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## Summary

Reactor configurations based on rotating solid foams for fast three-phase reactions are presented. Solid foams are used as catalyst support and stirrer to mix the gas and liquid phases and to create fine gas bubbles. Mass transfer data are presented for different solid foam stirrer configurations and are compared to a slurry reactor with a Rushton stirrer. The foam block stirrer shows a  $k_{GL}a_{GL}$  of  $0.18 \text{ s}^{-1}$ , which is 60% higher than using a Rushton stirrer. With a value of  $4.2 \times 10^{-3} \text{ ms}^{-1}$  the liquid-solid mass transfer coefficient is around 20% higher than for the Rushton stirrer with copper slurry particles.

*Keywords: Multiphase and particulate reactors, Novel reactor technologies, Process intensification*

## Introduction

The fine chemical industry commonly uses batch reactors and slurry catalysts due to their high flexibility. Drawbacks are the separation of catalyst and liquid after the batch process. Furthermore, attrition can affect the reusability of the catalyst. Agglomeration of particles can lead to reduced selectivity and activity, especially for highly viscous liquids.

In this work reactor concepts for fast three phase reactions are developed. The aim is to use highly porous materials, such as solid foams, both as stirrer and catalyst support. This paper compares the gas-liquid and liquid-solid mass transfer and reaction rates of two different foam stirrer configurations to a standard system consisting of slurry catalyst and Rushton stirrer.

## Foam stirrer configurations

Two foam stirrer configurations have been developed. The foam blade stirrer shown in Figure 1A consists of two foam blades. Bubbles are created by the turbulence at the gas-liquid interface. Therefore thick blades should be used, which also increase the geometric surface area for catalyst

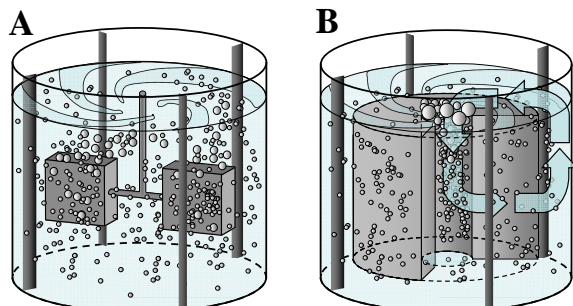


Figure 1: Foam Blade Stirrer (A); Foam Block Stirrer (B)<sup>1</sup>. deposition. The gas holdup can further be increased by using hollow tubes and a hollow stirrer shaft in order to induce bubbles at the blades. The foam block stirrer, shown in Figure 1B, fills a large part of the reactor volume and allows the deposition of more catalyst.

## Gas-liquid mass transfer

In various three-phase reactions, such as oxidation reactions, the dissolution rate of gas into the liquid is the rate limiting process.

The gas-liquid mass transfer rates are investigated by measuring the absorption of oxygen into water (Figure 2). The power input is measured by using a torque meter.

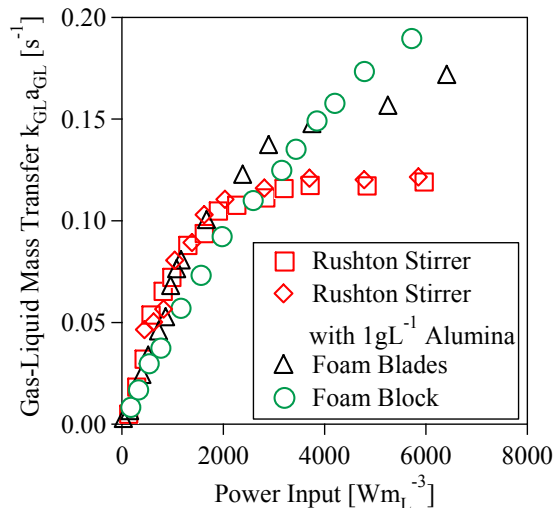


Figure 2: Gas-liquid mass transfer rates for two solid foam configurations (see Figure 1) and for a Rushton stirrer

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with and without alumina particles as a function of power input.

