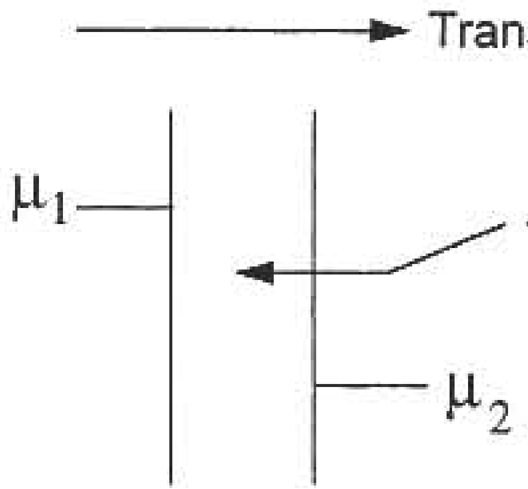
MEMBRANE TRANSPORT



Membrane materials and structure create barrier and semipermeable membrane barrier separating two fluid mixtures in which chemical potentials of one or more components differs

Δ Chemical potentials creates driving force

Types of Transport

- **Passive:** Down chemical potential gradient
- **Facilitated:** Carrier mediated transport in which one or more species binds to diffusible carrier
- **Active:** Up chemical potential gradient, coupled to metabolic chemical reaction

Chemical Potential of Species i (μ i)

$$u_i = u_i^o + \overline{S}_i T + \overline{V}_i P + RT \ln a_i + Z_i F \Psi + \ldots$$

μ_i^o = chemical potential of standard state

$\overline{S_i}$ = partial molal entropy

$\overline{V_i}$ = partial molal volume

R = ideal gas constant

Z_i = valence

F = Faraday' s constant

P = Pressure

$a_i = \gamma_i C_i$, chemical activity

γ_i = activity coefficient

C_i = concentration

Ψ = electrical field potential

→ Driving forces : T, P, C, ψ, ...
Two or more may act simultaneously

CATEGORIZATION OF MEMBRANE SEPARATION PROCESSES

NAME	UPSTREAM MIXTURE	DOWNSTREAM MIXTURE	DRIVING FORCE	PERMEANT	REJECTED SPECIES
Gas Permeation	Gas	Gas	Concentration or Partical Pressure	Gas	
Pervaporation	Liquid Solution	Gas	Concentration or Partical Pressure	Gas	
Dialysis	Liquid Solution	Liquid Solution	Concentration	Microsolutes	
Electrodialysis	Liquid Solution	Liquid Solution	Electrical Potential	Ions	
Filtration					
Reverse Osmosis (Hyperfiltration)	Liquid Solution	Liquid Solution	Pressure and Concentration	Solvent	Microsoluted
Ultrafiltration	Liquid Solution	Liquid Solution	Pressure and Concentration	Microsolutes	Macrosolutes
Microfiltration	Liquid Suspension	Liquid Solution	Pressure and Concentration	Macrosolutes	Colloidal Particles
Particle Filtration	Liquid Suspension	Liquid Suspension	Pressure and Concentration	Colloidal Particles	Macroscopic Particles

