Lecture 05

Mechanism of Drying

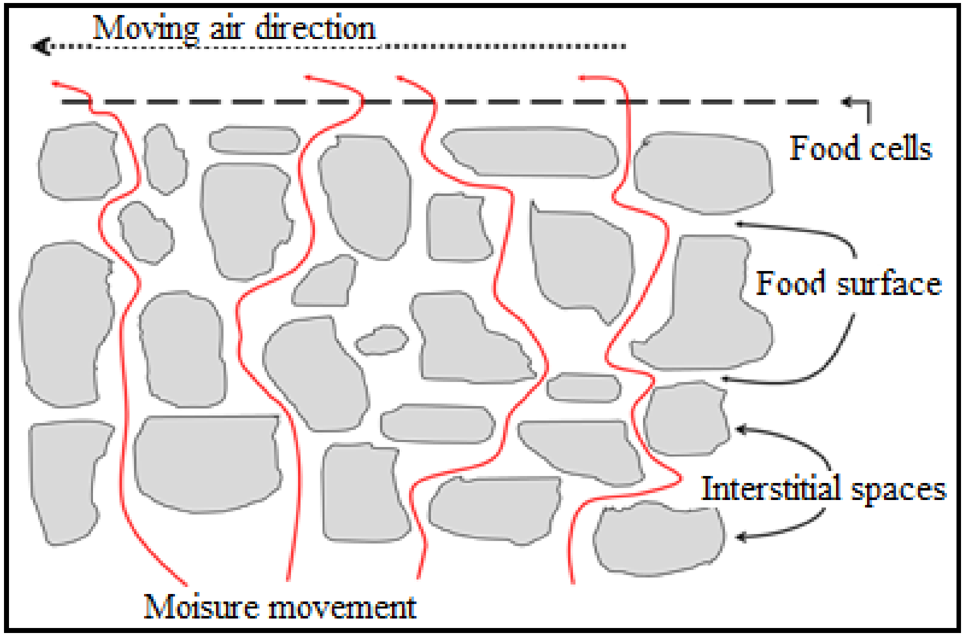
Drying & Storage Engineering

(PFE-304)

DRYING

- During drying it is necessary to remove free moisture from the surface and also moisture from the interior of the material.
- When hot air is blown over a wet food, heat is transferred to the surface, and the latent heat of vaporization causes water to evaporate
- Water vapour diffuses through a boundary film of air and is carried away by the moving air.

DRYING



1. Liquid movement by capillary force.
2. Diffusion of liquids, caused by concentration gradient.
3. Diffusion of liquids, which are absorbed in layers at the surfaces of solid components of the food.
4. Water vapour diffusion in air spaces within the food caused by vapour pressure gradients.

DRYING

- This creates a region of lower water vapour pressure at the surface of the food, and a water vapour pressure gradient is established from the moist interior of the food to the dry air.
- This gradient provides the driving force for the removal of water from the food.

