How to improve ejector system performance

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Ejector systems are widely used throughout the fats & oils processing industry for important processes, such as, solvent extraction, degumming, bleaching, deodorization, renewable diesel pretreatment or hydro-processing—wiped film evaporator and glycerin still are most common. Ejector systems provide reliable operation and pressure level for these critical fats & oils processing operations; however, there are instances where performance shortcomings arise. The root cause may not always be straightforward to troubleshoot.

This article describes four case studies in performance problem solving taken from a variety of documents produced by ejector system experts.

CASE 1: GLYCERIN STILL ICE BUILD-UP

A batch process glycerin production plant could not maintain the pressure (deep vacuum) necessary for proper operation. The elevated pressure resulted in lower glycerin purity, since the first stage ejector would "back stream." In other words, motive steam flowed into the glycerin still, impacting product quality.

The inlet pressure was designed to be 1.5 mm Hg absolute at the first stage ejector. When in operation the pressure initially held, but degraded with time. Ultimately, the inlet pressure more than doubled, to between 2.5 and 3.5 mm Hg absolute.

A performance improvement engineer was dispatched to the site to assess the installation, take ejector system pressure and temperature measurements, and determine the problem. Pressure measurements mirrored the issue noted by the processor. In addition, the ejector discharge exceed maximum capability and the ejector system had broken down.

The performance improvement engineer noted that the ejector system original equipment manufacturer did not provide a steam jacket or tracing on the inlet diffuser. Therefore, they suspected ice formation. The engineer asked plant personnel to remove a section of insulation (Fig. 1) in order to inspect the inlet diffuser of the ejector while the process was in operation.

Plant personnel doubted ice would form inside the ejector since the process conditions were well above the freeze point of water. How could the inlet diffuser surfaces become cold

Figure 1. Insulation removed from the first stage ejector, showing frost formation. Source: Graham Corporation

enough for frost to form when inlet and outlet flows for the first stage were all well above the freeze point of water?

The engineer determined that as the batch process began ejector performance was acceptable. Then, ice began to form inside the ejector along the inlet diffuser. As the ice grew thicker, the cross sectional flow area of the ejector decreased, disrupting flow and increasing pressure loss.

Surprised that ice formation was the root cause for poor performance, the refiner requested a deeper explanation for what was occurring. The engineer provided the processor with

