

MEŠANJE

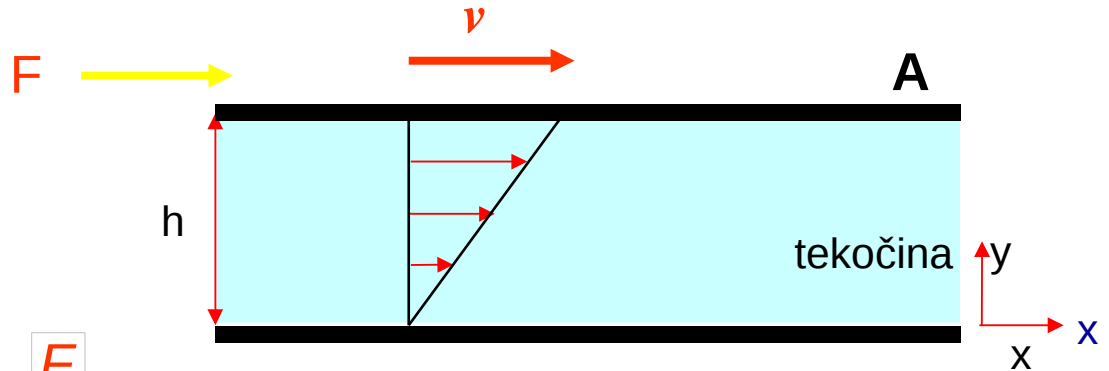
Reološke lastnosti tekočin

Mešanje

Mešalni bioreaktorji

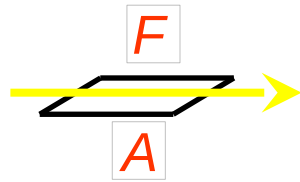
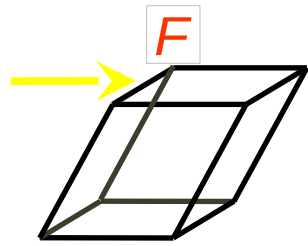
Reološke lastnosti tekočin

enostavni strig:



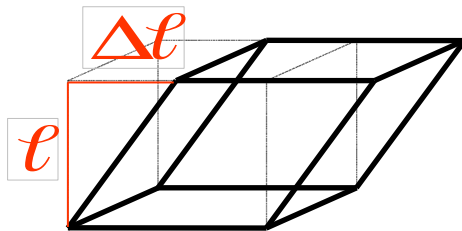
strižna napetost:

$$\tau = \frac{F}{A}$$



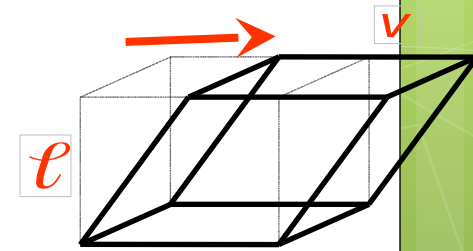
$$F = \eta \cdot A \cdot \frac{dv_x}{dy}$$

strižna deformacija:



$$F \propto \Delta \ell$$

strižna hitrost:

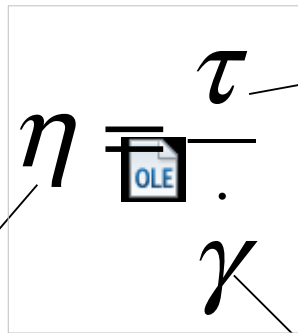


$$F \propto v$$

Reološke lastnosti tekočin

- newtonske tekočine:

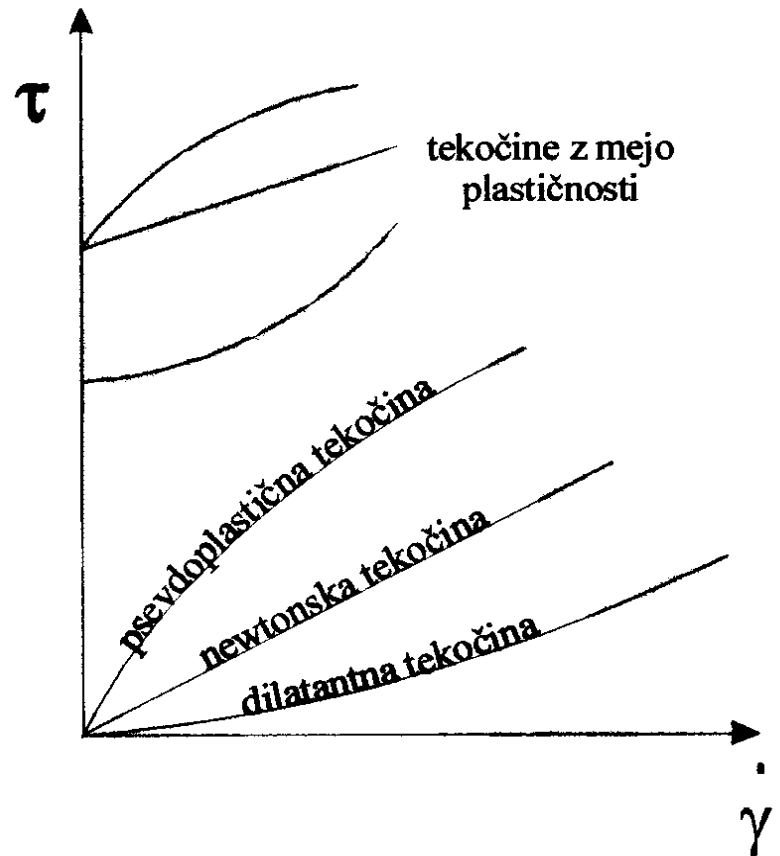
Newtonov zakon:



strižna
napetost
[Pa]

dinamična
viskoznost
[Pa s]

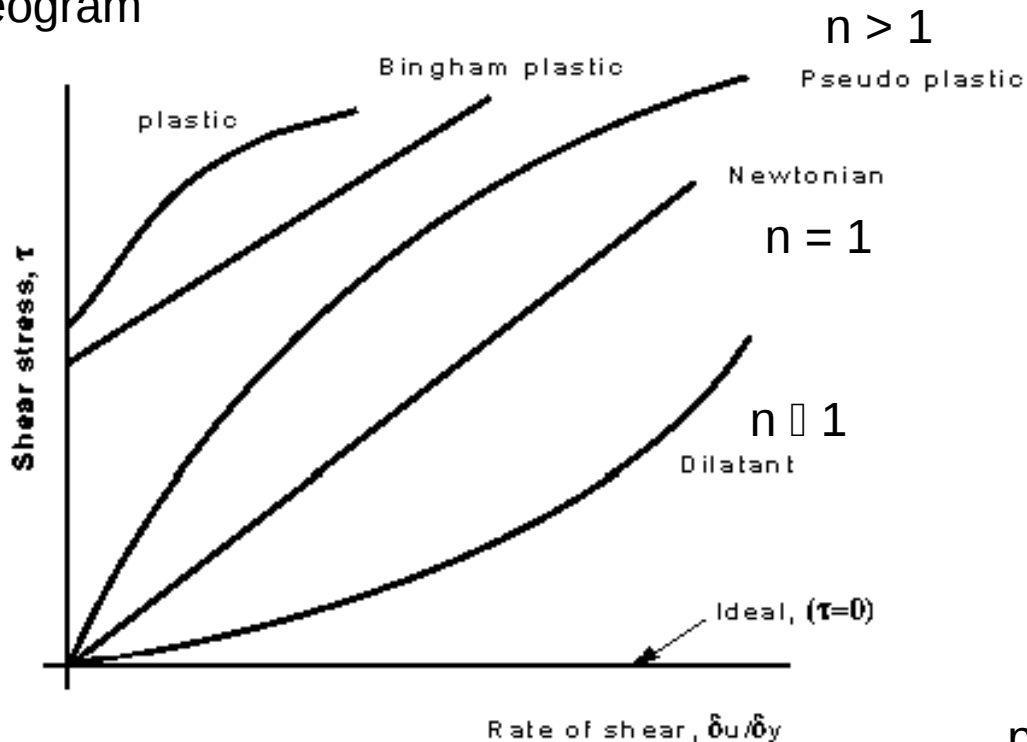
strižna
hitrost
[s⁻¹]



Nenewtonske tekočine

- viskoznost se spreminja s strižno hitrostjo

reogram



Material	viskoznost ·10 ³ (Pa s)	T (°C)
zrak	0,017	0
voda	1	20
jajčni beljak	12	20
glicerol	100	60
ricinovo olje	1000	20
glukoza	10000	10

pseudoplastične tekočine

Ostwald-de Waelejev
(potenčni) model:

$$\tau = K \dot{\gamma}^n \quad \text{in} \quad \eta_a = \frac{\tau}{\dot{\gamma}} = K \dot{\gamma}^{n-1}$$

Pseudoplastične tekočine

■ Ostwald – de Waelejev (potenčni) model:

$$\tau = K \dot{\gamma}^n \quad \text{in} \quad \eta_a = \frac{\tau}{\dot{\gamma}} = K \dot{\gamma}^{n-1}$$

n – indeks tokovnega obnašanja [-]
 η_a - navidezna viskoznost [Pa s]
 K – indeks konsistence [Pa sn],

$$n < 1: \dot{\gamma} = \frac{1}{K_s} N \quad (\text{Metzner \& Otto, 1957})$$

■ Izračun povprečne strižne hitrosti:

k_s - brezdimenzijska konstanta strižne hitrosti mešala

Rushtonova turbina: $k_s = 11,8$, propeler: $k_s = 10$

Reynoldsovo število pri mešalnih reaktorjih

- newtonske tekočine:

$$\text{Re} = \frac{\rho N D^2}{\eta}$$

- nenewtonske tekočine:

$$\text{Re} = \frac{\rho N^{2-n} D^2}{K k_s^{n-1}}$$

N vrtilna hitrost (s⁻¹)

