Revision[3] L-10 23/05/2022

Topic Page No.

Drying & Humidification

The removal of moisture from a wet solid is known as drying. {moisture + solid system}.

Increasing the moisture content is known as Humidification {gas / air में}.

Humidity / Absolute Humidity / mass Humidity / Specific Humidity:-

Humidity is defined as mass of the water vapor to mass of the dry air.

$$\boxed{H = \frac{\text{Mass of the water vapor}}{\text{mass of dry air}}}$$

$$\boxed{H = \frac{m_v}{m_a}}$$ units $\left(\frac{\text{kg of water vapor}}{\text{kg of dry air}}\right)$

(dimensionless).

Humidity को mass के term में express किया जाता है पर actually में calculate pressure के term में होता है, industry।

Assumption:-

Assuming the dry air & Water vapor behave as ideal Gas

$$P_v V_v = n_v R T_v \quad \text{——(i)}$$ for dry also water vapor

$$P_a V_a = n_a R T_a \quad \text{——(ii)}$$ for dry air.

(i) / (ii)

$$\frac{P_v V_v}{P_a V_a} = \frac{n_v R T_v}{n_a R T_a}$$

→ Dry air & water vapor are present at thermal equilibrium

by assumption :- $V_v = V_a$ {no volume correction}
Volume occupied by ideal gases are same.

→ so $V_v = V_a$.

$$\frac{P_v}{P_a}\frac{V_v}{V_a} = \frac{n_v}{n_a}\frac{R}{R}\frac{T_v}{T_a}$$

$$\frac{P_v}{P_a} = \frac{n_v}{n_a}$$

∵ $\text{moles} = \dfrac{\text{mass}}{\text{molar mass}}$

$$n_v = \frac{m_v}{M_v}, \quad n_a = \frac{m_a}{M_a}$$

$$\frac{P_v}{P_a} = \frac{(m_v/M_v)}{(m_a/M_a)} = \frac{n_v}{n_a} \quad \text{———} \quad (\text{iii})$$

$$\boxed{H = \frac{m_v}{m_a} = \frac{M_v}{M_a}\frac{P_v}{P_a}}$$

$$\boxed{H = 0.622\,\frac{P_v}{P_a}} \Rightarrow \boxed{H = 0.622\,\frac{P_v}{P - P_v}}$$

P_v = Partial Pressure exerted the water vapor in the given air - water vapor system.

P_a = Partial pressure exerted by the dry air

Date:
Page No.:

Topic:

$\boxed{\begin{array}{l}\text{Gases can be liquified vapor cannot} \\ \text{Vapor can be condense gases cannot be.}\end{array}}$

logically / conceptually correct नहीं आता इस formule से, humidity but there is No other method for the calculation of Humidity so it is correct.

* Mathematically Partial pressure = 0 होता सकता है
But actual में dry air नहीं होता है तो value zero से total ज्यादा।

* partial pressure की maximum value vapor Pressure होता है।

(2) Molar Humidity :— (H')

$$H' = \frac{\text{No of moles of water vapor}}{\text{No. of moles of dry air}}$$

$$H' = \frac{n_v}{n_a}$$

from eqn (iii)

$$H' = \frac{n_v}{n_a} = \frac{P_v}{P_a}$$

$$\boxed{H' = \frac{n_v}{n_a} = \frac{P_v}{P - P_v}}$$

Relation b/w mass Humidity & molar Humidity

$$\boxed{H = \frac{m_v}{M_a} H' = 0.622 H'}$$

Page No.

Topic

③ Saturated mass Humidity :—

जब Partial pressure Vapor pressure को achieve कर लेता है उसे saturated condition कहा जाता है।

$$\boxed{H_s = 0.622 \frac{P_v^v}{P - P_v^v}}$$

④ Saturated molar Humidity :—

$$\boxed{H_s' = \frac{P_v^v}{P - P_v^v}}$$

⑤ % Humidity or % saturation :—

$$\boxed{\phi = \frac{H}{H_s} \times 100}$$

or

$$\boxed{\phi = \frac{H'}{H_s'} \times 100}$$

$$\phi = \frac{P_v}{P - P_v} * \frac{P - P_v^v}{P_v^v} * 100 = \frac{P_v}{P_v^v} * \frac{P - P_v^v}{P - P_v} * 100$$

It tells,
How much our system is away from the saturation

Date

Page No.

