Volume 12
Number 3
March 2001

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ENGINEERING ANSWERS

ECOfreeze Vacuum System

Freeze Condensing Vacuum Systems for Deodorization

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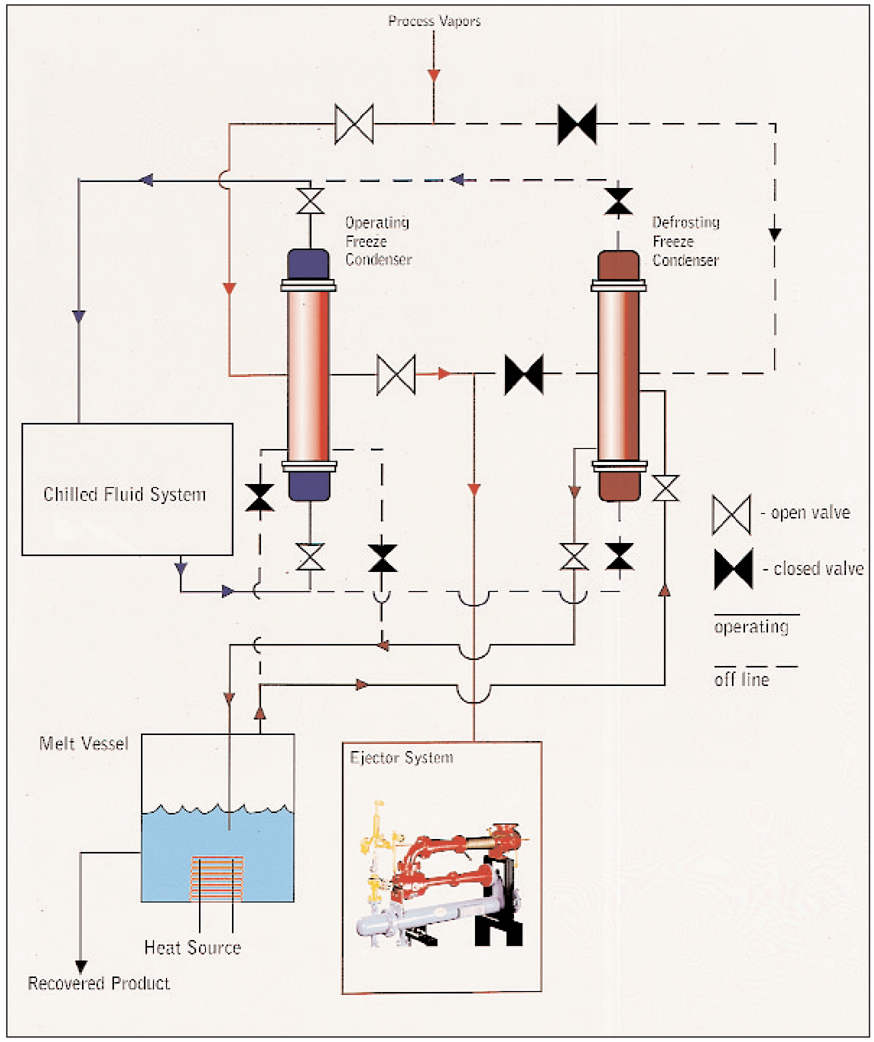

Schematic of a deodorizer vacuum system utilizing freeze-condensation

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Artwork provided by J. Lines

A deodorizer vacuum system utilizing freeze-condensation technology offers advantages not available with conventional ejector systems.

When revamping existing deodorizer systems, a freeze-condensing vacuum system allows deodorizer pressure to be reduced without incurring an excessive increase in utility consumption. The key concept at work is to remove stripping steam and free fatty acids before they enter an ejector system by freezing them onto a cold heat-transfer surface. The ejector system handles essentially air only.

This paper reviews freeze-condensation and offers a comparison to a conventional ejector system for a 75,000 pounds per hour (pph) deodorizer.

Freeze-condensation—what is it?

