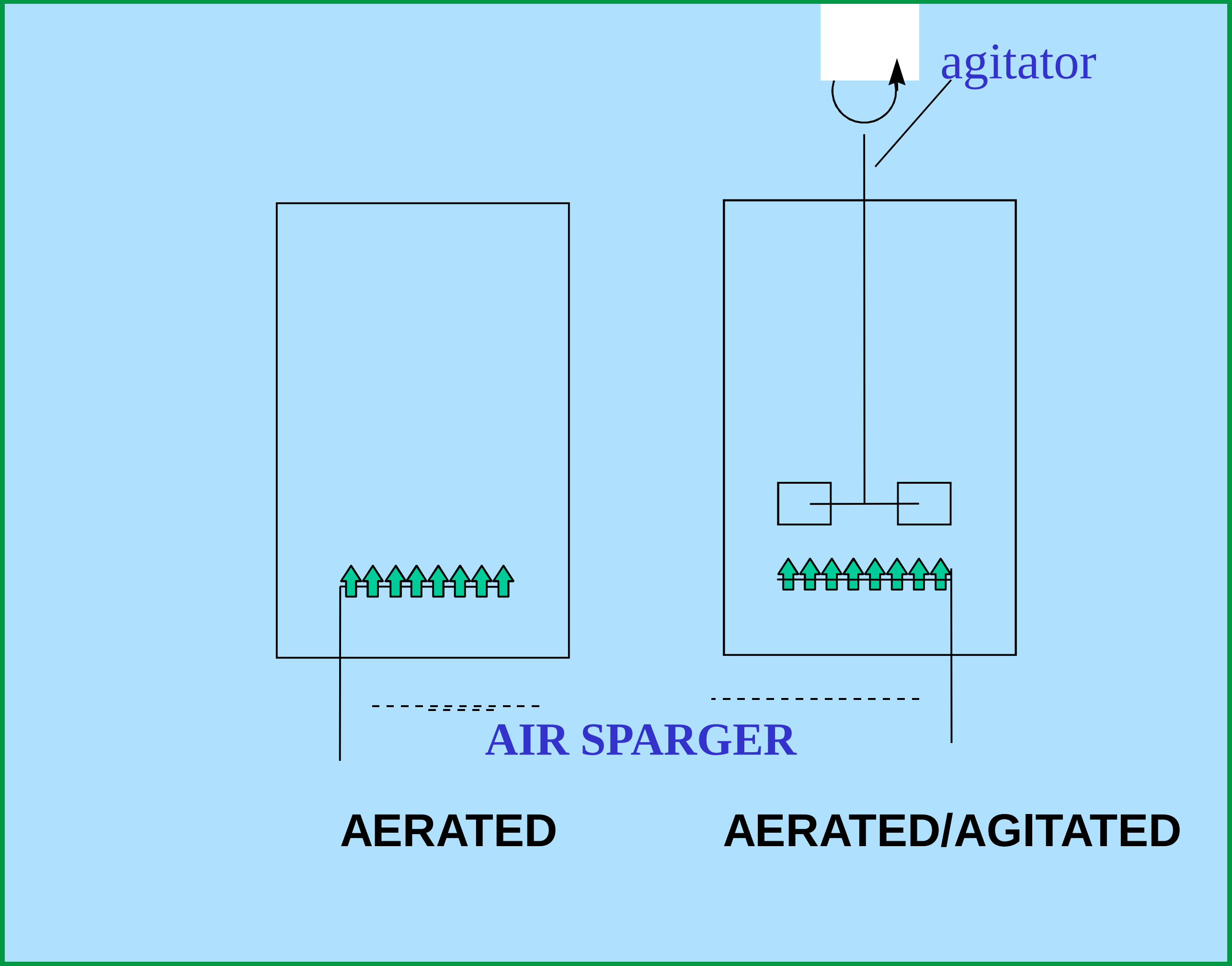
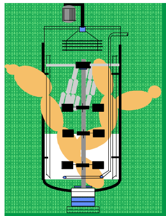
# AEARATION 2