STEADY-STATE CONVECTIVE TRANSPORT

Hydroststic Pressure Driving Force

Volume Flux = $J_V = \dfrac{k\Delta P}{\mu L}$

Darcy's Law $\left(\dfrac{k}{\mu L}\right)\Delta P = L_p \Delta P$

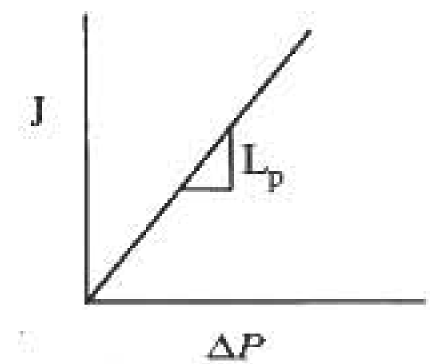
k = hydraulic permeability

μ = viscosity

P = hydrostatic presure

$J_V = L_p \Delta P$

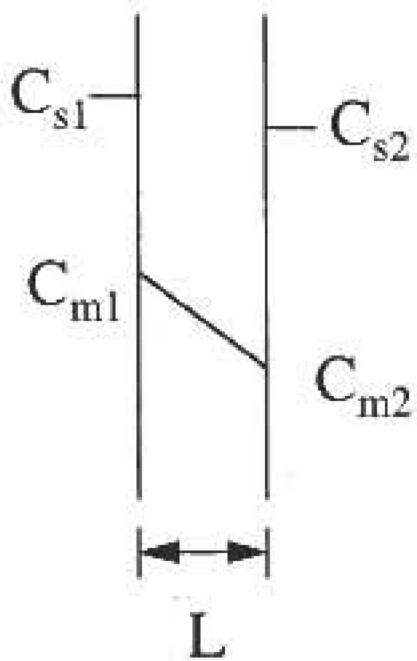
L_p = phenomenological hydraulic permeability = $\dfrac{k}{\mu L}$



STEADY-STATE
<u>DIFFUSIVE</u> TRANSPORT

Partitioning of solute between solution and membrane

$$K_p = \frac{C_m}{C_s}$$



Membrane Thickness

Mass Flux $=$ $J_s = -D\dfrac{dC}{dx}$

D = effective diffusion coefficient in membrane
C = concentration
x = distance

Integration across membrane:

$$J_s = D\frac{C_{m1} - C_{m2}}{L} = DK_p\frac{C_{s1} - C_{s2}}{L}$$

K_p = membrane partition coefficient = $\dfrac{C_m}{C_s}$

$$J_s = P_m \Delta C_s$$

P_m = membrane permeability = $\dfrac{DK_p}{L}$

Thus,

$$J_s = \frac{DK_p}{L}(Cs_1 - Cs_2) = P_m(\Delta Cs)$$

COMBINED DIFFUSIVE CONVECTIVE TRANSPORT
THE LINEAR CASE

Basis: Thermodynamics of Irreversible Processes

Key Assumption: Small departure from equilibrium

$$\frac{d\mu_i}{dx} = \frac{\Delta \quad i\mu}{\Delta X}$$

$J_V = L_p(\Delta P - \sigma\Delta\pi)$ ← The greater the rejection the greater the impact of $\Delta\pi$

$J_S = P_m \Delta C_S + (1-\sigma)\overline{C_S} J_V$ ← This describes solute pauses this membrane by convective flow

$\overline{C} =$ average solution concentration

$$\sigma = \text{Staverman reflection coefficient} = \frac{\text{actual}\Delta\pi}{\Delta\mu \text{ with } \sigma = 1}$$