D premer mešala (m)

ρ gostota tekočine (kg/m³)

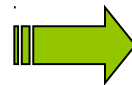
η viskoznost (Pa.s)

K – indeks konsistence [Pa sn],

k_s - brezdimenzijska konstanta strižne hitrosti mešala

η.... viskoznost = f (N)

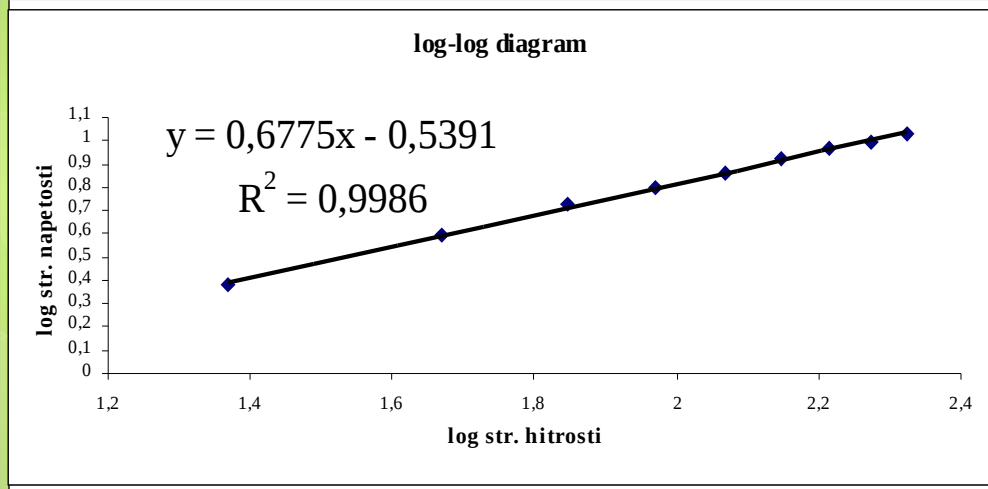
določiti je treba odvisnost



viskoznost tekočine merimo z viskozimetrom pri pogojih enostavnega striga

Določanje reoloških karakteristik

- Reogrami (za psevdoplastične tekočine pogosto simulacija z raztopino CMC)



$$\tau = K \dot{\gamma}^n$$

$$\log \tau = n \cdot \log \dot{\gamma} + \log K$$

□ K, n

- navidezna viskoznost pri različnih N:

$$\eta_a = K (ks N)^{n-1}$$

Reološke karakteristike

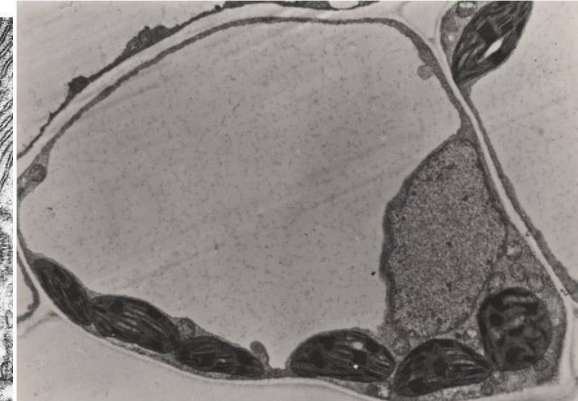
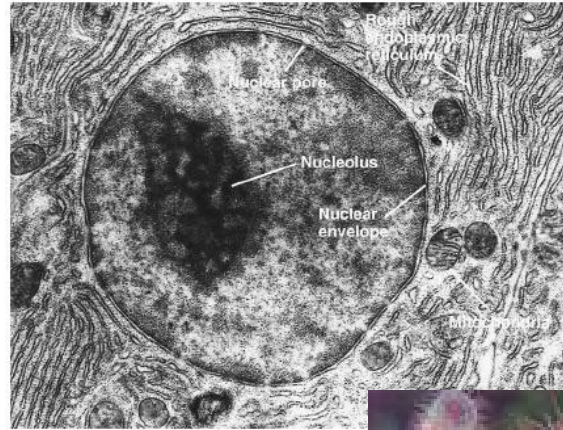
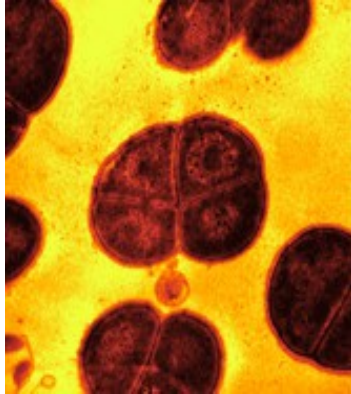
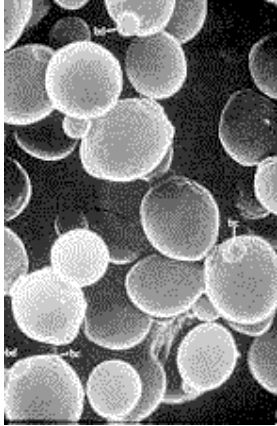
Table 1.9 Typical shear rates encountered in bioprocessing.

Operation	$\dot{\gamma}$ (s ⁻¹)
Expanded bed	<10
Packed bed	<10 ³
Stirred tank	10 ² –10 ³
High pressure homogenizer	10 ⁶

Table 1.10 Viscosities of various fluids at 20°C.

Liquid	Apparent viscosity mPa s
Water	1
Glycerol	1070
Ethanol	1.20
Acetonitrile	0.34
Clarified cell culture supernatant	<5
Blood	10
<i>E. coli</i> homogenate	<40
<i>E. coli</i> broth	<20
<i>Penicillium chrysogenum</i> fermentation broth	40 000
Heinz ketchup	50 000–70 000

Morfologija celic



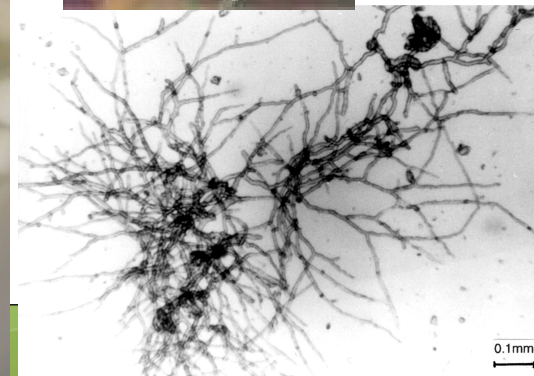
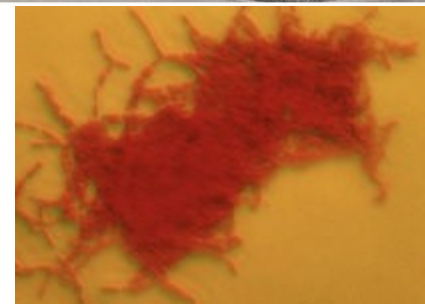
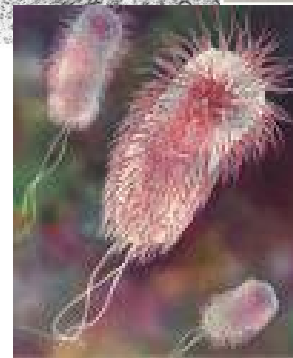
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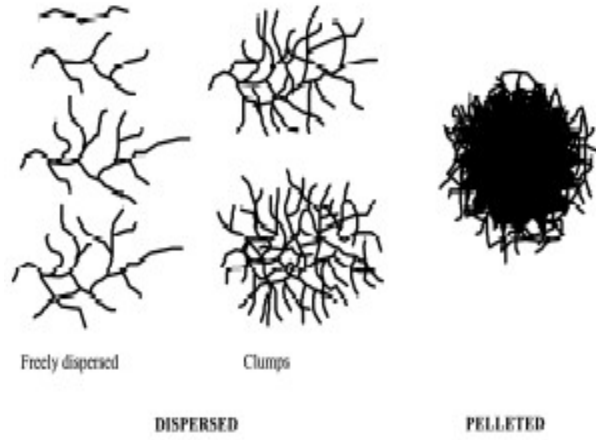
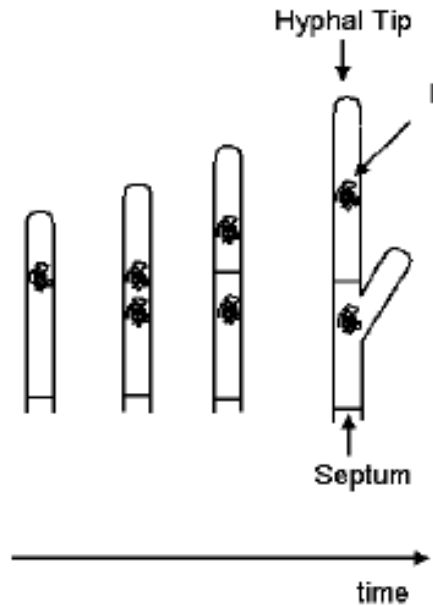
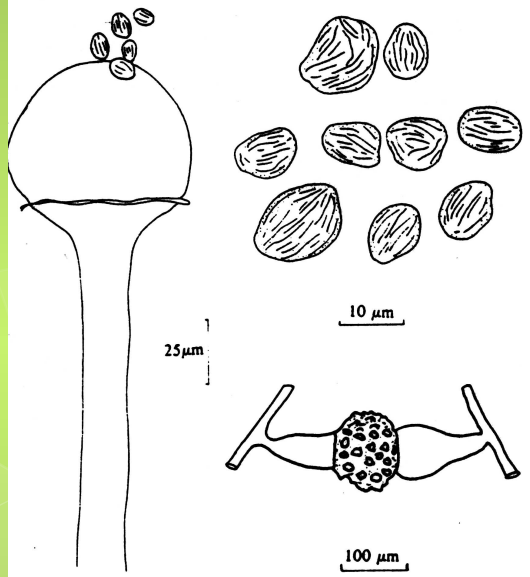
Third level

