10 PEMBEKUAN

Lecture Note
Principles of Food Engineering (ITP 330)

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BOGOR

PEMBEKUAN → Pengawetan pangan

Aspek engineering

→ design (keperluan refrigerasi, ΔT)
→ laju pembekuan (*the rate at which freezing progress*)

→ Mutu produk
→ Produktivitas

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PEMBEKUAN

- Penyimpanan produk pada T < suhu beku
- Umumnya pada T < 28 °F (-2 °C), atau khususnya pada < 0 °F (-18 °C)
- Sebagian besar air (~95%) beku
  - daya awet produk beku ` bbrp bulan --- tahun
  - Laju pembekuan dipengaruhi oleh bbrp faktor : perlu dikendalikan
- Pertumbuhan mikroorganisme dihambat, bbrp bahkan dirusak

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PENGARUH PEMBEKUAN PD PROD PANGAN

PENGARUH POSITIP

- Menurunkan/menghambat pertumbuhan m.o.
- Menurunkan laju reaksi kimia/biokimia
- Meningkatkan daya simpan produk
  - (3-40 lipat untuk setiap penurunan suhu 10 °C)

PENGARUH NEGATIP

- Kerusakan kimia
- Kerusakan fisik (*textural*)

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Sifat Produk Pangan Beku

- Penurunan titik didih = f (konsentrasi, BM)

$$\Delta T_f = \frac{R_g T_{A0}^2 BM_A .m}{\lambda}$$

$$\Delta T_f = K.m$$

Lar. X dlm air
$T_f = (1.86\ m)^oC$

dimana:

$$m = \text{molalitas}\left(\frac{\text{mol solut}}{1000\text{mg pelarut}}\right).$$

T_{A0} = titik beku pelarut murni (A) = air (^oK), 273^oK

$$R_g = \text{konstanta gas} = 8.314 \frac{J}{mol.K}$$

$$\lambda = \text{panas laten pembekuan}, \frac{kJ}{kg} \rightarrow \text{air} = 335 \frac{kJ}{kg}$$

BM_A = Berat Molekul pelarut
K = konstanta molal titik beku

$$\frac{\lambda^1}{R_g}\left(\frac{1}{T_{A0}} - \frac{1}{T_A}\right) = \ln X_A$$

X_A = fraksi mol air
λ^1 = panas laten pembekuan

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Contoh :

Ice cream mix dengan komposisi sbb:

- 10% butterfat
- 12% solid-not-fat (54.5%: laktosa)
- 15% sukrosa
- 0.22% stabilizer

37.22% → Air = 62.78%

Ditanya ΔT_f = ?

$$\Delta T_f = \frac{R_g T_{A0}^2 BM_A .m}{L}$$

m = ?

$$m = \frac{\text{mol solut}}{\text{kg solven}}$$

Asumsi bahwa hanya gula (laktosa+fruktosa) yang memp. Efek menurunkan titik beku) !!

Solut? sukrosa BM = 342
laktosa BM = 342
solut lain diabaikan !!

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Contoh : (lanj)

∴ Fraksi gula = 0.15 + 0.12 (0.545) = 0.2154 g/g

Fraksi air = 0.6278

Konsentrasi gula dlm air = $\frac{0.2154}{0.6278} = 0.3431 \frac{\text{g gula}}{\text{g air}}$

$= 343{,}1 \frac{\text{g gula}}{1000 \text{ g air}}$

$$m = \frac{\frac{343.1}{342}\text{mol gula}}{1000 \text{ g air}} = 1.003 \text{ m}$$

$$\Delta T_f = \frac{\left(8.314 \frac{J}{mol.K}\right)\left(\frac{1mol}{18g}\right)(273K)^2\left(18 \frac{g}{mol}\right)\left(1.003 \frac{mol}{kg}\right)}{1000.335 \frac{J}{kg}}$$

ΔT_f = 1,86 K

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Panas Laten Pembekuan

Air murni $\lambda = 335 \frac{kJ}{kg}$

Larutan solid x dlm air $\lambda = (335\ m_w) \frac{kJ}{kg}$

m_w = Fraksi massa air

Contoh:

	Kadar air	$\lambda \left(\frac{kJ}{kg}\right)$
Selada	94.8	316.3 (317.6)
Strawberi	90.8	289.6 (304.5)
Kacang panjang	88.9	297.0 (297.8)
Kentang	77.8	258.0 (260.0)
Daging kambing	58.0	194.0 (194.3)
Kacang merah, biji kering	12.5	41.9 (41.9)
Kurma kering	24.0	79.0 (80.4

} Perhitungan berdasarkan pd rumus $\lambda = 335\ m_w \frac{kJ}{kg}$

Air: $\lambda = 335 \frac{kJ}{kg} = \frac{335\ 10^3\ J}{kg}\left(\frac{18\ 10^{-3}}{1\ mol}\right)$

$\lambda = 6030 \frac{J}{mol}$

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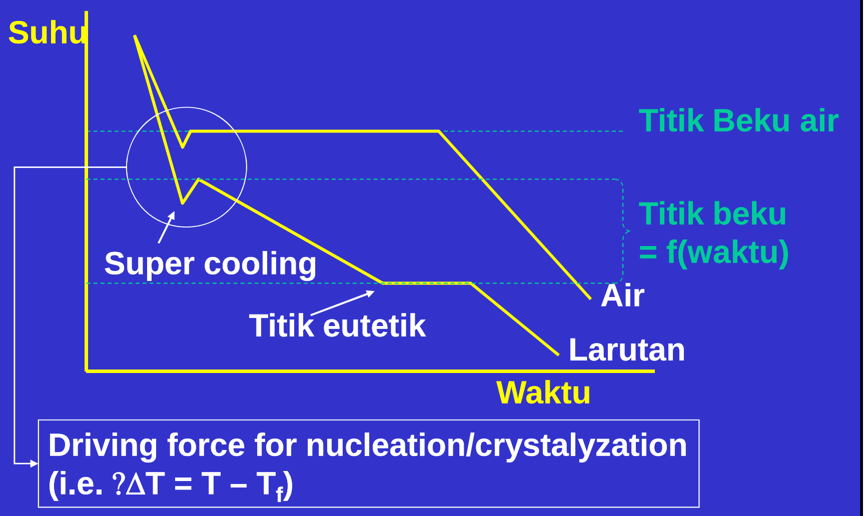
Kurva Pembekuan



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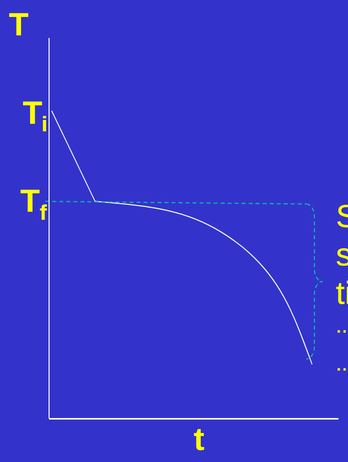
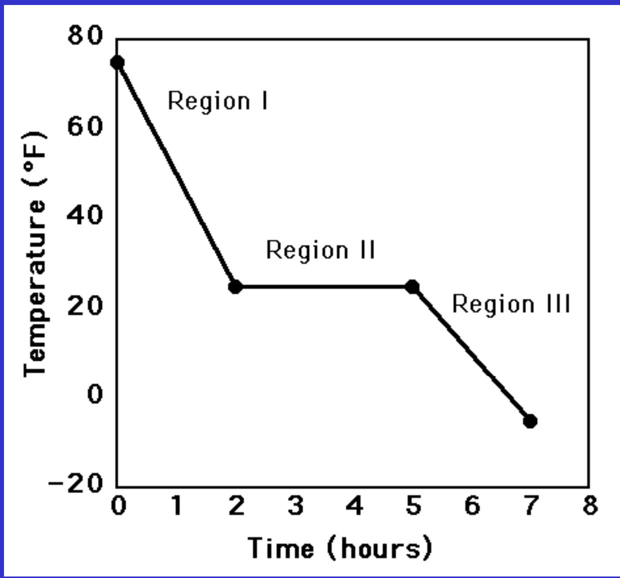
Kurva Pembekuan u/ Prod Pangan



Setelah terjadi pembekuan, konsentrasi solute pada sisa larutan menjadi lebih tinggi
·····> penurunan titik beku lebih besar
·····> T_f (↙)

You can't freeze all of the water
(Still have unfrozen water : 5-10%)

FREEZING OF WATER



T-t Diagram :

A schematic freezing curve for water, displaying sensible heat loss (Regions I and III) and latent heat loss (Region II).