Topic

(2) Relative Humidity :-

$$RH \text{ or } \mu = \frac{P_v}{P_v^{v}} \times 100$$

As the temp of liquid/gas ↑ vapor pressure ↑.

at the condition of saturation.

$$\Rightarrow P_v = P_v^{v}$$

$$\Rightarrow RH = 100\%$$

$$\Rightarrow \boxed{\phi = RH \, \frac{P - P_v^{v}}{P - P_v}}$$

So for any given of system the value of ϕ is less than RH.

at saturated condition both equal.

* As temperature increases (Keeping the amount of water vapor same)

(1) As temperature increases Relative Humidity Decreases
∵ vapor pressure also rises when vapor pressure ↑
RH ↓ decreases

* (2) As temperature increases saturated Absolute Humidity increase.

* (3) As temperature increases absolute Humidity / specific Humidity No change. (remains same).

As amount of water vapor increases (Keeping the temperature same) :-

(2) As amount of water vapor increases (Keeping the temperature same):—

(i) RH → increases
(ii) Saturated Absolute Humidity will be remain same. as vapor pressure remain same
(iii) Absolute Humidity:— Increases

Humid heat of an air – water vapor mixture:

The Humid heat c_s is the amount of heat in J (or KJ) required to raise the temperature of 1 kg of dry air plus the water vapor (wet effect) present by 1K or 1°C

Heat capacity of air & water vapor can be assumed constant over the temperature range usually encountered at 1.005 KJ/kg dry air·K and 1.88 KJ/kg water vapor·K, respectively.

for SI unit:—

c_s KJ/kg dry air·K

$$\boxed{c_s = 1.005 + 1.88H}$$

In some cases c_s will be given as $(1.005 + 1.88H)10^3$ J/kg·K

Topic: Page No.:

Total Enthalpy of an air water vapor mixture:

The total enthalpy of 1 kg of air plus its water vapor is H_y J/kg or KJ/kg dry air. If T_0 is the datum temperature chosen for both components, the total enthalpy is the sensible heat of the air-water vapor mixture plus the latent heat λ_0 in J/kg or KJ/kg water vapor of the water vapor at T_0.

Note that

$(T-T_0)°C = (T-T_0)\ K$ and that this enthapy is refferred to liquid water.

$$\boxed{\begin{aligned} H_y\ \text{KJ/kg dry air} &= c_s(T-T_0) + H\lambda_0 \\ H_y\ \text{dry air} &= (1.005 + 1.88)(T-T_0)°C + H\lambda_0 \end{aligned}}$$

If the total enthalpy is referred to a base temp T_0 of °C; the eqn for H_y becomes.

$$\boxed{H_y\ (\text{KJ/kg dry air}) = (1.005 + 1.88H)(T°C - 0) + 2501.4H}$$

L-11 24/05/2022

Date

Page No.

Topic

Enthalpy = Sensible Energy + latent Energy

$H_y = C_S(T - T_0) - \lambda H$

$H_y = C_S(T - 0) - \lambda H$

unit same [illegible] multiply [illegible]

latent energy

$H_y = (1.005 + 1.88H)(T - 0)$

Mass Humidity:-

$H = \frac{m_v}{m_a} = 0.622 \frac{P_v}{P - P_v}$ $T \uparrow$ $H \rightarrow$ remain same

$m_v \uparrow$ $H \uparrow$

Molar Humidity:-

$H' = \frac{n_v}{n_a} = \frac{P_v}{P - P_v}$ $T \uparrow$ $H' \rightarrow$ remain same

$m_v \uparrow$ $H' \uparrow$

Saturated mass Humidity:-

$H_S = 0.622 \frac{P_v^v}{P - P_v^v}$ $T \uparrow$, $H_S \uparrow$

$m_v \uparrow$ $H_S \rightarrow$ remain same

Saturated molar Humidity:-

$H_S' = \frac{P_v^v}{P - P_v^v}$ $T \uparrow$ $H_S' \uparrow$

$m_v \uparrow$ H_S' remain same

% Humidity:- $\phi = \frac{H}{H_S} \times 100 = RH \frac{P - P_v^v}{P - P_v}$

$T \uparrow$ $\phi \uparrow$

$m_v \uparrow$ ϕ

Date
Page No
Topic

Relative Humidity:

$$RH = \frac{P_v}{P_v^s} \times 100$$

$T \uparrow$ $RH \downarrow$

$m_v \uparrow$ $RH \uparrow$

Dry Bulb Temperature

The temp recorded by a thermometer whose bulb is perfectly dry and is not affected by the presence of any moisture present in air or by any radiation.

