EXPERIMENTAL AND NUMERICAL SIMULATION OF FILM FLOW ON A ROTATING DISK

Yuan Zong[1], Bin Deng[1], Hanguang Xie[1], Jianguang Hu[1],
Xiaogang Yang[2], Gance Dai[1]*
1. State Key Laboratory of Chemical Engineering, East China University of Science and Technology, Shanghai, China, 200237
2. International Doctoral Innovation Center, The University of Nottingham Ningbo, Ningbo, China, 310234

Abstract

Rotating disc reactors are typical devolatilizing devices with high mass transfer efficiency, which are attributed to the thin liquid film formed under the centrifugal action of the dick. The movement of the film determines not only the thickness, holdup and area of the film, but also the surface renewal frequency of the reactor. In the present work, an experimental study is reported on the effect of disk rotation speed and disk structure on film velocity. Numerical simulation is adopted to investigate the relationship between surface renewal and the rate of film deformation. Surface renewal frequency for laminar liquid film is derived in a simple form to assess the effect of open window in the disk on mass transfer. The results show that the film on the rotating disk can be divided into three regions according to different characteristic velocity and film thickness. Each region takes different responsibility for mass transfer. The renewal frequency of the free film formed in open window is 50% higher compared with the wall-bounded film. Moreover, the free film is found to intense the renewal efficiency of the neighboring wall-bounded film. The total surface renewal efficiency on the disk with open window is increased with increasing of free film area.

Keywords

Rotating disc reactor, Numerical simulation, Surface renewal, Free film, Wall-bounded film

Introduction

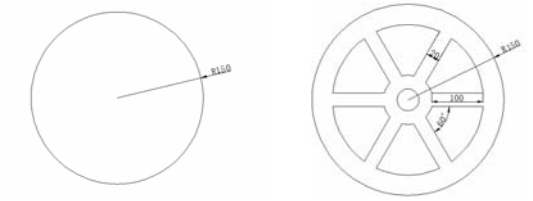
As a core equipment, rotating disk reactor (RDR) has been employed for devolatilization and polymerization for the final polycondensation reactions of many industrially engineering thermoplastics such as poly(ethylene terephthalate) (PET) since 1960s'. Due to its excellent heat and mass transfer performance, the application of the rotating disk reactor has been extended into photocatalysis[1], fine chemicals[2], petroleum[3], fuel cell[4], etc. It has long been known that the performance of the RDR mainly depends on the surface renewal of the thin liquid film. Despite a considerable number of experimental and theoretical investigations have focused on the transport phenomena of RDRs, few studies are done on the frequency of the surface renewal of its liquid film.

Danckwerts[5] proposed surface renewal theory by modified the penetration theory. He assumed that eddies at the interface are randomly replaced by fresh eddies from the bulk of the liquid and each of them has equal chance of being replaced. According to this theory, he introduced a fractional rate of surface renewal (*s*) and its distribution function to quantify the fraction of the surface area renewed in unit time. Extensions of this surface renewal model have been applied for many low-viscosity systems. In fact, surface renewal is ubiquitous and important mechanism for high-viscosity systems while the main flow pattern is laminar flow. Many researchers have found that the surface renewal frequency in such cases are closely related with fluid viscosity, liquid holdup, disk rotating speed and velocity of the film for RDR. Hence, it's of

great interest to explore the hydrodynamic behavior of the laminar liquid film flow on the disk.

In the present work, numerical and experimental investigation of the flow behavior and surface renewal are performed for the liquid film on the disk with open window. Surface renewal frequency for laminar liquid film is derived to analyze the reinforcement effect of open window for mass transfer.

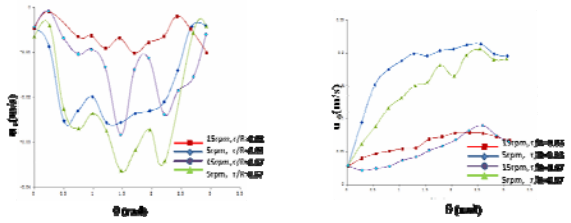
Flow field on two disks with different structure has been investigated by PIV. Disk A is a solid disk and Disk B is a disk with 6 open windows around the axis, as listed in Fig. 1.