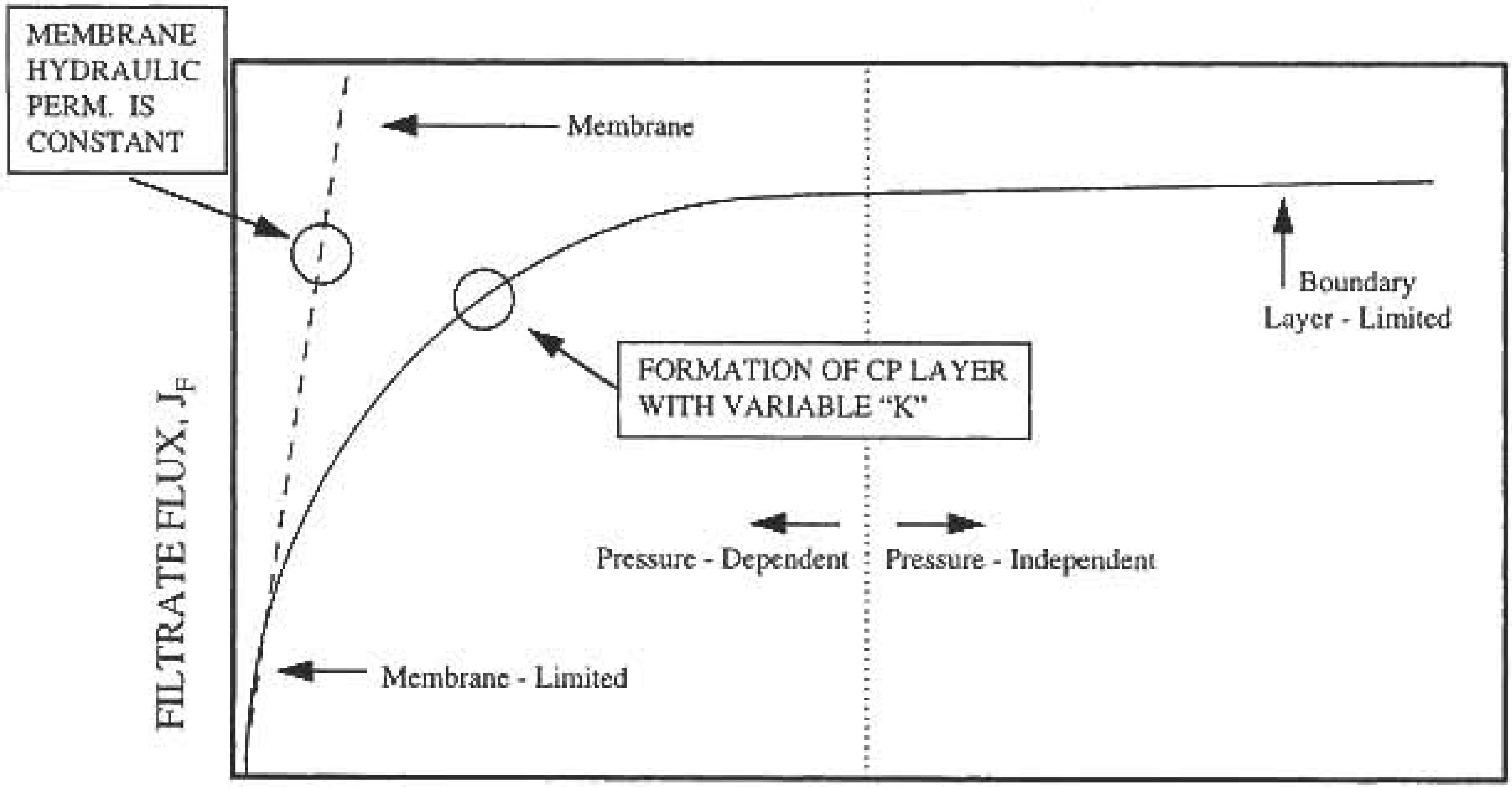
Limiting Cases:

$\sigma = 1$ Membrane completely retains solute

$\sigma = 0$ membrane freely permeable to solute

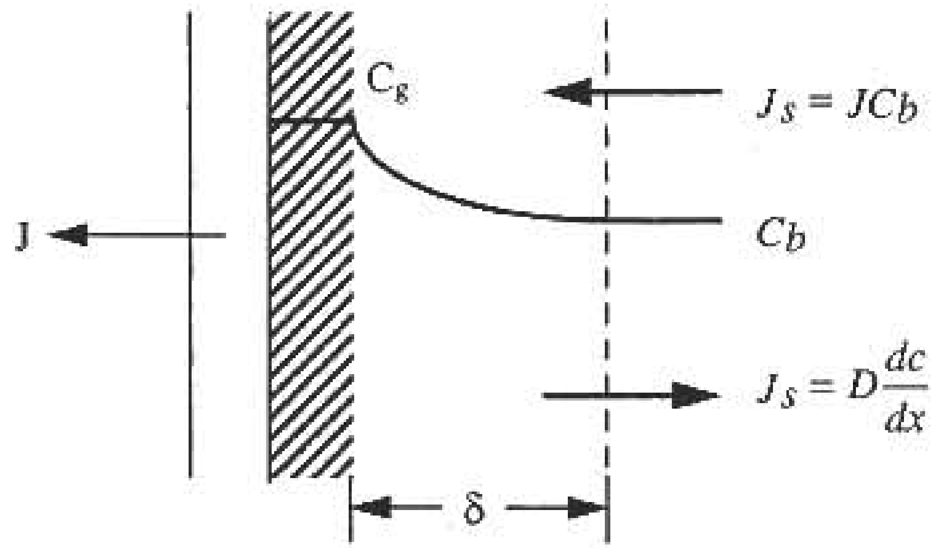
REGIMES OF CROSS-FLOW FILTRATION

$$J_U = J_F = L_P \Delta P \qquad L_P = \frac{K}{\mu L}$$



PRESSURE DIFFERENCE, ΔP

MASS TRANSFER MODEL FOR MEMBRANE FILTRATION