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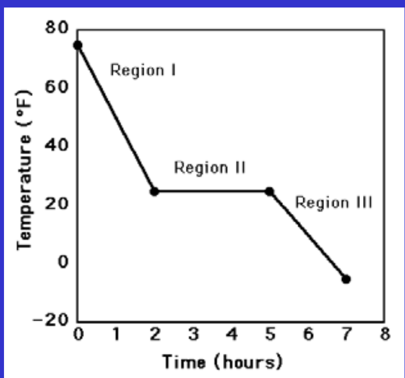
ENERGY REMOVAL ASSOCIATED WITH FREEZING



Removal of heat (Q) from Region I (sensible heat), II (latent heat), and III (sensible heat) :

(1) $Q_1 = mC_{p1}\Delta T_1$
- m = weight of food
- C_{p1} =specific heat of food above freezing
- ΔT = temperature difference

(2) $Q_2 = m_w \lambda$
- ········> m_w = weight of water
- ········> λ = latent heat

(3) $Q_3 = mC_{p2}\Delta T_3$
- ········> m = weight of food
- ········> C_{p2} = specific heat of frozen food
- ········> ΔT_3 = temperature difference

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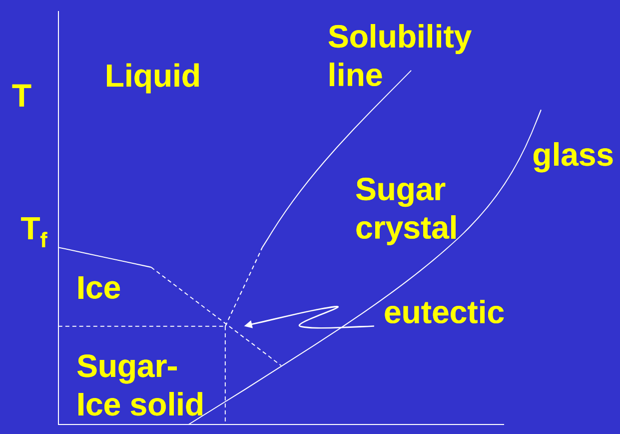

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INITIAL FREEZING TEMPERATURE

Buah anggur (grape) ········> kadar air 84.7%

········> T_f = -1.8°C (271.2°K)

$$\frac{\lambda^1}{R_g}\left(\frac{1}{T_{A0}} - \frac{1}{T_A}\right) = \ln X_A$$

$$\lambda^1 = 6003 \ \frac{J}{mol}$$

$$R_g = 8.314 \ \frac{J}{mol\,.K}$$

X_A=?

$$\frac{6003 \ \frac{J}{mol}}{8,314 \ \frac{J}{mol\,.K}}\left(\frac{1}{273\,K} - \frac{1}{271.2\,K}\right) = \ln X_A$$

Ln X_A = - 0.01755

X_A = 0.9826 (effective mol fraction of water) $\frac{m\ grape}{ml}$

INITIAL FREEZING TEMPERATURE

X_A = fraksi mol air = 0.9826

$$X_A = 0.9826 = \frac{\frac{84.7}{18}}{\frac{84.7}{18} + \frac{15.3}{BM_E}}$$

BM_E = 183.61

Juice anggur dapat dianggap bertingkah laku mirip/sama dgn

- lar. x dlm air
- $BM_x = 183.61 \ \frac{mol}{g}$
- X_A = 09826
- X_x = ... dst

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PERHITUNGAN PEMBEKUAN (DESIGN)

- Pendugaan keperluan pembekuan
  - ? ukuran sistem “mechanical compression”
  - ? evaluasi beban refrigerasi/pembekuan

-Disain peralatan + proses, untuk :
  - ? memperoleh pembekuan yg diinginkan
    - koef pindah panas
    - laju pembekuan

