OPTIMIZING PROCESS VACUUM CONDENSERS

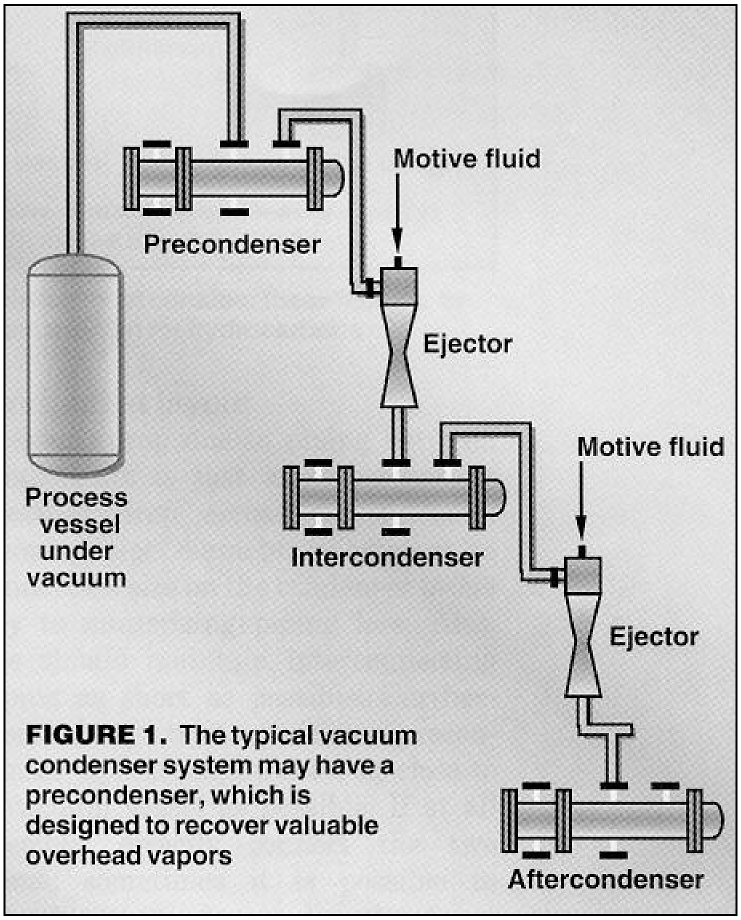

FIGURE 1. The typical vacuum condenser system may have a precondenser, which is designed to recover valuable overhead vapors

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OPTIMIZING PROCESS VACUUM CONDENSERS

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Designing these units properly involves more than just using standard heat-transfer software

Vacuum condensers play a critical role in supporting vacuum processing operations. Although they may appear similar to atmospheric units, vacuum condensers have their own special designs, considerations and installation needs. By adding vacuum condensers, precondensers and intercondensers (Figure l), system cost efficiency can be optimized. Vacuum condensing systems permit reclamation of high value product by use of a precondenser, or reduce operating costs with intercondensers.

A precondenser placed between the vacuum vessel and ejector system will recover valuable process vapors and reduce vapor load to an ejector system minimizing the system's capital and operating costs. Similarly, an intercondenser positioned between ejector stages can condense motive steam and process vapors and reduce vapor load to downstream ejectors as well as lower capital and operating costs.

Vacuum condensers cannot be designed or considered as typical process heat exchangers. Doing so will result in less than optimal performance with increased utility and condensate treatment costs. For instance, internal geometry may not be modeled well by standard heat transfer software because condenser design is proprietary and varies from one manufacturer to another. Also, tube-field layout and baffling are often unconventional and not suited for standard software. It is also vital to incorporate ejector operation into vacuum condenser design.

A number of primary CPI processes (ranging from glycerin manufacture to urea prilling) use vacuum condensers each requiring a special design that depends on the type of vacuum condenser needed. For example, in urea plants, the main vacuum condensers are outfitted with spray nozzles above the tube field for removal of solidified product buildup.

