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Wetting enhancement of polypropylene plate for falling film tower application

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ABSTRACT

Falling film towers are popular for simultaneous heat and mass transfer applications due to modest air pressure drop and low energy demanding liquid distribution. Conventionally, metals are used as gas liquid contacting surface in these towers. Corrosion prone metallic surfaces need expensive anticorrosive coating or frequent replacement, whereas non metallic surfaces such as plastics have poor wetting characteristics. In current study, wetting factor of plain polypropylene and aluminum plates has been measured. Wetting enhancement methods: surfactant addition (sodium lauryl sulfate-SLS) and surface modification have been used on polypropylene plate. Improvement of 50% (SLS 300 ppm) and 80% (Modified Surface C) wetting characteristics of polypropylene have been achieved. Modified Surface C average wetting factor is 41% superior to aluminum surface. A new generalized empirical correlation for wetted area estimation considering influences of solid surface and fluid characteristics has been proposed. Proposed equation shows good agreement with current and past studies (MAPE 8.5%).

1. Introduction

Conventionally three types of towers namely packed bed, spray and falling film towers are used in simultaneous heat and mass transfer applications [1]. For transfer of potential (heat and mass) from one fluid to another fluid in these chemical towers, one of the fluids (liquid) is dispersed across continuous phase of another fluid (gas). In the spray towers, liquid dispersion is required in form of fine liquid droplets. In case of the falling film towers, liquid flows in form of thin straight liquid film on solid surface. In case of the packed bed towers, liquid moves in form of distorted liquid film at solid surfaces and as liquid sheet between solid surfaces. Out of above, the packed bed towers are the most versatile and extensively used design. They relish benefit of high efficiency and very large contact area to volume ratio. Major drawbacks of these are high air side pressure drop and high m_l requirement [2]. Spray towers are quite popular in air pollution control [3]. Advantages associated with spray towers are simple design, and low initial and maintenance cost. Their major limitations are: poor efficiency, ineffective/absence of external heat interaction, high speeding liquid droplets (poor residence time of liquid droplets) and large liquid side pressure drop [4]. Falling film towers are better equipped to handle limitations of both packed bed and spray towers. Thin film of liquid attributes towards high heat transfer & mass transfer coefficient. Their air side pressure drop is quite less in comparison to the packed bed towers and they can operate efficiently at low m_l/m_a ratio. Liquid jet can be easily dispersed in form of a falling film at the expanse of less energy than the spray tower. Distinguished feature of the falling film tower is the instant removal/addition of heat along with mass transfer operation. Total power requirement is even lesser than packed bed and spray towers [5]. Hence, processes that can abide moderate parasitic losses use falling film towers (i.e. cooling tower, absorption refrigeration). Two main limitations of the falling film towers are the incomplete wetting of the solid surfaces and non-uniform distribution of the liquid across solid surfaces [6]. Unlike packed bed towers and spray tower, state-of-the-art of the falling film tower is still not matured. Proficient designs of liquid distributors and highly efficient solid liquid contacting surfaces (high wetting at low flow rates) can help in upgrading the performance of the falling film tower up to the packed bed towers.

Many researchers have carried out experiments related to design of liquid distributor with objectives of either to ensure

Abbreviations: Al, aluminum; LiCl, lithium chloride solution; LPM, liter per minute; MAPE, mean average percentage error; PP, polypropylene; ppm, parts per million; SLS, sodium lauryl sulfate; S.S., stainless steel.

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Nomenclature

Greek symbols
ε_w Wetting factor
α Thermal diffusivity (m^2/s)
ρ Density (kg/m^3)
σ Surface tension (N/m)
$\frac{\partial\sigma}{\partial T}$ Partial differential of surface tension of liquid
μ Viscosity (Pa s)
ν Kinematic viscosity (m^2/s)
γ Surface energy (J/m^2)
θ End cutting edge angle (°)

Symbols
A Area (cm^2)
$\frac{A_w}{A_{w,o}}$ Area ratio in Eq. (2)
B Breadth (cm)
d Depth of cut (mm)
g Acceleration due to gravity (m/s^2)
H Height (cm)
L Length (cm)
l_ν Viscosity length scale (m)
Ka Kapitza number
Ma^* Modified Marangoni number
m Mass flow rate (kg/s)
n Number of data points
p Distance between two consecutive slots (cm)
Re Reynolds number
Re_f film Reynolds number
T Temperature (°C)
T_l Average liquid film temperature (°C)
t Thickness (cm)
W Width of plate (cm)
Z Number of slots