At Steady State

$$\boxed{JC_b = D\frac{dC}{dx}}$$

Integration across the boundry layer δ

$$J = \frac{D}{\delta}\ln\frac{C_g}{C_b} = k\ln\frac{C_g}{C_b}$$

$$J = f(k) = f(V_s, \mu, P, \text{system geometry})$$

Mass Transfer coefficient

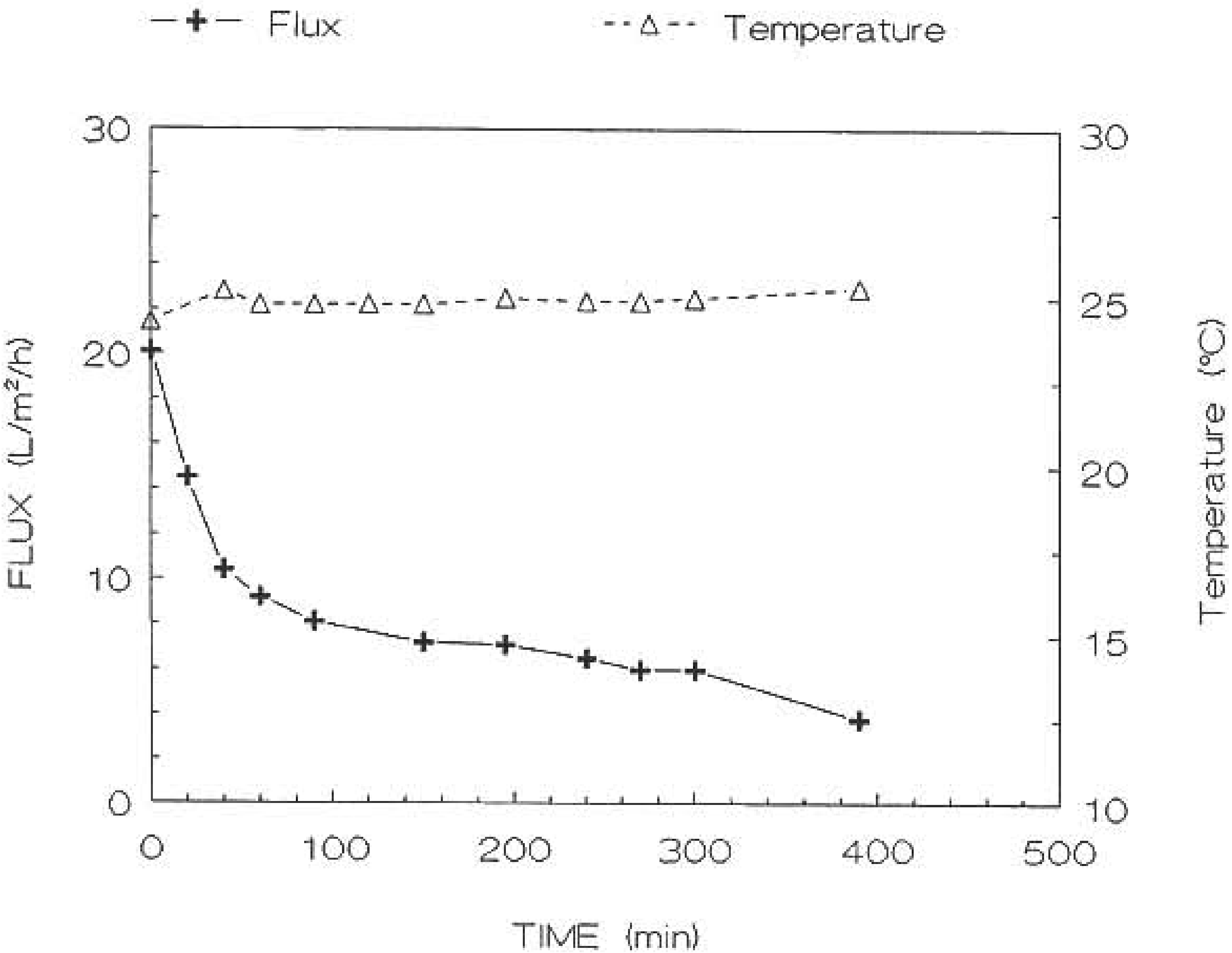
$$K = f(\mathrm{Re}, S_c)$$