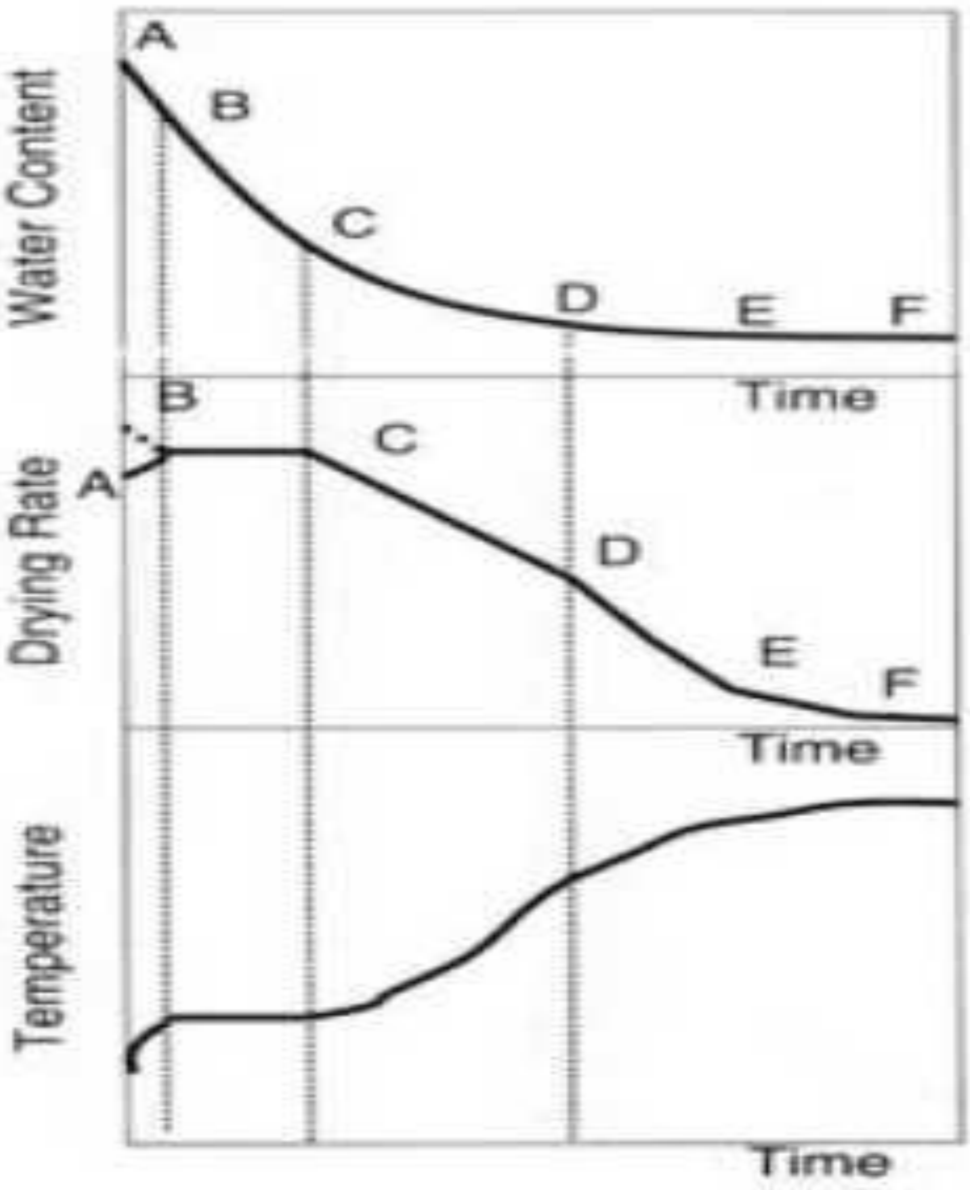
DRYING

- During drying moisture is removed continuously
- Not at a constant rate
- At the end almost no elimination of moisture
- Depending on initial moisture content of air, this approaches a constant minimum value, thereafter no moisture removal from food
- At equilibrium moisture content, no net mass transfer
- Drying is proceed only when actual moisture is above EMC

DRYING MECHANISM

- When the food is placed inside the drier, there is a short settling down period as the surface heats up to the wet bulb temperature.

- Drying then commences, and provided that water moves from the interior of the food material at the same rate as it evaporates from the surface, the surface remains wet. This period is known as the constant rate period.



