is connected to the chamber by heavy duty PVC lines and pneumatic isolating valve. The exhaust of the pump is vented to the exterior of the building. The pump is equipped with a gas ballast facility.

VAPOUR CONDENSER:
The ice vapour condenser is manufactured from type 316 stainless steel tube in parallel circuits to form a direct expansion refrigerated coil. The assembly is fitted beneath the heating shelves and forms a permanent fixture. Defrosting the accumulated ice from the coil is by water. Hot water is recommended if a quick defrost time is desired. Heat recovery from the refrigeration system can be selected as an optional extra that will provide hot water for this purpose.

MOTOR CONTROL CENTRE:
The plant is provided with a motor control panel housing a mains isolator, circuit breakers, motor starters, overload protection, thermistor modules, relays, and hours run meter. This board is pre-wired at our factory. A separate operators control panel houses a vacuum gauge, chart recorder, programmable temperature controller and function switches that interface to a PLC, this runs the auxiliary equipment and monitors drying conditions. Audible alarm functions alert the operator to irregular occurrences.

SPECIFICATIONS

MODEL FD600 STANDARD COMMERCIAL FREEZE DRYERS :

Chamber:	Stainless or Carbon Steel
Overall length:	4200mm
Overall Width:	1840mm
Overall height:	2275mm
Chamber finish:	No. 4 finish or Epoxy paint
Shelf modules: /td>	Two
Shelf area:	58 sq. metres
Shelf temperature:	-25°C to +60°C
Shelf heating:	48kW
Product trays:	Stainless Steel, 2B finish
Number of product trays:	90 (2 sets)
Product tray sizes (standard)	1010x620mm
Ice Condenser:	Internal 304 S/S coil
Condenser capacity:	600kg ice
Condenser temperature:	-40°C
Condenser refrigeration:	37 kW, Variable capacity screw
Condenser defrost:	Water
Vacuum pump:	Optional
Heat transfer medium:	Glycol
Power Requirements:	150Amps, 3 phase, 50Hz
Heavy lift:	7000kg

MODEL FD1000 STANDARD COMMERCIAL FREEZE DRYERS :