The term "freeze-condensation" is a misnomer for what thermodynamically happens, but it is descriptive to the extent it offers a visual image of what occurs. The triple point for water is 32°F and 4.6 torr—at that pressure and temperature, it is possible for ice, water, and steam to coexist. If the pressure and temperature are below the triple point, then it is possible for steam to go directly to the ice phase without passing through the liquid phase. The appropriate thermodynamic term for this phenomenon is “deposition”. Deposition is the opposite of “sublimation”, the more familiar term for a solid passing directly to the vapor phase without passing through the liquid phase. Freeze-condensation has been referred to as a misnomer because condensation is associated with vapor going to the liquid state; however, condensation in the classic sense of the formation of a liquid phase does not occur at the operating pressure and temperature of a freeze-condenser.

The operating conditions for deodorizer overhead effluent make deposition possible if a sufficiently cold cooling fluid is used. Pressure leaving a fatty acid scrubber may range from 1 to 4 torr, which is below the 4.6 torr triple point pressure. The temperature of the cooling fluid is a function of the operating pressure of the deodorizer. The lower the desired operating pressure, the colder the cooling fluid must be. Figure 1 depicts recommended cooling fluid temperature for differing deodorizer pressures. For example, if the deodorizer pressure is 1.5 torr, then the recommended temperature of the cooling fluid is –15 to –30°F., whereas at 0.75 torr, the recommended cooling fluid temperature is –27 to –42°F. Figure 1 offers a guide to recommended cooling fluid temperature; however, warmer or colder temperatures may be considered.

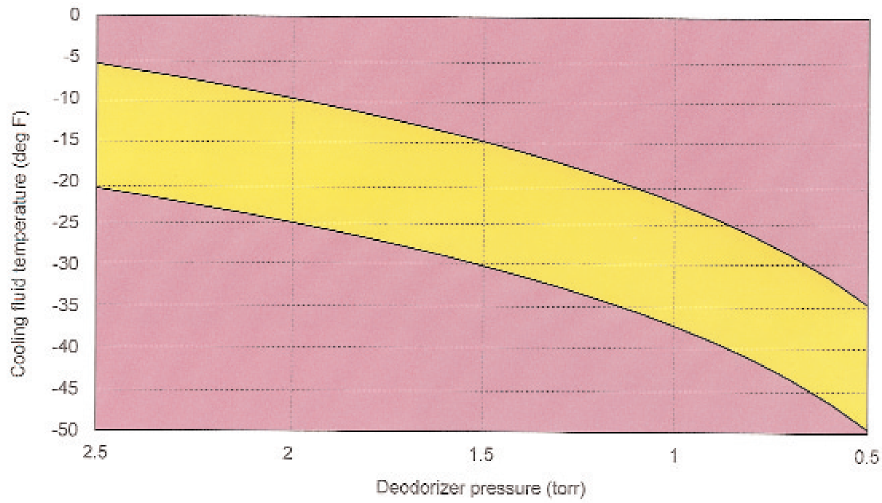

Figure 1. Recommended cooling fluid temperature vs. deodorizer pressure

Condenser design

The heart of a freeze-condensing vacuum system is the condenser itself. Actually, two condensers are used for a typical application. One condenser is on-line in the freezing or ice-building mode. The other is off-line defrosting and being readied to be brought on-line.

Process fluids to a freeze-condenser are steam, free fatty acid, and air, and they are on the shell side of the condenser. Steam is the stripping steam put into the deodorizer. Free fatty acid is what is carried out of the fatty acid scrubber. Air is from leakage into the system due to the subatmospheric operating pressure. The thermal design of the condenser is sophisticated; design software is not available. The design must take into consideration cooling of gases, deposition heat transfer, and ice-thickness growth. By no means is this an ordinary heat-transfer problem. This is further compounded by the low operating pressure and minimal available pressure drop. Designs with 0.1 to 0.25 torr pressure drop are typical.