## Technical realization of aeration

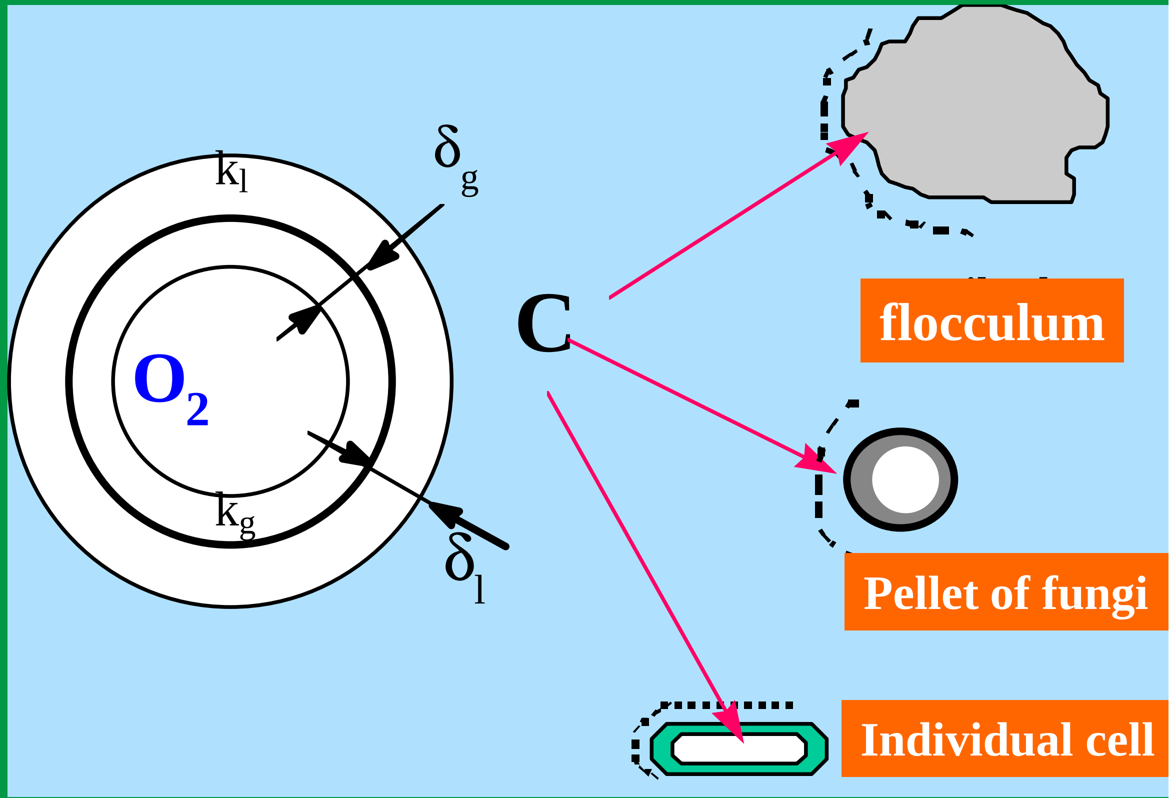




# AEARATION 2

## Oxygen mass transfer from air bubbles

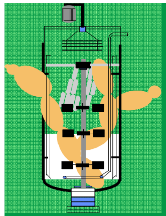
1. **Diffusion from bubble to g/l interface, $1/k_g$ resistance $k_g$ conductivity** **(mass transfer coefficient)**
2. **Diffusion through stagnant liquid film of $\delta_l$ thickness Resistance of which is $1/k_l$ , Conductivity: $k_l$ , mass tr. coefficient.**
3. **Entire mass of liquid. Convection, but...**




4. **Liquid film around microbes.**

***Mechanism of oxygen uptake*** **starts with a diffusion through a liquid film and continues with**

5. **A diffusion into the cell (microbe) or microbial flocs or hyfae or pellets.**
6. **Finally a certain resistance characterizes the oxygen utilization itself=reaction resistance = respiration is a time process,too.**

