DYNAMIC MODELING AND SIMULATION: MODEL VALIDATION AND SIMULATION STUDIES

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Contents

Summary

This chapter focuses on dynamic modeling for MSF desalination plants. An extensive set of dynamic test data has been collected during large-scale experiments on a 20 stage brine recycle plant to validate the suggested model. Simulation studies of the actual plant tests are presented and compared to the measured data.

For high TBT operation, the proposed model shows excellent steady-state and dynamic predictions for all important process quantities. Even the evaporator brine levels are accurately predicted considering the high signal-to-noise ratio present in the measurements.

For low TBT operation, the phenomenon of vapor blow-through has been identified from the measured data to occur simultaneously in several evaporator stages in conjunction. Transition between submerged flow and blow-through conditions leads to very sudden and strong changes in the affected brine levels, a phenomenon the model is not capable of predicting. It is shown that such blow-through transitions have a minor but noticeable impact on the TBT dynamics. Nevertheless, acceptable predictions for key process quantities are achieved despite blow-through transitions.

1. Introduction

Once the complex task of deriving a simulation model has been completed, the validity of the derived model still needs to be addressed. Here, it is common practice to check the model predictions versus data obtained from the actual process and to assess the observed plant model mismatch. Of course, the validation of a process model is essential prior to its use in a model-based control system.

The task of model validation depends on the amount of actual process data available and the range of plant operating conditions it spans. Due to safety or economic reasons, it is often not possible to impose significant changes in operating conditions on the plant for data gathering. On the other hand, strong plant excitations are desired for model validation in order to capture the true dynamic behavior of the plant.

Despite the importance of model validation, the topic was only recently addressed by Thomas et al. (1998) for the MSF process. However, this was a comparison between simulated and measured data for only one process quantity, the top brine temperature (TBT).

Previous sections of this encyclopedia have focused on important details of multistage flash (MSF) plant modeling. In this article, it is intended to give an overview of the complete MSF plant model suggested as well as to demonstrate the model performance in comparison to plant measurements. Therefore, an extensive experimental test program was conducted on an industrial 20 stage brine recycle MSF plant in order to gather a significant set of steady-state and dynamic plant measurements for the important process quantities such as the TBT or the brine levels.

A dynamic model of the MSF plant considered has been implemented in SPEEDUP™ a commercial process simulator which facilitates the formulation and solution of large-scale differential algebraic process models. Subsequently, the dynamic plant test were simulated by feeding the manipulated process variables into the simulation model.

2. Model Description

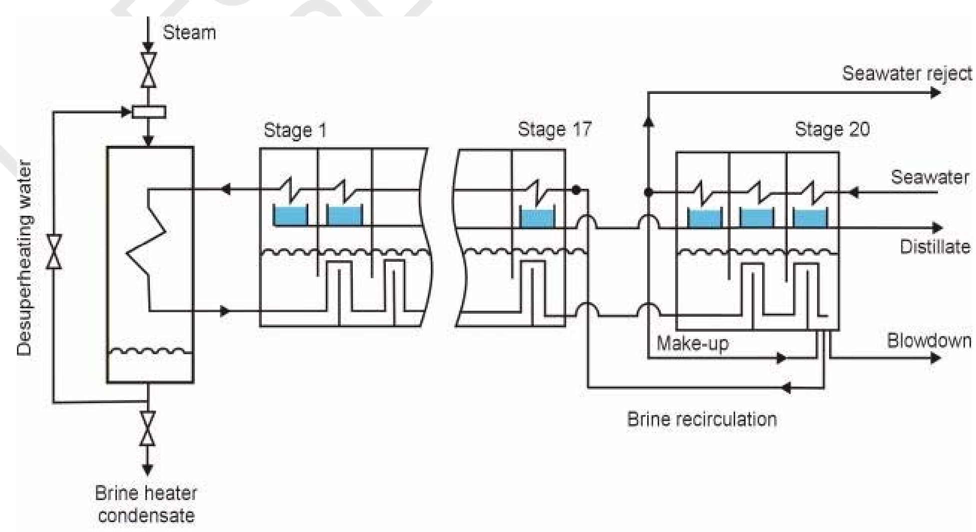

Figure 1. Schematic of 20 stage MSF desalination unit.

