Application of flow following sensor particles: Flow characteristics in stirred vessels

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Introduction

In this study, the application of flow following sensor particles for determination of mixing and flow characteristics (i.e. circulation time and axial distributions) in pilot and large-scale bioreactors has been examined. Results have been obtained in a pilot scale reactor and compared with a traditional experimental setup and CFD simulations.

It was found that circulation times and axial distributions can be determined in a simplistic manner, which is solely based on measurements of the hydrostatic pressure in the bioreactor.

The circulation time is proportional to the mixing time and is a useful measure of the degree of mixing in the bioreactor. The mixing time in a stirred reactor can be approximated by $t_m \approx 4t_c$ [1] or by $t_m \approx 5t_c$ [2].

Mixing in a production process is of great importance, as deficient mixing can result in the formation of gradients in important process parameters, which could potentially decrease cell yield and increase by-product formation [3] . The scope of this study is summarized in figure 1.

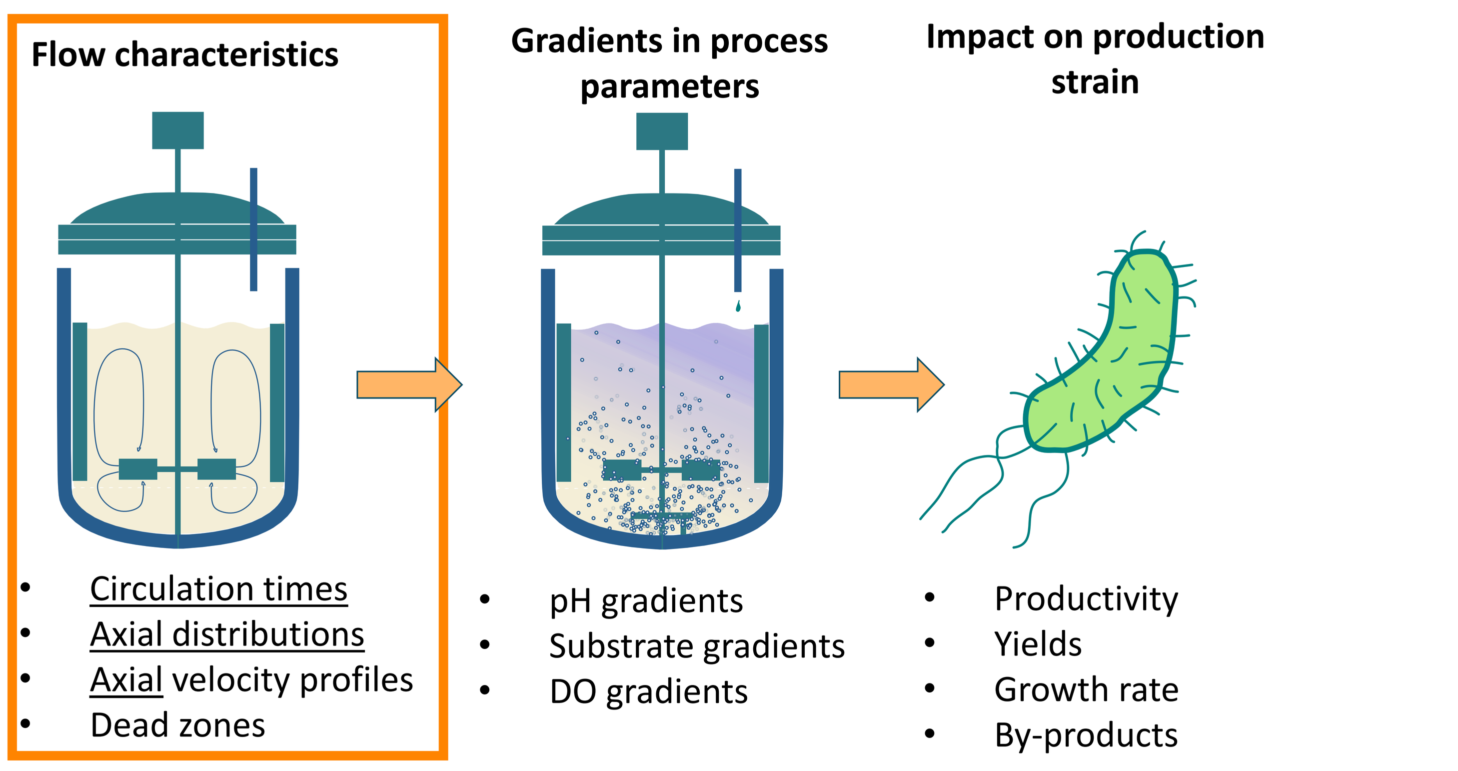


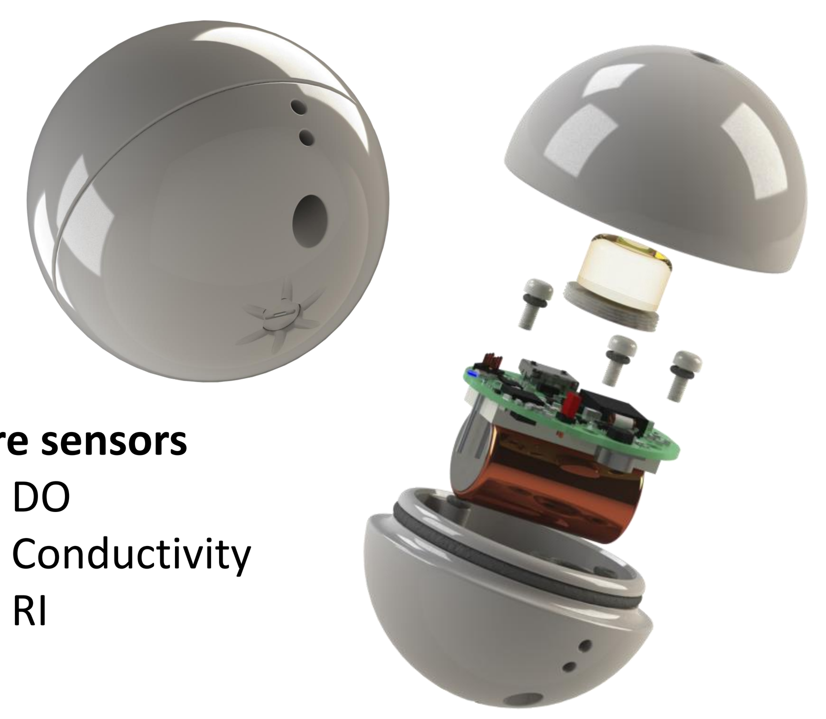
Figure 1. Deficient mixing can result in the formation of gradients, which will impact the production strain and thus lead to suboptimal process performance. In this study, the focus has been on the flow characteristics that can be used to indicate poor mixing.