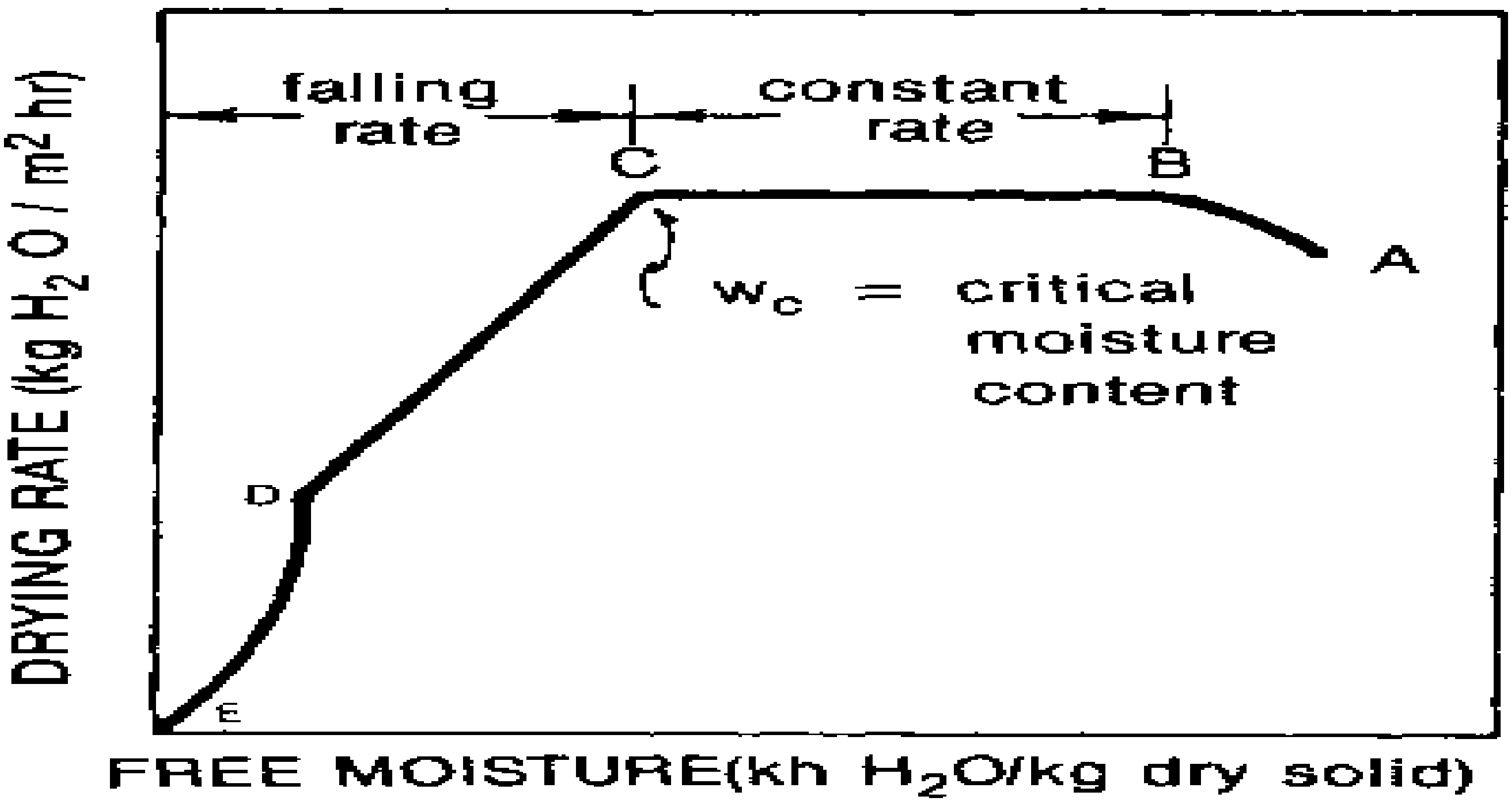
Water Content
A
B
C
D
E
F
Time
Drying Rate
B
C
A
D
E
F
Time
Temperature
Time

DRYING MECHANISM

- The constant rate period continues until the critical moisture content is reached. At this point drying enters what is known as the falling rate period.
- Food systems however present problems as in practice different areas of the surface of the food will dry out at different rates and overall, the rate of drying declines gradually during the 'constant rate period', in some cases it is accepted that the constant rate period does not exist.

