LIQUID-SOLID MASS TRANSFER IN A ROTOR-STATOR SPINNING DISC REACTOR

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Summary

Liquid-solid mass transfer coefficients in a rotor-stator spinning disc reactor are reported that were determined from measurements of reaction rates of the heterogeneously catalysed oxidation of glucose. The overall reaction rates are limited by both liquid-solid mass transfer and the intrinsic oxidation kinetics at the operating conditions used. The liquid-solid mass transfer increases with increasing rotational disc speed. The estimated liquid-solid mass transfer coefficient $k_{LS}$ increases from $1.5 \cdot 10^{-4}$ m s$^{-1}$ at 49 rad s$^{-1}$ to $3 \cdot 10^{-4}$ m s$^{-1}$ at 181 rad s$^{-1}$, which is at least a factor 3 higher than in conventional reactors.

Keywords

Process intensification, Novel reactor technologies, Multiphase reactors, Spinning disc reactor

Introduction

There is an increasing demand in the chemical industry for smaller, safer, and more cost efficient versatile reactors. In multiphase reactions, gas-liquid and/or liquid-solid mass transfer are often rate limiting and determine the size of the reactor. A higher mass transfer rate can increase the reactor performance and the reactor can be made smaller. Meeuwse et al.$^1$ showed that in a rotor-stator spinning disc reactor, the gas-liquid mass transfer rates are up to a factor 10 higher than in conventional gas-liquid reactors.

The rotor-stator spinning disc reactor consists of a rotating disc between two stator walls, at 1 mm distance. With a catalytically active disc, this new reactor type can also be used for heterogeneously catalysed reactions, making use of the high liquid-solid surface area available per unit reactor volume. In this study, we have estimated the rate of liquid-solid mass transfer in the rotor-stator spinning disc reactor with a heterogeneous catalyst deposited on the disc.

Experimental

The experimental setup is shown in Figure 1. Operating conditions and dimensions are indicated in the figure. Glucose is oxidized to gluconate by using a 20 wt% Pt/C catalyst coating on the bottom of the rotating disc. Glucose is present in excess in the reactor (0.5 mol l$^{-1}$) and is therefore not rate determining. The kinetics of the reaction are an intricate function of the oxygen concentration$^2$, because of catalyst overoxidation. Low oxygen concentrations of 5 and 25 vol.% are therefore used here.

The overall reaction rate coefficient $K_{ov}$ is a function of the volumetric liquid-solid mass transfer coefficient and the intrinsic kinetics reaction rate coefficient and can be calculated from the decrease in oxygen concentration:

$$K_{ov} = \frac{\phi_L \left( C_{O_2}^{in} \right)}{V_R \left( C_{O_2}^{out} \right)^{-1}} = \left( \frac{1}{k_{LS} d_{LS}} + \frac{1}{k_p \eta_{cat}} \right)^{-1}$$

The rotational disc speed in the reactor only influences the liquid-solid mass transfer term. The temperature in the

Figure 1. Schematic drawing of the experimental setup of the rotor-stator spinning disc reactor.

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reactor has a much larger influence on the kinetic term than on the liquid-solid mass transfer term. Whether the system is mass transfer limited or kinetically limited can be determined by varying the rotational disc speed and the temperature.

**Results**

Figure 2 shows the overall reaction rate coefficient versus the rotational disc speed. The reaction rate increases with a factor 2 from 45 to 50 °C, which indicates that intrinsic kinetics are rate limiting, because the temperature influences intrinsic kinetics most. The reaction rate also increases by a factor 2 by increasing the rotational disc speed from 50 to 179 rad/s, which shows that the liquid-solid mass transfer is rate limiting as well. The comparable effects of rotational disc speed and temperature indicate that the kinetics and the mass transfer are of equal magnitude.

The overall reaction rate coefficient $K_{oc}$ can be used to estimate the liquid-solid mass transfer coefficient, however, the catalyst gradually deactivates by over-oxidation\(^3\). This can be seen in Figure 2, where the reaction rate at 45°C and 181 rad s\(^{-1}\) decreases with 20% in 20 min. Regeneration in an oxygen free environment fully restored the catalyst activity. The overoxidation was less at a 5% oxygen concentration, see Figure 3, which led to higher overall reaction rate coefficients. Overoxidation was still observed though, given the observed hysteresis effect.

The volumetric liquid-solid mass transfer coefficient is at least equal to the overall reaction rate coefficient, but is likely to be twice as high. With a liquid-solid interfacial area $a_0$ of 274 m\(^2\) m\(^{-3}\), $k_0$ is then estimated to be 3 to 6 · 10\(^{-4}\) m s\(^{-1}\), at 181 rad s\(^{-1}\). This is higher than in conventional reactors, where $k_0$ is typically 10\(^{-4}\) m s\(^{-1}\).\(^4\)

**Conclusions**

The overall reaction rate coefficient of glucose oxidation in the rotor-stator spinning disc reactor is limited by both liquid-solid mass transfer and intrinsic kinetics. The overall liquid-solid mass transfer coefficient $k_{0}a_0$ is estimated to be between 0.08 and 0.16 m\(^3\)L m\(^{-3}\)R s\(^{-1}\) at 181 rad s\(^{-1}\). This value can be increased up to a factor 8 by coating the whole disc and both stators, leading to a value of $k_{0}a_0$, which is higher than in conventional reactors, and is of equal order of magnitude as the overall gas-liquid mass transfer coefficient in the spinning disc reactor\(^1\).

**References**


