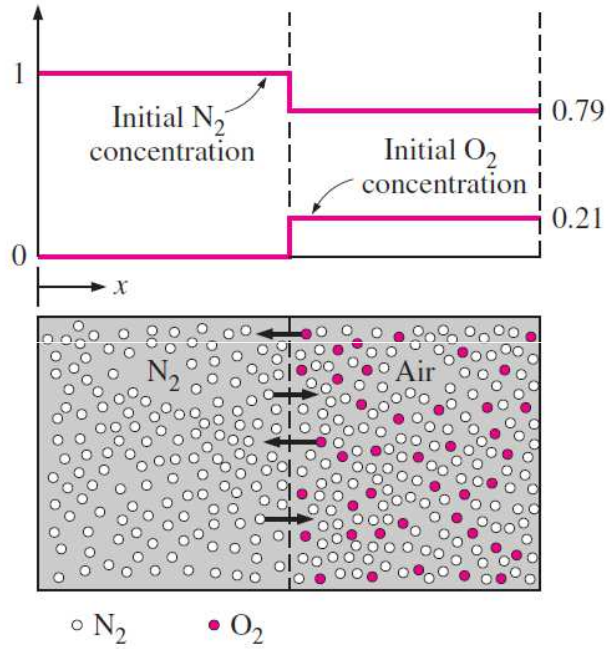
14. GAIA

MASA TRANSFERENTZIA

14.0 - HELBURUAK

- **Kontzentrazio-gradientea** eta **masa-transferentziako** mekanismo fisikoak ulertu
- **Bero- eta masa-transferentziaren** arteko **analogia**k ezagutu
- Toki bateko kontzentrazioa masan edo moletan oinarrituta deskribatu, eta difusio-abiadura eta kontzentrazio-gradientea lotu, **Fick-en legearen** bidez
- Baldintza **geldikorretan,** geruza lau batean zeharreko **masa-difusioaren** abiadura kalkulatu
- **Ur-lurrunaren migrazioa eraikinetan**
- **Konbekzio** bidezko masa-transferentzia kalkulatu
- Aldibereko bero- eta masa-transferentzia aztertu.



$$\dot{m} = -D_{AB} \cdot A \frac{dC}{dx}$$

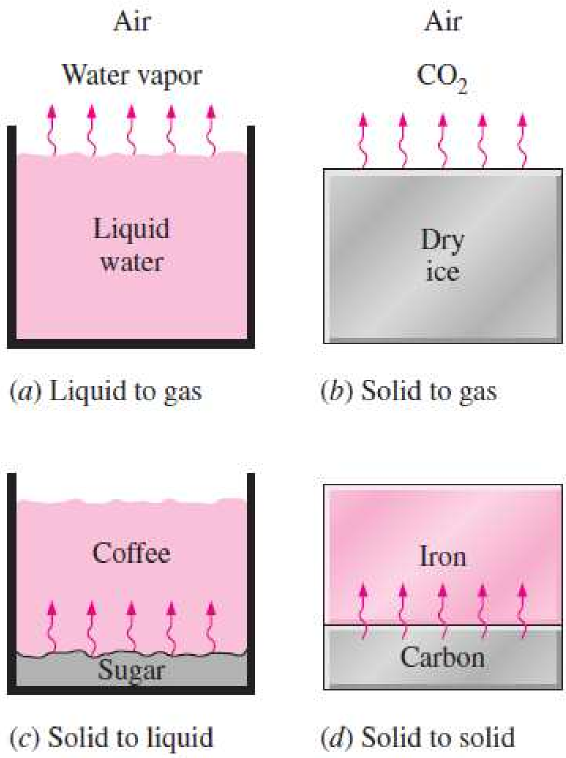
D_{AB}: Espezien difusio-koefizientea

dC/dx: kontzentrazio gradientea

Fenomenoa	Ezaugarri garraiatzailea	Indar bultzatzailea	Legea	Ekuazioa	Garraio koefizientea
Difusioa	Materia	Kontzentrazio diferentzia	**Fick**	m =-D_{AB} A dC/dx	Difusio koefizientea D_{AB}
Kondukzio termikoa	Energia	Tenperatura diferentzia	**Fourier**	Q = -k A dT/dx	Konduktibitate termikoa k
Kondukzio elektrikoa	Elektroiak	Potentzial diferentzia	**Ohm**	I = - σ A dV/dx	Konduktibitate elektrikoa σ
Biskositatea	Momentu kantitatea	Abiadura diferentzia	**Newton**	F = -μ A dv/dx	Biskositatea μ

14.1 - SARRERA

MASA TRANSFERENTZIA: LIKIDOAK, SOLIDOAK ETA GASAK



(*a*) Liquid to gas (*b*) Solid to gas (*c*) Solid to liquid (*d*) Solid to solid

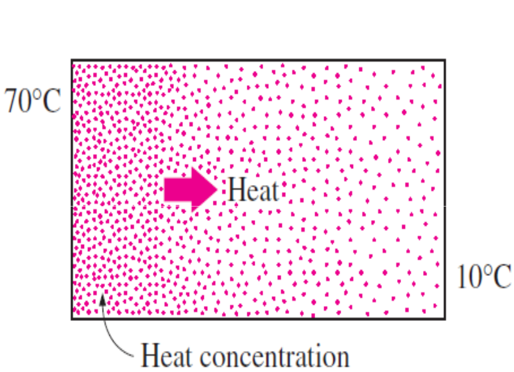
FAKTOREAK:

- Kontzentrazioa
- Tenperatura
- Tarte molekularra

14.2 – BERO- ETA MASA-TRANSFERENTZIEN ARTEKO ANALOGIA

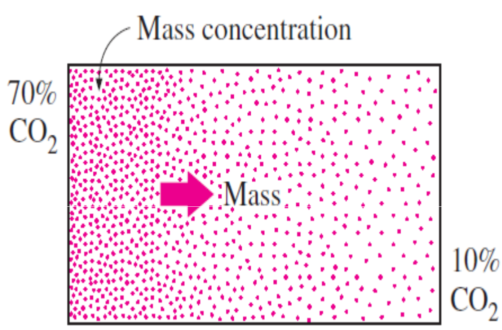
TENPERATURA

Bero Transferentzia



Indar bultzatzailea:
Tenperatura gradientea

Masa Transferentzia

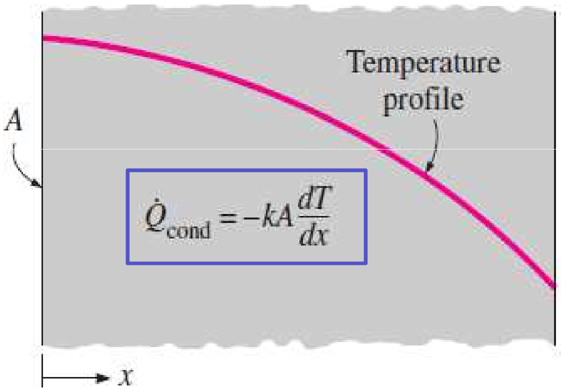


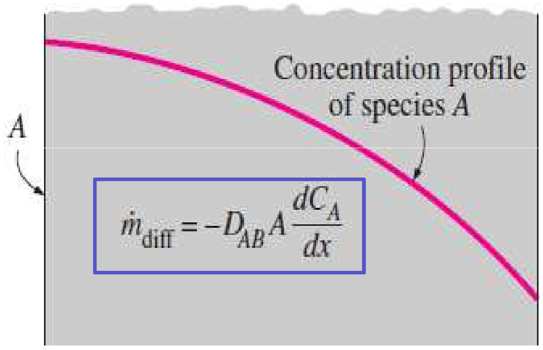
Indar bultzatzailea:
Kontzentrazio diferentzia

14.2 – BERO- ETA MASA-TRANSFERENTZIEN ARTEKO ANALOGIA

EROAPENA

Bero Transferentzia | **Masa Transferentzia**





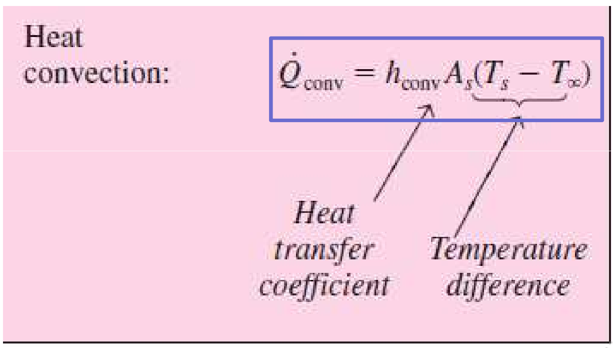
Fourier-en Legea

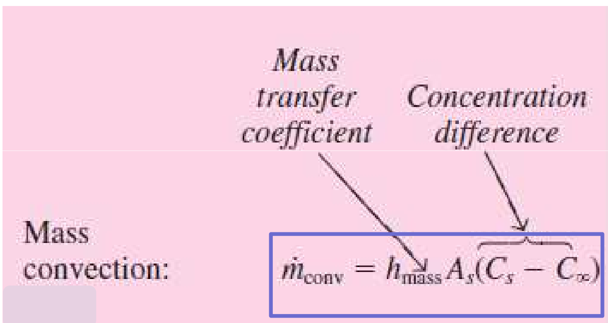
Fick-en Legea **Difusibitatea**

14.2 – BERO- ETA MASA-TRANSFERENTZIEN ARTEKO ANALOGIA

KONBEKZIOA

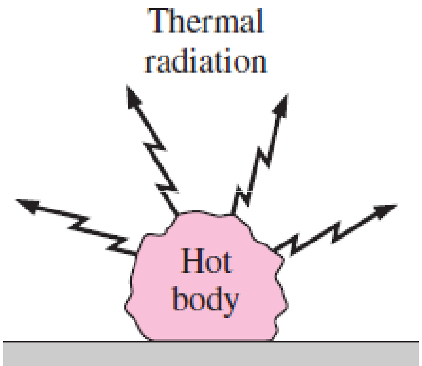
Bero Transferentzia | **Masa Transferentzia**

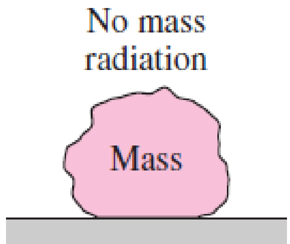




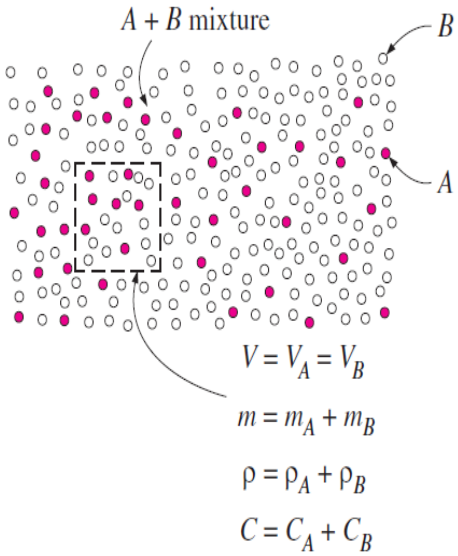
ERRADIAZIOA

Bero Transferentzia	*Masa Transferentzia*





14.3 –MASA DIFUSIOA



MASAN OINARRITUA:

Dentsitatea

$$\rho_i = m_i / V \quad [kg / m^3]$$

$$\rho = m / V$$

Masa Frakzioa

$$w_i = \frac{m_i}{m} = \frac{\rho_i}{\rho}$$

$$0 < w < 1 \qquad \sum w_i = 1$$

MOLETAN OINARRITUA:

Dentsitate Molarra

$$C_i = N_i / V \quad [kmol / m^3]$$

$$C = N / V$$

Frakzio Molarra

$$y_i = \frac{N_i}{N} = \frac{C_i}{C}$$

$$0 < y < 1 \qquad \sum y_i = 1$$

BIEN ARTEKO ERLAZIOA:

$$C_i = \rho_i / M_i$$

$$C = \rho / M$$

$$M : \text{masa molarra} \quad M = m / N$$

$$w_i = \frac{\rho_i}{\rho} = \frac{C_i \cdot M_i}{C \cdot M} = y_i \frac{M_i}{M}$$

GAS NAHASTURA IDEALAK

Presio Partziala: P_i

Gas presio partzialen batura : $P = \Sigma P_i$ ⟹ **Dalton-en Legea Presio gehigarriak**

$$\frac{P_i}{P} = \frac{N_i \cdot R_u \cdot T / V}{N \cdot R_u \cdot T / V} = \frac{N_i}{N} = y_i$$

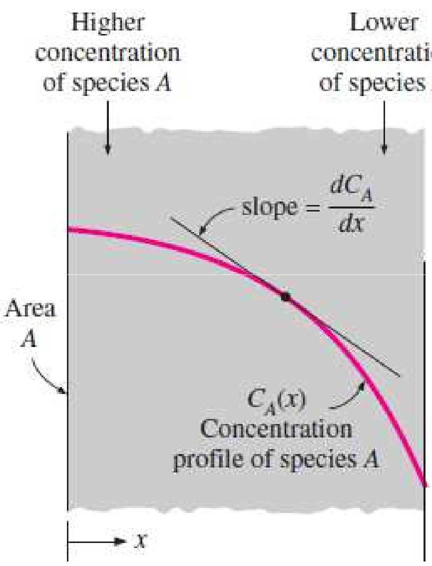
2 mol A
6 mol B
$P = 120$ kPa

A mixture of two ideal gases A and B

$$y_A = \frac{N_A}{N} = \frac{2}{2+6} = 0.25$$

$$P_A = y_A P = 0.25 \times 120 = 30 \text{ kPa}$$

FICK-EN DIFUSIO LEGEA: BI ESPEZIEZ OSATUTAKO INGURUNE GELDIA



Masan Oinarritua

$$\dot{m}_{\text{diff}} = -\rho A D_{AB} \frac{dw_A}{dx}$$

$$= -\rho A D_{AB} \frac{d(\rho_A/\rho)}{dx}$$

$$= -A D_{AB} \frac{d\rho_A}{dx} \quad (\text{if } \rho = \text{constant})$$

Moletan Oinarritua

$$\dot{N}_{\text{diff}, A} = -C A D_{AB} \frac{dy_A}{dx}$$

$$= -C A D_{AB} \frac{d(C_A/C)}{dx}$$

$$= -A D_{AB} \frac{dC_A}{dx} \quad (\text{if } C = \text{constant})$$

14.3 – MASA DIFUSIOA

DIFUSIO KOEFIZIENTEA (D_{AB})

Modu Esperimentalean kalkulatua $$D_{H_2O-Air} = 1{,}87 \cdot 10^{-10} \frac{T^{2{,}072}}{P}$$ [m²/s], 280K < T < 450K

T[K] eta P[atm]

- Gas-etan: nahasturaren konposizioarekiko independentea: T ↑ → D_{AB} ↑
  P ↑ → D_{AB} ↓

$$D_{AB} \cdot \alpha \frac{T^{3/2}}{P} \quad edo \quad \frac{D_{AB,1}}{D_{AB,2}} = \frac{P_2}{P_1}\left(\frac{T_1}{T_2}\right)^{3/2}$$

- Solidoak eta likidoak: T ↑ → D_{AB} ↑

(a) Diffusion through Liquids

Substance A (Solute)	Substance B (Solvent)	T, K	D_{AB}, m²/s
Ammonia	Water	285	1.6×10^{-9}
Benzene	Water	293	1.0×10^{-9}
Carbon dioxide	Water	298	2.0×10^{-9}
Chlorine	Water	285	1.4×10^{-9}

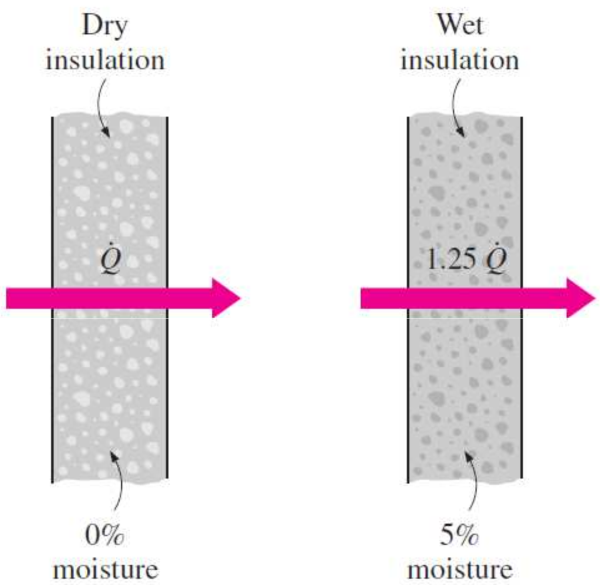
(b) Diffusion through Solids

Substance A (Solute)	Substance B (Solvent)	T, K	D_{AB}, m²/s
Carbon dioxide	Natural rubber	298	1.1×10^{-10}
Nitrogen	Natural rubber	298	1.5×10^{-10}
Oxygen	Natural rubber	298	2.1×10^{-10}
Helium	Pyrex	773	2.0×10^{-12}

Binary diffusion coefficients of some gases in air at 1 atm pressure (from Mills, Ref. 13, Table A.17a, p. 869)

