Kinetika Pertumbuhan

Agroindustri Produk Fermentasi

Kompetensi yang Diharapkan

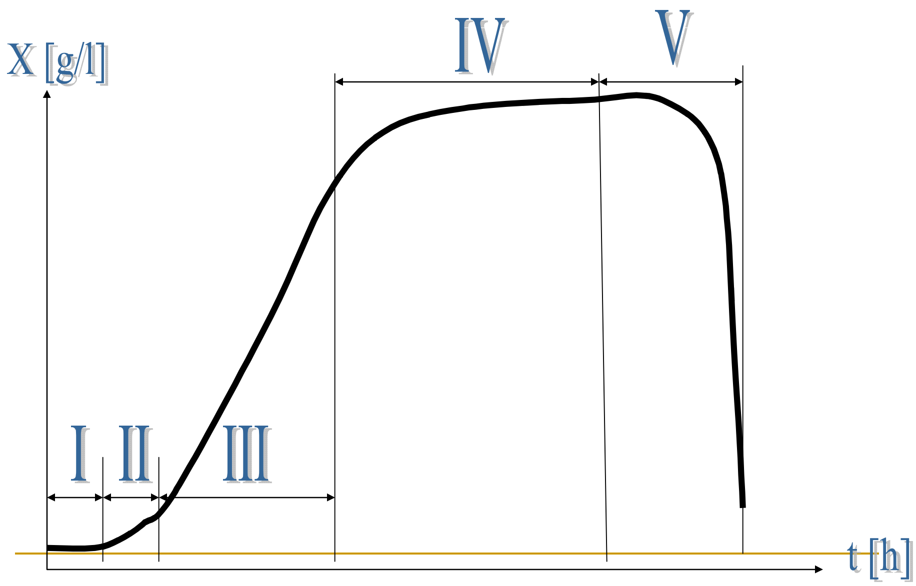
- **Menguasai kinetika pertumbuhan mikroorganisme sehingga tepat penerapannya untuk operasi industri fermentasi secara batch, kontinyu dan fed-batch.**
- **Menguasai kinetika pertumbuhan mikroorganisme sehingga tepat penerapannya untuk operasi industri fermentasi produk metabolit primer, metabolit sekunder, biomassa sel, dan produk biotransformasi.**

Microbial Growth

Microbial Cell Growth

- Mode of Growth
  - Selective assimilation of nutrients and convert into and also include Chemical rearrangement of protoplasmic material characteristic of the particular organism
  - Production of an increased amount of nuclear substance and cell division

Growth Phase



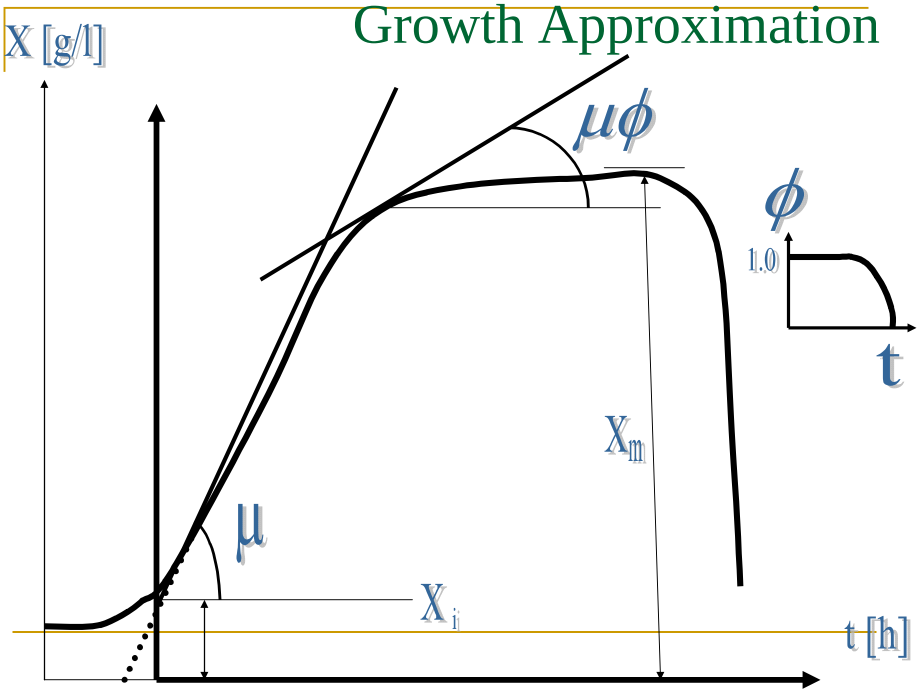
Growth Phase

- Induction Phase (Lag Phase)
- Transient Phase (Acceleration Phase)
- Exponential Phase
- Stationary Phase (Declining Phase)
- Death Phase

Question Sheet

- Why microbial growth have an lag phase?
- Why death phase could be occurred in microbial growth?
- What is essential nutrient for growth of organism especially *prokaryotes*?
- What is important factor for cell division?

