Transient response of a 2-tank flash evaporator
by Thomas William Holzberger

A thesis submitted to the' Graduate Faculty in partial fulfillment of the requirements for the degree of DOCTOR OF PHILOSOPHY in Chemical Engineering
Montana State University

Abstract:
To provide information for the design of flash desalination plants, the dynamics of a 2-tank flash evaporator were studied. Using the 2-tank evaporator available in the Montana State University Chemical Engineering Laboratory, transient data were obtained for step increases and decreases in the temperature of the hot feed water to the first flash tank in the system. A digital computer model was written for the 2-tank evaporator that describes the dynamic response of the system. The computer model was rewritten to describe a 4-tank evaporator, and tested for stability to upsets in temperature of the inlet flow streams.

The digital computer model proved to be very versatile in predicting both steady-state operating conditions and responses to various upsets in the inlet streams. Stability of a multi-tank flash evaporator follows from the stability of the end tanks of the system. Stable operation exists only over a narrow range of temperature and flow rates near specified design values. Upsets in the entering stream temperatures of greater than 5—10 degrees Centigrade cause the water levels in the evaporator tanks to rise or fall beyond the range of stable operations. Increasing the evaporator tank size slows the rate of response to upsets but does not change the equilibrium operating conditions. Changing the tube bundle heat transfer rate changes the equilibrium operating conditions but does not affect stability. Proportional-Integral control of the inlet temperature and flow rate to the first flash tank is necessary for stable operation. If the feed brine temperature is variable, it must also be controlled. Temperature upsets entering the system are quickly corrected by Proportional-Integral control, and do not upset the system more than 1/2 degree Centigrade past the second tank.

TRANSIENT RESPONSE OF A 2-TANK FLASH EVAPORATOR

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ABSTRACT

To provide information for the design of flash desalination plants, the dynamics of a 2-tank flash evaporator were studied. Using the 2-tank evaporator available in the Montana State University Chemical Engineering Laboratory, transient data were obtained for step increases and decreases in the temperature of the hot feed water to the first flash tank in the system. A digital computer model was written for the 2-tank evaporator that describes the dynamic response of the system. The computer model was rewritten to describe a 4-tank evaporator, and tested for stability to upsets in temperature of the inlet flow streams.

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INTRODUCTION

The steady growth of urban population centers in arid areas and the fixed quantities of ground water in non-arid areas have forced man to look to the sea to meet the ever-increasing demand for fresh water. Presently, the cheapest way to purify seawater or brackish water for human consumption is by flash desalination. In this evaporative process, seawater is heated to about 250 °C and cascaded through a series of tanks, each at a succeedingly lower temperature and pressure. Vapor flashes off from the brine and is condensed, yielding pure fresh water. Two flash desalination plants, one in Florida and one in Cuba, are currently producing fresh water from seawater where other supplies of fresh water are not available. The Office of Saline water, an agency of the Department of the Interior, is working to develop the technology of flash desalination to the point that fresh water from the sea will be economically attractive.

The proper design and instrumentation of a large flash desalination plant demands a knowledge of both steady-state and transient response data. No transient data for a flash evaporator has been published in the literature, and no digital computer model is available that describes unsteady-state behavior. This study was undertaken to obtain transient data from the 2-stage flash evaporator available in the Montana State University chemical engineering laboratory and to describe the transient behavior of the system in a digital computer simulation. It is hoped that the results of this study may be useful in the design of future flash evaporators.

BACKGROUND

A schematic drawing of an N-stage flash evaporator is given in Figure 1. Fresh seawater feed is circulated through a tube bundle starting with stage N. As the feed moves toward stage 1, it is warmed from its entering temperature. The warmed seawater exits from the evaporator and enters the steam heat exchanger, where its temperature reaches the inlet temperature. Seawater enters tank 1 and flashes to an equilibrium temperature less than the inlet temperature and reaches a corresponding vapor pressure. The water that flashes is condensed into drip trays and removed as product. The heat of condensation warms the incoming feed in the tube bundle. Tank 2 contains water at a lower temperature and vapor pressure; hence water flashes across the orifice between the two tanks. This process continues through tank N, where roughly 50% of the water has been flashed off. The waste brine is discarded. A more detailed flowsheet is available (19).

