LESSONS FROM THE FIELD - EJECTOR SYSTEMS

James R. Lines, Graham Corporation, USA, presents the problems associated with ejector system performance and subsequent solutions.

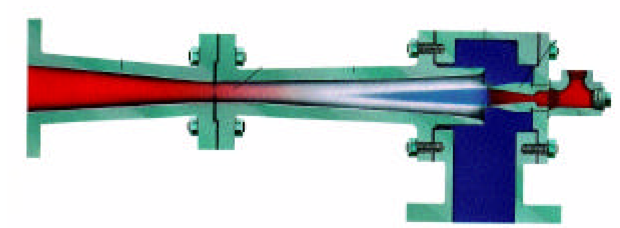

Figure 1. Ejector cross-sectional drawing

Hydrocarbon Engineering has previously reported on ejector system fundamentals, operating characteristics, and guides for troubleshooting[1]. Moving on from that stage, the current article provides real world ejector system performance limitations uncovered during routine performance surveys. Corrective action undertaken to improve performance is documented and discussed in detail. Principles from the initial article are used as the tools to define the cause of a particular limitation and the eventual solution. It should be noted that the corrective actions described were unique to the particular problems discussed. It will not always be possible to apply the same procedure to a comparable performance problem. A review of general corrective techniques is discussed where applicable. Ejector system manufacturers should be consulted as a first course of action, and guide fixes are often possible.

Survey 1 - nylon intermediate production facility

Nitrogen gas bleed for pressure control

A North American petrochemical company manufacturing nylon intermediates was operating a vacuum flasher supported by a precondenser and two stage ejector system. Overhead load from the vacuum flasher consisted of 160 000 pph (72 600 kg/hr) of mixed nitriles at a pressure of approximately 35 torr.

The precondenser produced adequate vacuum, but the two stage ejector system that extracted non-condensibles from the precondenser was performing in an unstable manner. Suction pressure of the first stage ejector was cycling between the design 35 torr and up to as high as 75 - 80 torr.

Vacuum flasher pressure was unaffected by the ejector instability, however, plant personnel had concerns that poor ejector performance may at some point have a negative impact on vacuum flasher operating pressure.

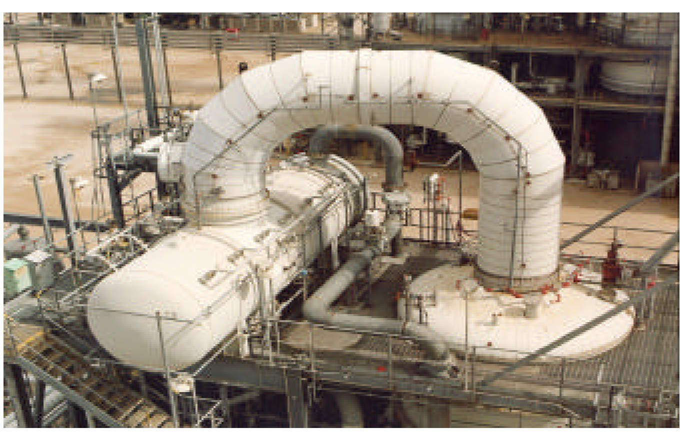

Figure 2. Precondenser to left of vacuum flasher

Both precondenser and vacuum system were supplied by the ejector system manufacturer. The manufacturer dispatched a service engineer to the site to survey the equipment and its performance. Figure 3 depicts the pressure profile of the equipment.

The service engineer initially inspected vapor piping and condensate drain legs to ensure equipment layout was satisfactory. Attention was then focused on the utilities. Motive steam pressure was measured at the inlet to each ejector, and actual motive steam supply pressure to the ejectors was 140 psig (9.7 barg). The ejector motive steam nozzles were designed to pass the required steam at 125 psig (8.6 barg). Although the motive steam pressure was above design and, consequently, more steam was being consumed by the ejectors, the excessive steam consumption was not enough to cause poor performance.

