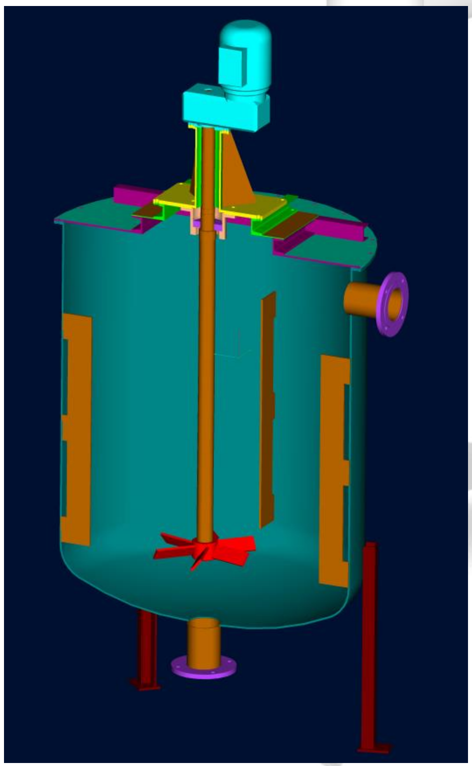
AGITATION AND MIXING OF FLUIDS

Purpose of agitation:

- intensification of transport processes in agitated batch (heat and mass transfer)
- preparation of materials of required properties (suspension, emulsion)

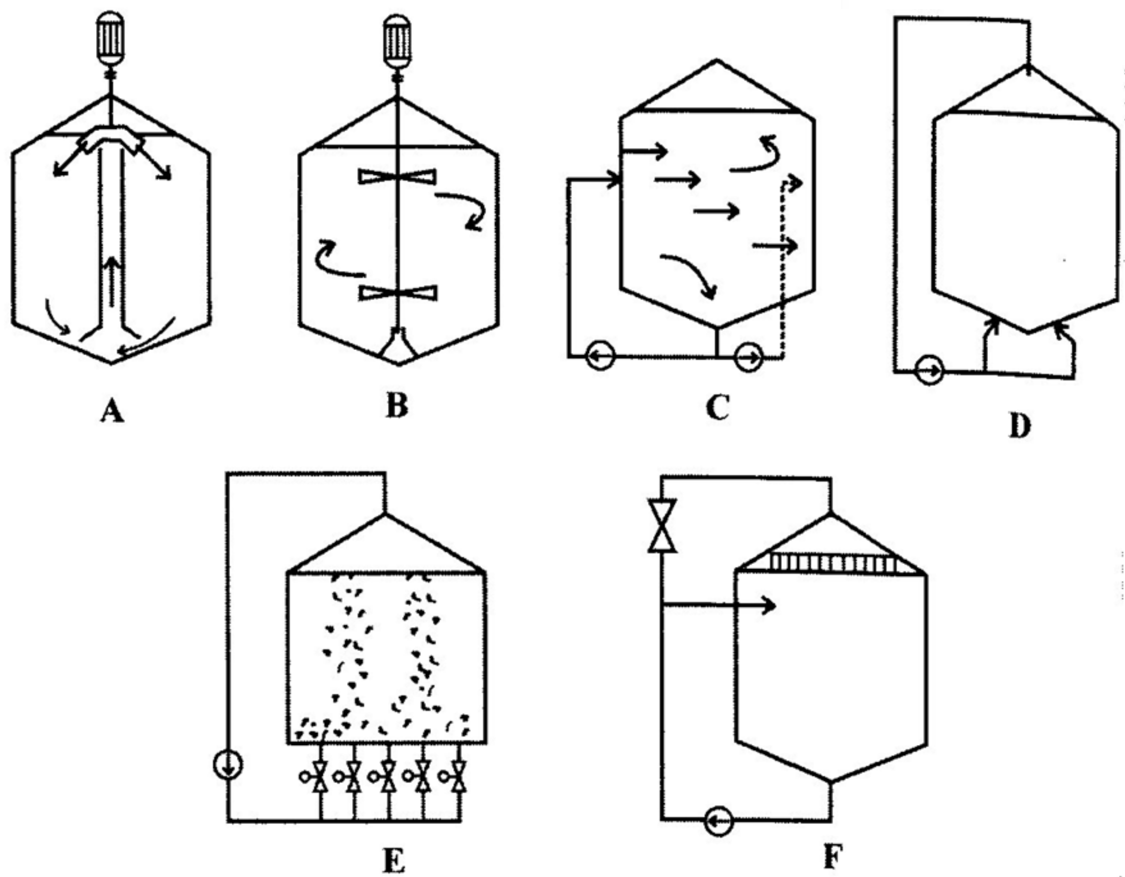


Examples of industrial applications:

- blending of two miscible liquids as ethyl alcohol and water
- dissolving solids in liquids, such as salt in water
- dispersing a gas in a liquid as fine bubbles, such as oxygen from air in a suspension of microorganisms for fermentation or for the activated sludge process in waste treatment
- liquid-liquid dispersion, such as dispersion of pigment in solvents
- suspending of fine solid particles in a liquid, as in catalytic hydrogenation of a liquid
- agitation of the fluid to increase heat tranfer between the fluid and a coil or jacket in the vessel wall

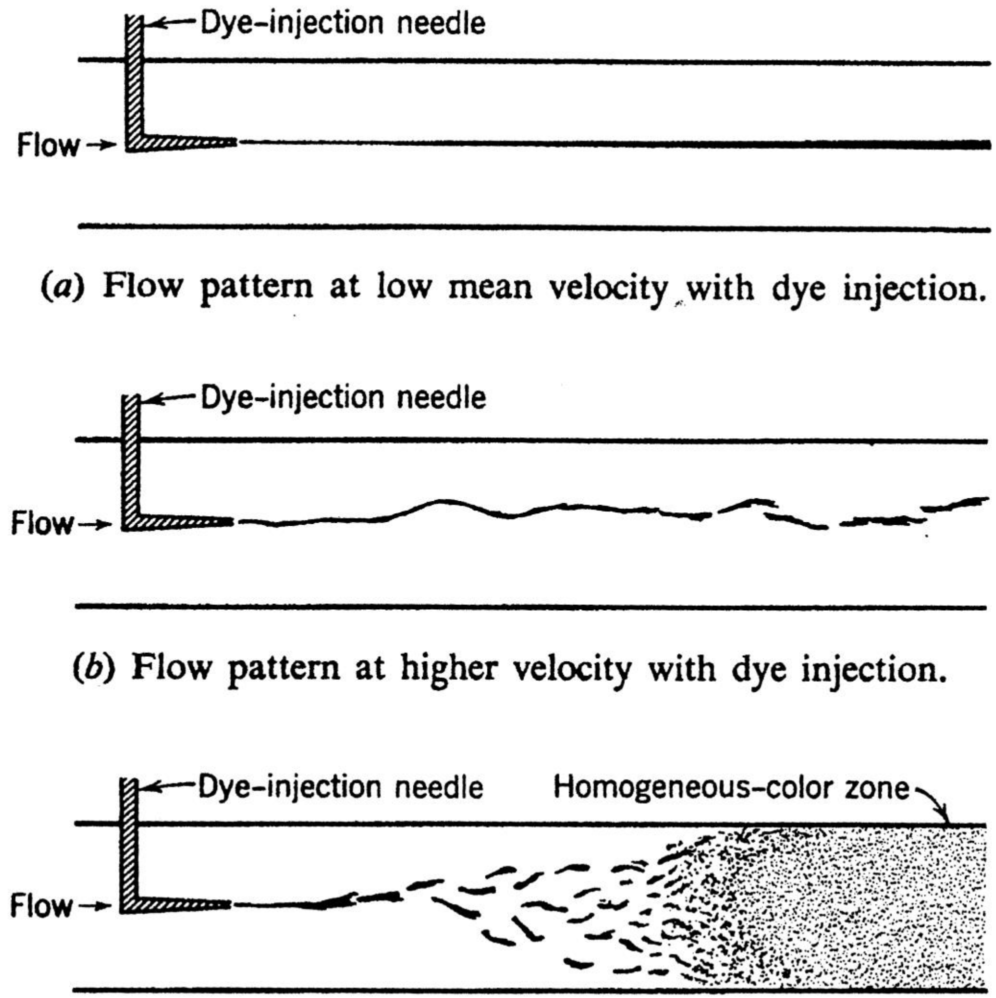
Method of mixing fluids

- **mechanical mixing** (rotating, vibrating)
- hydraulic mixing
- pneumatic mixing
- **pipeline mixing** (turbulent flow, static mixer)



A – mechanical mixing using turbines
B – mechanical mixing using blade impellers
C – hydraulic mixing
D – pneumatic mixing with stationary inputs
E – pneumatic mixing with automatic regulation
F – hydraulic mixing with antifoaming shower

Pipeline mixing – Reynolds experiments

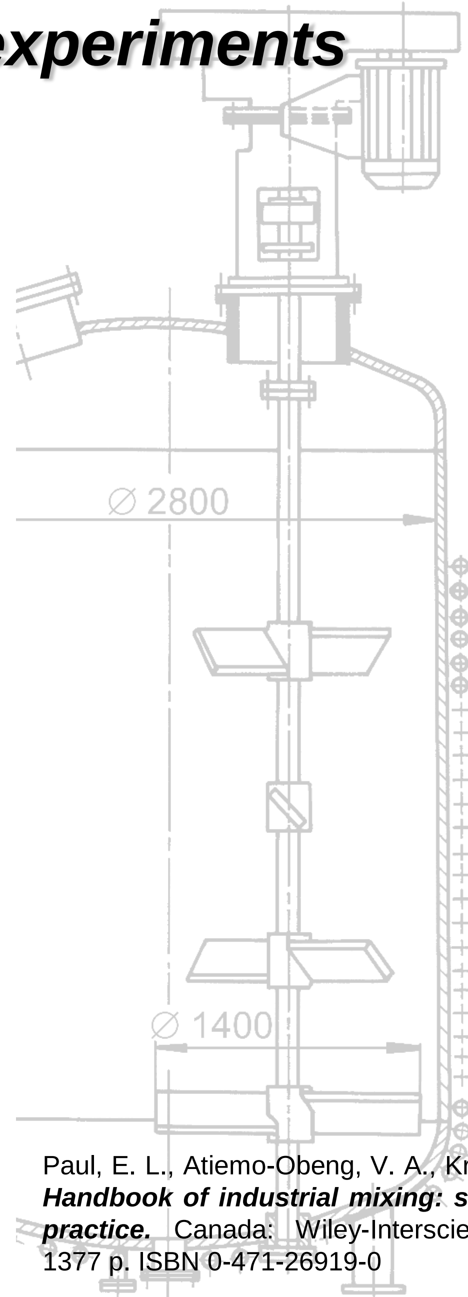


(*a*) Flow pattern at low mean velocity with dye injection.

(*b*) Flow pattern at higher velocity with dye injection.