T, K	Binary Diffusion Coefficient,* m²/s × 10⁵			
	O_2	CO_2	H_2	NO
200	0.95	0.74	3.75	0.88
300	1.88	1.57	7.77	1.80
400	5.25	2.63	12.5	3.03
500	4.75	3.85	17.1	4.43
600	6.46	5.37	24.4	6.03
700	8.38	6.84	31.7	7.82
800	10.5	8.57	39.3	9.78
900	12.6	10.5	47.7	11.8
1000	15.2	12.4	56.9	14.1
1200	20.6	16.9	77.7	19.2
1400	26.6	21.7	99.0	24.5
1600	33.2	27.5	125	30.4
1800	40.3	32.8	152	37.0
2000	48.0	39.4	180	44.8

14.6 – UR-LURRUNAREN MIGRAZIOA ERAIKINETAN



Eraikuntzako joskerako hezetasunaren eragina:
- Zuran: Dimentsioak, Itxura, ustelketak
- Metalak: korrosioa eta herdoiltzea
- Pintura: askatzea
- Lizuna: agertu

Lurrun heziak:
Material iragazgaitzak
Lurrun moteltzaileak

Presio Totala:
Aire Atmosferikoa

Presio Partziala:
Aire lehorra

Presio Partziala::
Ur lurruna **P_v**

Hezetasun erlatiboa Ø:
0-100 %

P_{sat}: Lurrunaren saturazio presioa airearen tenperaturan

$$P_v = \phi \cdot P_{sat}$$

Saturation pressure of water at various temperatures

Temperature, °C	Saturation Pressure, Pa
−40	13
−36	20
−32	31
−28	47
−24	70
−20	104
−16	151
−12	218
−8	310
−4	438
0	611
5	872
10	1,228
15	1,705
20	2,339
25	3,169
30	4,246
35	5,628
40	7,384
50	12,349
100	101,330
200	1.55×10^6
300	8.58×10^6

GERUZA LAU BATEAN ZEHARREKO HEZETASAUNAREN MASA EMARIA:

$$\dot{m}_v = \mathrm{P} \cdot A \frac{P_{v,1} - P_{v,2}}{L} = \mathrm{P} \cdot A \frac{\phi_1 \cdot P_{sat,1} - \phi_2 \cdot P_{sat,2}}{L} \quad [kg/s]$$

Non: P lurrun-iragazkortasuna (ng/s m Pa) ($1ng=10^{-12}$ kg)

Permeantzia (M) $$M = \frac{\mathrm{P}}{L} \quad [kg/s\,m^2 Pa]$$

Lurrun erresistentzia (R_v) $$R_v = \frac{1}{M} = \frac{L}{\mathrm{P}}$$

Egitura konposatua:

$$R_{v,total} = R_{v,1} + R_{v,2} + \ldots + R_{v,n} = \sum R_{v,i}$$

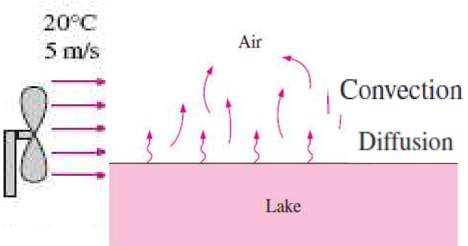
Lurrun trasmisioa egitura konposatuan:

$$\dot{m}_v = A \frac{\Delta P_V}{R_{V,total}} \quad [kg/s]$$

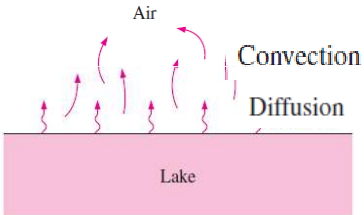
Sartzen / irteten den hezetasuna:
Difusioz <<< aire infiltrazioz

Materials and Its Thickness	Permeance ng/s · m² · Pa
Concrete (1:2:4 mix, 1 m)	4.7
Brick, masonry, 100 mm	46
Plaster on metal lath, 19 mm	860
Plaster on wood lath, 19mm	630
Gypsum wall board, 9.5 mm	2860
Plywood, 6.4 mm	40–109
Still air, 1 m	174
Mineral wool insulation (unprotected), 1 m	245
Expanded polyurethane insulation board, 1 m	0.58–2.3
Aluminum foil, 0.025 mm	0.0
Aluminum foil, 0.009 mm	2.9
Polyethylene, 0.051 mm	9.1
Polyethylene, 0.2 mm	2.3
Polyester, 0.19 mm	4.6
Vapor retarder latex paint, 0.070 mm	26
Exterior acrylic house and trim paint, 0.040 mm	313
Building paper, unit mass of 0.16–0.68 kg/m²	0.1–2400

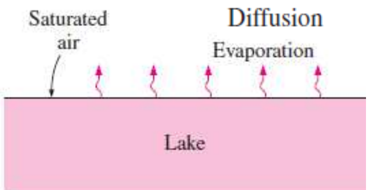
Gainazal baten eta mugitzen ari den fluido baten arteko masa transferentzia



