Process Modeling and Optimization of Design Parameters in a Falling Film Plate and Frame Evaporator

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Abstract

Evaporators are widely used as thermal separation equipment to concentrate liquid solutions or to recover volatile constituents in solvent recovery. Vertical falling film evaporators are popular due to their shorter residence times and relatively high heat and mass transfer potential at low liquid flow rates. Higher thermal efficiency can be realised by maximizing the steam economy in a multi-effect evaporator design, which uses the effluent of the previous effect to heat the subsequent effects.

This work focuses on the detailed computational analysis of a plate and frame multi-effect evaporator, designed at Dalhousie University (Figure 1). It explores the impact of distributor width on the film thickness, and the resulting sensitivity of overall thermal efficiency of the system. A stable film is crucial to maintain a minimum wetting rate, to circumvent the "dry-out condition" where the breakdown of the falling film can cause fouling.

Using COMSOL Multiphysics® software and Heat Transfer Module, time-dependent parametric simulations were carried out for different geometries, with a refined physics controlled free tetrahedral mesh. The hydrodynamics of stable film development as a function of distributor width was investigated using the the level-set based laminar two-phase-fluid (tpf) flow model. The impact of phase change on the two-phase (gas-liquid) film flow in an effect was modelled using the Apparent Heat Capacity method, which accounts for latent heat in terms of the phase transition function, that quantifies changing material properties over the transition temperature interval.

Computational results are interpreted relative to a triple-effect evaporator designed to concentrate saltwater from 35 to 50 weight% at a feed rate of 20kg/h. The graphical results of the iterative design procedure for sizing the evaporator are shown in Figure 2. The velocity distribution and pressure drop as the liquid flows from the inlet into the accumulator and through the distributor is explored for different distributor widths(1/4'',1/8'',1/16'',1/48''), as shown in Figure 3. It is seen that for distributor gaps below 1/16'' ,the deviation of the center line velocity from the spread velocity across the evaporator width is reduced. Using this distributor geometry, the predicted film thickness from simulation, under the conditions of effect 1 (Figure 4) correlate well with Nusselts' prediction, indicating a near laminar film development.

The vapor generation in an effect is largely dependent on the overall heat transfer coefficient of each effect, which is controlled by the film thickness. Hence the broader implication of this paper is to verify the final design based on analytical film thickness predictions, with experimental results; and to assess the impact of film thickness and operating pressures of the effects on the thermal efficiency of the system.

Reference

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Figures used in the abstract

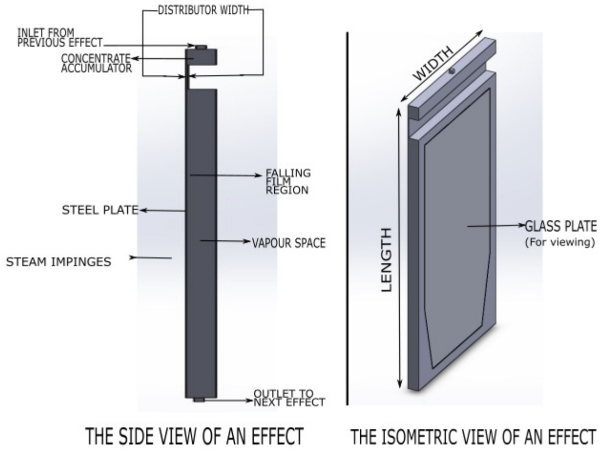

Figure 1: Illustration of the geometry of an evaporator effect.

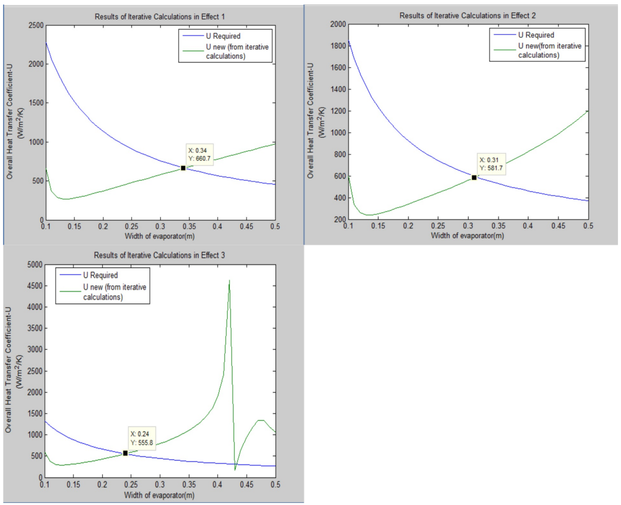

Figure 2: Graphical results of the iterative design procedure for sizing the evaporator effects.

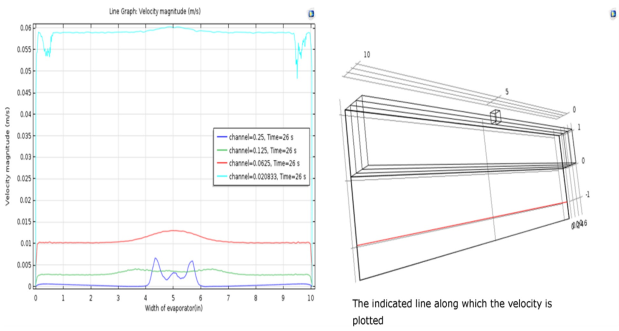

Figure 3: Velocity profiles for different geometries of the distributor channel.

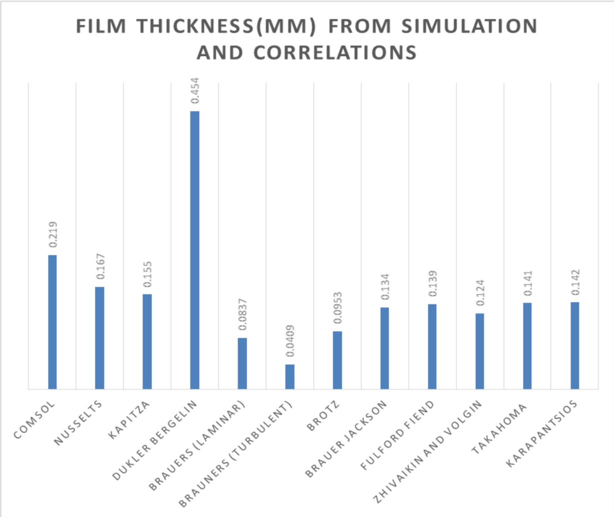

Figure 4: Graphical comparison of film thickness(mm) obtained from various correlations with the COMSOL® Simulations in the first effect.