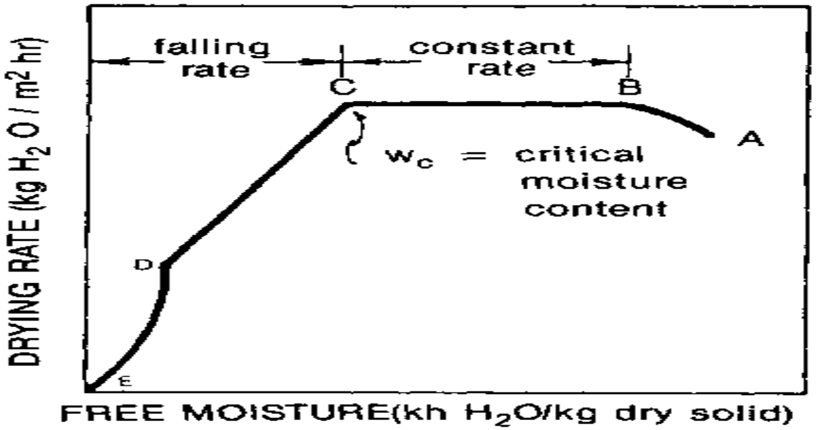
PHASES OF DRYING

1. Initial warm up period
2. Constant drying rate period
3. Falling drying rate period



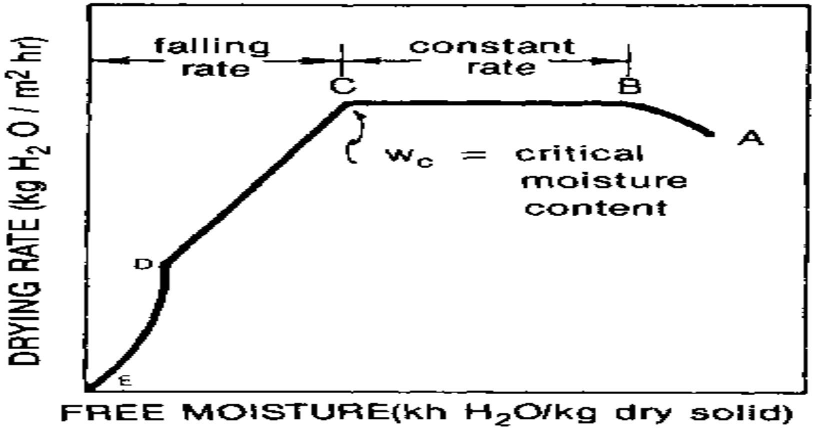
DRYING MECHANISM - (A-B)

- Period A-B is a settling down or equilibration period. The surface of the wet solid comes into equilibrium with the air.
- This period usually short compared to the total drying time



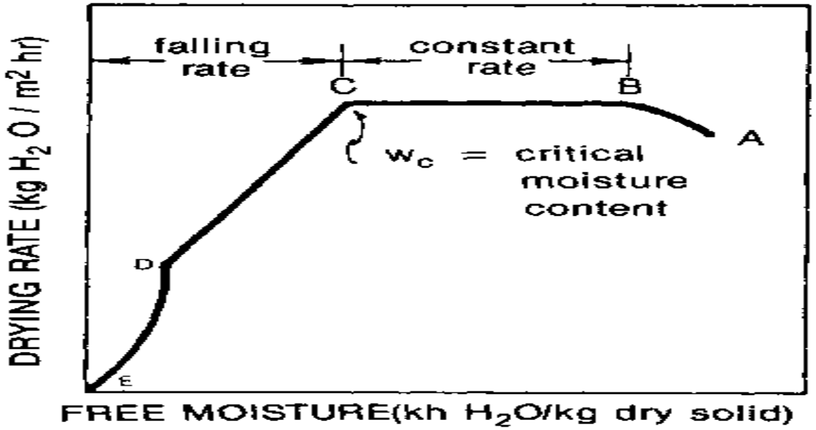
DRYING MECHANISM - (B-C)

- Period B-C is known as the *constant rate period*.
- Throughout this period the surface of the solid is saturated with water.
- As water evaporates from the surface, water from within the solid moves to the surface, keeping it in a saturated state.
- The rate of drying during this period remains constant, So also does the surface temperature, at a value corresponding to the wet bulb temperature of the air.