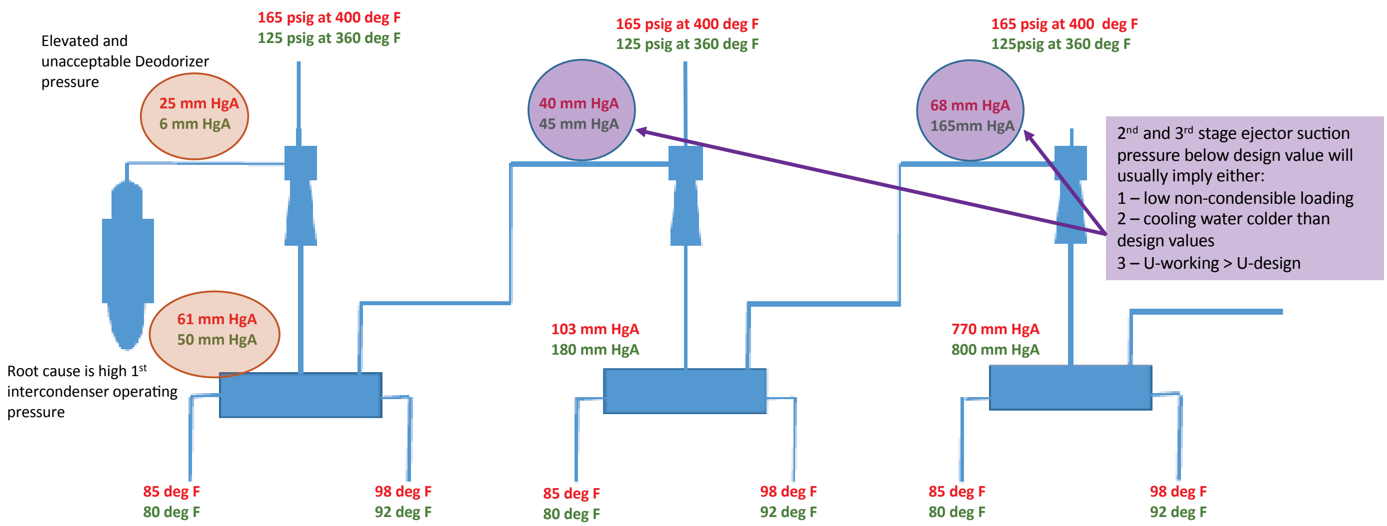

Figure 2. Deodorizer column ejector system with the design specifics in green and field measurements in red. Source: Graham Corporation

information on thermodynamic fundamentals and an illustration for what was occurring. Although motive steam is hot, the process loads to the ejector are warm, and the ejector exhaust temperature is hot, ice can (and will) form when operating pressure is below water's triple point, specifically when inlet pressure to an ejector is below 4.6 mm Hg absolute. When operating below this pressure, the inlet diffuser must remain hot to avoid ice formation. An ejector should be designed and constructed accordingly.

Ideally, the ejector should have had a steam jacket that kept the inlet diffuser metal surface above the freeze point of water. The root cause of this manufacturer's problem was a lack of heating on the inlet diffuser. The engineer recommended a retrofit electrical steam tracing.

CASE 2: HIGH COOLING WATER TEMPERATURE AND MOTIVE STEAM PRESSURE

A deodorization ejector system, meant to operate at 6 mm Hg absolute, was operating at 25 mm Hg absolute instead. Under these conditions, the deodorizing process did not function properly and the plant could not run produce quality, marketable product.

A performance improvement engineer was dispatched and determined that the equipment installation and orientation were in order. They then surveyed the operating pressures and temperatures throughout the plant and compared the measured to designed values.

The first stage ejector was operating with a backpressure above its maximum discharge pressure capability and consequently the deodorizer pressure rose.

The operating variable responsible was a cooling water temperature at 85 degrees Fahrenheit (F) rather than the design specification of no warmer than 80 deg F.

The problem was further exacerbated by a motive steam pressure running at 165 psig rather than 125 psig. The higher pressure meant greater motive steam consumption and higher heat injection needed for the condensers.

The first inter-condenser seemingly had a high pressure drop on the vacuum side. That was due to the second stage ejector over venting the condenser; meaning, it was pulling more vapor along with the air in order to match the vapor load handling capability of that ejector. However, the over venting caused no particular issue for the ejector system. The warm cooling water and higher motive steam pressure were the root cause, with warm water the primary issue.

The oils processor reviewed the data with the process improvement engineer, but it was not clear to the refiner why warmer inlet cooling water would impact the first stage ejector as it did. The performance improvement engineer explained the interplay between an ejector and its downstream condenser:

> If the cooling water inlet temperature is higher than designed, condenser pressure will rise to increase the condensation temperature of the steam and thereby increase the logarithmic mean temperature difference. If the first intercondenser pressure is greater than the first stage ejector discharge pressure capacity, the ejector performance breaks down and the vacuum column pressure rises sharply.

A key axiom for ejector-condenser interplay is that the condenser will reject the heat from the exhaust of the ejector and what matters is the pressure at which that occurs.

In this case, the motive supply pressure was 165 psig and not the design specified 125 psig. Due to a greater supply pressure about 25% more motive steam passes through the motive nozzle, which when added to the deodorizer overhead load,

Best practices for optimal ejector system performance

During ejector system installation

1. Ensure there are instrument connections at suction and discharge of each ejector to permit measuring pressure and temperature
2. Ensure intercondensers have connections for measuring pressure and temperature at inlet and outlet connections
3. Motive steam piping is insulated, there are cyclonic separators to remove moisture in steam line, no vertical upward flowing steam piping after the separator, connection to measure pressure and temperature
4. Condenser drain legs are vertical or sloped less than 45 degrees from vertical. There is no horizontal condensate piping
6. Condenser drain legs have appropriate elevation between condenser outlet and condensate hot well
7. Evaluate piping length between components, such as distance between ejector discharge and inlet to condenser. Was piping pressure drop considered? Is piping circuitous adding pressure drop.
8. Where is last stage ejector discharging to. Is it an aftercondenser vented to atmosphere or is the system exhaust vented to downstream process equipment? Was back pressure properly considered?
9. Does a second process tie into the ejector system and is the tie-in at the correct location. Was the ejector system design to accommodate a secondary load from another process vessel?
10. Is a liquid drain and drainage piping at the bottom of the suction chamber for any ejector mounted vertically and pointing upward?
11. For barometric condensing ejector systems is there valving to throttle cooling water flow to avoid flooding or drainage problems?

