Kirk-Othmer Encyclopedia of Chemical Technology.

SOLVENT RECOVERY, CONDENSATION

As had been noted in the previous edition of this *Encyclopedia,* the removal of solvents by condensing them from an inert gas in a water-cooled condenser is inefficient, and may create a potentially hazardous condition at the point of discharge. Vapor pressures of most solvents are relatively high. Therefore, at temperatures obtainable in a water-cooled heat exchanger, these substances maintain an appreciable partial pressure in the discharging gas. An environmentally unacceptable high VOC (volatile organic compound) level in the emitted gas, and the fact that the remaining solvent concentration is in many cases above the lower explosive limit, makes a water-cooled heat exchanger an unlikely instrument for solvent removal to an environmentally acceptable level.

Chilling the vent stream with a refrigerated solution can appreciably reduce the discharge of VOCs, but requires detailed calculations to assure that any solvents remaining in the exiting gas stream is within acceptable limits. Reducing the gas temperature to $-25^\circ\mathrm{C}$ ($-3^\circ\mathrm{F}$) may be economically viable if it accomplishes this goal. The following examples illustrate the reductions that are feasible when mechanical refrigeration is applied.

Solvent mole fraction	Equilibrium mole fraction in air at 25°C	Equilibrium mole fraction in air at −25°C
methanol	0.075	0.0065
benzene	0.13	0.004
acetone	0.30	0.019

If regulations governing specific emission limit VOC concentrations to the low ppm range then, of course, vapor fractions such as those illustrated by the above tabulation will not be acceptable. It may, however, still be justified to consider VOC condensation as a precursor to a final abatement device such as an adsorption bed. Removing most of the solvent from a vent stream by condensation, can drastically reduce the size and cost of a downstream cleanup system.

For optimum solvent removal, the heat exchanger should be arranged so the exiting gas temperature approaches that of the incoming cooling medium. This is best accomplished in a reflux condenser (dephlegmator) wherein solvent laden vapor is introduced into the bottom head of a vertical tubular heat exchanger, and lean vapor leaves from the top. The condensed solvent will flow countercurrent to an upflowing gas and is withdrawn from the bottom head. Cooling medium is introduced at the top of the shell to assure that uncondensed gas leaves at the lowest possible temperature.

The principal concern in designing a tubeside reflux condenser is that an excessive velocity of the entering gas will prevent downflow of the condensed solvent. This is usually not a problem in atmospheric condensation. However, because of the higher gas velocities at low pressures, it may cause flooding under vacuum conditions unless an adequate number of tubes is provided to lower the velocity. This can produce a heat-exchanger configuration that uses many more tubes (albeit shorter ones) than might ordinarily be required were the design based strictly on heat-transfer considerations. A horizontal shell side reflux condenser is less prone to flooding, but is usually not as effective in lowering the exiting gas temperature. A demonstrated procedure for designing in-tube reflux condensers that will not flood was developed by Holmes and has been published in *Perry's Chemical Engineers' Handbook* (1).

It is the author's judgment that the thermal design of a vent condenser is best accomplished by estimating an overall heat-transfer coefficient based on past experience in a similar service. Although detailed design procedures for sizing partial condensers are available through such organizations as HTRI, HTFS, B-Jac, etc, it is very difficult to determine accurately the actual amounts of inerts and VOCs that are being discharged from a process. Employing a complex calculation procedure while using imprecise input data cannot be justified.

If solvent recovery is maximized by minimizing the temperature approach, the overall heat-transfer coefficient in the condenser will be reduced. This is due to the fact that a large fraction of the heat transfer area is now utilized for cooling a gas rather than condensing a liquid. Depending on the desired temperature approach the overall heat-transfer coefficients in vent condensers usually range between 85 and 170 W/m^2K (ca 15 and 30 $Btu/h{\cdot}ft.^{2\circ}F$).

BIBLIOGRAPHY

"Solvent Recovery" in *ECT* 1st ed., Vol. 12, pp. 641–654, by C. M. Cooper, Michigan State College; "Solvent Recovery" in *ECT* 2nd ed., Vol. 18, pp. 549–564, by C. M. Cooper, Michigan State University; "Solvent Recovery" in *ECT* 3rd ed., by C. M. Cooper, Michigan State University.

Cited Publications

1. *Perry's Chemical Engineers Handbook*, 6th ed., McGraw-Hill, New York, 1984, 5–59.

OTTO FRANK
Air Products and Chemicals, Inc.

Related Articles

Heat exchange technology; Solvents, industrial