# Pseudo-CFD Model for Impeller Mixed Stirred Tank Bioreactor for Energy Dissipation Rate (EDR)

## 1. Purpose of the Model

The goal is to estimate local shear rate ($\dot{\gamma}$) and energy dissipation rate ($\varepsilon$) distribution inside a mixing tank without running CFD. This helps predict zones of high and low mixing intensity, average vs. maximum EDR, and scale-up comparability between reactors.

## 2. Core Assumptions

| Concept | Simplified Assumption in Model |
|---|---|
| Fluid Type | Newtonian (viscosity constant, water-like: $\mu = 0.001$ Pa·s) |
| Density ($\rho$) | Constant throughout volume |
| Impeller Power | Estimated by classic correlation $P = Np\, \rho\, N^3 D^5$ |
| Flow Pattern | Approximated by a Gaussian intensity field (no CFD mesh solving) |
| Shear Rate | Estimated locally from power density $\dot{\gamma} \approx \sqrt{(\varepsilon/\nu)}$ |
| Energy Dissipation | Derived from $\varepsilon = \mu\, \gamma^2$ |
| Boundary & Baffles | Ignored (axisymmetric assumption) |



Correspondence: Naveenganesh Muralidharan | mnaveen2710@gmail.com | bench2batch.com

## 3. Step-by-Step Logic

Step 1: Input & Geometry

- The user provides tank diameter (T), liquid volume (V), and impeller data (diameter, speed, clearance, power number).
- Tank height $H$ is computed from the volume:

$$H = \frac{V}{\pi(R)^2}$$

where $R = T/2$.

---

Step 2: Impeller Power Calculation

Each impeller contributes mechanical power:

$$P_i = N_{p,i}\rho N^3 D_i^5$$

All impellers' power adds up to total:

$$P_{total} = \sum P_i$$

Then, the global power density (P/V) is:

$$\frac{P_{total}}{V}$$

This represents an *average* EDR in the entire tank.



Correspondence: Naveenganesh Muralidharan | mnaveen2710@gmail.com | bench2batch.com

Bench2Batch Insights | Technical White Paper Series

---

Step 3: Define Spatial Grid (Pseudo-CFD Field)

- The tank is divided into a 2D grid (r × z = 50 × 50 cells).
- Each cell represents a small annular volume $dV = 2\pi r dr dz$.
- Arrays intensity[j][i] hold local "power density proxy" values.

---

Step 4: Local Power Distribution Around Impellers

Each impeller produces a *Gaussian decay* of power with distance from its center (r,z):

$$\varepsilon(r,z) = \varepsilon_0 \exp\left[-\left(\frac{r}{0.75D}\right)^2 - \left(\frac{z - z_i}{0.6D}\right)^2\right]$$

where

- $\varepsilon_0 = P_i/V$ = average contribution from that impeller
- $z_i$ = clearance height
- $D$ = impeller diameter

This defines an energy "cloud" centered around each impeller.

---

Step 5: Compute Shear and Local EDR



Correspondence: Naveenganesh Muralidharan | mnaveen2710@gmail.com | bench2batch.com

Once local ε (power density) is estimated for every grid cell:

- Shear rate is approximated from local ε and kinematic viscosity (ν):

$$\dot{\gamma} = \sqrt{\frac{\varepsilon}{\nu}}$$

- EDR (Energy Dissipation Rate) is then:

$$\varepsilon_{local} = \mu\dot{\gamma}^2$$

Thus, each grid point gives:

- Local shear rate (1/s)
- Local EDR ($W/m^3$)

---

Step 6: Compute Averages

Two averages are calculated:

1. Simple arithmetic mean

$$\bar{\varepsilon}_{simple} = \frac{1}{N}\sum\varepsilon_{local}$$



Correspondence: Naveenganesh Muralidharan | mnaveen2710@gmail.com | bench2batch.com

2. Volume-weighted mean

$$\bar{\varepsilon}_{vol} = \frac{\sum \varepsilon_{local} V_{cell}}{\sum V_{cell}}$$

This is directly comparable to P/V from power balance.

The maximum EDR (ε_max) is also tracked to capture the most energetic (or shear-intensive) zone in the tank.

## 7. Physical Interpretation

| Parameter | Meaning | Significance |
|---|---|---|
| `avgEDR_W_m3_volumeWeighted` | Volume-weighted mean EDR | Comparable to mechanical P/V, good for scale-up |
| `maxEDR_W_m3` | Maximum EDR in domain | Indicates shear "hot spots" that may damage cells or proteins |
| `avgShearRate_1_per_s` | Mean flow-averaged shear rate | Related to overall mixing intensity |
| `maxShearRate_1_per_s` | Peak shear rate | Predicts cell damage potential |

## 8. Strengths and Limitations

Strengths: Fast, physics-based, CFD-like, suitable for comparative and scaling studies.

Limitations: Axisymmetric, no turbulence model, assumes Newtonian fluid, ignores baffles and free-surface effects.



Correspondence: Naveenganesh Muralidharan | mnaveen2710@gmail.com | bench2batch.com

## 9. Practical Use

The model helps compare impeller designs, estimate energy uniformity, assess scale-up consistency, and visualize pseudo-CFD contour plots in Retool dashboards or process reports.



Correspondence: Naveenganesh Muralidharan | mnaveen2710@gmail.com | bench2batch.com