The first practical multi-stage flash evaporation plant constructed in the United States was completed at San Diego in 1962 and moved to the Guantanamo Naval Base in Cuba in 1964 (12,6), where it was combined with a steam power generation plant. Subsequently, the Bolsa Island project was proposed in Southern California as a combined power-desalting project, but was discontinued when cost estimates rose dramatically. The Office of Saline Water (OSW) has proposed other large projects, ranging from 50 to 250 million gallons product water per day. Designs with comprehensive

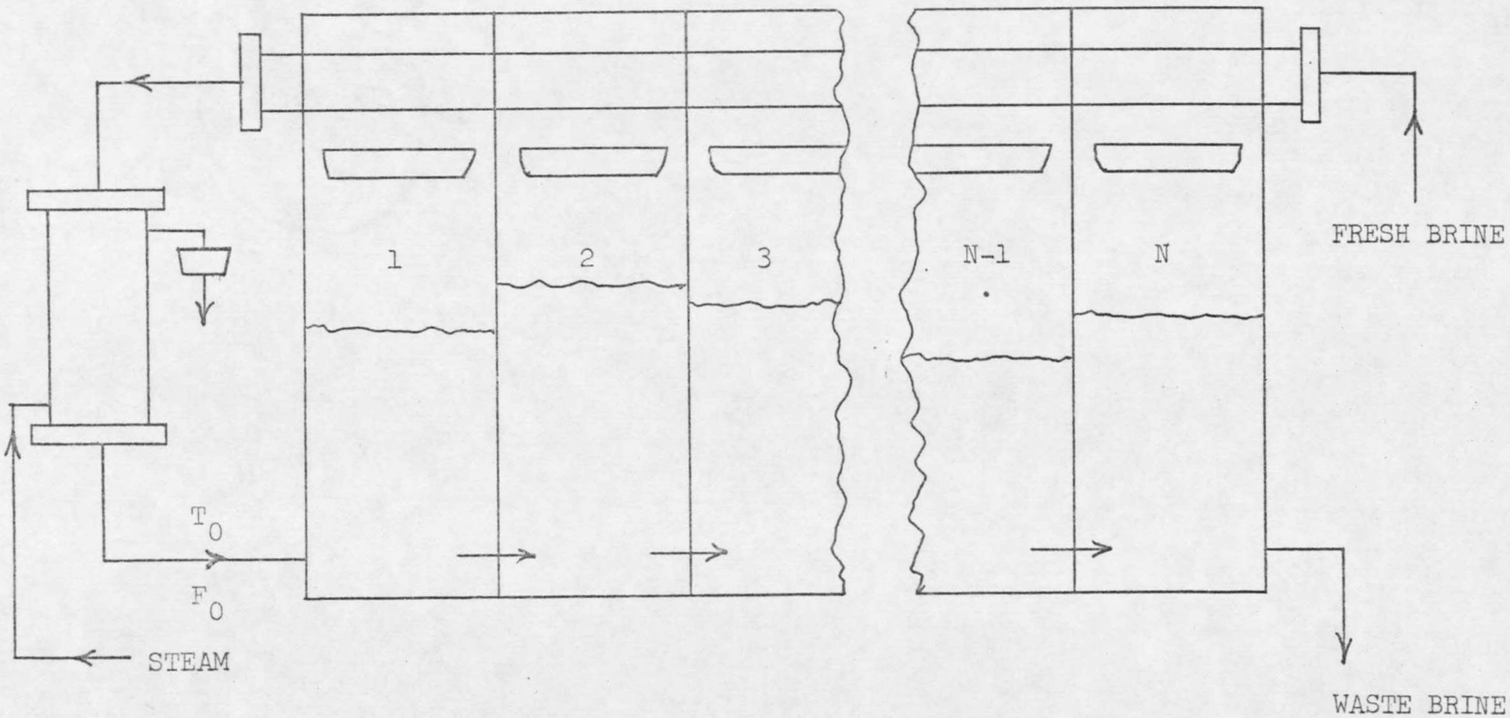

Figure 1. N-Stage Flash Evaporator

cost estimates and complete scale drawings of equipment and instrumentation were done (18,19,20), but no flash desalination plants were constructed. A comprehensive hybrid computer simulation (21) was written by Electronic Associates, Inc., to test the design submitted by Fluor (19) to the Office of Saline Water. Using 12 differential equations and 44 supporting equations to describe the conditions in each flash tank, EAI developed a mathematical model for a 39-tank flash evaporator. Because no experimental data were available describing the operation of a flash evaporator, Electronics Associates, Inc., could not test the model for transient response to upsets. By estimating data where needed, EAI did develop a startup procedure and predict that for steady-state operation the specified product water rates could be met. To supply practical experimental data for large flash desalination plants, the OSW is presently building a flash test module with a capacity of 17 million gallons product water per day (22).

Kogan (14) derived equations that describe the flash evaporator with respect to greatest steam economy and maximum thermodynamic efficiency. Arad (4) has done a system analysis of a large flash desalination plant in which he studied plant cost versus plant life, performance, efficiency, and effectiveness. Narsimhan (17) derived the differential equations describing a multiple-effect concentrating evaporator, simplified these equations, applied boundary conditions, and solved the differential equations mathematically. Andre and Ritter (3) took experimental data on a double-effect concentrating evaporator and wrote a digital computer model describing their system. Andersen, Glasson, and Lees (2) compared experimental data from a single-effect concentrating evaporator with the results of an analog computer simulation of the system, and suggested possible control schemes. Itahara (11) used dynamic programming to optimize the design and operation of both a multiple-effect concentrating evaporator and a multi-stage multi-effect flash evaporator in the steady state.