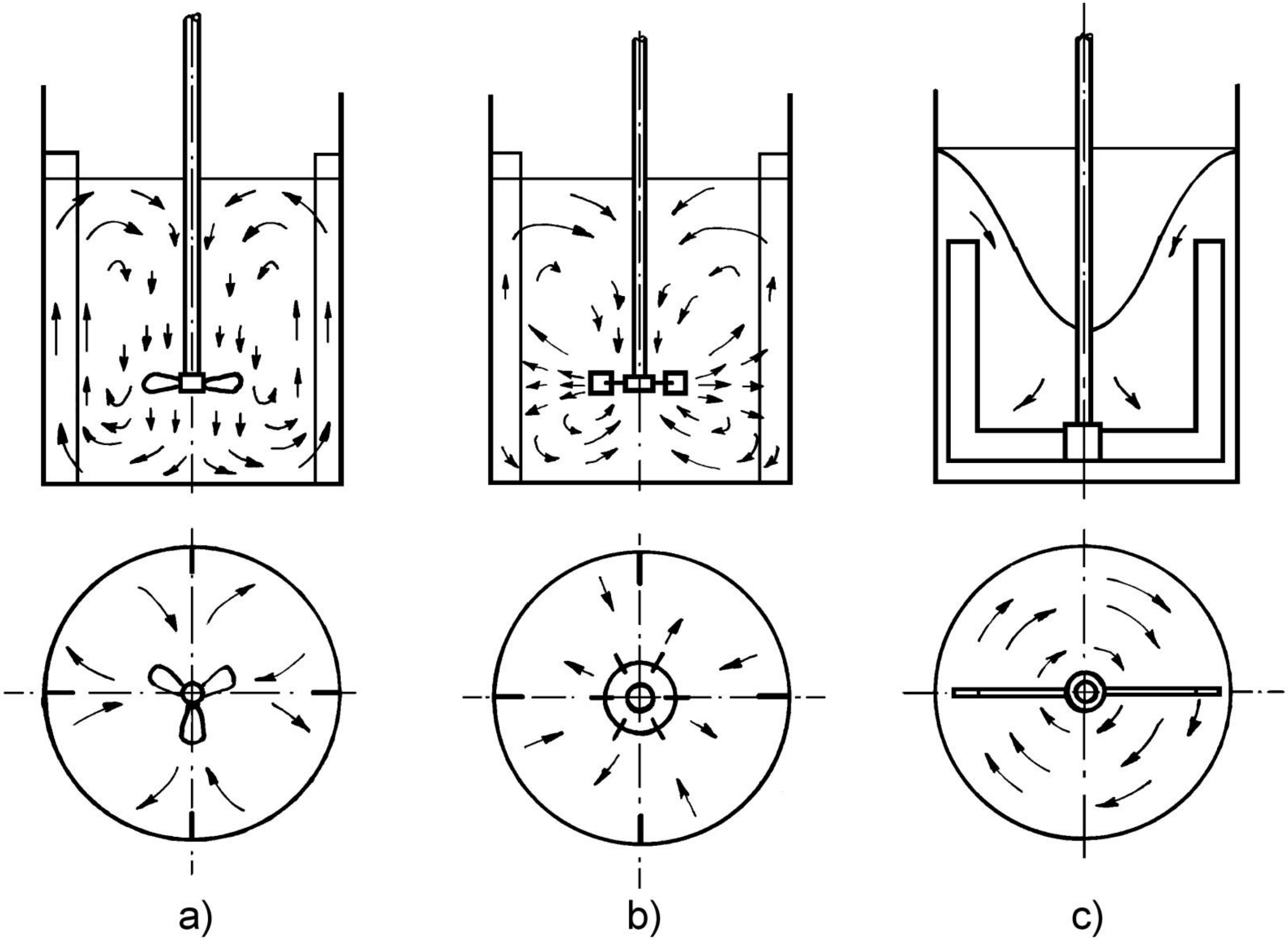
(*c*) Flow pattern at high velocity with dye injection.

Figure 7-1 Reynolds experiments.



Paul, E. L., Atiemo-Obeng, V. A., Kresta, S. M.: ***Handbook of industrial mixing: science and practice.*** Canada: Wiley-Interscience, 2003, 1377 p. ISBN 0-471-26919-0

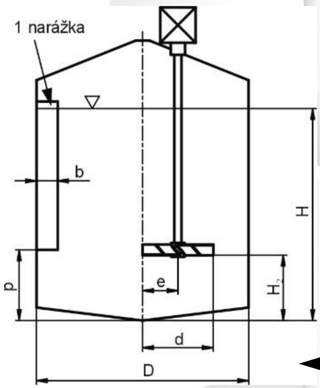
Flow in agitated batch

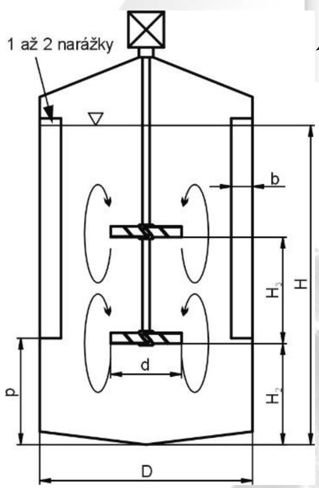


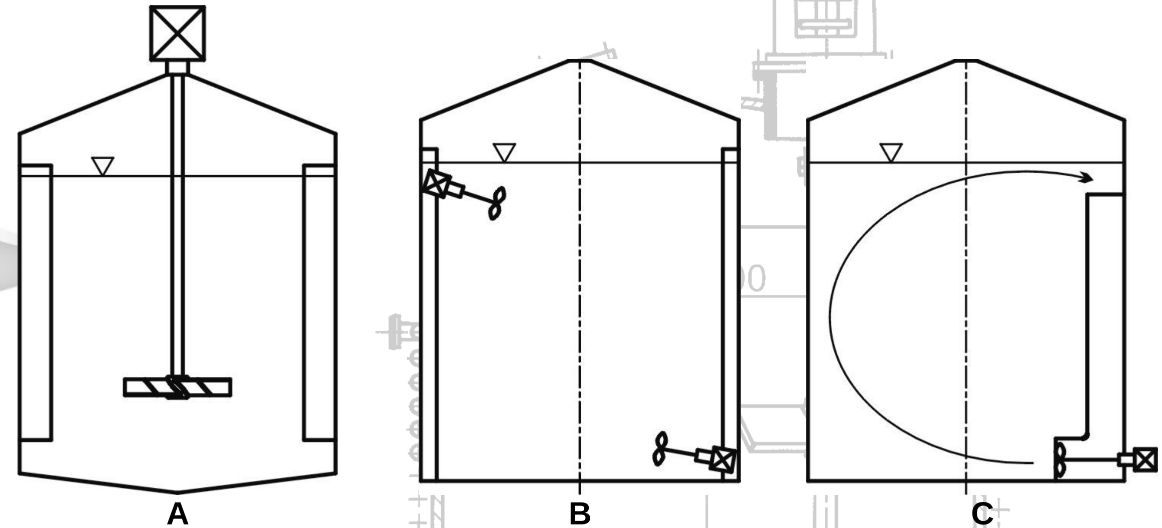
a *– axial-flow pattern, baffled vessel,* ***b*** *– radial-flow pattern, baffled vessel,*
c *– tangential-flow pattern, unbaffled vessel*

Equipment for mechanical mixing

Design layout of mixing equipments

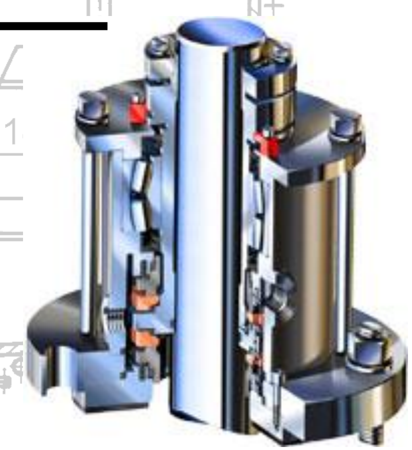


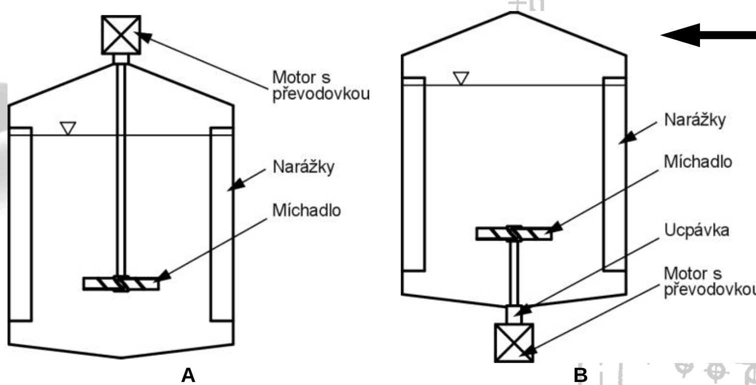




A *– Centrally placed impeller in bafled vessel,* ***B*** *– Side-entring propeller,* ***C*** *– Agitator with draught tube*

Mechanical seal

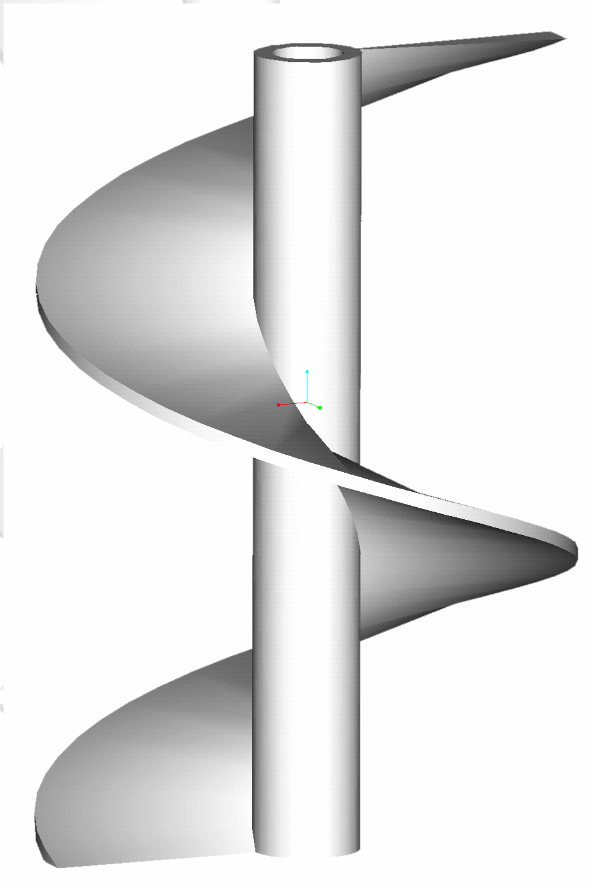




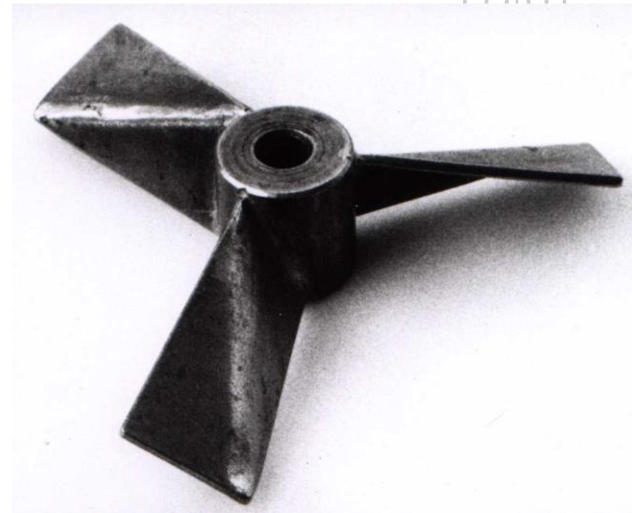
A *– Equipment with a drive at the top,* ***B*** *– Equipment with a drive at the bottom*

