Originally appeared in:
December 2018, pgs 51-55.
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HP | Maintenance and Reliability

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Maintenance and turnaround planning critical to successful ejector vacuum system operation

Steam ejector vacuum systems are generally considered to be reliable and require little maintenance. However, when preventive or corrective maintenance is required, ensuring it is done correctly is imperative. Failing to properly perform maintenance or turnaround work can result in a loss of performance or worse, a loss of production capacity. Many of the services that ejector systems operate in are critical services to the overall process.

Opportunities for maintenance work are also often heavily dependent on turnaround and shutdown schedules. This further increases the importance of getting the maintenance work done correctly every time. Unfortunately, this lesson is often learned the hard way with improper maintenance work resulting in poor performance and lost capacity. Multiple case studies have been outlined and selected to cover a variety of services and industries, and to provide useful insight so these issues can successfully be avoided.

Highlighted below are four such case studies, which have been selected from a pool of examples and represent real issues that have been faced by plants of various industries. The case study examples highlight the thought processes that lead to these errors and detail the impact that these errors had on the vacuum system's operation.

Case study 1: The importance of sealing strips. This case study focuses on a vacuum distillation ejector system for a Middle Eastern refinery.

Condensers can be supplied in a variety of different configurations, and fixed tubesheet designs are one of the most basic arrangements. In a fixed tubesheet design, the tubesheets are welded to the shell. While cheaper in cost, this prohibits the mechanical cleaning of the shell side of a condenser. In a dirty process, such as vacuum distillation, it is more common for a removable bundle to be selected. Floating head or U-tube bundle designs often utilize sealing strips. The internal baffles cannot be welded to the shell, as that would prevent the bundle from being removed. However, the baffling needs to seal to the shell to prevent vapor bypassing. This is where sealing strips are utilized, as shown in **FIG. 1.**

Many maintenance activities, such as cleaning, require the bundle to be pulled from the shell. When this is done, the sealing strips can become damaged. Over time, corrosion is often a contributing factor to sealing strip damage and degradation. Because of this, it is recommended that they are replaced each time the bundle is pulled to ensure a good seal is maintained.

The refiner's vacuum distillation system undergoes maintenance every 5 yr during each major turnaround. The ejector system is run continuously between these maintenance outages with little to no opportunity to service the equipment. It was decided that the system's condenser bundles would be pulled and cleaned during the turnaround. The condensers were believed to be fouled, based on the declining performance of the system during the hotter months of the year. The vacuum tower historically ran close to its design operating pressure. In the year or so leading up to the turnaround, the vacuum system became unstable at cooling water temperatures nearing the design point for the system, causing degradation in tower pressure.

When the ejector system was brought down for maintenance during the turnaround, the fouling buildup on both the tube and shell sides of the system's condensers was removed. The tubes were lanced to remove scaling, and the shell side was water blasted to remove the process buildup. The system was reassembled and brought back online after the turnaround activities.

FIG. 1. Sealing strips are utilized to seal to the shell to prevent vapor bypassing.

To everyone's surprise, the system performance after being brought back online was substantially worse than prior to the shutdown. The tower vacuum was recorded to be near 60 mmHgA, when it had previously been operating at a pressure closer to the design point of 15 mmHgA. It was expected that cleaning and maintenance would improve the system's performance, but the results were the opposite. This was a terrifying prospect, since the system was not scheduled for additional maintenance until the next turnaround in 5 yr.

Discussion and onsite assistance identified that the condenser bundle sealing strips were not replaced during the turnaround. The condenser bundles had either been installed without sealing strips or the original sealing strips were severely damaged. Thermal images of the condensers (**FIG. 2**) were taken, and the temperature profile indicated bypassing through the sealing strips. This bypassing steam acts as a load to the downstream and, in this case, that bypass was severe enough that it was overloading the ejectors. This was directly responsible for the tower's poor performance.

The economic impact of running a vacuum tower at 60 mmHgA vs. the design of 15 mmHgA for 5 yr is unacceptable.

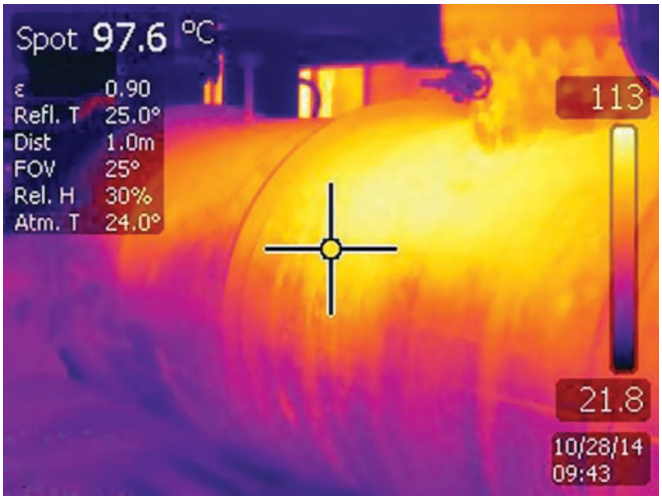


FIG. 2. Thermal images of the condensers were taken and indicated bypassing through the sealing strips.

