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ORIGINAL ARTICLE

Investigating droplet separation efficiency in wire-mesh mist eliminators in bubble column

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Abstract Effects of design parameters on performance of wire-mesh mist eliminators were experimentally investigated in 15 cm bubble column. The demisters performances were evaluated by droplet collection efficiency as a function of wide ranges of operating and design parameters. These parameters include: droplet size exiting the demister (250–380 μm), specific surface area (236–868 m^2/m^3), void fraction (97–98.3%), wire diameter (0.14–0.28 mm), packing density (130–240 kg/m^3), and superficial gas velocity (0.109–0.118 m/s. All demisters were 15 cm in diameter with 10 cm pad thickness, made from 316L stainless steel layered type demister pad wires. Experiments were carried out using air–water system at ambient temperature and atmospheric pressure. The experimental data on the droplet removal efficiency were obtained using Malvern Laser Droplet Sizer. The removal efficiency was found to increase with the increasing the demister specific surface area, packing density, and superficial gas velocity. In contrast, the removal efficiency was found to increase with decreasing the demister void fraction and wire diameter. The separation efficiency is correlated empirically as a function of the design parameters. A good agreement was obtained between the measured values and the correlation predictions with ±5% accuracy.

1. Introduction

In many operations in chemical plants, it is frequently necessary to remove droplets from gas vapor streams. Droplets separation is required to recover valuable products, improve product purity, increase throughput capacity, protect down stream equipment from corrosive or scaling liquids, avoid undesired reactions, and to improve emissions control. Mist eliminators are devices that can remove entrained liquid from gas flow effectively. For example, in thermal desalinations plants, the droplets must be removed before vapor condensation over condenser tubes. If the mist eliminator doesn't separate efficiently the entrained water droplets, reduction of

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Nomenclature

A (m^2) bubble column cross sectional area
A_s (m^2/m^3) specific surface area
D_{av} (μm) average droplet diameter exiting the demister
D_d (μm) droplet diameter
D_w (mm) demister wire diameter
M_{in} (kg) mass of entrained droplet upstream the demister
M_{out} (kg) mass of entrained droplet downstream the demister
n (–) number of layers
Q_g (m^3/s) volumetric flow rate
St (–) Stokes number
V_g (m/s) superficial gas velocity
(Vol)$_{\text{liq}}$ (m^3) bubble column liquid inventory volume
z (m) distance between two successive layer

Greek letter
ε (–) void fraction
η (%) separation efficiency
η_{ST} (%) efficiency of single target
μ_g (kg/ms) gas viscosity
π (–) constant (3.14)
ρ_g (kg/m^3) gas density
ρ_l (kg/m^3 liquid density
ρ_p (kg/m^3) packing density

distilled water quality and formation of scale on the outer surface of the condenser tubes occurs. The last effect is very harmful because it reduces the heat transfer coefficient and enhances the corrosion of the tube material (Souders and Brown, 1934).

Another example is the two phase bubble column reactors. Bubble columns have been widely used in industry because of their simple construction and operation. Important applications include hydrogenation, oxidation, polymerization, Fischer–Tropsch synthesis, ozonolysis, carbonylation, carboxylation, alkylation reactions as well as for petroleum processes. Other important application area of bubble columns is their use as bioreactors in which microorganisms are utilized in order to produce industrially valuable products such as enzymes, proteins, and antibiotics. In the bubble column, the gas is introduced in the form of bubbles into a pool of liquid via a distributor. The mass transfer and hence the reaction takes place between the gas bubbles and the liquid. The gas stream leaving the liquid pool entrains droplets of liquid with it, which must be removed before it exits the reactor. Failure to do so will cause the reaction to continue in the exit streamlines. In polymerization reactions for example, the entrainment will cause plugging of the exit streams and overhead lines.

Mist eliminators belong to various groups that operate under different principles and are applied for the droplets removal with a specific size range. When selecting a mist eliminator, careful considerations should be given to performance parameters and one must weight several important factors so as to ensure a cost effective installation (Bell and Strauss, 1973; York, 1954). Collection efficiency is primarily a function of droplet size distribution, superficial gas velocity, mist loading and the mist's physical properties. Table 1 shows various groups of mist eliminators according to some performance parameters.

The knitted wire-mesh mist eliminator is one of these devices which have a widespread application in many industrial plants. The separation process in the wire-mesh mist eliminator includes three steps; first 'inertia impaction' of the liquid droplet on the surface of wire. The second stage is the coalescence of the droplet impinging on the surface of the wires. In the third step, droplet detach from the pad. Wire-mesh mist eliminator has gained extensive industrial recognition as a low cost, easy installation, minimum tendency for flooding (re-entrainment), high capacity, small size, and efficient means for removal of entrained liquids droplets from vapor and gas streams. It is probably outnumber all other types of mist eliminators combined specially in petrochemical equipments such as scrubbers, evaporators and distillation columns. Although knitted wire mesh has been used by industry for broad ranges of entrainment elimination operations, the volume of fundamental work published regarding their performance characteristics is scant. The work of Satsangee (1948) was concerned primarily with wire mesh as column packing and contacting media and not specifically entrainment elimination. The detailed investigation of Carpenter and Othmer (1955) studied wire mesh as an entrainment separator in an evaporator handling salt solution and defined the efficiency, pressure drop, and capacity of knitted wire structure. As generally used, knitted wire-mesh mist eliminator consists of a bed, usually 10.16–15.24 cm deep, of fine diameter wires interlocked by a knitting to form a wire-mesh pad with a high free volume, usually between 97% and 99%. The primary performance parameters affecting demister droplet removal are gas velocity, surface area, free volume, packing and hence, diameter of fibers used in mesh knitting and thickness of a demister.

2. Prediction of droplet separation efficiency

Semi-empirical equations based on the Souders–Brown relationship are commonly used for designing wire-mesh mist eliminators (York, 1954). However, their technique is rough

Table 1 Equipment selection versus mist particle size (Ziebold, 2000).

Style	Brownian fiber beds	Impaction fiber beds	Mesh pads	Vane separator
Collecting fiber diameter (μm)	8–10	10–40	100–300	> 300
Bed velocity (m/s)	0.05–0.25	1.25–2.5	2–4	2.5–5.0
Pressure drop (mm H_2O)	100–450	100–250	10–75	3–25
Particle size collected (μm)	< 0.1–3	1–3	2–20	> 20