Design layout of agitators

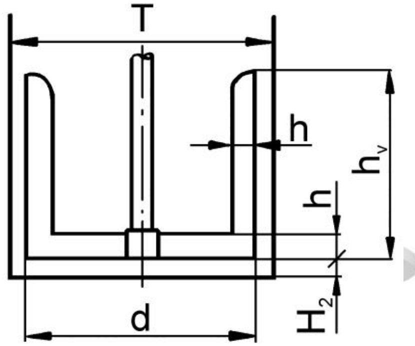
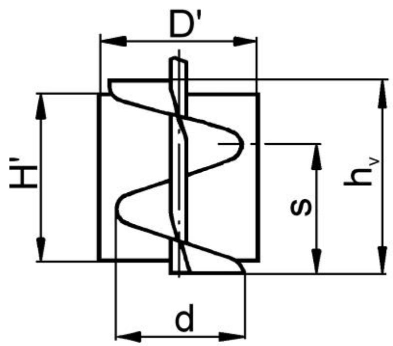
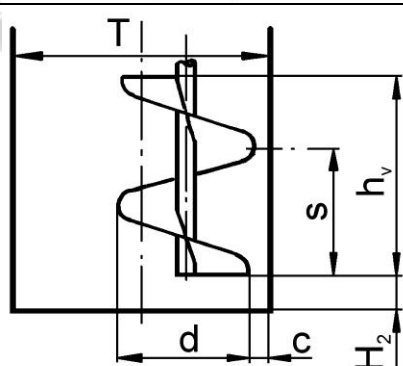
Close clearance agitator

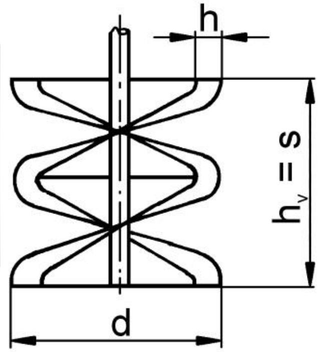
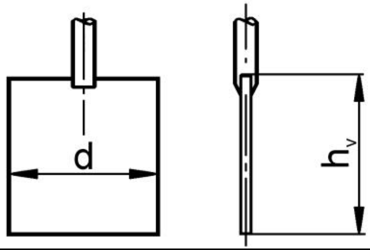
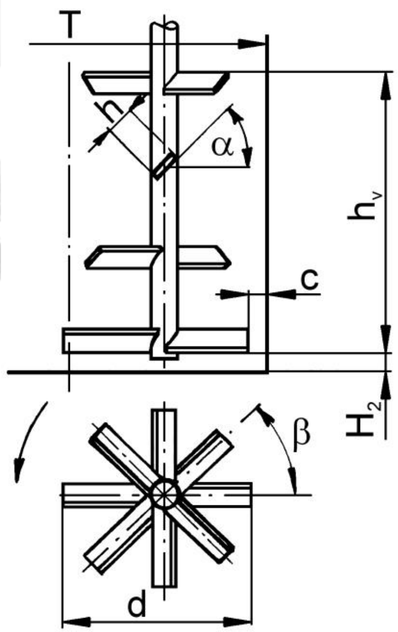


High-speed impeller

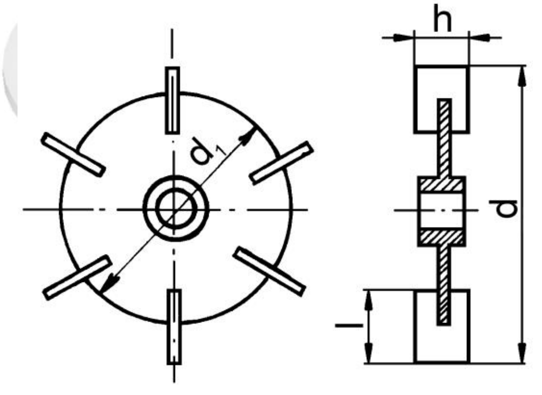
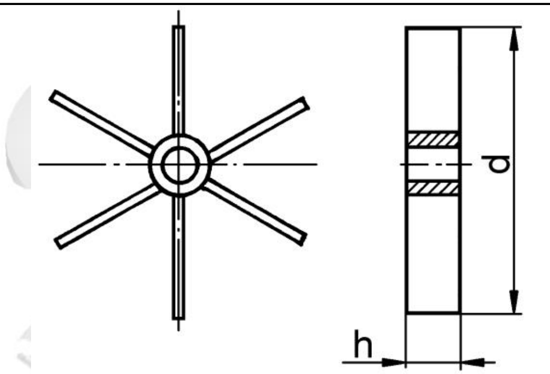
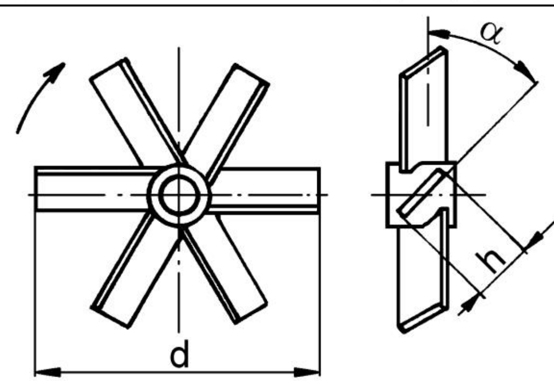


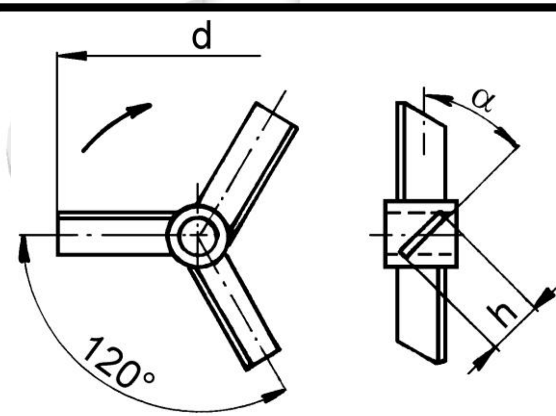
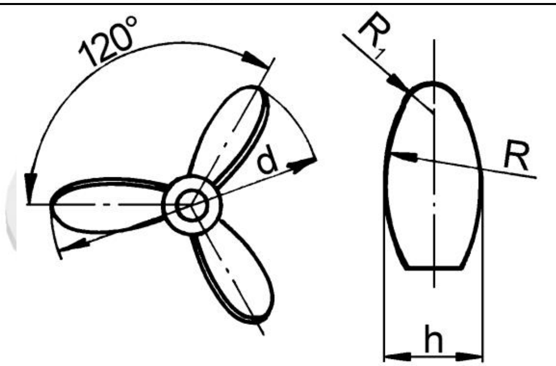
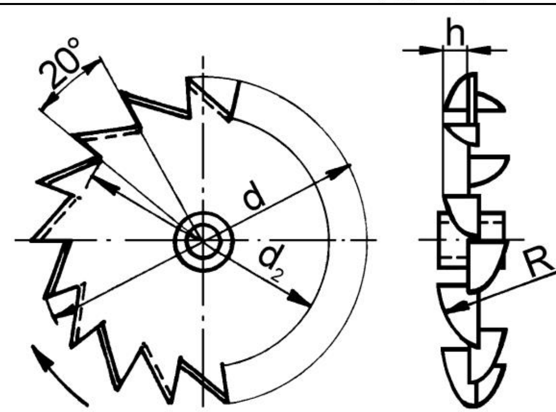
Maine type of close clearance agitators

No.	***Layout of agitator***	***Name***	***T/d***	***Geometrical parameters***
1		Anchor (paddle) agitator CVS 69 1014	1,11	$h_v / d = 0{,}8$ $h / d = 0{,}12$ $H_2 / d = 0{,}055$
2		Helical-screw agitator with draught tube CVS 69 1028	2	$h_v / d = 1{,}5$ $s / d = 1$ $D' / d = 1{,}1$ $H' / D' = 1{,}15$
3		Eccentrically placed helical-screw agitator	2	$h_v / d = 1{,}5$ $H_2 / d = 0{,}25$ $s / d = 1$ $c / T = 0{,}02$

No.	Layout of agitator	Name	T/d	Geometrical parameters
4		Helical-ribbon agitator CVS 69 1029	1,05	$h_v / d = 1$ $s / d = 1$ $h / d = 0{,}1$
5		Leaf agitator CVS 69 1016	2	$h / d = 1$
6		Multi-stage agitator	2	$h / d = 0{,}2$ $h_v / d = 1{,}65$ $\alpha = 45°$ $\beta = 45°$ $c / T = 0{,}02$ $H_2 / d = 0{,}175$

Main type of high-speed impellers

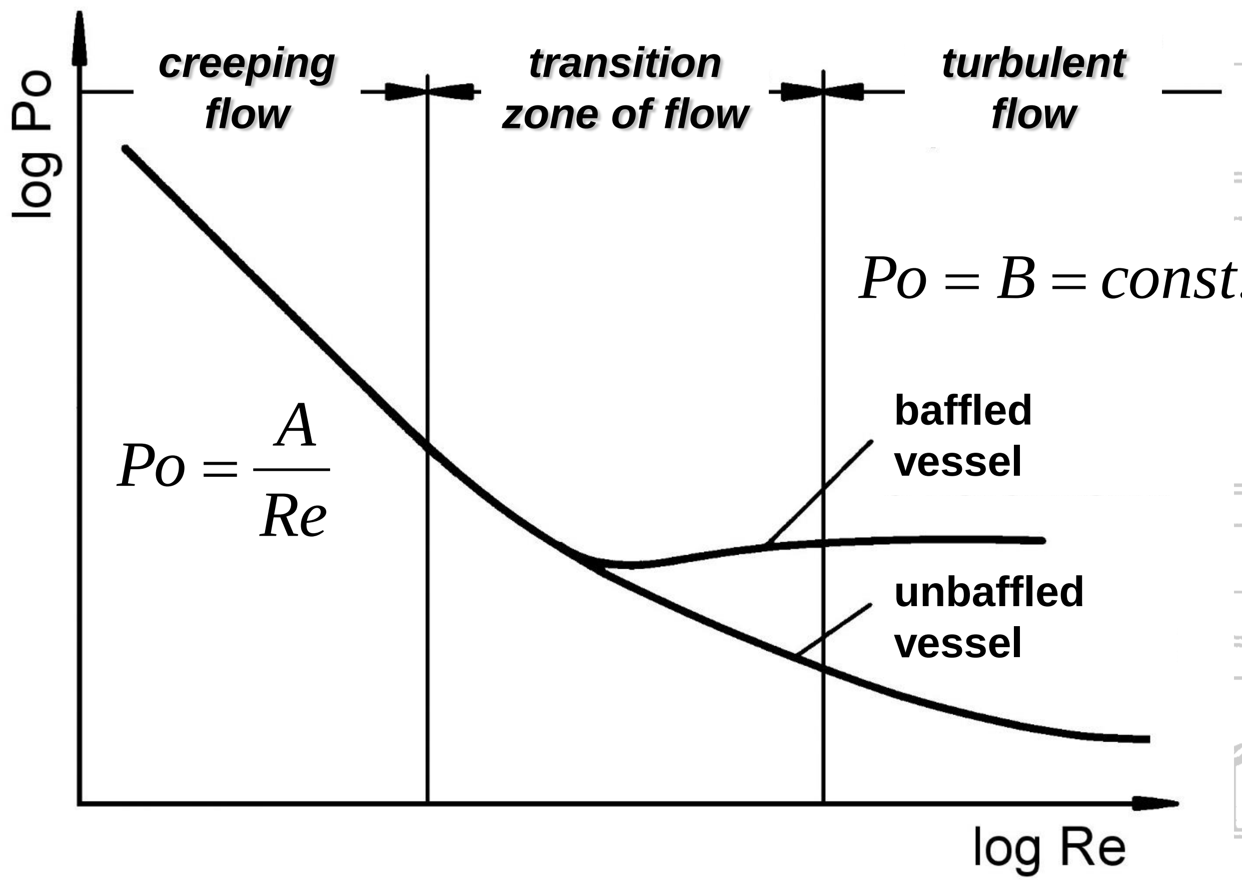
No.	Layout of impeller	Name	T/d	Geometrical parameters
1		Six-blade turbine with disk (Ruschton turbine) CVS 69 1021	$3 \div 4$	$h/d = 0,2$ $l/d = 0,25$ $d_1/d = 0,75$ 6 blades
2		Six-blade open turbine	$3 \div 4$	$h/d = 0,2$ 6 blades
3		Pitched six-blade turbine with pitch angle 45 CVS 69 1020	$3 \div 4$	$h/d = 0,20$ $\alpha = 45°$