The design of the tube bundle is the key. Tube pitch and layout are tailored

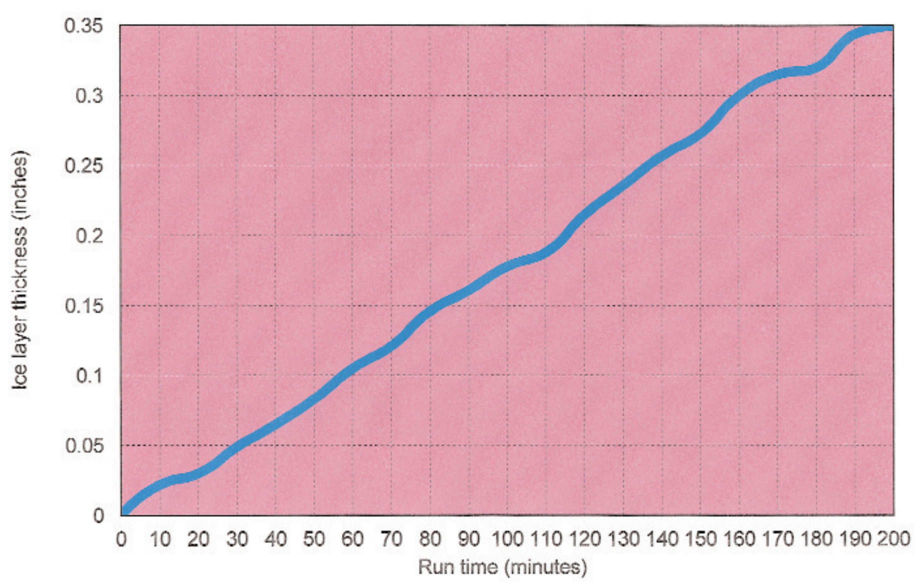

Figure 2. Measured ice thickness vs. time (–30°F cooling fluid temperature)

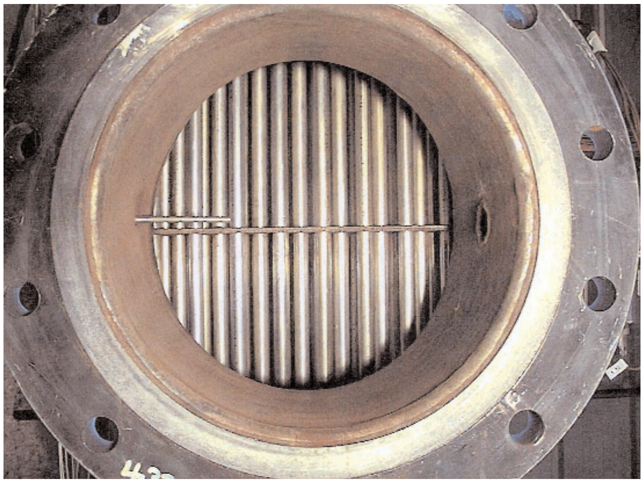

Figure 3a. Start of cycle (when there is no ice and the tubes are bare)

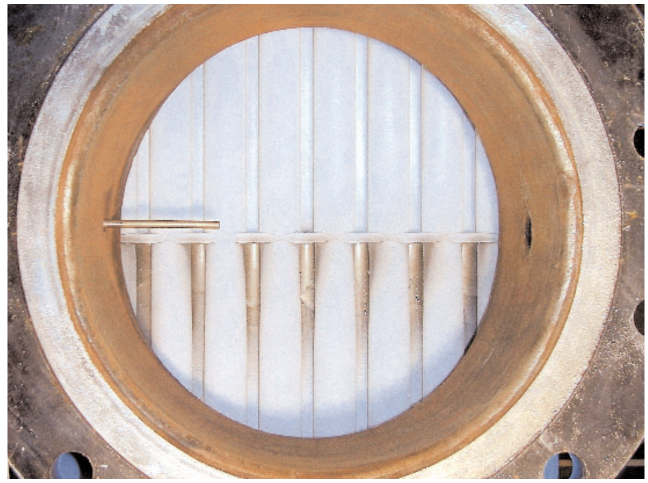

Figure 3b. End of cycle (when there is substantial ice buildup)