Vacuum condenser systems

The prevalent type of vacuum condensers are shell-and-tube. These look similar externally to conventional shell-and-tube heat exchangers; however, their internal geometry is notably different. The major components of a vacuum condenser (Figure 2) include:

- Tubes
- Tubesheet(s)
- Shell
- Support plates
- Baffles
- Channels or bonnets

The design and optimum operation of a vacuum condenser is application specific, and determined by its tube-field layout and flow baffling. These geometries strongly affect condensation efficiency and pressure drop minimization. Under sub-atmospheric conditions, the need to minimize pressure drop is the key design consideration. Pressure drop across a vacuum condenser reduces condensation efficiency or product recovery and, therefore, increases the operating cost of a vacuum system.

Vessel geometry affects both vapor distribution and flow pattern, which ultimately impacts condenser performance and pressure drop. Poor flow distribution may result in localized "dead spots" in a condenser that essentially reduce effective heat transfer surface area. Furthermore, improper baffling may result in noncondensable binding and, consequently, a loss in the system's efficiency and vacuum.

At higher vacuum levels, the design of vacuum condensers becomes more critical and the units are characterized by unique geometries or features. For instance, in glycerin plant condensers, which operate below 10 mm Hg, spacing between tubes varies. Initially, the top tube row has spacing increased to 1.62 times tube diameter. This allows high specific volume vapors to distribute above the tube field, and flow into the bundle at velocities suitable for low pressure drop. Tube spacing is then

TABLE 1. IMPACT OF PRESSURE DROP ACROSS A PRECONDENSER

Pressure drop, mm Hg	Amount condensed, lb/h
1.0	925
2.0	900
3.0	850
4.0	700
Amount exiting as a vapor, lb/h	**Reclamation, %**
75	92.5
100	90.0
150	85.0
300	70.0

Basis: An overhead load exiting an evaporator is 29 lb/h air (molecular weight, MW = 29) and 1,000 lb/h hydrocarbon (MW = 100) at a pressure of 8 mm Hg. A precondenser is designed to achieve an exit gas temperature of 100°F, at which the hydrocarbon has a vapor pressure of 3 mm Hg. As would be expected, the lower the pressure drop (ranging from 1 to 4 mm Hg), the greater the amount of reclaimed hydrocarbon as condensate. (Note: 1 mm Hg = 0.019 psi = 0.5 in. water column.)

reduced to a normal 1.25 times tube diameter near the final tube row, which ensures that velocities are sufficiently high to maintain proper heat transfer.

Types of vacuum condensers

The geometries of surface condensers generally follow three basic designs that comply with standard nomenclature established by the Tubular Exchanger Manufacturers Assn. (TEMA; Tarrytown, N.Y.):

1. Shellside-condensing design fixed tubesheet type, designated as: AXL, BXM, AEL or BEM. Figure 3 provides a clearer description of the various "mix and match" geometries and their designations
2. Shellside-condensing design removable bundle type: AXS, AXU, AES or AEU
3. Tubeside-condensing design fixed tubesheet type: AEL or BEM

Shellside condensing

Key features of vacuum condensers with shellside condensation include:

- Vapor inlet connection
- Vapor distribution space above the tube field
- Main condensing zone
- Noncondensable-gas cooling and final condensing zone
- Noncondensable-gas outlet connection (or vapor outlet)
- Condensate outlet connection

Condensers with shell diameters greater than 26 in. often have a longitudinal baffle that runs virtually the entire tube length. This type of condenser is denoted as a TEMA crossflow "X" shell. A majority of the condensation occurs in the tube field prior to the longitudinal baffle.

Noncondensable gases and associated vapors of saturation are drawn underneath the longitudinal baffle by a low-pressure region created by a downstream ejector, which is designed for that purpose. As noncondensables and vapors are drawn underneath the longitudinal baffle, that change in direction separates condensate from the vapors. Condensate drops down via gravity to the bottom of the shell and is subsequently drained from the unit. Meanwhile noncondensables and associated vapors are drawn through tubes beneath the longitudinal baffle for additional cooling and condensation. This separation of condensate from noncondensables and remaining vapors permits final cooling of noncondensables to a temperature below the bulk condensate temperature.