a) Forced convection



b)Free convection



c) Diffusion

<u>Konbekzio masa-transferentzia hurrengo parametroen arabaerakoa da:</u>

Gainazalaren forma

Fluxu erregimena

Fluidoaren abiadura

Fluidoaren propietateen aldaketak

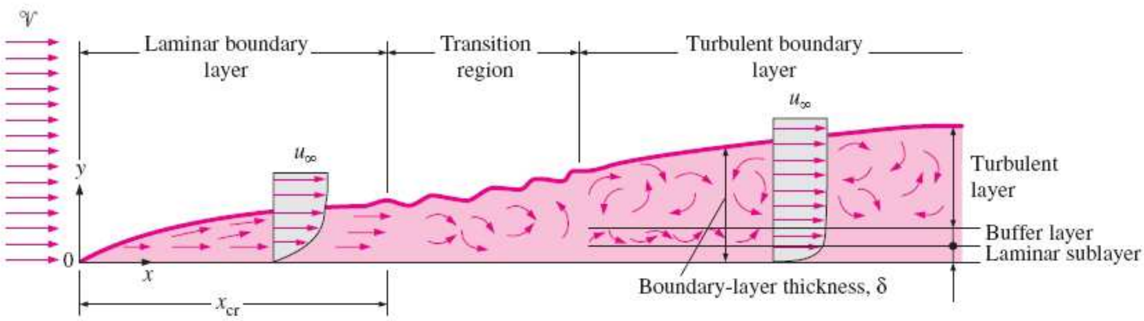
Konposisio aldaketak

Erlazio Esperimentalak

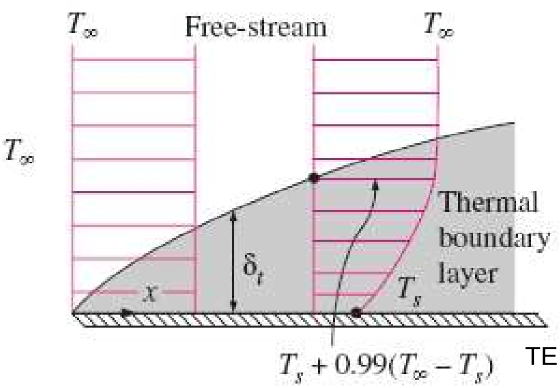
Bero Transferentzia	***MasaTransferentzia***
$\dot{Q}_{conv} = h_{conv} \cdot A_s (T_s - T_\infty)$	$\dot{m}_{conv} = h_{mass} \cdot A_s (\rho_{A,s} - \rho_{A,\infty})$

$$\dot{m}_{conv} = h_{mass} \cdot \rho A_s (w_{A,s} - w_{A,\infty})$$

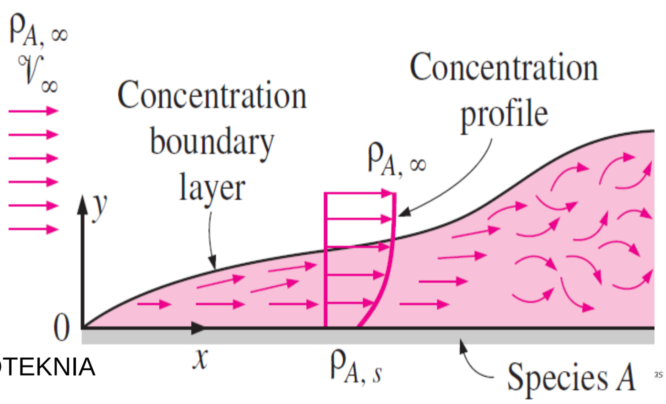
ABIADURA MUGALDE GERUZA



BERO MUGALDE GERUZA



KONTZENTRAZIO MUGALDE GERUZA

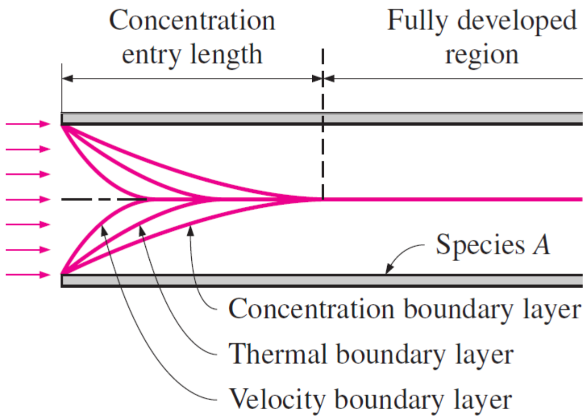


KONTZENTRAZIO MUGALDE GERUZA

Kanpo Fluxua

$$\frac{\rho_{A,S}-\rho_A}{\rho_{A,S}-\rho_{A,\infty}}=0{,}99$$

Barne Fluxua



Erabat garatutako eskualdea

$$\frac{\partial}{\partial x}\left(\frac{\rho_{A,S}-\rho_A}{\rho_{A,S}-\rho_{A,b}}\right)=0$$

Batez besteko dentsitate globala

$$\rho_{A,b}=\frac{1}{A_c\cdot V_{ave}}\int_{A_c}\rho_A V\cdot dA_c$$

Bero Transferentzia

$$\Pr=\frac{\nu}{\alpha}=\frac{\mu\cdot c_p}{k}$$

Prandtl Zenbakia = $\frac{\text{Momentu difusibitatea}}{\text{Bero difusibitatea}}$

MasaTransferentzia

$$Sc=\frac{\nu}{D_{AB}}$$

Schmidt Zenbakia = $\frac{\text{Momentu difusibitatea}}{\text{Masa difusibitatea}}$

FLUXU LAMINARRA

Pr ≈ 1

S_C ≈ 1

$$Le=\frac{Sc}{\Pr}=\frac{\alpha}{D_{AB}}$$

Lewis Zenbakia = $\frac{\text{Bero difusibitatea}}{\text{Masa difusibitatea}}$

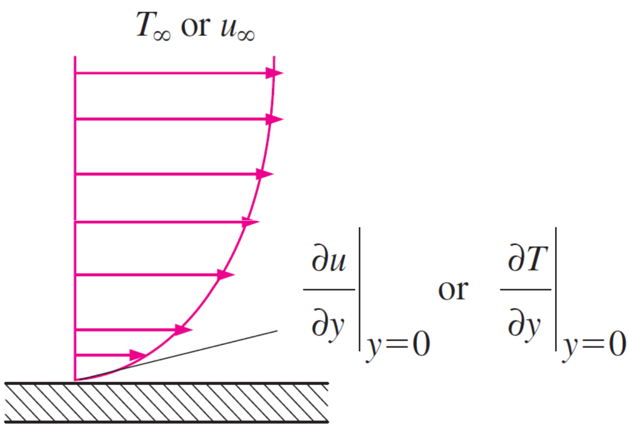
FLUXU LAMINARREAN, ABIADURAREN ETA KONTZENTRAZIOAREN MUGALDE-GERUZEN NAHIZ MUGALDE-GERUZA TERMIKOAREN LODIERA ERLATIBOAK