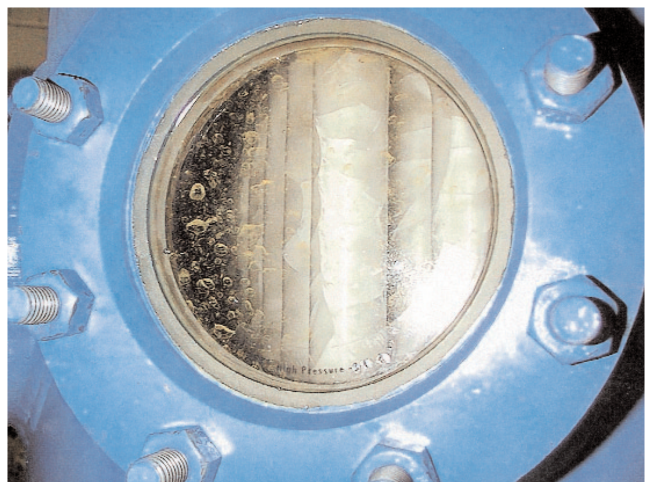

Figure 3c. End of cycle (when there is substantial ice buildup)

for each particular application to provide the longest run time economically possible. The design must factor velocity and heat transfer at the start of operation as well as at the end when there is considerable ice buildup. Figure 2 shows how ice thickness increases with run time. In this particular instance, a properly designed tube field allowed the unit to perform at or below the design operating pressure for longer than two hours, by which time the ice thickness on the tubes was approximately three-eighths of an inch.

As ice builds up on the surface of the tubes, two negative effects occur.

First, the ice layer is an insulator that diminishes heat-transfer effectiveness. As thickness increases, the temperature at the ice layer surface becomes warmer, thus reducing the available logarithmic mean temperature difference (LMTD). In a case where boiling ammonia is the cooling fluid, LMTD is approximately the difference between the ice surface temperature and the boiling ammonia temperature.

Second, the cross-sectional flow area decreases as ice layer thickness increases. For example, at the start of operation when tubes are bare and ice has not formed, the gap between tubes at the inlet section of the condenser is 1.25". As Figure 2 shows, after two hours of operation the ice thickness is 0.35", therefore, the gap between tubes is 0.55". The reduction in the gap between tubes results in higher velocity and, consequently, greater pressure drop.

Figure 3 shows a comparison of the top tube row at the start of the cycle (Fig. 3a), when there is no ice and the tubes are bare, and the end of the cycle when there is substantial ice buildup (Figs. 3b, 3c).

The tube bundle layout for a well-designed freeze-condenser will have a variable tube pitch. The spacing between tubes will vary. This permits the entry of high volumetric flow into the tube bundle at velocities conducive to low-pressure drop throughout the entire operating cycle. A 75,000 pph deodorizer will have approximately 4,000 ft^3/s flow entering a freeze-condenser. The tube layout is open where the high volumetric flow enters and is tighter at the back end of the tube bundle. Leaving the freeze-condenser, the volumetric flow rate is approximately 50 ft^3/s. The open spacing at the front not only permits reasonable velocities at the entrance to the tube field but also