The cooling water inlet temperature to the condensers was below design, and temperature rise across each condenser was less than the design. Inlet cooling water was designed for 89.6 °F (32 °C) and the water flowed in series from the first intercondenser to the aftercondenser. The actual inlet water was at 85 °F (29.4 °C). The total temperature rise across both condensers at design was 29 °F (16.1 °C). The actual temperature rise was 13 °F (7.2 °C). The lower temperature rise would suggest greater cooling water usage or lower condensible vapor discharge from the precondenser, neither of which would cause poor ejector system performance.

An ejector system experiencing unstable suction pressure is typically operating in a broken mode. Broken ejector performance is often caused by low motive steam pressure, which has already been ruled out, a fouled intercondenser, high cooling water temperature or water flow, both of which have been ruled out, non-condensible loading.

While inspecting the ejector system, the service engineer noticed a periodic audible change in ejector operation. This audible change plus an unstable suction and discharge pressure first stage ejector confirmed that this particular ejector was the trouble

The service engineer noticed plant personnel had installed a pneumatically controlled control valve that bled nitrogen to the suction of the first stage ejector. Plant personnel installed a nitrogen bleed as a means of controlling suction pressure to allow the vacuum flasher to operate at a consistent pressure even at reduced charge rates. Pressure in the top of the vacuum flasher was sensed and a signal sent to the control valve to bleed nitrogen to the first stage ejector if the vacuum flasher pressure fell below design. Bleeding nitrogen, which is non-condensible, to the suction of a multi-stage condensing ejector system will result in unstable performance.

An ejector system is designed to handle non-condensible loading associated with the process. Ejectors downstream of the first intercondenser are designed to handle process related non-condensibles and associated vapors of saturation. Bleeding in nitrogen to act as an artificial load for the first stage ejector and to elevate suction pressure resulted in non-condensible overloading of the downstream ejector, which is the ejector that is downstream of the first intercondenser.

