Excerpt from the Proceedings of the 2011 COMSOL Conference in Stuttgart

Mass Transfer from a Rotating Cylinder in a Confined Gas Flow

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Abstract: The flow around a rotating cylinder is of primary importance to many chemical engineering application fields. The purpose of this work is to investigate the isothermal sublimation of a rotating vertical cylinder of naphthalene immersed in a cylindrical container where a small stream of nitrogen was uniformly blowing gently. The study is developed on both experimental and theoretical aspects. A number of mass transfer experiments and simulations have been planned and performed, in order to obtain engineering estimates in terms of amount of naphthalene sublimated per unit time at various operating conditions such as surface temperature, inert flow rate and the rate of rotation. The experimental values have been compared with the simulated results.
Both, 2D axisymmetric and 3D, stationary models based on transport phenomena in dilute solutions and incompressible fluid flow have been adopted.

Keywords: incompressible fluid flow, dilute solutions, rotating cylinder.

1. Introduction

The study is developed on both experimental and theoretical aspects.

1.1 Theoretical aspect

The naphthalene sublimation technique has been employed to obtain heat and mass transfer coefficients for a large number of flows past on the fixed surfaces, which justify the absence in the literature of technical correlations for estimation of mass and heat transfer coefficients in the case of solid rotating cylinders submerged in the flow of gases. The fine enhancements are expected based on available electrochemistry results, where the electrode rotations in liquid solutions are extensively reported as a good enhancement procedure.

1.2 Experimental aspects

An appropriate experimental apparatus with subsections for inlet gas preliminary heating and metering, gas composition sampling in the vessel and other auxiliary instruments has been designed, constructed and assembled and different experimental runs have been conducted to study the effect of rotation. Also the gas sampling device configuration and its influence on the measurement accuracy and precision is investigated. The cylindrical symmetry for the system is assumed and ensured experimentally by appropriate devices and restoring to simple tricks. Estimations of amount of naphthalene sublimated per unit time, at various operating conditions, have been obtained. At present, very few correlations are available in the scientific literature.
In the figure 1 is represented the experimental rig, which is realized in the Laboratory of University of L'Aquila.

Figure 1. Experimental Apparatus

2. Mathematical Models and Governing Equations

The model of a Newtonian-incompressible flow has been adopted to simulate the nitrogen flow through the vessel. The governing equations are the well known Navier-stokes; whereas, the naphthalene concentration in the vessel is calculated by the model of mass transfer in dilute solutions.:

$$\frac{Dc_A}{Dt} = v \cdot \nabla c_A = D_{AB} \cdot \nabla^2 c_A$$

Where, C_A is the concentration of the Naphthalene and D_{AB} is the binary diffusion coefficient of naphthalene - nitrogen.
All the governing equations are just implemented in Comsol. As can be seen, the last model is coupled through the velocity filed with the first one.

3. Use of COMSOL Multiphysics
2D axisymmetric and 3D stationary mathematical models based on transport phenomena in diluite solutions and incompressible fluid flow have been utulised. The conservation of dilute species with constant Fickician diffusion coefficient is coupled both with incompressible Newtonian fluid flow by Navier-Stocks equations in laminar regimes, when the cylinder of naphthalene is nearly at rest; and with Reynolds Average Navier-Stocks in the turbulent regime with rotating cylinder.

The geometry of the experimental apparatus is reproduced in scale and all boundary conditions are imposed.

4. Simulations: Boundary conditions

All simulations are performed in stationary regime and represented by:

- 2D Laminar flow with cylinder at rest,
- 2D Turbulent flow with rotating cylinder,
- 3D laminar flow with cylinder at rest.

The Relevant boundary conditions are summarized as follows:

A constant concentration equal to the saturation pressure of solid naphthalene is imposed on the surfaces of rotating cylinder;
To simulate the rotation of cylinder, a tangential velocity is imposed by adding the swirl flow function, available in 2D modeling package.
No slip conditions is imposed on all internal surfaces at rest.
A uniform inlet velocity in accord of experimental flow rates is assumed.

