INVESTIGATION OF ACTIVE MASS TRANSPORT PHENOMENA INSIDE A MICROCAPSULE

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Microcapsules are used in many chemical or biochemical processes. They consist of semi-permeable membranes, which enclose absorbing solutions or vital biomaterial. The flow field generated by the motion of the body inside the capsule and the mass transport improvement by this flow field were investigated by utilizing computational fluid dynamics (CFD) and particle image velocimetry (PIV) methods.

INTRODUCTION

In general, the capsules have a spherical shape with a diameter of about 3 mm. The microcapsules are surrounded by a fluid, which contains the nutrients and other components required for the process. A convective flow of this fluid transports nutriments and metabolic products to and from the outer membrane. These substances pass the membrane of the microcapsule by diffusion. The transport within the microcapsule depends also only on diffusion. However, the diffusion is a slow process, which can render the whole process uneconomic. A new approach is used here to accelerate the transport process within the microcapsule by introducing convection. This convection conveys substances from the membrane into the center of the microcapsule and vice versa. This is achieved by a placing of movable body inside the microcapsule. It has a different density from the fluid within the microcapsule. It can be moved relatively to the microcapsule by applying an external force through a magnetic field or acceleration/deceleration.

METHODS

A CFD method was used to investigate the possible effect of the mass transport improvement inside the microcapsule by convection. The CFD flow program packet FLUENT5 was used. It creates a structured or unstructured computational mesh and is well suited for incompressible flow and transport problems. A simplified model was applied: a spherical body was placed in the spherical shape capsule. Only transversal motion of the body along the microcapsule axes was considered. Such simplification requires the solution of a two-dimensional axial-symmetrical problem. Three numerical models with different diameters of the body were generated with geometrical pre-processor Pre-BFC. A steady convective flow field inside the microcapsule was generated and a non-stationary transport process inside sphere with a steady flow field was calculated. A constant concentration of the diffusing substance outside the capsule was defined as the boundary condition. During this non-stationary simulation the position of the body was kept constant. The Peclet number $Pe = D\langle V\rangle/D_f$ is a dimensionless parameter, which defines a relation between convection and diffusion. D is the diffusion path, $\langle V\rangle$ is the averaged velocity magnitude of the flow field and D_f is the diffusion constant of the transported material. Two parameters of the Peclet number were varied in our investigation: The diffusion path by use of different body diameters and different values of the averaged velocity produced by the body movement inside the microcapsule. The measurement of the transport improvement effect was made by the comparing the times needed to achieve an 80% saturation in the capsule. This reduced the time of numerical calculations. Furthermore, the relation between velocity magnitude of the body motion and the average velocity in the microcapsule was investigated. This was done experimentally. An experimental set-up for flow field investigation in the enlarged microcapsule model was build (see Fig. 1). The flow field in the capsule was measured with the PIV method. The flow was assessed with a digital camera MX12 (1024x1024 Pixel). The light sheet was generated with an Argon laser Exel 3000 (2 W). A cross-correlation method implemented in the Visiflow software was used to analyze the velocity field.

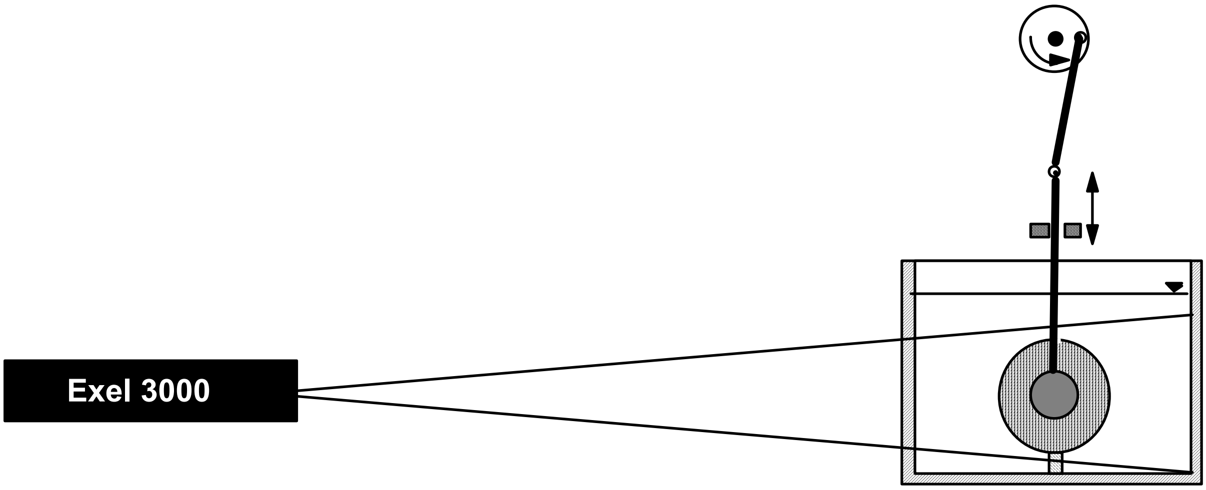

Figure 1: Schematic drawing of the experimental set up. The rotational movement of the motor is converted in the linear motion of the body in the fixed capsule. The capsule made of transparent polysterene is filled with water containing particles Vestosint 7182 (BASF) and placed in the transparent water bath.