Growth Approximation



Growth Constants

Exponential – Stationary Growth Phase

Total Biomass Production(G)

$$G = (X_m - X_i)$$

Incident growth rate, Incident mean division rate (μϕ)

$$\mu\phi = \left[\frac{\ln\frac{X_2}{X_1}}{t_2 - t_1}\right] \approx \frac{1}{X} \cdot \frac{dX}{dt}$$

Specific growth rate, Beginning mean division rate (μ)

$$\mu = \lim_{t \to 0} \frac{1}{X} \cdot \frac{dX}{dt}$$

Doubling time of population (τ_D); exponential growth phase

$$\tau_D = \frac{\ln 2}{\mu}$$

Classical Growth Kinetics

Empirical Approximation

- *Monod* Growth Kinetic $\boldsymbol{\mu\phi = \mu \cdot \frac{s}{K_s + s}}$
- *Tessier* Growth Kinetic $\mu\phi = \mu \cdot \left(1 - e^{-s/K_s}\right)$
- *Moser* Growth Kinetic $\mu\phi = \mu \cdot \left(1 + K_s \cdot s^{-\lambda}\right)^{-1}$
- *Contois* Growth Kinetic $\mu\phi = \mu \cdot \frac{s}{B \cdot X + s}$

Empirical Growth Kinetics

Medium constituent Inhibition

- *Andrews* Growth Kinetic

$$\mu\phi = \mu \cdot \frac{s}{K_s + s + s^2/K_i}$$

- *Aiba* Growth Kinetic

$$\mu\phi = \mu \cdot \frac{s \cdot K_p}{K_s + s \cdot (K_p + p)}$$

Growth Kinetics

Multiple essential nutrient

- Bailey Growth Kinetic

$$\mu\phi = \mu \cdot \frac{s_1}{K_{s1} + s_1} \cdot \frac{s_2}{K_{s2} + s_2} \cdot \frac{s_3}{K_{s3} + s_3} \cdot \ldots$$

Home Work

- Which kinetic approximation do you choose in case of microbial growth of Hepatotoxin produced *Oscilatoria Agardhii* NIVA CYA 97 in low temperature?
- Which empirical equation that you choose of inoculation of microorganism in case of multiple content limitation of nutrients, such as Mg^{2+}, phosphate, Nitrate and organic compound?
- Which kinetic approximation do you choose of cultivation photosynthetic microorganism that did not grew up in pH above 7.8?

Simple Bio-Production Kinetic

- Cellular growth rate

$$\frac{dX}{dt} = \mu \cdot \phi \cdot X$$

  - Monod approximation

$$\mu\phi = \mu \cdot \frac{s}{K_s + s}$$

$$\frac{dX}{dt} = \mu \cdot \frac{s \cdot X}{K_s + s}$$

  - Yield factor

$$Y_{X/s} = \frac{(\Delta X)}{(\Delta s)} = \frac{\left(\frac{dX}{dt}\right)}{\left(\frac{ds}{dt}\right)} \qquad Y_{P/X} = \frac{(\Delta P)}{(\Delta X)} = \frac{\left(\frac{dP}{dt}\right)}{\left(\frac{dX}{dt}\right)}$$

- Substrate Utilization

$$-\frac{ds}{dt} = \frac{\mu}{Y_{X/s}} \cdot \frac{s \cdot X}{K_s + s}$$

- Product Formation

  (Beginning of *Stationary Phase*)