After commercial operation

1. Conduct an operating survey to measure system critical performance variables, such as pressure and temperatures, to establish a baseline
2. Ideally conduct the survey during warm summer months when cooling water temperature is elevated
3. Have in inventory replacement motive steam nozzles for each ejector
4. Consider having in inventory complete replacement ejectors for any ejector with 6" suction or smaller
5. Have drawings of ejectors defining critical internal dimensions archived for ease of access

Annual or periodic inspection when process is shutdown

1. Inspect ejector internals and also steam nozzle for signs of wet steam
   a. typically there are erosion marks on the inlet diffuser
   b. steam nozzle will begin to show signs of wear
   c. elbows in piping downstream of ejector discharge will show signs of erosion
   d. Ejector exhaust temperature is low, should usually be > 200 deg F
2. Is there product build up inside the ejector
3. Inspect condensers for fouling
4. Isolate process from ejector system and conduct no load test to assess air inleakage rate. If air rate is high, find and repair holes, cracks, open connections, etc

Conduct annual and bi-annual performance survey

1. Compare current performance to initial baseline
2. Discuss variation with ejector system OEM
3. Watch for leading indicators of pending maloperation
   a. Motive pressure is falling below design
   b. intercondenser pressure drop, shellside or tubeside, is elevated
   c. intercondenser operating pressures are increasing

If performance break occurs

1. Consult with Ejector OEM Performance Improvement Engineer
2. Share performance benchmark and current operating data with OEM
3. For deodorizer system with vertical shell & tube 1st intercondenser,
   a. is caustic flushing installed and operating to remove fatty acid build up on the inlet tubesheet
   b. are cooling water filters or backflushing systems installed and working to remove dust sediment that enters the cooling tower water
4. Seek OEMs direction or have OEM engineer dispatch to plant site

increased condenser heat rejection. This too causes the condenser pressure to rise.

The only practical and long term beneficial path to take for the refiner was to replace the first stage ejector and first intercondenser appropriately designed for cooling water at 85 deg F inlet and 165 psig motive. Upon doing so, performance was fine.

CASE 3: STEAM LEAK FROM DAMAGED MOTIVE STEAM NOZZLE

A soybean oil processor was unable to achieve 1.5 mm Hg abs deodorizer pressure. Instead, they were operating at 8 to 14 mm Hg absolute. The system was unstable and surging with deodorizer pressure fluctuating well above designed operating pressure.

A performance improvement engineer conducted a pressure and temperature survey of the ejector system and identified that the fourth stage ejector was maintaining 400 mm Hg abs. It was designed to operate at 250 mm Hg abs; therefore, it was operating well above the discharge pressure capability of the third stage ejector. The high pressure led to a breakdown in ejector system performance, resulting in high deodorizer pressure and poor product quality.

Excessive air in leakage was ruled out quickly as the after condenser vent for the ejector system was valved to permit discharge to the atmosphere. The after condenser exhaust

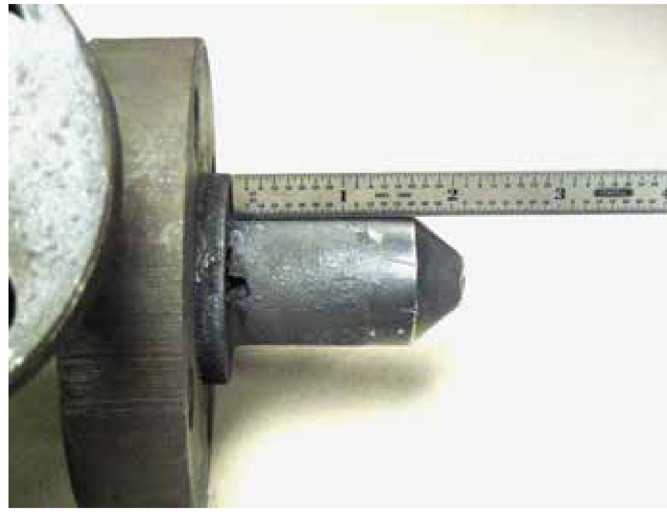

Figure 3. A steam nozzle with a hole through which motive steam leaks into the suction chamber of an ejector. Source: Graham Corporation

stream did not hint to high air load since there was not meaningful vent mass flow.

