Residence time distribution in a rotor-stator spinning disc reactor

RESIDENCE TIME DISTRIBUTION IN A ROTOR-STATOR SPINNING DISC REACTOR

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Summary

This paper describes the residence time distribution in a rotor-stator spinning disc reactor. This reactor consists of a disc with high rotation speed (up to 2000 rpm), between two stators with a small rotor-stator gap (0.5 to 3 mm). Residence time distribution experiments, at flow rates of 0.45 to 1.8 L/min, show that the flow in the rotor-stator spinning disc reactor can be described by a plug flow – mixer model. Predicted hydrodynamic velocity profiles confirm plug flow conditions in the center, and well mixed behavior near the rim of the disc. For higher rotation speeds ideal mixing behavior was found.

Keywords

Residence time distribution; Fluid flow modeling; Rotor-stator spinning disc reactor, multiphase reactor, Process intensification.

Introduction

In this paper we present a model of the single phase fluid flow in a rotor-stator spinning disc reactor (SDR) which is based on residence time distribution (RTD) measurements. The SDR consists of a rotating disc with two stationary discs. These rotor and stators are located at low axial clearance, typical in the range of millimeters. Due to the difference in rotational disc speed, a velocity gradient is present between the rotor and the stators, causing a high shear force to act on the reactor contents. This is shown in Figure 1.

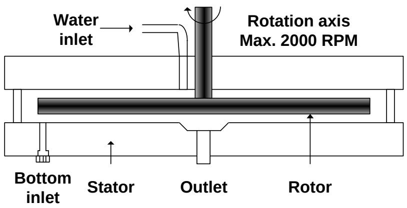

Figure 1. Schematic view of the rotor-stator spinning disc reactor.

For this reactor high liquid-liquid, liquid-solid, and gas-liquid mass transfer rates are published, together with micromixing times up to 0.5 ms [1-3]. This multiphase reactor is there for a promising tool to achieve process intensification goals. The single phase fluid flow pattern in enclosed rotor-stator systems is extensively studied because it simulates conditions found in a wide range of rotating machinery [4].

RTD is a concept used to characterize mixing and flow in chemical reactors and can be measured from a stimulus-response technique. The tracer concentration at the reactor outlet gives the RTD function, E(t).

$$E(t) = \frac{C(t)}{\int_0^\infty C(t)\, dt}$$

For comparison of reactors under different operational condition the normalized RTD-function is used, $E(\theta)=t_m E(t)$ where t_m is the mean residence time and θ the dimensionless time, $t\, t_m^{-1}$. The mean residence time and its variance, σ, are given by:

$$t_m = \int_0^\infty tE(t)\, dt \quad \sigma^2 = \int_0^\infty (t - t_m)E(t)dt$$

With the RTD known for a reactor, the selectivity and conversion in a multiphase reactor can be estimated for reactions which obey first-order kinetics. It is therefore a valuable tool to analyze the reactor performance.

Experimental approach

Water soluble ink was injected pulse wise through a T-piece at the inlet. At the inlet and the outlet of the reactor, the ink pulse was measured through an in-line UV-VIS flow cell. A typical time-absorbance diagram is shown in Figure 2.

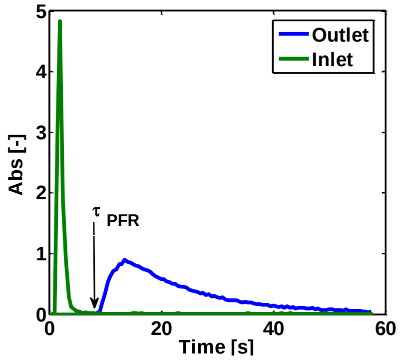

Figure 2. Measured ink concentration at the reactor inlet and outlet ($Q=7.5\cdot10^{-6}$ m³ s^{-1}, $\Omega=250$ RPM, and $h=1\cdot10^{-3}$ m).

The normalized residence time distribution curve is shown in Figure 3, together with a fit of three tanks-in-series with equal volume.

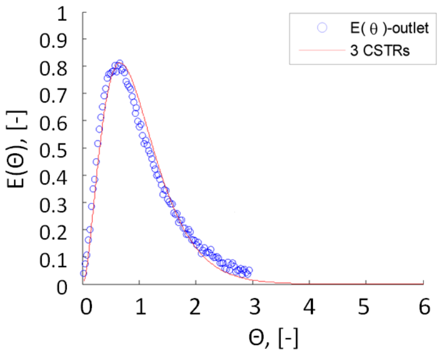

Figure 3. Normalized RTD curve together with a fit of three tanks-in-series with equal volume (t_m=18 s, τ_{PFR}=8 s, τ=22.3 s).

The residence time of the plug flow volume, τ_{PFR}, is determined from the first time at which the tracer is detected at the reactor outlet, as is shown in Figure 3. From the Q and τ_{PFR} the volume with plug flow behavior, V_{PFR} is calculated. This is shown in Figure 4. V_{PFR} decreases with increasing rotor speed and increases with the volumetric flow rate.

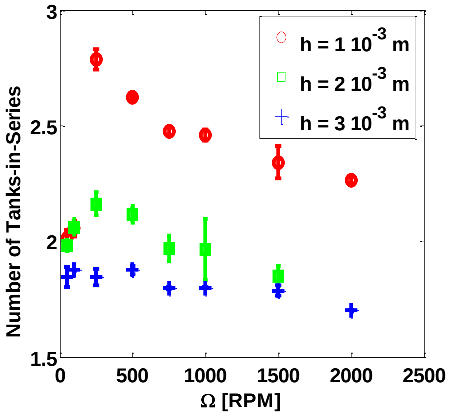

Figure 4. Rotational disc speed versus the measured plug flow volume at a disc spacing of $2.0\cdot10^{-3}$ m, for different flow rates.

Figure 4 shows that with increasing rotation speed the reactor becomes more ideally mixed. It also shows that the effect of the rotor speed is equally large for the investigated disc spacings. The number of tanks-in-series needed for a fit of the normalized RTD curve is given by $n = t_m^2\ \sigma^{-2}$. The relation between the rotational disc speed and the number of tanks-in-series is shown in Figure 5 and decreases with increasing rotational disc speed and decreases with increasing disc spacing.

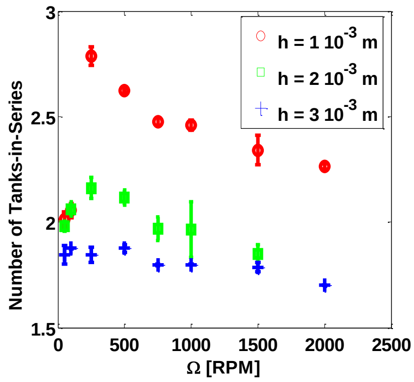

Figure 5. Number of tanks-in-series versus the rotational disc speed for varying disc spacings ($Q = 7.5\cdot10^{-6}$ m³ s^{-1}).

The residence time of the ideally mixed volume, t_m, in the reactor is determined from the normalized RTD-curve. Over all measurements a deviation of at most 8% is observed between the sum of τ_{PFR} and t_m with the theoretical residence time ($\tau = V/Q$).

Conclusions

- Single phase RTD measurements are performed as a function of rotation speed, volumetric flow rate and axial disc spacing.
- The RTD can be described by a plug flow - mixers-in-series model.
- The measured RTD allows for better predictions of yield and selectivity in this multiphase reactor.

References

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