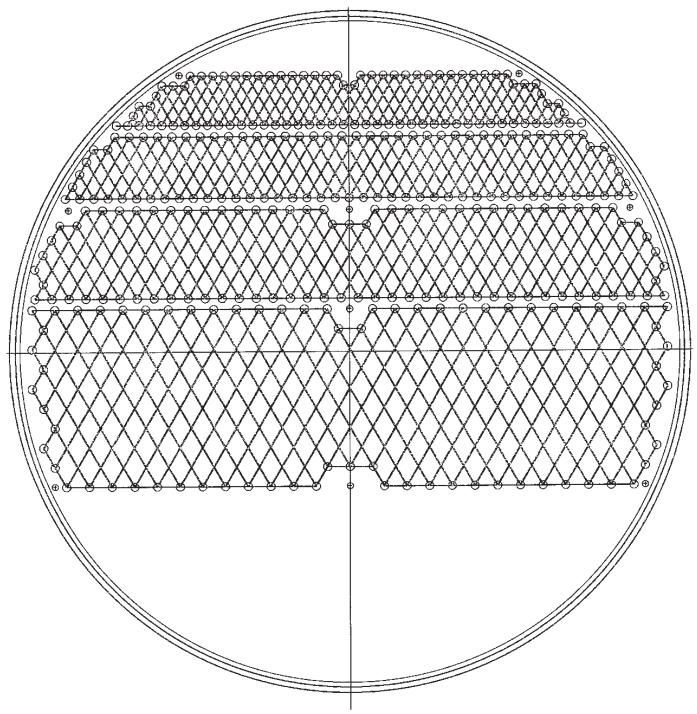

Figure 4. Tube field layout for freeze-condenser that supports 75,000 pph deodorizer

Table 1
Cooling fluid temperature efficiency analysis for 75,000 pph system

Cooling fluid temperature (°F)	Run time to reach 1.5 torr	Reclamation (%)
0	Not possible	0
–10	58 minutes	96
–20	102 minutes	99.5
–30	105 minutes	100
–40	125 minutes	100
–50	128 minutes	100

Table 2
Air load efficiency analysis for 75,000 pph system

Air load (%)	Run time to reach 1.5 torr	Reclamation (%)
0	220 minutes	100
100	140 minutes	100
200	110 minutes	100
300	110 minutes	100
400	80 minutes	99

allows maximum ice growth because the spacing between tubes is wide. Figure 4 illustrates the tube field layout for a freeze-condenser that supports a 75,000 pph deodorizer.

Freeze-condenser performance characteristics

Performance of a freeze-condenser is affected by cooling fluid temperature, the amount of noncondensable gas (air), and steam loading.

A sensitivity analysis for cooling fluid temperature was done for a 75,000 pph system (Table 1). The design operating pressure was 1.5 torr or below. Cooling fluid temperature was varied and condenser operation monitored over time. Cooling fluid temperature was varied from 0 to –50°F in 10°F increments. Run time until 1.25 torr operating pressure was reached was measured along with reclamation efficiency. The steam load to the condenser was metered through a fixed orifice. After defrosting, the weight of condensate was measured. Reclamation efficiency is pounds of condensate collected divided by pounds of steam put in over the run time.

A 100% reclamation indicates that all the stripping steam was converted to ice. No stripping steam was entering the ejector system. The condenser operated as an effective cold trap.

Operating pressure as a function of time is shown by Figure 4.

A similar analysis was done for noncondensible air load (Table 2). A high desired vacuum level is affected by the amount of air inleakage once a set vacuum system is installed. It is important to specify a vacuum system that supports the freeze-condenser but does not set the operating pressure. The analysis measured performance with 0, 100,

