VacAdemics

Issue 3

Applying Vacuum Technology

Understanding Process Vacuum Condensers

Process vacuum condensers are an integral part of a vacuum system

So often, a process vacuum condenser is considered stand-alone equipment, with little consideration given to how best to integrate it into a vacuum system. Common practice has the vacuum condenser specified as just another heat exchanger. There is a benefit to evaluating the condenser and vacuum system as a complete unit. The benefits are reduced operating cost, less environmental impact, lower capital cost and improved product reclamation. Evaluate a process vacuum condenser and vacuum system as a complete unit so an optimal engineering answer is realized.

Terminology

An overview of terminology is important since definitions may vary from one engineer to the next.

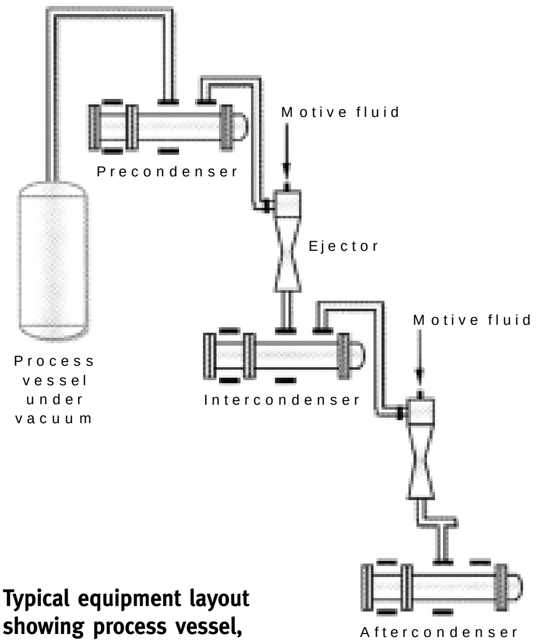
- **Precondenser.** A vacuum condenser positioned after a process vessel, such as a still, evaporator or distillation column, but before the vacuum system. In this issue, a precondenser is the process vacuum condenser.
- **Intercondenser.** A vacuum condenser situated between two stages of vacuum producing equipment, for example, two ejector stages.
- **Vent condenser.** A vacuum condenser sometimes placed behind a precondenser. It uses a chilled cooling fluid to affect additional condensation and product recovery.
- **Surface type condenser.** A condenser with a heat transfer surface that separates vapors undergoing condensation from a cooling fluid.
- **Barometric condenser.** A direct contact condenser where vapors and cooling fluid are in contact with each other.
- **Immiscible condensate.** When multiple vapors condense and the condensate formed does not mix, such as oil and water.
- **Miscible condensate.** When multiple vapors condense and the condensate mixes, like water and ethylene glycol.

Where to Begin

It is most advantageous for particular processes to use a vacuum condenser ahead of a vacuum system. A preliminary assessment of the application is appropriate to determine vacuum condenser design. Key variables to assess include:

Pressure drop importance. This analysis should consider pressure drop between the process vessel and vacuum condenser, pressure drop across the condenser and pressure drop between the condenser and vacuum system.

Behavior of the condensate. Does a single component condense? If there are multiple condensables, are the condensates immiscible, ideally miscible or nonideally miscible?



Typical equipment layout showing process vessel, precondenser and ejector system.

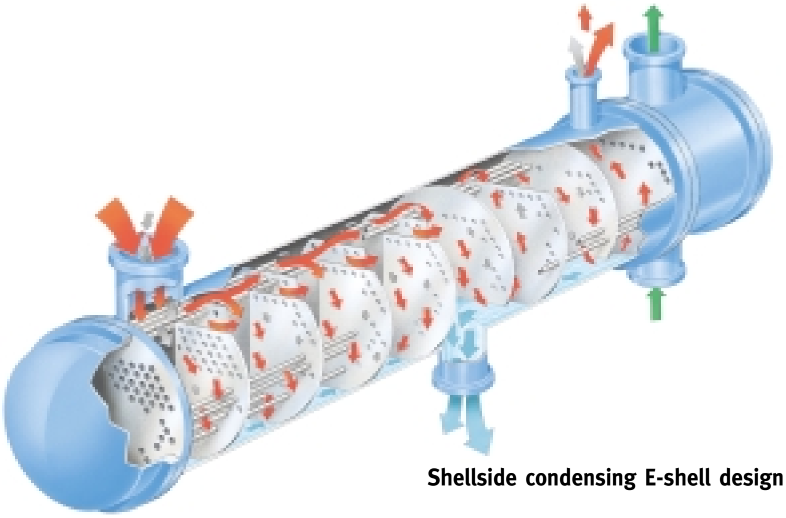
The amount of noncondensable gases. Noncondensable gases may come from the process itself or air leakage.

