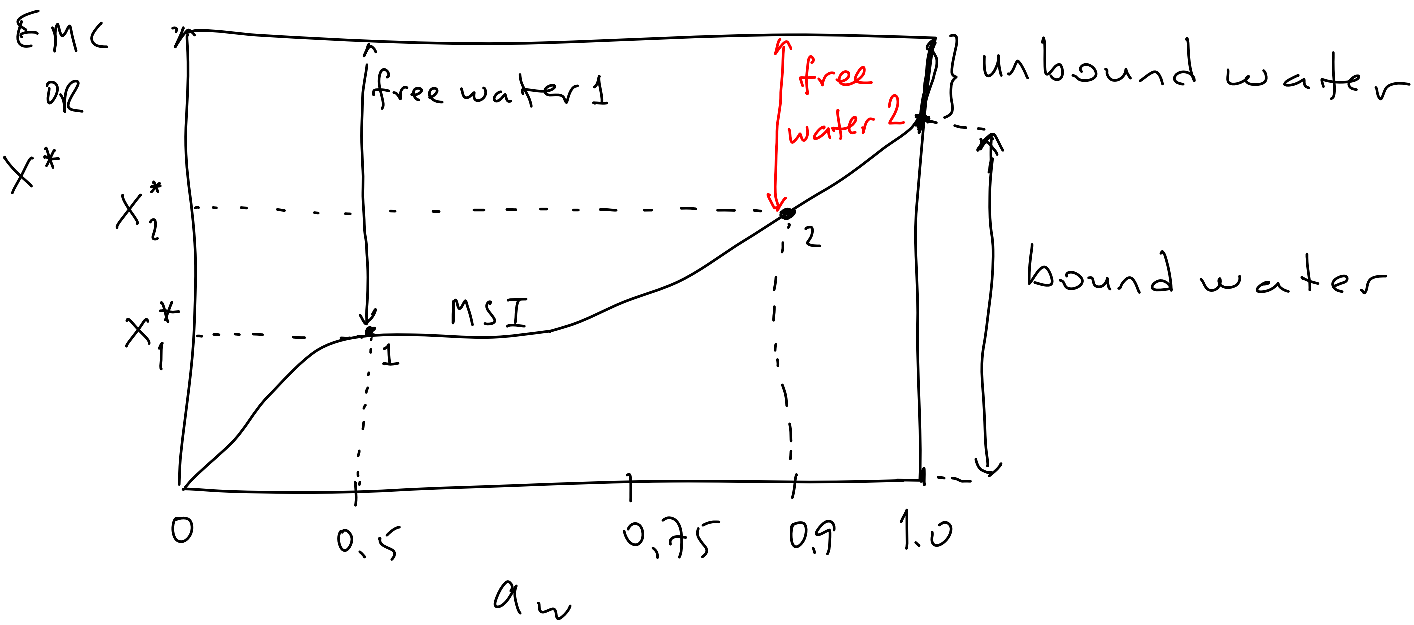


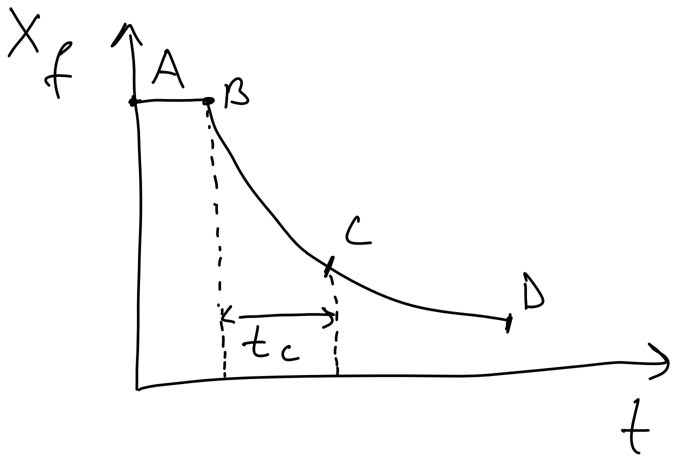
Drying Kinetics