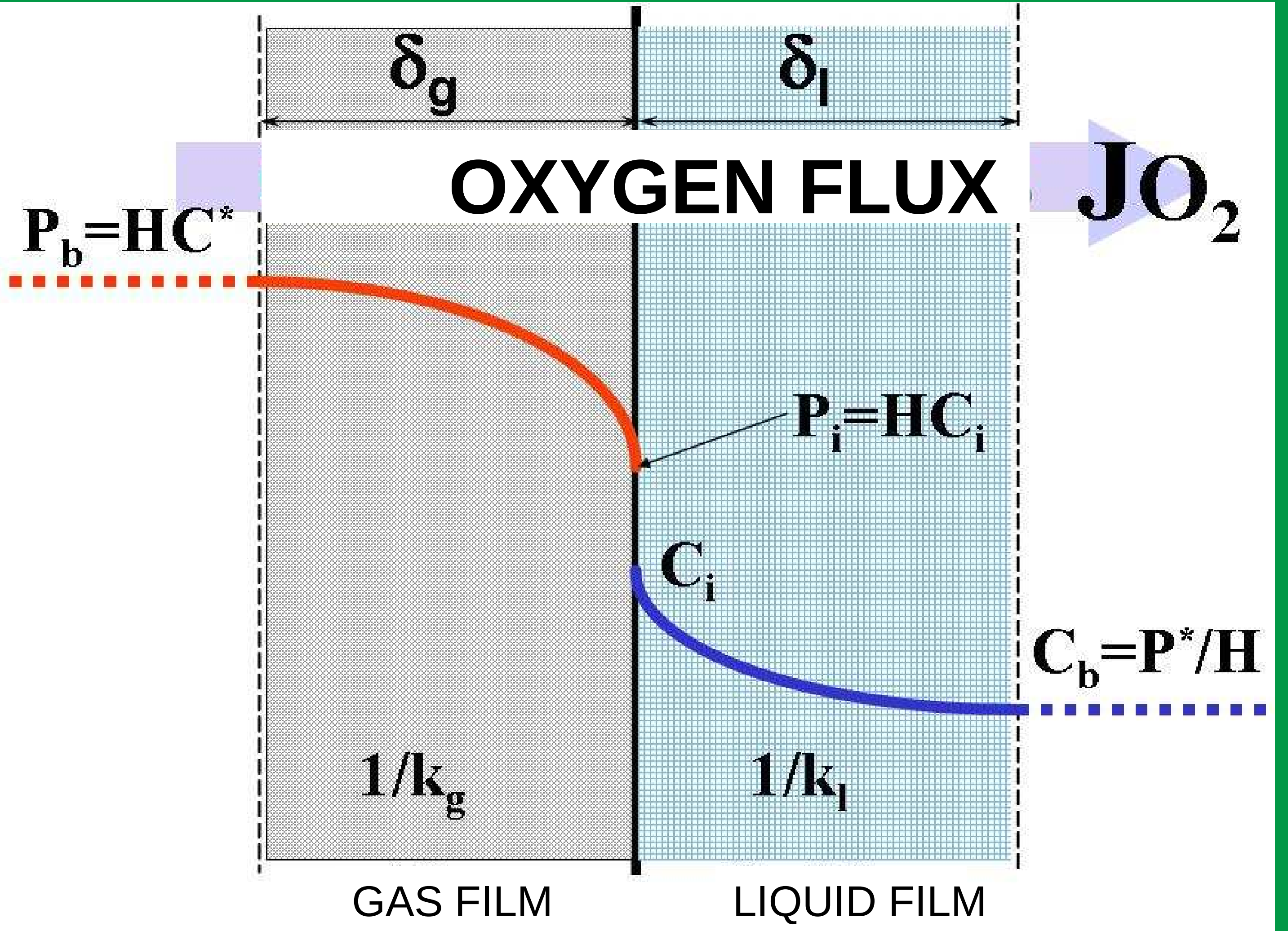


AEARATION 2

**Which is the rate limiting step?**

$$k_g = \frac{D_{O_2}^{gas}}{\delta_g} \quad \text{and} \quad k_l = \frac{D_{O_2}^{liquid}}{\delta_l}$$

**TWO FILM THEORY**



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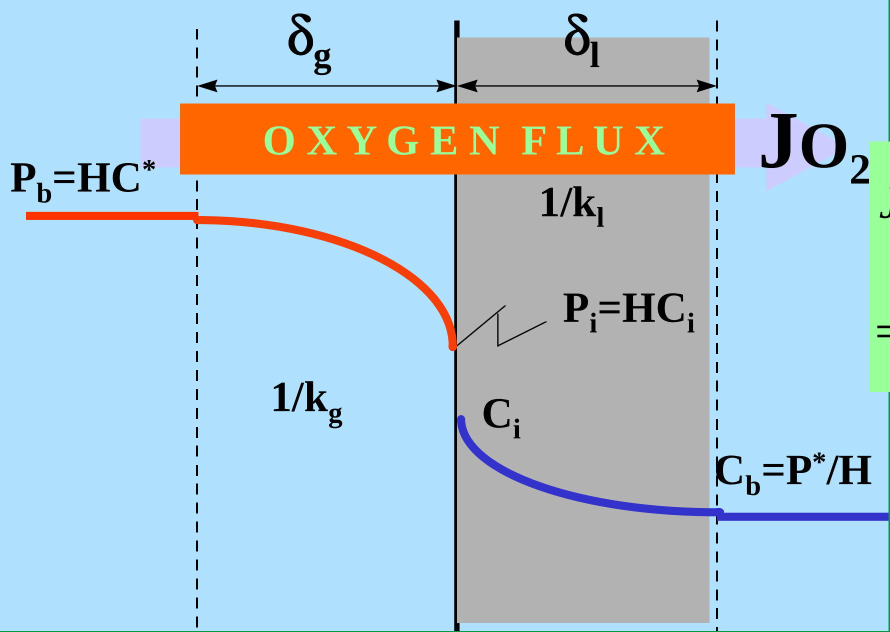



$$J_{O_2} = \frac{O_2 \text{ transferred through interface (mol vagy g)}}{\text{surface}}$$

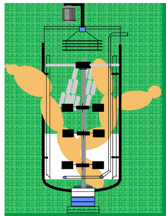
$$= \frac{\text{drivingforce}}{\text{resistance}}$$

**GAS BUBBLES→G/F INTERFACE** **G/F INTERFACE → LIQUID**

$$J_{O_2} = \frac{p_b - p_i}{\dfrac{1}{k_g}} = \frac{C_i - C_b}{\dfrac{1}{k_l}}$$

**OR**

$$J_{O_2} = Hk_g\left(C^* - C_i\right) = \frac{\dfrac{p_i}{H} - \dfrac{p^*}{H}}{\dfrac{1}{k_l}}$$



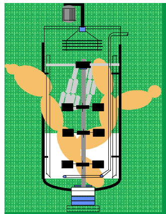
# AEARATION 2

**H** **Henry- constant**

**$p_b$** **oxygen partial pressure in gas bubble**
**C* (hypothetical oxygen cc. in equilibrium)**

**$C_b$** **dissolved oxygen cc.in liquid,**
**p* would be partial pressure in equilibrium**

**$C_i$ , $p_i$** **dissolved oxygen cc. and partial pressure on interface.**



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$$J_{O_2} = k_g\left(p_b - p_i\right) = \frac{k_l}{H}\left(p_i - p^*\right)$$