No.	Layout of impeller	Name	T/d	Geometrical parameters
4		Pitched three-blade turbine with pitch angle 45° CVS 69 1025.3	3 ÷ 4	$h/d = 0,2$ $\alpha = 45°$
5		Propeller CVS 69 1019	3 ÷ 4	$s/d = 1$ $h/d = 0,22$ $R/d = 0,4$ $R_1/R = 0,16$
6		High shear stress impeller CVS 69 1038.1, .2	2 ÷ 4	1st variant $h/d = 0,1$ $d_2/d = 0,8$ 2nd variant $h/d = 0,075$ $d_2/d = 0,85$

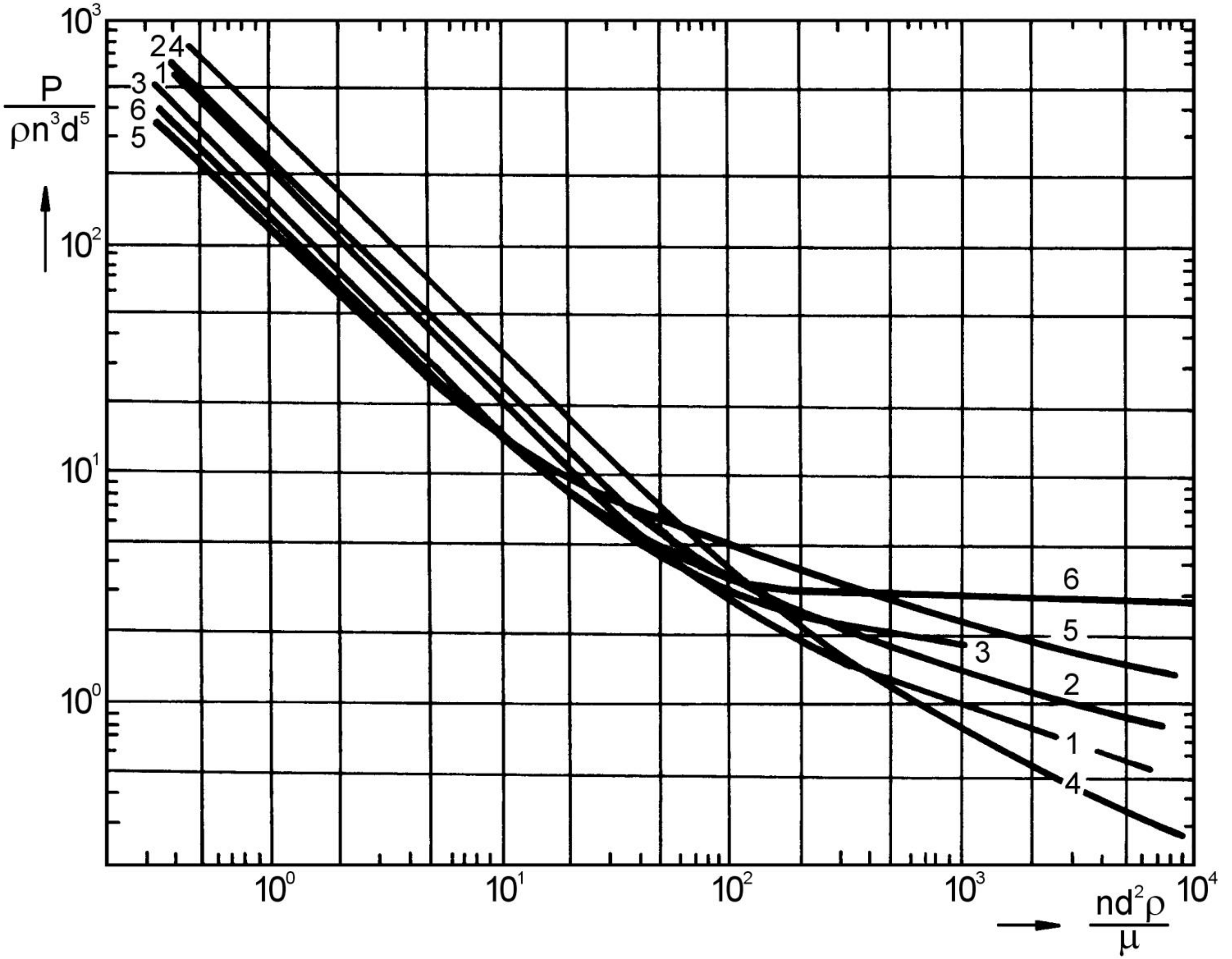
Characteristics of mixing system

Power consumption of agitator

$$Po = \frac{P}{\rho n^3 d^5} \longrightarrow \boxed{Po = f(Re)} \longleftarrow Re = \frac{n d^2 \rho}{\mu}$$

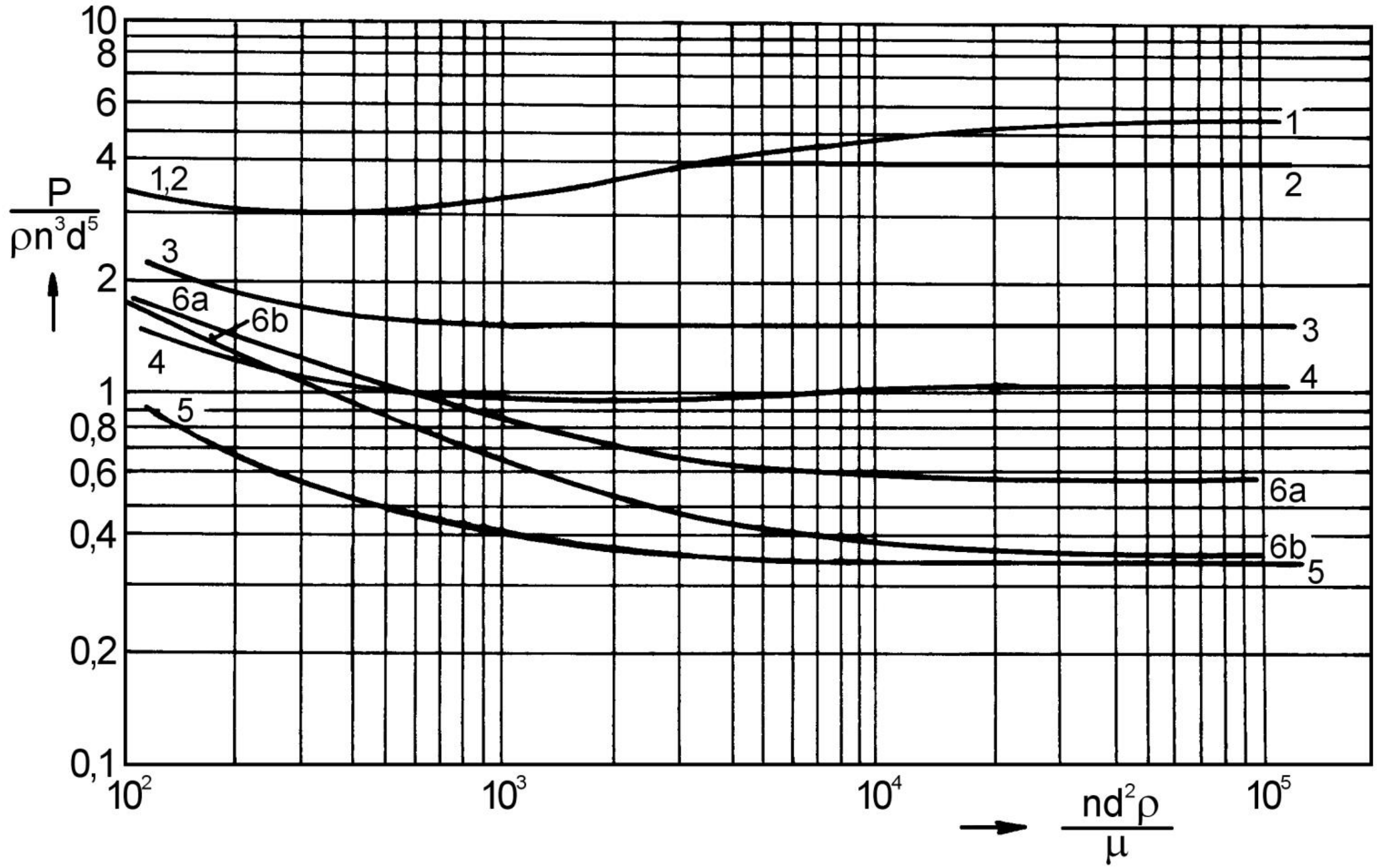


Power characteristics of close clearance agitators



***1** – anchor agitator (CVS 69 1014), **2** – helical-screw agitator with draught tube (CVS 69 1028), **3** – eccentrically placed helical-screw agitator, **4** – helical-ribbon agitator (CVS 69 1029), **5** – leaf agitator (CVS 60 1016), **6** – multi-stage agitator*

