Transformation of Data

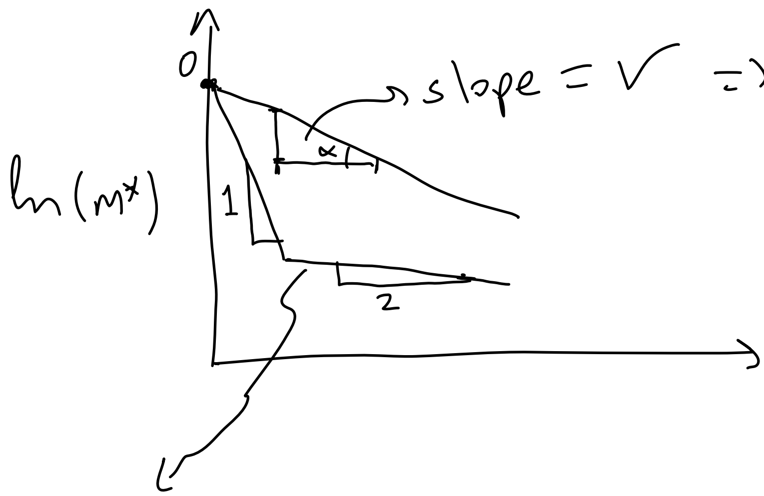
- Deff is typically determined by plotting experimental drying data vs time.

X	t	m^*
⋮	⋮	⇒ calculate
⋮	⋮	⋮

For a sphere ⇒

$$m^* = \frac{X - X^*}{X_0 - X^*} = \frac{6}{\pi^2} \cdot \exp\left(-\frac{D_{eff} \cdot \pi^2 \cdot t}{L^2}\right)$$

$$\ln(m^*) = \ln\left(\frac{6}{\pi^2}\right) - \frac{D_{eff} \cdot \pi^2 \cdot t}{L^2} \rightsquigarrow \text{linear eqn}$$



→ slope = ✓ ⇒ slope $= -\dfrac{D_{eff} \cdot \pi^2}{L^2}$

$\left.\begin{array}{l}\text{slope} \\ L \\ \pi\end{array}\right\}$ known ⇒ calculate D_{eff}.

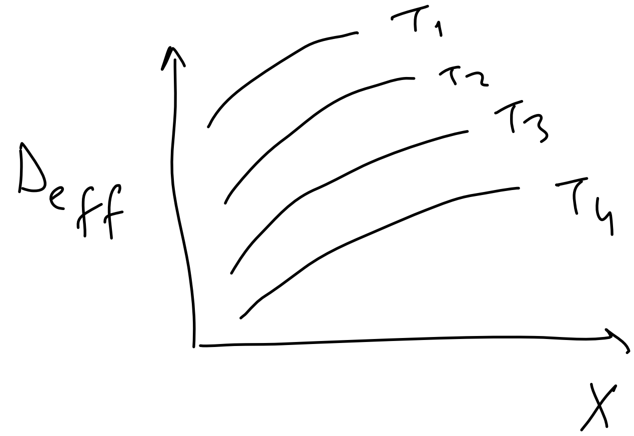
two falling rates ⇒ D_{eff_1} and D_{eff_2}

$D_{eff_1} > D_{eff_2}$

⊛ D_{eff} changes with MC and T.

as T ↗ ⇒ D_{eff} ↗

as MC ↓ ⇒ D_{eff} ↓



$T_1 > T_2 > T_3 > T_4$

⊛ The temperature dependence of diffusivity is described by an Arrhenius type equation.

$$D_{eff} = D_0 \times \exp\left(-\frac{E_a}{RT}\right)$$

D_0: diffusivity constant.