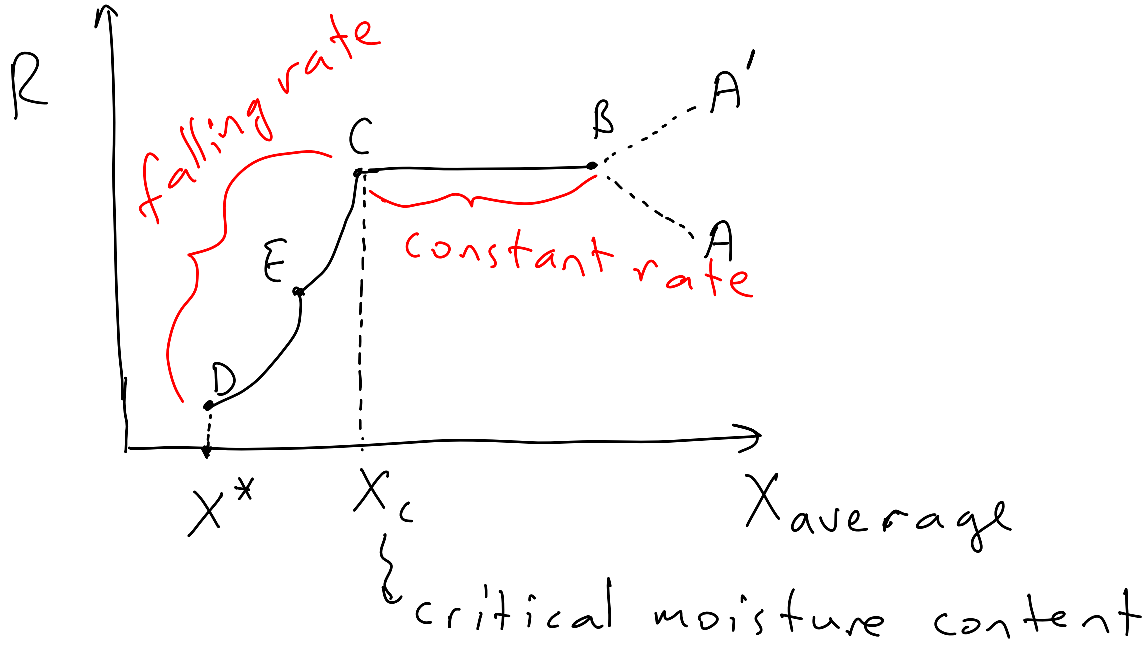
Consider the drying of a wet food under fixed drying conditions (e.g., T, air velocity).