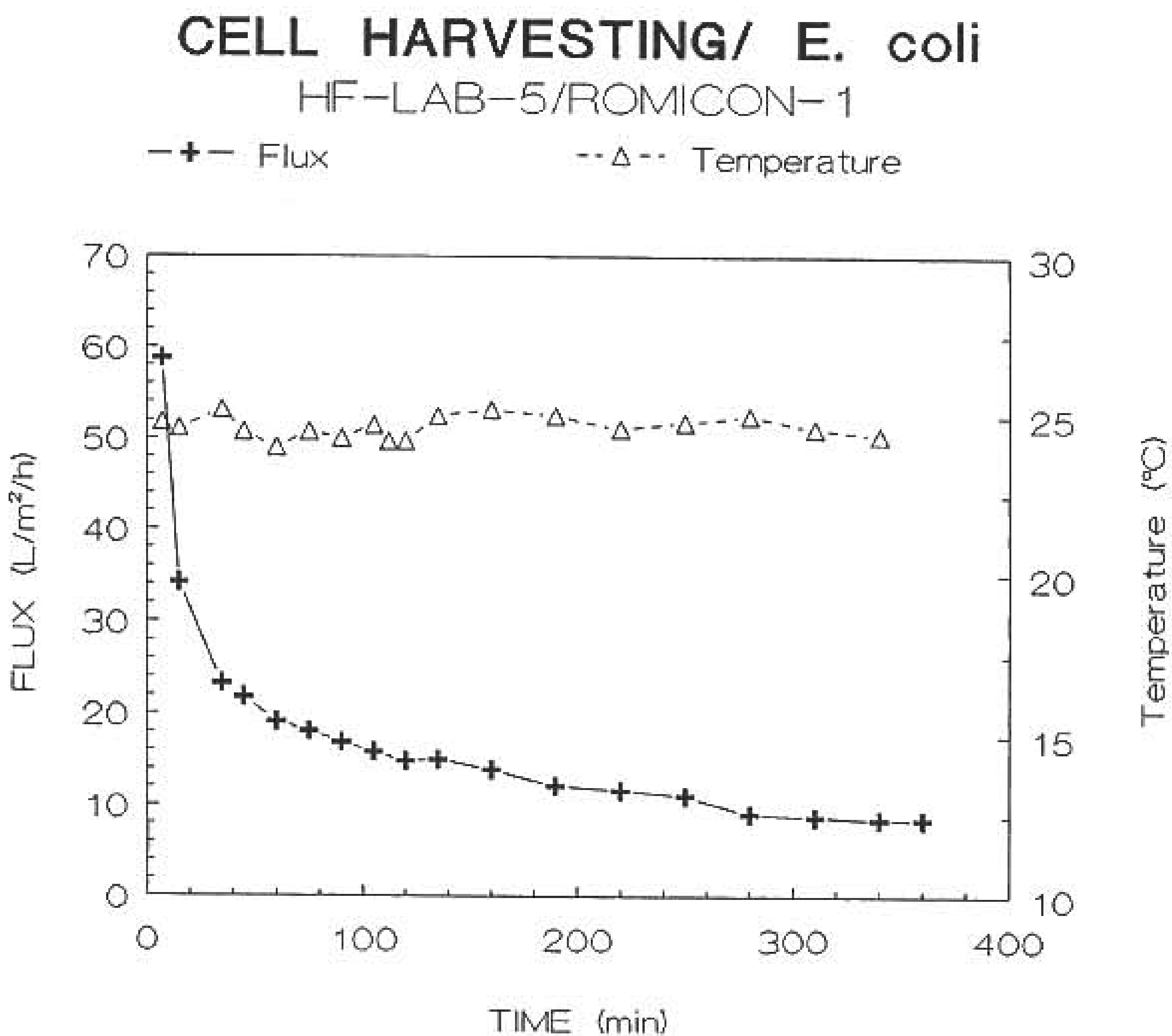
$$R_e = \frac{vdP}{\mu}$$

$$S_c = \frac{\mu}{PD}$$

CELL HARVESTING/ E. coli

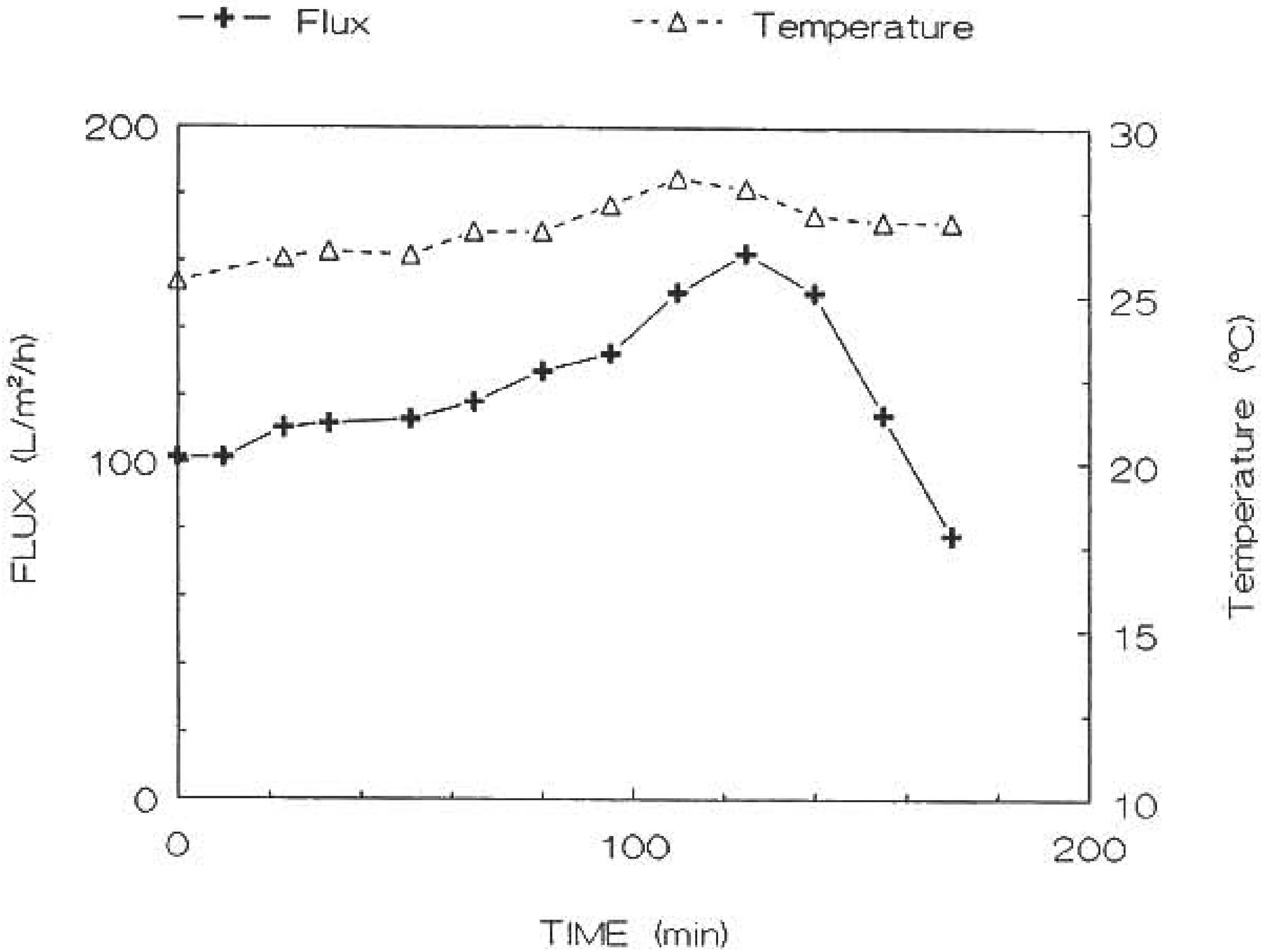
PROSTAK-1

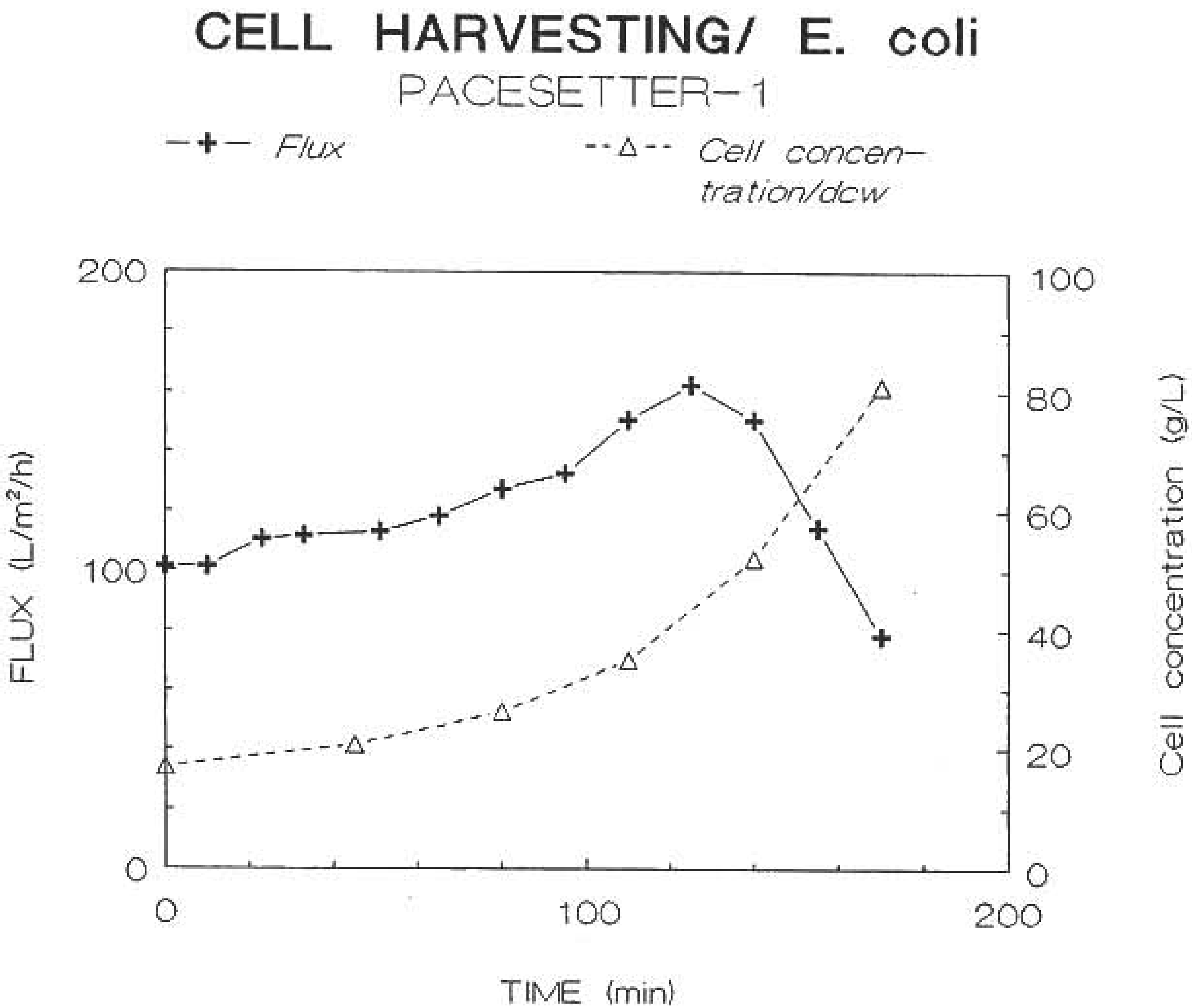



CELL HARVESTING/ E. coli
HF-LAB-5/ROMICON-1
Flux
Temperature
FLUX (L/m²/h)
Temperature (°C)
TIME (min)
0
10
20
30
40
50
60
70
100
200
300
400
15
25

CELL HARVESTING/ E. coli

PACESETTER-1





CELL HARVESTING/ E. coli
PACESETTER-1
Flux
Cell concentration/dcw
FLUX (L/m²/h)
Cell concentration (g/L)
TIME (min)
0
100
200
0
20
40
60
80
100
0
100
200

Cell harvesting of E. coli

Membrane filtration