The SPEEDUP™ model describes a 20 stage recycle MSF plant with three heat recirculation stages which is depicted schematically in Figure 1. In order to provide the necessary degree of understanding of the model applied in the simulation studies, a brief description is given in the following. Due to the complexity of the modeling task, this description refers to previous sections of this encyclopedia, each focusing on important details of the MSF plant modeling and simulation problem.

2.1. Balance Equation

The MSF plant model consists of the dynamic balance equations for each stage covering mass, energy, and dissolved solids that are treated in a lumped way through a single salt pseudocomponent. A model overview, the plant model structure, and the associated balance envelopes are given in Chapter Dynamic Modeling and Simulation: Modeling Concepts and Model Overview.

The inclusion of rigorous electrolyte thermodynamics is nowadays still beyond feasibility due to the many and highly non-ideal ionic species occurring in seawater in relatively small concentrations. Specifically tailored numerical algorithms are required in order to solve the set of equations arising for calculation of the simultaneous chemical and vapor-liquid-solid equilibria. Moreover, the thermodynamic modeling approaches still need to be adapted for seawater applications.

Therefore, neither electrolyte chemical reactions nor vapor-liquid-solid equilibria are considered within the model. The prediction of salt precipitation or non-condensable gas release is thus impossible.

2.2. Brine Flow

One of the important constitutive model equations in the MSF plant model is the correlation relating the interstage brine flow to the up- and downstream brine levels and some other process quantities. The brine levels are important process constraints which have to be considered during the design and operation of MSF plants. High brine levels may cause salt contamination of the distillate due to increased entrainment or even stage flooding, whereas blow-through may occur due to low brine levels reducing the stage efficiency because of energy losses.

In Chapter Dynamic Modeling and Simulation: Brine flow Hydraulics some of the numerous correlations to describe the interstage brine flow and the related brine levels quantitatively were summarized from the literature. Due to the losses caused by the blow-through of vapor to the downstream evaporator stage, most MSF plants are operated such that blow-through is avoided. Consequently, literature approaches to calculating the interstage brine flow focus on the normal situation for sufficiently high brine levels without occurrence of blow-through.

Most likely, this is the reason why an empirical brine flow correlation with blow-through extension was shown to perform better than the correlations suggested in literature in Dynamic Modeling and Simulation: Brine flow Hydraulics (See: Dynamic Modeling and Simulation: Brine flow Hydraulics). Therefore, this approach has been chosen for the description of the interstage brine flow in the suggested MSF plant model. Although it is capable of describing the flow under normal as well as under blow-through conditions, the occurrence or disappearance of blow-through is not captured in the model. Hence, during an entire simulation run, an evaporator stage is assumed to rest either in normal flow or in the blow-through condition.

2.3. Non-equilibrium

Despite the fact that perfect equilibrium is never reached in any technical system, it is a frequently applied modeling assumption for the description of two-phase systems. Thermal non-equilibrium is taken into account in desalination by an efficiency factor, the non-equilibrium temperature difference, which is usually calculated from an empirical correlation derived from laboratory scale experiments.

To answer the question of which of the assumptions, equilibrium or non-equilibrium, is convenient for modeling the MSF process, the statistical significance of both assumptions is investigated in Dynamic Modeling and Simulation: Non-equilibrium effects and heat transfer. (See: Dynamic Modeling and Simulation: Non-equilibrium effects and heat transfer). on the basis of production plant measurements. It can be shown that the inclusion of a non-equilibrium correction leads to a statistically insignificant modification of the simulated process variables given the limited accuracy of the measurements obtained from an industrial MSF plant with conventional sensor instrumentation. Therefore, the less complex equilibrium model is preferred.

Hence, the model is based on the equilibrium assumption and does not make use of an empirical and apparently extremely uncertain correlation in describing non-equilibrium effects.

2.4. Heat Transfer

The amount of distillate produced in each evaporator stage and, thus, the amount of heat transferred to the cooling brine is governed by a standard heat transfer law that relates the heat flux to an appropriately defined temperature difference and the corresponding heat-transfer coefficient.

