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CFD analysis of flow pattern in the agitated thin film evaporator

Sanjay B. Pawar[a], *A.S. Mujumdar*[b], *B.N. Thorat*[a,*]

[a] *Department of Chemical Engineering, Institute of Chemical Technology (ICT), Nathalal Parekh Marg, Matunga (E), Mumbai 19, India*
[b] *Department of Mechanical Engineering, National University of Singapore, Singapore 117576, Singapore*

ABSTRACT

Agitated thin film evaporator (ATFE) is widely used in chemical, pharmaceuticals and food industries to concentrate the feed solutions. The flow pattern in ATFE has been analyzed using ANSYS-CFX 10.0 software. The flow phenomenon is simulated using free surface multiphase model considering two continuous phases, water and water vapour. The geometry is created in ANSYS-ICEM-10 with 110,300 tetrahedral nodes. The k–ε and Reynolds stress homogeneous turbulence models are used with appropriate boundary conditions. The occurrence of bow wave and its variation with respect to flow rate is studied. A thin film of thickness equal to the clearance between blade tip and inner wall is found to adhere to the inner wall. The bow wave is found to travel helically along the inner wall of the evaporator. The shear rate and kinetic energy dissipation is found to be significant at the clearance between blade and inner wall. These values are 10–50 times more than that observed in rest of the volume.

Keywords: CFD modeling; Thin film evaporator; Two phase; Turbulence modeling

1. Introduction

Agitated thin film evaporator (ATFE) is widely used in chemical, pharmaceuticals and food industries to concentrate the feed solution with complete solvent recovery. The combination of short residence time, high turbulence and rapid surface renewal permits the agitated thin-film evaporator successfully operate the heat-sensitive, viscous and fouling feed streams. The agitated thin film evaporator (further referred as ATFE) consists of two major assemblies: a heated body and a close clearance rotor as shown in Fig. 1. The shaft rotates with a fixed angular velocity and the blades lay out a thin film on the wall of the evaporator. If the inlet feed flow rate is high enough, the film formed on the wall of the evaporator would be thicker than the clearance between the wiper blade and outer wall which result in a fillet/bow wave of liquid on its front edge.

The flow patterns and heat transfer mechanism in falling film evaporator (FFE) is different than that in ATFE. ATFE is also referred as wiped film evaporator (WFE). There is continuous falling of film over the heating wall in the FFE whereas in ATFE the film is being scraped off from the heating wall by blades after some periodic time span. McKelvey and Sharps (1979) examined the velocity profile and flow structure of the bow wave in a wiped film evaporator (WFE) and studied the dependence of blade clearance, film thickness and throughput. Komari et al. (1988, 1989) examined the flow structure and mixing mechanism in the bow wave both theoretically and experimentally in WFE. It was found that about 70–90% of fluid flow in the device could be in the bow wave when the evaporator was equipped with vertically aligned blades. McKenna (1995) presented the model for the design of a wiped flow evaporator (WFE). They considered the fluid transport and mass transfer aspects of devolatilisation of polymer solution. They have reported that there is a limiting rotational speed for mixing in WFE above which significant gain in the mass transfer can be obtained at the expense of very large power consumption. Chawankul et al. (2001) studied the concentration of orange juice in ATFE using AspenPlus^{TM}. They considered the thermo-physical properties of orange juice as a function of temperature and solid content along the height of evaporator. Recently, Zeboudj et al. (2006) have reported that the hydrodynamic conditions of the flow have a direct effect on the film thickness and on the residence time of fluid elements.

* *Corresponding author*. Tel.: +91 22 24145616x2022.
E-mail addresses: sanjay6282@gmail.com (S.B. Pawar), bn.thorat@ictmumbai.edu.in (B.N. Thorat).
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Nomenclature

