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ORIGINAL CONTRIBUTION

Hydrodynamic Characterization of Spinning Basket Membrane (SBM) Module

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ABSTRACT

Dynamic Shear Enhanced (DSE) membrane modules are able to make its strong footprint in membrane industry by efficiently handling high fouling feed solution than cross flow modules. DSE devices are capable of generating the shear, which is independent of the feed flow rate. Rotating Disk (RD), Rotating Disk-Membrane (RDM), Vibratory shear enhanced processing (VSEP) units, Multi-Shaft Disk (MSD) etc are very much familiar as DSE membrane module. In spite of high shear, high permeate flux generation than cross flows, decline of permeate flux for concentration polarization is not fully restricted in advanced DSE module. Intermittent chemical cleaning and hydrodynamic cleaning leave a great effect on permeate flux generation. Present module with its in built cleaning facility overcome efficiently all drawbacks of former DSE module and make a smooth start of DSE modules in membrane industry. This is well known as Spinning Basket Membrane (SBM) module because of its structural similarity with the well-known spinning basket reactor. Present work has been reported to explore hydrodynamic characteristics of SBM module using CFD. The k-ε realizable turbulent model was chosen to simulate current module. Study was based on variation of transmembrane pressure and rotational velocity. Results of CFD fully satisfied physical condition.

KEYWORDS: *Dynamic Shear Enhanced membrane, Concentration polarization, Fouling, SBM, CFD.*

1. INTRODUCTION

Efficient separation, simple design, low energy budget and easy operation of membrane based processes make it as a promising method in separation industries. Regardless of aforementioned complimentary properties, enormous potential of membrane technology in diverse field is partially restricted because of two operational nonidealities, namely reversible concentration polarization and irreversible fouling [1-3] which is triggered by polarization effects.

Throughout last two decades abundant works were reported on concentration polarization (CP) [4], its thermodynamic interpretation [5], viscosity effect on CP [6], and relation between reversible concentration polarization phenomena with irreversible membrane fouling [1] etc.

Plenty of restorative methods [7 - 11] were recommended to alleviate fouling. Different remedial techniques of fouling had extensively studied [12-14]. It was also reported that concentration polarization should be maintained at lowest possible threshold value to control membrane fouling. High shear production near the membrane surface has long been regarded as a competent technique to arrest concentration polarization and subsequent fouling [15-16].

Cross flow module was first introduced at late 1960s [17]. High shear creation near membrane surface is controllable efficiently by increasing circulation fluid velocity. On the contrary this high velocity restrict uniform flow through membrane surface as a result the permeate throughput is decreased [18]. Dynamic shear enhanced (DSE) membrane module was recognized in seventies to overcome abovementioned inlet velocity dependent shear

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field generation problem [19]. Gradually different types of DSE modules came in scene to control the fouling reasonably. Initially single stirred [20] was introduced. Halstrom first proposed basic structure of Rotating Disk Membrane (RDM) module [21]. In RDM membrane and stirrer of same size separated by small gap, rotates counter currently as a consequence high shear is developed. Membrane speed had an effect more on permeate flux than the stirrer speed [22]. The effectiveness in reducing polarization effect found higher for membrane speed than transmembrane pressure (TMP).

Multiple Shaft Disk (MSD) pilot is capable of producing high permeate flux at highest rotational speed and transmembrane pressure [23-24].

Vibratory Shear Enhanced Processing (VSEP) can only withstand higher pressure upto 15 bar which make it necessary for nanofiltration and reverse osmosis. It first proposed by Armando et. al.(1992). VSEP has 3 to 10 times higher throughput than the conventional cross flow units [25].

Even with enormous variety of DSE modules, the decline of permeate flux is not remarkably arrested. Spinning Basket Membrane (SBM) module with inbuilt cleaning facility showed significant result over it [26-27].

In present work hydrodynamic study of SBM is going to analyze. Polyethersulfone (PES) membrane of 5000 Da was used. Hydrodynamics study was done by Computational Fluid Dynamic (CFD). This characterization comprised with study of velocity vector, shear stress, turbulent kinetic energy, turbulence dissipation energy under varied rotational velocity of basket and transmembrane pressure.