RESULTS

The results of CFD simulation show that a transport process can be improved only due to introduction of the movable body. The period to achieve 80% saturation in the microcapsule was reduced by 40% with body diameter equal to the half of the capsule diameter. This is a result of a diffusion path length reduction. The convection in the microcapsule results in further acceleration of the transport. The period can be reduced in further by 60% (Peclet number Pe = 600) in comparison to the transport process with a stagnant body without convection. Hence, the transport process can be accelerated 4-5 times by the introduction of the body inside a microcapsule and the generation of convection by body motion. Fig. 2 shows results of the transport after some time in the capsules with a body, which generate a convection (left) and with a body, which stay at rest (right).

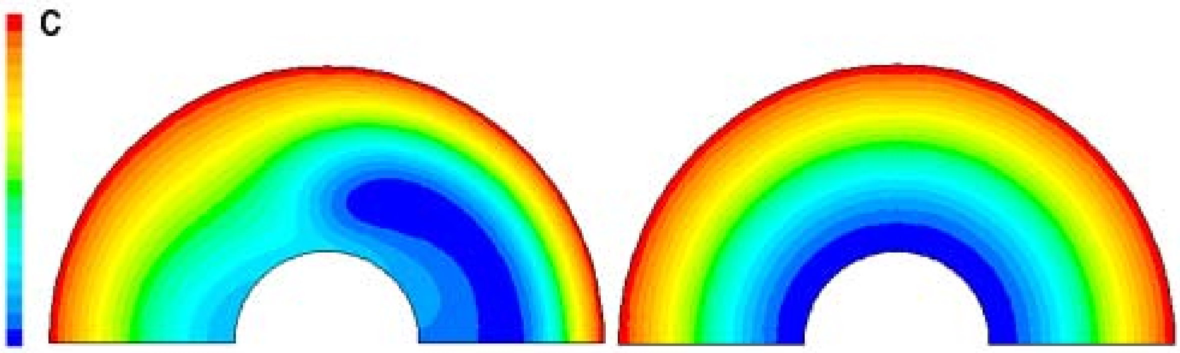

Figure 2: Concentration distributions in the microcapsule model with convective flow field (left) and with only diffusive transport (right) after the same period.

Fig. 3 shows some examples of flow field generated by a body movement inside a capsule assessed in our experiments. The experiments showed that the relation between the averaged flow field in the microcapsule <V> and body velocity V is about <V>/V=0.09 for a body diameter of half the capsule diameter. Moreover, the experiments showed that the relation is a function of the body velocity.

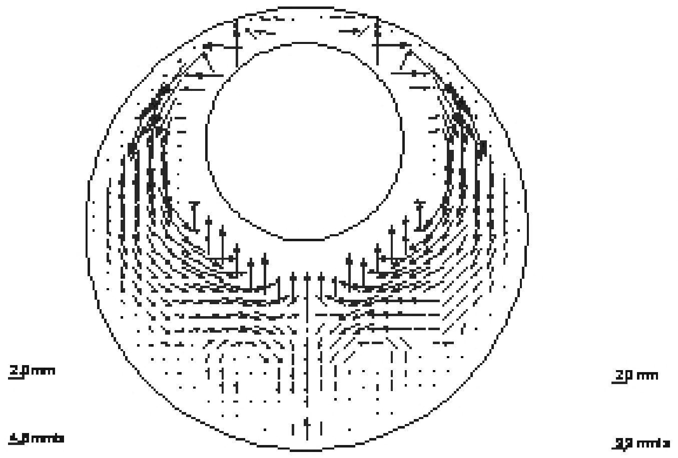

Figure 3: Examples of two velocity fields generated by the motion of the spherical body in the capsule.

CONCLUSIONS

The results of the investigation show that a significant improvement of the material transport in the microcapsule can be achieved by the generation of a convective flow field inside the microcapsule. The effect was investigated as a function of Peclet number. The results showed a complex character of this process. The resulting effect depends on generated flow field inside a microcapsule, which depends on size, velocity and position of the body.