Power characteristics of high-speed impellers operated in baffled vessel



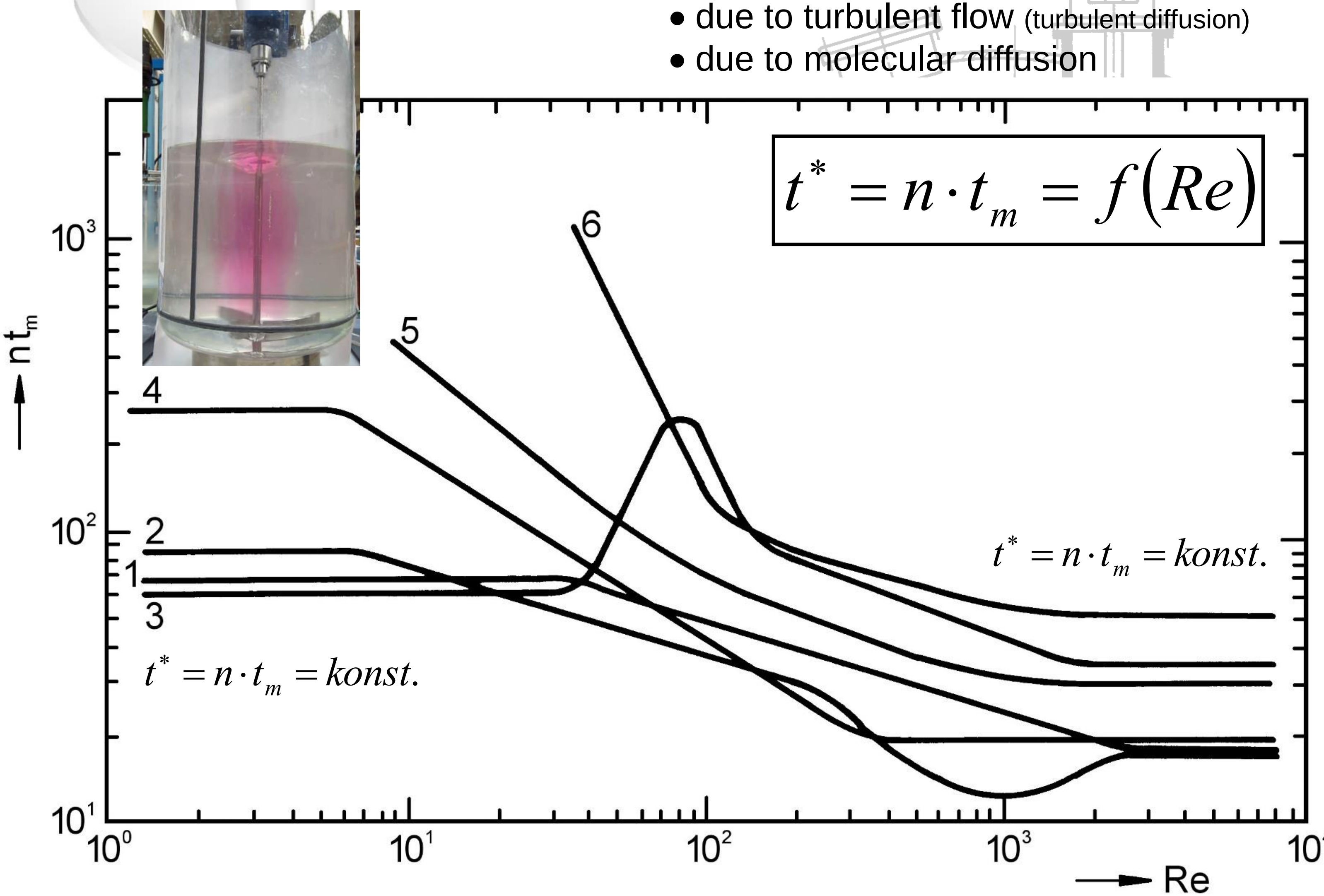
__1__ – six-blade turbine with disk (Ruschton turbine) (CVS 69 1021), __2__ – six-blade open turbine, __3__ – pitched six-blade turbine with pitch angle 45 (CVS 69 1020), __4__ – Pitched three-blade turbine with pitch angle 45° (CVS 69 1025.3), __5__ – propeller (CVS 60 1019), __6a,b__ – high shear stress impeller (CVS 69 1038.1.2)

Blending effect of agitator

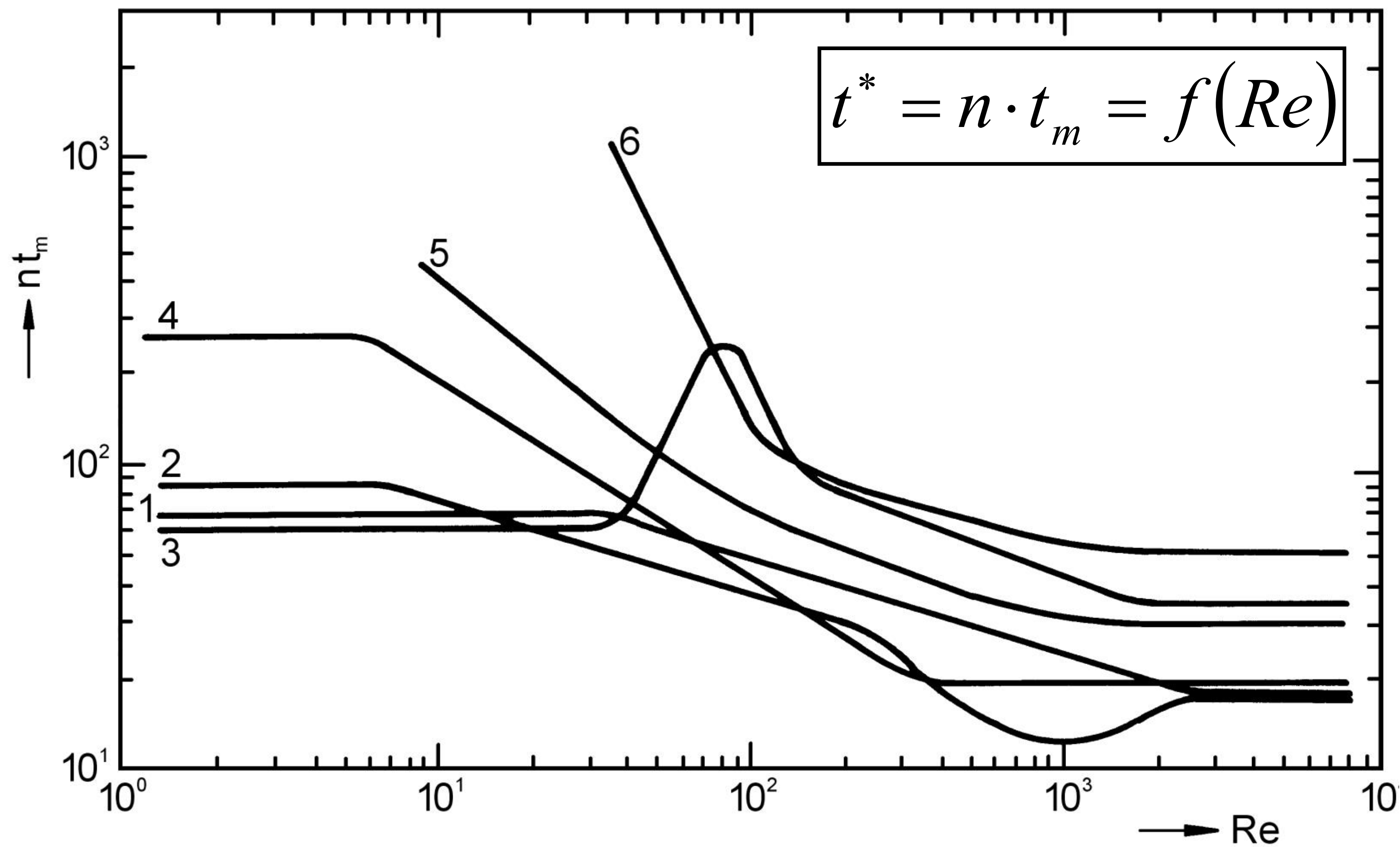
During homogenization (or blending) of miscible liquids are compensated temperature and concentration differences in agitated batch.

Homogenization of miscible liquids:

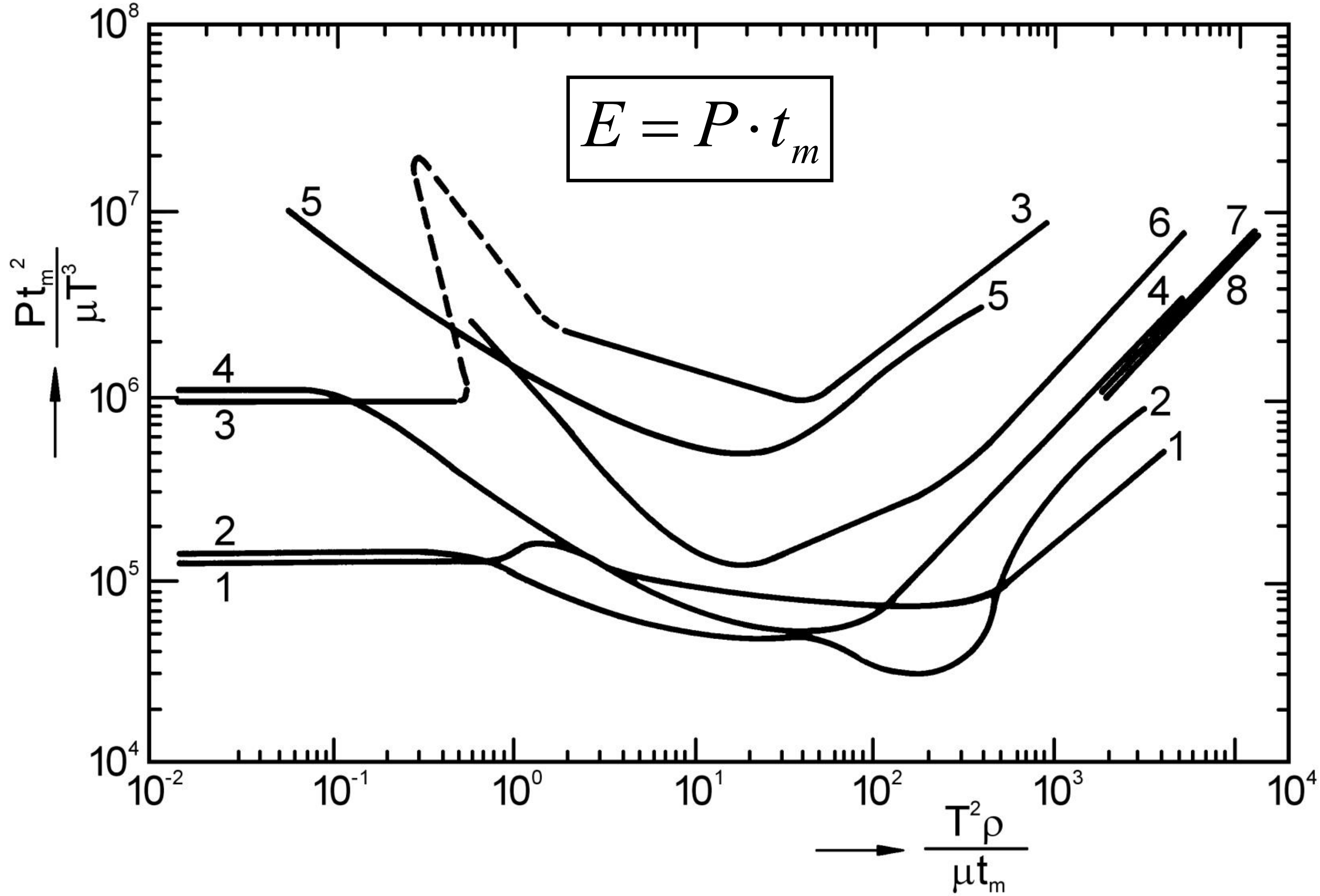
- due to recirculation flow (convective diffusion)
- due to turbulent flow (turbulent diffusion)
- due to molecular diffusion



Homogenization characteristics of agitators



1 *– helical-screw agitator with draught tub (CVS 69 1028),* ***2*** *– eccentrically placed helical-screw agitator,* ***3*** *– helical-ribbon agitator (CVS 69 1029),* ***4*** *– eccentrically placed multi-stage agitator,* ***5*** *– anchor agitator (CVS 69 1014),* ***6*** *– six-blade turbine with disk (Ruschton turbine) (CVS 69 1021)*