2. MATERIALS AND METHODS

Experiment and Design

Sbm module

In SBM, spinning basket was attached with a hollow shaft, which is driven by help of belt-pulley system. This spinning basket has four radial arms which consist of four flat membranes on the alternate sides of four radial arms as exposed Fig. 1. This complete system was positioned in a stainless steel cylindrical tank, with inlet and outlet ports.

High speed of basket rotation generates high shear stress on attached membrane surface. Small clearance is created between the edge of the radial arm and the cylindrical tank. After reaching steady state basket rotates in opposite direction to dislodge the solutes efficiently and maintain the permeate flux. In this work, SS316 was used for manufacture of SBM module. The Gurpreet Engineering Works, Kanpur, UP (India), helps us by making module following our design criteria.

Material

Polyethylene glycol (AR grade) of molecular weight 5000–7000 was acquired from Merck, India and PES asymmetric moist membrane with 5000 Da molecular weight cut-off was collected from Koch Membrane Systems (USA).

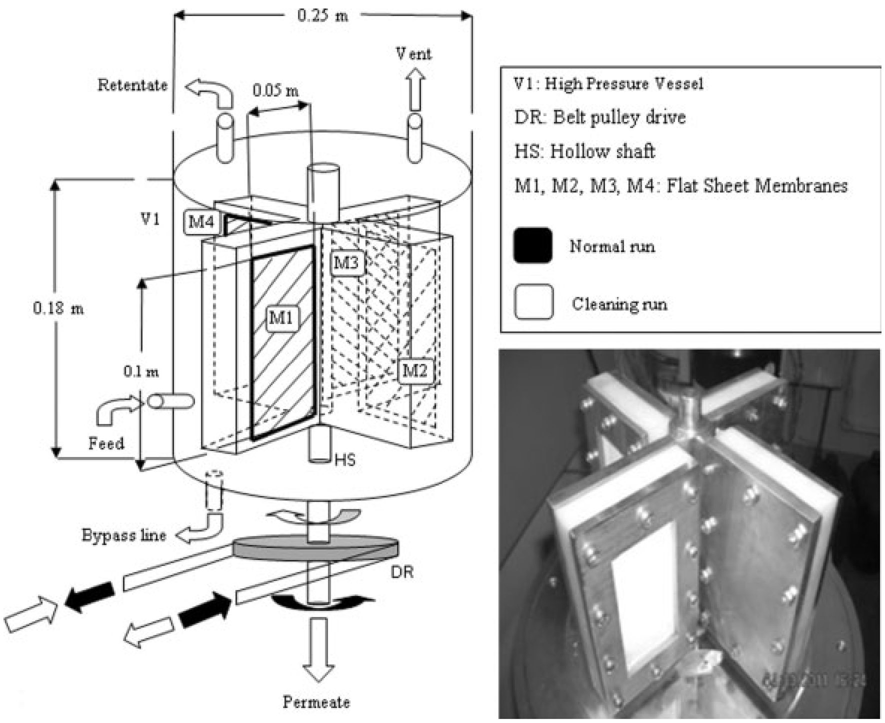

Figure 1**:** Schematic diagram of the Spinning Basket Module (insert showing a photograph of the spinning basket)

CFD Simulation and Model Analysis

Model assumptions

This study was followed standard hydrodynamic simulation as permeate flow rate was remarkably small in amount than retentate flow. Continuity and momentum equations are two governing equations were effortlessly solved by finite volume method (FVM) in coupled solver such as GAMBIT and FLUENT. Rotating reference frame was selected here as basket rotates within cylinder without facing any other obstruction in flow field except the fluid itself.

Following assumptions were considered for making simplicity in simulation:

i. Flow is steady.
ii. Fluid is incompressible, Newtonian.
iii. No slip at solid boundaries.
iv. Pressure inlet boundary condition was selected as pressure was measurable from inlet pressure gauge effortlessly.
v. Turbulent flow regime.

Grid creation

Flow domain was meshed in GAMBIT (2.3.16). Finer grid gives good accuracy with increasing computation time. Therefore optimization of grid is an important portion of mesh generation. Normally finer grid was generated at large gradient zone and fewer fines at uniform flow region. Grid independence test was conducted to select optimum grid for present module.