Fourth level

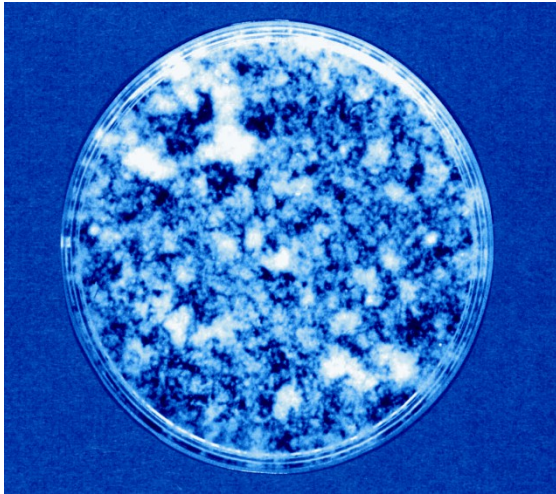
Fifth level



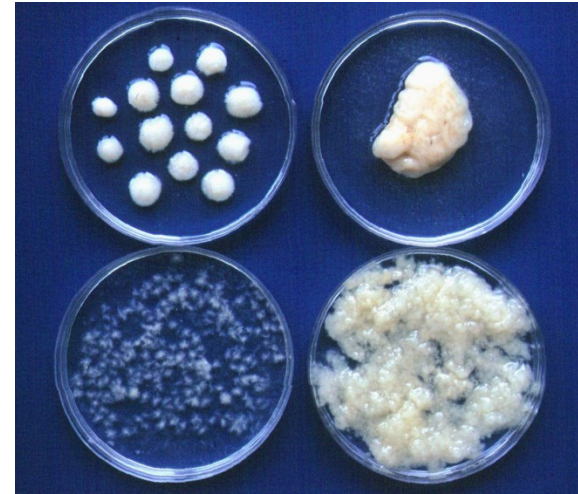
Submerzna rast nitastih gljiv



Morfologija nitastih gljiv



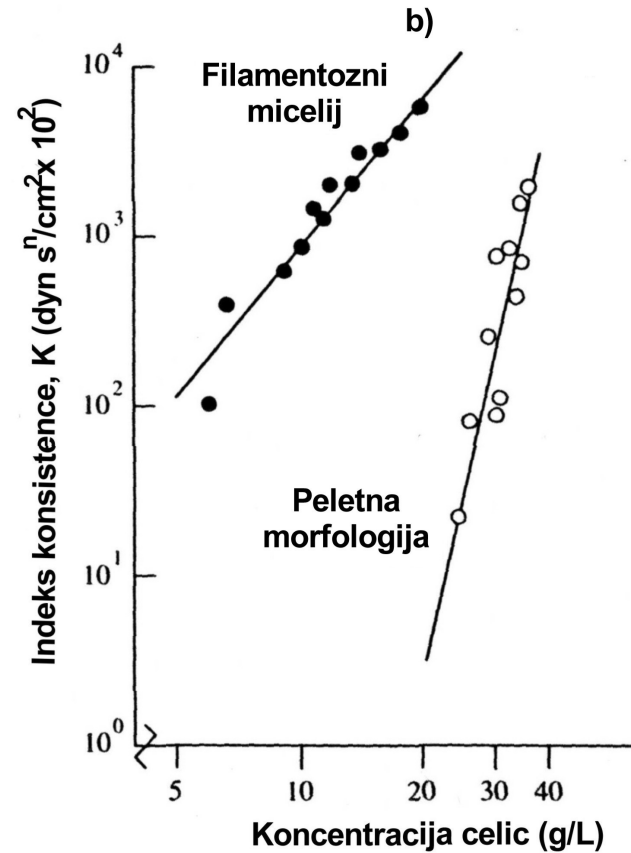
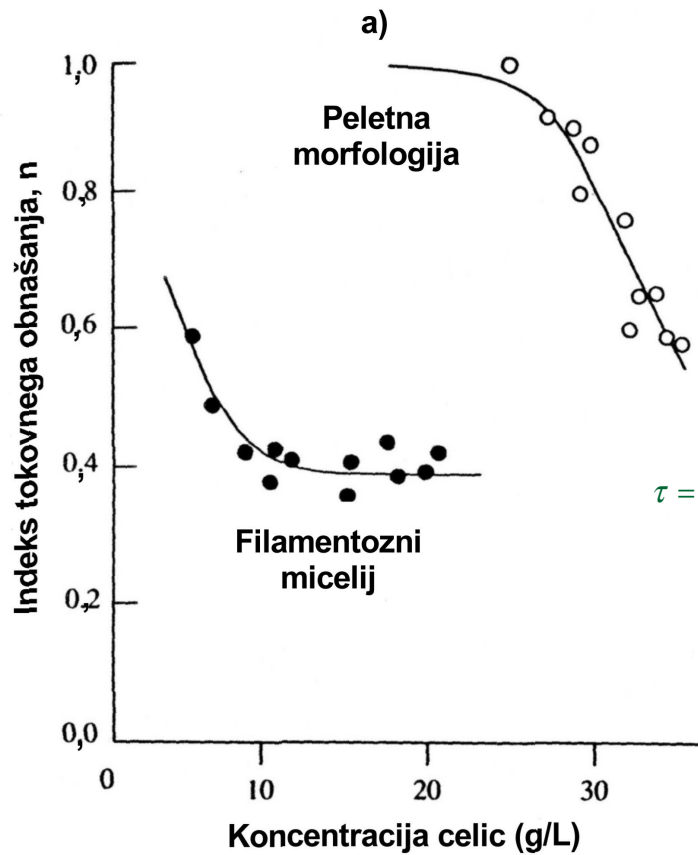
dispergirana (filamentozna) rast



dispergirane flokule, peleti, kepe, sprijeta biomasa

- sestava celic
- metabolizem celic
- reološke lastnosti fermentacijskih brozg

Morfologija in reološke lastnosti fermentacijskih brozg



Potenčni model:

$$\tau = K \cdot \dot{\gamma}^n$$

MEŠANJE

Hidrodinamska operacija:

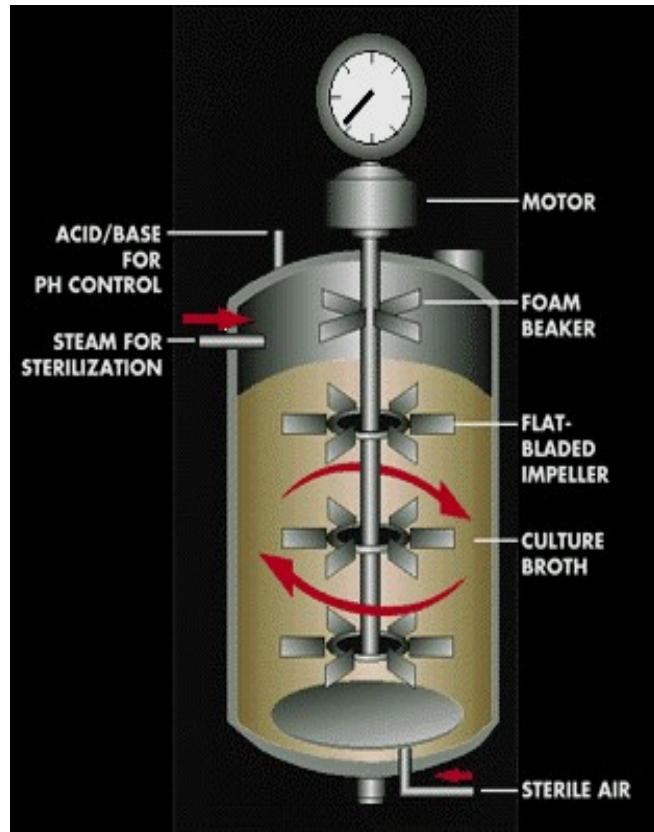
- doseganje enotne sestave in temperature medija
- pospešitev prenosa hranil in metabolnih produktov
- hitrejši prenos toplote
- suspendiranje trdnih delcev
- dispergiranje tekočine v tekočini (dodatki protipenilca)

ter pri aerobnih procesih:

- dispergiranje plinske faze v tekočini
- pospešitev prenosa kisika iz mehurčkov v tekočino

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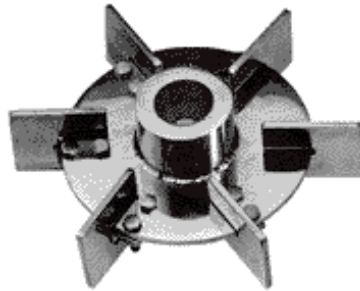
MEŠALNI BIOREAKTOR



