Flow Generated by Fractal Impeller in Stirred Tank: CFD Simulations

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Abstract: Stirred tank has been the research area for many decades due to its applicability in chemical, pharmaceuticals, polymers, food and paints industries for variety of operation. Most of the energy supplied by the impeller is dissipated in the impeller region which leads to non-uniformities in the energy dissipation throughout the reactor. In order to reduce the extent of non-uniformities we propose the use of Fractal Impeller (FI) for mixing and dispersion. Here we present the flow patterns generated by fractal impeller using CFD simulation (k-ε model). Mean velocities have been compared with the experimental data and show good agreement. But turbulent kinetic energy is under-predicted or over-predicted in some part of the vessel.

Introduction:

Mixing using impeller in stirred tank is often used in the chemical and its allied industries. Design of impellers and stirred tank geometry is the key thing for mixing operations. Usually in the industries stirred tank reactors operate at the turbulent regime (expect for viscous fluid) and the most active zone of the stirred tank is considered to be the impeller region[1]. Uniformity in energy dissipation in the stirred tank with conventional impeller is hard to achieve. Wu and Patterson[2] studied the energy dissipation for Rushton turbine; authors concluded that about 30% of the total energy was dissipated in the impeller region, 30% in the impeller discharge region and rest in the bulk of the tank. Similarly, Zhou and Kresta[3] studied the maximum energy dissipation in the stirred tank for various geometry and impellers. They found the bulk of the energy dissipated in the impeller region and the impeller discharged stream. In order to reduce the non-uniformity and to make the entire reactor hydrodynamically active in a similar manner, here we propose the use of Fractal Impeller (*FI*) for mixing and dispersion. Fractal impeller occupies less than 0.4% of the total volume of the reactor which is nearly equal to the conventional impellers. The impeller does not have any blades that sweep the liquid with it but the arrangement of blades only allows to cut the fluid thereby lowering the friction throughout the tank. Performance of the present impeller design in terms of power consumption, mixing time, solid-liquid suspension and gas-liquid dispersion has been studied[4]. The power number (N_P) was found 0.38 which is lower than the conventional impellers (Ruston turbine = 6, PBTD = 1.84). Mixing performance was also relatively better than the conventional impellers. Bubble size distribution in gas-liquid dispersion was very much narrow which helps proving the self similarity hypothesis.

Computational Modelling:

In CFD model, three dimensional time averaged Reynolds transport equations were solved with the k-ε model for turbulence. The equations were solved using rotating frame of reference formulations. The transport equation for a generalized flow variable ϕ are written as

$$\frac{\partial\left(u_j\emptyset\right)}{\partial x_i} = \frac{\partial}{\partial x_i}\left(\tau\frac{\partial\emptyset}{\partial x_j}\right) + S_Q \tag{1}$$

Here ϕ stands for u_j, k, ε etc. The source terms for different flow variables (S_Q) are different.

Fig. 1 shows the computational domain of the stirred tank with Fractal Impeller (FI) along with the grid statistics. Post processing of the data has been done using MATLAB.