Modeling and solution

GAMBIT created meshed domain was analyzed in FLUENT (6.3.26). For simulation pressure based solver with implicit formulation was considered. Green-Gauss theorem was preferred for gradient values evaluation. Turbulent flow model was widely validated by k-ε realizable model [28]. SIMPLEC (Simple-Consistent) scheme was understood to be appropriate for this high Reynolds number flow case.

The work was completed in a computer with following arrangement: Windows 7, Intel® Core ™ i5-5200U CPU@ 2.20GHz 2.20 GHz, with installed memory 4.00 GB, 64 bit operating system.

3. RESULTS AND DISCUSSION

Hydrodynamic Simulation

Velocity Field in SBM Module

CFD simulation helps to explore hydrodynamic characterization of inside SBM efficiently. Fig. [2 (a-I), (a-II), (b-I) and (b-II)] clearly shows velocity vector distribution within SBM module. Basket rotation creates there vortices and swirling flows. Fig. [2 (a-I) and (a-II)] considered at lower rotational velocity [10.47 rad s^{-1}] and [2 (b-I) and (b-II)] at 41.9 rad s^{-1} keeping TMP [588.4kPa] fixed. No significant changes were observed during this velocity variation. Rotating baskets creates high turbulence in entire domain with that high velocity was observed near the feed inlet and basket arm tips.

Shear Stress Variation

Viscous and Reynolds stress are generally two categories of stress in turbulent flow region. In flow region Reynolds stress is significant in value than viscous, whereas at surfaces viscous stress is more vital. As a consequence wall shear stress on membrane surface mainly consists of viscous stress.

Fig.3. was well explained wall shear stress variation on rotating basket with different transmembrane pressure (TMP) and rotational speed (Ω) of basket. Stress magnitude was continuously in increasing order from basket rotational axis towards arm tip. As basket rotates in clockwise direction in normal run, more shear stress was developed in leading face than trailing face of basket surface. Moreover as membranes were attached with leading face of basket, this excess shear stress helps to control concentration polarization and as a consequence helps to increase permeate flux. Variation of basket rotational speed with fixed TMP shows significant increase in shear stress. On another side shear stress distinction was comparatively less at fixed speed, various TMP.

Contour of Turbulent Kinetic Energy and Turbulence Dissipation Energy

Fig. 4.was enlightened with turbulent kinetic energy and turbulent dissipation energy variation on basket surface at higher rotational speed and maximum TMP. Turbulent kinetic energy (TKE) is mean kinetic energy per unit mass associated with eddies in turbulent flows and turbulence dissipation is the viscous conversion of mechanical energy to heat. Fig. 2 depicts efficiently variation of vortices and swirling flows in default interior. Fig. 4 (a-I) was elucidated that turbulent kinetic energy gradually increasing towards arm tip than rotational axis fully satisfied with above explanation. In leading face of basket more turbulent kinetic energy was noticed than trailing face as flows were directly collision with basket surface. Moreover more eddies in front of foremost face justified this. Fig 4 (a-II) was well explained variation of turbulence dissipation energy on basket surface. Turbulence dissipation energy following same trends with turbulent kinetic energy only higher in magnitude as it is expressed kinetic energy per unit mass per second, with units of velocity squared per second.

4. CONCLUSION

CFD simulation and hydrodynamic analysis was considered in present study. As module is geometrically identical with eminent spinning basket reactor is commonly known as Spinning Basket Membrane (SBM) module. CFD study