$$\frac{dP}{dt} = Y_{P/X} \cdot \mu \cdot \frac{s \cdot X}{K_s + s}$$

Environmental Alteration Studies

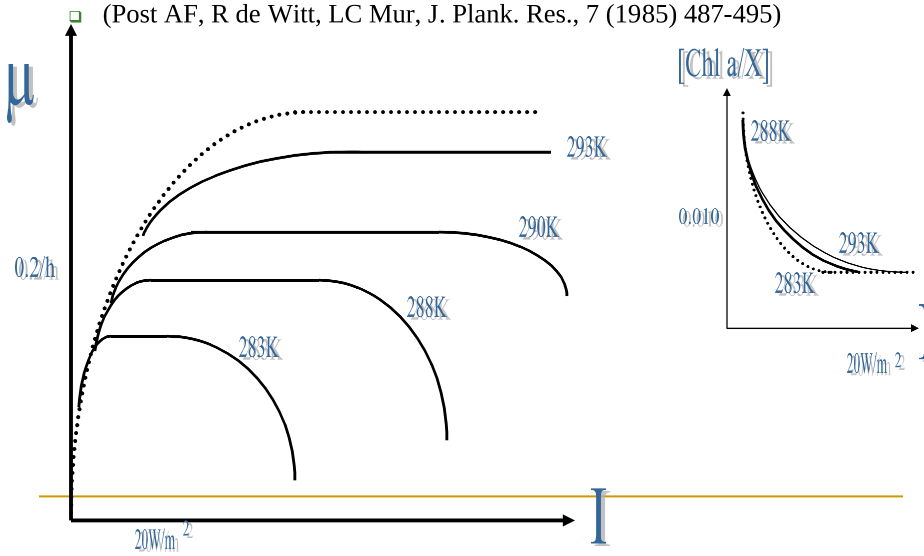
Microbial Growth Kinetic

Enviromental Condition

- Direct Effects
  - Light Illumination (Energy Source)
  - Temperature
  - Essential nutrients content
- Indirect Effects
  - Gas inlet volumetric rate
  - Gas inlet content
  - Liquid circulation rate
  - Non essential nutrients content

Light Illumination Effect

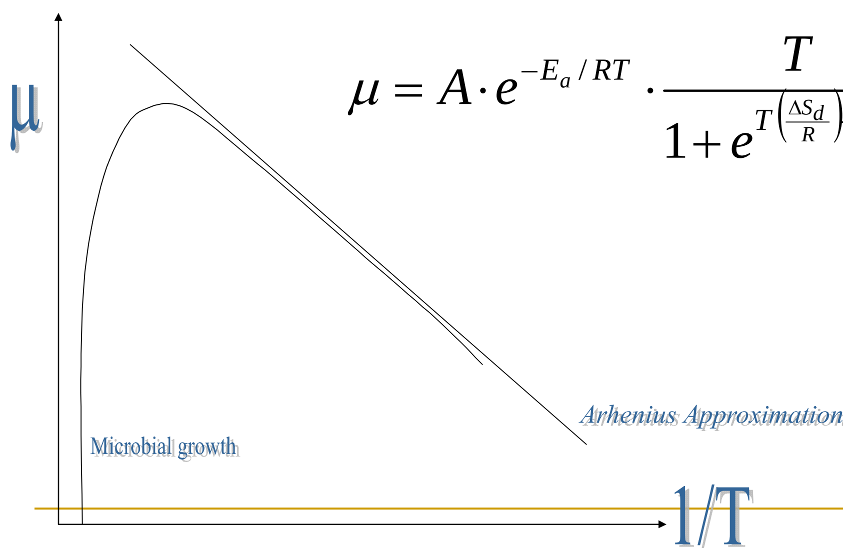
- *Oscillatoria agardhi* Gomont
  - (Post AF, R de Witt, LC Mur, J. Plank. Res., 7 (1985) 487-495)



Temperature effect

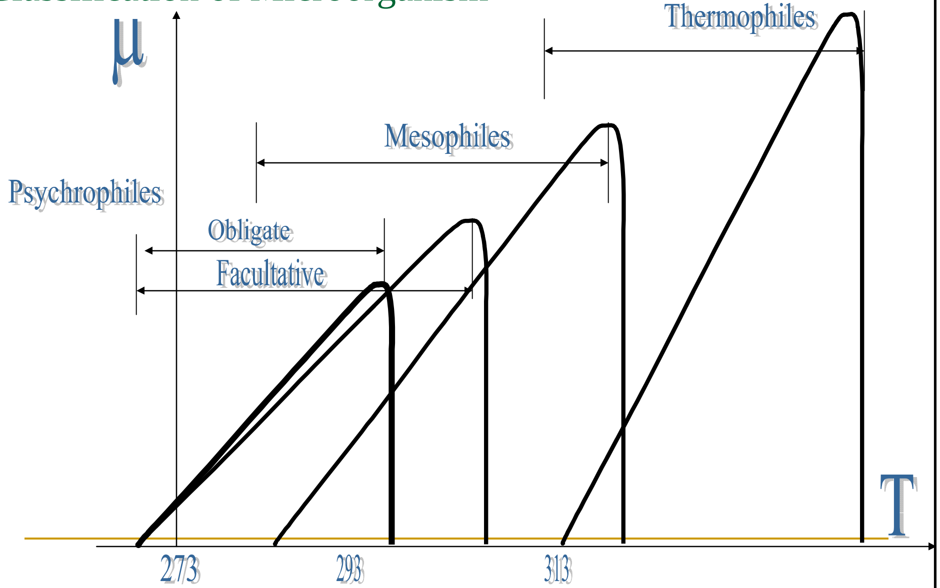
- Modified *Arhenius* Model

$$\mu = A \cdot e^{-E_a/RT} \cdot \frac{T}{1 + e^{T\left(\frac{\Delta S_d}{R}\right) - \left(\frac{\Delta H_d}{R}\right)}}$$



