Use of Packed Beds for Demisting Gases: High-Temperature Applications

G. J. Suppes and J. Manning
Dept. of Chemical Engineering, University of Kansas, Lawrence, KS 66045

The performance of commercially available wire mesh packing was compared to three different ceramic materials in packed bed demisters. Removal efficiencies similar to wire-mesh pads were achieved by certain ceramic packing; however, pressure drops were greater than those associated with commercially available wire mesh demisting pads. Despite higher-pressure drops, ceramic materials have operational advantages at higher temperatures where most metal materials would fail. In particular, ceramic packed beds would be useful with coal- or biomass-fueled slagging combustors, molten salt oxidation of hazardous wastes, molten carbonate fuel cells, and direct contact heat exchange for removing entrained salts and metals from effluent gases. Commercially available ceramic packing of sizes less than 0.75 cm represent a good initial choice for high-temperature demisting; however, further work is needed to optimize both the packing and equipment configuration.

Background

While demisting pads are commercially available for routine distillation and other near ambient temperature operations, little data and no commercial options are available for the more demanding high-temperature operations. For high-temperature operations such as coal- or biomass-fueled slagging combustors (Cowell et al., 1992), molten salt oxidation of hazardous wastes, molten carbonate fuel cells (Baker et al., 1993), and direct contact heat exchange (Copeland et al., 1982; Suppes et al., 1994), liquid-gas separation methods are needed to remove molten ash, salt, and metals from the carrier gas. Ceramic packed beds have been proposed to capture these entrained droplets as they pass through the system. These packed beds are suggested for their ability to withstand very high temperatures and for their relatively low capital and operating costs. A study was conducted with the liquid-gas system of salt water and air at room temperature to compare the separation efficiencies of the packed particle bed to conventional mist eliminators. These results show ceramic packing is an effective mist eliminator and should work at high temperatures where wire mesh eliminators would fail.

Entrained liquids less than 10 micron in size (mists) are traditionally filtered from gas streams by various means including demisting pads, filters, cyclones, impingement separations, and wet scrubbers. Unfortunately, in all but demisting pads and filters, these options have inherent drawbacks. These drawbacks are relatively high capital costs, high operating costs, a lack of endurance, and limited temperature ranges (Capps, 1994).

To bypass these obstacles and to account for the high temperatures of application, ceramic packing is suggested for a variety of reasons. Ceramics can withstand extremely high temperatures and are corrosion resistant; therefore, they would be useful for high-temperature applications with corrosive medium such as a salt bath. Ceramic packed beds are also relatively simple and inexpensive. These separators also have no moving parts and are thus quite robust.

Ceramic filters are also being developed for high-temperature applications (Lippert et al., 1993); however, filters are more costly, have a greater pressure drop, and require more maintenance than packing. For applications where the entrained phase is predominantly liquid, demisting pads or packed beds would be preferred.

Typical demisting pads are comprised of wire mesh, which is a grid of interlocking iron or steel that is packed to fit any volume. The wire mesh mist-pads [6 in. (152 mm) thick, 0.011-in. (0.28 mm) wire, 9 lb/ft^3 (144 kg/m^3) density] remove approximately 80% of the salt water particle diameters of roughly three microns by the method of Langmuir and Blodgett (Capps, 1994). To test the viability of ceramic packed beds, an assortment of ceramic packings were compared against wire mesh mist-pads. Experiments were conducted at room temperature and pressure to evaluate their removal of an aqueous sodium chloride solution from air.

Procedure/Results

Two apparatuses were designed and built to verify the effects of varying conditions on entrainment. Figure 1 shows the apparatus used for preliminary studies. A needle valve and rotameter were used to control the flow of 446 kPa of compressed air to the experimental apparatus. The air enters the column, passing through the salt solution to entrain particulates as the air bubbles out of solution. Air and entrained liquid then pass through the packed bed section of the col-