(DBT) refers to the true temperature of the air.

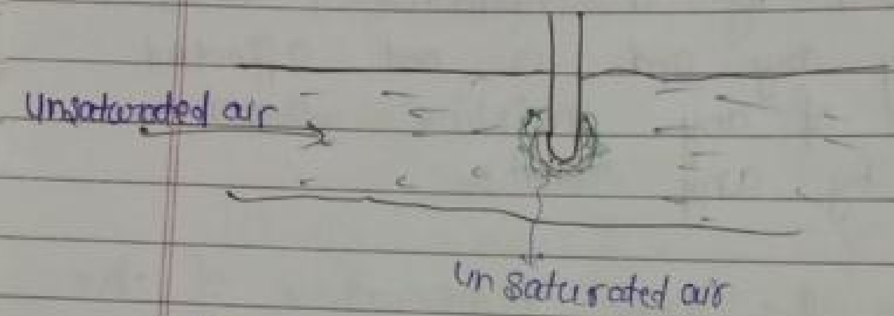
(DBT) can be calculated experimentally in lab but in day today life it can not be calculated b/z of the presence of the air and also the radiation effects.

Wet Bulb temperature

WBT is the temperature recorded by a thermometer whose bulb is converted with a wetted musclin wick & moved pass an air which is moving at a particular speed, a then layer of air gets developed around the Musclin wick & saturated that is responsible for the mass transfer so start from the musclin wick towards the thin film.

Date :
Page No. :
Topic :

Heat required for the vaporization is taken by the musclin wick only and then the mass transfer proceed due to temperature difference. A time comes when the thin layer of air becomes saturated. At this point the temperature recorded by the thermometer is known as wet bulb temperature.



The process so explained can be performed in the lab only not in the day today life.

In day today life temp recorded by the temperature recorded by a thermometer is a wet bulb temperature as the moisture is present in the air & it wets the surface of the bulb or affect the temperature measurement.

WBT can be refined as DBT when the moisture content is very-very less.

Dew Point Temperature

$P = 1$ atm
$T = 323$ K (WBT)
$P_v^v = 12.26$ kPa (Antonie's eqn)
$P_v = 6.30$ kPa
$R_H = 51.3\%$ $H = 0.04124$
$H_s = 0.0856$

0.04124 Kg of water vapor is present in 1 kg of dry air.

0.0856 kg of water vapor can be present at maximum in 1 kg of dry air at 323K.

$P = 1$ atm
$T = 303$ K (WBT)
$P_v^v = \downarrow$ let 8.56 kPa
$RH = \uparrow$ 73.59 $R_H = \frac{P_v}{P_v^v} \times 100 \Rightarrow \frac{6.3}{8.56} \times 100$
$P_v = \longrightarrow$
$H = \longrightarrow$ 0.04124
$H_s = \downarrow$ 0.0574.

0.0574 kg of water vapor can be present at maximum in 1 kg of dry air at 303K.

$P = 1$ atm
$T = 293$ K $\rightsquigarrow$ DPT $H = 0.04124$
$P_v^v = 6.30$ kPa $H_s = 0.04124$
$P_v = 6.30$ kPa
$RH = 100\%$

0.04124 kg of water vapor can be present at maximum in 1 kg of dry air at 293K.

Topic

Dew point temperature:-

(1) Dew Point temp is the temp at which RH become 100%

(or)

(2) at Dewpoint temp is the temperature at which the partial pressure exerted by the water vapor in the given air water system become equals to the vapor pressure of pure water at the same temperature

(or)

(3) DPT is the temp at which the absolute Humidity become equals to the saturated absolute Humidity

(4) DPT is the temperature at which the amount of water vapor is enough to saturate the given air-water vapor mixture.