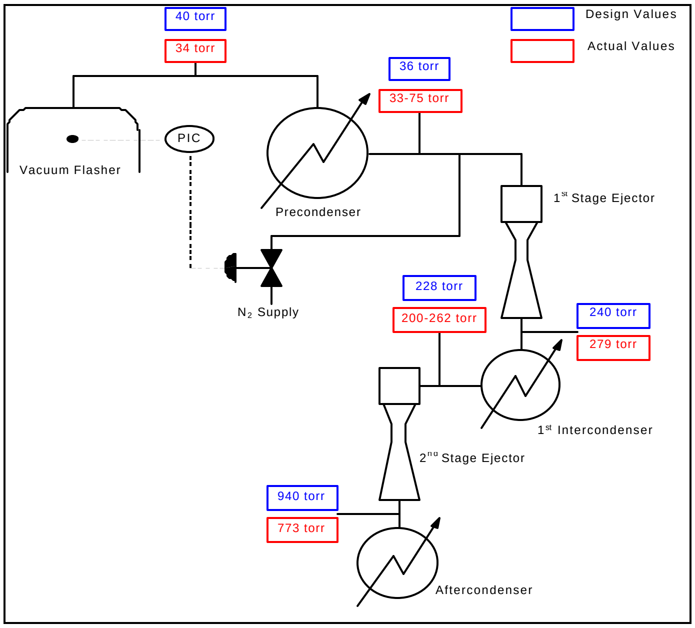

Figure 3. Survey 1 pressure profile

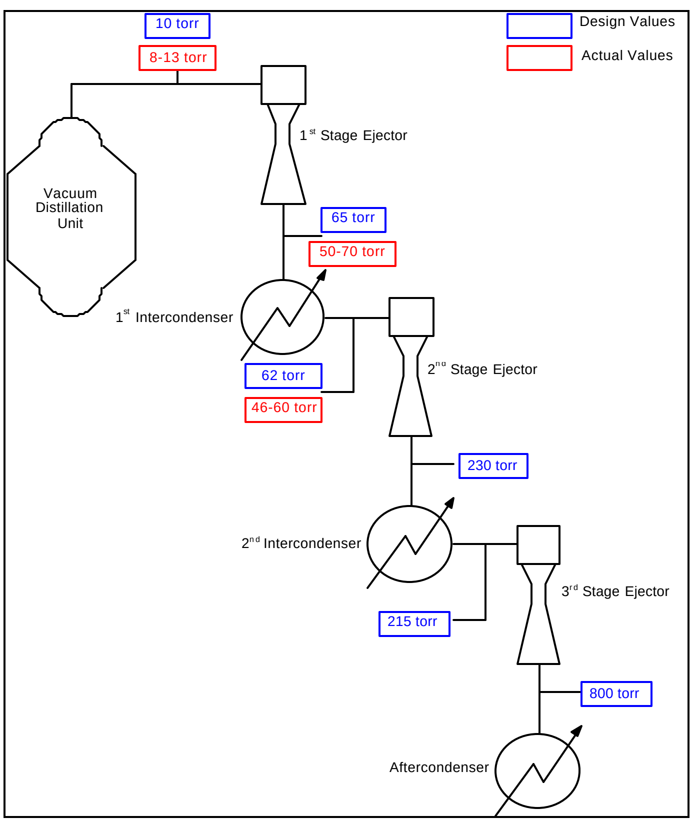

Figure 4. Survey 2 pressure profile

Once the first stage ejector began to handle more non-condensible loading than it was designed for, the down-stream ejector could not handle that increased non-condensibles, plus the proportionate increase in vapors of saturation, at the achievable discharge pressure of the first stage ejector. This discontinuity in the achievable discharge pressure of the first stage ejector and suction pressure maintained by the second stage ejector based on higher non-condensible loading resulted in the first stage ejector breaking operation.

The service engineer instructed plant personnel to dis-assemble the nitrogen bleed arrangement and to install recycle control piping around the first stage ejector. For any multi-stage condensing ejector system, the preferred way to maintain performance and suction pressure is to recycle discharge from an ejector immediately preceding the first intercondenser back to the suction of the system. In this way, non-condensible loading is never allowed to increase above design, thus ensuring broken ejector operation will not occur. Again, vacuum flasher pressure is sensed and a signal sent to the recycle control valve, which will modulate and permit the recycle of vapor flow back to the suction of the first stage ejector. Once the plant installed this form of recycle control, stable ejector operation was maintained.

A caveat for this correction is that the most practical method of controlling operating pressure of a precondenser/ejector system is to control cooling water flowrate. Cooling water flowrate may be reduced when process charge rate is below design. By lowering water flowrate, the water temperature rise across the precondenser will increase, which has the effect of lowering the lmtd. Controlling lmtd will control operating pressure of the precondenser.

The recycle control arrangement suggested and used to correct first stage ejector instability will not work if the operating pressure of a precondenser permits condensation of steam. The composition of recycle flow around an ejector consists of non-condensibles plus steam. As the recycle flow is brought around to the suction of the first stage ejector, the recycled steam will be drawn to the precondenser if the operating pressure permits condensation of steam. When this occurs and recycled flow goes to the precondenser rather than through the first stage ejector, control of suction pressure is not possible.

Survey 2 - West Coast fuels refinery

Improper replacement intercondenser

A West Coast refiner was operating a fuels vacuum distillation unit that experienced erratic performance after replacing an intercondenser supplied by the original ejector system manufacturer with one designed and built by a local heat exchanger fabrication shop. The as sold system was designed to provide performance described in Figure 4. The service engineer had no prior knowledge that the user installed a replacement intercondenser.

The first stage ejector was operating in a broken mode, with both suction and discharge pressure remaining unstable. Furthermore, shellside pressure drop across the first intercondenser was almost three times the design pressure drop.
Motive steam supply condition was approximately at the design value, so the service engineer ruled out inadequate steam pressure. High pressure drop across the first intercondenser would suggest a fouling problem, cooling water flowrate limitation, high inlet water temperature, high noncondensible loading, or excessive hydrocarbon loading. Prior to detailing a method to determine the actual cause, the service engineer discussed general performance characteristics with unit operators. At that time, it was discovered that the first intercondenser was replaced.