When $T \longrightarrow \infty \Rightarrow D_{eff} \cong D_0$

E_a: activation energy (kJ/mol)

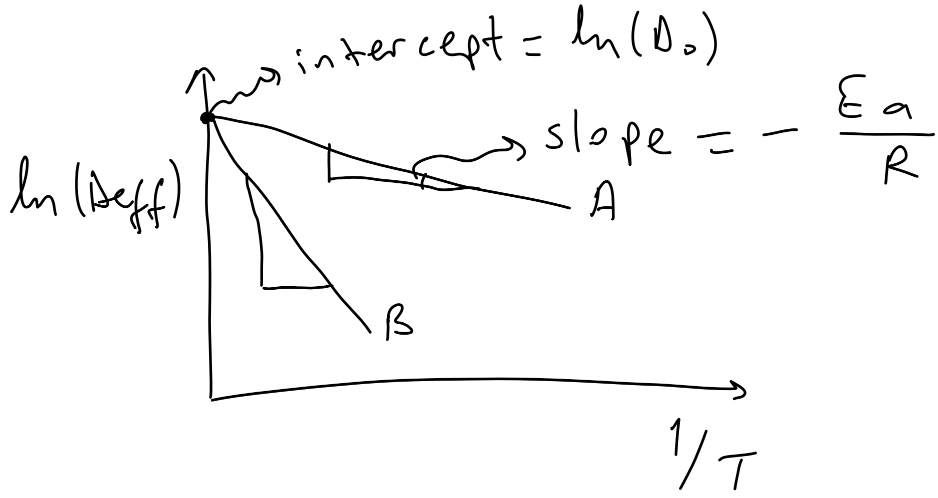
R : gas constant (8.314 kJ/mol.K)

T: absolute temp. (K).

* E_a values are in the range of 15 – 40 $\frac{kJ}{mol}$ for various foods.

* The E_a can be determined by plotting $\ln(D_{eff})$ vs $1/T$.

$$\ln(D_{eff}) = \ln(D_o) - \frac{E_a}{R} \cdot \frac{1}{T}$$



$\Rightarrow$ slope, R } known $\Rightarrow$ Calculate E_a.

The food B is more T sensitive than A.

i.e., D_{eff} values of B varies with T easily than A.

i.e., it is not necessary to dry A at very high T's. Because D_{eff} value doesn't change with T. It is important to dry it at possible minimum temperatures in order to save energy and keep the quality properties of food at high levels.

Example: 2.78 kg of grape leather (initial MC = 64 % wb) with a thickness of 1 mm was spread on a 0.06 m^2 area and dried in a tray dryer using hot air. A typical time (min)-MC (kg H_2O/kg dry solids) data was obtained as shown below:

a) Plot MC vs time
b) Plot drying rate (kg H_2O/m^2.min) vs MC
c) Estimate diffusivity values
d) Estimate Ea value.

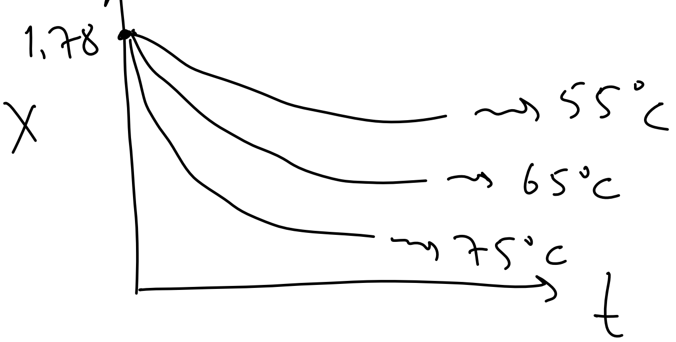
Data:

db

t (min)	X (75°C)	X (65°C)	X (55°C)
0	1,78	1.78	1.78
10	0.85	1.19	1.31
20	0.36	0,71	1.00
30	0,21	0,39	0,61
40	0,13	0,22	0,39
50	0.11	0.14	0,23
60	0,098	0,11	0,18

Solution:

a)