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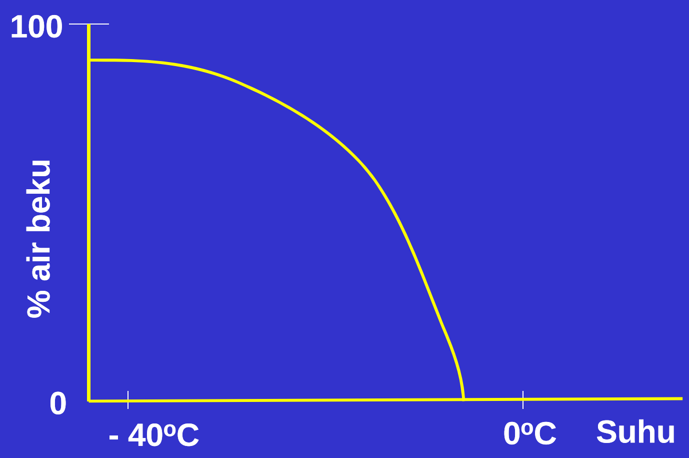
Hubungan antara % air beku vs. suhu



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LAJU PEMBEKUAN

- EQUIPMENT RELATED
  - rate of heat transfer
  - size of refrigeration unit
- FOOD/PRODUCT QUALITY
  - slow freezing
    - result in formation of few, large ice crystals
    - damaging to cell structure/quality
  - rapid freezing
    - results in many small ice crystals
    - gives best product quality
    - leads to IQF techniques
- water ......> ice: ~ 9% increase in volume

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FREEZING TIME

- Time-temperature method +
  - Time required to freeze between two temperatures (usually T = -5ºC or –10ºC)
- Velocity of ice front
  - rate of freezing
  - must be able to see ice front
- Appearance of specimen
  - internal conditions
- Thermal methods
  - calorimetric techniques
  - not real-world condition

+ *Time-temp. methods most common*
+ *many people use time to freeze to –10ºC as standard.*

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PERHITUNGAN WAKTU PEMBEKUAN

- panas laten adalah energi utama yang hrs diperhitungkan pada proses pembekuan
  - ~ 75% total energi pd proses pembekuan
    333.3 kJ/kg air
    144 BTU/lb air

- Terjadi perubahan sifat fisik bahan selama proses pembekuan ~ f (T,m)

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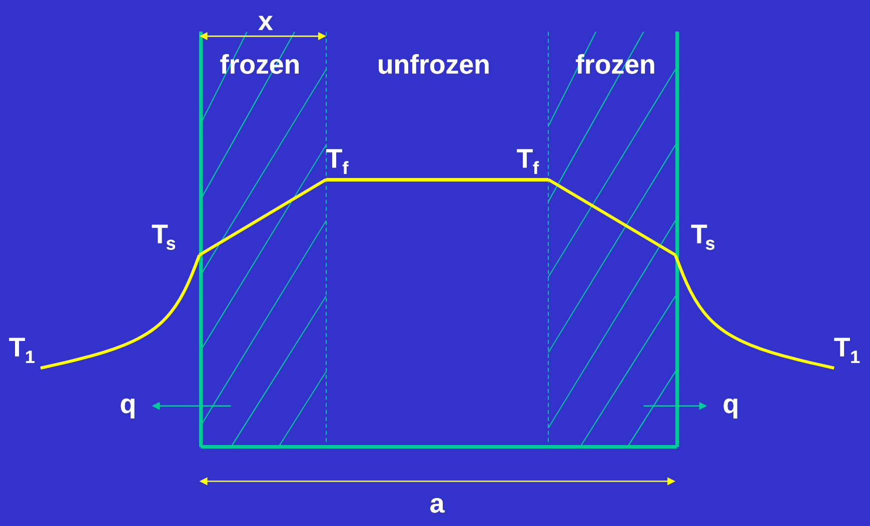
Plank's Method (for infinite slab)



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Plank's Method (for infinite slab)

Convection:

$$q\left(\frac{BTU}{hr}\right) = Qt = hA\,(T_s - T_1) \quad \text{...... Pers. 1}$$

h = convective heat transfer coeff. at the product surface.