1 *– helical-screw agitator with draught tub (CVS 69 1028),* ***2*** *– eccentrically placed helical-screw agitator,* ***3*** *– helical-ribbon agitator (CVS 69 1029),* ***4*** *– eccentrically placed multi-stage agitator,* ***5*** *– anchor agitator (CVS 69 1014),* ***6*** *– six-blade turbine with disk (Ruschton turbine) (CVS 69 1021)*

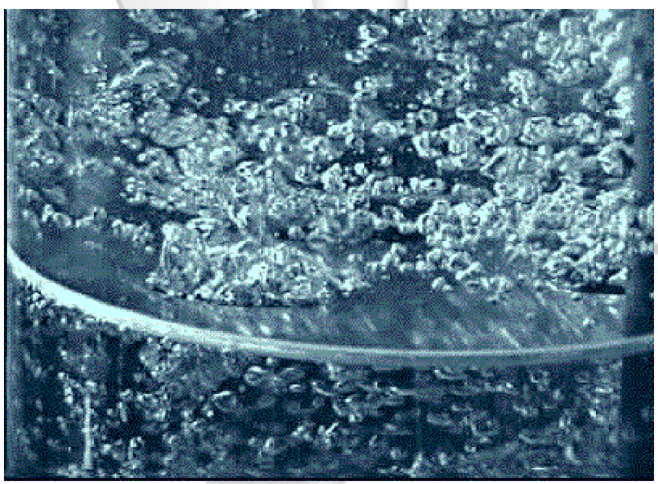
Mixing of heterogenous batch

Heterogeneous batch:

- liquid – gas
- liquid – liquid (emulsion)
- liquid – solids (suspension)

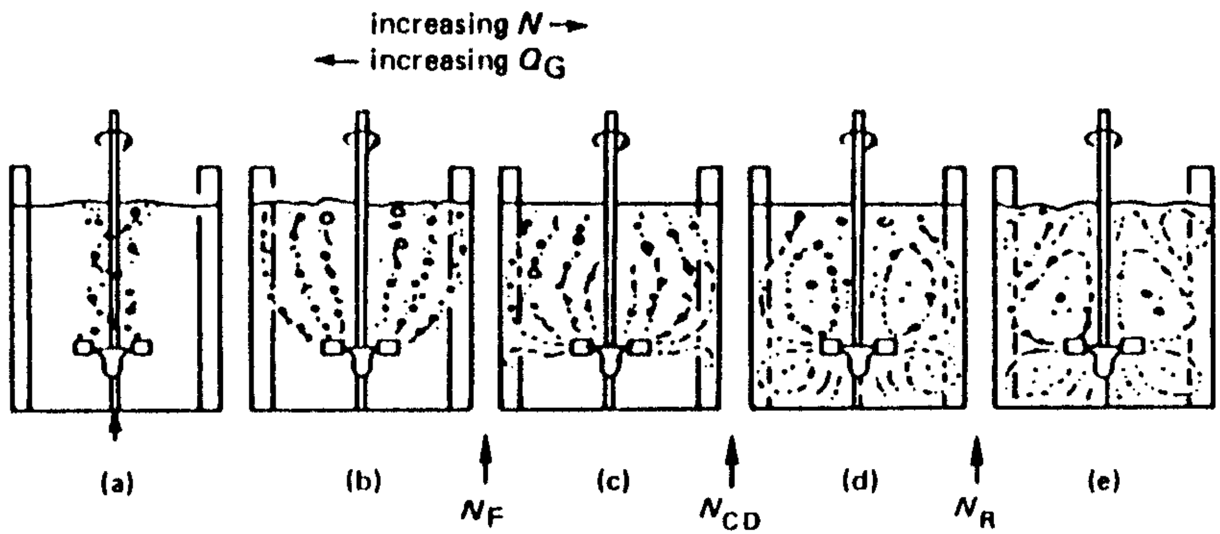
Purpose of agitation

→ ***Intensification of mass transfer***



$$\dot{m} = \beta S \Delta\rho_A$$

Dispersion of gas in liquid



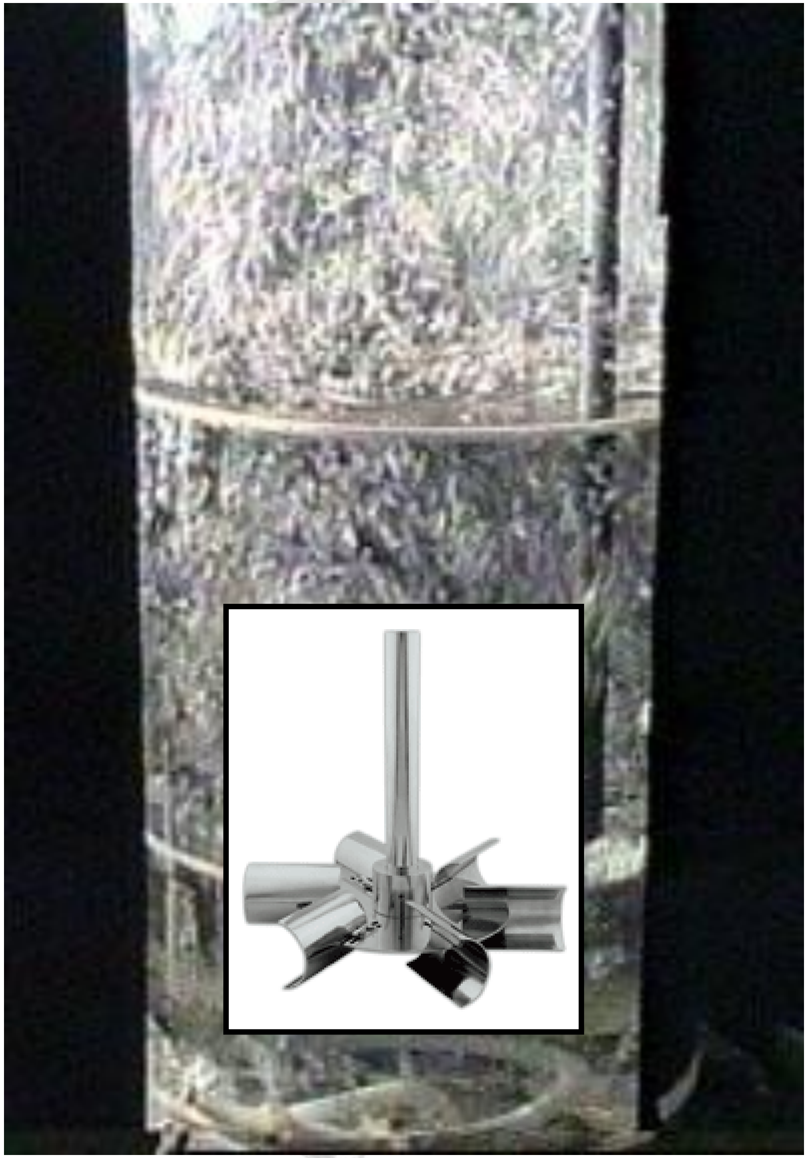
- ***Flooding of impeller*** $\frac{\dot{V}_g}{nd^3} \approx 16{,}6 Fr \left(\frac{d}{T}\right)^{3,4}$
- ***Recommended gas flow-rate*** → VVM = 1 ÷ 1,5

  (volumetric flow of gas per liquid volume per minute)
- ***Size of dispersed bubbles*** → $\boldsymbol{d_b \approx (P/V)^{-0,4}}$

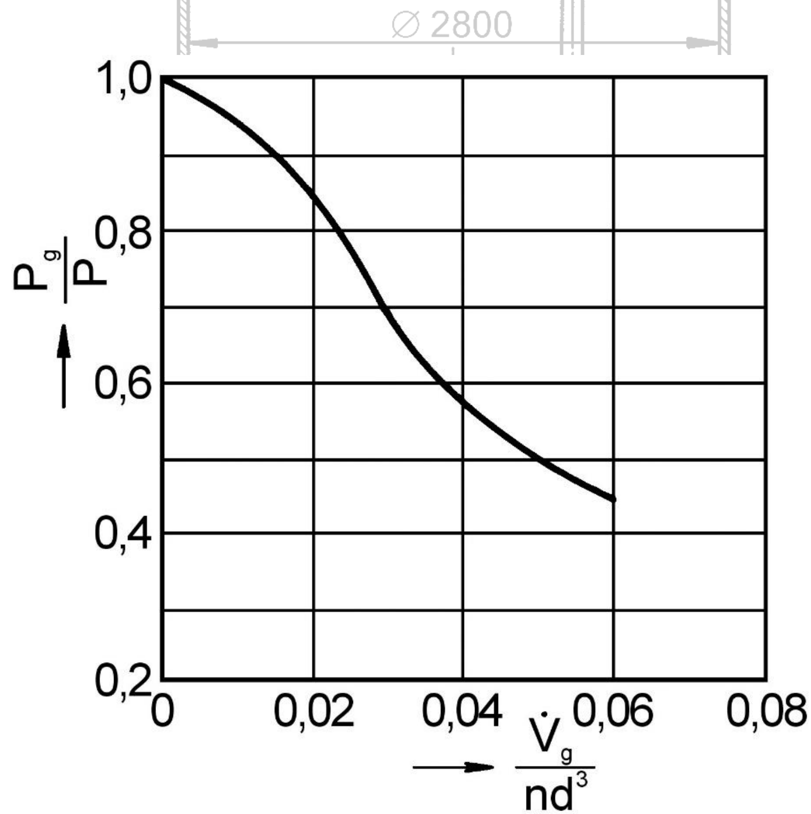
e.g. water – air:

$$d_b = 4{,}15 \frac{\sigma^{0,6} c_v^{0,5}}{\rho^{0,2} (P/V)^{0,4}} + 9 \cdot 10^{-4}$$

Impeller power consumption for gas – liquid dispersing



$$\frac{P_g}{P} = f\left(\frac{\dot{V}_g}{nd^3}\right)$$



Dispersion of liquid – liquid systems

(preparation of emulsion)