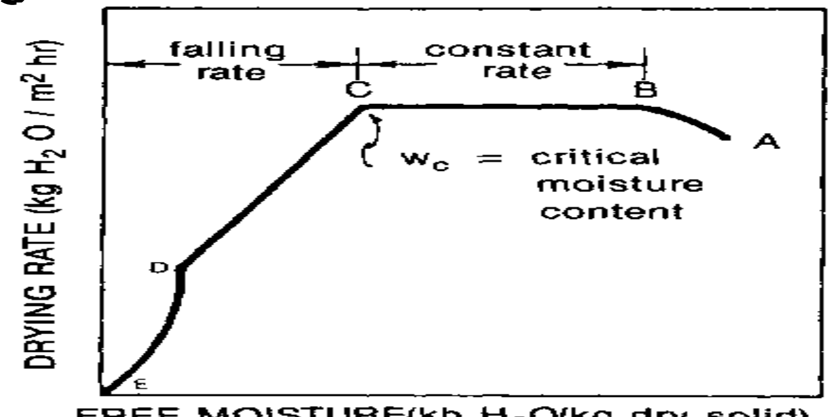
DRYING MECHANISM - (C-D)

- As drying proceeds, at some point the movement of water to the surface is not enough to maintain the surface in a saturated condition. The state of equilibrium at the surface no longer holds and the rate of drying begins to decline.
- Point C is known as the critical point and the period C-D is the *falling rate period.*
- From point C on, the temperature at the surface of the solid rises and approaches the dry bulb temperature of the air as drying nears completion.
- Hence, it is towards the end of the drying cycle that any heat damage to the product is likely to occur.



DRYING MECHANISM - (C-D)

- Many research workers claim to have identified two or more falling rate periods where points of inflexion in the curve have occurred.
- During the falling rate period, the rate of drying is governed by factors which affect the movement of moisture within the solid.
- The influence of external factors, such as the velocity of the air, is reduced compared to the constant rate period.
- In the dehydration of solid food materials, most of the drying takes place under falling rate conditions.



DRYING EQUATION

A simple drying equation was proposed on the basis of Newton's equation as,

$$\frac{dt}{d\theta} = -K\ (t - t_e) \qquad \ldots 3.38$$

In the equation 3.38 by replacing the temperature unit 't' by moisture content unit 'M', we get the following equation

$$\frac{dM}{d\theta} = -K\,(M - M_e) \qquad \ldots 3.39$$

where,
$M =$ moisture content, % (db)
$\theta =$ time, hour
$M_e = EMC$, % (db)
$K =$ drying constant

or,

$$\frac{dM}{M - M_e} = -K\,d\theta \qquad \ldots 3.40$$

By integrating between limits $M(r,\ 0) = M$, initial moisture content and $M(r_0,\ \theta) = M_e$ (EMC) we get;

$$\frac{M - M_e}{M_0 - M_e} = \exp\ (-k\,\theta) \qquad \ldots 3.41$$

or,

$$\theta = \frac{1}{-k}\ ln\ \frac{M - M_e}{M_0 - M_e} \qquad \ldots 3.42$$

$\frac{M - M_e}{M_0 - M_e}$ is called as moisture ratio

EXAMPLE

Q.1. In a drying experimentation the moisture ratio at 50 min duration was 0.45, calculate the amount of moisture content of sample at every 30 min up to 5 hrs, if the initial and equilibrium moisture content of the pulp was 5.7 (db) and 0.04 (db) respectively.

$$\frac{M - M_e}{M_0 - M_e} = \exp\ (-k\theta)$$

$$\text{or,} \quad \theta = \frac{1}{-k}\ ln\ \frac{M - M_e}{M_0 - M_e}$$

$\frac{M - M_e}{M_0 - M_e}$ is called as moisture ratio

K = 0.015 per min, M_{30}=3.5,M_{60}=2.34, 1.5, 0.97, 0.63, 0.42, 0.28, 0.194, 0.138, 0.102