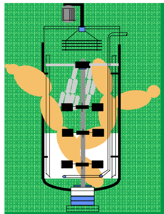
$$J_{O_2} = Hk_g\left(C^* - C_i\right) = k_l\left(C_i - C_b\right)$$

$$p_i = \frac{\dfrac{p^*}{k_g} + \dfrac{H}{k_l}p_b}{\dfrac{H}{k_l} + \dfrac{1}{k_g}}$$

$$C_i = \frac{Hk_g C^* + k_l C_b}{k_l + Hk_g}$$

$$J_{O_2} = \frac{C^* - C_b}{\dfrac{1}{Hk_g} + \dfrac{1}{k_l}}$$

$$J_{O_2} = \frac{p_b - p^*}{\dfrac{H}{k_l} - \dfrac{1}{k_g}}$$



$$J_{O_2} = \frac{C^* - C_b}{\ldots}$$

$$J_{O_2} = \frac{p_b - p^*}{\ldots}$$

$$\frac{1}{K_L} = \ldots + \frac{1}{k_l} \quad \longrightarrow \quad K_L \cong k_l$$

**OVERALL (LIQUID SIDE) OXYGEN ABSORPTION COEFFICIENT**

$$\frac{1}{K_g} = \frac{H}{k_l} + \frac{1}{k_g}$$

**OVERALL (GAS SIDE) OXYGEN ABSORPTION COEFFICIENT**

$$k_g \rangle\rangle k_l$$

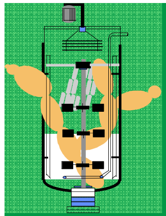
$$\frac{k_g}{k_l} \cong \frac{D_{O_2}^{gáz}}{D_{O_2}^{folyadék}} \approx 10^4$$

**OVERALL MASS TRANSFER**

$$J_{O_2} = K_L\left(C^* - C_b\right)$$

$$J_{O_2} = K_g\left(p_b - p^*\right)$$

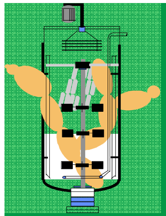
$$\longrightarrow \quad \frac{dC}{dt} = K_L a\left(C^* - C\right)$$



# AEARATION 2

$$\frac{dC}{dt} = K_L a\left(C^* - C\right)$$

**$K_L$** – overall liquid side mass transfer coefficient [$cm.s^{-1}$]
**a** – specific mass transfer surface area [$cm^2.cm^{-3} = cm^{-1}$]
**$K_L$a** - overall volumetric oxygen absorption coefficient [$s^{-1}$] (most often $h^{-1}$ ).
**C*** - saturation dissolved oxygen concentration ($mg/dm^3$)
**C** - actual dissolved oxygen concentration ($mg/dm^3$)



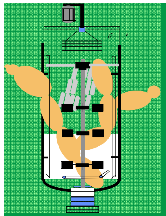
# AEARATION 2

$$\frac{dC}{dt} = K_L a\left(C^* - C\right)$$

LET US SOLVE IT!