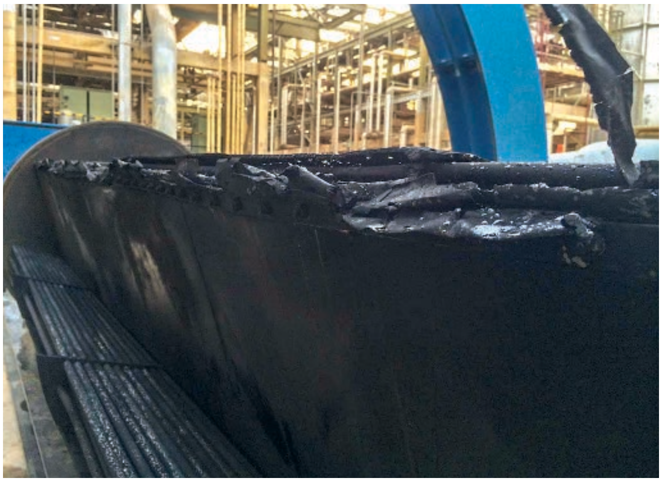


FIG. 3. Damaged sealing strips.

The refiner procured the required sealing strips and placed them into stock. Within 1 yr, an opportunity presented itself when the boiler that supplies steam to the ejector system had an unplanned outage. The refiner used this opportunity to pull the condenser bundles and confirmed that the sealing strips were either missing or in very poor condition (**FIG. 3**).

After the bundles were reinstalled with new sealing strips and the system was brought back online, the vacuum returned to the design of 15 mmHgA. To prevent this from reoccurring, this refiner has placed a hold point for engineering to inspect the cleaned bundles and verify new sealing strips have been installed prior to bundle reinstallation on all future condenser work.

Case study 2: Equipment replaced with improperly designed copy. This case study examines a compressor drive steam turbine exhaust condenser at a Caribbean fertilizer company.

Steam turbines often utilize a condenser on their discharge, which services two main purposes. One reason for placing a condenser at the discharge of a steam turbine is to improve its efficiency. The condenser allows the turbine to discharge to a vacuum, which creates a larger pressure differential across the turbine, increasing its efficiency. The other purpose of a condenser is to capture the steam in the form of condensate so it can be recycled back to the boiler. For condensers to perform both tasks, they are designed in a very specific way that differs significantly from similar looking heat exchangers.

This fertilizer company installed a new steam turbine exhaust condenser built by a third-party heat exchanger manufacturer. The equipment was purchased to replace an original equipment manufacturer (OEM)-built 1965 condenser. After more than 40 yr of service, the mechanical integrity of the original condenser was questionable. The decision was made that it would be more cost-effective to replace the unit rather than trying to rebuild it, which is normally the better choice.

The equipment user sourced the replacement condenser from a well-known and trusted heat exchanger company due to price and lead time concerns with the OEM's offer. The plant in question has a 4-yr turnaround cycle, allowing for limited opportunities to service equipment between outages. The replacement condenser was installed during one of these outages.

The design vacuum for the condenser is 3.75 inHgA at full load. Upon completion of the outage, the steam turbine was brought back online with poor results. The condenser was only able to reach an operating pressure of 20 inHgA at 90% of the design steam load. Although the cooling water temperature and flow were also found to be better than the design, the unit was nearly 16 inHg off its ideal operating point. This proved to be catastrophic for the plant, which was steam limited. Expansions to the plant left no additional boiler capacity. This meant it could not overcome the poor turbine back pressure with additional steam, ultimately preventing the plant from running at full capacity. It is one thing to operate a unit inefficiently, but it is a more serious issue when it limits a plant's production. The estimated monetary costs of this performance shortcoming were truly astronomical and career ending.

The heat exchanger manufacturer had no field assistance or experience with turbine condensing systems and could not provide the end user with support. To determine how this issue originated, the original condenser's manufacturer was contacted to review the problem and inspect the equipment onsite.

A review of the replacement condenser drawings revealed ignorance on the part of the heat exchanger manufacturer and showed that the unit was incorrectly designed. It was built like a heat exchanger, as opposed to a turbine exhaust condenser. Although these appear similar on the outside, the internals are very different, and they have two very different functions. It is important to remember that although condensers exchange heat, their purpose is to facilitate a phase change in the process flow, turning vapors into liquids. Heat exchangers are designed to transfer heat from one medium to another.