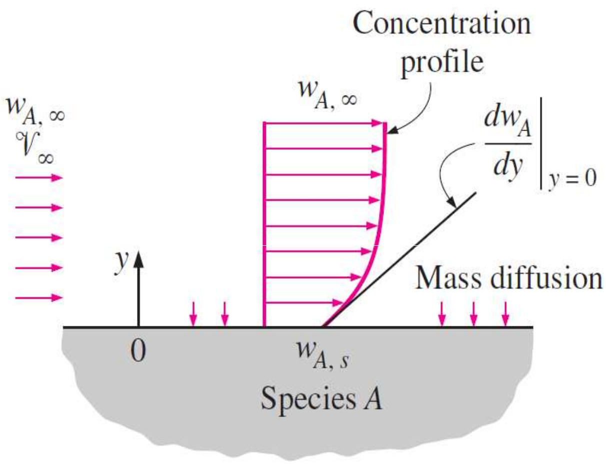
$$\frac{\delta_{velocity}}{\delta_{thermal}} = \Pr^n \qquad \frac{\delta_{velocity}}{\delta_{concentration}} = Sc^n \qquad \frac{\delta_{thermal}}{\delta_{concentration}} = Le^n$$

Kasu gehienetan → n=1/3

Bero Transferentzia

Masa Transferentzia





$$h_{conv} = \frac{-k_{fluid} \cdot (\partial T/\partial y)_{y=0}}{T_s - T_\infty} \qquad [W/m^2 \cdot {}^oC]$$

$$h_{mass} = \frac{-D_{AB} \cdot (\partial w_A/\partial y)_{y=0}}{w_{A,s} - w_{A,\infty}} \qquad [m/s]$$

Bero Transferentzia

Masa Transferentzia

NUSSELT-EN ZENBAKIA

$$Nu = \frac{h_{conv} \cdot L_c}{k}$$

SHERWOOD-EN ZENBAKIA

$$Sh = \frac{h_{mass} \cdot L_c}{D_{AB}}$$

STANTON-EN BERO TRANSF. ZENBAKIA

$$St = \frac{h_{conv}}{\rho \cdot V \cdot Cp} = \frac{Nu}{\mathrm{Re} \cdot \mathrm{Pr}}$$

STANTON-EN MASA TRANSF. ZENBAKIA

$$St_{mass} = \frac{h_{mass}}{V} = \frac{Sh}{\mathrm{Re} \cdot Sc}$$

KONBEKZIO BEHARTUA

$$Nu = f(\mathrm{Re}, \mathrm{Pr})$$

$$Sh = f(\mathrm{Re}, Sc)$$

KONBEKZIO NATURALA

$$Nu = f(Gr, \mathrm{Pr})$$

$$Sh = f(Gr, Sc)$$

Bero Transferentzia

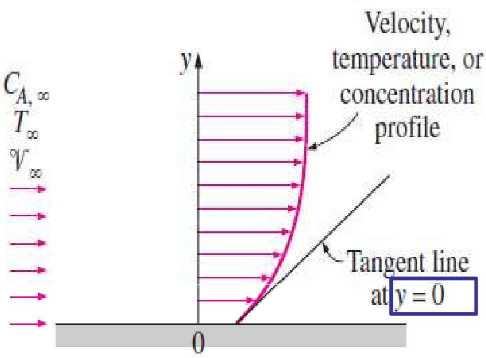
$$T$$
$$h_{conv}$$
$$\delta_{thermal}$$
$$\mathrm{Re} = \frac{V \cdot L_c}{\nu}$$
$$Gr = \frac{g \cdot \beta \cdot (T_s - T_\infty) L_c^3}{\nu^2}$$
$$\mathrm{Pr} = \frac{\nu}{\alpha}$$
$$St = \frac{h_{conv}}{\rho \cdot V \cdot c_p}$$
$$Nu = \frac{h_{conv} \cdot L_c}{k}$$
$$Nu = f(\mathrm{Re}, \mathrm{Pr})$$
$$Nu = f(Gr, \mathrm{Pr})$$

Masa Transferentzia

$$C, y, \rho, w$$
$$h_{mass}$$
$$\delta_{concentration}$$
$$\mathrm{Re} = \frac{V \cdot L_c}{\nu}$$
$$Gr = \frac{g (\rho_s - \rho_\infty) L_c^3}{\rho \nu^2}$$
$$Sc = \frac{\nu}{D_{AB}}$$
$$St_{mass} = \frac{h_{mass}}{V}$$
$$Sh = \frac{h_{mass} \cdot L_c}{D_{AB}}$$
$$Sh = f(\mathrm{Re}, Sc)$$
$$Sh = f(Gr, Sc)$$

MARRUSKADURAREN, BERO-TRANSFERENTZIAREN ETA MASA-TRANSFERENTZIAREN KOEFIZIENTEEN ARTEKO ANALOGIA

KANPO KLUXUA



Horma marruskadura
$$\tau_s = \mu \frac{\partial u}{\partial y}\bigg|_{y=0} = \frac{C_f}{2}\rho \cdot V_\infty^2$$

Bero Transf
$$\dot{q}_s = -k \frac{\partial T}{\partial y}\bigg|_{y=0} = h_{heat}(T_s - T_\infty)$$

Masa Transf
$$j_{A,s} = -D_{AB}\frac{\partial w_A}{\partial y}\bigg|_{y=0} = h_{mass}(w_{A,s} - w_{A,\infty})$$

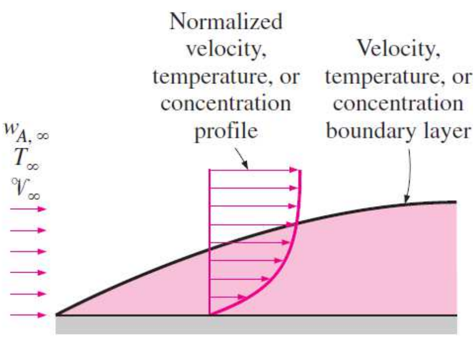
BARNE FLUXUA

Horma marruskadura
$$\frac{d(u/V_\infty)\partial u}{d(y/L)}\bigg|_{y=0} = \frac{C_f}{2}\frac{\rho \cdot V_\infty \cdot L}{\mu} = \frac{f}{2}\mathrm{Re}$$