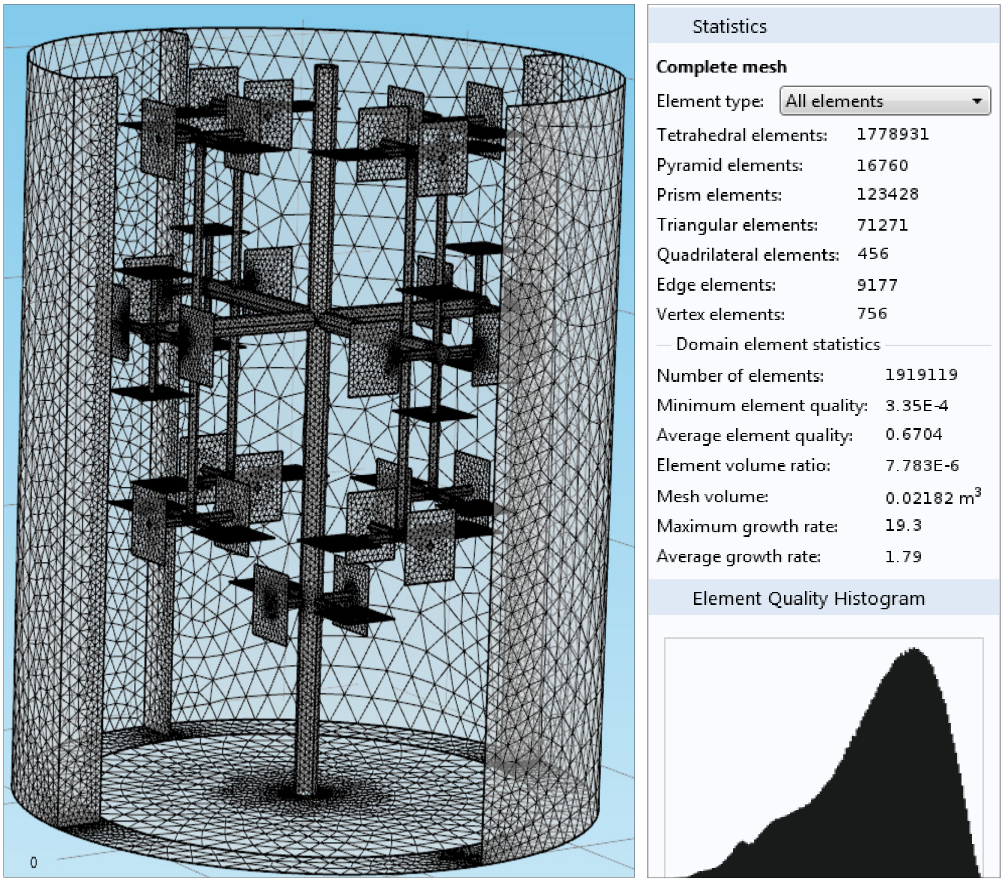
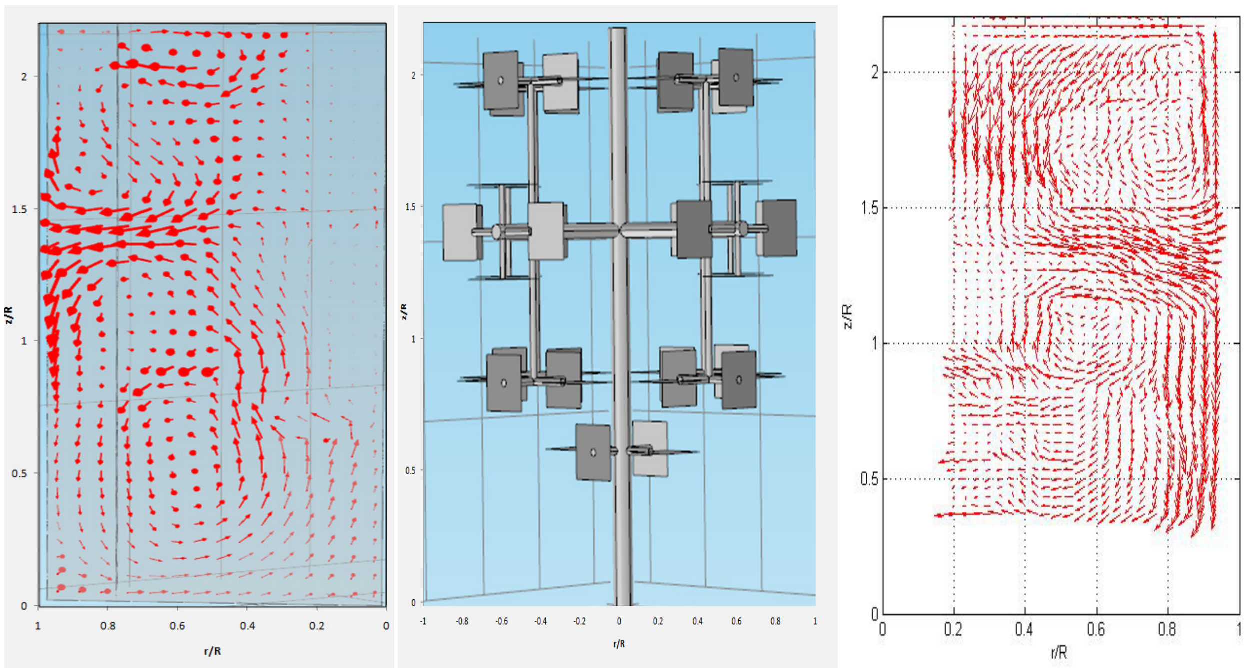


Figure 1: Computational domain and grid statistics of stirred tank with fractal impeller

Result and discussion:

The design of the fractal impeller is such that it does not have fluid sweeping blades, therefore; large eddies induced due to fluid sweeping is avoided. Moreover, shear zones observed in the stirred tank with conventional impeller are also eliminated. The main branches of the fractal impeller induce radial discharge stream towards the wall of the tank. Near tank wall, the radial discharge divides into opposite streams forming several circulation loops. Moreover, the flow generated by the fractal impeller is largely a tangential flow as all blades simply cut the fluid in different planes. Thus, it helps the interaction of different mixing zones. In such situations, interaction of eddies in different zones helps obtain uniform mixing even at relatively low RPM especially in gas-liquid dispersion.



a) b)

Figure 2: Flow pattern generated by Fractal Impeller a) CFD at 50 RPM b) UVP at 100 RPM

Conclusion:

Flow pattern generated by Fractal Impeller in a stirred tank has been studied using CFD simulations. Flow generated by Fractal Impeller was observed to have strong tangential flow and small circulating eddies. The interaction of eddies help obtain uniform mixing even at small RPM.

References:

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