Flow following sensor particle

Sensor particle overview:

- Diameter: 45 mm
- Adjustable density (≈ 1 kg/L)
- Steam sterilizable
- Robust PEEK capsule

- **Current sensors**
  1. pH
  2. Pressure
  3. Temperature
  4. Inertial measurement unit
- **Future sensors**
  1. DO
  2. Conductivity
  3. RI



Methods

Data on hydrostatic pressure has been collected by three sensor particles in a pilot scale reactor at different impeller speeds. The reactor has a diameter of T = 0.94 m and a working volume of V = 0.7 m^3. The reactor configuration is shown in figure 2.

- The distributions have been calculated as the sum of the time spent in each compartment divided by the total experimental time.
- Axial velocities have been calculated as the mean of all axial average velocities in a compartment
- The circulation times have been determined as the time between the intersection of lines between each depth measurement and a detection plane, Z = ½h.

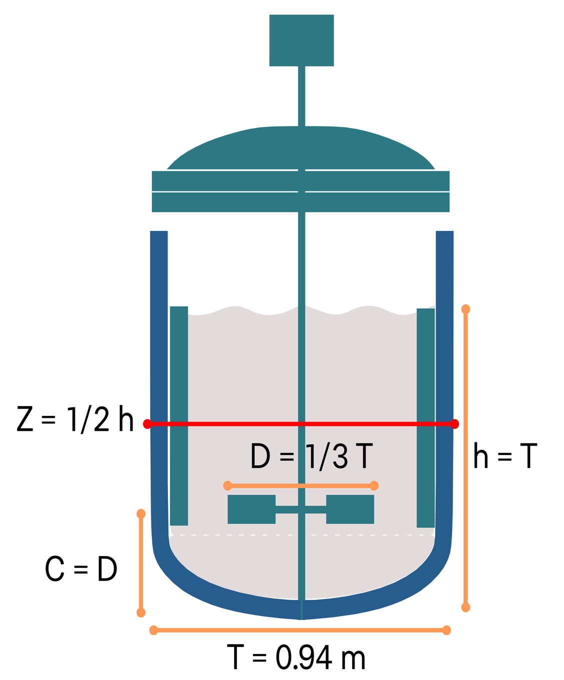


Figure 2. Pilot reactor configuration.
Z: detection plane.
T: tank diameter.
D: impeller diameter.
C: clearance.
h: liquid height

Results and discussion

The axial distributions in figure 3 give an indication of which compartments the sensor particles spend most time within. The axial velocities are prominent outside the impeller region and can be used to investigate the degree of agitation.