Bero Transf
$$\frac{d\left[(T-T_s)/(T_\infty - T_s)\right]}{d(y/L)}\bigg|_{y=0} = \frac{h_{heat} \cdot L}{k} = Nu$$

Masa Transf
$$\frac{d\left[(w_A - w_{A,s})/(w_{A,\infty} - w_{A,s})\right]}{d(y/L)}\bigg|_{y=0} = \frac{h_{mass} \cdot L}{D_{AB}} = Sh$$

REYNOLDS-EN ANALOGIA Pr ~ Sc ~ 1 KASURAKO



Reynolds analogy
$\nu = \alpha = D_{AB}$
(or Pr = Sc = Le)

$$C_f \frac{\mathrm{Re}_L}{2} = Nu = Sh$$

$$\frac{C_f}{2} = St = St_{mass} \qquad (\mathrm{Pr} = \mathrm{Sc} = 1)$$

$$St = \frac{h_{conv}}{\rho \cdot V \cdot C_p} \qquad St_{mass} = \frac{h_{mass}}{V}$$

CHILTON-COLBURN-EN ANALOGIA

Non 0,6 < Pr < 60 eta 0,6 < Sc < 3 000

$$\frac{C_f}{2} = \frac{h_{conv}}{\rho \cdot V \cdot c_p} \cdot \mathrm{Pr}^{2/3} = \frac{h_{mass}}{V} \cdot \mathrm{Sc}^{2/3}$$

Chilton–Colburn Analogy

General:

$$h_{\text{mass}} = \frac{h_{\text{heat}}}{\rho C_p}\left(\frac{D_{AB}}{\alpha}\right)^{2/3} = \frac{1}{2} f \mathcal{V}\left(\frac{D_{AB}}{\nu}\right)^{2/3}$$

Special case: $\nu = \alpha = D_{AB}$

$$h_{\text{mass}} = \frac{h_{\text{heat}}}{\rho C_p} = \frac{1}{2} f \mathcal{V}$$

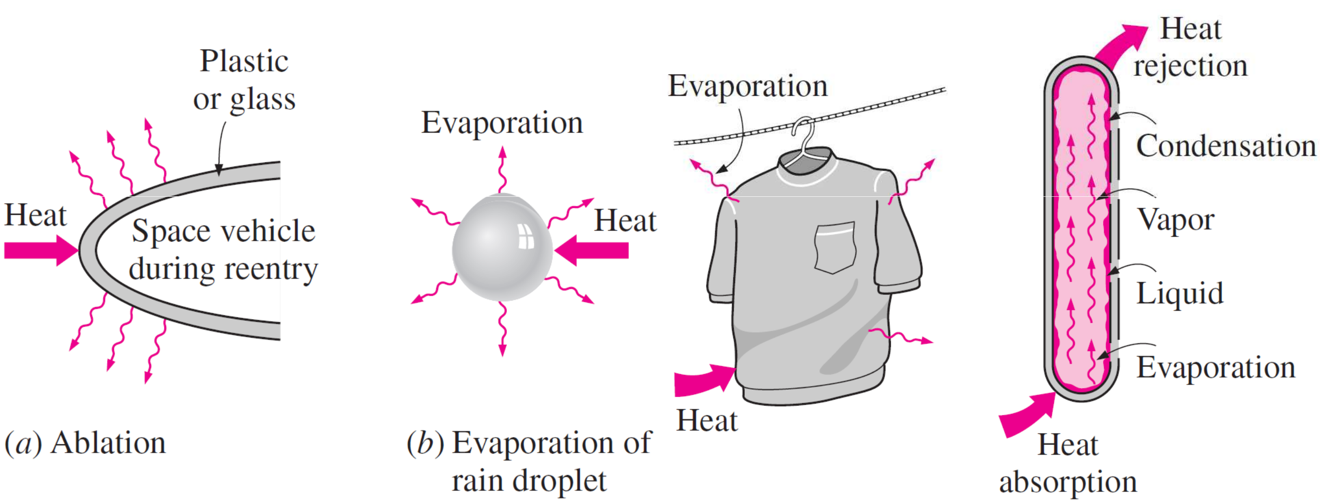
Sherwood number relations in mass convection for specified concentration at the surface corresponding to the Nusselt number relations in heat convection for specified surface temperature

