MODEL EXPERIMENTS ON THE MASS TRANSFER IN A TUBULAR SOFC

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ABSTRACT

A theoretical calculation of different channel shapes based on the connection between mass transfer and heat transfer shows that a tubular-helix design increases the mass transfer within a SOFC tube. The theoretical model indicates that the geometric influences can be separated. Thus a cold model test rig is applicable where a porous tube replaces the SOFC. The test rig consists of two separated loops one filled with salt solution and one filled with water connected by the porous test tube element only. The mass transfer between the salt solution inside the porous tube and the water outside the porous tube can be identified by conductivity meters installed at the end of test tube element and flow meters installed in both loops. The first measurements confirm the theoretical predictions that the tubular-helix design leads to the highest mass transfer per volume. The proposed method is comparable cheap, the test rig costs less than 2000.- Euro. A further use of the method will show its borders. However an indicative screening can be done by this experiments.

INTRODUCTION

The mass transfer within a stack influences its power density. Thus an interesting question of engineering is to find the optimal geometry to get the highest possible mass transfer in a certain volume. An analysis about the geometric influences was made in (1). By using the connection between mass transfer and heat transfer the mass transfer coefficient can be calculated like the heat transfer coefficient if we use the Sherwood number Sh and the Schmidt number Sc instead of the Nusselt number Nu and the Prandtl number Pr in the expressions of an adequate heat transfer problem as given in (2). The transferred molar flux \( N_X \) (mol/s) between a wall and the bulk flow is defined by :

\[
N_X = \beta \cdot A \cdot \Delta c_X. \tag{1}
\]

\( \beta \) is the mass transfer coefficient (m/s), \( A \) is the active area (m\(^2\)) and \( \Delta c_X \) (mol/m\(^3\)) is the concentration difference between bulk flow and solid surface. The Sherwood number \( Sh \) is defined as:

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Sh = β * L / D. \[2\]

L is the characteristic length (m) and D is the diffusion coefficient (m²/s). The Schmidt number Sc is defined as:

\[ Sc = \nu / D. \] \[3\]

\( \nu \) is the kinematic viscosity. The third dimensionless number - the well known Reynolds number Re - is defined with the velocity \( w \) (m/s) as:

\[ Re = w * L / \nu. \] \[4\]

In [4] the hydraulic diameter \( d_H \) of the considered flow channel is the characteristic length \( L \) for all types of stacks. The length of the flow channel is \( l_e \) and the Sherwood number \( Sh \) can be calculated by expressions like:

\[ Sh = Sh(Re, d_H/l_e ; Sc). \] \[5\]

The influence of the geometry can be separated as shown in (1) from the other effects as thermodynamic data, SOFC operation etc. Figure 1 gives an impression. The terms of the mass transfer coefficient \( \beta \) containing the geometric influences are marked.

**Fig. 1** The influence of the geometry on the mass transfer coefficient

The different interesting flow channel shapes of a tubular and a planar design have been studied in (1). The proposal of the tubular-helix design is a result of the analysis done in (1). The reason of this proposal is the weak mass transfer by convection occurring in the laminar flow of a fuel cell. The geometry of the tubular-helix design is given in figure 2. The helix integrated in the tube has a similar influence on the mixing of the flow as an extruder.

**Fig. 2** The tubular-helix design

The base of the calculations had been the collection of certain geometric shapes of the
flow channel considering the heat transfer. The use of collected data as from (2) restricts the geometry to be studied on certain shapes that can be found. Thus there is a demand on testing different shapes that cannot be found in the literature.

THE MEASUREMENT PRINCIPLE AND THE TEST RIG

The experiments with original SOFC with different shapes are very expensive. Thus it is useful to look for a screening method to evaluate the different proposals even only relatively. As shown above the influence of the shape can be separated from the other influences if we only compare the different shapes and we get:

\[
\beta = \beta_0 \cdot FG. \tag{6}
\]

\(\beta_0\) is the mass transfer coefficient of a reference shape and \(FG\) is the geometric factor representing the influences of a changing of the shape. Because of (6) we can change the temperature and the thermodynamic properties of the fluids. Thus a cold model built with plastics can be used. The fuel cell is replaced by a membrane with bores to allow the mass transfer. A salt solution is at one side of the porous membrane and pure water is at the other side. The flow of the solution influences the mass transport of salt to the other side of the porous membrane and the pure water becomes a solution. This mass flow of salt changes the electric conductivity of the flows. The conductivity can be detected by a

\[\text{Fig. 3 View of the test tube element}\]

side of the porous membrane and the pure water becomes a solution. This mass flow of salt changes the electric conductivity of the flows. The conductivity can be detected by a
conductivity meter. Figure 3 gives an overview of the test tube element to be used for experiments for the shape of a tubular SOFC.

The test tube can be fitted with an annular tube or different helixes. The outside of the test tube element can be fitted with parallel tubes. A helix is mounted at the outside of the test tube element to assure a sufficient outside flow for experiments with one single tube.

Fig. 4 The test rig with the integrated test tube for studies on the mass transfer

The test tube element is integrated into two separate loops. At the beginning the primary loop is filled with the solution and the secondary loop is filled with water. Any loop is fitted with a circulation pump. The membrane is the only connection between the two loops. The conductivity meter is placed at the outlet of the both loops at the end of the test tube element. The flow in both loops is continuously measured by flow meters. The signals of the conductivity meters and the flow meters are registered by a PC. The transferred mass flow and thus the mass transfer coefficient can be easily calculated. A benefit of this arrangement is that any concentration difference measured can be used to calculate the transferred mass of salt.

The cost of such a test rig is comparable cheap. Depending on the equipment an amount of about 2000.- Euro plus a PC is sufficient. The results as shown below allow to compare the influence of different shapes of flow channels on the mass transfer. Figure 5 gives an impression of the original dimensions of the test tube element integrated in the test rig.
THE EXPERIMENTAL RESULTS

The resulting measurements of the first tests (3) are shown in figure 6. The line T1 is representing the test tube without any equipment. The lines TA represent two tubular annular flows with the two different hydraulic diameters dH of 4 and 8 mm.

![Figure 5](image_url) View of the test tube integrated in the test rig

![Figure 6](image_url) The conductivity of the flow of the primary loop

The tubular-helix design is represented by the line TH1. Figure 6 clearly shows that the fastest decrease of the conductivity is caused by the tubular-helix design as predicted by the theoretical model.

These results can be used to calculate the geometry factor FG by using equation [6]. The tubular design T1 is the reference design thus FG = 1 here. Again the results show the benefit of the tubular helix design TH1 as shown in figure 7.
CONCLUSIONS

The measurements confirm the theoretical predictions of the higher mass transfer in a tubular-helix design. The method to measure the conductivity of a salt solution in two loops connected by a porous test tube as an indication of the mass transfer within a tubular SOFC is a cheap method to identify interesting geometric solutions. The first results of measurements of different shapes confirm the tendency of the theoretical calculations of the mass transfer based on heat transfer relations. But the method has to be further studied to identify its borders.

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Fig. 7 The geometry factor FG resulting from the flow experiments with different tubular shapes