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The role of enhancement techniques on heat and mass transfer characteristics of shell and tube spray evaporator: a detailed review

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HIGHLIGHTS

- Heat and mass transfer of shell and tube spray evaporators are still subjective for further enhancement.
- The advantage of spray cooling is its capability of additional heat removal.
- Highlight the key areas, which need attention such as enhancement techniques and falling film flow.
- Traditional heat transfer fluids have inherently poor thermal conductivities.
- Combining advanced and new technologies together can enhance functions and properties.

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ABSTRACT

Falling film heat transfer of horizontal shell-side evaporators remains of interest to scientists due to the complexity of these phenomena for practical applications. However, characteristics of heat and mass transfers of spray evaporators are still subject to further enhancement. This study is to review the enhancement techniques and falling film flow especially the effect of nanoparticles suspended with refrigerants in order to confirm their role. The study covers the influence of surface geometry (bundles and external of tubes), normal single tube, low fins, and enhanced geometrical tubes; effect of additives; and the applications and problems related to refrigerant-based nanofluids. Heat transfer area with energy related cost and the significant efforts on empirical correlations for heat transfer coefficient are discussed. It is found that the interaction of the heat and mass transfer process on falling film flow and contradictions of thermal physical properties of nanofluids should all be taken into careful consideration. In addition, existing research on both heat and mass transfer regarding nanofluids are found to be inadequate, and still requires extensive experimental and theoretical work on their salient parameters. Finally, this study highlights the factors affecting efficiency, compactness, and cost of the spray evaporator and the potential of enhancement techniques.

1. Introduction

In industrial settings, falling-film evaporators can substitute flooded evaporators in refrigeration systems, as its use is widespread, owing to its high solution side heat transfer coefficient, and its rather minuscule liquid inventory as opposed to flooded evaporators. Despite the fact that evaporators of this form was initially patented in 1888 [1], there were only a small number of researchers that were seriously working on it prior to the 1970s. Since then, many investigators have studied this technology; however, the work during the 1970s emphasized the utilization of falling-film evaporators for ocean thermal energy conversion (OTEC) systems, and this field was revived in the 1980s due to the second world oil crisis. The working fluid used was water, or ammonia in the case of (OTEC). The phasing out of CFC in the 1990s prompted a more widespread usage of falling-film evaporators. Despite the obvious advantages vis-à-vis refrigeration and air-conditioning, falling-film evaporators are not widely used for both applications. The reluctance of utilizing this technology is due to the complications in disseminating liquids in a uniform

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Nomenclature

C_P	specific heat, (J/kg K)
Do	outside diameter, (m)
dp	nanoparticle diameter, (nm)
g	gravitational acceleration, (m/s)
Ga	modified Galileo number or (kaptiza number), $(\rho^*\sigma^3/\mu^4{}^*g)$
H	liquid feeder height, (m)
h	heat transfer coefficient, (W/m^2 K)
k	thermal conductivity, (W/m K)
Nu	Nusselt number, $(h/k_l)(v_l^2/g)^{1/3}$, dimensionless
p	pressure, (N/m^2)
Pr	Prandtl number, $k/\rho C_P$, dimensionless
Re	Reynolds number
T	temperature

Greek letters

α	pool boiling heat transfer coefficient, (W/m^2 K)
Ø	concentration ratio of nanofluids
Γ	liquid mass flow rate per unit length of tube (each side), (kg/m s)
μ	dynamic viscosity, (kg/m s)
ν	kinematic viscosity, (m^2/s)
ρ	density, (kg/m^3)
σ	surface tension, (kg/s^2)
ξ	capillary constant given by $[\sigma/\rho_l{}^*g]^{1/2}$, (m)

Subscripts

crit	referred to the critical state
l	liquid
sat	saturation
v	vapor

manner over a surface of a tube array to form thin films that are suitable for evaporative heat transfers. This renders process optimization of this system for the purpose of evaporation extremely difficult. Also, the optimization of falling-film heat exchanger requires a detailed comprehension of both the influence of wall superheat and solution sub-cooling on the ratio of evaporation-to-sensible heat transfer. Evaporation heat transfer is still a relevant and challenging research topic, despite the fact that intense work on this area has been ongoing for decades. Thome [2] and Ribatskia and Jacob [3] focused on studies published from 1994 to 2005. Recently, Fernández-Seara and Pardiñas [4] focused mainly on heat transfer and fluid dynamics of falling film evaporation and to the best of our knowledge, only a few data is present in literature on falling-film heat and mass transfers. This paper reviews the literature on horizontal-tube and falling-film-type evaporators, with special emphasis on defining the characteristics of both heat and mass transfers of falling-film evaporators under different enhancement techniques. Furthermore, other factors, including pressure losses and cost effects, are studied as well.

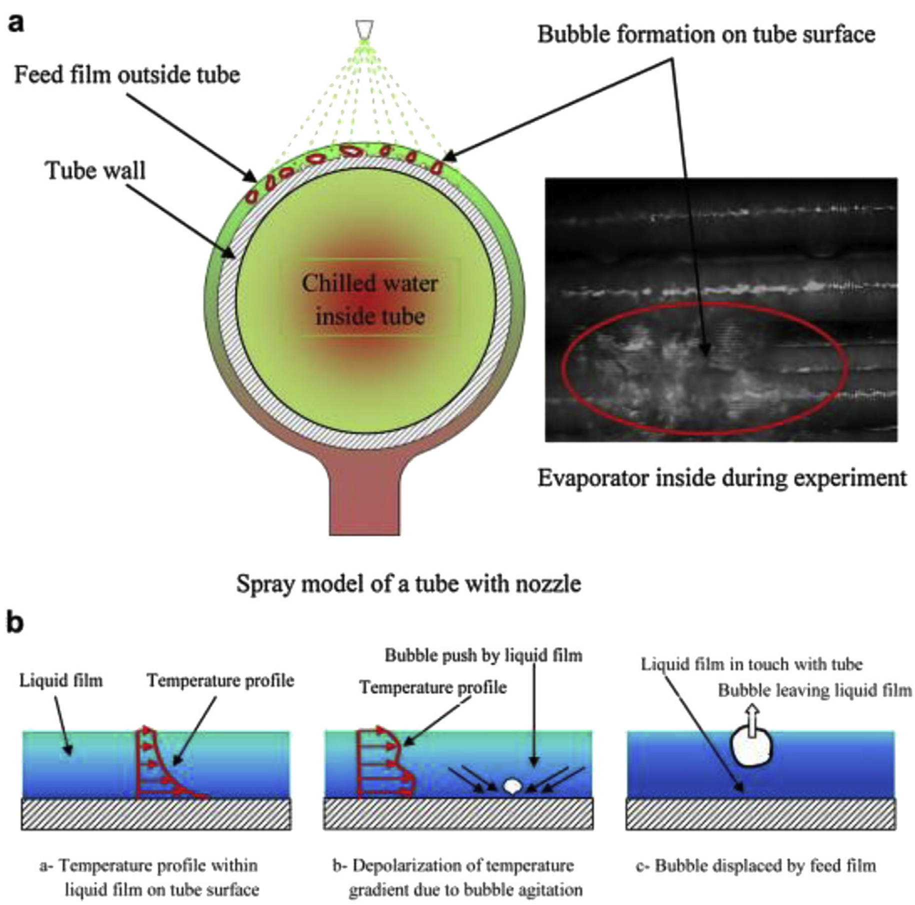

Fig. 1. (a) Bubble formation on tube surface and spray model. (b) Bubble agitation in liquid film [6].

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