FLUID DYNAMICS SIMULATION 2021-2022, GUIDED PROBLEM N.2

Description: The geometry under consideration is a stirred tank agitated by two impellers attached at the same shaft. The top impeller is an axial pitched blade turbine while the impeller at the bottom is a six blades Rushton turbine.
The purpose of the simulation is to analyse the system under different conditions: the mixing of the liquid phase and the mixing in a gas-liquid system where gas enters the system by a bottom ring sparger and is free to exit from the top by a degasser.
Grid size and quality: Mesh has been initially provided; important features of the mesh are in any case reported:

CELLS	205316
FACES	1373796
NODES	1093547
MINIMUM ORTHOGONA	2.03937E-01
MAXIMUM ASPECT TYPE	2.33875E+01
TYPE OF GRID	hybrid polyhedron

POINT 1

Starting by the initial geometry few changes has been made:

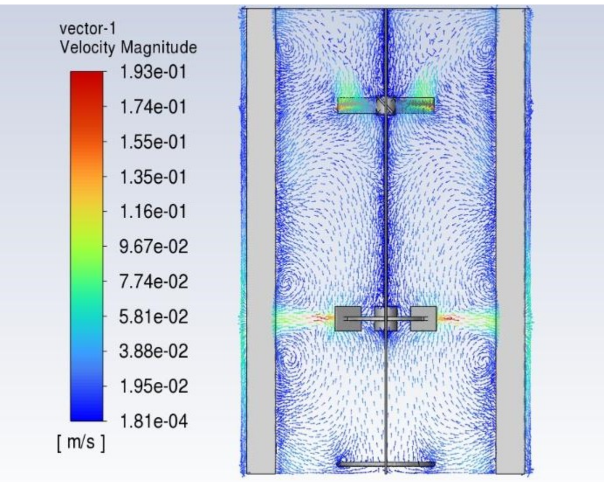
1. No gas is injected in the system so boundary conditions at the sparger (gas-inlet) are updated. Particularly all the gas sparger is set to act as a wall.
2. The main material in the whole domain is set to be water so we ensure that no gas is considered inside the system.
3. The condition of the degasser area is changed and update to act as a wall with the same conditions of the other walls.

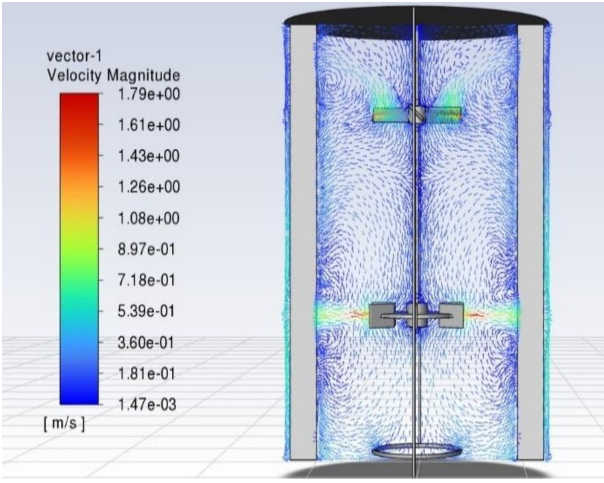
To decide the correct method to implement a Reynolds calculation it's needed: $Re = \frac{\rho N D^2}{\mu}$, so:

- Re (N=450rpm) = 30070 (Turbulent Regime)
- Re (N=50 rpm) = 3341 (Mixed Regime)

The system in described using the following properties and conditions:

- **Fluid properties**: Water like fluids.
- **Boundary conditions:**
  - **Pitched blade impeller:** Using the MRF model a rotation speed of 50 and 450 rpm is set.
  - **Rushton turbine:** Using the MRF model a rotation speed of 50 and 450 rpm is set.
  - **Wall**: Stationary Wall, No slip condition
- **Turbulent model:** K-omega is used for both systems even if the one at 50 rpm is in mixed regime, other more sophisticated methods could be used to solve the problem like the k-kl-w model.
- **Convergence criterion:** No change has been made in the convergence criterion.
- **Relaxation factors:** No changes have been made. Default values are maintained.
- **Solutions Methods:** No change has been applied. Second order upwind method has been maintained to obtain better accuracy.
- **Iterations until convergence:** For 450 rpm case simulation converges after 742 iterations.
  For 50 rpm case simulation converges after 936 iterations.
- **Mass/Energy Balances:** System is closed so we only check that no mass or energy fluxes are present.





Velocity magnitude is shown for both 50 rpm (on the left) and 450 rpm (on the right).
We can observe that:

- As we expected the Rushton turbine pumps the flow radially, while the PBT pumps the flow axially.
- Regions at higher velocity are the one close to the impeller, in fact fluid velocity close to the impeller should be equal to impeller (wall) velocity.
- Looking at the case at 450 rpm we can observe that a better recirculation in some zones (e.g. Tank bottom)
- The vector plot of the water velocity shows that the water moves in a circular motion, creating a closed loop since it cannot escape the reactor.
- As expected from the impeller's geometry the radial impeller (Rushton turbine) creates 2 different zones of recirculation above and below the impeller
- The axial impeller (PBT) also creates recirculation near baffles.
- For the system at N=50 rpm a simulation with a model suitable for the transitional regime has been performed; the results were however similar to the one obtained in the figure.

