Ind. Eng. Chem. Res. **1993**, *32*, 2387–2389

Direct-Contact Heat Transfer from a Liquid Spray into a Condensing Vapor

John G. Kunesh

Fractionation Research, Inc., P.O. Box 2108, Stillwater, Oklahoma 74076

Previously published work has shown that the direct-contact heat-transfer performance of a liquid spray into a hot noncondensing vapor is intermediate between the performance of a single baffle tray and 2 ft of random packing. Data obtained when spray nozzles were utilized to introduce subcooled reflux into dew point vapor above a pan distributor indicate that it would be extremely difficult to find a more efficient heat-transfer device than the nozzles plus a few inches of void space.

Introduction

Direct-contact heat-transfer is utilized in a variety of applications such as quench towers, de-superheating sections of fluid catalytic cracking main fractionators, and pumps around zones in crude oil distillation towers. Contacting devices utilized include baffle trays, sieve trays, valve trays, random packings, grids, and structured packings. Their performance is generally characterized in terms of a volumetric heat-transfer coefficient (Fair, 1968, 1971, 1972).

A previous publication presented results that indicated that, for a noncondensing vapor, performance of spray nozzles above 2 ft of void space was intermediate between a single baffle tray and 2 ft of random packing (Ognisty, 1990). The data reported in this work indicate that when subcooled reflux is sprayed into dew point vapor, about 3 in. of void space is all that is required to reach as close an approach to thermal equilibrium as is achievable.

Since these results are a by-product of other experiments that were not intended as heat-transfer studies, quantitative heat-transfer coefficients cannot be deduced with any degree of confidence. It is felt, however, that the qualitative conclusions are significant.

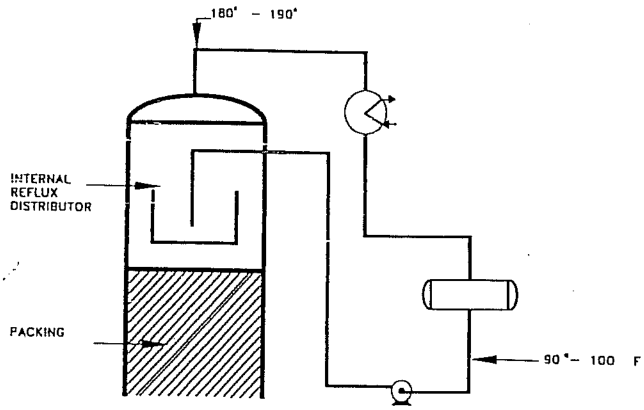

Figure 1. Process sketch.

Experimental Section

Figure 1 is a process sketch of the packing installation in the Fractionation Research, Inc., column. The program objective was to study the mass-transfer performance of the packed bed in response to changes in the internal reflux distribution. Operation was at total reflux utilizing the cyclohexane/*n*-heptane system at atmospheric pressure. Overhead product composition changes caused the overhead vapor temperature to vary from about 180 to 210 °F (82–99 °C). The external reflux temperature, measured near the pump discharge, varied from 90 to 110 °F (32–43 °C).

Figure 2 is a sketch of the configuration around the reflux distributor. It was a pan type distributor equipped with slotted liquid distribution tubes. Flow through the tubes was by gravity, so the liquid head in the pan varied as a function of rate and distribution pattern from almost 0 up to 24 in. (610 mm), the full pan depth. To minimize wave action on the liquid surface, the reflux was introduced into the pan via a triangular header fitted with nine, full cone, wide angle spray nozzles (1/2G30W, Spraying Systems, Inc.). The header with the nozzles was suspended 17 in. (432 mm) above the floor of the pan so that the distance from the nozzles to the liquid surface varied, with the nozzles being totally submerged for the high head runs. Pressure drop across the nozzles was not measured, but according to the manufacturer's literature it varied from 2 to 50 psi for the liquid flow rates employed. Temperature of the reflux immediately upstream of the nozzles was not measured. Pan temperature and liquid depth were measured so that the water calibration of the distribution tubes could be verified in hydrocarbon service.

Results

The observed variation in pan temperature was a surprise. It was concluded that the best way to make sense out of it was to look at the approach of the pan temperature to the overhead vapor temperature as a function of liquid depth in the pan. Figure 3 is that plot. As may be seen, when the liquid depth in the pan is between 0 and about 14 in. (355 mm), the temperature difference between the overhead vapor and the bulk liquid in the pan is between 2 and 5 °F (1° and 3 °C), indicating extremely efficient heat-transfer from the vapor to the liquid spray. In the 3 in. (75 mm) between a liquid depth of 14 and 17 in. (355–432 mm) where the nozzles become submerged, the temperature difference rapidly rises to a value of approximately 55 °F (31 °C), where it stabilizes and remains constant up to the full depth of the pan. The observation that the active heat-transfer zone is so short is particularly significant in view of the fact that there is no net vapor flow countercurrent to the spray (vapor is conducted through the pan via the indicated chimneys). In fact, the flow generated by condensation of the vapor represents a reversal of the upward velocity of the vapor exiting the chimneys.