$P = 1\,atm$

$T = 283$ kelvin

P_v^v	↓	5.101kPa let
P_v	↓	5.101kPa
RH	→	100% Saturation
H	↓	0.039297
H_s	↓	0.03297

$0.622 \times \frac{P_v}{P-P_v}$

$0.622 \times \frac{P_v^v}{P-P_v^v}$

$T\downarrow \Rightarrow P_v^v\downarrow$ RH remains same can't be more than 100% ie $RH = \frac{P_v}{P_v^v} \times 100 \Rightarrow P_v \downarrow$ होगा

रहेगा। $\because P_v\downarrow$ ie $H = \frac{P_v}{P-P_v} \Rightarrow H\downarrow$ $H_s \Rightarrow \downarrow$

Topic: .... Date: .... Page No. ....

एक बार जब हमारा system 100% saturation achieve कर लेता है, फिर भी temp down किया जाए तो भी 100% saturated ही रहता है। b/z 100% से ज्यादा saturation नही होसकती है। RH = 100%

By the antonies eqn T ↓ P_i° ↓.

(0.00827) kg of water vapor condensate out as liquid droplets in 1 kg of dry air.

Just for knowledge

At temp 283 K amount of moisture content should be 0.03297 but moisture content present is 0.04124 that means 0.00827 kg of moisture system मे extra है। इसे supersaturation कहा जाता है। But system saturation से ज्यादा नही होता सकता है तो जितना supersaturation का amount है सब condense हो कर बाहर आ जाएगा in the form of liquid droplets.

L-12

DPT

cooling without achieve DPT

(*) Cooling without condensation.

(*) Cooling with condensation.

DPT से पहले condensation नहीं होती है।

It can be cooled till DPT →

DPT से पहले condensation होती है।

(both correct)

Just like 1 km तक LRH = 4 km तक LHS]

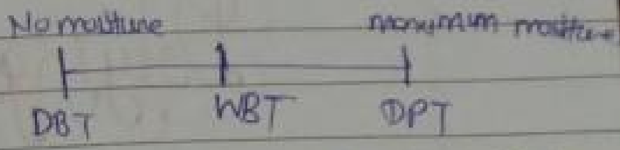
Commercial definition of DPT :—

(5) DPT is the temperature (upto) which a given a gas liquid vapor system can be cooled without condensation.

(6) DPT is the temperature (After) which a given a gas-liquid vapor system can be condensed along with cooling.

Topic : Date : Page No. :

$\boxed{DBT > WBT > DPT}$ **



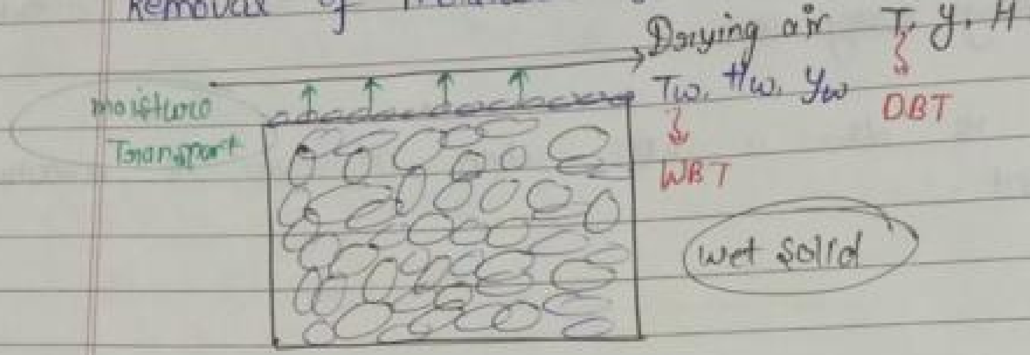
Note ① DBT is name given to WBT when moisture content is very very less.

Note II DPT is also a WBT when moisture is maximum present.

Topic

Drying

Removal of moisture from a wet solid



Wet solid के just upar air की wt layer होती है वही T_w, H_w, y_w है।

WBT = T_w :- Temp of the layer of air present adjacent of wet solid.

y_w :- mole fraction of water vapor of the layer of air present adjacent of wet solid.

H_w :- Humidity of the layer of air present adjacent of wet solid.

this WBT is maximum moisture content तो पहली layer की temp को DPT होना चाहिए पर यहाँ हमारा Aim cooling नही नही है so WBT temp ही माना जाता है।

T ⇒ for dry air. ie moisture content is very low / zero.