$$\int_0^C \frac{dC}{C^* - C} = \int_0^C -d\ln(C^* - C) = \int_0^t K_L a.dt$$

$$C = C^*\left(1 - e^{-K_L a.t}\right)$$



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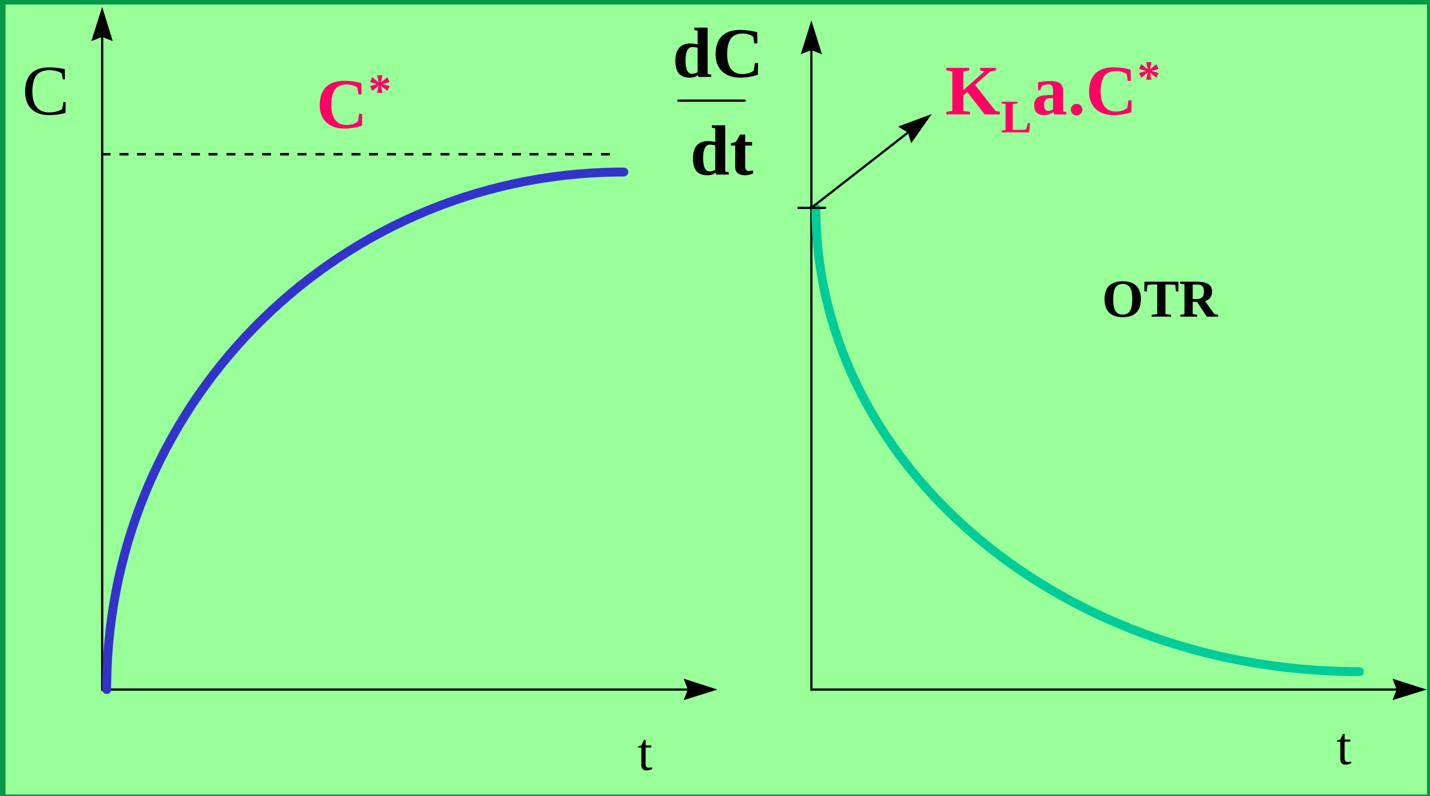
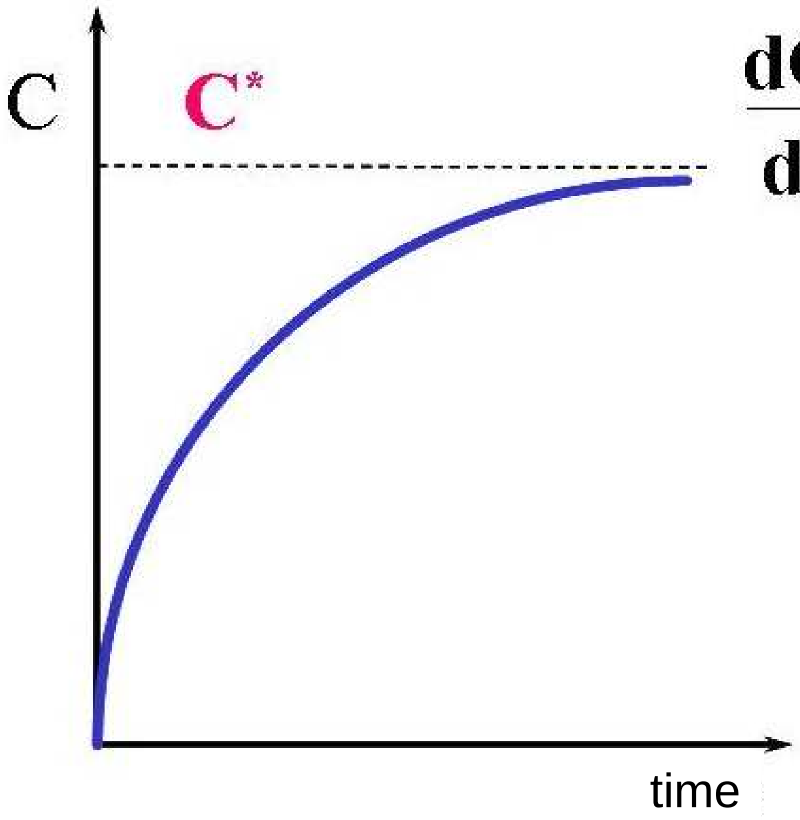
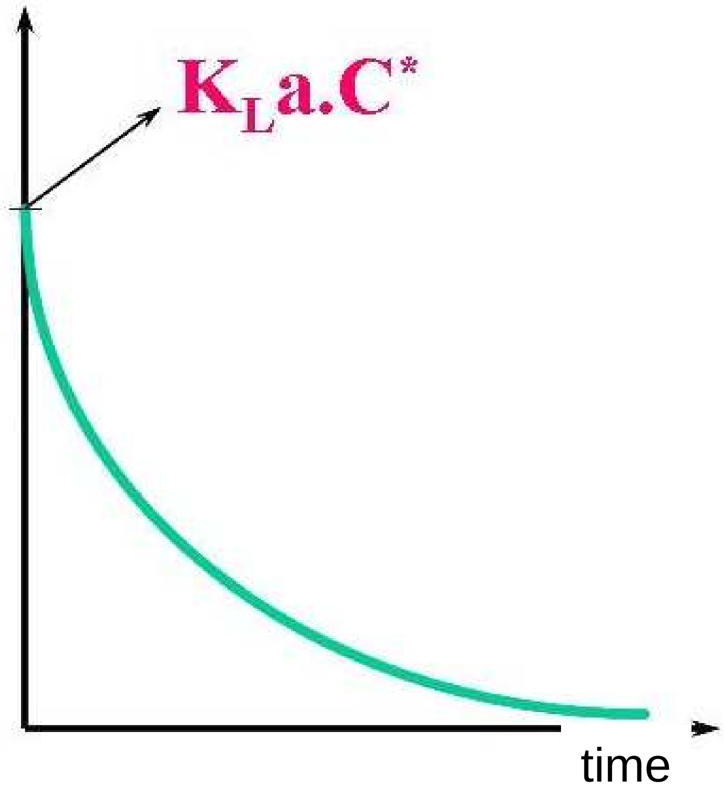