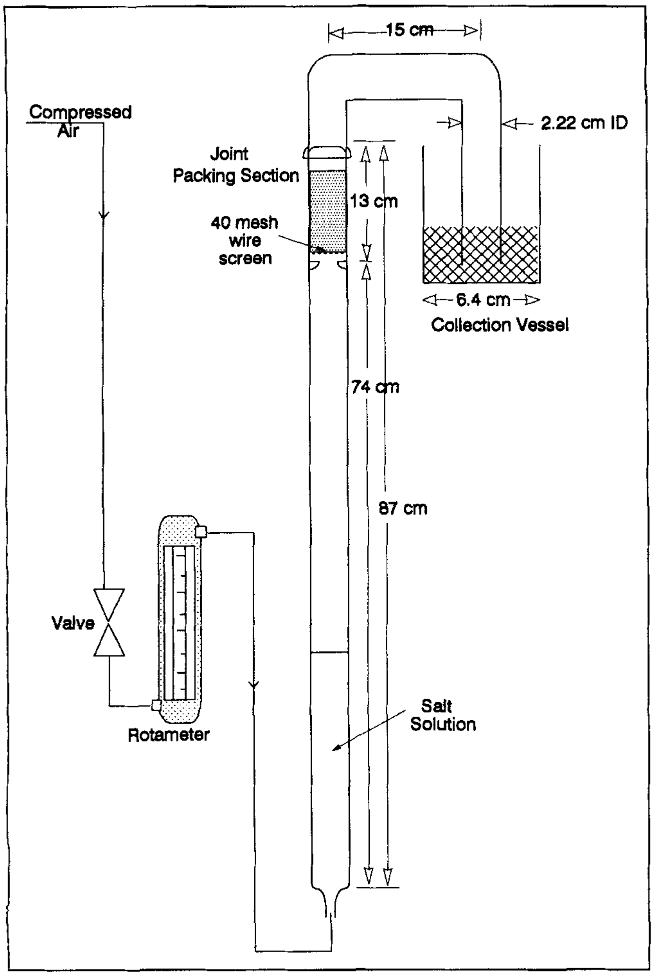

Figure 1. Initial apparatus used to evaluate ceramic packed-bed demisters.

umn, which is held in place by two retaining screens. As the air and particulate liquid flow out of the column, the entrained salt is scrubbed from the air by passing it through deionized water in the collection vessel. The scrubbing occurs by agitation of the solution and because the vessel has gas velocities about five times less than those in the column. The amount of entrainment in the exiting gas was assumed to be proportional to the rate of change in conductivity of the collection vessel solution. A calibration curve showed the conductivity to be proportional to the salt concentration at low salt concentrations.

This apparatus is useful for observing entrainment trends. As anticipated, the depth of liquid in the column did not impact the amount of salt entrained in the carrier gas, as entrainment occurs only at the interface surface area between the liquid and vapor phases. As illustrated by Figure 2, a drawback of this apparatus is that the 40-mesh retaining screens used to hold the packing in place removed the majority of salt being entrained.

A second apparatus was built to eliminate the impact of the retaining screens and to compare ceramic packings with the conventional wire mesh mist eliminator. The majority of the second apparatus was constructed with PVC drain pipe, with dimensions shown in Figure 3. The salt solution section

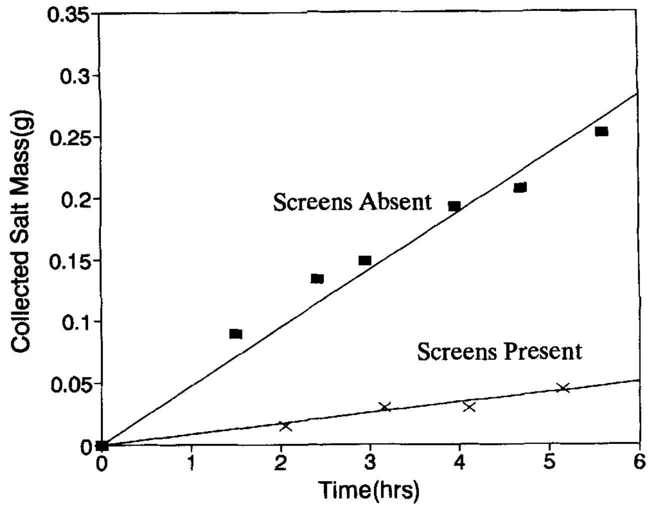

Figure 2. Impact of 40 mesh wire screens on salt concentration in effluent gases.