T ⇒ DBT

Heat flux :- $q = h(T - T_w)$

Molar flux :- $\boxed{N_v = k_y(y_w - y)}$

mole fraction :- $\dfrac{\text{Partial Pressure}}{\text{total pressure}}$

$$\boxed{N_v = k_y\left(\frac{p_w}{P} - \frac{p_v}{P}\right)}$$

partial pressure exerted by the water vapor in drying air. p_v

partial pressure exerted by in the layer of air adjustent of to the wet solid. p_w

$$N_v = \frac{k_y}{p}(p_w - p_v) \qquad p \Rightarrow \text{total pressure.}$$

$$\boxed{N_v = k_G(p_w - p_v)}$$

$$N_v = k_G \cdot \frac{P_v^v}{P_v^v}(P_w - P_v)$$

$$N_v = k_G P_v^v\left(\frac{P_w}{P_v^v} - \frac{P_v}{P_v^v}\right)$$

bz यहाँ saturated है

$RH = \frac{P_v}{P_v^v}$

$$N_v = k_G P_v^v(RH_w - RH_{drying\ air})$$

$$\boxed{N_v = k_G P_v^v(1 - RH)}$$

(Relative Humidity of drying air).

Relative Humidity of adjacent layer of water vapor.

In general Partial pressure of water vapor very-2 less in comparision to total pressure.

$$P_v <<<<<<< P$$

$$H = \frac{M_v}{M_a} \frac{P_v}{P - P_v}$$

$$H = \frac{M_v}{M_a} \frac{P_v}{P}$$

$$H = \frac{M_v}{M_a} y$$

$$\boxed{H_w = \frac{M_v}{M_a} y_w}$$

{ saturated है तो भी बहुत ज्यादा ~~भी~~ थोड़ी है क्योंकि 78% N_2, 21% O_2 होती है बची मे water vapor, CO_2 etc. — } होती है

$$N_v = k_y \left(\frac{M_a}{M_v} H_w - \frac{M_a}{M_v} H \right)$$

$$\boxed{N_v = k_y \frac{M_a}{M_v} (H_w - H)}$$ *

$$\boxed{N_v = k_y (y_w - y) = k_G (P_w - P) = k_G P_v^v (1 - RH) = k_y \frac{M_a}{M_v} (H_w - H)}$$

$N_v \Rightarrow$ molar flux (kmol/m² sec)

$N_v M_v \Rightarrow$ mass flux (kg/m² sec)

$N_v M_v A \Rightarrow$ rate of mass transfer (kg/sec)

↳ This much of mass of the moisture is transported.

Date
Page No
Topic

Latent Heat :- latent heat is the heat required to liquid for vaporise.

$$(\underbrace{N_V M_V}A \cdot \lambda) \rightarrow \text{latent heat}$$

$$\frac{kg}{sec} \cdot \frac{J}{kg} \Rightarrow \frac{Joule}{sec.}$$ { Heat required to carry out this transfer }.

$$Q = hA(T - T_W)$$

$\hookrightarrow$ Amount of heat supplied

Amount of heat required = Amount of heat supplied

$$(N_V M_V A \cdot \lambda) = hA(T - T_W)$$

$$k_y \frac{M_a}{M_V}(H_W - H) M_V \lambda = h(T - T_W)$$

$$k_y M_a (H_W - H) \lambda = h(T - T_W)$$

** Imp

$$\boxed{k_y M_a (H_W - H) = \frac{h(T - T_W)}{\lambda}}$$ = Drying Rate $\left(\frac{kg}{m^2 sec}\right)$

flux wala

$$N_V = k_G P_V^v (1 - RH)$$

$$N_{V_1} = k_G P_V^v (1 - RH_1)$$

$$N_{V_2} = k_G P_V^v (1 - RH_2)$$

**

$$\boxed{\frac{N_{V_1}}{N_{V_2}} = \frac{1 - RH_1}{1 - RH_2}}$$

L-13

Topic

At DPT = $P_v = P_v^v$ $\because$ RH = 100%

Imp. Point In the GATE exam partial pressure of the water vapor is not given. vapor pressure of pure water at due point temperature is given. We know At DPT

$$P_v^v = P_v$$

Hence partial pressure (P_v) can be determine

Random data:

DBT → 70°C   40mm of Hg

WBT ⇒ 60°C   30mm of Hg

DPT ⇒ 50°C   20mm of Hg

Absolute Humidity ?

$$H = 0.622 \times \frac{P_v}{P - P_v}$$

at DBT $P_v = P_v^v$

can be calculated by antonis eqn.