Notations

C	constant
C_s	Reynolds stress model constant
$C_{\varepsilon 1}$	Reynolds stress model constant
$C_{\varepsilon 2}$	Reynolds stress model constant
D	diameter of ATFE (m)
D_e	equivalent diameter (m)
D_r	diameter of rotor (m)
D_s	diameter of shell (m)
k	turbulence kinetic energy (m^2/s^2)
M_α	interfacial force between two phases (N/m^3)
n	number of phases
p	pressure (N/m^2)
$\tilde{p}$	turbulent energy production ($kg\,m^{-1}\,s^{-3}$)
r_h	hydraulic radius (m)
S_{ij}	shear strain tensor (s^{-1})
S	shear strain rate (s^{-1})
S_{cor}	Coriolis force (N/m^3)
S_{cfg}	centrifugal force (N/m^3)
$S_{M\alpha}$	momentum source term due to external body force (N/m^3)
U	velocity (m/s)
U_x	x-velocity (m/s)
U_y	y-velocity (m/s)
U_z	z-velocity (m/s)
U_t	tip velocity (m/s)

Greek symbols

τ	molecular stress tensor (N/m^2)
ρ	density of liquid (kg/m^3)
ε	turbulence energy dissipation (m^2/s^3)
μ	viscosity of liquid (kg/ms)

Subscript/superscripts

i	direction *i* or species
j	direction *j* or species
eff	effective
lam	laminar
turb	turbulent

From the above discussion and existing literature, it can be said that the flow pattern in ATFE is a combination of a rotational or tangential film flow induced by the mechanical action of the blades and a downward or axial flow. The dimensions of bow wave depend on the feed flow rate and its physical properties. When the thin film flow is of concern in the scraped geometry, the flow can be distinguished in two sections: bow wave which constitutes the major portion of feed and the thin film adhering to the inner wall.

ATFE is used to concentrate the biological and polymeric solutions and sometimes the viscosity can be varied along the height of the evaporator. Moreover, there would be solid deposition over the inner wall when soluble solid overcomes the solubility limit. This phenomenon forces the system to operate under laminar regime which is having very poor heat transfer characteristics. In present work, the simulations were performed for two systems (A) water and (B) 65% sugar solution which behave under turbulent and laminar regime, respectively at given operating speed of rotor. The objective was to study the flow patterns in ATFE for these cases. The

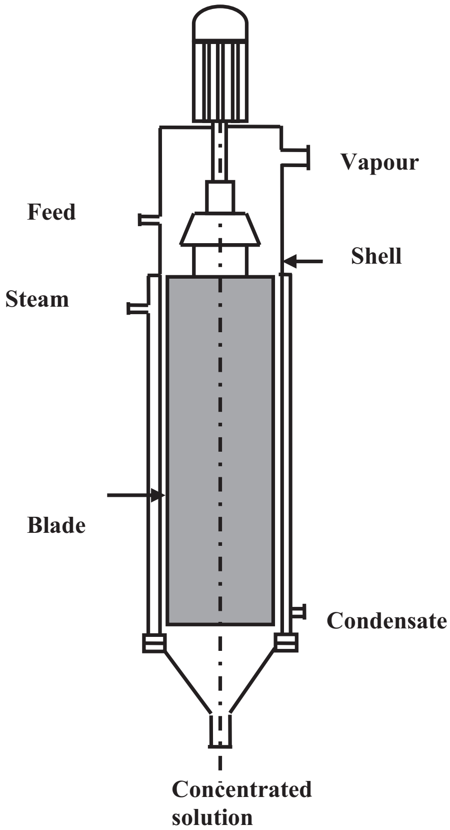

Fig. 1 – Schematic of agitated thin film evaporator (ATFE).

shear strain rate due to wiper rotation and the turbulent kinetic energy dissipation are also determined for the given system.

2. CFD methodology

2.1. Governing equations

The ATFE is operated under the vacuum and as soon as the vapour forms it is removed using vacuum pump. Actually there is no interaction between the water phase and the vapour phase. So in reality there is no significant interaction. Hence the model is steady state—two continuous incompressible phases (one is "water" and another is "water vapour").

The equations for conservation of mass and momentum are solved for each phase. The flow model is based on solving Navier–Stokes equations for the Eulerian multiphase model along with homogeneous multiphase k–ε turbulence model. Free surface model was used for two phases to track the surface sharply between two phases. Free surface interphase transfer model explains how the fluids interact in multiphase simulation and how particles interact with the fluid when particles are included. It has three options: mixture model, particle model and none. We selected "None" for this case because there is no interaction of any type in fluids. CFX uses phase-weighted averaging for turbulent multiphase flow.

The mass conservation equation for each phase can be written as:

$$\nabla \cdot (\alpha_i \rho_i \bar{U}_i) = 0.0 \quad (1)$$