Diffusion

- Mass flow process by which species change their position relative to their neighbours
- Driven by ***thermal energy*** and a ***gradient***
- Thermal energy → thermal vibrations → Atomic jumps

Gradient
- Concentration / chemical potential
- Electric
- Magnetic
- Stress

❑ Flux (J) *(restricted definition)* → Flow / area / time [Atoms / m^2 / s]

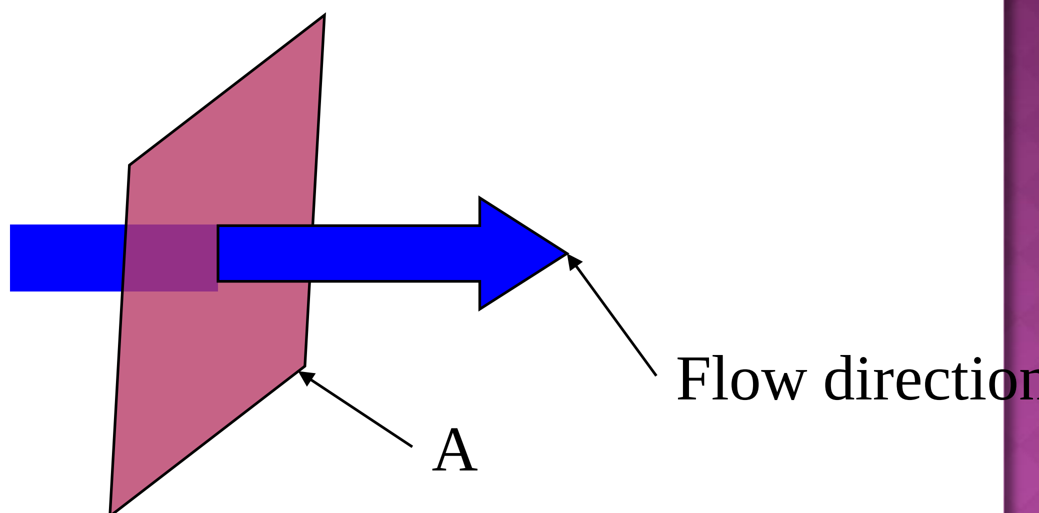
❑ Assume that only B is moving into A

❑ Assume steady state conditions → $J \neq f(x,t)$ *(No accumulation of matter)*

Fick's I law

$$\frac{dn}{dt} = -DA\frac{dc}{dx}$$

- $\frac{dn}{dt}$: No. of atoms crossing area A per unit time
- D: Diffusion coefficient/ diffusivity
- A: Cross-sectional area
- $\frac{dc}{dx}$: Concentration gradient
- $-$: Matter transport is down the concentration gradient



- As a first approximation assume D $\neq$ f(t)