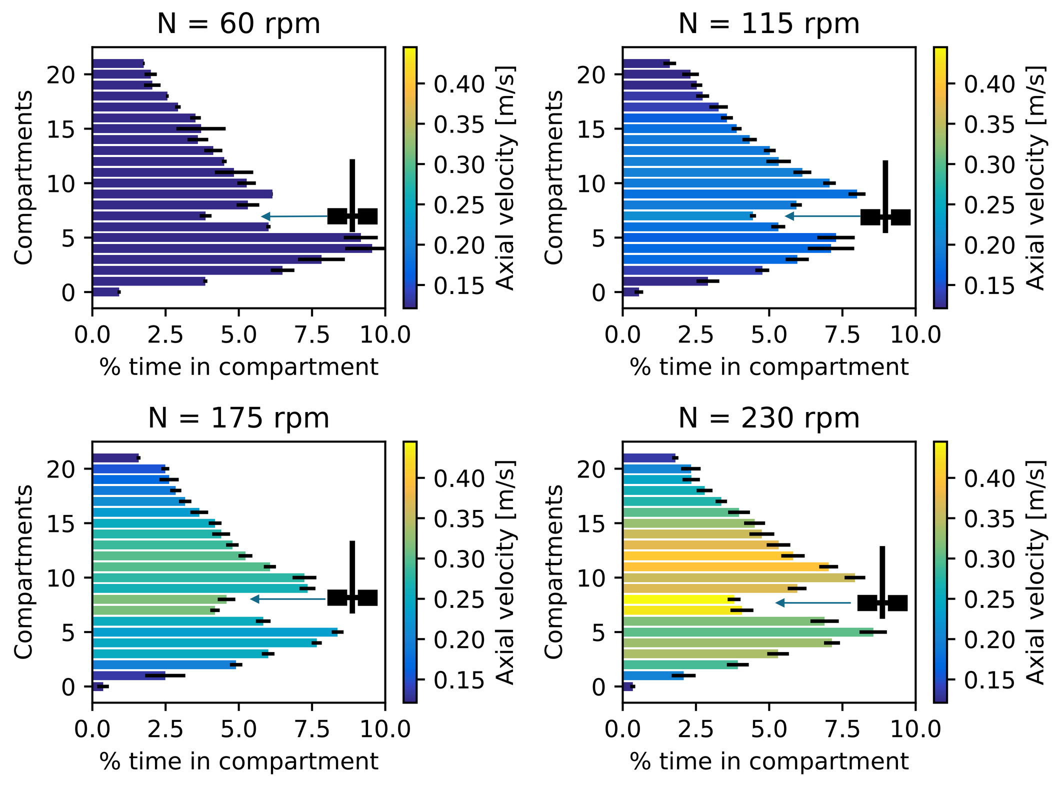


Figure 3. Axial time distributions [%] and average axial velocities of the sensor device at increasing values of the rotational speed of the impeller, N.

The determined circulation times are clearly correlated with mixing times (figure 4). Consequently, the circulation times can be used to compare mixing at different agitation intensity levels or between different tanks.