POINT 2

By using the simulation made on fluent we can easily estimate the power number of the impeller using the simulation for N =450.

Moments - Moment Center (0 0 0) Moment Axis (0 0 -1)

Zone	Moments [N m] Pressure	Viscous	Total	Coefficients Pressure	Viscous	Total
wall_impeller_1	0.038779312	0.0001118567	0.038891169	0.063313163	0.00018262318	0.063495786
wall_impeller_2	0.0046331041	5.5204342e-05	0.0046883085	0.0075642516	9.0129539e-05	0.0076543812
Net	0.043412416	0.00016706104	0.043579477	0.070877414	0.00027275272	0.071150167

1. $P = 2\pi N T_q$, using the value relative for the total torque we obtain a power equal to 2.046 [W].
2. From the general formula used for estimating power number $N_P = \frac{P}{\rho N^3 D^5} = 4.71$.

   For the calculation, the value of D (0.063478 [m]) is obtained using(D/T = 0.4) T(0.15869 [m]), retrieved by knowing the tank surface (A= 0.01978 [m^2]) .
3. We evaluate Re to establish the turbulent conditions in our flow so: $Re = \frac{\rho N D^2}{\mu}$ =30070 (system is turbulent since re>4000).
4. In case of turbulent flows, we can use the general correlation $N_p^{\frac{1}{3}} Re = \frac{5.2}{Fo}$ and so we can easily estimate the Fourier number so that Fo^{-1}=9693.
5. To estimate the blend time, we need to evaluate the tank height, from geometrical analysis we can calculate that H=0.2411 [m].

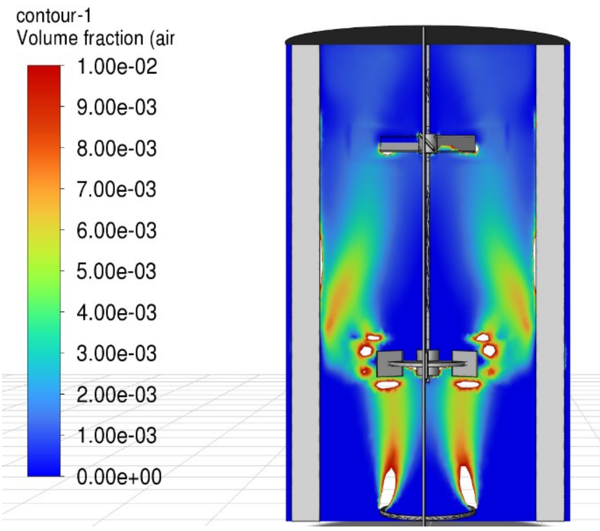
- Using the Fourier dimensionless number definition, we can estimate the blend time at 95% of homogeneity. $\tau = \frac{5.2}{N_p^{1/3} N} \frac{T^{1.5} H^{0.5}}{D^2}$ = 3.19 [s] so the blend time obtained is compatible with the small system we are analysing.

In addition, we should notice that:

- The power number is the results calculated for the system composed of both Rushton and PBT impellers. Common values for the Rushton turbine and the PBT are usually 6 and 1.5. However, in this situation we have multiple impellers on a shaft and so real power number can be obtained by experimental measurement or by our simulation[1].
- This type of system is designed to mix gas into liquid, without the gas in the system, the Rushton turbine loses its helpfulness for the system efficiency of mixing, probably in this situation a hydrofoil impeller could be a better solution.

POINT 3

In the third task, it is required to evaluate and compare the behaviour of the system simulated in the tutorial and compare the obtained gas distribution to the case of the single-phase simulation.



- The sparger at the bottom of the tank is the inlet point for the air, and as we can see in the figure the concentration in volume fraction of air in that zone is very high.
- When air encounters the Rushton turbine is pumped radially close to the wall.
- During to the recirculating action of the axial impeller two zones at higher air concentration are created, those zones are related to turbulence and help to create a good gas dispersion in the middle part of the reactor.
- The air is mixed in water during the rise and the second impeller competes to pump the air down towards the Rushton turbine.
- When air reaches the liquid free surface, leave the systems described in the boundary condition for the degassing area.
- The system presents some cavitations both in the radial and in the axial impeller due to the depression areas created behind the rotating blade. However, if we check the flooding condition and the large condition is not reached so the impeller is still able to mix the two phases.

$Fl_G = \frac{Q_g}{ND^3} = 4.834e - 03$ $Fr = \frac{N^2 D}{g} = 0.364;$ Flooding condition: $Fl_G > 0.025 \left(\frac{D}{T}\right)^{-0.3} = 0.442$

Large cavitation conditions: $Fl_G > C_l Fr \left(\frac{D}{T}\right)^{3.5} = 0.041$ (Cl=70, Qg=9.2727e-06 [m3/s] from simulation)

Conclusions & Improvements

We have seen as different situations change the mixing conditions in our system. To improve the system, we should understand in what type of system we are treating since different considerations can be made at different mixing scale. In general, if we want to improve macromixing without changing the impeller speed, we may install an hydrofoil impeller instead of PBT to pump more mixture to the Rushton turbine (we should make an economical analysis). In addition, increasing the diameter of the Rushton turbine increases the residence time of the air in the system; it could create greater recirculation at the boundaries and baffles.

1. *https://www.sciencedirect.com/topics/engineering/power-number*

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