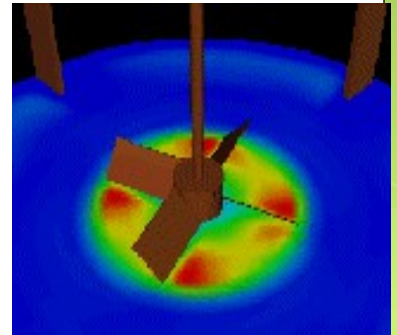
MEŠALA

- diskaste turbine (visoke strižne sile)

Rushtonova
turbina



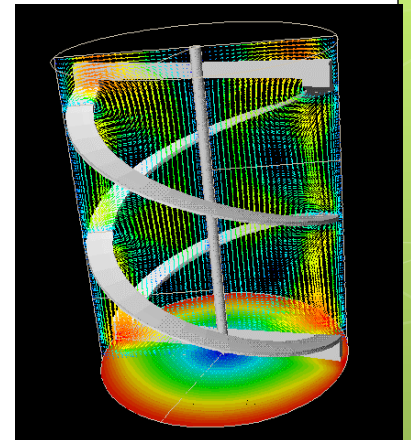
turbina z
nagnjenimi
lopaticami



- propeler

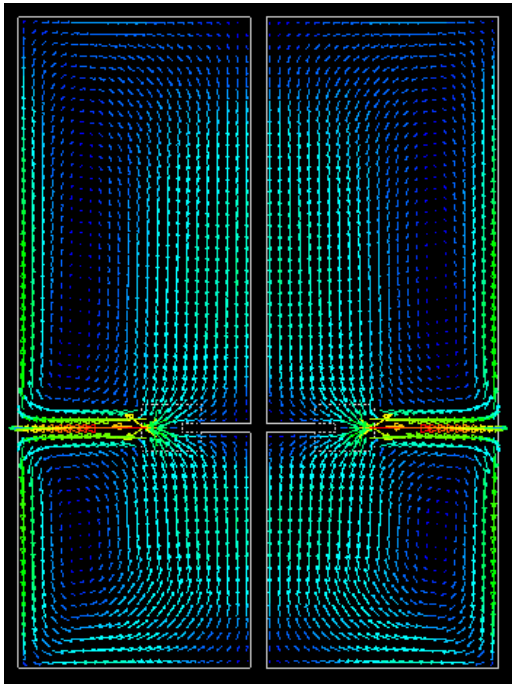


- vijáčno mešalo

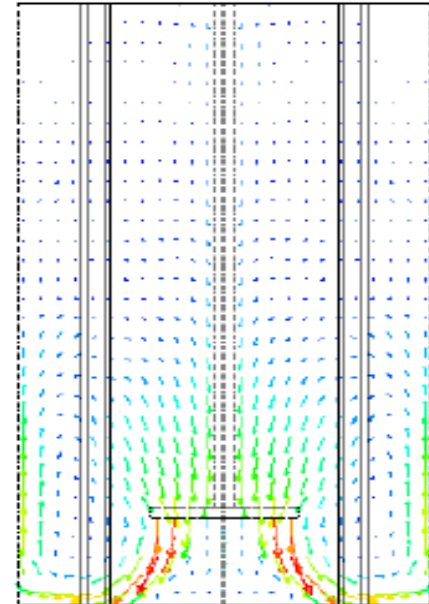


TOKOVNI PROFILI

- radialni tok kapljevine
 - Rushtonova turbina



- aksialni tok kapljevine
 - propeler



MEŠALA

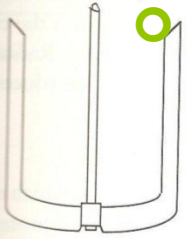
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Fi propeler



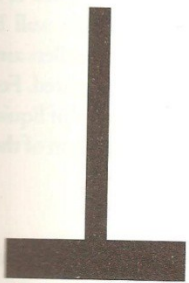
sidrasto mešalo



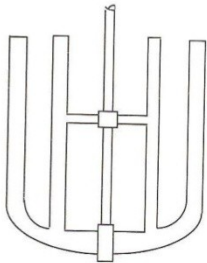
Fi propeler



turbina s 6 lopaticami



veslasto mešalo

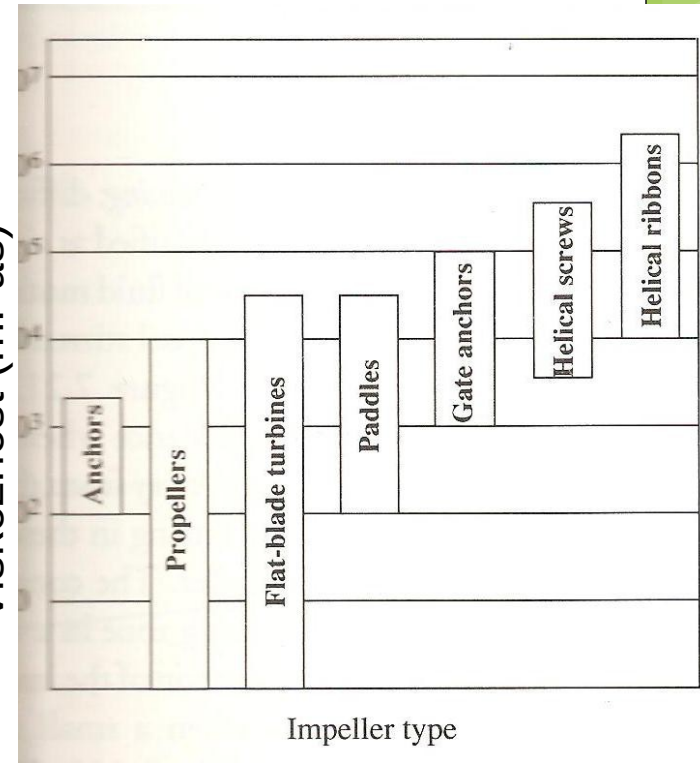


sidrasto mešalo z zaporo

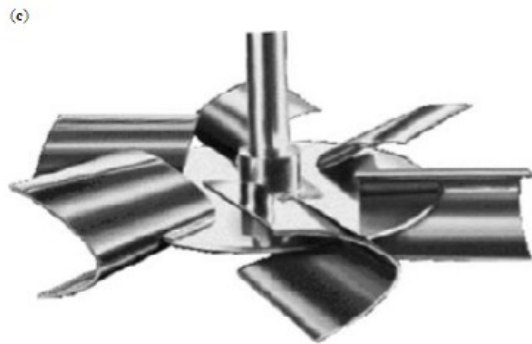


vijačno mešalo

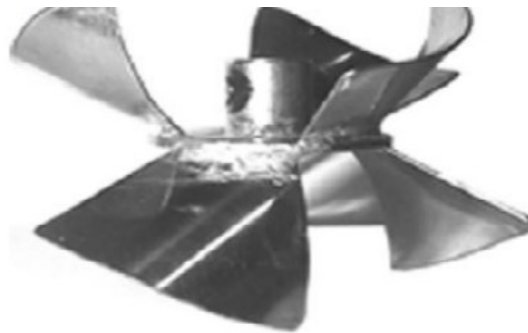
Viskoznost (mPas)



Mešala – radialni tok



Chemineer BT-6

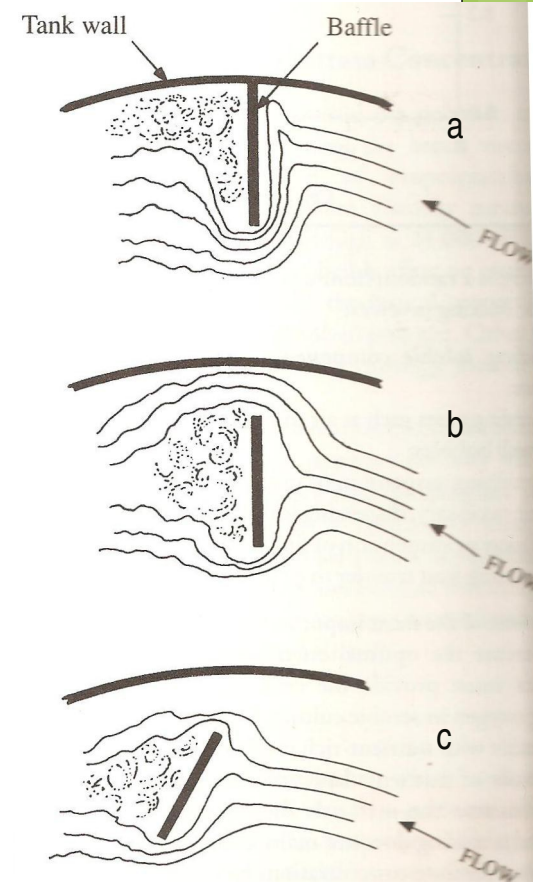
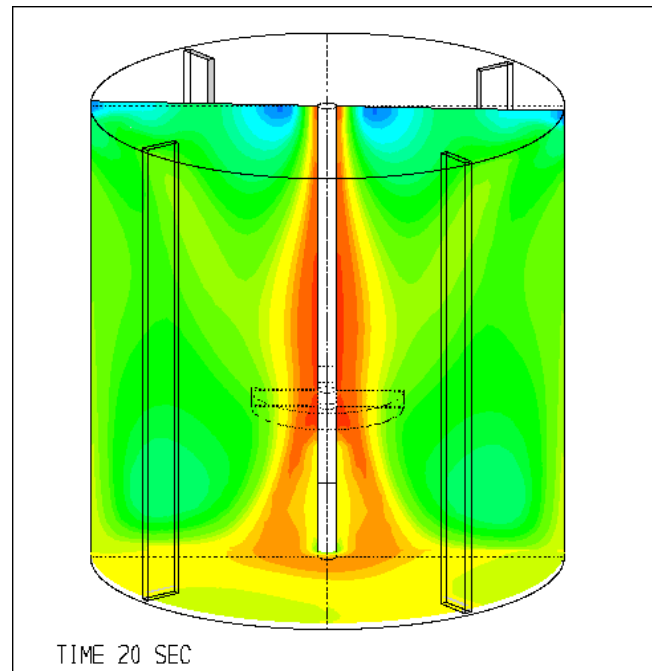
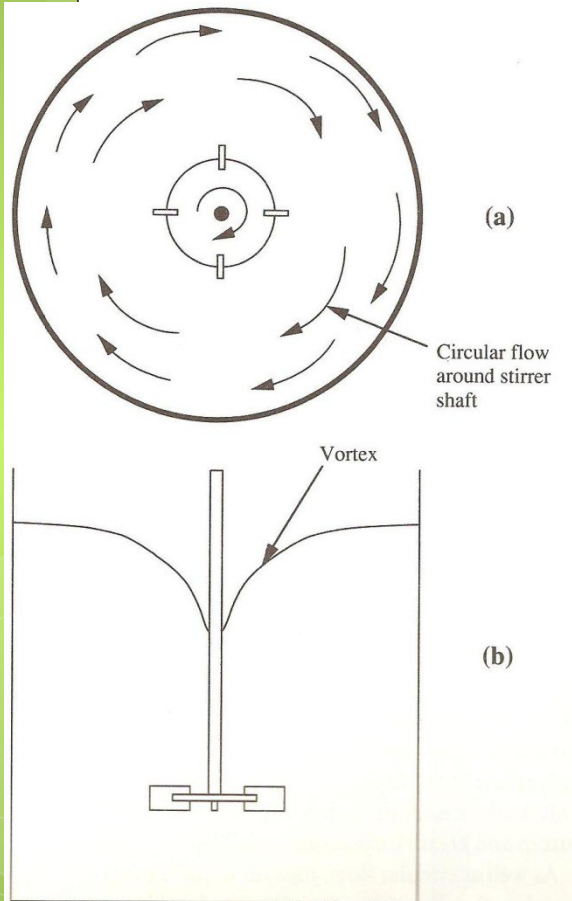