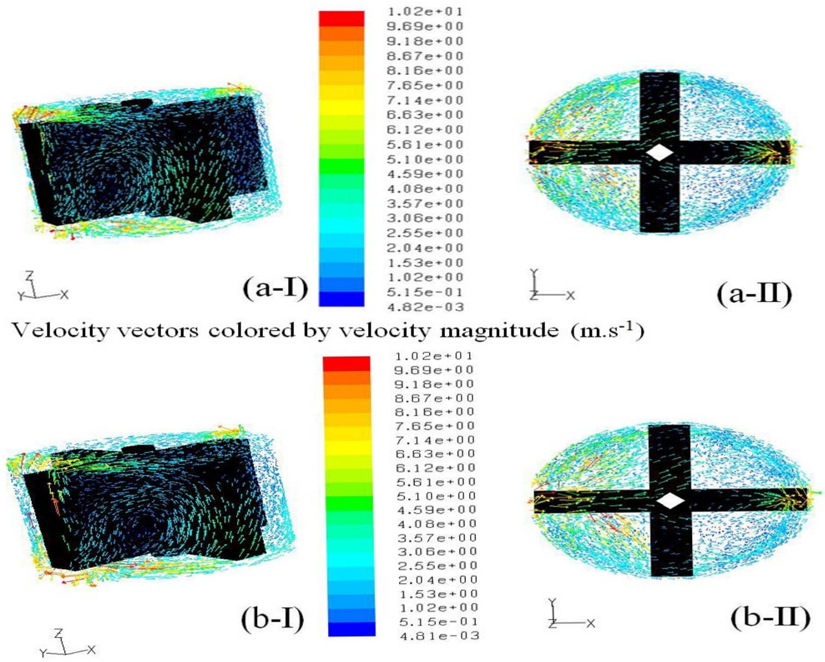

Figure 2: Distribution of velocity vector in default interior of SBM module for (a-I) and (a-II) **Ω** = 10.47 rad s^{-1} and TMP = 588.4 kPa, (b-I) and (b-II) **Ω** = 41.9 rad s^{-1} and TMP = 588.4 kPa.

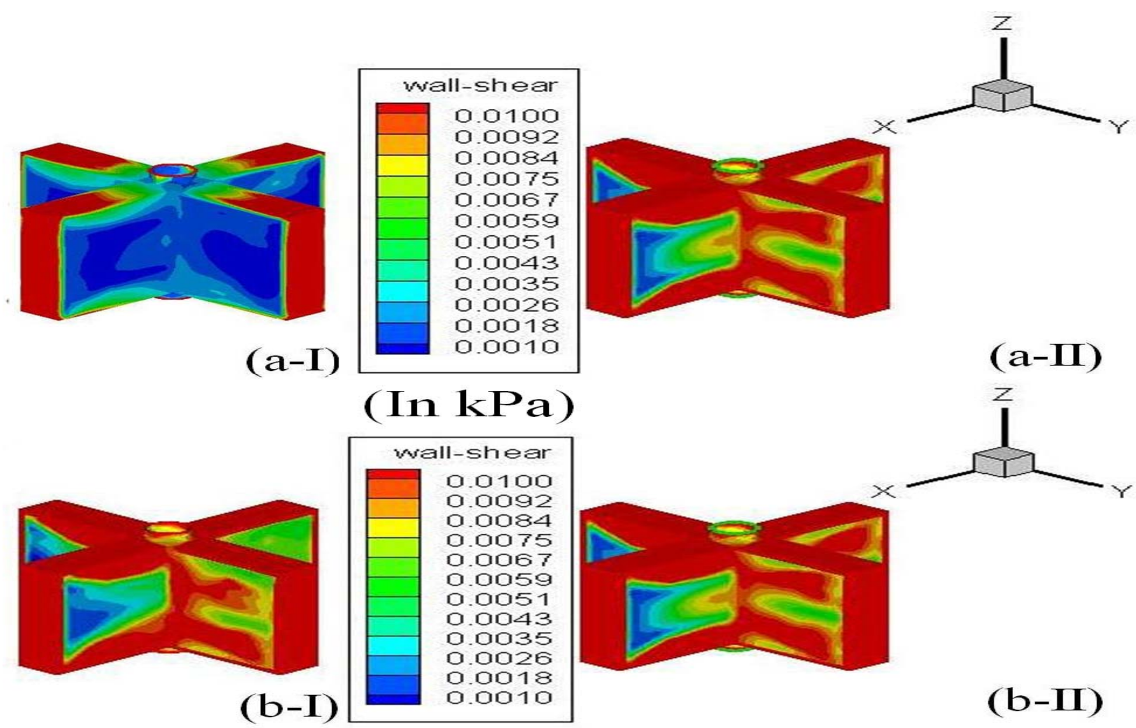

Figure 3: Contour of wall shear stress on basket surface (a) at different speed (TMP = 588.4 kPa): (I) 10.47 rad s^{-1} (II) 41.9 rad s^{-1} and (b) at different TMP (**Ω** = 41.9 rad s^{-1}): (I) 98 kPa (II) 588.4 kPa.