The improvement engineer requested a system shut down so the fourth stage ejector could be pulled from the system for inspection. The ejector was disassembled and inspected. Visual inspection determined that a hole developed in the steam nozzle assembly. This caused steam to leak into the suction chamber of the fourth stage ejector and increase the mass flow rate it had to handle. The suction pressure then increased above the third stage ejector maximum discharge capability. The result was the ejector system could not function.

The improvement engineer learned that, against best practices, the ejector system had been in operation for about 10 years without maintenance or replacement parts. All refiners should adhere to routine maintenance guidelines (see box).

CASE 4: IMPROPER EJECTOR INSTALLATION

An edible oil refinery can have a number of different ejector systems. Ejector systems are used for solvent extraction, degumming, deodorization, bleaching, renewable or biodiesel, wipe film evaporation, and vacuum flasher.

In this case study, a particular edible oil processor had performance issues with a couple of their ejector systems and plant personnel could not resolve the problems by troubleshooting the issues. The refiner maintained an inventory of replacement ejectors and motive steam nozzles. However, poor inventory management lead to the installation of the incorrect ejectors.

Prior to conducting system performance pressure and temperature surveys, the improvement engineer inspected each installation to assess orientation and routing for motive steam, cooling water and condensate drains. While inspecting the various ejector systems they noted that the nameplates for certain ejectors did not match the serial numbers that should be associated with those systems.

Third and fourth stage ejectors for deodorizers, wipe film evaporators, and glycerin stills all appear similar to each other and to ejectors for the bleaching system. While they may look the same, each is designed specifically for their respective ejector system.

For example, the 4 feet long ejector for the deodorizer has similar suction and discharge connections as an ejector for the bleacher system. Externally both look similar. Internally, however, the geometries are quite different.

In this case, a refinery maintenance crew inserted a spare deodorizer ejector from inventory into the bleaching system.

At a glance the two ejectors are indistinguishable. A first stage ejector for a bleaching system is approximately 4 feet long, with a 4 inch suction and discharge connections. The same dimensions are true for the third stage deodorizer ejector. However, ejector diffuser geometry is specifically designed for a particular compression ratio.

The ejector pulled from inventory was designed for a different compression ratio and motive steam nozzle than specified for the bleaching system.

The diffuser for a 3.5 compression ratio is different from one for a 7.2 compression ratio even though, externally, they look the same. Also at 115 psig motive steam pressure, the 0.3125 inch throat will pass 90 percent more motive steam than a 0.228 inch throat would.

At the plant in this instance, the higher motive steam consumption overloaded the downstream condenser, elevating the pressure at which it operates and the system ran poorly overall. This same mismatch was done on another system with a similar unfavorable outcome.

The key takeaway was while ejectors and motive steam nozzles may appear similar externally, they are uniquely designed for a given process or system. It is not possible to mix and match ejectors and expect adequate performance. Always be certain ejector serial numbers and motive steam nozzles match those applicable for the system where they may be installed. Failure to do so will result in unsatisfactory performance.

Ejector systems are critical for fats and oils processing. They are applied throughout the extraction and refining processes. While typically providing robust and reliable operation, variables with the process, utilities, or the ejector system itself can result in an undesirable pressure level. Ejector performance and behavior is not always intuitive, being that they are devices that compress supersonic flow and ejector-condenser interplay is not well understood.

Troubleshooting a performance issue with an ejector system can be difficult. It is best practice to seek the counsel and assistance of an ejector system performance improvement engineer when facing system underperformance. The performance improvement engineer can assist plant personnel in quickly diagnosing root cause and providing options to return performance to an acceptable level.

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