Do any of the components freeze at the colder temperatures? This is particularly common for applications in plastics, resins and plasticizer processes.

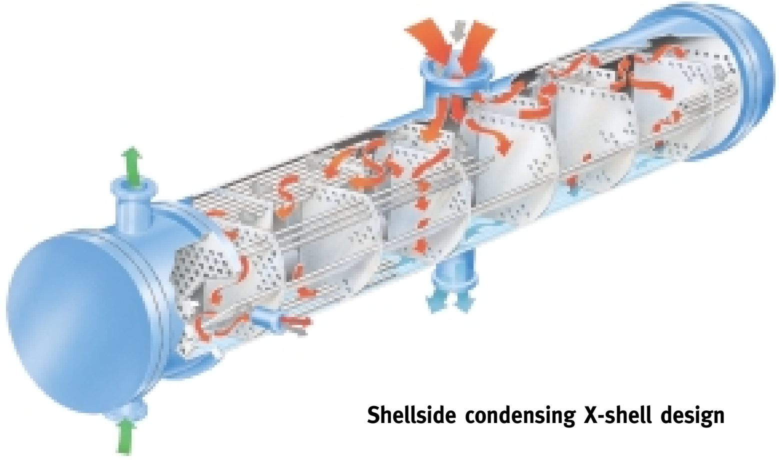
Do any of the components undergo exothermic or endothermic chemical reactions? For example, ammonia vapor and water react exothermically and that adds to the heat duty that must be rejected by a condenser.

Is there reliable physical property, vapor pressure and vapor-liquid equilibrium data available?

Different Vacuum Condenser Configurations



Shellside condensing E-shell design



Shellside condensing X-shell design

Pressure Drop

Pressure drop is a parasitic loss of unit efficiency. That is true for any system and is not a unique phenomenon of vacuum condensers. However, the effect is more significant because of the vacuum condition. A 5 torr pressure drop is only 0.1 pounds per square inch (psi), however, at 15 torr operating pressure it is a 33 percent loss in pressure. Pressure drop is an important engineering constraint that must be minimized.

Pressure drop reduces product reclamation in the vacuum condenser, increases the size and cost of the vacuum system, adds to the utility use of the vacuum system and causes the vacuum condenser to be larger. A well-designed process vacuum condenser will not have pressure drop of more than 10 percent of the operating pressure. Lower pressure drop is the result of specialized designs for high-vacuum applications. A high vacuum process condenser is not like an ordinary heat exchanger. It has a markedly different tube field layout and baffle arrangement.

Condensate Behavior

The type of condensate formed affects condenser design. Furthermore, the type of condensate formed determines the type of vapor-liquid equilibrium calculations used. If condensates are miscible, whether ideally or nonideally, the condensate should remain in intimate contact with the vapors so each is at the same temperature. Common practice for miscible condensates is tubeside condensing, since the vapors and condensate remain in contact with each other and are at the same temperature.

Tubeside condensing meets the primary objective of contact and identical temperature but it is not always a practical choice. High-vacuum applications result in a massive volumetric flowrate, which cannot effectively be managed with tubeside condensing. For example, 50,000 pounds per hour (pph) of mixed hydrocarbon vapors (MW-80) at 15 torr and 300°F is 293,000 actual cubic feet per minute (ACFM). For in-tube condensing the condenser size is a 100 x 72 AXL because so many tubes are required to ensure reasonable vapor velocity. When shellside condensing is chosen, the bundle layout may be opened to increase cross-sectional flow area to maintain reasonable velocities. The comparable unit based on shellside condensing is a 66 x 144 AXL, substantially smaller and less expensive.