Convective Heat Transfer	Convective Mass Transfer
1. *Forced Convection over a Flat Plate*	
(*a*) Laminar flow ($Re < 5 \times 10^5$)	
$Nu = 0.664\, Re_L^{0.5}\, Pr^{1/3}, \quad Pr > 0.6$	$Sh = 0.664\, Re_L^{0.5}\, Sc^{1/3}, \quad Sc > 0.5$
(*b*) Turbulent flow ($5 \times 10^5 < Re < 10^7$)	
$Nu = 0.037\, Re_L^{0.8}\, Pr^{1/3}, \quad Pr > 0.6$	$Sh = 0.037\, Re_L^{0.8}\, Sc^{1/3}, \quad Sc > 0.5$
2. *Fully Developed Flow in Smooth Circular Pipes*	
(*a*) Laminar flow ($Re < 2300$)	
$Nu = 3.66$	$Sh = 3.66$
(*b*) Turbulent flow ($Re > 10{,}000$)	
$Nu = 0.023\, Re^{0.8}\, Pr^{0.4}, \quad 0.7 < Pr < 160$	$Sh = 0.023\, Re^{0.8}\, Sc^{0.4}, \quad 0.7 < Sc\ 160$
3. *Natural Convection over Surfaces*	
(*a*) Vertical plate	
$Nu = 0.59(Gr\,Pr)^{1/4}, \quad 10^5 < Gr\,Pr < 10^9$	$Sh = 0.59(Gr\,Sc)^{1/4}, \quad 10^5 < Gr\,Sc < 10^9$
$Nu = 0.1(Gr\,Pr)^{1/3}, \quad 10^9 < Gr\,Pr < 10^{13}$	$Sh = 0.1(Gr\,Sc)^{1/3}, \quad 10^9 < Gr\,Sc < 10^{13}$
(*b*) Upper surface of a horizontal plate	
Surface is hot ($T_s > T_\infty$)	Fluid near the surface is light ($\rho_s < \rho_\infty$)
$Nu = 0.54(Gr\,Pr)^{1/4}, \quad 10^4 < Gr\,Pr < 10^7$	$Sh = 0.54(Gr\,Sc)^{1/4}, \quad 10^4 < Gr\,Sc < 10^7$
$Nu = 0.15(Gr\,Pr)^{1/3}, \quad 10^7 < Gr\,Pr < 10^{11}$	$Sh = 0.15(Gr\,Sc)^{1/3}, \quad 10^7 < Gr\,Sc < 10^{11}$
(*c*) Lower surface of a horizontal plate	
Surface is hot ($T_s > T_\infty$)	Fluid near the surface is light ($\rho_s < \rho_\infty$)
$Nu = 0.27(Gr\,Pr)^{1/4}, \quad 10^5 < Gr\,Pr < 10^{11}$	$Sh = 0.27(Gr\,Sc)^{1/4}, \quad 10^5 < Gr\,Sc < 10^{11}$

- MASA-TRANSFERENTZIAKO prozesu asko MODU ISOTERMIKOAN gertatzen dira:

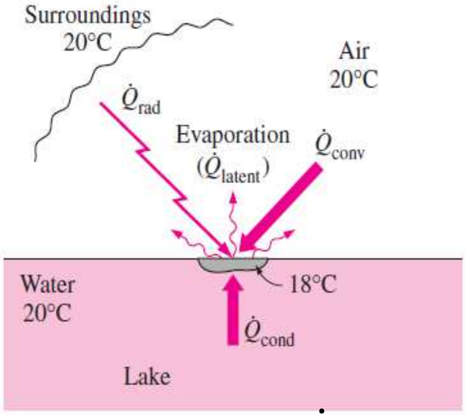
  EZ da bero-transferentziarik izaten
- INGENIARITZA-APLIKAZIO-ETAN:

Likido bat lurrundu egiten da eta lurruna inguruko gasean barreiatzen da h_{fg}-ren bitartez



(*a*) Ablation (*b*) Evaporation of rain droplet (*c*) Drying of clothes (*d*) Heat pipes

14.10 – ALDIBEREKO BERO- ETA MASA-TRANSFERENTZIA



a) $T_{air} = T_{water} = 20$ºC

Aire asea→ Ø =100%

Ez bero ez masa tansferentziarik

b) $T_{air} = T_{water} = 20$ºC

Aire EZ asea→ Ø < 100%

Masa transferentzia

$$\dot{Q}_{sensible,transferred} = \dot{Q}_{latent,absorbed}$$

$$\dot{Q} = \dot{m}_v \cdot h_{fg} \quad \dot{Q} = \sum \dot{Q}_{cond} + \dot{Q}_{conv} + \dot{Q}_{rad}$$

$Q_{cond} \approx 0$ eta $Q_{rad} \approx 0$ bada →

$$\dot{Q}_{conv} = \dot{m}_v \cdot h_{fg} \rightarrow h_{conv} \cdot A_s (T_\infty - T_s) = \frac{h_{conv} \cdot A_s \cdot h_{fg}}{C_p \cdot Le^{2/3}} \frac{M_v}{M} \frac{P_{v,s} - P_{v,\infty}}{P}$$

$$T_s = T_\infty - \frac{h_{fg}}{C_p \cdot Le^{2/3}} \frac{M_v}{M} \frac{P_{v,s} - P_{v,\infty}}{P}$$

14.10 – ALDIBEREKO BERO- ETA MASA-TRANSFERENTZIA

Various expressions for evaporation rate of a liquid into a gas through an interface area A_s under various approximations (subscript v stands for vapor, s for liquid–gas interface, and ∞ away from surface)

Assumption	Evaporation Rate
General	$\dot{m}_v = h_{mass} A_s(\rho_{v,s} - \rho_{v,\infty})$
Assuming vapor to be an ideal gas, $P_v = \rho_v R_v T$	$\dot{m}_v = \frac{h_{mass} A_s}{R_v}\left(\frac{P_{v,s}}{T_s} - \frac{P_{v,\infty}}{T_\infty}\right)$
Using Chilton–Colburn analogy, $h_{heat} = \rho C_p h_{mass} Le^{2/3}$	$\dot{m}_v = \frac{h_{heat} A_s}{\rho C_p Le^{2/3} R_v}\left(\frac{P_{v,s}}{T_s} - \frac{P_{v,\infty}}{T_\infty}\right)$
Using $\frac{1}{T_s} - \frac{1}{T_\infty} \approx \frac{1}{T}$, where $T = \frac{T_s + T_\infty}{2}$ and $P = \rho R T = \rho (R_u/M) T$	$\dot{m}_v = \frac{h_{heat} A_s}{C_p Le^{2/3}} \frac{M_v}{M} \frac{P_{v,s} - P_{v,\infty}}{P}$

14.11 – IRAKATSIKO EZ DIREN ATALAK

- 14.4 atala: MUGALDE-BALDINTZAK
- 14.5 atala : HORMA BATEAN ZEHARREKO MASA-DIFUSIO GELDIKORRA
- 14.7 atala : MASA-DIFUSIO IRAGANKORRA
- 14.8 atala : DIFUSIOA MUGIMENDUAN DAGOEN INGURUNE BATEAN