Furthermore, tubes beneath a longitudinal baffle contain the coldest cooling water. This enables a system design whereby final noncondensable gas and the saturated vapor outlet temperature is below the cooling water outlet temperature.

Units with smaller diameter shells (less than 26 in.), denoted as TEMA "E" shells, are characterized by "up and over" baffles in the final noncondensable cooling section. Here again, the majority of condensation takes place in the tube field area before the "up and over" baffle section. Internal geometry is such that there is separation of the condensate from noncondensables and vapors of saturation. Only noncondensables and associated vapors of saturation are drawn into the "up and over" baffle section to ensure that heat transfer is maximized. Once again, it is possible to cool noncondensables to a temperature below the cooling water outlet temperature or below the average condensate temperature.

In either case of shellside condensing, the dominant design factor is to cool noncondensables to the coldest temperature possible, while at the same time maintaining minimum pressure loss. Ensuring that noncondensables are cooled to the lowest temperature possible minimizes the amount of condensable vapors that saturate those noncondensable gases. Effective condenser optimization requires cooling

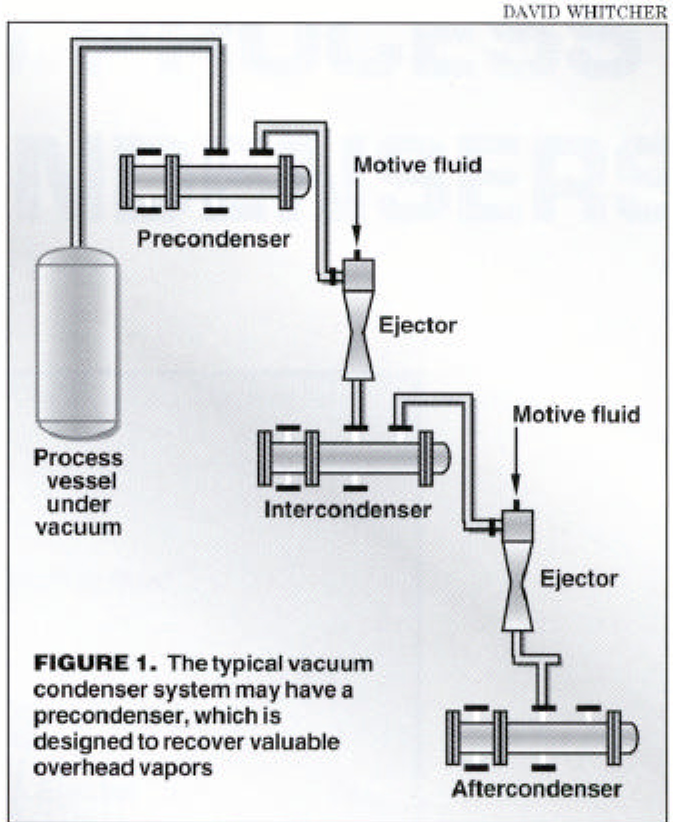

FIGURE 1. The typical vacuum condenser system may have a precondenser, which is designed to recover valuable overhead vapors