Sub- and Superscripts
a Air
ext Extended
i Interception point
l Liquid
o Isothermal condition
s Solid surface
w Wet

uniform flow of liquid across each solid surface or to ensure stable liquid film across solid surfaces. Luo et al. [7] designed a tangential inlet (liquid flow direction) single vertical tube falling film evaporator. They investigated the effect of an annular slit opening (0.5–2 mm) and liquid spray density on the film uniformity and stability. They recommended the annular slit opening of 1.5–2 mm and spray density between 0.07–0.19 kg/(m s) for optimum film stability, distributor inlet tube was rotated tangentially by 270° inside distributor header for ensuring uniform film thickness around whole periphery. Qi et al. [8] investigated experimentally the factors affecting the wetted area and film thickness on single channel internally heated vertical regenerator of a liquid desiccant system in the mass flow range of 0.025–0.15 kg/s. They observed that due to increase in slit opening from 1.0 to 1.25 mm decreased the wetted area by around 51%. A rectangular box distributor with parallelly welded lamellas was suggested by Glebov and Settervall [9], liquid was fed in the distributor through three inlet pipes. They reported that minimum specific flow rate has to be 0.26 kg/(m s) for full wetting of lamella type surface. Distributor and redistribution components in combination were used by Gonda et al. [10] for getting uniform distribution of solution on both sides of a plate. Water flows firstly through the distributor, each side edges of distributor are drilled 13 semi-cylindrical holes of 3 mm diameter. Then, water flows along the internal wall of the header until it reaches the redistributor. They reported removal of dry patch formation due to shrinkage of liquid film with proposed assembly.

Wetting or adhesion of the liquid on the solid surface depends on properties of contacting mediums i.e. surface tension of the liquid and surface energy of the solid. Hence, spreading of the liquid on the solid surface can be improved by increasing surface energy of solid and reducing surface tension of liquid [11]. Many experimental studies have been carried out by researchers using surfactant addition or surface modification techniques as wetting enhancing medium. Effect of the surfactant 2-methyl-1-pentanol (500–700 ppm) on absorption chiller ($LiBr/H_2O$) was investigated by Glebov and Settervall [12]. They found 30–35% overall enhancement in cooling capacity of chiller. Cheng et al. [13] experimentally investigated the effect of the surfactants (2-ethyl-1-hexanol and 1- octanol) on the heat transfer in falling film absorber. They found improvement up to 100% in heat transfer coefficient with optimum concentration at (~40 ppm) for these surfactants and noticed decrease in the heat transfer coefficient with any further increase in the surfactant concentration. Kang et al. [14] observed 34% improvement in the wetted area with triton X 100 surfactant (500 ppm) addition in water. Kim et al. [15] investigated the effect of enhanced surface (micro-scale hatched tube) on horizontal falling film tubular absorber using $LiBr/H_2O$ solution. They reported 10% improvement in wetting characteristic of a hatched tube surface than smooth one. Koroglu et al. [16] studied the effect of copper oxide layer deposition on copper tubes in the horizontal tube falling film tower. They reported full wetting in case of the oxidized tubes at low flow rate (Re ~86) than the plain tube (Re ~114). Hoffman et al. [17] used knurled tubes and 2-ethyl-1-hexanol (80 ppm) for the horizontal tube falling film tower. They found 20–40% improvement in mass transfer coefficient for knurled tubes and 60–140% improvement for surfactant addition case. Kim and Ferreria [18] experimentally compared the effects of modified surface geometry (clamping of copper wire mesh on copper surface) and a surfactant 2-ethyl-1-hexanol (100 ppm) addition on film pattern of copper plate using LiBr–water absorbent solution. They reported enhancement in mass transfer of 40% and 60–110% through copper wire clamped surface and surfactant addition respectively. Zhang et al. [19] experimentally investigated the role of Marangoni effect on the mass transfer of falling film tower (inclined SS plates). They proposed generalized effective enhancement factor correlation in terms of ethanol concentration, inclination angle of surface and liquid flow condition.

Use of metallic gas-liquid contacting surface in the falling film tower is very common due to good wettability of metallic surface. But, corrosion problem is the main limitation of metallic surface and it mandates the replacement of solid surfaces after certain time interval thus adding up significant maintenance cost. Plastic plates can be used as an alternative of metallic surface provided wetting characteristics of plastic surface can be elevated up to metallic surface. They have excellent corrosion resistance property, low cost and light weight. In the present investigation, wetting factor of aluminum (Al) and polypropylene (PP) plates have been experimentally measured. Effect of the sodium lauryl sulfate (SLS) surfactant addition and the surface modification technique have been used for improving the wetting characteristics of PP for vertical falling film tower application.