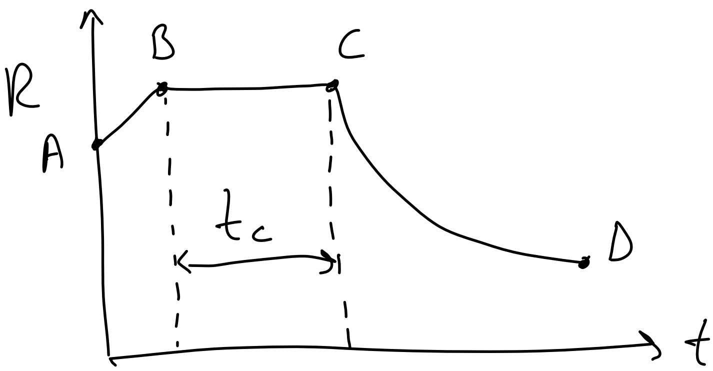
If you have X vs time data ⇒

$X_f = X - X^*$, when $X_f = 0 \Rightarrow \frac{dX_f}{dt} = 0$

X_f	t
⋮	⋮







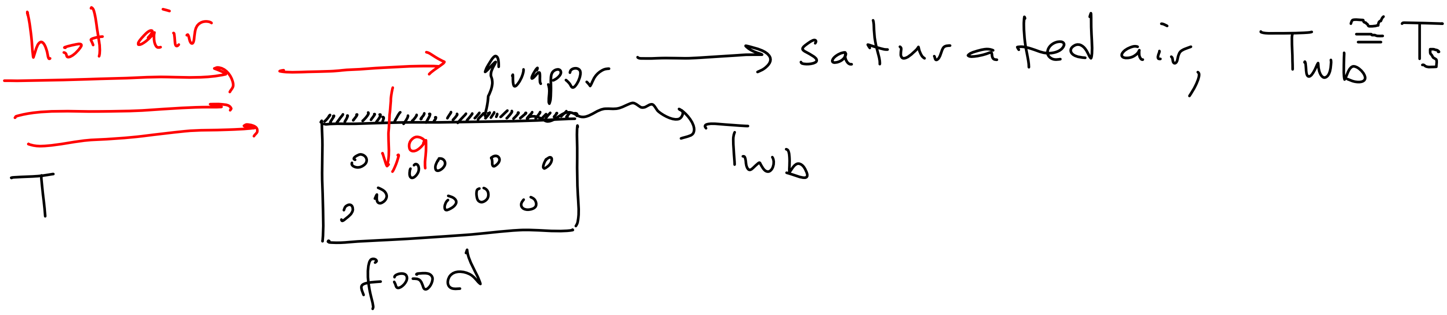
⊛ <u>Stage A–B and A'–B:</u> These stages represent a settling down period during which the solid surface conditions come into equilibrium with the drying air.

- This period is generally negligible.
- At A–B, the solid is at a colder T than its drying T ⟹ R ↗.
- At A'–B, the solid is quite hoter than its drying T ⟹ R ↓

⊗ Stage B–C: This stage is known as the constant rate period of drying.

During this period;

- a film of water is always available at evaporating surface.
- the surface of the solid is saturated with liquid water.
- drying takes place by movement of water vapor from the saturated surface into the main stream of drying air.



⊗ Stage C–D: At point C, the drying rate begins to fall and the falling rate period starts.

- the surface T begins to ↗ continuously approaching the T_{db} of the air as the material approaches dryness.

⊛ <u>Stage C–E</u>: It is the first falling rate period.

- the surface is drying out and drying rate falls.

⊛ <u>Stage E–D</u>: It is the second falling rate period.

- the plane of evaporation moves into the solid and drying rate falls further.
- in this case the driving force is the water vapor pressure rather than moisture content.

Rate of Drying Curves for Constant Drying Conditions:

Obtain data as W vs time.

W	t
⋮	⋮ during drying.

W: total weight of food during drying period.

t: drying time

M_s: kg dry solids in food material

X_t : MC at any time.

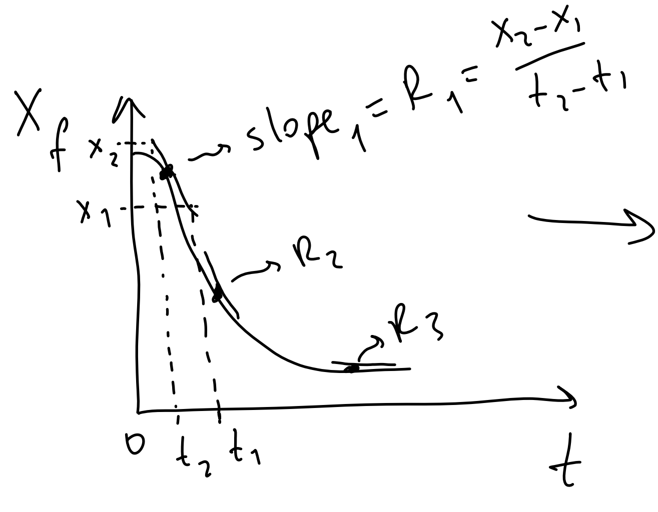
X_f : free moisture content

$$X_t = \frac{W - M_s}{M_s} = \frac{kg\ H_2O}{kg\ DS}$$

$$X_f = X_t - X^*$$

X_f	t
⋮	⋮

} transfer this data into drying rate (R). $R = \frac{dx}{dt}$



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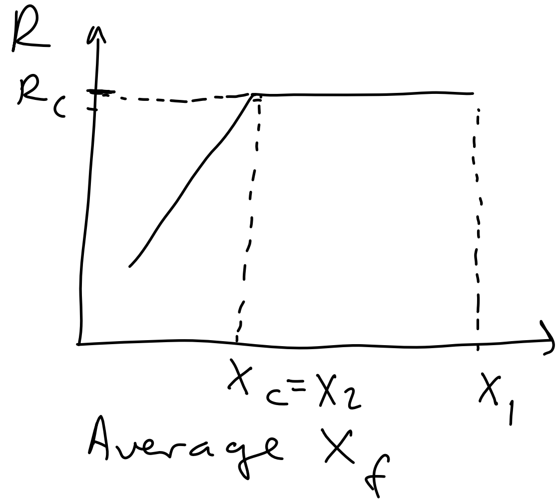