Conduction:

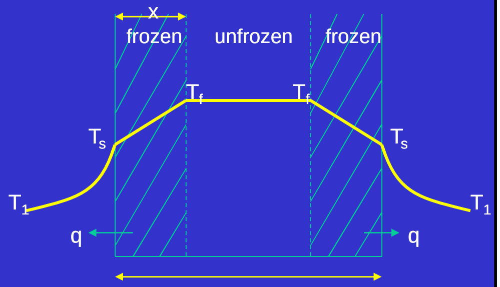
$$q = \frac{k_f.A}{x}\left(T_f - T_s\right) \quad \text{...... Pers. 2}$$

T_f = initial freezing point

x = x (t)

Combine 1&2:

$$q = \frac{\left(T_f - T_1\right)}{\frac{x}{k_f} + \frac{1}{h}} \quad \text{....... Pers. 3}$$



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Plank's Method (for infinite slab)

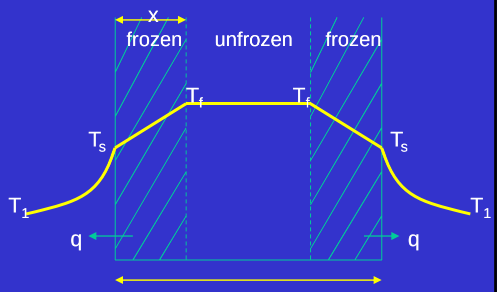
Jumlah energi yang dibebaskan selama proses pembekuan

$$qdt = m_i \lambda_f = \rho_f \, dV \, \lambda_f$$
$$qdt = \rho_f \lambda_f A \, dx$$

so, $q = \rho_f \lambda_f A \, dx/dt$ .... Pers. 4

Ingat Pers 3 :

$$q = \frac{(T_f - T_1)}{\frac{x}{k_f} + \frac{1}{h}}$$



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Plank's Method (for infinite slab)

Kombinasi Pers. 3 dan 4 ········> $\rho_f \lambda_f A \frac{dx}{dt} = \frac{(T_f - T_1)A}{\frac{x}{k_f} + \frac{1}{h}}$

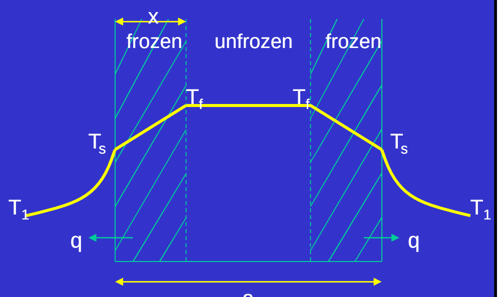
Pembekuan selesai lempeng jika x = a/2

$$\rho_f \lambda_f \left(\frac{x}{k_f} + \frac{1}{h} \right) dx = (T_f - T_1) dt$$

$$\rho_f \lambda_f \int_0^{\frac{a}{2}} \left[\frac{x}{k_f} + \frac{1}{h} \right] dx = (T_f - T_1) \int_0^{T_f} dt$$

$$t_f = \frac{\rho_f \lambda_f}{T_f - T_i} \left[\frac{a^2}{8k} + \frac{a}{2h} \right]$$

T_i = Suhu Pembekuan
Suhu ruang pembeku



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GENERAL FLANKS EQUATION

$$t_f = \frac{\rho_f \lambda_f}{(T_f - T_i)}\left[\frac{Ra^2}{k_f} + \frac{Pa}{n}\right]$$

Where:

	Infinite slab	Sphere	Infinite sylinder	Cube
P	1/2	1/6	1/4	1/8
R	1/8	1/24	1/6	1/24
a	Thickness	Diameter	Diameter	Edge

λ_f = latent heat of fusion [=] $\frac{kJ}{kg}$

λ water $= 333.22 \frac{kJ}{kg} = 144 \frac{BTU}{lb}$

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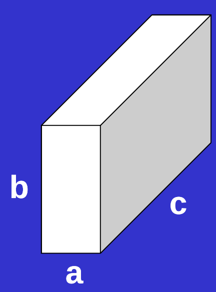
GENERAL FLANKS EQUATION



P dan R untuk bentuk bata

a : dimensi terpendek
c : dimensi terpanjang

B_2 = c/a
B_1 = b/a

Lihat chart/diagram :
dengan diketahui nilai B_2 dan B_1 maka dapat dibaca nilai P dan R

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Limitation of Plank's method:

- no superheating or supercooling
- thermal properties are constant
- can't incorporate a variable heat transfer coeff.
- can't handle varying freezing point

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Selesai ……………

Sekarang ke…….

Psikrometrik