Size of dispersed liquid drops → balance of dynamic and surface forces

$$d_{32} \approx \left(\frac{\sigma}{\rho_c}\right)^{3/5} \varepsilon^{-2/5}$$

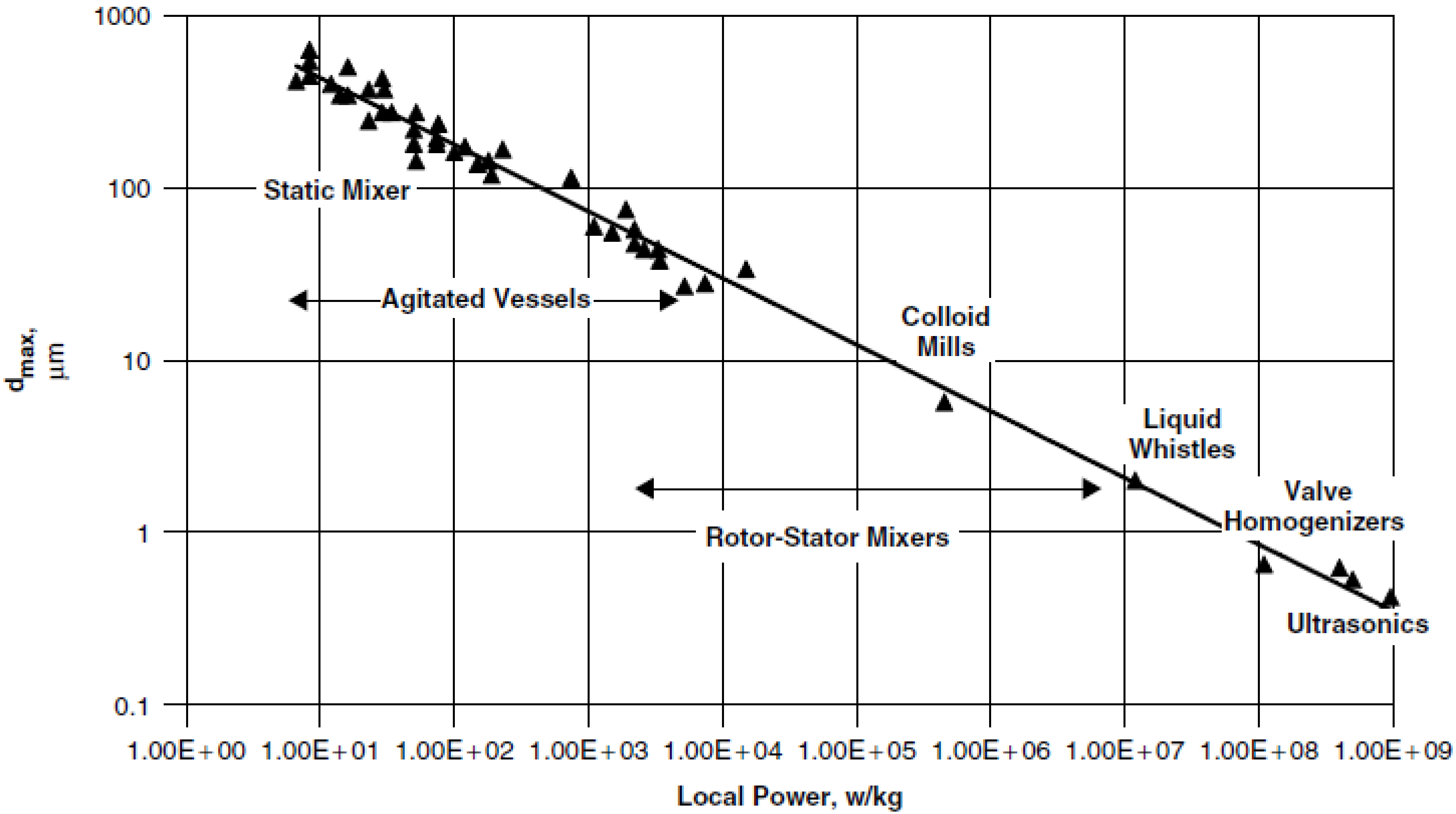
↑

$$We = \frac{n^2 d^3 \rho_c}{\sigma}$$

⇓

$$\frac{d_{32}}{d} \approx We^{-3/5}$$

Limits of dispergation technology and equipment

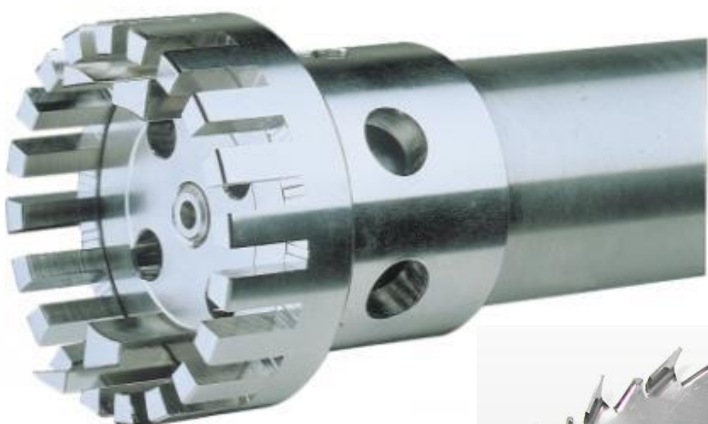


Impeller power consumption for liquid – liquid dispersing

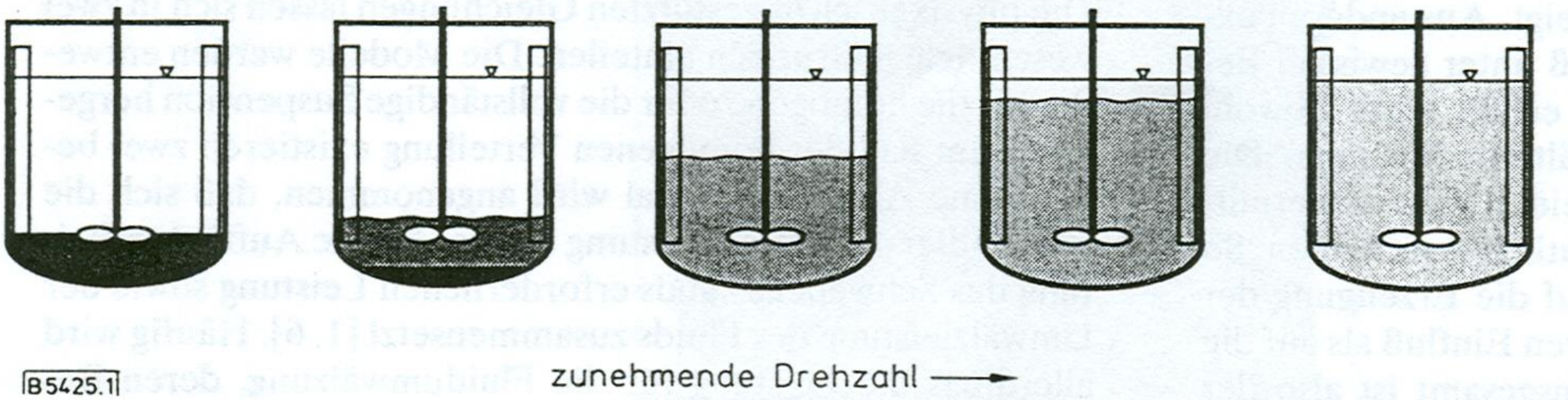
$$Po = \frac{P}{\rho_{mix}\, n^3 d^5} \longrightarrow \boxed{Po = f(Re)} \longleftarrow Re = \frac{n d^2 \rho_{mix}}{\mu_{mix}}$$

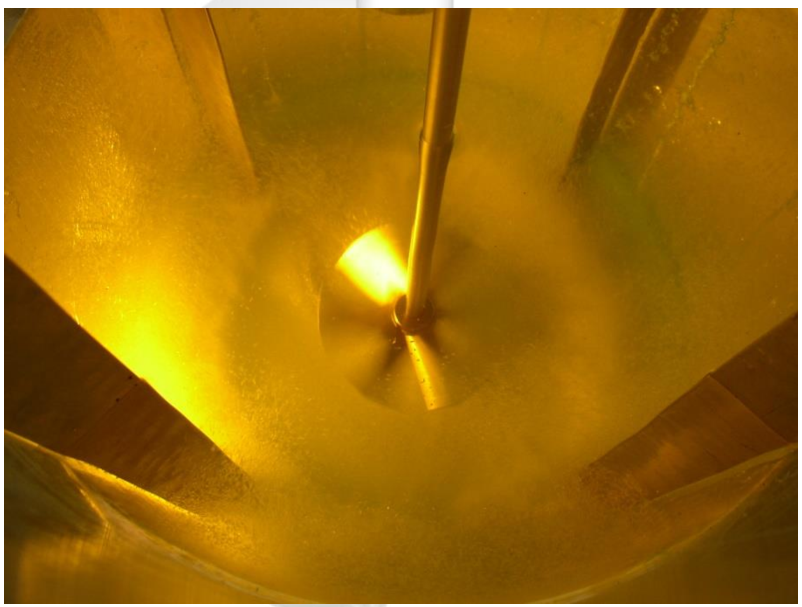
$$\rho_{mix} = c_v \rho_d + (1 - c_v)\rho_c$$