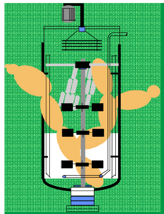

Nézzük a fermentációs rendszert! Mikorobák is jelen vannak és lélegeznek
LOOK AT A REAL FERMENTATION SYSTEM: microbes are present
and they are respiring




SATURATION WITH OXYGEN




RATE OF THE SATURATION



# AEARATION 2

Absorption rate  consumption rate

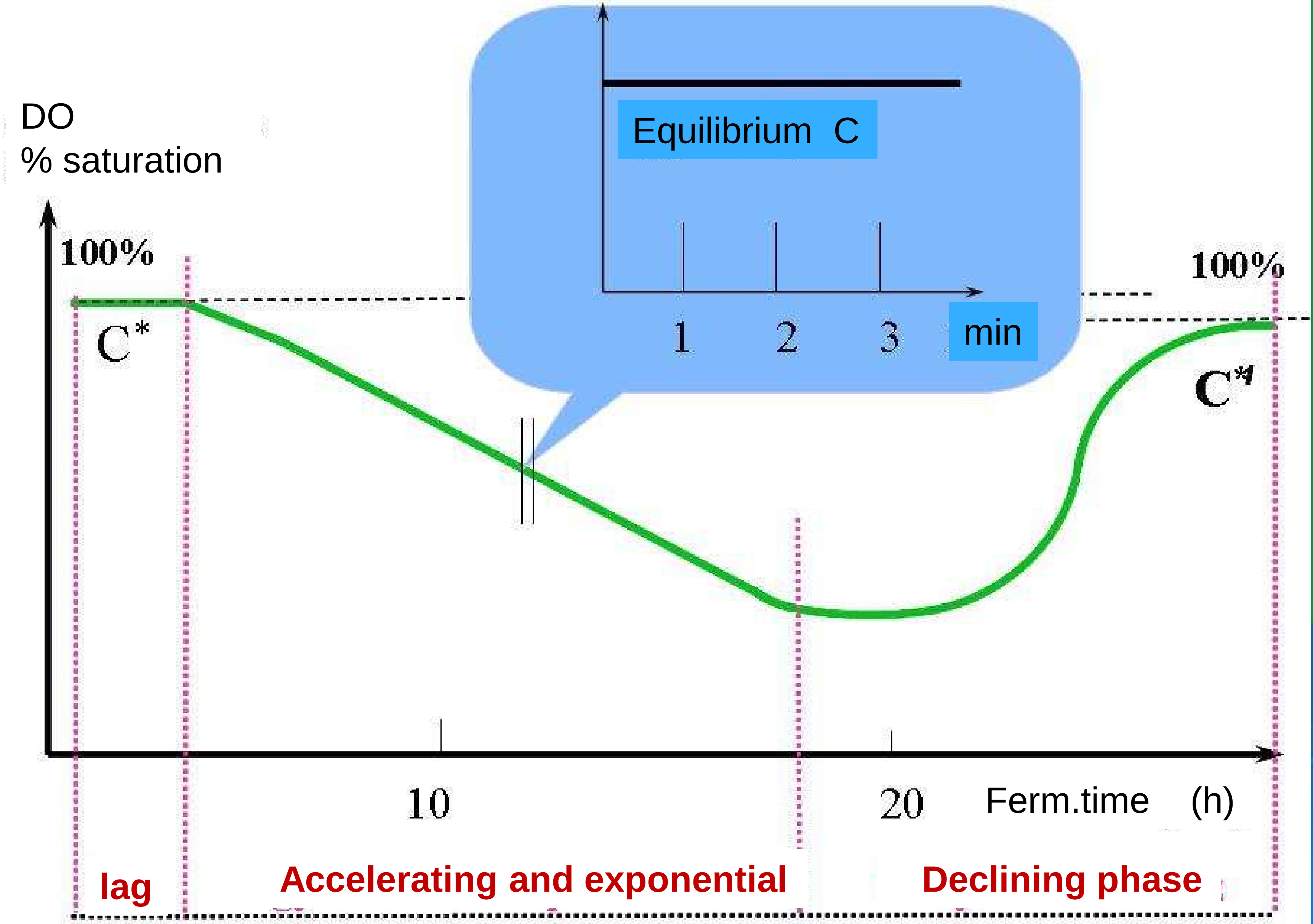
$$\frac{dC}{dt} = K_L a\left(C^* - C\right) - xQ$$