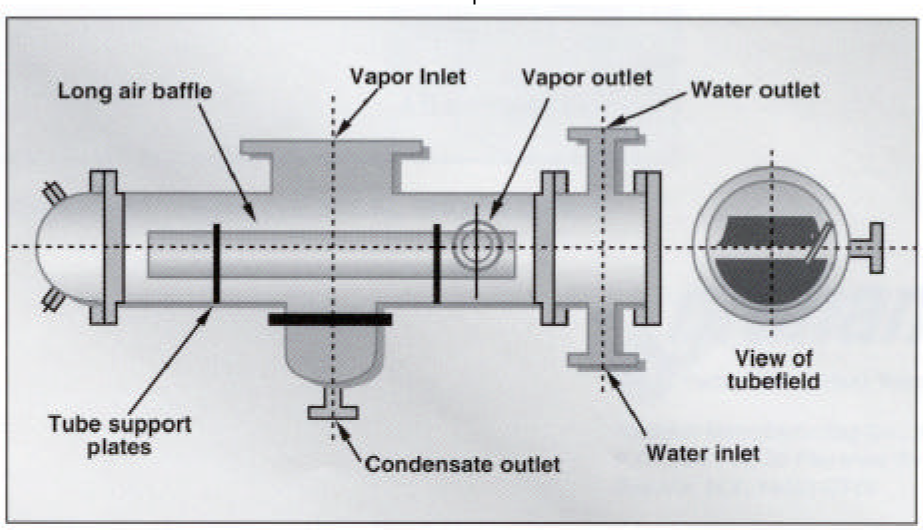

FIGURE 2. The elements of a typical vacuum condenser are shown for a crossflow shell unit that makes use of a long baffle

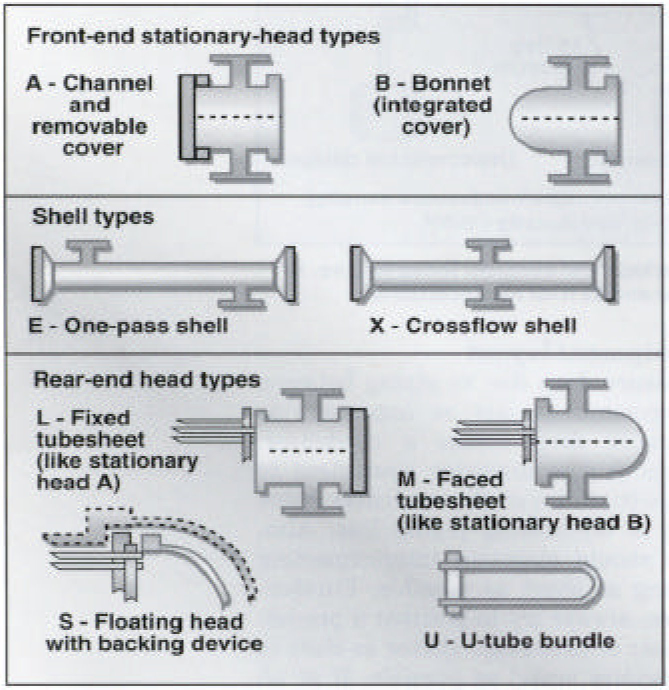

FIGURE 3. Condenser design allows for a "mix-and-match" of geometries that follows standard TEMA designations

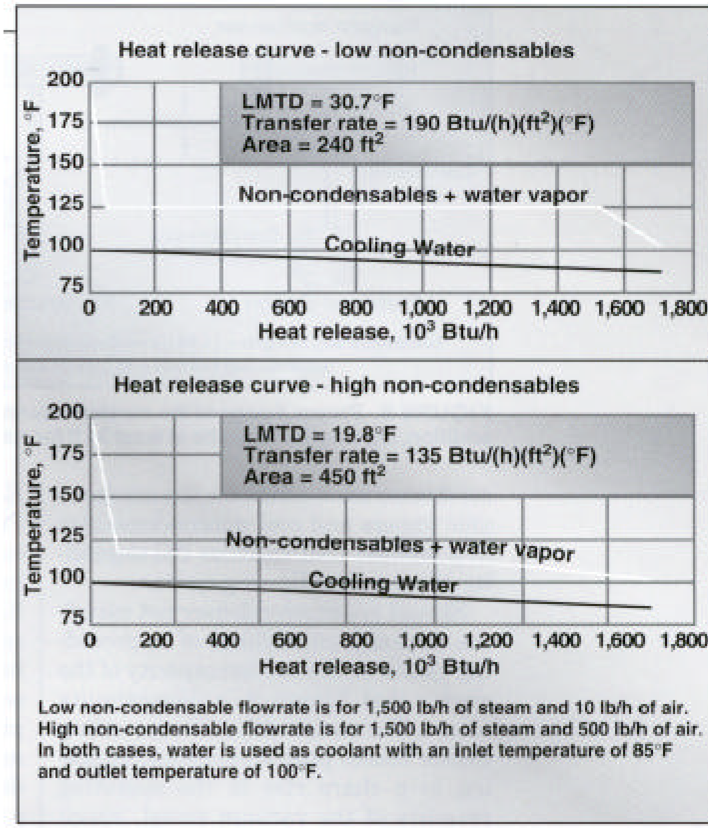

FIGURE 4. High non-condensable loadings can cause poor LMTD, reduce heat transfer rates and require greater surface areas