R	Average X_f
R_1 →	$\frac{x_2 + x_1}{2}$
⋮	⋮

$$R_c = -\frac{M_s}{A} \times \frac{dX_f}{dt} = -\frac{M_s}{A} \times \frac{(X_2 - X_1)}{(t_2 - t_1)}$$

(X_2 → X_c)

X: free MC

R: drying rate $\left(kg\,H_2O / h \cdot m^2\right)$

A: exposed surface are for drying (m^2).

$$R_1 = -\frac{M_s}{A} \times \frac{(X_2 - X_1)}{(t_2 - t_1)}, \quad X_{average_1} = \frac{X_2 + X_1}{2}$$

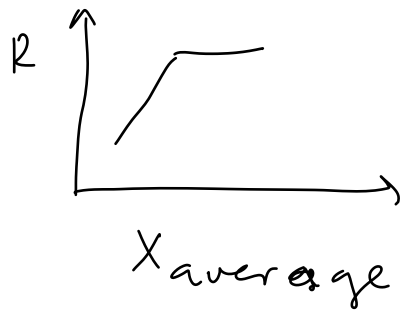
$$R_2 = -\frac{M_s}{A} \times \frac{(X_3 - X_2)}{(t_3 - t_2)}, \quad X_{average_2} = \frac{X_3 + X_2}{2}$$

⋮

R_f $\quad$ $X_{average_f}$

R	Xaverage
⋮	⋮

$\Rightarrow$



Constant Drying Rate Period

$$R_c = -\frac{M_s}{A} \times \frac{dx}{dt} \Rightarrow \int_{t_1=0}^{t_2=t} dt = -\int_{X_1}^{X_2} \frac{M_s}{A} \times \frac{dx}{R} \Rightarrow$$

$$t = +\frac{M_s}{A} \times \int_{X_2}^{X_1} \frac{dx}{R}, \quad \text{if } R = R_c \Rightarrow t = t_c$$

$$t_c = \frac{M_s}{A \cdot R_c} \times (X_1 - X_2)$$

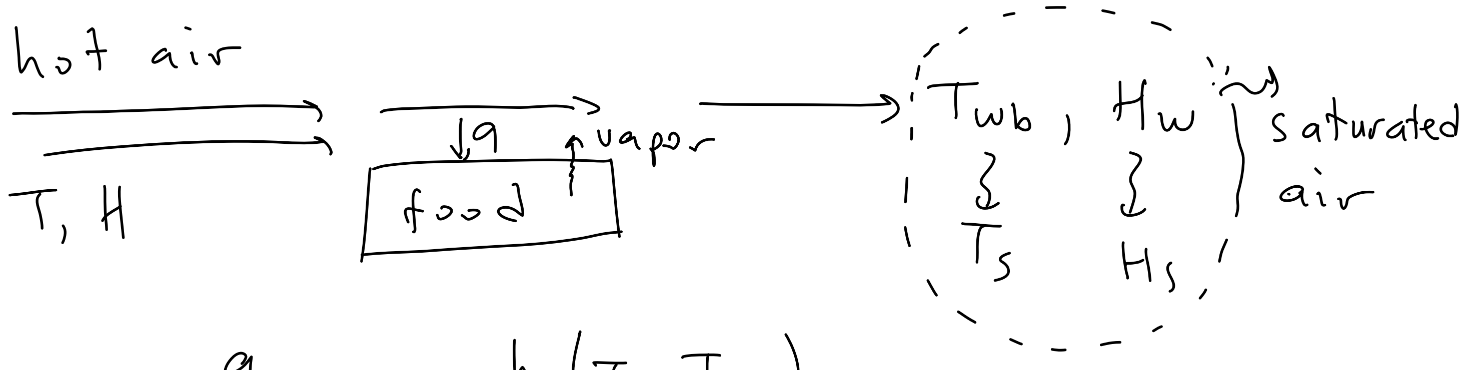
Example: A solid is to be dried from the free moisture content

X_1 = 0.38 kg water/kg DS to X_2 = 0.2 kg water/kg DS. Estimate the time required for drying. Given : M_s/A = 21.5 kg/m^2, Rc = 1.51 kg/ h.m^2)