5. Results and discussion
To evaluate the entity of mass transfer taking place form the naphthalene surfaces, the total flow rate of sublimated naphthalene is calculated by integrating the convective concentration flux on the outlet section. This integration is conveniently performed by using an average function applied to the product of concentration and axial velocity.

In the case of simulation by 2D axisymmetric models; for the laminar regime, as expected, the rotation implemented by the swirl flow function, produced no effect on the concentration field, as shown in the figure. This could be explained, as the concentration gradient is everywhere orthogonal to the additional tangential velocity no contribution will come. The situation is not so clear in the turbulent regime simulated by RANS. Our simulation presented no effect also in this case. It is noteworthy and shown by experimental data that the effect of motion on the concentration field is important particularly near the naphthalene cylinder.

Some results for 2D simulation in the case of the rotating cylinder are reported in the table 1.

Q[l/hr]	T[°C]	omega[rpm]	N[mmol/hr]
332	47	200	16,200
636	47	300	10,224
332	47	380	16,560
636	47	400	10,3

Table 1. values of the Naphtalene flow rate in 2D turbulent flow.

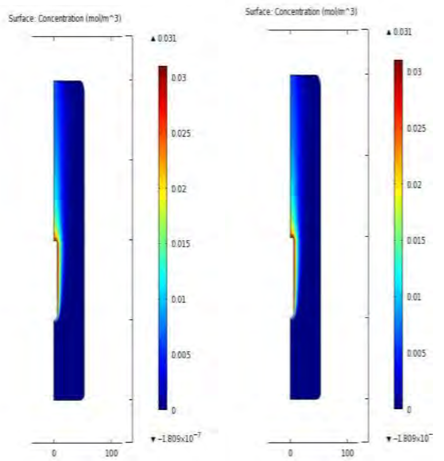

Figura 2. concentration profiles at 47°C 636 lit/hr. a) on the left 0 rpm; b- 200 rpm

In case of the 3D simulations. The results obtained were not in agreement with the 2D simulation data even in the absence of any rotation and in the presence of laminar regime (see figure 3). Unfortunately, the reason is not clear for us.

Figure 3. concentration profile for Q=636l/hr, T=47°C, ω=200rpm

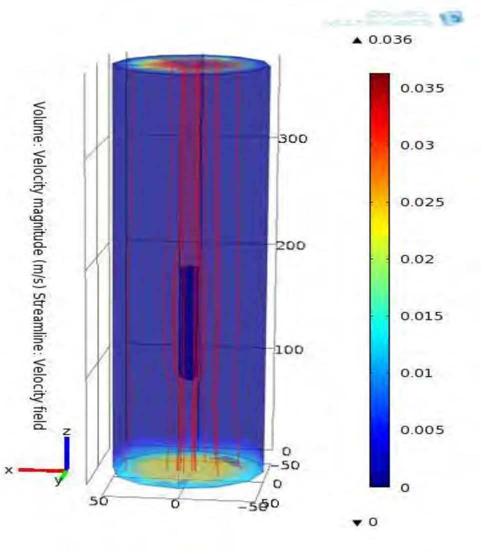

Figure 3. 3D velocity field , Q=636l/hr, T=47°C, ω=0 rpm, laminar flow

Different 2D and 3D simulations are performed in laminar regime by increasing the inlet velocity up to 20 times. The comparison of sublimated naphthalene data indicates that the discrepancy of the values also depends on the magnitude of the inlet velocity.

6. Conclusion

Sublimation of naphthalene from a rotating solid cylinder is investigated by simulation in comosl multiphysics. 2D axisymmetric and 3D simulation are performed. the 2D and 3D produced different results by an order of magnitude even in laminar flow with no rotation of cylinder. The swirl flow function is utilised in 2D simulation and some inadequacy is obtained when the flow model is coupled with other physics. the results and conclusions reported here could be not correct and need further confirmation due to the author's limited knowledge and ability to run efficiently comsol.

7. References

2. Annalisa Scarpetta, Studio del trasporto di materia da un cilindro di naftalene rotante in una corrente assiale di azoto, Bsc. Thesis, 2011 Chemical Engineering. Dept., UNIVAQ.