DYNAMIC MODELING AND SIMULATION: BRINE FLOW HYDRAULICS

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Contents

Summary

This article tackles the problem of modeling the interstage flow for MSF desalination plants. Particular attention is paid to the application of the brine flow model within a dynamic model for the whole plant. Measured brine levels obtained from large-scale experiments on a 20-stage industrial size MSF plant serve to evaluate several brine flow models under steady-state as well as under dynamic plant operating conditions.

Two alternative models to describe the submerged jet flow are discussed. One of the various differing contraction coefficient correlations published in the literature (see Section 8 in this encyclopedia for a detailed survey) is studied as a representative example for those correlations preferably applied for plant design. In addition, a new correlation tailored to the requirements of dynamic simulation is presented. It was identified from the experimental data available for this particular industrial-size plant.

On comparison, the newly derived correlations outperforms the contraction coefficient correlation in predicting measured steady-state brine levels accurately. Dynamic simulation studies involving the contraction coefficient correlation failed almost immediately due to unrealistic brine levels. Hence, this approach seems inapplicable for dynamic problems.

Apparently, blow through occurs on some stages during plant operation. Justified by the fact that the brine levels are close to the orifice height under blow through conditions, a very simple model for the blow through case is suggested. However, due to the simplicity of the postulated blow through model, switching between the two flow regimes, blow through and submerged jet, cannot be captured in the lumped brine flow model. The experimental data illustrate that this phenomenon can lead to sudden and strongly increasing brine levels which pose the danger of stage flooding. Consequently,

the suggested brine flow model is not capable of describing an important physical phenomenon although it otherwise gives rise to reasonable and accurate brine level predictions.

1. Introduction

Mathematical modeling of the interstage brine flow is a complex task since flashing may take place instantaneously at the brine orifice and highly turbulent, low-density flow prevails there. Rigorous approaches rely on three-dimensional CFD simulations, for example Miyatake et. al. (1992), which is far too complex for simulation of an entire MSF desalination plant.

A survey on much simpler correlations derived and employed during MSF plant design can be found in Chapter Dynamic Model of this encyclopedia. However, brine flow modeling for dynamic simulation is not particularly treated in the literature.

Typical calculation approaches suited for entire plant models are based on the simplifying assumption of single phase flow such that the well understood theory of open channel hydraulics may be applied. Open channel single phase flow is characterized by the Froude number *Fr* giving the relation between the potential and the kinetic energies in the flow,

$$Fr = \frac{v^2}{gh} \qquad (1)$$

where v denotes the mean velocity, g the gravitational acceleration and h is the liquid depth. Flow with a Froude number less than one is called subcritical, whereas supercritical flow is said to occur for Froude numbers larger than one. For a given steady flow two equal states of total mechanical energy exist. The first state, shooting flow, is characterized by high kinetic energy and shallow flow. For the second state, tranquil flow, the high kinetic energy is converted into a larger liquid depth giving rise to a higher potential energy. Consequently, shooting flow prevails for Froude numbers less than one, whereas tranquil flow prevails for Froude numbers larger than one. The transition between the two flow regimes may occur instantaneously in terms of a hydraulic jump.

Various differing types of interstage flow regulation equipment may be found in MSF plants and the interstage brine flow model naturally depends on the type of equipment installed. We focus here on the slot orifice which is most commonly used. Brine flow models for other orifice installations are derived from a similar physical basis. References for further reading on other installation equipments can be found in Chapter Ancillary Equipment and Electrical Equipment of this encyclopedia.

Depending on the operating conditions, several flow regimes are conceivable for single phase flow in MSF plants from which only one is considered to be desirable and stable (Ball 1986). Four out of the five flow regimes depicted in Figure 1 are undesirable. They involve either efficiency losses due to blow through, such as shooting flow (a) and of course the two blow through flow regimes (d) and (e), or they are unstable and consequently only temporary such as the jump flow (b).