Three liquid rates were utilized in these studies: 6000–6300 lb/h (2700–2900 kg/h), designated as "low rate" on Figure 3; 12 500–13 000 lb/h (5700–5900 kg/h), "medium

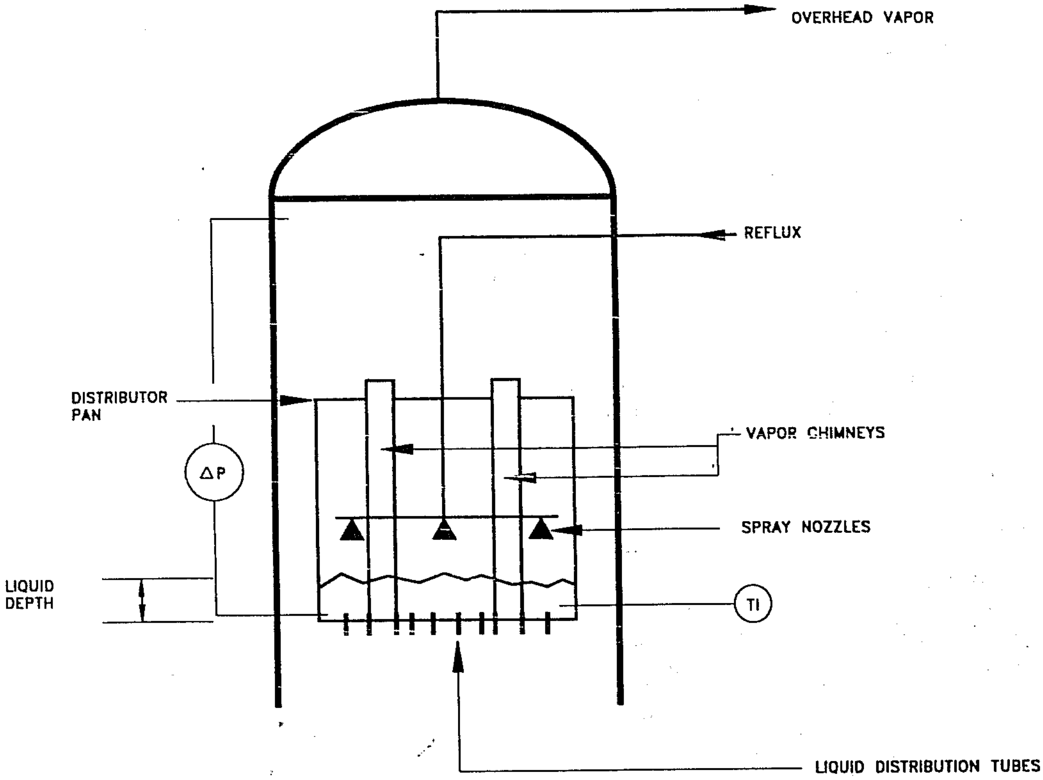

Figure 2. Experimental column configuration.