⇒ ie 40mm of Hg is P_v & P_v^v.

$$H = 0.622 \times \frac{20}{760-20}$$

$$H = 0.622 \times \frac{20}{740}$$

$$H \Rightarrow 0.0168$$ Ans

Date
Page No.
Topic

$k_y M_a (H_w - H) = \frac{h(T-T_w)}{\lambda}$

$$\boxed{\frac{H_w - H}{T - T_w} = \frac{h}{k_y M_a \lambda}}$$

Basic of Pschrometry

Pschrometic line

$\frac{h}{k_y M_a C_s}$ → this ratio is also known as Pschrometric Ratio.

$$\boxed{\frac{h}{k_y M_a} = C_s}$$

→ is known as lewis Relation. for ~~air~~ air-water vapor system

$$\boxed{\frac{h}{k_y M_a C_s} = 1}$$

& this ratio / No. is known as pschrometric No.

k_y पहले से mass के term में है।

→ this k_y mole के terms में है। i.e formula में M_a का होना compulsary नहीं नहीं है।

$\frac{h}{k_y C_s} = 1$

Pscyhrometric Ratio is $1.0 \frac{kg}{kg\ dry\ air\ K}$

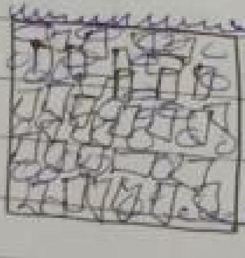
***

$$\boxed{C_s = \frac{h}{k_y M_a}}$$

Unbound Moisture:-

The moisture that is present on the surface of the system is known as "Unbounded" moisture. (solid body)

	Unbound moisture	Bound moisture
①	This moisture content is present on the surface of solid body.	This moisture content is present inside the solid Body.
②	This moisture content is not bound by the solid body or independent of the the structure of the solid body.	This moisture content is bound by the solid body or dependent on the structure of the solid body.
③	Layer of air adjacent to the surface of solid is saturated w.r.to unbound moisture	Layer of air adjacent to the surface of solid is unsaturated w.r.to Bound moisture. * Unsaturation increases as the amount of bound moisture decreases. → Unsaturation ↑ i.e water vapour content is low.
④	Relative Humidity of the layer of air adjacent to the surface solid is 100%.	R.H. of the layer of air adjacent to the surface solid is less than 100%.
⑤	It means unbound moisture	Bound moisture is the



Date :

Page No. :

Topic :

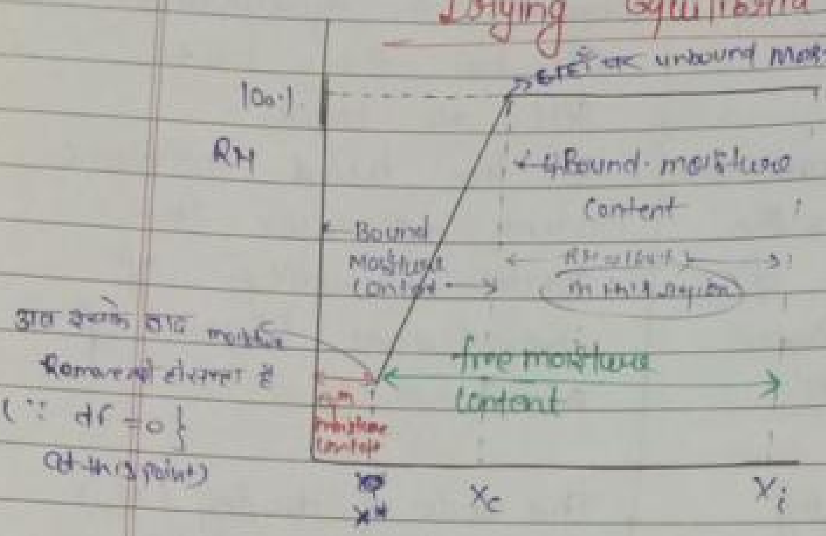
	is the moisture content that remains in eqm with 100% RH air layer.	moisture content that remains in equilibrium with less than 100% RH air layer.
6)	As the unbound moisture content decreases the Relative Humidity of the adjustent layer of layer 100% ((Remains same)).	As the bound moisture content decreases the Relative Humidity of the adjucent layer of air Decreases
7	The rate of drying (N_u) wrto unbound moisture Constant (Remains same) & Highest.	The rate of drying (N_u) wrto. bound moisture is Varies & Decreases as bound moisture Decreases.