and collection vessel were constructed from 0.3175-cm-thick glass with dimensions shown. Several improvements on the original design are apparent. The addition of a large tank was used for the leveling out of variations in air-flow rate throughout the column. The trap used for the packing sec-

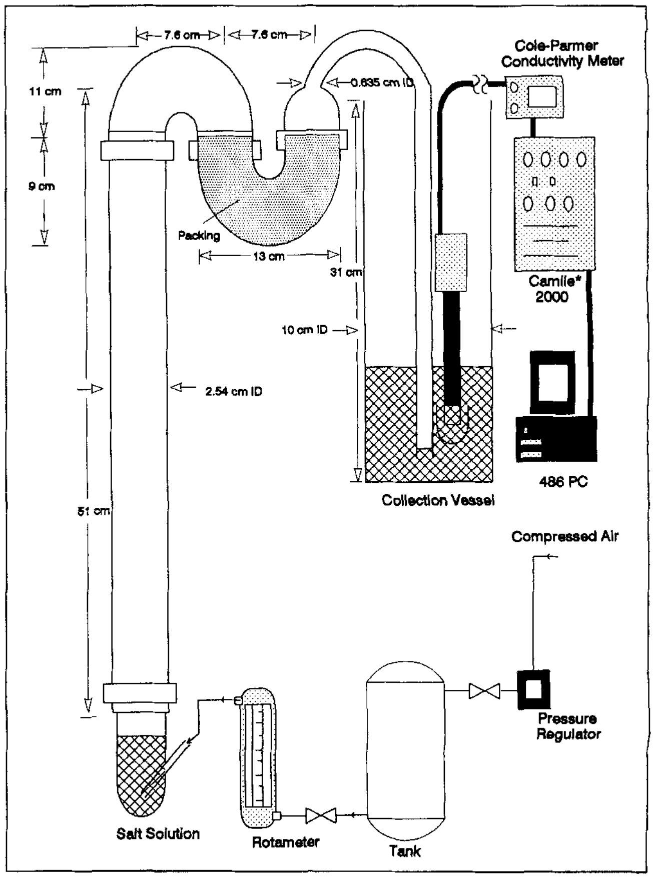

Figure 3. Experimental apparatus using a trap to hold packing.

No screens are required to hold the packing in place.

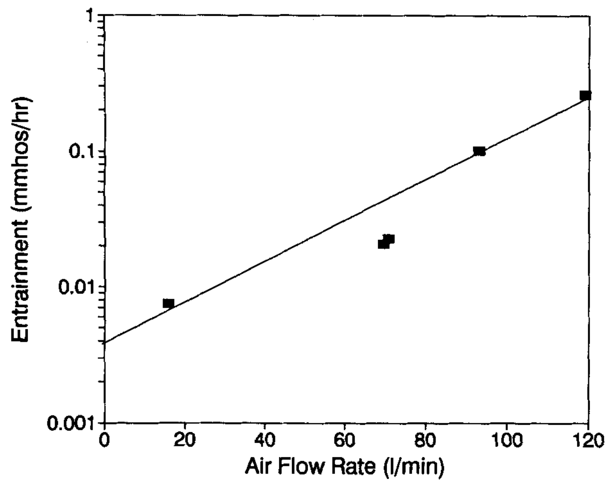

Figure 4. Impact of air-flow rate on salt entrainment.

tion was added to negate the effects of retaining screens on entrainment. Finally, a Cole Parmer ECE meter 19101-00 was added that measures conductivity more precisely, down to 0.001 μmho with an accuracy of $\pm 0.15\%$. Data obtained from this conductivity meter was recorded on-line with a 486 PC via the CAMILE 2000 control system.