Although excellent correlation for the heat transfer coefficients under clean conditions are available in the literature the real plant heat transfer coefficients are unknown due to scaling on the brine tube side and due to the influence of non-condensable gases (See: The Problem of Non-condensable gas release in Evaporators) for further reading on heat transfer coefficients). Consequently, some compensation is required for the aforementioned phenomena in order to represent the real plant operating conditions in the simulation model reasonably. Such compensations are studied in Dynamic Modeling and Simulation: Non-equilibrium effects and heat transfer. (See: Dynamic Modeling and Simulation: Non-equilibrium effects and heat transfer).

It is shown there that the non-condensable gas impact on the evaporator stage heat-transfer coefficients imposes a significant problem for stage heat-transfer modeling. Due to the highly varying amount of non-condensable gases released in the plant operating condition envelope, the plant model mismatch is undesirably high if the same heat transfer coefficients were assumed for the whole range of operating conditions even if a correction for heat exchanger scaling is applied. Moreover, the lack of validated approaches for calculating the non-condensable gas release forbids the description of this effect in a rigorous way.

Therefore, the heat-transfer coefficients are considered constant during the simulation of one particular dynamic plant test, but are adjusted to meet the initial plant operating conditions. This approach is motivated by on-line, model-based control applications where model parameters are regularly updated by means of plant measurements in order to meet the real plant operating conditions.

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Bibliography and Suggestions for further study

A. Gambier, E. Badreddin, (2002), *Application of hybrid modeling and control techniques to desalination plants*, Desalination **152**, Elsevier, pp. 175-184.

Adrian Gambier, Essameddin Badreddin, (2004), *Dynamic modelling of MSF plants for automatic control and simulation purposes: a survey*, Desalination **166**, Elsevier, pp. 191-204.

Aspen Technology, Inc. (1993) *SpeedUp User Manual*.

Bourouis M, Pibouleau L, Floquet P, Domenech S and Al-Gobaisi D M K (1998) Simulation and data validation in multistage flash desalination plants. *Desalination* **115**, 1-14.

C. Thirumeni (2005), *Deutsche Babcock rehabilitation and uprating of Ras Abu Fontas MSF, desalination units: process optimisation and life extension*, Desalination **182**, pp. 63-67.

Corrado Sommariva ,(2010),COURSES IN DESALINATION,Thermal Desalination

E.E. Tarifa and N.J. Scenna, ((2001),A dynamic simulator for MSF plants, Desalination

Emad Ali, (2002), *Understanding the operation of industrial MSF plants Part II: Optimization and dynamic analysis*, Desalination **143**, Elsevier pp. 73-91.

Emad Ali, (2002), *Understanding the operation of industrial MSF plants Part I: Stability and steady-state analysis*, Desalination **143**, Elsevier pp. 53-72.

Glade Heike, Meyer Jan-Helge, Will Stefan, (2005),Strategies for optimization of the Reverse Osmosis Plant in Fujairah

Goetz-D. Wolff, Stefan Lauxtermann, Ramesh Kumar (2007),Plant optimization Online optimization of hybrid desalination plants,ABB Review

M.S. Tanvira and I.M. Mujtaba (2006), Neural network based correlations for estimating temperature elevation for seawater in MSF desalination process, Desalination

P.J. Thomas, S. Bhattacharyya, A. Patra and G.P. Rao (1998), Steady state and dynamic simulation of multi-stage flash desalination plants: A case study, Comp. Chem. Eng.

Peter Pechtl,Bijan Davari(2003)Integrated Thermal Power and Desalination Plant Optimization,General Electric Energy Services, Optimization Software,PowerGen Middle East

Thomas P J, Bhattacharyya S, Patra A and Rao P (1998) Steady-state and dynamic simulation of multi-stage flash desalination plants: a case study. *Computers and Chemical Engineering* 22(10), 1515-1529.

Woldai A, Al-Gobaisi D M K, Johns A T, Dunn R W and Rao G P (1997) Data reconciliation for control of MSF desalination processes. *Desalination and Water Reuse* (Proceedings of IDA World Congress, Madrid, Spain, October 6-9, 1997), Vol. III, pp. 181-187, CEDEX Centro de Estudios y Experimentacion de obras Publicas, Madrid, Spain.