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Distributed Parameter Model of Black Liquor Falling-Film Evaporators. 2. Modeling of a Multiple-Effect Evaporator Plant

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In the first of two parts of this work, a distributed parameter model, based on first-principles knowledge about the fluid dynamics and heat-transfer processes, was developed for the evaporation side of a single plate (lamella) of a falling-film evaporator. In the second part, the work expands on the single-plate model to develop a fundamental model of a falling-film evaporator that accounts for the condensation side of the plate, the heating/flashing section at the evaporator entrance, the evaporator inventory, mixing, and recirculation flows. On the basis of the single evaporator model, a multiple evaporator plant that consists of one superconcentrator (three falling-film evaporators as one unit) and four falling-film evaporators is modeled. The model, its numerical solution, and its behavior at different operating conditions are presented and discussed.

1. Introduction

The first part of this work presented a first-principles-based model of the evaporation side of one plate (lamella) in a falling-film type of evaporator. Two simplifying assumptions were made in the development: uniform heating along the plate wall and the absence of a heating section at the beginning of the plate. In reality, there is generally nonuniform heating along the plate wall, and there may be a nonnegligible heating section.

In this work, these assumptions are removed. The plate wall is heated by saturated steam whose condensation is not uniform because the condensate film parameters are functions of the plate length. Additionally, the corresponding heat-transfer coefficient changes along the length of the plate. A heating section is introduced at the beginning of the plate if the temperature of the fluid feed to the plate is below the boiling point that corresponds to the current saturation pressure. If the temperature of the fluid feed to the plate is above the boiling point, flashing rather than heating occurs.

Figure 1 is a schematic of a falling-film evaporator. On the basis of experimental investigations by Patterson et al.,[1] the wall dynamics are assumed to be very fast (the wall thickness is ∼1.5 mm). When the liquor leaves the plate stack, it enters the evaporator inventory (see Figure 1), which is controlled. Thus, the evaporator inventory can be considered a buffer and a sink. The evaporator inventory is modeled as a well-mixed thermal mixing tank.

The recirculation pump mixes the feed with the contents of the evaporator inventory. This pump is modeled as a steady-state thermal mixer with the assumptions that the mixing dynamics are extremely fast and that the pump is an ideal mixer. The pump discharge is split into two flow streams; one flow stream is returned to the plate stack, and the other is the product stream.

Two other assumptions made are as follows: heat loss to the surroundings is negligible, and the saturation pressures at the condensation and evaporation sides of the plate are time-invariant. When multiple evaporators (MEVs) are considered, the pressure dynamics will be explored more closely.

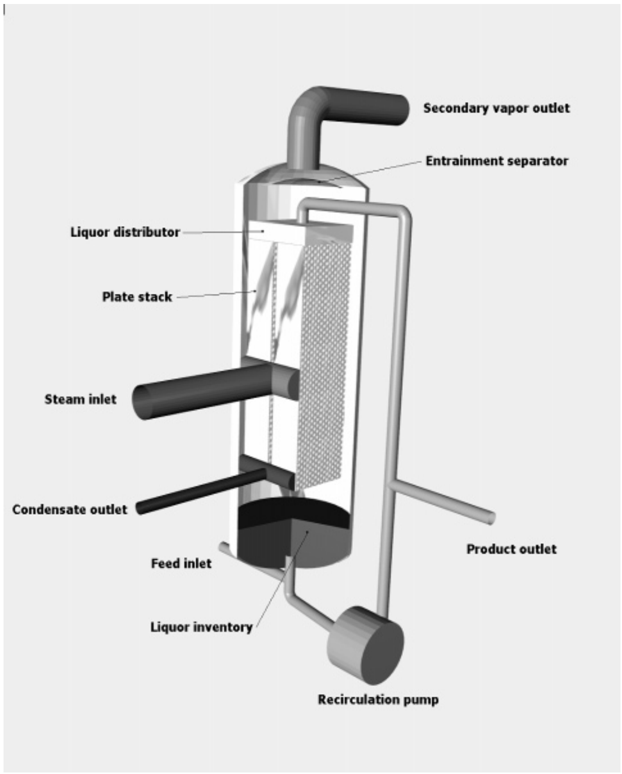

Figure 1. Schematic representation of a falling-film evaporator.

The paper is organized as follows. Section 2 describes the development of the model for one falling-film evaporator detailing the transport phenomena that occur (heating, flashing, and condensation) as well as accounting for the evaporator inventory and an energy balance at the wall. Section 3 develops a fundamental model for an evaporator plant that contains four falling-film plate-type evaporators and one superconcentrator. The model development pays particular attention to the pressure dynamics and unit−unit interdependencies.

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