(a) Disk A (b) Disk B

Fig. 1 Disk structure

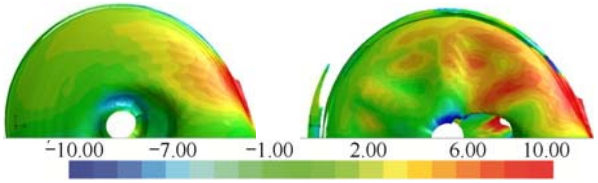
Generally, it can be found that there exists three regions on the disk, i.e. initiation, acceleration, and steady region. Due to lack of the wall support, gravity force and rotation of the disk is found to increase the radial velocity in the free film, while the open window doesn't have obvious effect on the tangential velocity of the liquid film, as seen in Fig.2.



(a) radial velocity (b) tangential velocity

Fig.2 Velocity distribution on the disk for Disk B by PIV

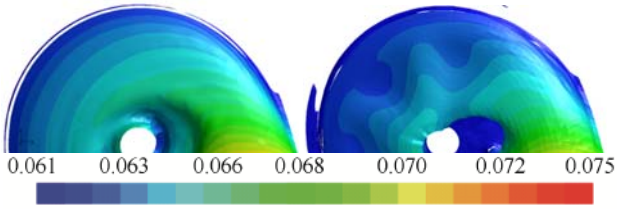
The numerical study is coupled with volume of fluid (VOF). Fig.3 plots the surface renewal frequency of the film surface. It can be found that the acceleration region in Disk B has faster surface renewal frequency, by about 50%. And the total surface renewal frequency in Disk B is higher than that of Disk A by about 65%. This proves the intensified effect of free film on the wall-bounded film.



(a) Disk A (b) Disk B

Fig.3 Distribution of surface renewal frequency on disks

Fig.4 shows the film thickness for the two disks. It can be seen that the film thickness is higher in the initiation region, and the film is gradually thinning in the acceleration region, while it keeps constant in the steady region for both disks. Besides, it can be seen that there exists corrugation with the rotation of Disk B, which has been proven to enhance mass transfer between phases.



(a) Disk A (b) Disk B

Fig.4 Distribution of film thickness (m) on the disks

Conclusion

1.There exists initiation region, acceleration and steady region in the film flow on the rotating disk. In the initiation region, the film is the thickness and velocity is the slowest. In the acceleration region, film thickness is found reduced and the surface renewal frequency is the highest. In the steady region, the liquid film has steady flow, its thickness is the thinnest and velocity is the highest.

2. Disk with open window has two kinds of film, i.e. free film and wall-bounded film. Free film has thinner thickness but its surface renewal rate is faster. The acceleration of renewal caused by the open window can intensified the renewal of the neighboring wall-bounded film. Hence, the total surface renewal frequency is improved.

References

[1] Li K, Yang C, Xu Y, et al. (2012). Effect of inorganic anions on Rhodamine B removal under visible light irradiation using Bi2O3/Ti rotating disk reactor. Chemical Enginggering Journal, 211: 208-215.

[2] Vasiliadou I A, Molina R, Martínez F, et al. (2014). Experimental and modeling study on removal of pharmaceutically active compounds in rotating biological contactors. Journal of Hazardous Materials, 274: 473-482.

[3]Afanasiev K., Munch A., Wagner B., (2008). Thin film dynamics on a vertically rotating disk partially immersed in a liquid bath. Applied Mathematical Modelling, 32: 1894-1911.

[4] Suor D, Ma J, Wang Z, et al. (2014). Enhanced power production from waste activated sludge in rotating-cathode microbial fuel cells: The effects of aquatic worm predation. 248: 415-421.

[5] Danckwerts P.V., (1951). Significance of liquid film coefficients in gas absorption. Industrial & Engineering Chemistry Research. 43, 1960-67