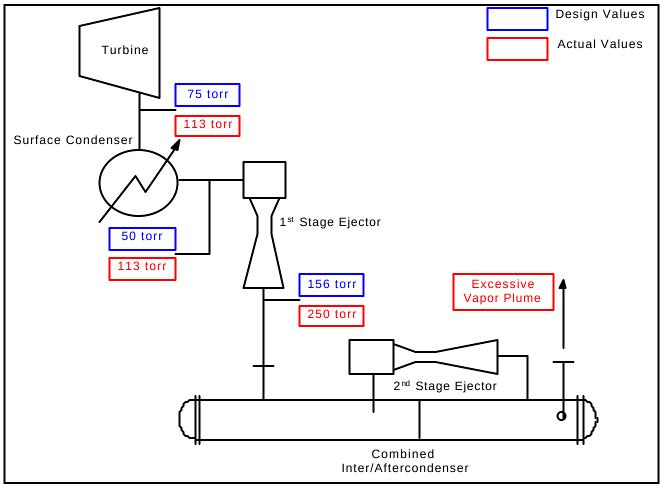

Figure 5. Survey 3 pressure profile.

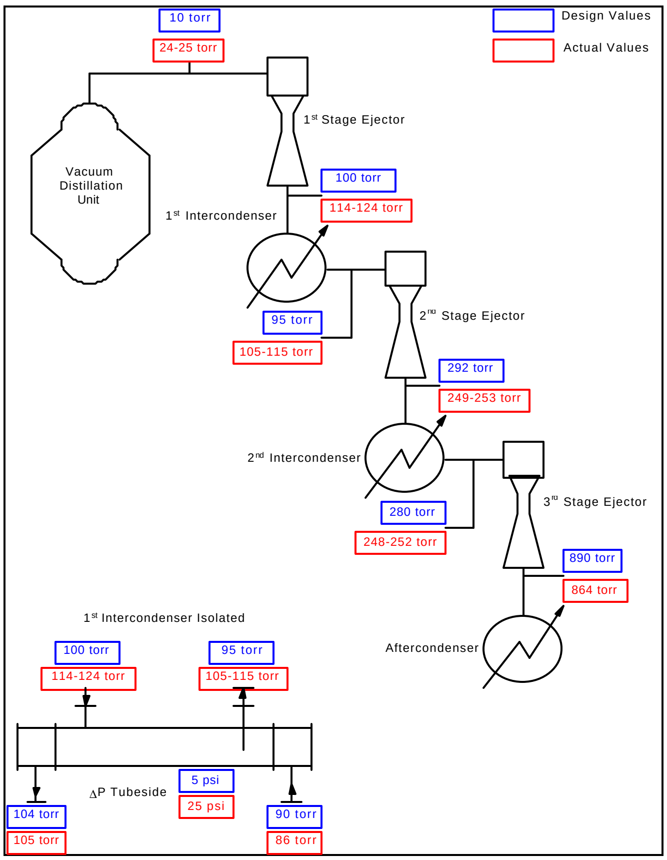

Figure 6. Pressure and temperature profile.

Upon visual inspection of the installed unit and its name-plate, the service engineer realized it was the design of another vendor. That vendor did match the original intercondenser's tube count and external dimensions, but after a thorough review of fabrication drawings, it was evident the vendor failed to design the shellside baffling properly to manage hydraulic and thermal requirements. Vacuum condensers have special shell side baffling to ensure minimal pressure drop, non-condensible gas cooling, and separation of non-condensibles and condensate. It is typical to have different baffle spacing at strategic locations within the shell of a vacuum condenser or to incorporate a long air baffle design. The vendor who replaced the intercondenser used conventional software to model the performance. This in turn resulted in a design having fully baffled flow, and consequently, excessive pressure drop on the vapor side.

In this particular instance, high pressure drop across the shellside caused the system to break performance. The first stage ejector could not overcome the added pressure drop and reach a discharge pressure where the second stage ejector would operate. This discontinuity resulted in the first stage ejector breaking operation, which was characterized by unsteady suction pressure and back-streaming of motive steam into the vacuum distillation tower. Both performance conditions were unsatisfactory to the refiner.

Although the plant engineers were reluctant to accept that the condenser was the problem, they did agree to install a new condenser designed by the ejector system manufacturer. Once the properly designed condenser was installed and the system restarted, performance returned to a satisfactory level.