noncondensables to within 10-15°F of the inlet cooling-water temperature. This serves to minimize the amount of vapors that saturate the noncondensables and must be handled by a downstream ejector.

Tubeside condensing

Although shellside condensation is more prevalent, tubeside condensing may also be used. In this case, cooling water is on the shellside, while noncondensables and vapors are directed through the tubes. In this configuration, vapors and condensate remain in intimate contact throughout the heat transfer area and exit this area together at the same location. The shellside is baffled (as in any typical heat exchanger) because the shellside fluid is simply water.

One special feature of tubeside condensers is in the bottom head, where the condensate drops to an outlet drain and noncondensable gases are extracted through a connection on the side of the head.

Noncondensable gases

Due to the sub-atmospheric condition of vacuum systems, air inleakage is always a potential problem. In addition, a particular process may already have various noncondensable gases in the process load. With noncondensables being present, condensation occurs along the cooling curve, and vapors of saturation exit the condenser along with the noncondensables.

The tube-field layout is designed to separate condensate from noncondensables and their vapors of saturation. It is common to have noncondensables, along with their vapors of saturation, exit a condenser at one location while condensate exits another.

Flow distribution above the tube field is important so as to ensure that vapors and noncondensables enter the bundle uniformly and that there is full utilization of available heat transfer area. Also, pressure drop is minimized by proper flow distribution, thus reducing utility and capital costs.

Figure 4 shows heat release curves for the extreme cases of low noncondensable and high noncondensable flow. Note the shape of the respective curves and the effect that noncondensable load has on logarithmic mean temperature difference (LMTD), heat transfer rate and required surface area. Noncondensable gases serve to lower LMTD and heat transfer rate, while consequently increasing required surface area of the condenser.

Precondenser pressure drop

Pressure drop in a precondenser has a compounded impact. Depending on the process, precondensers are positioned to recover valued overhead vapors as condensate prior to their introduction to an ejector system. As pressure drop increases, more condensable vapors exit the precondenser with noncondensable gas. Not only does this reduce the amount of condensable vapor recovered, it increases the gas load to the ejector system and its compression requirements. As load and compression range increases, so do utility requirements and wastewater treatment costs. Pressure drop across the intercondenser similarly increases utility requirements for an ejector system. Table 1, p. 102, highlights the impact of pressure drop across a precondenser.

System interdependency

Within a vacuum system, there is an interdependency between an ejector and intercondenser. This relationship must be understood for optimum design and to ensure reliable operation. An intercondenser is designed to handle discharge load from a preceding ejector at a pressure equal to, or below, that which is achievable by that ejector. Furthermore, the intercondenser