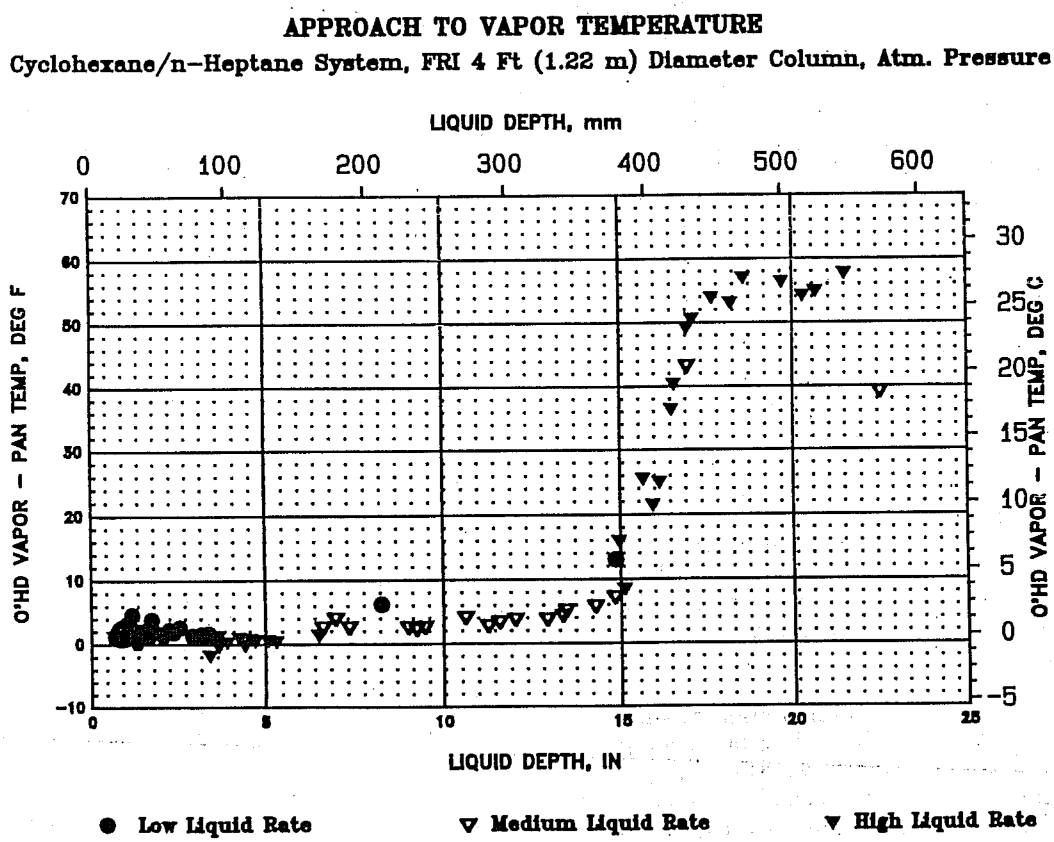

Figure 3. Direct contact heating of spray.

rate"; and 19 500–20 000 lb/h (8600–9100 kg/h), "high rate". There is some indication that the heat-transfer was less efficient in the low rate operation, which is to be expected since that should result in larger droplets. The only drop size distribution data available from the manufacturer, however, is for water in air.

Estimation of Heat-Transfer Coefficient

The following estimation of a heat-transfer coefficient must be regarded as speculative although it does lead to a reasonable conclusion. As noted previously, the liquid temperature was not measured at the spray nozzle exit

However, if one makes the reasonable assumption that heat-transfer to the bulk liquid in the pan is negligible, a volumetric heat-transfer coefficient can be estimated based on an active heat-transfer zone 3 in. (75 mm) high and column cross-sectional area of 12.56 ft^2 (1.17 m^2). The assumption of negligible heat-transfer to the liquid in the pan leads to the conclusion that the nozzle discharge is always 55 °F (31 °C) cooler than the vapor. Temperature differences are thus 5 °F (3 °C) on the one end of the zone and 55 °F (31 °C) on the other. Further, almost all heat given up by the vapor is by condensation. Temperature change of the relatively high purity vapor due to condensation is very small so vapor temperature may be taken as constant from the point where it exits the packing, through the pan and up to the point in the overhead vapor line where it is measured (the difference between overhead vapor temperature and a point 6 in. below the top of the packing rarely exceeded 3 °F). Thus the heat-transferred to the liquid may be computed from the mean flow rate (19 500 lb/h; 8600 kg/h) and the difference between the two temperature differences, viz. 50 °F (28 °C). This results in a volumetric heat-transfer rate of 152 000 BTU/(h ft^3). The arithmetic mean temperature difference is 30 °F (17 °C), and the log mean temperature difference is 21 °F (12 °C). This results in a volumetric heat-transfer coefficient of 5000–7000 BTU/(h ft^2 °F). Although this value is surprisingly large compared to the value of 100–300 reported by Ognisty (1990) for sensible heat-transferred from a hot noncondensable vapor to a cold nonvolatile oil, it is not unreasonable.

Conclusion

In a direct-contact heat-transfer application where it is desired to heat a liquid by condensing a dew point vapor, if it is a nonfouling service, there appears to be no need to employ a device more complicated than a bank of spray nozzles and a short vapor space.

Literature Cited

Fair, J. R. Designing Direct Contact Coolers/Condensers. *Chem. Eng.* 1972, *79* (13), 91–100.

Fair, J. R. Design of Direct-Contact Gas Coolers. *Petro-Chem. Eng.* 1961, Aug, 57–64.

Fair, J. R. Process Heat Transfer by Direct Fluid-Phase Contact. Presented at the Process Heat Transfer Symposium of the Twelfth National Heat Transfer Conference, Tulsa, OK, August 1971; Series No. 118, 68 (1).

Ognisty, T. P. The Direct-Contact Heat Transfer Performance of a Spray Nozzle, a Notched Trough Distributor and Two Inch Pall Rings. Presented at the American Institute of Chemical Engineers Spring National Meeting, Orlando, FL, 1990.

Received for review January 21, 1993
Revised manuscript received April 19, 1993
Accepted April 28, 1993®

® Abstract published in *Advance ACS Abstracts,* September 1, 1993.