L-14

Topic

Date
Page No.

Drying Equilibria



(moisture content) = $X = \frac{\text{Kg moisture}}{\text{Kg dry air}}$

$X_i \Rightarrow$ Initial moisture content
$X_c \Rightarrow$ critical moisture content
$X^* \Rightarrow$ Equilibrium moisture content.

Equilibrium moisture content:-

It is defined as the moisture content that can not be removed from the solid body for A given drying condition.

(or)

It is also defined as the moisture content that exerts a partial pressure in the adjucent layer equals to the partial pressure exerted by water vapor in the drying air such that net driving force is zero. (Driving force = 0 ; rate of drying = 0)

It can also be defined as the moisture content for which the rate of drying decome zero.

(or)

(2 Pg)

It is also defined as that moisture content which is left in the solid body at equilibrium conditions

Free moisture content:- $(X_i - X^*)$ The moisture content that can be removed from the system (or) moisture content present above than equilibrium moisture content.

Critical moisture content:- It is defined as the moisture content at which unbound moisture is over and surface of solid become dry.

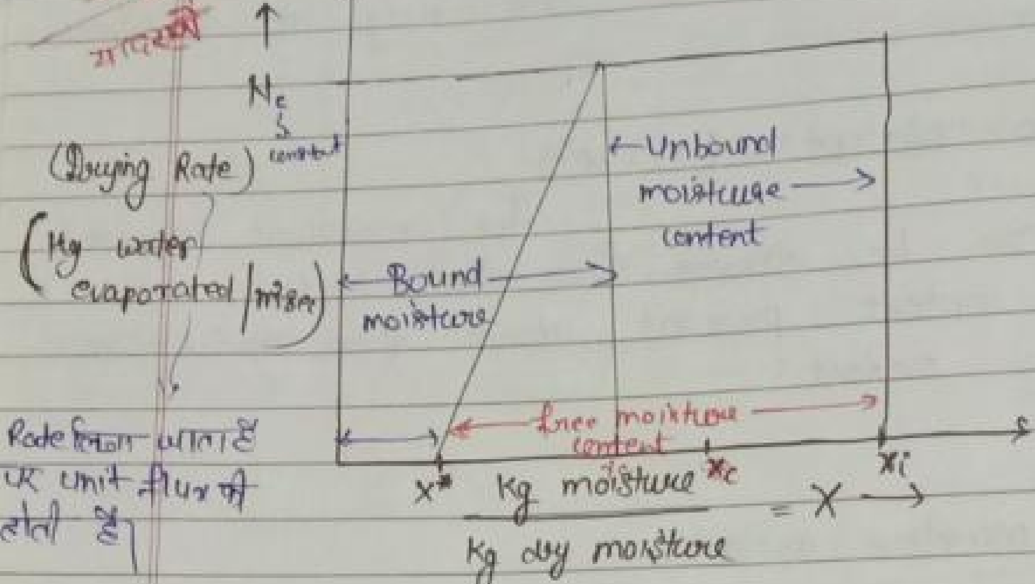
(or)

It is defined as the moisture content at which bound moisture content starts and moisture from inside starts to come on the surface of solid

(or)

It is defined as the point of intersection of the unbound moisture line and bound moisture line and that is why it lies on both the lines.

Imp graph



N_c :- Constant drying rate $\left\{ \frac{\text{Kg water evaported}}{m^2 \text{ second}} \right\}$

(This drying Rate is w.r.t. the unbound moisture content) (Temp of drying air)

$$\boxed{k_y M_a (H_w - H) = \frac{h(T - T_w)}{\lambda} = \text{Drying Rate } \underset{\text{Constant}}{(N_c)}}$$

This is valid only for the unbound moisture content.

This is valid only ~~for~~ when radiation affect are neglected.