Ceramic packing elements of 1.27-cm OD Raschig Rings, 0.64-cm Intalox Saddles, and +6 to −20 mesh zirconium oxide were evaluated for their demisting capabilities. The performance of conventional wire mesh mist eliminator [0.011 in. (0.28 mm), 9.0 lb/ft^3 (144 kg/m^3) 304SS] from ACS Industries, Inc., Houston and 0.32-cm iron rings were compared to the ceramic packings. The packing volume was 121.8 cm^3 and was continuous in the packing material. In practice separation is improved by alternating packing with settling sections.

Prior to demisting studies, the vapor flow rate was varied to determine the impact on entrainment. Entrainment rate increases as an exponential function of air-flow rate, as illustrated by Figure 4. Equation 1 (Henley and Seader, 1981) was used to estimate the column flood velocity at 233 cm/s. Figure 5 illustrates the relatively high rate of entrainment

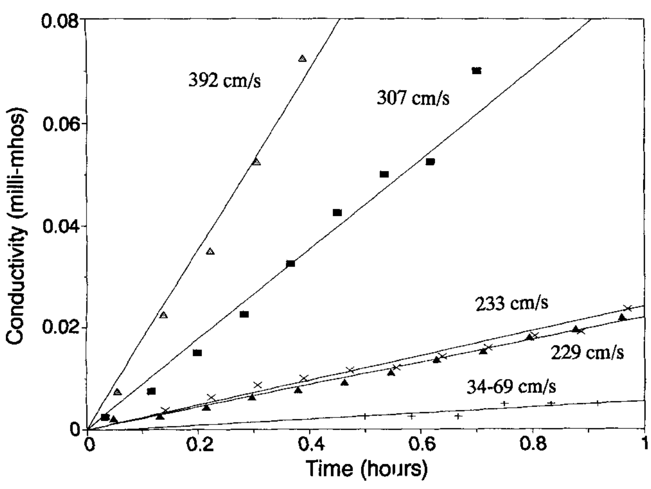

Figure 5. Conductivity of water in collection vessel as function of time for gas flowing at different flow rates.

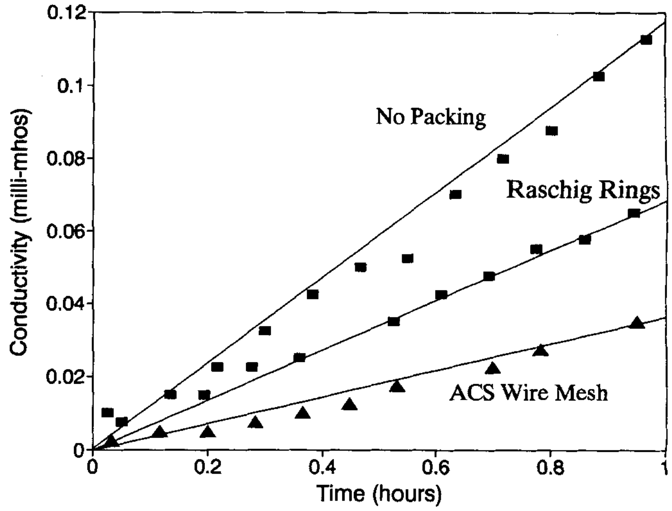

Figure 6. Comparison of the performance of Raschig Rings to ACS wire mesh.

above the flooding velocity. For Eq. 1, ρ_V is the vapor-phase density, ρ_L is the liquid-phase density, and C is the Souders and Brown capacity parameter.

$$U_f = C\left(\frac{\rho_L - \rho_V}{\rho_V}\right)^{1/2} \tag{1}$$

Discussion

Figure 6 compares the performance of Raschig Rings to the ACS wire mesh. The wire mesh removes about twice as much of the entrained particulates as the Raschig Rings. The amount of entrained particulates of the packing effluent was relatively constant after a startup time of roughly ten minutes. Therefore, the separation efficiency of the packings was determined from the slope of a least-squares line through the conductivity data. Values of the removal efficiency are listed in Table 1. The wire mesh efficiency is lower than the reported 80% (Capps, 1994) due to using only one pass through the packing and using no settling sections. Four of the five separation methods were observed to be almost equivalent to the wire mesh packing at the specified conditions. The Raschig Rings were too large and the air gaps were too big; insufficient inertial impaction resulted in low efficiency.

