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Flash recovery system analysis and flashing tank optimization in desalination plants

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ABSTRACT

This study established and calculated the flash system model of 7-effects low-temperature multi-effect distillation (LT-MED) system with an installed capacity of 4500 m^3/d. The calculation results showed that the brine and distillate flashing accounts for 6.0% of the total water production, which indicate the significant effect of such flashing heat recovery system. Furthermore, a three-dimensional simulation of water–vapor flow in the flashing tank of a LT-MED plant was conducted by using a FLUENT CFD code coupled with a user-defined function. The factors related to the flash efficiency, including flashing tank diameter, length, and internal platform height, were simulated and analyzed. Finally, an improved scheme for setting a platform inside the flashing tank was proposed. The simulation results revealed that the improved scheme ensures the sufficient flash of water inside the tank. These finds of the present study can serve as a reliable reference for the design of flashing tank in LT-MED plant.

1. Introduction

Water is one of the most essential sources for living things to survive. The demand for good quality water is continuously rising owing to the rise in the population, intense agricultural practice, industrialization and overall rise in living standards. Desalination of seawater is the method used to currently to produce drinking water [1]. The low-temperature multi-effect distillation (LT-MED), in which the highest evaporation temperature of seawater is below 70 °C, has already become to one of the mainstream desalination technology [2].

In a typical LT-MED system, a series of stage-by-stage depressurized flashing tanks are set up. The flashing tanks include distillate and brine flashing tanks. Distillate and brine enter into the corresponding flashing tank and flash subsequently. The heat energy will be recovered during the flashing process. Meanwhile, the generated steam in flashing tank will provide the heat for freshwater generation in the next-effect evaporator, which can increase freshwater yield.

As mentioned above, the setting of flashing tank can bring heat back into the evaporator, and the recovered heat will increase the overall efficiency of LT-MED. Therefore, the flashing plays an important role on LT-MED performance. At present, researchers have conducted different degree of researches and explorations on the flashing process. Miyatake et al. [3] carried out experimental study on static flash of pure water with superheats varied between 3 and 5 K. Results suggested that the sensible heat released in the temperature drop of water film could be consider to all change into the latent heat of generated steam. He also defined coefficient of evaporation rate and gave its empirical formula by considering the pressure difference between saturated pressure at liquid temperature and final equilibrium pressure as the main driving force for flash evaporating. Saury et al. [4,5] carried out experimental study on the water mass evaporated by flash evaporation and examined the influences of water film height and depressurization rate on non-equilibrium function (NEF) elevation and evaporated mass. Liu et al. [6] presented experiment on flash evaporation of aqueous NaCl droplet. Results suggested that evaporation rate can be minimized by higher concentration or environment pressure. Zhang et al. [7] studied the steam-carrying effect in static flash of both pure water and aqueous NaCl solution. Non-equilibrium fraction (NEF), evaporated mass and heat transfer coefficient were studied based on static/circulatory flash evaporation experimental systems. Gopalakrishna et al. [8] performed

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Abbreviations: CFD, computational fluid dynamic; LT-MED, low temperature multi-effect distillation; MED, multi-effect distillation; UDF, user defined function; VOF, volume of fluid.

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Nomenclature

B	the flow rates of brine, m^3/h
C_p	the specific heat at constant pressure, kJ/(kg·°C)
D	the flow rates of distillate, m^3/h
d_i	the amount of vapor formed by brine flashing, m^3/h
$d_i{}'$	the amount of vapor formed by distillate flashing, m^3/h
F_i	force, N
H_1	the hydrostatic difference of the tank without platform, mm
H_2	the hydrostatic difference with platform, mm
$\dot{m}_{pq}$	the mass transfer from p phase to q phase
$\dot{m}_{qp}$	mass transfer from q phase to p phase
n	number of effects
$(NEA)_i$	the non-equilibrium allowance of effect i
P	pressure, MPa
P_r	Pranlt number
S_Φ	source term
$S_{\alpha q}$	source term
S_{LG} and S_{GL}	the mass transfer source term between gas and liquid
T	temperature, °C
T_i	the temperature of effect i, °C
T'	the temperature at which the brine cools down to as it enters the effect, °C
T_{ci}	the temperature at which the condensing vapor from the effect i, °C
T''_{i}	the temperature at which the condensing vapor cools down to as it enters the flashing tank, °C
T_{vi}	the effect vapor temperature, °C
ΔT_i	temperature difference between the effect evaporator, °C
t	time, s
T_s	heating steam temperature, °C
T_{cw}	seawater temperature, °C
U_{1i}, $U_{2\mathrm{i}}$	the corresponding overall heat transfer coefficient, kW/(m^2·°C)
U_c	overall heat transfer coefficient for condenser, kW/(m^2·°C)
u_i	velocity, m/s
u_L	velocity of liquid phase, m/s
u_G	velocity of gas phase, m/s