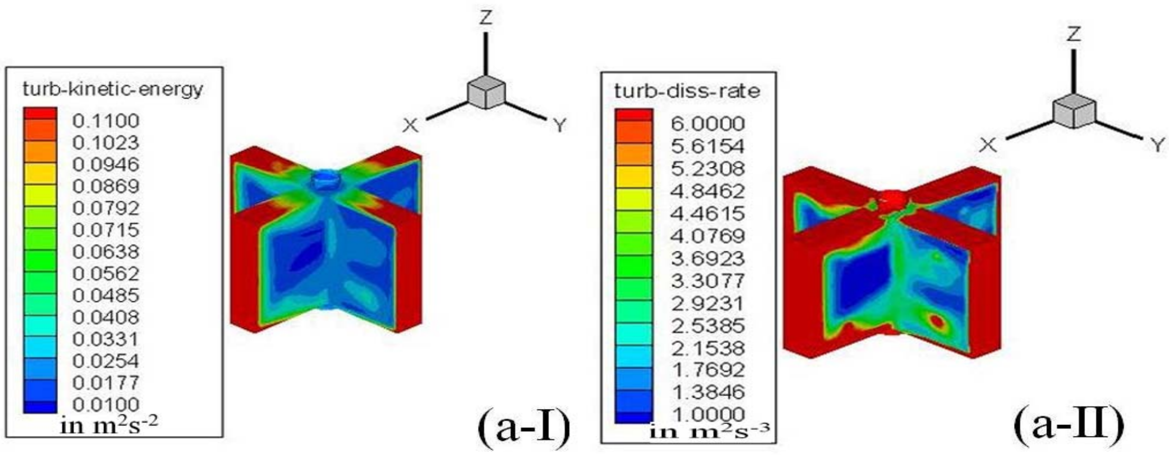

Figure 4: Contour of (a-I) turbulent kinetic energy and (a-II) turbulence dissipation energy at TMP = 588.kPa and Ω = 41.9 rad s^{-1}.

undoubtedly clarify shear stress intensification on basket surface leads to control concentration polarization and subsequently increase in permeate flux. Self cleaning facility also added an extra advantage to maintain the permeate flux at acceptable range for long duration. More shear stress was obtained at higher transmembrane pressure of 588.4 kPa and higher rotational speed of 41.9 rad s^{-1} unambiguously generate more permeate flux. Moreover this present module with proper scale up may use for large extent fouling feed solutions and make its position very much prominent in membrane industry.

NOMENCLATURE

TMP transmembrane pressure (kPa)

Greek letters

Ω rotational speed of the basket (rad s^{-1})

References

[1] Sablani, S. S., Goosen, M.F.A, Al-Belushi, R., Wilf M., Concentration polarization in ultrafiltration and reverse osmosis: a critical review, Desalination 141 (2001) 269–289.

[2] Mulder, M., Basic Principles of Membrane Technology, 2nd ed Kluwer, 1996.

[3] Sarkar, A., Moulik, S., Sarkar, D., Roy, A., Bhattacharjee, C., Performance characterization and CFD analysis of a novel shear enhanced membrane module in ultrafiltration of Bovine Serum Albumin (BSA), Desalination, 292 (2012) 53–63.

[4] Youm, K. H. , Fane, A.G., Wiley, D. E., Effect of natural convection instability on membrane performance in dead end and cross flow ultrafiltration, J. Membrane Sci., 116 (1996) 229.

[5] Peppin, S. S. L., Elliott, J. A. W., Non-equilibrium thermodynamics of concentration polarization, Adv. Colloid Interface Sci. 92 (2001) 1.

[6] Gill, W. N., Wiley, D. E., Fell, C. J. D., Fane, A. G., Viscosity effect on concentration polarization, AlChE J. 34 (2004) 1563.

[7] Trettin, D. R., Doshi, M. R., Limiting flux in ultrafiltration of macromolecular solutions, Chem. Engg. Commun., 4 (1980) 507.

[8] Mollee, T. R., Annisimov, Y. G., Roberts, M. S. , Periodic electric field enhanced transport through membrane, J. Membrane Sci. 278 (2006), 28.