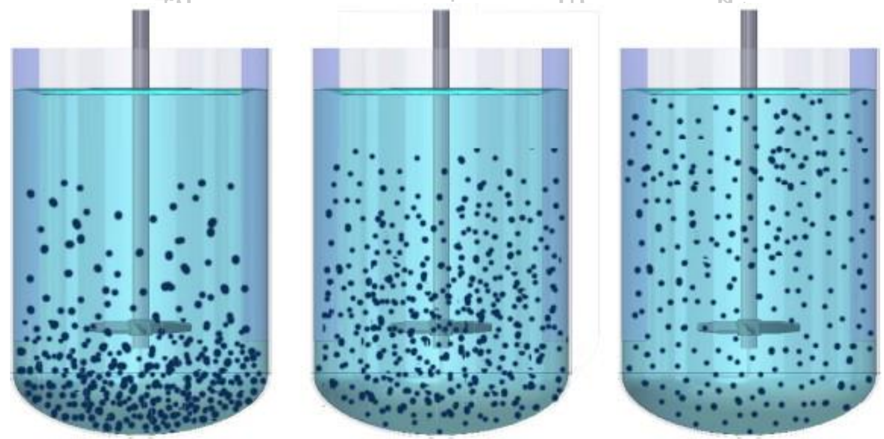
∅ 2800



Mixing of suspension







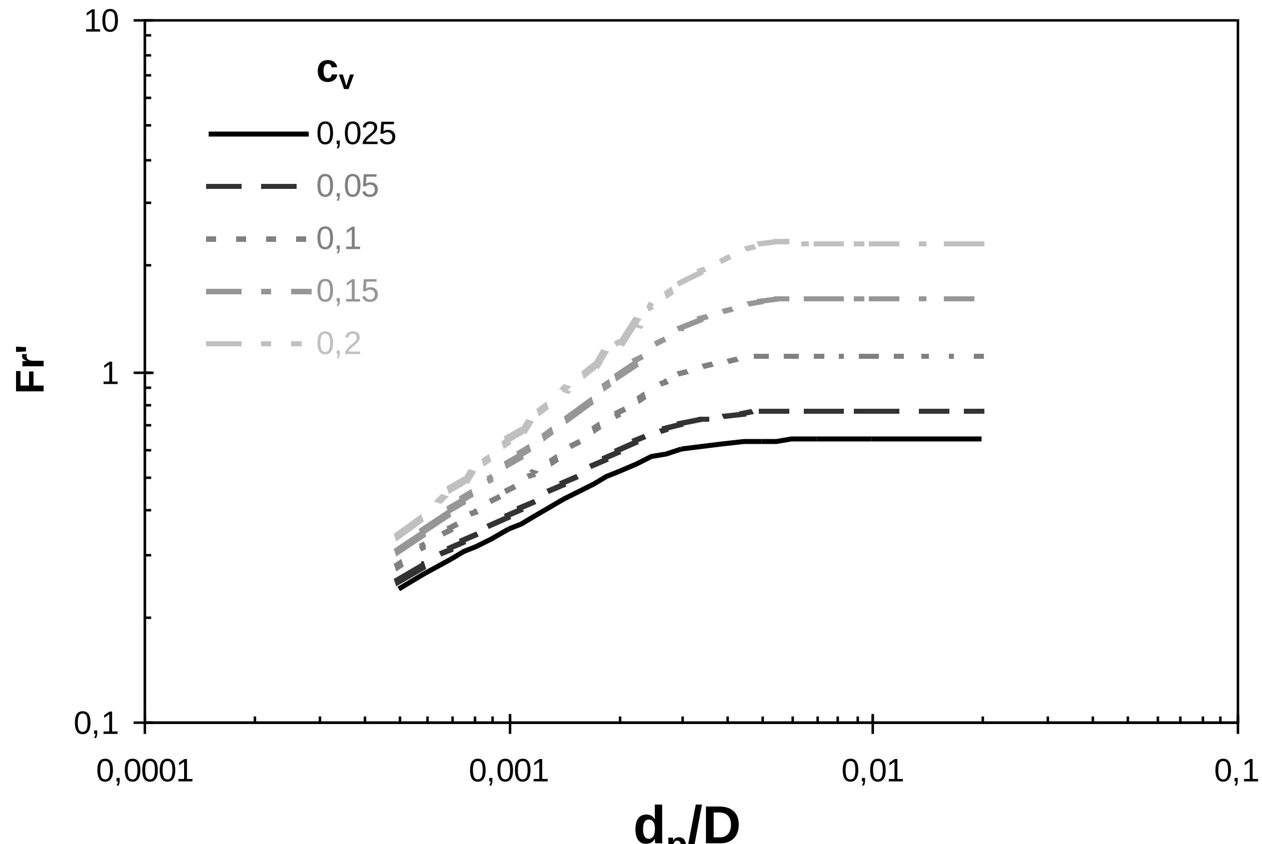
Just-suspended impeller speed

$$Fr' = \frac{\rho n^2 d}{g \Delta\rho}$$

$$Fr' = C\left(\frac{d_p}{D}\right)^c$$

$$c = \alpha + \beta c_v$$

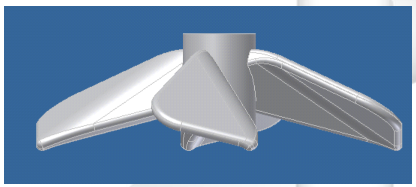
$$C = A \exp\left(B c_v\right)$$

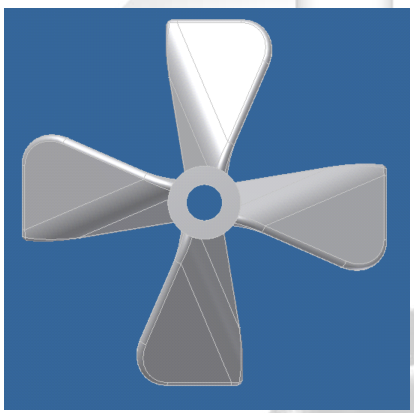


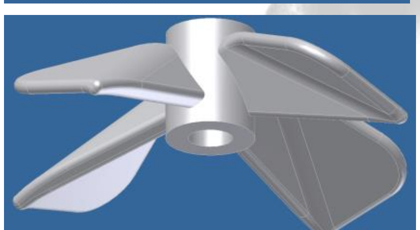
Impeller power consumption for mixing of suspension

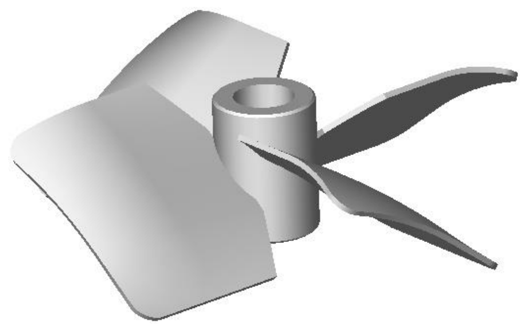
$$Po = \frac{P}{\rho_{su}\, n^3 d^5} \longrightarrow \boxed{Po = f\left(Re\right)} \longleftarrow Re = \frac{n d^2 \rho_{su}}{\mu}$$

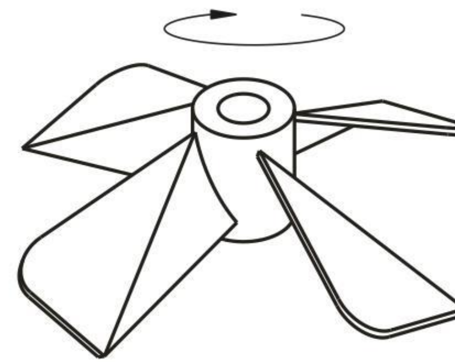
$$\rho_{su} = c_v \rho_s + \left(1 - c_v\right)\rho$$



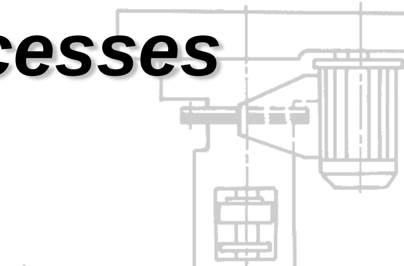




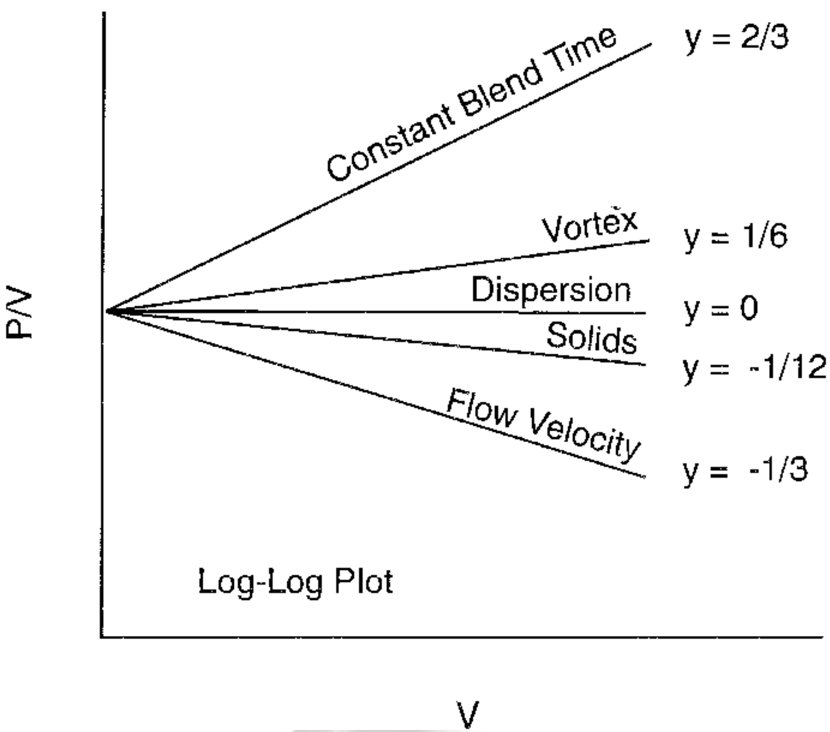




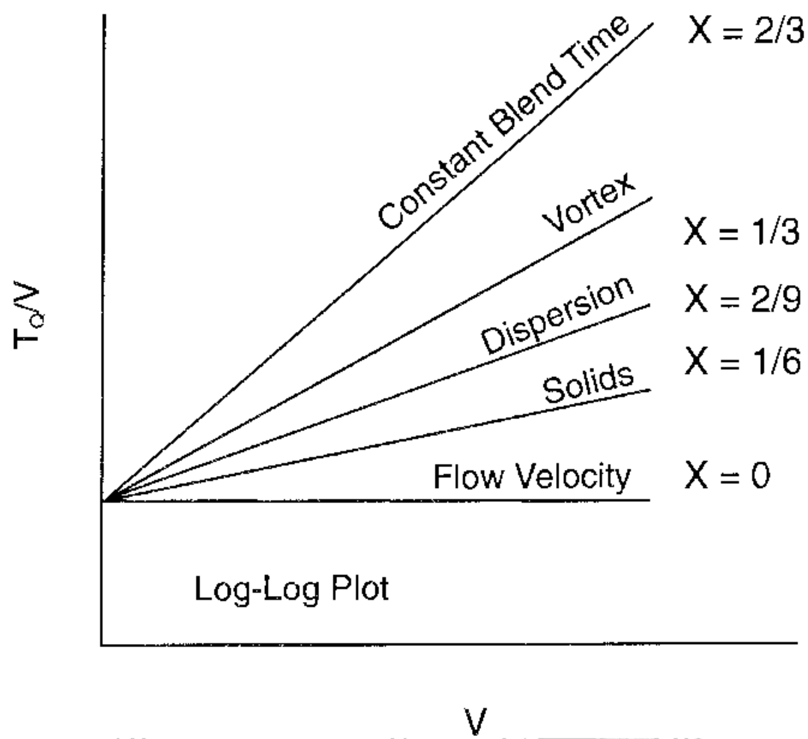
Scale-up of mixing processes

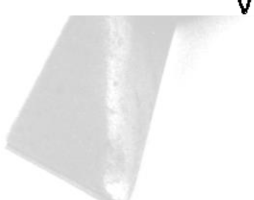


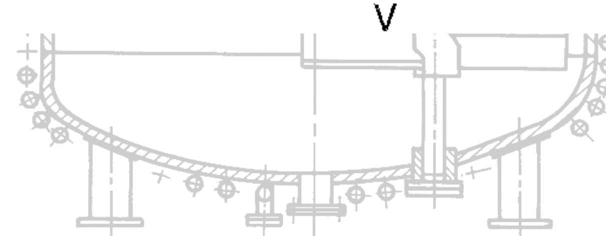
$P/V = \text{Constant } V^{y}$



$T_Q/V = K_T V^{X}$

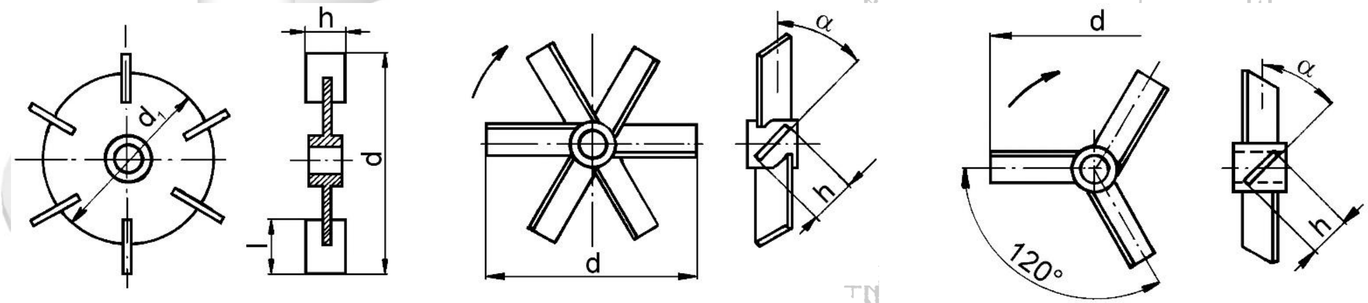






EXAMPLE: Blending efficiency of impellers

Select type of high-speed impeller with minimum energetic requirements for continual blending (homogenization) of two miscible liquids A + B (μ = 5 mPa·s, ρ = 1100 kg·m^{-3}) with flow rate of mixture 10 l·s^{-1}. For suitable degree of homogenization must be residence time of liquids in equipment 5 x longer than blending time. Mixing equipment has standard geometrical configuration (baffled cylindrical vessel with diameter T = 1200 mm, T/d = 3.3; H_2/d = 1, H/T = 1).



Dimensionless blending time of high-speed impellers in turbulent flow regime

Type of impeller	***T/d***	***H_2/d***	***$n \cdot t_m$***
Six-blade turbine with disk (Ruschton turbine), CVS 69 1021	3.3	1	51.8
Pitched six-blade turbine with pitch angle 45, CVS 69 1020	3.3	1	53.1
Pitched three-blade turbine with pitch angle 45°, CVS 69 1025.3	3.3	1	60.5