Temperature Effect

Classification of Microorganism

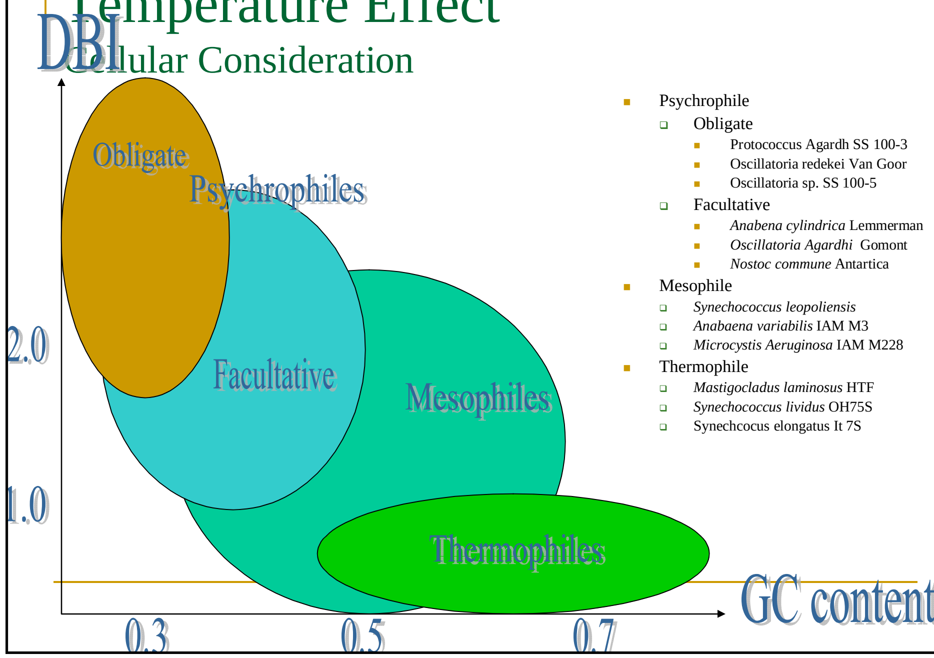


Question Sheet

- What is happen if microorganism is at 90^{o}C? Why?
- In case of decreasing of temperature about 20^{o}C from optimum temperature, what is happen in case of microbial growth rate?
- In case of ethanol production that was *S. sake* have ethanol tolerance around 10%, what do you do to make an whisky industry?
- Why a shade microbe does not grew well in high light illumination and commonly have not high temperature resistance?

Temperature Effect

Cellular Consideration



- Psychrophile
  - Obligate
    - Protococcus Agardh SS 100-3
    - Oscillatoria redekei Van Goor
    - Oscillatoria sp. SS 100-5
  - Facultative
    - *Anabena cylindrica* Lemmerman
    - *Oscillatoria Agardhi* Gomont
    - *Nostoc commune* Antartica
- Mesophile
  - *Synechococcus leopoliensis*
  - *Anabaena variabilis* IAM M3
  - *Microcystis Aeruginosa* IAM M228
- Thermophile
  - *Mastigocladus laminosus* HTF
  - *Synechococcus lividus* OH75S
  - Synechcocus elongatus It 7S

Home Work

- Why optimum specific growth rate values of psychrophile factually, lower than thermophile?
- Why GC content of microbial DNA is important for classification of organism in terms of growth rate dependence on temperature?
- What is DBI?