Narcissus



Intermig

PREGRADE



preprečujejo tvorbo lijaka

Figure 7.14 Baffle arrangements. (a) Baffles attached to the tank wall for low-viscosity liquids. (b) Baffles set away from the wall for moderate-viscosity liquids. (c) Baffles set away from the wall and at an angle for high-viscosity liquids. (F. Holland and F.S. Chapman, 1966, *Liquid Mixing and Processing in Stirred Tanks*, Reinhold, New York.)

NAČRTOVANJE MEŠANJA

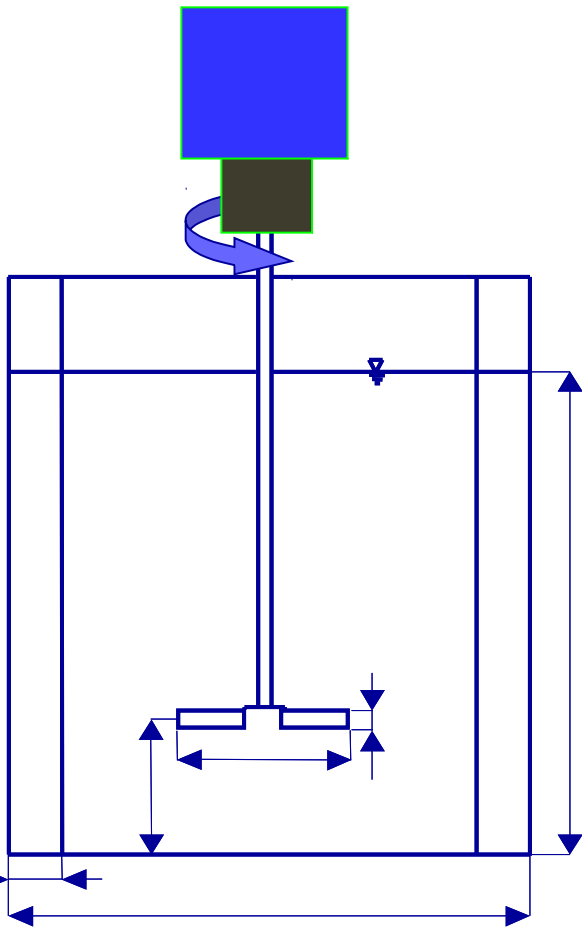
- izbor ustreznega mešala
- pogoji mešanja:
 - majhna poraba energije za učinkovito mešanje

$$E = P \cdot t_m$$

moč za mešanje

čas pomešanja

Mešanje



Glede na agregatna stanja

S stališča moči

Časov pomešanja

Tokovni modeli

Mehansko mešanje:

Zunanja sila premaguje napetosti v sami kapljevini

$$P = M \cdot \omega = (F \cdot R) \cdot (2 \cdot \pi \cdot N)$$

P: moč (W)

M: navor ($\text{kgm}^2/\text{s}^2 = \text{Nm}$)

ω : kotna hitrost (s^{-1})

N: vrtilna hitrost mešala (s^{-1})

F: sila (N)

R: ročica (m)

VNOS MOČI V BIOREAKTORJIH Z MEŠALOM

- neprezračevan sistem:

$$P = P_o \rho N^3 D^5$$

gravitacijske sile

ŠTEVILO MOČI: $P_o = f(Re, Fr, We)$

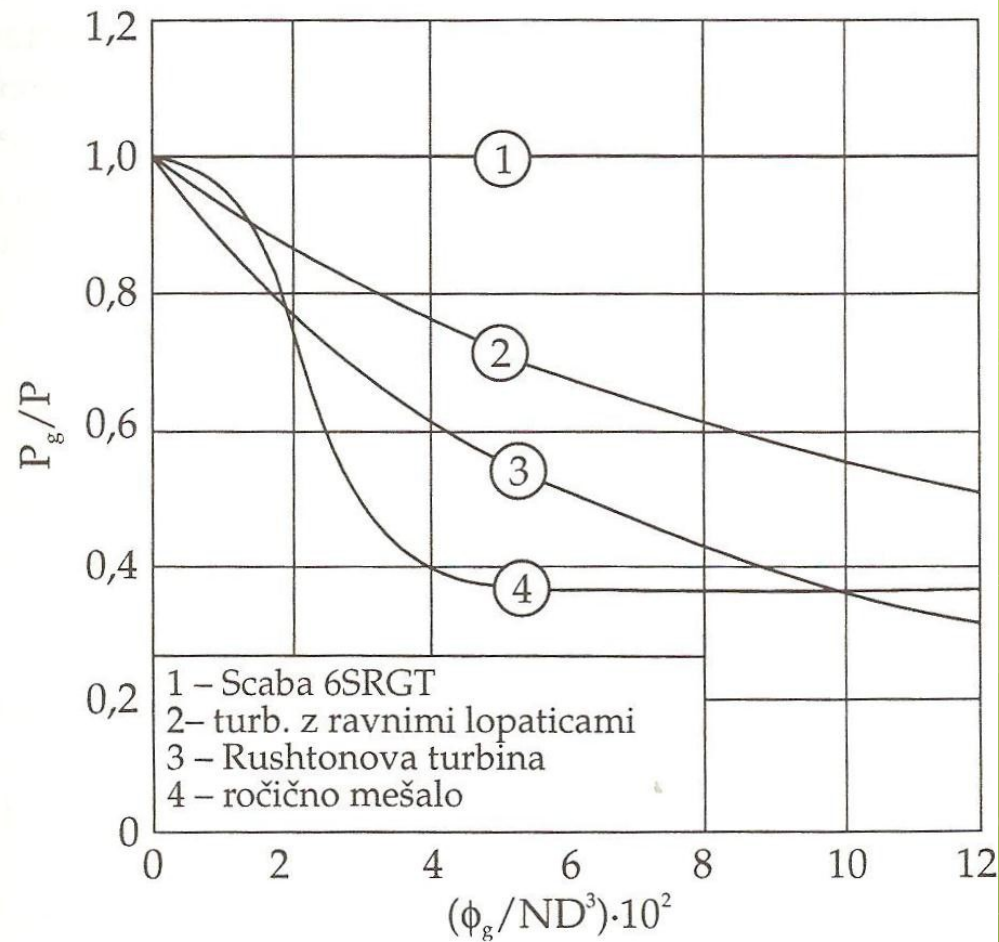
površinske sile

pregrade, enofazni sistem: $P_o = f(Re)$

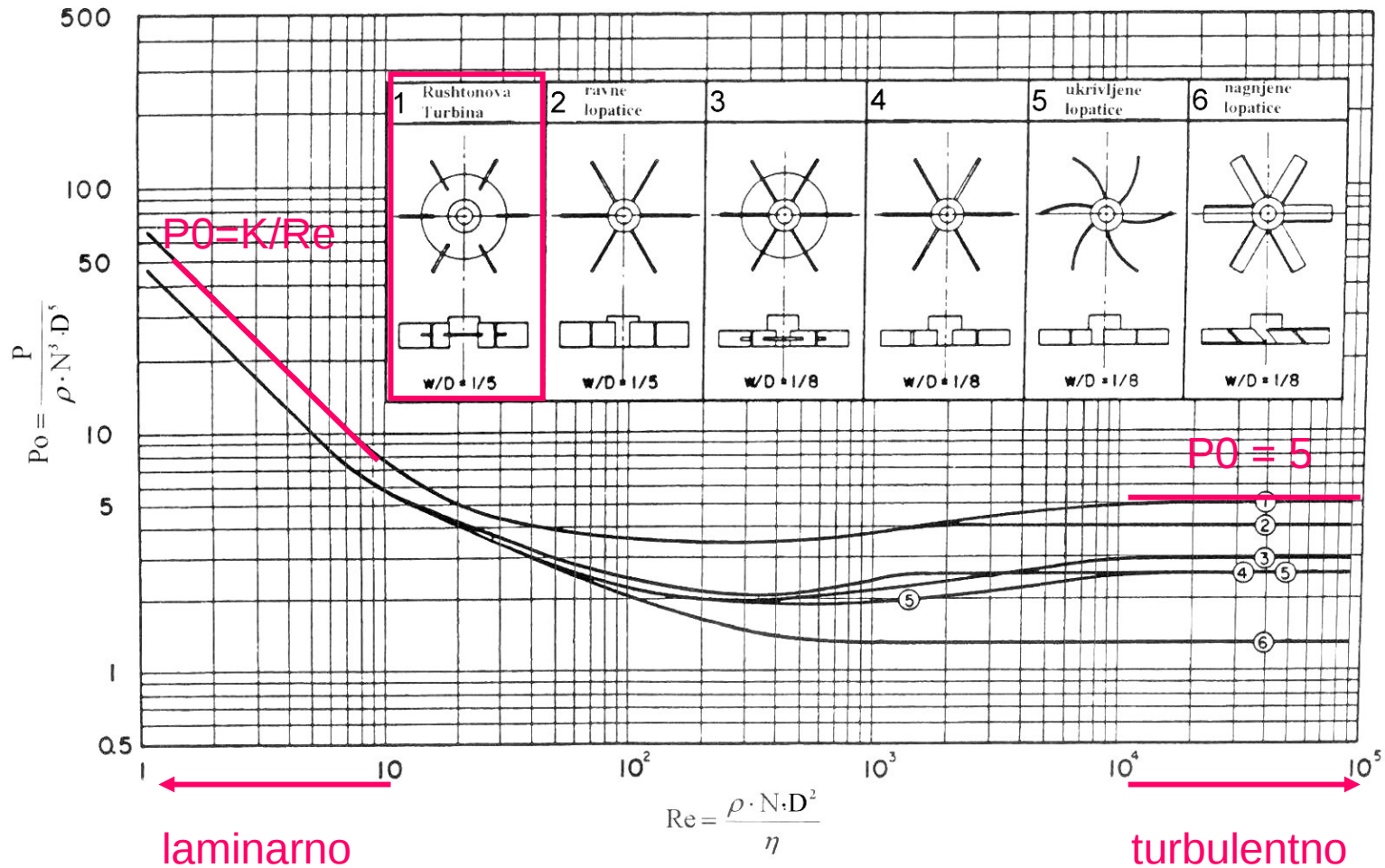
VNOS MOČI V BIOREAKTORJIH Z MEŠALOM

- Prezračevan sistem

$$Pg = K \left(\frac{P^2 ND^5}{\phi_g^{0.56}} \right)^{0.45}$$



FUNKCIJA MOČI $P_0 = f(Re)$



ČAS POMEŠANJA t_m

- čas, ki je potreben, da dosežemo določeno stopnjo homogenosti
- odvisen od naših zahtev pomešanja in od natančnosti določitve homogenosti medija
- lokalna nehomogenost:

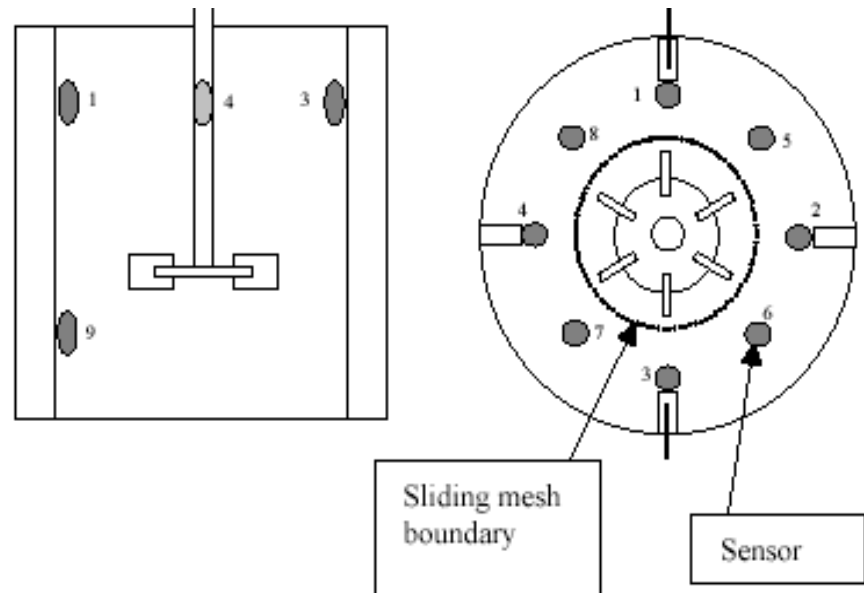
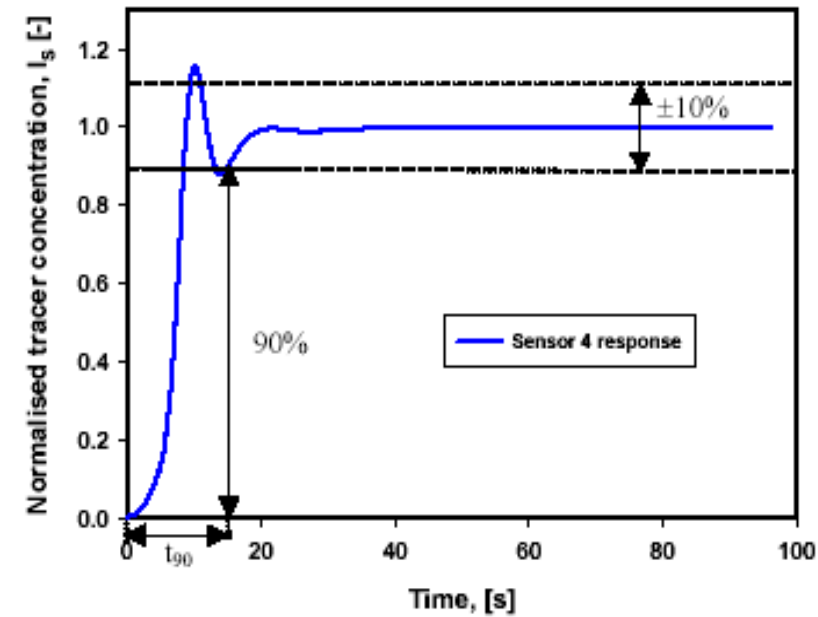
$$i = \left| \frac{C_{\infty} - C(t)}{C_{\infty} - C_0} \right|$$

$t = 0$: največja nehomogenost, $i = 1$

$t = \infty$: doseženo ravnotežje, $i = 0$

Čase pomešanja običajno določimo pri 90-99% homogenosti
($0,1 \geq i \geq 0,01$)