Specialized designs can accommodate miscible condensates on the shellside, and for most applications, it is less expensive to condense high-volumetric flowrates shellside.

Noncondensable Gas

Vacuum condenser size and reclamation efficiency is greatly influenced by the amount of noncondensable gas. An accurate determination of noncondensable gas is critical. Erring on the conservative side is recommended. The table shows the amount of noncondensable gas is directly proportional to the amount of condensable vapors not condensed. The greater the

Equations for Predicting the Amount of Vapor Not Condensed

Immiscible condensate

$$M_j = \frac{\left(\frac{M_{nc}}{MW_{nc}}\right)(VP_j)(MW_j)}{\left(P-\sum_{i=1}^{n} VP_i\right)}$$

Ideally miscible condensate

$$M_j = \frac{\left(\frac{M_{nc}}{MW_{nc}}\right)(VP_j)(x_j)(MW_j)}{\left(P-\sum_{i=1}^{n}\left[(VP_i)(x_i)\right]\right)}$$

Nonideally miscible condensate

$$M_j = \frac{\left(\frac{M_{nc}}{MW_{nc}}\right)(\gamma_j)(VP_j)(x_j)(MW_j)}{\left(P-\sum_{i=1}^{n}(\gamma_i)\left[(VP_i)(x_i)\right]\right)}$$

Terms:

M = Mass flowrate, pph
VP = Vapor pressure, torr
MW = Molecular weight, lb/lb mole
P = Pressure, torr
x = Mole fraction in condensate
γ = Activity coefficient

Subscript:

j = Condensable component being evaluated
nc = Noncondensable gases
i = All components that condense

noncondensable gases, the greater the amount of condensable vapors that exit the condenser with the noncondensables. If noncondensable loading doubles, there is twice the amount of condensable vapors that will not condense, assuming operating pressure and temperature are constant. Additionally, the amount of noncondensable gas changes the shape of the heat release curve. Greater amounts of noncondensable gas result in larger vacuum condensers and lower effective logarithmic mean temperature differences (LMTDs).

The graphs are an example of 100 torr operating pressure and 1500 pph of steam plus either 10 pph of air or 500 pph or air. The cooling fluid enters at 85°F and exits at 100°F. Process vapors are cooled to 100°F.

Freezing or Reactions

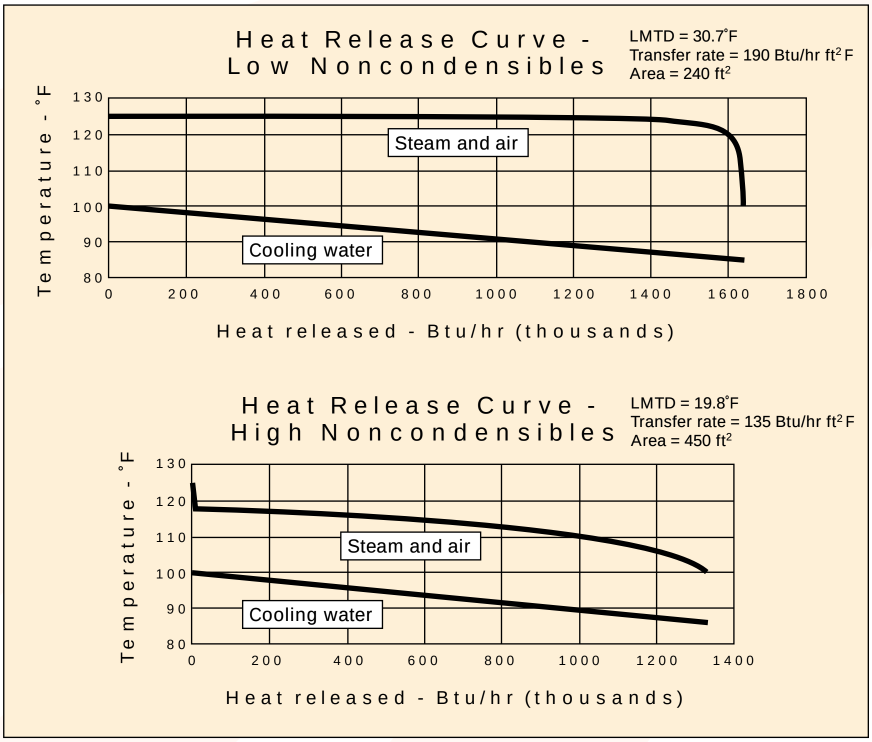
If the process fluids undergo freezing or some type of chemical reaction, it must be properly accounted for and identified. There are specialized designs for each of those particular applications.