Microbial Kinetic Studies

Non Elementer Reaction

- Common reaction rate

$$-\frac{ds}{dt} = k \cdot s^n$$

  - N = integer → Elementer
  - N = non integer → Non Elementer

Non Elementer Example :

$$CH_3CHO \rightarrow CH_4 + CO \qquad -\frac{d[CH_3CHO]}{dt} = k \cdot [CH_3CHO]^{3/2}$$

$$H_2 + Br_2 \rightarrow 2HBr \qquad -\frac{d[Br_2]}{dt} = \frac{k_1' \cdot [Br_2]^{3/2} \cdot [H_2]}{[HBr] + k_2' \cdot [Br_2]}$$

Reaction Mechanism

Mechanism path is microscopic description of a chemical reaction that was composed in term of elementer reactions

Chemical reaction

$$2NO + 2H_2 \rightarrow N_2 + 2H_2O$$

Mechanism Path

$$2NO \underset{k_{-1}}{\overset{k_1}{\Leftrightarrow}} N_2O_2 \quad \text{Fast reaction}$$

$$N_2O_2 + H_2 \xrightarrow{k_2} N_2 + H_2O_2 \quad \text{Slow reaction, DECISIVE Path}$$

$$H_2 + H_2O_2 \xrightarrow{k_3} 2H_2O \quad \text{Fast reaction}$$

Intermediete species N_2O_2 / H_2O_2

$$\frac{d[H_2O_2]}{dt} = 0 \qquad k_2 \cdot [N_2O_2] \cdot [H_2] - k_3 \cdot [H_2O_2] \cdot [H_2] = 0 \qquad [H_2O_2] = \frac{k_2}{k_3}[N_2O_2]$$

$$\frac{d[N_2O_2]}{dt} = 0 \qquad k_1 \cdot [NO]^2 - k_{-1} \cdot [N_2O_2] - k_2 \cdot [N_2O_2] \cdot [H_2] = 0 \qquad [N_2O_2] = \frac{k_1}{k_{-1} + k_2} \cdot \frac{[NO]^2}{1 + [H_2]}$$

$$\frac{d[N_2]}{dt} = k_2 \cdot [N_2O_2] \cdot [H_2] = k_2 \cdot \left(\frac{k_1}{k_{-1} + k_2} \frac{[NO]^2}{1 + [H_2]} \right) \cdot [H_2] = \frac{k_1 \cdot k_2}{k_{-1} + k_2} \cdot [NO]^2 \cdot \frac{[H_2]}{1 + [H_2]}$$

Question Sheet

- What is mechanism path?
- What definition of intermediate species?
- What was become determining factor of reaction rate?

Microbial Growth

Enzymatic Reaction/Kinetic consideration

- *Michaelis-Menten* Kinetics
  - Reaction mechanism

$$E + S \underset{k_{-1}}{\overset{k_1}{\longleftrightarrow}} ES \qquad ES \overset{k_2}{\longrightarrow} P + E$$

  - Kinetic equation

$$\mu\phi = \frac{\mu \cdot s}{K_m + s}$$

- Substrate Actvation and Inhibition
  - Reaction mechanism

$$E + S \underset{k_{-1}}{\overset{k_1}{\longleftrightarrow}} ES \qquad ES + S \underset{k_{-2}}{\overset{k_2}{\longleftrightarrow}} ES_2 \qquad ES \overset{k_3}{\longrightarrow} P + E$$

  - Kinetic equation

$$\mu\phi = \frac{\mu \cdot s}{K_m + s + s^2 / K_i}$$

- Product Activation and Inhibition
  - Reaction mechanism

$$E + S \underset{k_{-1}}{\overset{k_1}{\longleftrightarrow}} ES \qquad ES \overset{k_2}{\longrightarrow} P + E \qquad ES + P \underset{k_{-3}}{\overset{k_3}{\longleftrightarrow}} ESP$$

  - Kinetic equation

$$\mu\phi = \mu \cdot \frac{s \cdot K_p}{K_s + s \cdot (K_p + p)}$$

Michaelis-Menten Kinetics

- Reaction mechanism

$$E + S \underset{k_{-1}}{\overset{k_1}{\longleftrightarrow}} ES \qquad ES \overset{k_2}{\longrightarrow} P + E$$

- Kinetic derivation

$$E_0 = E + [ES] \qquad [ES]_0 = 0$$

$$\tfrac{d}{dt}[ES] = 0$$

$$\tfrac{d}{dt}[ES] = k_1 \cdot S \cdot E - (k_{-1} + k_2) \cdot [ES]$$

$$[ES] = \frac{k_1}{k_{-1} + k_2} \cdot S \cdot E = \frac{k_1}{k_{-1} + k_2} \cdot S(E_0 - [ES])$$

$$[ES] = \frac{E_0 \cdot S}{S + \frac{k_{-1} + k_2}{k_1}}$$

$$\tfrac{d}{dt} P = k_2 \cdot [ES] = \frac{(k_2 \cdot E_0) \cdot S}{S + \left(\frac{k_{-1} + k_2}{k_1}\right)} = \frac{[\tfrac{d}{dt} P]_{\max} \cdot S}{S + K_m}$$