The incorrectly designed and installed unit was missing most of the critical features that can be expected in a surface condenser. It also incorporated many heat exchanger features that are counterproductive in a vacuum condenser. The site's engineering staff believed that because the replacement had the required surface area, it should have performed well. The underperforming exchanger was modeled with heat exchanger software that supported the poor design. Heat exchanger software does a poor job of modeling condensers.

One major issue was a complete lack of understanding as to why condensers are installed with an air removal system. The air removal system is installed on a condenser to pull a deep enough vacuum that any air leaking into the condenser can be swept from the bundle. Air in a condenser will blanket tubes displacing steam, resulting in poor operating pressure. The internals of a condenser are set up to direct the air that is leaking into a vacuum system toward the air removal equipment. In this instance, the replacement unit was pulling the noncondensables out of a connection that was located adjacent to the steam inlet (**FIG. 4**). Most of what the venting package was pulling over was condensable steam, rather than noncondensables. This allowed for large dead areas in the condenser where noncondensables were gathering, preventing a deeper vacuum from being achieved.

An operational fix was unavailable for this problem; the new unit needed to be completely replaced. Plans were put in place to replace the condenser at the next outage in 4 yr. The cost of a new, properly design condenser as well as the cost of the improperly designed unit was high, but ultimately that price was small compared to the cost of the lost production.

Case study 3: Incorrectly fabricated non-OEM parts.

This case study details the poor performance of a steam vacuum refrigeration ejector system at a US paper mill.

An interesting application for steam-powered ejectors is a steam vacuum refrigeration unit (SVRU). Although it seems counterintuitive, steam can be used with an ejector system to generate chilled water. This is achieved by pulling deep vacuum on a water stream and flashing off some of that water, which in turn chills that water. Achieving a chilled water temperature of 40°F (4.4°C), as the unit was designed to do, is not uncommon with one of these systems. This is a particularly attractive process for paper mills, since their process requires chilled water and they normally have an abundance of available steam, although SVRUs are also found in other industries.

This SVRU is 49-ft tall and utilizes two flash chambers to achieve its designed chilled water temperature of 40°F (4.4°C). Mounted on the top of the SVRU is a direct contact barometric condenser and a small two-stage air venting system. The air venting system sets the discharge pressure for two large booster ejectors that are pulling the deep vacuum on the flash tanks. After nearly 45 yr of operation, the SVR system's capacity suddenly dropped to an unacceptable level, setting off a series of costly errors.

Since chilled water is critical to making paper, a mechanical chiller was rented to provide the mill's chilled water. This chiller would remain in service until the issue with the SVRU could be identified and corrected. The rented mechanical chiller was costly, prompting the user to resolve the SVR problems quickly.

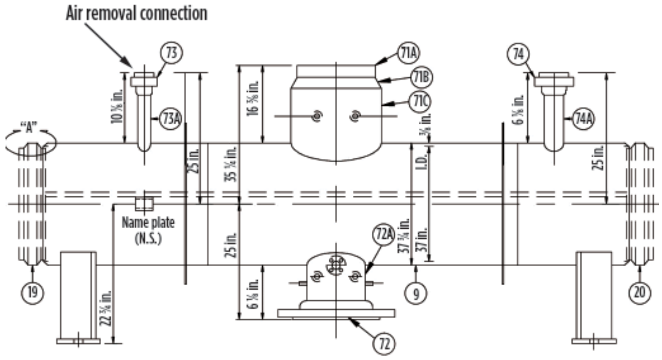


FIG. 4. An incorrectly reverse engineered air removal system connection.

The equipment user identified that the large booster ejector had developed a significant hole in the side of one of the diffusers, causing the issue. This was allowing air to be pulled into the system, overloading the air venting ejectors and causing a significant loss in performance. Due to price and lead time concerns, the user had a local fabricator reverse engineer both booster diffusers. The newly fabricated replacement diffusers were then installed, which successfully eliminated the air leak but never returned the performance of the system. This prevented the rented mechanical chiller from being removed from service.

The equipment user, baffled by the ongoing problem, contacted the SVRU's manufacturer to perform a site survey of the vacuum equipment and determine the cause of the continuing issues. While several smaller issues were identified and corrected, the source of the continued poor performance was determined to be the replacement diffusers, which were improperly designed and failed to meet the system's needs.

Examining these diffusers highlighted several glaring issues, including:

- The replacement diffusers were not concentric. As is often an issue with non-OEM diffusers, the replacement diffusers were oblong, which was negatively impacting performance.
- The alignment was incorrect, meaning the new diffuser was not straight relative to the air chamber and motive nozzle. When the motive nozzle is incorrectly aligned with the diffuser, the motive steam will be focused towards one side of the ejector, reducing its efficiency.