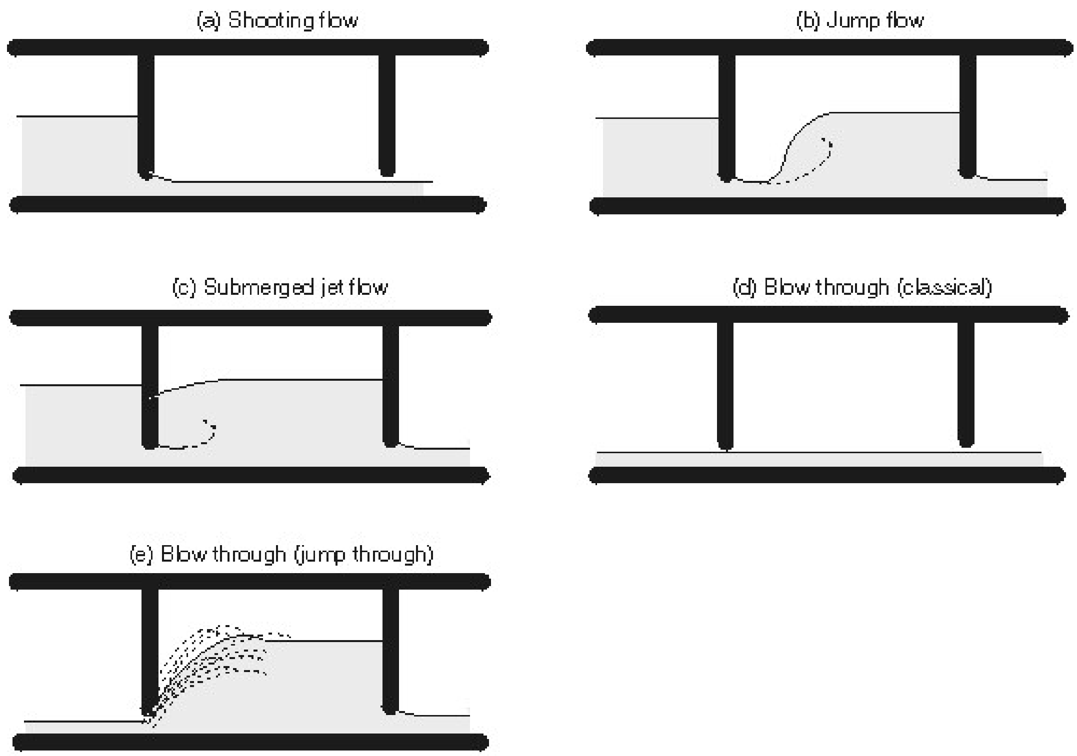

Figure 1. Conceivable single phase and blow through flow regimes in MSF plants.

The desired flow regime is the submerged jet flow that is schematically depicted in Figure 1(c). A liquid brine jet exits through the orifice opening and contracts along the flow path. The maximum jet contraction appears at the so-called vena contracta which is located roughly one orifice height downstream of the brine gate. A hydraulic jump occurs further downstream from the liquid jet. Its occurrence is commonly ensured by installation of a kick-plate on the stage floor behind the orifice. The recirculation zone appears above the liquid brine jet for this flow regime.

In this situation, the liquid brine prevents the vapor from passing to the downstream stage through the orifice. Vapor blow through occurs if the upstream brine level decreases below the orifice height which is undesirable due to the exergy loss and increased droplet formation in the downstream stage. The two flow patterns (d) and (e) in Figure 1 may be observed during blow through depending on the occurrence of a hydraulic jump in the downstream stage (Ball 1986).

The physical description of the interstage brine flow depends on the flow regime prevailing in the evaporator stages. Hence, the brine flow model should be discontinuous if both normal submerged flow and blow through may occur under the conditions prevailing in the plant either during normal operation or changing transients.

The need to cover both possible flow regimes in the plant model is also emphasized by experimental data from an industrial-size MSF plant in Section 2. Following experimental data, the mathematical description of the brine flow for both possible flow regimes is addressed. A new correlation suitable for dynamic simulation is suggested and some important facts regarding its application are identified. Finally, simulation results for the suggested brine flow model are presented in comparison to steady-state and dynamic experimental data from an industrial-size MSF desalination plant.

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