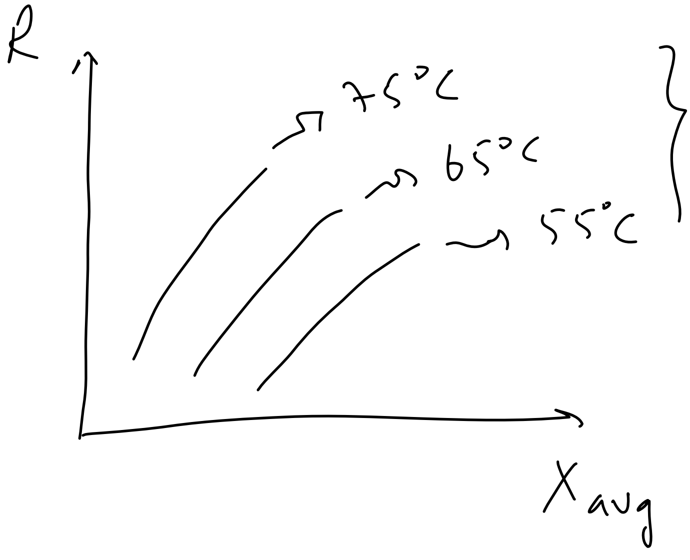


b) $R = -\frac{M_s}{A} \times \frac{(X_{i+1} - X_i)}{(t_{i+1} - t_i)}$

$M_s = 2.78 \times (1 - 0.64) \cong 1.0 \text{ g Ds.}$

$\frac{M_s}{A} = \frac{1}{0.06} = 166.6 \text{ kg Ds}/m^2 = \text{constant.}$

$(t_{i+1} - t_i)$	$(X_{i+1} - X_i)$ 75°C	$(X_{i+1} - X_i)$ 65°C	$(X_{i+1} - X_i)$ 55°C	$X_{average}$ 75	$X_{average}$ 65	$X_{average}$ 55	R 75	R 65	R 55
10	−0,93			1.315			15.5		
10	−0,49			0,605			8.16		
10	−0,15			0,285			2,5		
10	−0,08			0,17			1.33		
10	−0,02			0,12			0,33		
10	−0.012			0.104			0,2		



drying is in the falling rate period.

Calculate t_f =>

$$t_f = \frac{M_s}{A}\left(\frac{X_1 - X_2}{R_1 - R_2}\right) \times \ln \frac{R_1}{R_2}$$

$$t_{75} = 166.6 \frac{kg\,DS}{m^2} \times \frac{(1.315 - 0.104)\, kg\,H_2O / kg\,DS}{(15.5 - 0.2)\, \frac{kg\,H_2O}{m^2.min}} \times \ln\left(\frac{15.5}{0.2}\right)$$

$t_{75°C} \cong 57.4$ min.

t_{65} and t_{55} => calculate at home.

c) Assume slab shape =>

$$m^* = \frac{X - X^*}{X_0 - X^*} = \frac{8}{\pi^2} \exp\left(-\frac{\pi^2 . D_{eff}}{4 \times L^2} \times t\right)$$

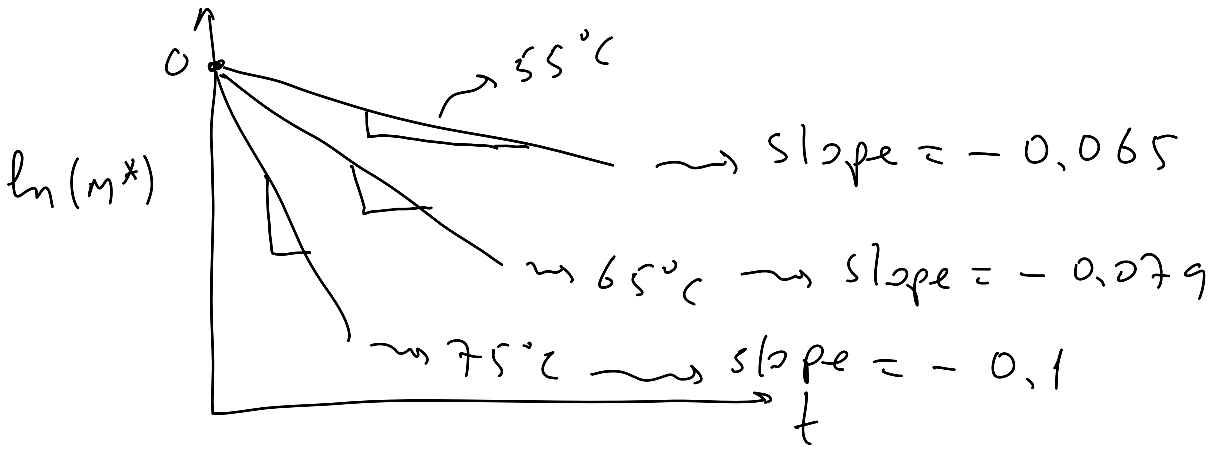
$$\ln(m^*) = \ln\left(\frac{8}{\pi^2}\right) - \frac{\pi^2 . D_{eff}}{4 \times L^2} . t$$