Replacement booster ejectors (**FIG. 5**) were ordered from the SVRU's OEM. Following installation, the performance of the system returned to design. Although ejectors appear simple from the outside, precision and alignment are critical. Small, seemingly unnoticeable deviations can be detrimental to successful performance. Going forward, this site plans a yearly inspection so potential system issues can be identified before they fail, and necessary parts are stocked so that any failure can quickly be addressed.

Failing to properly perform maintenance or turnaround work on critical ejector systems can result in a loss of performance or worse, a loss of production capacity.

Case study 4: Condenser tube bundles improperly replaced by a third-party. This case study examines a US refinery vacuum distillation ejector system.

Vacuum distillation ejector systems are normally comprised of three stages of ejectors, although other arrangements are used. To improve the efficiency of a vacuum system, condensers are utilized between the ejectors. This allows for steam and condensable hydrocarbons to be removed from the process stream, making the downstream equipment smaller and more efficient. Condensers are designed with low process side pressure drops to maximize efficiency, allowing the upstream ejector to be designed for a lower discharge pressure and lowering its required compression range. This reduces the system's steam consumption. The condensers and their design are an integral component of any condensing vacuum system.

The refiner in question was operating a three-stage ejector system that was pulling vacuum on a distillation column. The system contained three condensers, one between each stage of ejectors and an additional condenser after the ejectors. Over the course of roughly 20 yr of continual operation, the condenser tube bundles began to suffer from corrosion and wear. This specific refinery undergoes a turnaround every 2 yr, and it was decided that the tube bundles for the condensers would be replaced during the next turnaround. Since the condensers for this system are of a U-tube design, the bundles can be changed out without having to replace the shell.

The replacement bundles were purchased from a reputable local heat exchanger manufacturer to acquire them inexpensively. However, two critical mistakes were made by the refinery that led to additional costs and lost production. Had the bundles been replaced in kind and by the original vacuum system's manufacturer, these problems would have been avoided, saving the plant a substantial amount of money and time in the long run.

The material of the replacement bundles was changed. The original condensers were supplied with 304SS tubes, but the replacement carbon-steel tube bundles were procured from the heat exchanger manufacturer. While carbon-steel tubes are used successfully in various refinery applications, they are a notoriously bad materials selection for a vacuum system. The refinery selected carbon steel for two reasons: it has better heat transfer properties than stainless steel and is significantly cheaper. In a vacuum distillation service, the tubes are exposed to both oxygenated cooling water on one side and corrosive vapors, which contain trace amounts of oxygen, on the process side.

FIG. 5. OEM replacement ejectors on an SVRU.

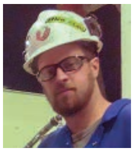
FIG. 6. A maintenance yard filled with failed bundles.

The original stainless-steel bundles lasted roughly 20 yr, whereas the replacement bundles lasted 18 mos. This short service life was due to the carbon steel oxidizing and developing a multitude of cooling water leaks. Another unfortunate side effect of selecting carbon steel is that rust buildup on the tubes impedes heat transfer and restricts cooling water flow, resulting in a reduction in performance. Although carbon steel works well at first, its performance quickly dissipates, resulting in tower instability and poor vacuum. As leaks develop, vast amounts of cooling water are also lost into the waste stream, increasing the load to the water treatment plant.

Due to the constant failure of the carbon-steel bundles, the refinery began replacing them every shutdown going forward. Before reaching out to the OEM for assistance, a total of 18 new carbon-steel condenser bundles were purchased from the heat exchanger vendor and installed, far exceeding the cost of stainless bundles. **FIG. 6** shows failed bundles waiting to be scrapped. Replacing bundles has additional ancillary costs beyond the bundles themselves that include planning, shipping costs, cranes, additional manpower and lost production.

While onsite, it was also noted that the replacement bundles were designed incorrectly. The heat exchanger manufacturer was ignorant in their understanding of vacuum condensers. They utilized multiple features that were incorrect for a vacuum service. A pressure and temperature survey of the vacuum system highlighted this impact on the tower's top pressure. The system, designed to operate at 10 mmHgA, could only achieve a pressure of 72 mmHgA. The poor tower pressure became status quo, and many of the plant's engineering staff began to accept the poor pressure and constant replacements as inevitable, as opposed to correctable. To this day, the plant in question continues to operate under these inefficient conditions, despite the evidence presented regarding the cause of these issues.

Takeaway. These examples represent a small percentage of the potential issues that equipment users encounter when not sourcing the correct material or improperly completing maintenance work. Often, the desire to save money and time on the front end requires additional work on the back end, which is detrimental to system performance. Turnaround schedules amplify most vacuum system mistakes, limiting the timely correction of errors and increasing the economic impact of those mistakes. While glaring mistakes are often learned the hard way, equipment and maintenance costs are often minor when compared to the cost of lost production and downtime. Carefully planning maintenance activities and procuring OEM replacement parts far in advance of a shutdown helps reduce risk and ensures the continued success of the vacuum system. HP



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