Fundamental Modeling and Analysis of Falling Film Evaporators

Z. Stefanov and K. A. Hoo*
Department of Chemical Engineering, Mail Stop 3121
Texas Tech University, Lubbock, TX 79409-3121
Ph: (806) 742-4079 Fax: (806) 742-3552

April 30, 2003

Falling film evaporators are used to concentrate material because they promote high heat transfer coefficients, they can operate at small driving forces, and they deter scaling. In the pulp and paper industry, such evaporators are used to concentrate the black liquor that results from the pulp washing. However, an incomplete understanding of this operation exists primarily due to the black liquor itself, i.e. its composition is not well known and its properties change nonlinearly during the evaporation. For example, the black liquor viscosity rises from about 2 to 3000 mPa · s, thus creating different operating conditions for the various units of the multiple effect evaporation system.

The evaporator models published in the open literature are in general lumped, black box or steady state models. However, the complexity of the system requires a dynamic distributed parameter model to better understand the system behavior and to design an effective control strategy. This work develops a fundamental model of the falling film multiple effect evaporator system that includes, the condensation, heating, and evaporation zones of the plate stack, the bottom zone of the evaporator, the recirculation loops, and the pressure dynamics between the evaporators.

A one dimensional distributed parameter model that is represented by system of partial differential equations (PDEs) is used to model the plate stack. This one dimensional fundamental model is justified by actual experimental investigation of the behavior of the falling film flow on a plate.

*author to whom all inquires should be addressed, khoo@coe.ttu.edu

The bottom zone, recirculation loops, and the pressure dynamics are lumped models described by systems of ordinary differential equations (ODEs).

Special attention is paid to the calculation of the model parameters such as the heat transfer coefficients and the film velocity profiles since it was determined that turbulent and wavy laminar film flow regimes are present in different units of the evaporation system that result in different heat transfer rates. Only one particular three-layer film flow model was found to be accurate enough for the unusually high Prandtl numbers that characterize this system.

The system of PDEs describing the evaporator are discretized using the method of Orthogonal Collocation on Finite Elements (OCFE). The resulting system of DAEs (Differential-Algebraic equations) is solved using LSODI procedures. The lumped models are solved using LSODE procedures. The initial conditions, design parameters, and operating conditions are obtained from industrial data. The model is examined, by simulation, at various operating conditions. This includes: parameter sensitivities to variations in liquor dry solids content, saturation pressures in evaporation and condensation zones and heat transfer limitations during condensation and evaporation. These results are validated against real plant data. The key modeling and experimental features will be presented and the results of the simulation discussed.