[9] Enevoldsen, A. D., Hansen, E. B., Jonsson, G., Electro ultrafiltration of industrial enzyme solution, J. Membrane Sci. 299 (2007) 28.

[10] Wang, H. M., Li, C. Y., Chen, S. J., Cheng, T. N., Chan, T. L., Abatement of concentration polarization in ultrafiltration using n- hexadecane/water two-phase flow, J. Membrane Sci. 238 (2004) 1.

[11] Cui, Z., Taha, T., Enhancement of ultrafiltration using gas sparging: a comparison of different membrane module, J. Chem. Technol. Biotechnol. 78 (2003) 249.

[12] Redkar, S. G., Davis, R. H., Cross-flow microfiltration with high-frequency reverse filtration, AlChE Journal, 41 (3) (1995) 501-508.

[13] Sarkar, D., Chakraborty, D., Naskar, M., Bhattacharjee, C., Characterization and modelling of radial flow membrane (RFM) module in ultrafiltration, Desalination, 354, (2014) 76-86.

[14] Chen, J. P., Kim, S. L., Ting, Y. P., Optimization of membrane physical and chemical cleaning by a statistically designed approach, J. of Membrane Sci. 219 (20030 27-45.

[15] Bhattacharjee, C, Datta, S., Simulation of continuous stirred ultrafiltration process: an approach based on analytical solution couples with turbulent back transport, J. Chem. Technol. Biotechnol., 78 (2003), 1135-1141.

[16] Bhattacharjee, C, Datta, S., Analysis of mass transfer during ultrafiltration of PEG-6000 in a continuous stirred cell: effect of back transport, J. Membr. Sci., 119 (1996) 39-46.

[17] Jaffrin, M. Y., Dynamic shear-enhanced membrane filtration: a review of rotating disks, rotating membranes and vibrating systems., J. Membr. Sci., 324 (2008) 7-25.

[18] Ding, L. H., Jaffrin, M. Y., Mellal, M., He, G., Investigation of performances of a multishaft disk (MSD) system with overlapping membranes in microfiltration of mineral suspensions, J. of Membr. Sci., 276 (2006) 232-240.

[19 Kroner, KH., Nissingen, V., zdynamic filtration of microbial suspensions using an axially rotating filter, J. Membr. Sci., 36 (1988) 85-100.

[20] Bhattacharjee, S., Sharma, A., Bhattacharjya, P. K., A unified model for prediction of flux in stirred and unstirred batch ultrafiltration, J. Membr. Sci., 111 (1996) 243.

[21] Halstrom, B., Lopez-Liva, M, Description of rotating ultrafiltration module, Desalination 24 (1977) 39.

[22] Sarkar, D., Bhattacharya, A., Bhattacharjee, C., Modeling the performance of a standard single stirred ultrafiltration cell using variable velocity back transport flux, desalination, 261 (2010) 89-98.

[23] He, G., Ding, L. H., Paullier, P., Jaffrin, M. Y., Experimental study of a dynamic filtration system with overlapping ceramic membranes and non permeating disks rotating at independent speeds, Journal of Membrane Science, 300 (2007) 63-70.

[24] Jaffrin, M. Y., He, G., Ding, L. H., Paullier, P., Effect of membrane overlapping on performance of multishaft rotating ceramic disk membranes, Desalination, 200 (2006) 269-271.

[25] Armando, A., Culkin, B., Purchas, D., Proceedings of the Euromembrane, 92, (1992) Lavoisie, Paris.

[26] Sarkar, A., Sarkar, D., Bhattacharjee, C., Design and performance characterization of a new shear enhanced module with in-built cleaning arrangement, JCTB, 2012.

[27] Sarkar, D., Sarkar, A., Roy, A., Bhattacharjee, C., Performance characterization and design evaluation of spinning basket membrane (SBM) module using computational fluid dynamics (CFD), Separation and purification technology, 94 (2012) 23–33.

[28] Naskar, M., Rana, K., Chatterjee, D., Dhara T., Sultana R., Sarkar D., Design, performance characterization and hydrodynamic modeling of intermeshed spinning basket membrane (ISBM) module, Chemical Engineering Science 206 (2019) 446–462.