DOLOČANJE t_m

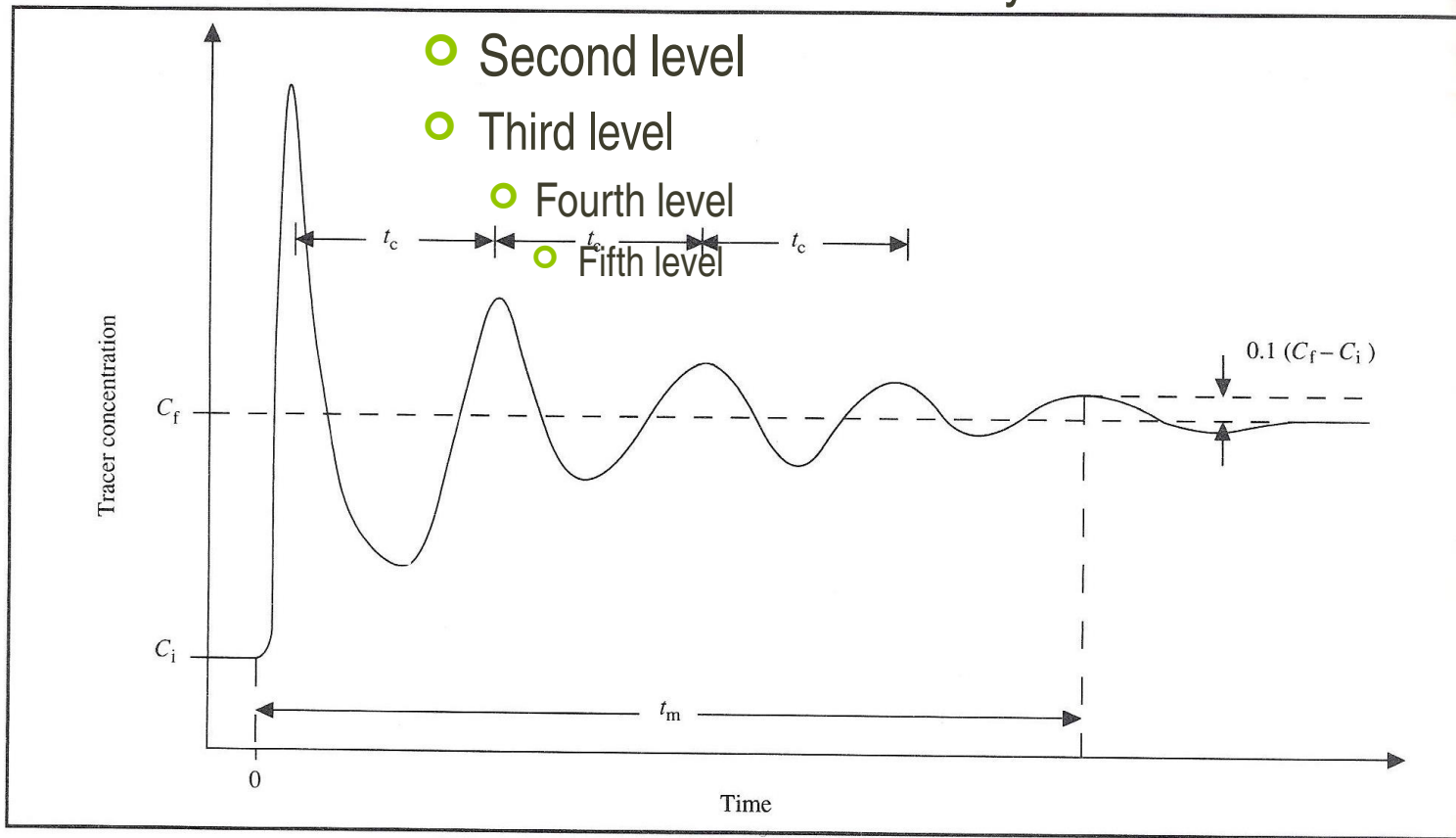


$i = 0,1$ (90% homogenost)

t_m odvisen od mesta vnosa sledilca in lokacije senzorja

DOLOČANJE t_m

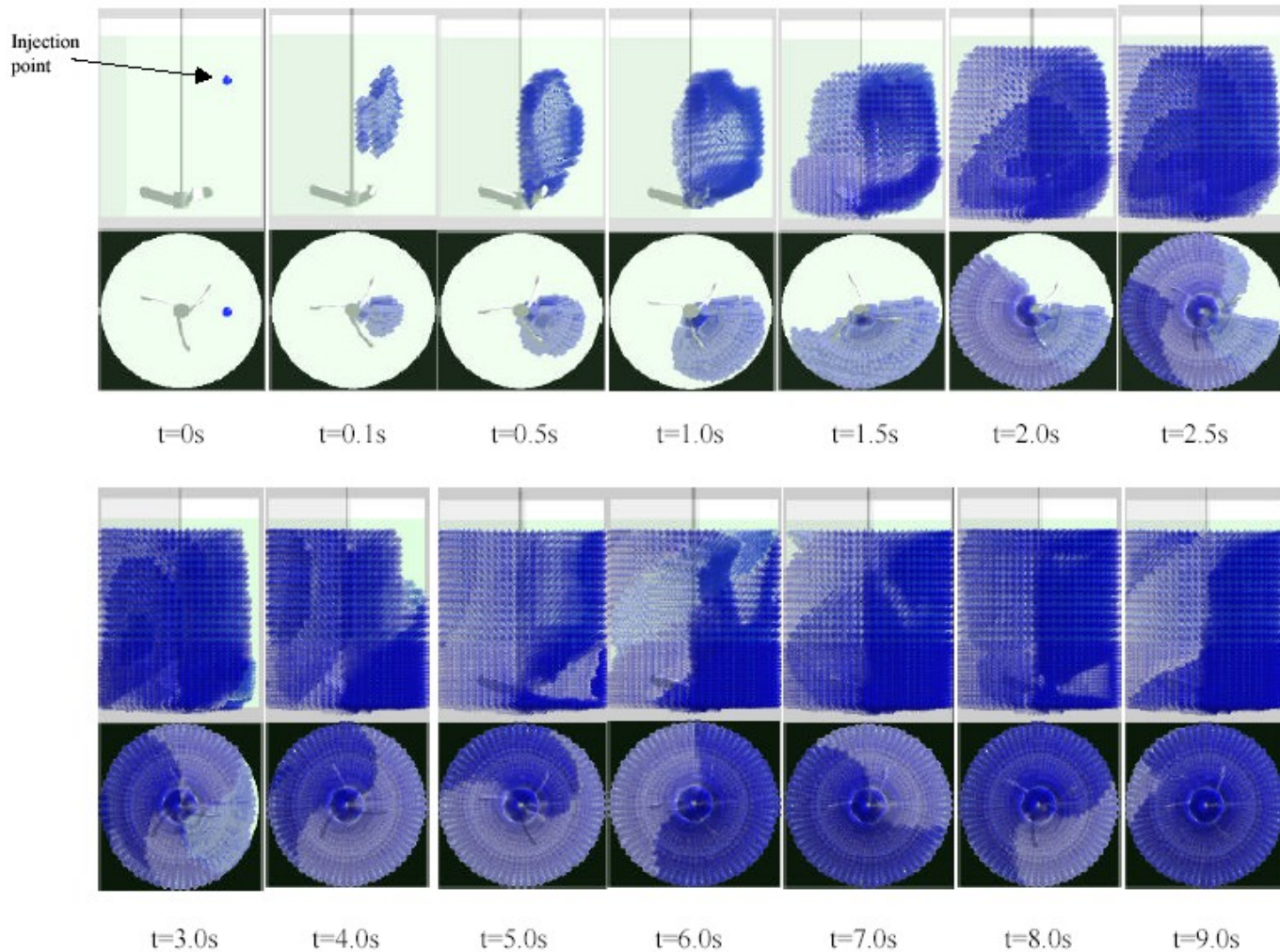
Figure 7.22 Concentration response after dye is injected into a stream tank.



METODE DOLOČANJA t_m

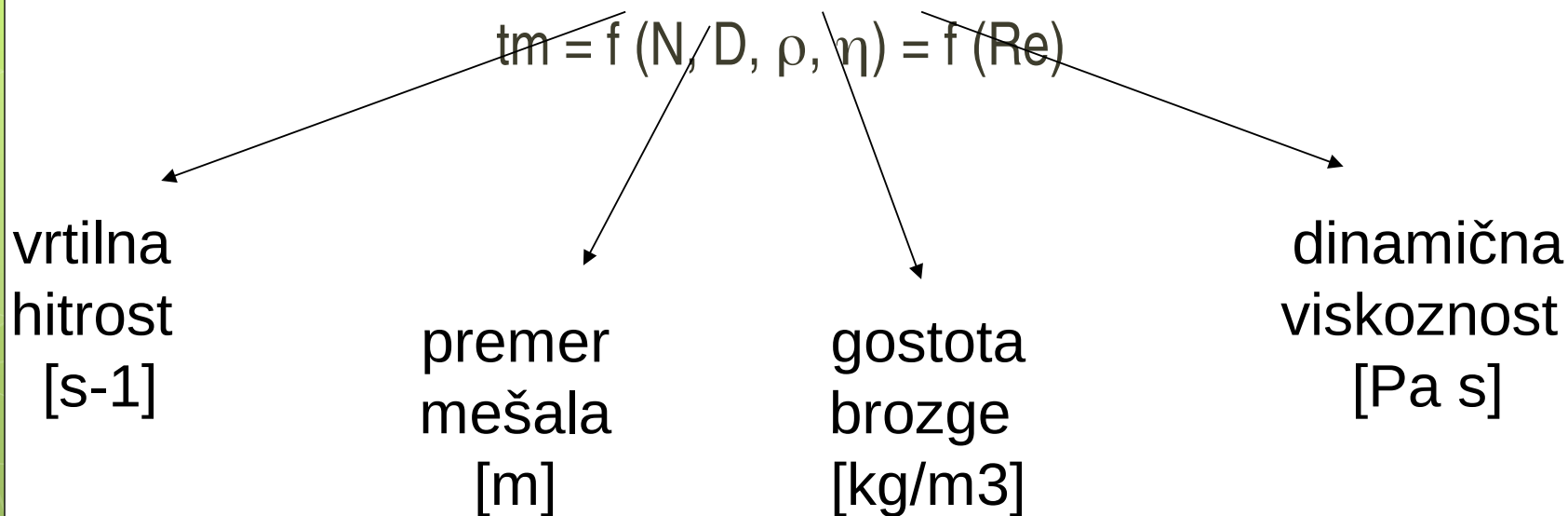
- električna prevodnost
- pH
- temperatura
- fluorescenca
- magnetne lastnosti
- radioaktivnost
- obarvanje ali razbarvanje tekočine
(omogoča vizualizacijo mirujočih con)

DOLOČANJE t_m



ČAS POMEŠANJA t_m

- odvisen od velikosti in geometrije sistema, intezivnosti mešanja in lastnosti brozge