Equipment Layout

The positioning of a vacuum process condenser is important. There are designs where the condenser is mounted directly on top of the process vessel to permit refluxing of condensate into the process vessel or to eliminate piping pressure drop altogether. If there is piping between the process vessel and vacuum condenser, a hydraulic analysis of the piping is necessary for the condenser design. The same is true for piping downstream of the condenser. It is always preferable to install the condenser and first stage of the vacuum equipment as close to the vacuum vessel as possible to minimize the costly impact of pressure drop. Remember, a piping pressure drop of 2 torr at 10 torr operating pressure has more impact than a 10 torr piping loss at 75 torr operating pressure.

Design Software

There is a lack of commercially available software available to accurately design or performance check process vacuum condensers when the operating pressure is below 40 torr. Almost invariably, the commercial software will result in high-pressure drop and, consequently, poor reclamation efficiency. Therefore, product recovery suffers, the vacuum system capital and operating costs appreciably increase, and less than optimal designs are installed.



Comparison of low and high noncondensable unit design. Note the change in shape of the heat release curve and the effect that has on LMTD and exchanger size.

Styrene Example

Overhead vapors consist of 10,000 pounds per hour (pph) of styrene at an operating pressure of 51 torr and 150°F; 200 pph air leakage is included as well. The following table describes how much styrene is condensed at different temperatures. The comparison is an isobaric assessment, with no pressure drop, vs. a 5 torr pressure drop.

Isobaric Case

Temperature	Vapor	Condensate	% Condensed
140	2753	7247	72.5
130	1168	8832	88.3
120	663	9337	93.4

5% Pressure Drop Case

Temperature	Vapor	Condensate	% Condensed
140	5282	4718	47.5
130	1574	8426	84.2
120	817	9183	91.8

Approximately 150 pph of styrene was not reclaimed at 120°F because of pressure drop; 817 pph of styrene remains a vapor rather than 663 pph. That pressure drop could be from piping or caused by the condenser. The additional 150 pph that remains vapor is lost revenue and now must be handled by the vacuum system. The vacuum system loads become 1720 actual cubic feet per minute (ACFM) rather than 1395 ACFM, or stated differently, 1017 pph at 46 torr rather than 863 pph at 51 torr.

Pressure drop is always present, however, the illustration demonstrates the importance of minimizing pressure drop. Pressure drop is a parasitic loss of process efficiency that only adds to capital and operating costs.

Companies specializing in this field have proprietary software and specialized engineering experience to develop the right answer for each unique application. Bundle design and tube layouts are vastly different from that normally used for typical shell and tube type condensers.

Summary

There is much to consider when a process vacuum condenser is required. The initial strategy must involve evaluating the condenser and vacuum equipment as one system. Much can be gained through effective integration of the process vacuum condenser design into a condenser-vacuum equipment system. To take full advantage of this, you need to understand the options. The benefits, limitations, capital costs and environmental impact vary based on the approach taken. To ensure the maximum advantages, involve a vacuum equipment vendor with proven experience in design, manufacture and installation of high vacuum process condensers as early as possible. By evaluating the various options, the right engineering answer will be realized.

Flasher process vacuum condenser with piping from the process vessel to condenser.

Fatty alcohol distillation column with the vacuum condenser attached directly to the distillation column. No piping or pressure drop between the two components.

This is the third in a series of six educational newsletters on vacuum equipment. Watch for the next issue of VacAdemics in July.

FREE

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