$$J \equiv atoms / area / time \propto concentration\ gradient$$

$$J \propto \frac{dc}{dx}$$

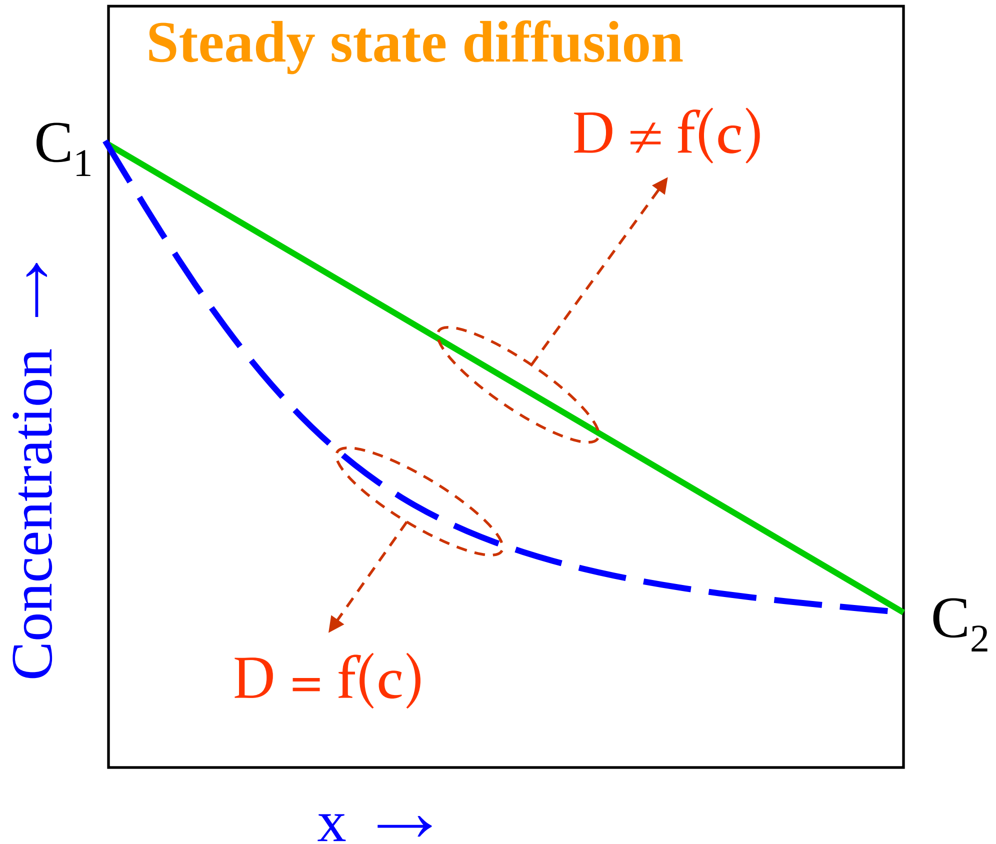
$$J = -D \frac{dc}{dx}$$

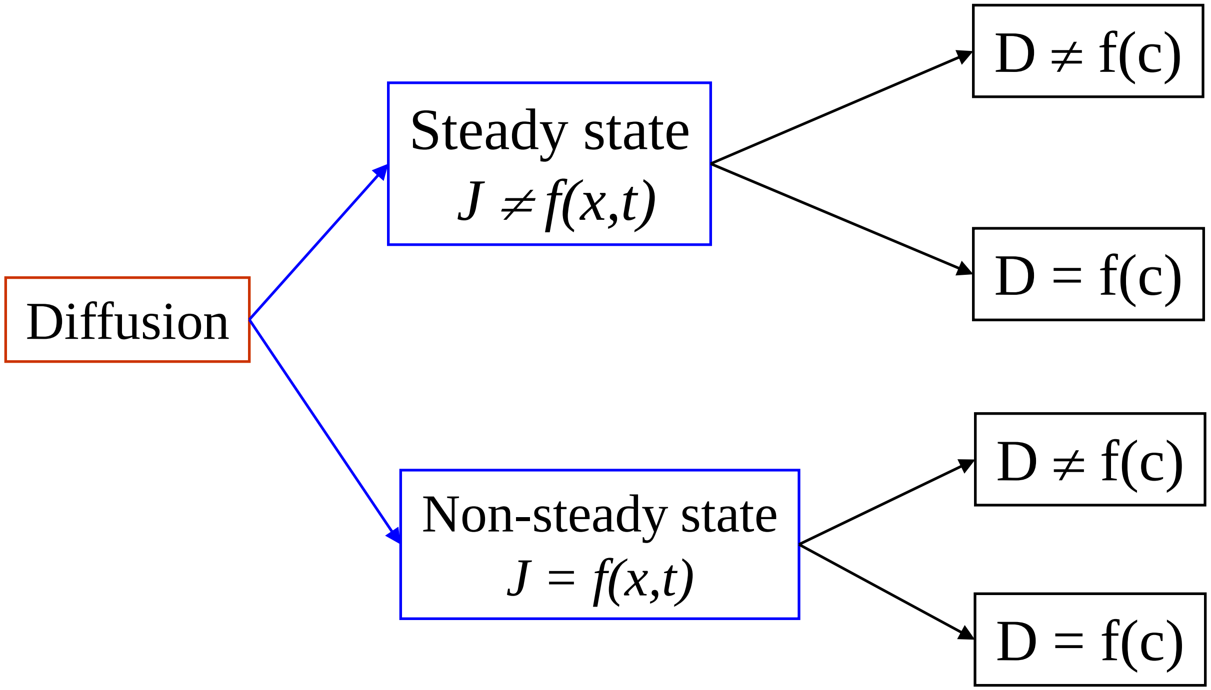
$$J = \frac{1}{A} \frac{dn}{dt} = -D \frac{dc}{dx}$$