T	X_0	X^*
75 →	1.78 →	0.098
65 →	" →	0.11
55 →	" →	0.18

For 75°C =>

t	m^*
0 →	1
10 →	0.44
20 →	0.15
⋮	⋮
60	

t	m^* 75°C	m^* 65°C	m^* 55°C	$\ln(m^*)$ 75	$\ln(m^*)$ 65	$\ln(m^*)$ 55
0 →	1	1	1	0	0	0
10 →	0,44	⋮	⋮	→ −0,80	⋮	⋮
20 →	0,15			→ −1,85		
30 →	0,06			→ −2,7		
40 →	0,01			→ −3,9		
50 →	0,007			→ −4.9		
60 →	0			→ ∞		



$$\text{slope} = -\frac{D_{eff} \cdot \pi^2}{4 \times L^2}$$

For 55°C ⇒ $-0{,}065 = -\dfrac{D_{eff} \cdot \pi^2}{4 \times (1 \times 10^{-3})^2 \, m^2}$ ⇒

D_{eff} at 55°C = 2.63×10^{-8} m^2/min

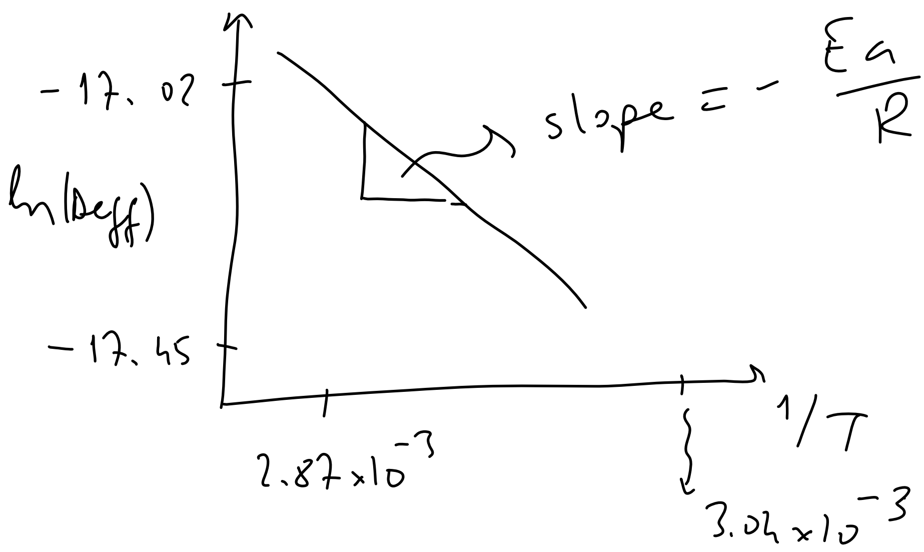
D_{eff} at 65°C = 3.2×10^{-8} m^2/min

D_{eff} at 75°C = 4.056×10^{-8} m^2/min

d) $D_{eff} = D_0 \times \exp\left(-\frac{E_a}{RT}\right) \Rightarrow$

$$\ln(D_{eff}) = \ln(D_0) - \frac{E_a}{RT}$$

T	$1/T$	D_{eff}	$\ln(D_{eff})$
$75+273$	$\to 2.87\times10^{-3}$	$\to 4.056\times10^{-8}$	$\to -17.02$
65 "	$\to 2.95\times10^{-3}$	$\to 3.2\times10^{-8}$	$\to -17.25$
55 "	$\to 3.04\times10^{-3}$	$\to 2.63\times10^{-8}$	$\to -17.45$



$\left.\begin{array}{l}\text{slope}\\ R\end{array}\right\}$ known $\Rightarrow$

$E_a = 20.4\ \frac{kJ}{mol}$.