Advantages of wire mesh packing are apparent from the pressure drop associated with these packings as shown in

Table 1. Removal Efficiencies and Pressure Drops for Different Demisting Materials

Packing	Air-Flow Rate cm/s	Pres. Drop Pa	Removal
Wire Mesh	314	62.2	69%
Raschig Rings	314	93.3	42%
Metal Rings	314	280.0	77%
Intalox Saddles	314	342.0	77%
Intalox Saddles	161	93.3	
Zirconium Oxide	48.6	1,166.1	78%

Table 1 at two air-flow rates, 307 and 151 cm/s. Ceramic packing produces a larger-pressure drop than wire mesh packing when operating with gases having the same apparent velocities; however, the performance of ceramic packing is good over a wider range of temperatures. The pressure drop of zirconium oxide was significantly larger than packing materials and would not be a preferred demisting material.

The 0.64-cm Intalox Saddles performed better than the other ceramics by removing entrained liquid at high efficiencies with reasonable pressure drops. The good performance most likely resulted from a good combination of small packing size and relatively large void volumes to reduce pressure drops. In general, ceramic packing for packed-bed distillation columns is designed to minimize pressure drop while creating large surface areas for liquid-gas contact—essentially the same desired characteristics as demisting pads. Hence, commercially available ceramic packing of sizes less than 0.75 cm represent a good option for demisting process gases at temperatures too high for available wire mesh demisting pads.

Conclusions

It has been shown that ceramic packed beds are a viable method for demisting gases. Pressure drops are greater than those associated with commercially available wire mesh demisting pads; however, ceramic materials would allow operation at higher temperatures where most metal materials would fail. In particular, ceramic packed beds would be useful with coal- or biomass-fueled slagging combustors, molten salt oxidation of hazardous wastes, molten carbonate fuel cells, and direct contact heat exchange for removing entrained salts and metals from effluent gases. Commercially available ceramic packing of sizes less than 0.75 cm represent a good initial choice for high-temperature demisting; however, further work is needed to optimize both the packing and equipment configuration.

Literature Cited

Baker, B. S., C. R. Bentley, and D. R. Glenn, "Overview of ERC's Molten Carbonate Fuel Cell Development Program," *Proc. Joint Contractors Meeting: FE/EE Advanced Turbine Systems and FE Fuel Cells and Coal-Fired Heat Engines Conf.*, U.S. DOE, METC, Morgantown, WV, p. 239 (1993).

Capps, R. W., "Properly Specify Wire Mesh Mist Eliminators," *Chem. Eng. Prog.*, **90**, 49 (1994).

Copeland, R. J., J. W. Leach, and C. Stern, "High-Temperature Molten Salt Solar Thermal Systems," *Proc. Intsoc. Energy Convers. Eng. Conf.*, **4**(17), p. 2032 (Aug., 1982).

Cowell, L. H., A. M. Hasen, R. T. LeCren, and C. E. Tenbrook, "Two-Stage Slagging Combustor Design for a Coal-Fueled Industrial Gas Turbine," *J. Eng. For Gas Turbines and Power*, **114**, 359 (1992).

Henley, E., and J. D. Seader, *Equilibrium-Stage Separation Operations in Chemical Engineering*, Wiley, New York, p. 503 (1981).

Lippert, T. E., G. J. Bruck, R. A. Newby, and E. E. Smelter, "Specific Filter Designs for PFBC," *Proc. Coal-Fired Power Systems: Advances in IGCC and PFBC Rev. Meeting*, U.S. DOE, METC, Morgantown, WV, p. 71 (1993).

Newitt, D. M., N. Dombrowski, and F. H. Knelman, "Liquid Entrainment: 1. The Mechanism of Drop Formation From Gas or Vapour Bubbles," *Trans. Instn. Chem. Engrs.*, **32**, 244 (1954).

Suppes, G. J., K. C. Poon, and J. M. Manning, "Gas-Gas Heat Transfer Using a Direct Contact Heat Exchange Fluid and Two Packed Columns," paper 192f, AIChE Meeting, San Francisco (Nov., 1994).

Manuscript received June 5, 1995, and revision received Aug. 17, 1995.