always $\frac{dC}{dt} = 0$ és $K_L a\left(C^* - C\right) = xQ$

**S T E A D Y  S T A T E**

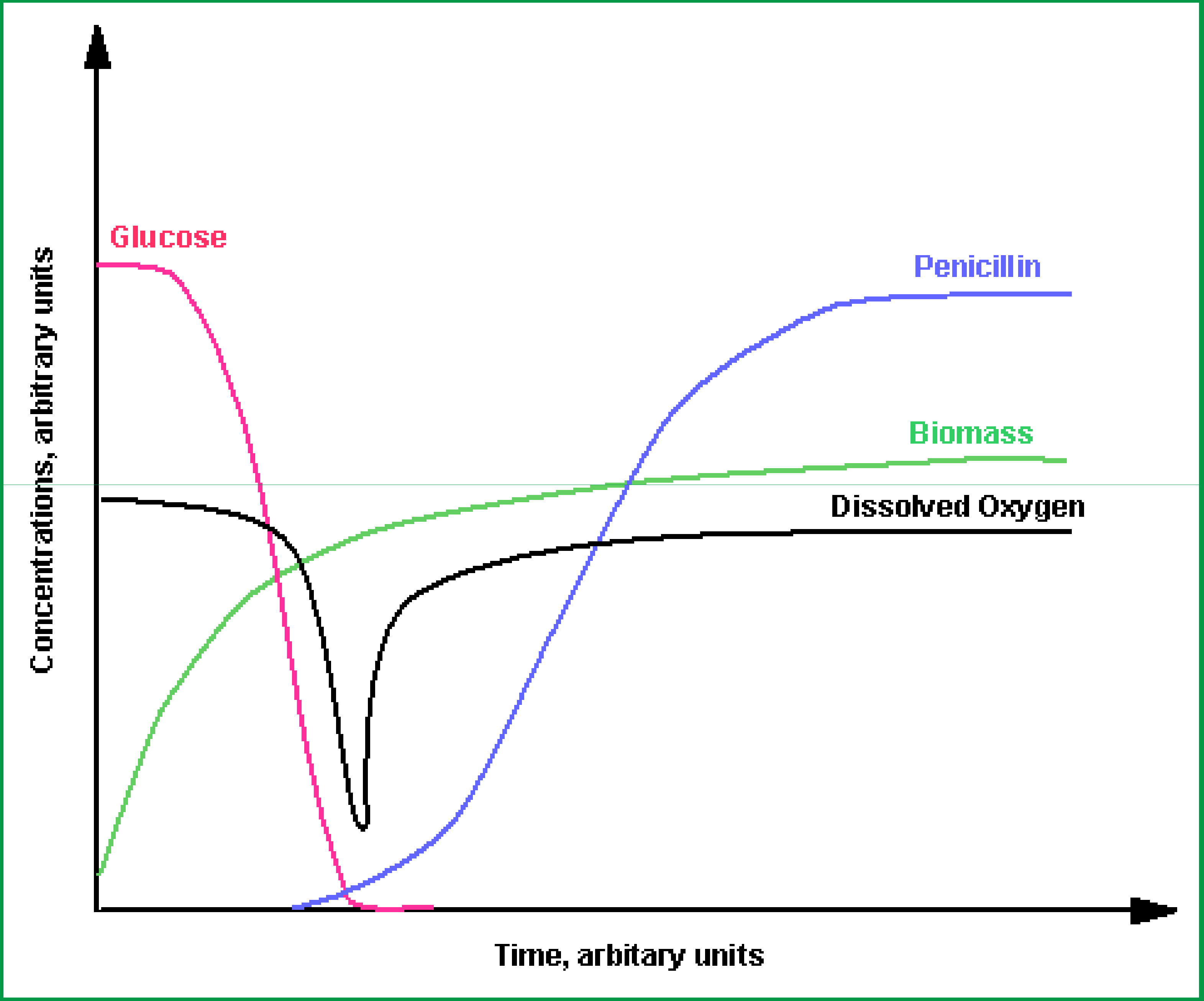
**verification**

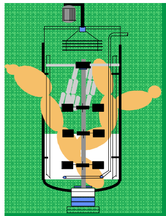
$K_L a(C^* - C) > xQ$ **...IF...** $K_L a(C^* - C) < xQ$



DO
% saturation
100%
C*
Equilibrium C
1
2
3
min
100%
C*
10
20
Ferm.time (h)
lag
Accelerating and exponential
Declining phase

# AEARATION 2


Glucose
Penicillin
Biomass
Dissolved Oxygen
Concentrations, arbitrary units
Time, arbitary units



# AEARATION 2

$$\frac{dC}{dt} = \quad \ldots \quad - C\Big) - xQ$$

**What and how solubility depends on?** **C* ?**

**What and how $K_l$ depends on ?**

**What and how a depends on ?**

**What and how $K_l a$ depends on ?**

AEARATION 2

# What and how does C* depend on?

1. PARTIAL PRESSURE - Henry's law :

$$C^* = \frac{1}{H} p_{O_2}$$

H - Henry-constant [ bar/molfraction; bar.dm$^3$/mol; bar.dm$^3$/mg ]

$p_{O2}$- partial pressure of oxygen

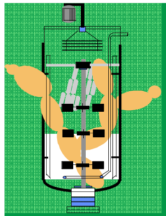
(which could be measured above a liquid of C* cc. and which is in equilibrium with the gas phase [bar].)