The diameter of a Rushton stirrer is commonly between one third and a half of the reactor diameter. This leads to the creation of a high shear region in the reactor center. However, the momentum added is not extended to the entire reactor volume and the gas-liquid mass transfer rate levels off at  $2000 \text{ W/m}_L^3$  (Figure 2).

The diameter of the foam stirrers is three quarters of the reactor diameter. This distributes the momentum over the entire reactor volume. Additionally, gas bubbles are broken by collisions with the foam struts. The fine bubbles passing the foam struts experience strong velocity fluctuations leading to an almost linear increase of the gas-liquid mass transfer rate for the foam block stirrer. At a power input, of  $6000 \text{ W/m}_L^3$  the mass transfer rate is around 60% higher than for the Rushton stirrer with slurry particles.

## Liquid-solid mass transfer

The mixing of the reaction components and the diffusion through the boundary layer to the catalyst surface is another essential step in three phase reactions. Especially in the fine chemical industry large molecules are converted, which have low diffusivities compared to the gas component.

In this section the liquid-solid mass transfer is compared between the foam block stirrer (Figure 1B) and a standard system consisting of slurry particles and a Rushton stirrer. The corrosion of copper by sodium dichromate is chosen as a liquid-solid model reaction. The concentration change of chromate(VI) is measured using UV/Vis-absorption. Passing gas bubbles can affect the turbulence at the liquid-solid interface and therefore the mass transfer.

Figure 3 shows the liquid-solid mass transfer coefficients for the copper slurry particles. Similar to the gas-liquid mass transfer at high rotational speeds, in this case the momentum added does not lead to an appreciable increase of the liquid-solid mass transfer coefficient either.

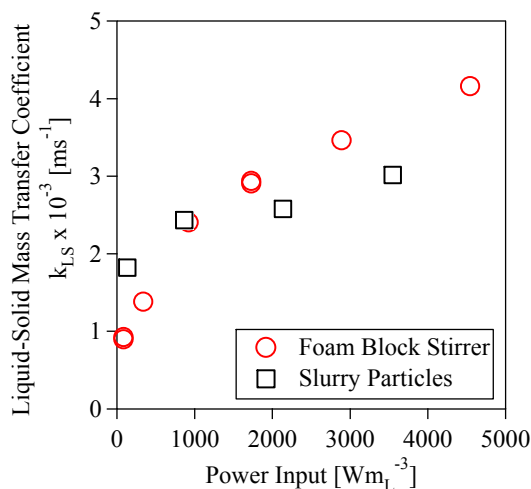


Figure 3. Liquid-solid mass transfer coefficients for slurry particles and foam block stirrer (Figure 1B).

For the foam block stirrer, the liquid-solid mass transfer coefficient still increases in the range of high power input. An important aspect is the effect of the pore size and porosity of the solid foam structure. A fine pore structure increases the liquid-solid interfacial area. However, finer pores lead to a higher pressure drop and lead furthermore to a less turbulent flow. This reduces the liquid-solid mass transfer coefficient. In the paper this aspect will be discussed extensively.

## Three phase model reaction

In the previous sections high gas-liquid and liquid-solid mass transfer rates could be obtained using the foam block stirrer. As a proof of concept the performance will further be compared to a slurry catalyst system using the oxidation of glucose by  $\text{Pt}/\text{Al}_2\text{O}_3$  as fast three phase model reaction<sup>2</sup>. Alumina layers are deposited on the foam structures applying a wash coating procedure used for coating of monoliths<sup>3</sup>. Prior to the coating the foam is anodized. It results in mechanically stable coatings with a thickness up to  $20 \mu\text{m}$  and a bimodal pore size distribution. Large pores in micrometer size range increase the diffusion through the catalyst layer. Small pores in nanometer size range increase the specific surface area. Platinum is deposited using deposition precipitation. The reaction rate is measured by the change of the pH. Furthermore the liquid oxygen concentration is measured, which allows to draw conclusions on the rate of gas-liquid mass transfer.

## Conclusions

Especially the foam block stirrer shows a promising performance. The reactor volume is filled out with the solid foam structure. The mass transfer rates are superior compared to the Rushton stirrer and slurry particles. It shows high potential for further optimization of the liquid

circulation and therefore for a further increase of the mass transfer rates.

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