If given a choice then constant drying rate can be calculated by the help of $\frac{h(T-T_w)}{\lambda}$ because of the accuracy of the data.

In the case of Humidity calculation, data is not accurate b/z of the assumption

Topic : Date : Page No

$$N \propto \frac{dx}{dt}$$

drying Rate expression:—

$$\boxed{N \propto \underbrace{-\frac{1}{A}\frac{dx}{dt}}}$$

$\frac{\text{Kg moisture}}{m^2\ \text{sec}}$ $\quad \frac{1}{m^2} \cdot \frac{\frac{\text{Kg moisture}}{\text{Kg dry solid}}}{\text{sec}}$

$$N = -\frac{W_s}{A}\frac{dx}{dt}$$

where $W_s \rightarrow$ Kg dry solid or also known as weight of bone dry solid. (completely free from moisture)

Time of Drying:—

$$N = -\frac{W_s}{A}\frac{dx}{dt}$$

$$\int_0^{t_f} dt = \int_{X_i}^{X_f} -\frac{W_s}{AN}\,dx = -\left[\int_{X_i}^{X_c}\frac{W_s}{AN}\,dx + \int_{X_c}^{X_f}\frac{W_s}{AN}\,dx\right]$$

$$t_f = \int_{X_c}^{X_i}\frac{W_s}{AN_c}\,dx + \int_{X_f}^{X_c}\frac{W_s}{AN}\,dx$$

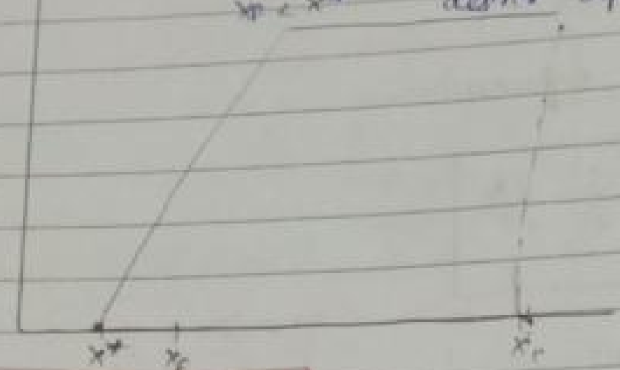
$$\boxed{t_f = \frac{W_s}{AN_c}(X_i - X_c) + \frac{W_s}{A}\int_{X_f}^{X_c}\frac{dx}{N}}$$

$$t_f = \underbrace{t_c}_{\text{constant drying rate}} + \underbrace{t_v}_{\text{variable Drying rate}}$$

if $X^* = X_f$ infinite time

$X_f > X^*$ finite time

$X_f < X^*$ desired separation is never achieved



$$\boxed{t_v = \frac{W_c}{A}\int_{X_f}^{X_c} \frac{dX}{N}}$$

* To solve this integral we need the relation of n terms of x.
* Let us assume that the relation is linear.

$$N = pX + q$$

B.C ① $X = X^*$, $N = 0$

$$0 = pX^* + q$$

$$q = -pX^*$$

B.C ② when $X = X_c$ $N = N_c$

$$N = pX - pX^*$$

$$N = p(X - X^*)$$

$$\boxed{N_c = p(X_c - X^*)}$$

constant rate of drying

$$t_v = \frac{W_s}{A}\int_{x_f}^{x_c} \frac{dx}{px - px^*} = \frac{W_s}{A}\frac{1}{p}\int_{x_f}^{x_c} \frac{dx}{x - x^*}$$

$$t_v = \frac{W_s}{Ap} \ln|x - x^*| \Big|_{x_f}^{x_c} = \frac{W_s}{Ap} \ln\left|\frac{x_c - x^*}{x_f - x^*}\right|$$

$$\boxed{t_v = \frac{W_s}{A N_c}(x_c - x^*) \ln\left|\frac{x_c - x^*}{x_f - x^*}\right|}$$

If given linear assumption then directly use this formula (नहीं भी दिया हो तो भी use किया जा सकता है)

If the relation of N wrt x is given then use them if not given use this formula directly.

$$\boxed{t_f = \frac{W_s}{A N_c}(x_i - x_c) + \frac{W_s}{A N_c}(x_c - x^*) \ln\left|\frac{x_c - x^*}{x_f - x^*}\right|}$$

याद रखो ! very very imp.