C* - saturation dissolved oxygen concentration; solubility [mol/dm$^3$; mg/dm$^3$ ]

2. TEMPERATURE : Cl-Cl

$$\frac{d \ln H}{d\left(\frac{1}{T}\right)} = \frac{\Delta G}{R}$$

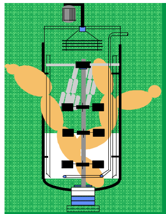
T – temp. in ($^o$K) $\Delta$G – absorption enthalpy of oxygen (negative)



# AEARATION 2

Henry-constants for various gases at different temeratures

| **Temperature** | **Henry-constant *10 $^{-4}$ [bar/molfraction** | | |
|---|---|---|---|
| **$^{O}C$** | **$N_2$** | **$C0_2$** | **$0_2$** |
| **0** | **5,29** | **0,073** | **2,55** |
| **10** | **6,68** | **0,104** | **3,27** |
| **20** | **8,04** | **0,142** | **4,01** |
| **30** | **9,24** | **0,186** | **4,75** |
| **40** | **10,40** | **0,233** | **5,35** |
| **50** | **11,30** | **0,283** | **5,88** |
| **60** | **12,0** | **0,341** | **6,29** |



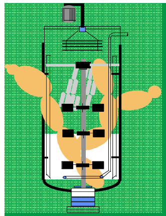
# AEARATION 2

Wilhelm' approach for 1 bar pressure:

$$R \ln X = A + \frac{B}{T} + C \ln T + DT$$

X : mol fraction of $O_2$ or $CO_2$

| | T (range) | A | B | C | D |
|---|---|---|---|---|---|
| OXYGEN | 274-348 $^oK$ | -286,94 | 15450,6 | 36,5593 | 0,0187662 |
| CARBON-DIOXIDE | 273-353 $^oK$ | -317,66 | 17371,2 | 43,0607 | -0,00219107 |



# AEARATION 2

Cl-Cl approaching equation

$$C^* \cong \frac{A}{B+t}$$

In the range of 4-33 $^oC$

C* - (mg/dm$^3$)

A = 468 B = 31,6 t - ($^oC$).

Polinomial approach for estimation of C*

$$C^* \cong 14,16 - 0,3943.t + 0,007714.\, t^2 - 0,0000646.t^3$$

C* - (mg/dm$^3$) t - hőmérséklet ($^OC$)

**Solubility of the oxygen decreases with increasing temperature !!!!!**

## 3. DEPENDENCE ON COMPOSITION OF CULTURE MEDIA

***Setchenov,***
***van Krevelen***
***Hoftijzer,***
***Dankwerts***

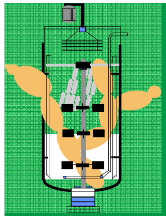
EFFECT OF ELECTROLITES

$$\lg \frac{C_0^*}{C^*} = \sum_i H_i I_i$$

$C_0^*$ - in pure water
$C^*$ - in the given electrolite solution
$H_i$ – ionspecific „desalting”constant
$I_i$ - ionic strength of the $i^{th}$ ion
**ionerősség**

$$I_i = 0{,}5 c_i z_i^2$$

$c_i$ - molarity of the $i^{th}$ ion (g ion/dm$^3$ )
$z_i$ - electric charge of the $i^{th}$ ion.



# AEARATION 2

## Ionspecific constants for $CO_2$ and $O_2$ (25 $^oC$)

| **Kations** Hi (l.g-ion$^{-1}$) | | | **Anions** $H_i$ (l.g-ion$^{-1}$) | | |
|---|---|---|---|---|---|
| | $O_2$ | $CO_2$ | | $O_2$ | $CO_2$ |
| $H^+$ | -0,774 | -0,311 | $Cl^-$ | 0,844 | 0,340 |
| $Na^+$ | -0,550 | -0,129 | $Br^-$ | 0,820 | 0,324 |
| $K^+$ | -0,596 | -0,198 | $J^-$ | 0,821 | 0,311 |
| $NH_4^+$ | -0,720 | -0,264 | $OH^-$ | 0,941 | |
| $Mg^{2+}$ | -0,314 | -0,079 | $NO_3^-$ | 0,802 | 0,291 |
| $Ca^{2+}$ | -0,303 | -0,071 | $SO_3^{2-}$ | 0,453 | 0,213 |
| $Mn^{2+}$ | -0,311 | | $CO_3^{2-}$ | 0,485 | |
| | | | $PO_4^{3-}$ | 0,320 | 0,147 |

# AEARATION 2

Effect of organics on the solubility of oxygen

$$\lg \frac{C_o^*}{C_{org}^*} = KC_{org}$$

K Setchenov-constant

$C_{org}$ organics concentration in culture medium

LINEAR APPROACH

$$C_{ORG}^* = C_o^* \left(1 - mC_{ORG}\right)$$

FOR glucose, lactose, szaccharose

$m = 0{,}0012\ dm^3/g$ in 150-200 $g/dm^3$ sugar cc. range.

## HOW CAN WE INCREASE C* ?

$p_{O2}$

**TOTAL PRESSURE**

GAS COMPOSITION

**PURE OXYGEN**

~~**TEMPERATURE**~~

~~**CULTURE MEDIA COMPOSITION**~~