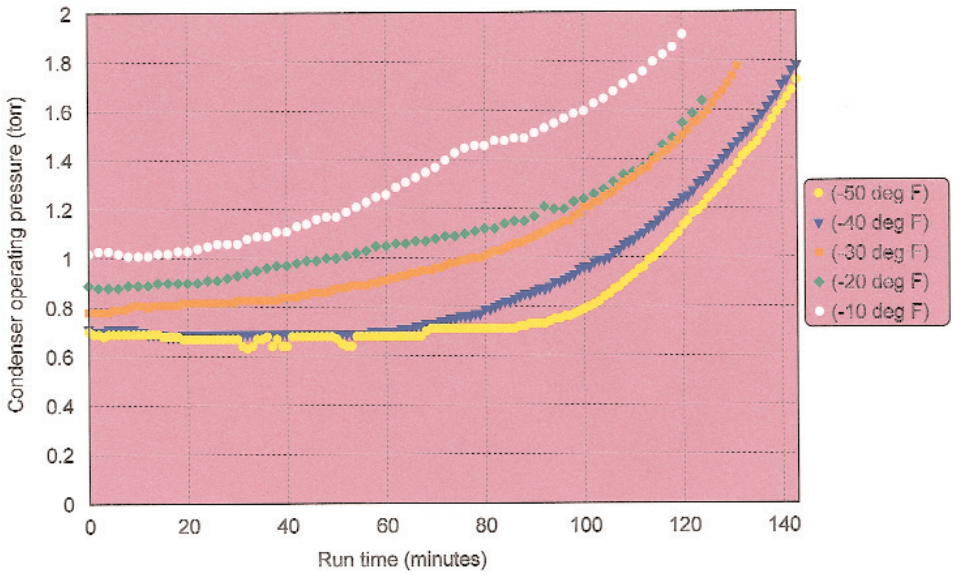

Figure 5. Freeze-condenser performance vs. cooling fluid temperature

200, 300, and 400% noncondensible load. Cooling fluid inlet temperature was fixed at –30°F for the analysis. In this case the run time to reach 2.0 torr operating pressure was measured.

The data indicate that a well-designed freeze-condenser with a properly matched ejector system yields excellent performance across a wide range of operating conditions.

Another assessment pertained to increasing the stripping steam load to the condenser. The condenser handled the additional stripping steam without problems. At 200% loading the condenser behave favorably the change in run time was reduced because ice deposition was greater. Again, reclamation was essentially 100%.

Comparison of freeze-condensation vs. conventional ejector system

Table 3 shows a comparison of costs for a freeze-condenser vacuum system vs. a conventional ejector system. The comparison is for a 75,000 pph edible oil deodorizer operating at 1.5 torr. The load exiting the fatty acid scrubber is 1,000 pph stripping steam, 20 pph air, 7 pph free fatty acids, at 1.25 torr and 160°F to the vacuum system.

A freeze-condensing vacuum system has a greater capital cost when compared with a conventional ejector system. The advantages, however, provide a reasonable payback for that added capital cost. Those advantages include:

- Substantially lower consumption of high-pressure motive steam, 1,100 pph vs. 10,000 pph;
- The caustic flush system used with a conventional ejector system is eliminated. The 15 gallons per minute (gpm)

Table 3
Comparison of freeze-condensation vs. conventional ejector

	Freeze-condenser vacuum system	Conventional vacuum system
Capital cost [a]	$500,000	
Capital costs for ejector system		$150,000
Utilities		
Motive steam (200 psig D&S)	1,100 pph	10,000 pph
Water (87°F)	125 gpm	2,000 gpm
Cooling fluid (–25°F liquid ammonia)	2,200 pph	
Waste steam for defrost mode (25 psig or greater)	2,600 pph	
Caustic flush solution		15 gpm
Additional costs not shown	Cooling tower Refrigeration system Installation	Cooling tower Caustic system Installation

[a] For twin freeze-condensers, isolation valves, ejector system, and melt vessel

NaOH solution is eliminated and so is chemical treatment with sodium hydroxide;

• Cooling water is dramatically reduced, 125 gpm vs. 2,000 gpm;

• The ejector system is much smaller and easier to maintain, with the largest ejector being 10 to 12 ft long vs. 40 ft long. A conventional ejector system's first two ejector stages are mounted vertically, resulting in accessibility and maintenance difficulties. The smaller ejectors for the freeze-condensing option are mounted horizontally within the structure, making accessibility and maintenance less difficult;

• Capability to isolate deodorizer from vacuum system;

• Environmental effects are less because far less waste water is produced. Only 1,100 pph of motive steam contacts the process effluent rather than 10,000 pph;

• Capability to run deodorizer at lower pressure to improve tocopherol recovery without a substantial increase in utility usage; and

• Flexible operation makes future expansion possible.

Summary

Although freeze-condensation is relatively new in the edible oil market, many refiners are evaluating the applicability of the technology. It does provide substantial benefits, but a properly designed freeze-condenser that is matched with a well-designed ejector system is vital for reliable operation. Operating cost and environmental effects are lower when freeze-condensation is used. These factors make it worthwhile—when considering a new deodorizer to evaluate revamp options, or determine options to lower operating pressure for greater tocopherol recovery—to evaluate freeze-condensation along with conventional technology.❑