Solution:

$$t_c = \frac{M_s}{A \cdot R_c} \times (X_1 - X_2) = \frac{21.5 \text{ kg DS}/m^2}{1.51 \text{ kg } H_2O / h \cdot m^2} \times (0.38 - 0.2) \frac{\text{kg } H_2O}{\text{kg DS}}$$

$$t_c = 2.56 \text{ h}$$



$$R_c = \frac{q}{A \cdot \lambda_w} = \frac{h \cdot (T - T_{wb})}{\lambda_w}$$

q = heat flow rate, J/s = W or kJ/s

λ_w = latent heat of vaporization at T_{wb}.

λ_w : kJ/kg H_2O

T_{wb}: wet bulb T,

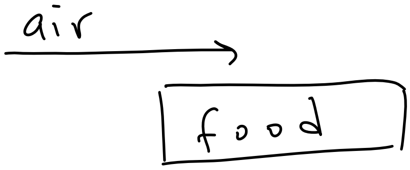
h: convective heat transfer coefficient,

h: $\frac{W}{m^2.K}$, $\frac{KJ}{h.m^2.K}$

h = ?

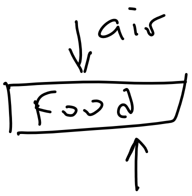
⊗ For air T of 45–150°c and mass velocity G of 2450 – 29300 kg/h.m² or a velocity of 0.61 – 7.6 m/s and air flowing <u>parallel</u> to drying surface ⇒

$h = 0.0204 \times (G)^{0.8}$ ⟶ SI



⊗ for air T of 45 – 150°c and mass velocity of G of 3900 – 19500 kg/h.m² or a velocity of 0.9 – 4.6 m/s and air is flowing <u>perpendicular</u> to drying surface ⇒

$h = 1.17 \times (G)^{0.37}$ ⟶ SI



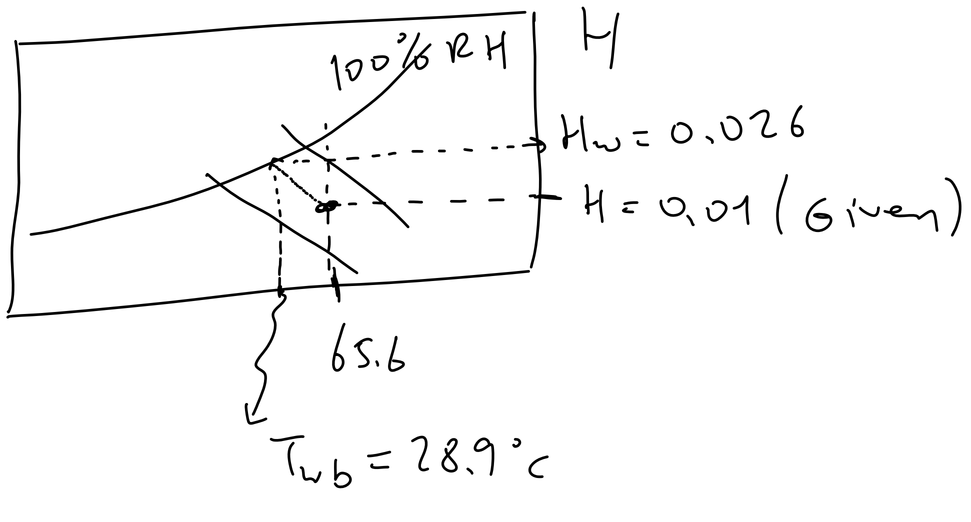
$$G = v \times \rho = \frac{m}{s} \times \frac{kg}{m^3} = \frac{kg}{m^2 . s}$$

Drying time during constant rate period =)

$$t_c = \frac{M_s \times \lambda_w \times (X_1 - X_2)}{A \times h \times (T - T_{wb})}$$

Example: **An insoluble wet granular material is dried in a pan 0.457x0.457 m and 25.4 mm deep. The material 25.4 mm deep in the pan and the sides and bottom can be considered to be insulated. Heat transfer is by convection from an air stream flowing parallel the surface at a velocity of 6.1 m/s. The air is at 65.6ºC and has a humidity of 0.01 kg water/kg DA. Estimate the rate of drying for the constant rate period.**

