CFD simulation of hydrodynamics and heat transfer in a rotor-stator spinning disc reactor

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Highlights

- 2D RANS simulation of the flow profiles in a rotor-stator spinning disc reactor.
- Heat transfer simulation of a RSSDR with a modified *chtMultiRegionSimpleFoam* solver.
- Locally resolved temperature distributions and heat transfer coefficients are determined.
- The average heat transfer coefficients are in qualitative agreement with experimental results.

1. Introduction

The aims of process intensification (PI) are the improvement of ecological, economic and safety aspects of a chemical process by using inventive reactor technologies [1]. To overcome heat transfer limitations of chemical reactions is a key aspect of PI, since insufficient heat removal might lead to a decrease in selectivity or thermal runaways. A novel reactor technology addressing the intensification of heat and mass transfer limitations of chemical reactions is the rotor-stator spinning disc reactor (RSSDR), a schematic of which is shown in Fig. 1. The regarded RSSDR consists of a rotor (r = 65 mm) enclosed in a cylindrical housing. The distance between the rotating and static parts is 1 mm. High shear forces are induced in the fluid in the reactor gap. In dependence of the operating conditions (dimensionless throughput C_w and rotational Reynolds number Re_ω) turbulences and the formation of different flow regimes are caused [2,3], which influences the heat transfer in the reactor setup. A 2D axisymmetric study of the experimental reactor setup is performed using the open-source software OpenFOAM®, since former experimental studies on the heat transfer in a RSSDR did not allow for a detailed investigation of the flow conditions, local temperature distributions and local heat transfer coefficients.

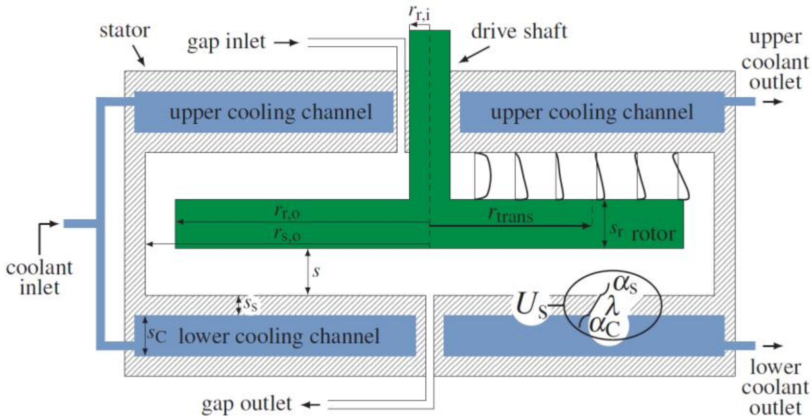

Figure 1. Schematic of the rotor-stator spinning disc reactor [4].

2. Methodology

The different regions of the reactor setup (reactant gap, upper and lower cooling channel, rotor and stator) were meshed with the *blockMesh* utility of OpenFOAM®, whereby only 5° of the rotationally symmetric regions were considered in order to reduce computational cost. Preliminary work on similar rotor-stator cavities investigating the applicability of different Reynolds-averaged Navier-Stokes (RANS) turbulence models, revealed that the Lien-Leschziner model is well suited for the simulation of rotor-stator cavities with superimposed throughput. Hence, this model was used for the flow simulation of the reactant gap and the cooling channels using the steady-state solver *simpleFoam*. The solutions of the cold flow simulations were used in the heat transfer simulation of the regarded rotor-stator setup using a modified *chtMultiRegionSimpleFoam* solver. The modification considers the dissipative power input due to rotation as additional term in the energy balance. A parameter study for the flow profiles and heat transfer were performed within the parameter range $Re_\omega = \omega\, r^2\, \nu^{-1} = 6.5 \cdot 10^4 - 4.25 \cdot 10^5$ and $C_w = V_R\, r^{-1}\, \nu^{-1} = 232 - 400$.