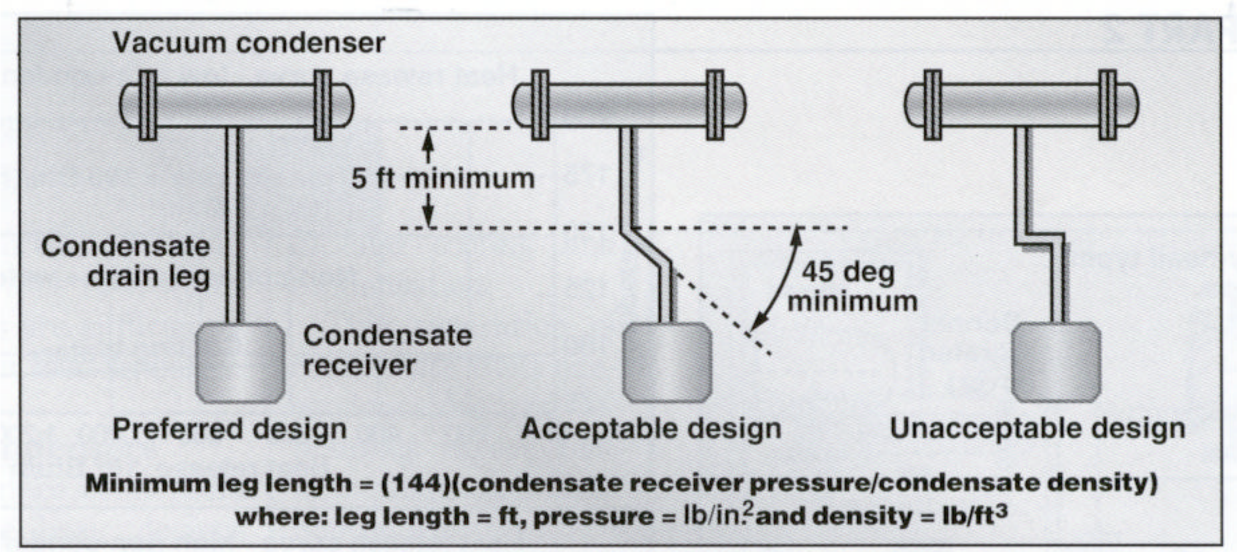

FIGURE 5. Proper design of the condensate drain leg must consider these factors. In addition, leg length should be at least 34 ft for water and 45 ft for hydrocarbons

must condense the condensable vapors and cool noncondensables in a manner that satisfies the capability of the next following ejector.

Should an intercondenser not satisfy the discharge capabilities of its preceding ejector or the suction capacity of the ejector that follows it, a discontinuity occurs. The result is that the preceding ejector ceases proper operation, resulting in a sharp rise in the operating pressure of the vacuum vessel, which ultimately affects product quality. It is for this reason that ejector-condenser interdependency must be understood and taken into account.

Equipment installation

Proper installation of vacuum condensers is important for smooth operation. Typical plant layouts allow vacuum condenser condensate to drain by gravity to a condensate receiver. The leg height of the condensate drain must be sufficient to ensure that condensate is not lifted into the intercondenser because of the vacuum operation.

A straight vertical drain leg is preferred. This may not always be possible, however. Should a layout require an offset, horizontal runs of pipe should not be used. Horizontal piping runs allow the formation of air pockets, which offer additional resistance to drainage, and may cause the flooding of a condenser.

The suggested practice is to lay out a drain leg with no less then a 45 deg angle, measuring from the horizontal axis, and ensuring at least a 5ft straight length prior to the angled run of piping. Remember to always take into account the operating pressure of the condensate receiver. As the condensate receiver's operating pressure increases, so does required drain leg height. Figure 5, above, shows acceptable drain design.

Equipment layout

Pressure drop due to piping between components is just as important as pressure drop across a condenser. Keeping pipe diameter equivalent to connection size on the condenser is one key to minimizing piping loss. Also, one should maintain interconnecting piping as short as possible. Furthermore, always try to position a precondenser or first-stage ejector as close to a vacuum vessel as possible. If at all possible, directly connect the two items; sometimes it is possible to mount a precondenser directly atop a vacuum vessel. First stage ejectors may be coupled directly to the vacuum vessel, as well.

Remember the importance and negative impact of even a small pressure drop loss in a high vacuum processing system. A 2 mmHg pressure loss due to piping has a greater impact on equipment size, utility and cost when that pressure drop is taken at 15 mm Hg absolute rather than at 80 mm Hg absolute pressure.

Edited by David J. Deutsch

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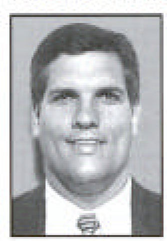

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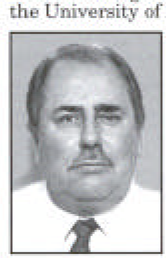

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