Solution:



$$V_H = (2.83 \times 10^{-3} + 4.56 \times 10^{-3} \times H) \times T$$

(V_H: humid volume)

$$V_H = (2.83 \times 10^{-3} + 4.56 \times 10^{-3} \times 0,01)(273 + 65.6)$$

$$= 0,974 \ m^3/kg \ DA$$

$H = 0{,}01 \dfrac{kg\,H_2O}{1\,kg\,DA} \Rightarrow$ mass of this air $= 1 + 0{,}01$

$= 1{,}01$ kg wet air

$$\rho_{air} = \frac{1.01\ kg/kg\,DA}{0{,}974\ m^3/kg\,DA} = 1.037\ \frac{kg}{m^3}\ \text{air}$$

$$G = V \times \rho = \left(6.1\ \frac{m}{s}\right)\left(1.037\ \frac{kg}{m^3}\right) \times \frac{3600\,s}{1\,hr} = 22770\ \frac{kg}{m^2.h}$$

$h = 0.0204\,(G)^{0,8}$ ⇝ for parallel flow

$$h = 0{,}0204\,(22770)^{0.8} = 62.45\ W/m^2.K$$

At $T_{wb} = 28{,}9\,°C \Rightarrow \lambda_w = 2433\ \dfrac{kJ}{kg\,H_2O}$ (from saturated steam table)

$$R_c = \frac{h}{\lambda_w}(T - T_w) = \frac{62.45\ J/s.m^2.K}{2433\ \frac{kJ}{kg\,H_2O} \times \frac{1000\,J}{1\,kJ}} \times (65.6 - 28.9)\,K \times \frac{3600\,s}{1\,h} \Rightarrow$$

$R_c = 3.39\ kg\,H_2O/m^2.h$

Total evaporation rate for a surface area of $0.457 \times 0.457\ m^2 = R_c \times A \Rightarrow$

$$\text{Total } R_c = 3.39\ \frac{kg}{m^2.h} \times (0.457 \times 0.457)\,m^2 \Rightarrow$$

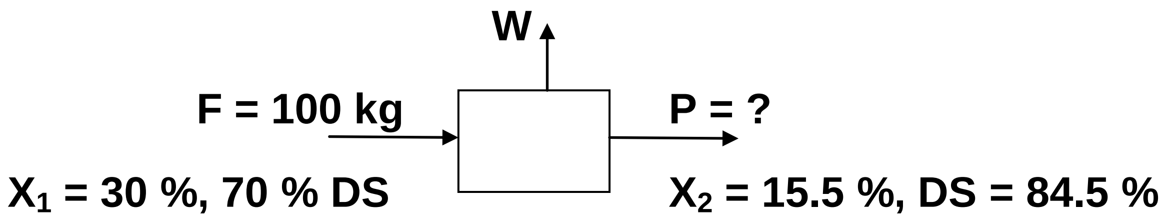
$= 0{,}708\ kg/h$

Example: **A 100 kg batch of granular solids containing 30 % moisture is to be dried in a tray drier to 15.5 % of moisture by passing a current of air at 350 K tangentially across its surface at a velbcity of 1.8 m/s. If the constant rate of drying under these conditions is 0.0007 kg/s.m^2 and the critical moisture content is 15 %, calculate the approximate drying time. Assume the drying surface to be 0.03 m^2/kg dry dry solids.**

Solution:

Mass of water = (100×0.30) = 30 kg

and mass of dry solids = (100-30) = 70 kg



Dry Solids Balance : F = W + P = 100x0.7 = Wx0 + Px0.845 ⟹ P=82.84 kg

Moisture in product = 82.84 – 70 (kg DS) = 12.8 kg moisture

X_1 = 30/70 = 0.429 kg water/kg DS,

X_2 = 15.5/84.5 = 0.183 kg water/kg DS

Water to be removed = 100x0.30 = Wx1 + 82.84x0.155 ⟹ W = 17.2 kg

The surface area for drying=(0.03 m^2/kg dry DS)x70 kg DS = 2.1 m^2 and hence the rate of drying during the constant period=(0.0007x2.1)=0.00147 kg/s.

As the final moisture content is above the critical value, all the drying is at this constant rate and the time of drying is:

t = (17.2/0.00147) = 11.700 s or 3.25 h.