3. Results and discussion

Exemplary results of axial temperature profiles at different radial positions in the lower reactant gap for a rotational Reynolds number $Re_\omega = 2{\cdot}10^5$ and a dimensionless throughput of $C_w = 232$ are shown in Fig. 2. With increasing radial position, the axial temperature profile features a steeper increase and the thermal boundary layers at the rotor and stator side become smaller (Fig. 2). The same behavior is observed with higher rotational disc speeds for a fixed radial position, which is attributed to a higher degree of turbulence due to a higher local energy input. An increase in volumetric throughput on the one hand reduces the thermal boundary layers, and on the other hand reveals an axial temperature profile being less steep. Fig. 2 further shows that a determination of a bulk temperature in the reactant gap is possible, as the stator- and rotor-side thermal boundary layers are not merged in contrast to the observed hydrodynamic layers. This allows the determination of local heat transfer coefficients α via $\dot{q} = \alpha\,(T_{wall} - T_{bulk})$. The local heat transfer coefficients generally increase with increasing radial positions depending on the interplay between C_w and Re_ω. Fig. 3 shows average stator-side heat transfer coefficients for the regarded reactor setup in dependence of the Re_ω and C_w. An increase in the heat transfer coefficient with increasing Reynolds number is visible and at $Re_\omega > 2{\cdot}10^5$ a slight increase with a rise in C_w can be observed. The results obtained from this numerical study are in qualitative agreement with experiments performed in a RSSDR with the same dimensions and the results are about the same magnitude [4].

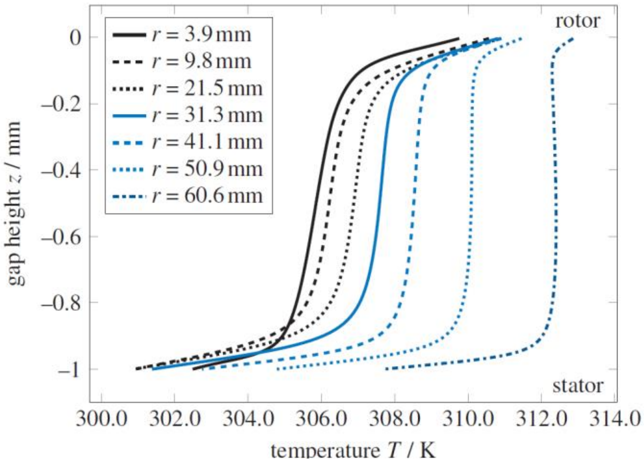

Figure 2. Axial temperature profiles at different radii in the lower reactant gap for $Re_\omega = 2{\cdot}10^5$ and $C_w = 232$.

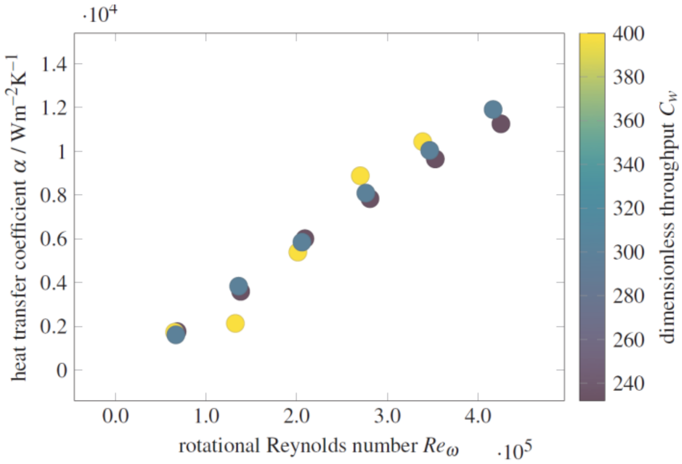

Figure 3. Average stator-side heat transfer coefficients in dependence of the rotational Reynolds number and the dimensionless throughput.

4. Conclusions

A 2D study of the flow profiles and heat transfer in a RSSDR has been performed using OpenFOAM®. Locally resolved temperature distributions of the reactor gap are retrieved, which allows the determination of radially resolved heat transfer coefficients. The average values of the determined local heat transfer coefficients are of the same order of magnitude in comparison to experimental results. This study shows the possibility of determining the heat transfer within a RSSDR with the aid of a simplified 2D model of the regarded reactor setup using a RANS turbulence model in OpenFOAM®.

References

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Keywords
Rotor-stator spinning disc reactor; heat transfer; local temperature distribution; computational fluid dynamics.