Dynamic studies have been done concerning the behavior of reactors (7,15), packed liquid-liquid extraction columns (5), and distillation columns (24). Several other papers, perhaps more closely related, have been written concerning heat exchanger dynamics (1,8,13). In each paper, a mathematical model was analyzed using an analog computer, a digital computer, or a tabulated solution to a differential equation.

When this project was begun in October 1966, no experimental data could be found in the literature describing either the transient or steady-state operation of a flash evaporator. No computer simulation of a flash evaporator was available at that time. The EAI hybrid computer simulation was completed in October 1967, and the results were published in condensed form in January 1969. A complete copy of the EAI simulation was not obtained until September 1969.

Transient experimental data were taken on the flash evaporator in the Montana State University chemical engineering laboratory from September 1968 through February 1969. To explain the data, a simulation of the 2-tank flash evaporator was needed. First an analog computer simulation was used, and when this proved inadequate a digital computer simulation was written. The subsequent examination of the complete EAI report showed that the approach of each of the two projects was considerably different. A detailed comparison will be made later.

DESCRIPTION OF EQUIPMENT

The 2-stage flash evaporator available in the Montana State University chemical engineering laboratory had been used previously to correlate 2-phase flow through an orifice (10). Original instrumentation consisted of 10 thermocouples used to measure various temperatures, 2 temperature recorder-controllers, a temperature recorder, a thermopile, and 2 U-tube manometers. (See Figure 2.)

To better monitor the evaporator and produce controlled upsets, several changes in instrumentation were made. A Masoneilan Little Scotty 1/2" pneumatic control valve was placed in the inlet flow line and connected to a Foxboro proportional flow controller to regulate the inlet flow rate. Two Magnetrol level transducers were purchased, one for each tank, to indicate the liquid levels. A pressure transducer was obtained to monitor the pressure in tank 1, and a differential pressure transducer was ordered to monitor the pressure drop between tanks. Thermocouple wells 2, 3, and AA' (Figure 2) were used to monitor respectively the inlet temperature, the temperature in tank 1, and the temperature drop between tanks.

Modifications to the equipment included:

1. Closing the valve to the product-water pump so that no air could leak back into the system through the pump packing. Product water condensed as before, maintaining the heat balance, and dripped back into the tank in small quantities that did not alter the material balance.