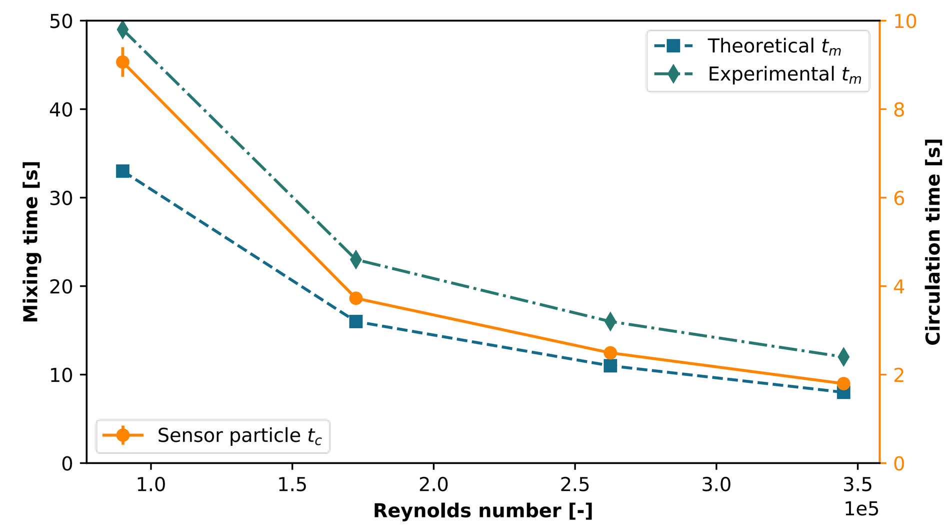


Figure 4. Determined mean circulation times and a comparison with both experimental [4] and theoretical mixing times under the same conditions. It is evident that the circulation times and mixing times are correlated.

By compartmentalization of the velocity field vectors in the z-direction obtained by CFD simulations, a direct comparison can be made with the axial velocities obtained by the sensor particles. Results from the pilot scale case study are shown in figure 5. Overall, the velocities are similar in magnitude and the shapes similar, but an irregularity seems to result around the impeller of the sensor particle data. This is likely to be a result of the physical size of the sensor particles.

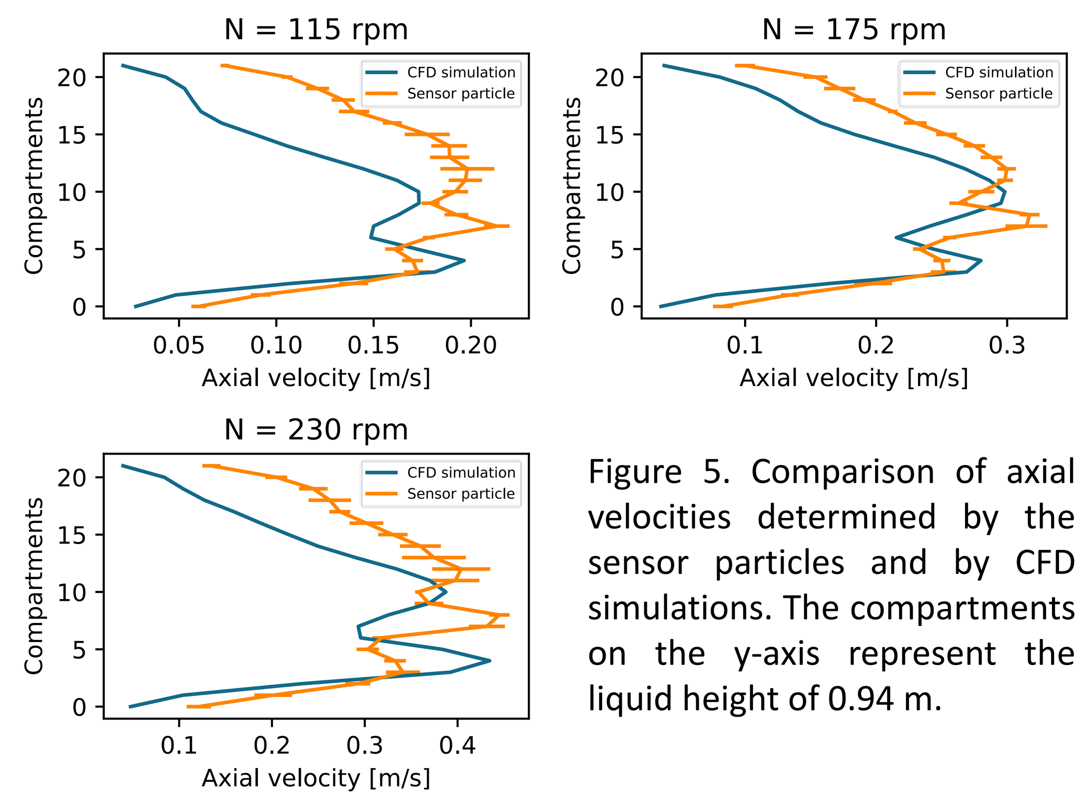


Figure 5. Comparison of axial velocities determined by the sensor particles and by CFD simulations. The compartments on the y-axis represent the liquid height of 0.94 m.

Conclusions

- Distributions of the sensor particles do not change significantly with increasing impeller speed.
- The circulation times determined by the sensor particles correlate with the experimental and theoretical mixing times: $t_c \approx (1/4)\ t_{m,theoretical}$ and $t_c \approx (1/6)\ t_{m,experimental}$.
- The determined axial velocities can serve as validation parameters of z-velocity vectors of CFD models.

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