$$\frac{dn}{dt} = -DA \frac{dc}{dx}$$

Fick's first law

- Diffusivity (D) → f(A, B, T)



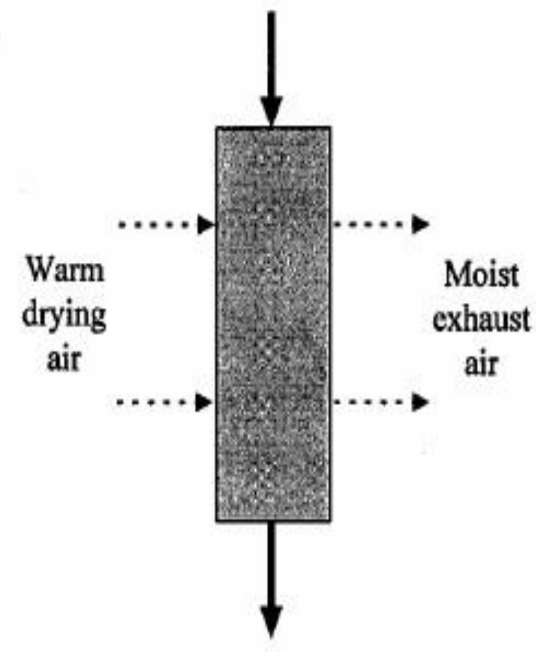

Diffusion
Steady state
$J \neq f(x,t)$
Non-steady state
$J = f(x,t)$
$D \neq f(c)$
$D = f(c)$
$D \neq f(c)$
$D = f(c)$

TYPES OF FLOW IN DRYING

- Cross flow
- Concurrent flow
- Counter flow

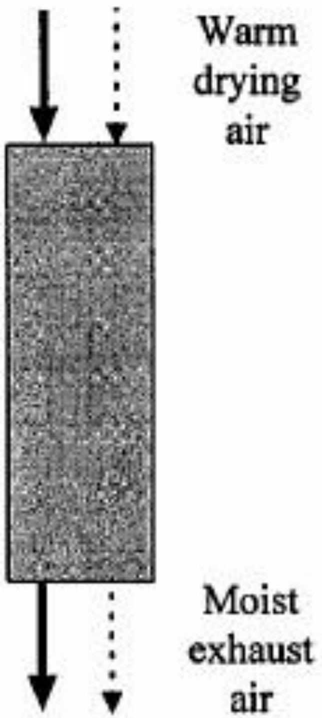
CROSS FLOW

- In cross flow dryers, the flow of grain and drying air takes place at 90◦ because of this the layer of grains which come in contact with heated air dries early. The temperature of grain layer nearest to flow of heated air approaches near the drying air temperature



CONCURRENT FLOW

- In concurrent flow dryers, the direction of flow of grains and heated air is parallel to each other. The cool and wet grains meet the heated air first Therefore, during evaporation of moisture the sensible heat for drying is adsorbed as latent heat, as a result cooling of air takes place and this restricts the elevation of grain temperature to a level of drying air temperature.



COUNTER FLOW

- In counter flow dryers, the direction of flow of grains and heated air is opposite to each other, thus the hottest grains come in contact with heated air. since, at this point drying is almost complete, therefore, very little amount of latent heat is adsorbed for evaporation of moisture.