$\vec{u}$	velocity vector, m/s
X	the salinity, mg/L
X_b	salinity of rejected brine
x_i	x coordinate, m
α	the fraction of input heat consumed by vapor formation
α_q	the volume fraction of the q^{th} phase in the control volume
α_L	the volume fraction of the liquid phase in the control volume
α_G	the volume fraction of the gas phase in the control volume
λ	the latent heat, kJ/kg
δ_o	outer diameters of the heat exchanger tube, mm
δ_i	inner diameters of the heat exchanger tube, mm
Φ	main variable in the conservation equation
Γ_Φ	corresponding diffusion coefficient of Φ
ρ	density, kg/m^3
ρ_L	density of liquid phase, kg/m^3
ρ_G	density of gas phase, kg/m^3
μ	viscosity, Pa·s
μ_t	turbulence viscosity, Pa·s

Superscripts

$'$	the distillate flashing
$''$	the brine flashing

Subscripts

b	brine
f	feed
i	the effect number
c	condenser
cw	seawater
v	the vapor
t	turbulent
q	q^{th} phase
L	liquid phase
G	gas phase
s	heating steam
cw	seawater

experiments with concentration of aqueous NaCl solution ranging from 0 to 3.5% and proposed an expression for evaluating flashed mass of pool flash. Mutair and Ikegami [9] examined flash evaporation from superheated water jets and found that higher initial water temperature or superheats can improve the intensity of flash and increase evaporated mass. Jin [10,11] studied the influence of the average water surface height on the reversed flow area and the number of vortices in the circulation system. Several bubble parameters such as size, velocity and growth rate under different superheat conditions were estimated and analyzed in their study. They found that the flash characteristics of the multiphase flow was mainly depended on the superheat and nucleation distribution of the fluid. Miyatake et al. [12] carried out experiments on multi-stage flash (MSF) and indicated the methods to enhance evaporating. Yan et al. [13] improved the MSF system by extracting part of the flash vapor in flash room into the next stage to heat the flashing brine. And the evaporation amount of MSF system before and after improvement was compared by means of theoretical calculation and analysis. Onishi et al. [14,15] proposed a superstructure of multiple-effect evaporation system includes as many evaporation effects as there are flashing tanks, placed intermittently. As a result, process energy efficiency is further enhanced by recuperating the condensate vapor. Meanwhile, there are also some researches about flashing system modeling. Nigim et al. [16] developed a computational field model for the flashing process in a MSF desalination chamber. This model is applied to solve for steady multiphase flow inside a flashing chamber without a baffle, and thus to predict the chamber flow details and behavior. Simulation results can be used to estimate MSF design factors such as non-equilibrium temperature difference and flashing efficiency. Fan [17] conducted simulation research on a 6-stage MSF system. The flash chamber effectiveness β was defined to technically evaluate the flash chamber performance. It was found that increasing brine superheat, flashing surface area, number of active nucleation sites and residence time can enhance flash chamber effectiveness. A new vacuum spray flash desalinator proposed by Hosseini Araghi et al. [18] was modelled using a CFD model. Droplets size, velocity, temperature and concentration profiles are predicted and the underlying physics are discussed regarding the desalinator geometry.

It should be underlined that all of the above-mentioned works were applied only to the basic flash principle, flash efficiency, and MSF system. However, the above research findings cannot be directly applied to the flashing system of LT-MED. At present, the contribution of flashing system to water production of LT-MED has not been studied systematically. Furthermore, the detailed