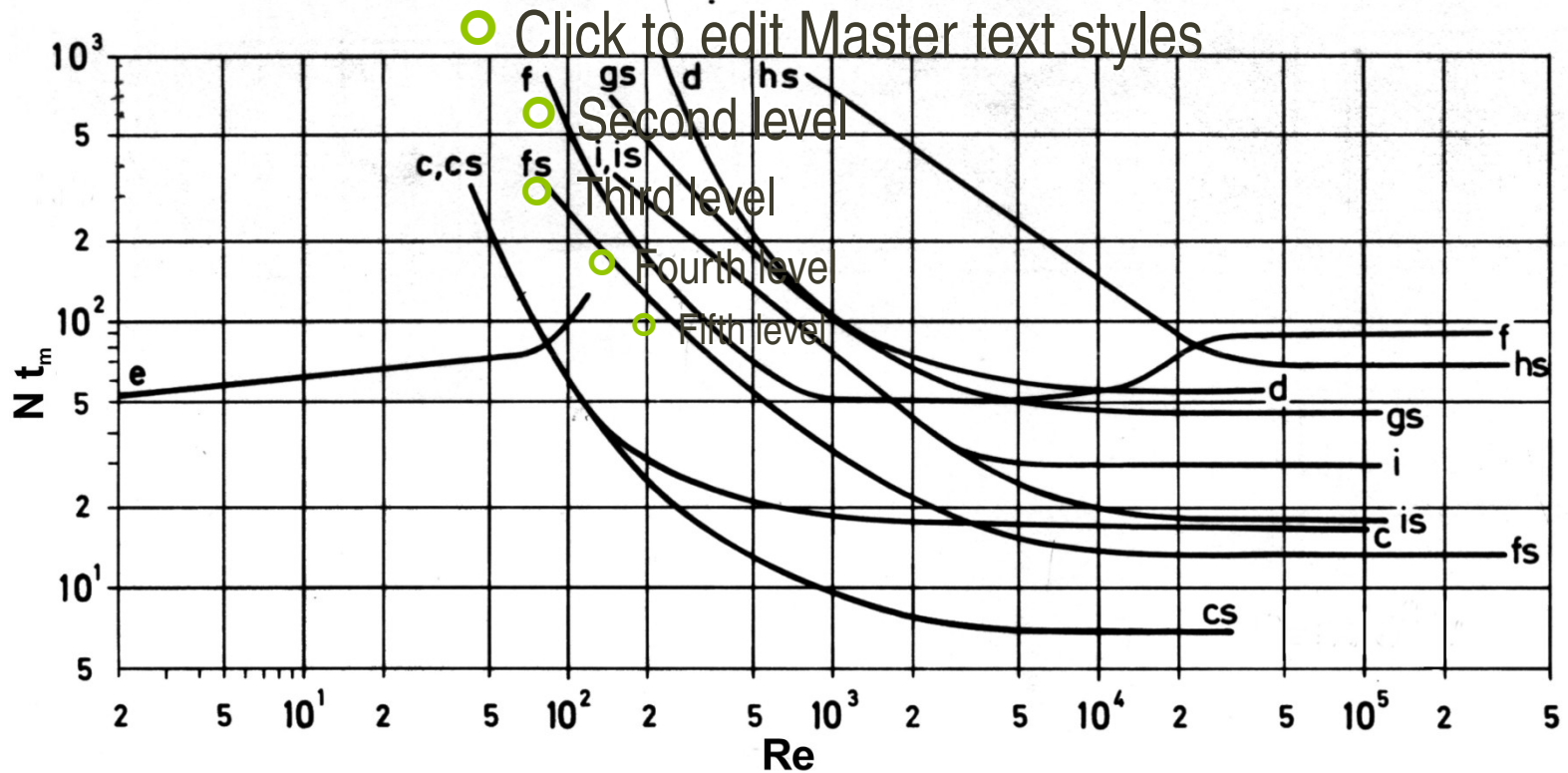
Brezdimenzijski čas pomešanja

- Produkt časa pomešanja in vrtilne hitrosti mešala:

$$N \cdot t_m$$

- V turbulentnem območju konstanten in neodvisen od velikosti reaktorja
 - laminarni tok: $Re \leq 1$
 - turbulentni tok: $Re > 104$
 - prehodno območje: $10 < Re < 104$

Brezdimenzijski čas pomešanja

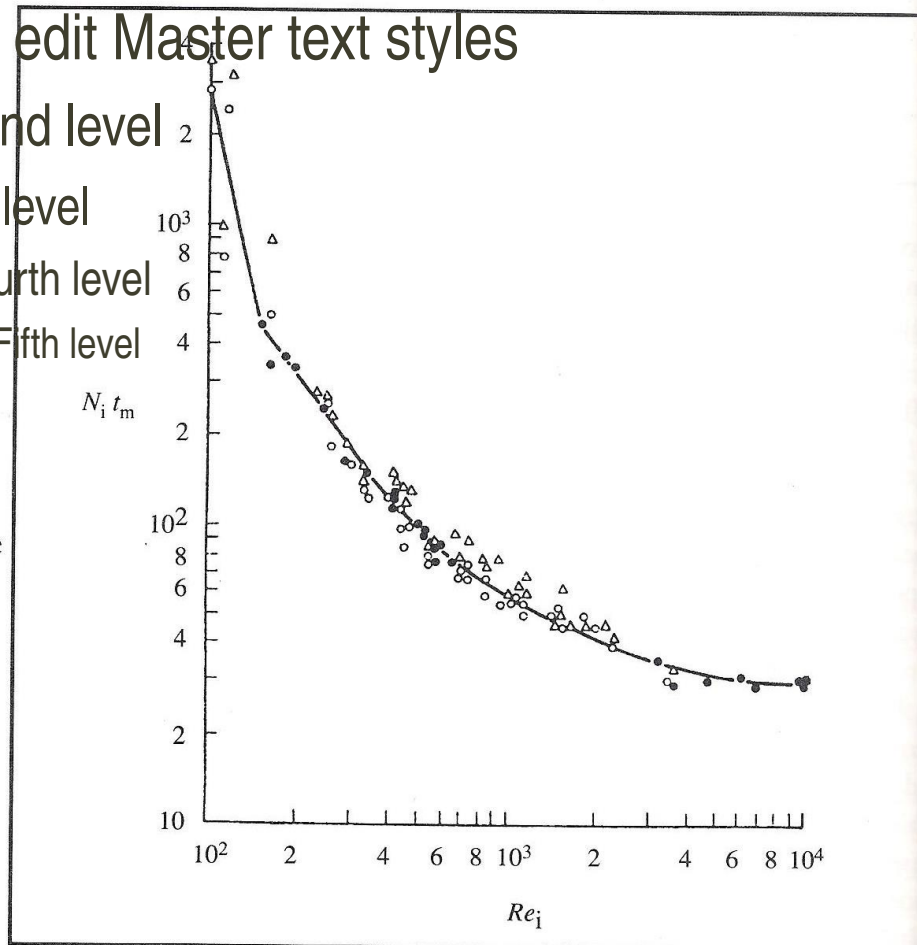


hs – propelersko m. gs – turbinsko m. c, cs – lopatasto m. e – tračno m.
 i, is – impelersko m. d – sidrno m. f, fs – protitočno (MIG) mešalo

Brezdimenzijski čas pomešanja

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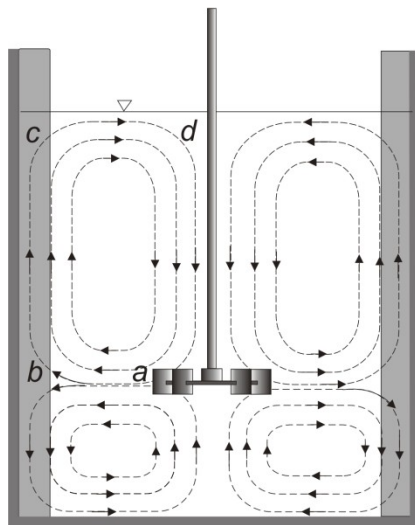
Figure 7.23 Variation of mixing time with Reynolds number for a six-blade Rushton turbine in a baffled tank. The impeller is located one-third the tank diameter off the floor of the vessel; the impeller diameter is one-third the tank diameter. The liquid height is equal to the tank diameter; the tank has four baffles of width one-tenth the tank diameter. Several measurement techniques and tank sizes were used: (●) thermal method, 1.8-m diameter vessel; (○) thermal method, 0.24-m vessel; (△) decoloration method, 0.24-m vessel. (Reprinted from C.J. Hoogendoorn and A.P. den Hartog, Model studies on mixers in the viscous flow region, *Chem. Eng. Sci.* 22, 1689–1699. Copyright 1967, with permission from Pergamon Press Ltd, Oxford.)



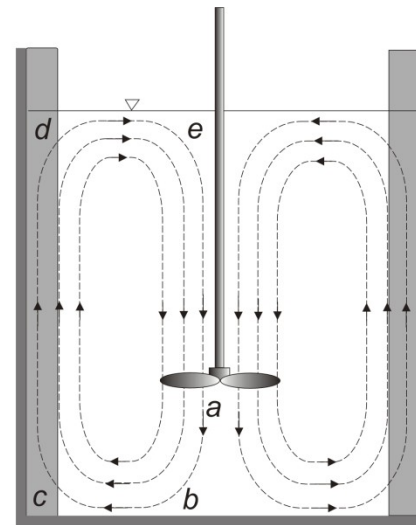
OCENE ČASA POMEŠANJA

- Iz teorije kroženja tekočine (velja le v turbulentnem območju)
 - tcir sorazmeren najdaljši poti kroženja

Rushtonova
turbina



propeler



- tcir obratno sorazmeren v_{cir} in torej $N \cdot D$
- $t_m = 5 t_{cir}$

OCENE ČASA POMEŠANJA

- Korelacije:

- za Rushtonovo turbino:
$$N t_m = 1,88 \left(\frac{H + T}{T} \right) \left(\frac{T}{D} \right)^{\frac{13}{6}}$$

- za propeler z usmerjanjem toka navzdol:
$$N t_m = 6,0 \left(\frac{2H}{D} + \frac{T}{D} \right) \left(\frac{H_m}{D} \right)$$