Survey 3 - Canadian ammonia/urea fertilizer complex

An ammonia plant syngas compressor provided less than design horsepower due to high back pressure from a condensing turbine steam surface condenser. The turbine exhaust condenser maintained 113 torr back pressure, but based on the cooling water temperature, the expected back pressure should have been 75 torr. A service engineer was dispatched to the site to evaluate the steam surface condenser and exhauster performance to determine the cause of the elevated back pressure.

The steam surface condenser was supported by a two stage ejector system condenser exhauster (Figure 5). The service engineer noticed a substantial exhaust plume from the aftercondenser vent.

Normally, steam surface condenser and exhauster systems are vacuum tight, with air inleakage less than Heat Exchange Institute design values, with typical air inleakage of 5 lbs/hr or less. An excessive exhaust plume from an aftercondenser does suggest high air inleakage. There was an air leakage meter installed on the vacuum system, and when activated, the measurement was off the scale.

The service engineer elected to isolate the surface condenser from the ejector system. By isolating the surface condenser, it would be possible to determine if excessive air leakage was from the surface condenser or upstream piping, or if it was within the exhauster itself. Once a surface condenser is isolated from a vacuum system and the operating pressure of the condenser does not appreciably increase over time, the air inleakage must be downstream of the surface condenser.

The condenser was isolated from the vacuum system and pressure stayed fairly constant. This confirmed the air inleakage was downstream of the condenser and that it was in the exhauster system. A closer look at the installation determined that a l/4 in. instrument connection was left open and was not plugged. Evidently, a pressure gauge was damaged and plant personnel removed it but failed to replace it. The open connection permitted substantial quantities of air to leak into the ejector system and cause poor operation. The condenser was then brought on line once the connection was plugged and after the system was allowed to stabilize, steam surface condenser operating pressure reached 80 torr, which was in the range of what was expected. The syngas compressor returned to full power once this correction was made.

Survey 4 - Gulf Coast refinery

Fouled intercondenser

A Gulf Coast refiner was operating a damp crude vacuum distillation tower that was designed for 10 torr tower top pressure but was maintaining only 24 -25 torr. The first stage ejector was surging and back-streaming into the vacuum distillation unit. A factory service engineer was dispatched to the site to perform a system survey and evaluate causes of the poor performance.

Figure 6 documents as sold performance and what was measured in the field.

Broken first stage ejector performance may be caused by improper motive steam pressure, elevated inlet cooling water temperature, lower than design cooling water flowrate, a fouled first intercondenser, or poor operation of a downstream ejector. The performance survey indicated motive steam supply conditions were satisfactory. Cooling water temperature rise and pressure drop across the first intercondenser suggested the problem was here.

Figure 7. First stage ejectors for CVDU.

Design cooling water temperature rise across the first intercondenser was 14 °F (7.8 °C), however, the actual temperature rise was 19 °F (10.6 °C). Possible causes for an elevated temperature rise would be lower than designed cooling water flow or an increase in condensible load to the condenser. Pressure drop across the tubeside of the condenser gave an indication that something was wrong. The actual tubeside pressure drop was 25 psi (1.7 bar) while the design was only 5 psi (0.35 bar).

The tubeside of the condenser was fouled and the increased pressure drop across the condenser caused the recirculating pumps to circulate less water. Tubeside fouling to produce such an elevated pressure drop would be severe and actual tube blockage must have occurred.

Tubeside fouling deterred heat transfer and did not permit proper condensation of shell side vapors. This increased the pressure drop on the shell side of the condenser and elevated its operating pressure. By not permitting proper condensation of shellside vapors, the increased outlet flow of vapors caused an increase in pressure drop.

The first stage ejector could not overcome the elevated shell side pressure drop and, consequently, broke operation. The broken operation resulted in unstable suction pressure, surging and back-streaming of motive steam into the vacuum distillation unit. The first intercondenser was pulled from the platform and taken down to grade. At grade, the bundle was removed to inspect the shell side for fouling and to rod out the tubes. The shell side did not experience excessive fouling, but the tubeside had tubes blocked with solidified calcium carbonate and other inverse solubility salts.

Once the tubeside was cleaned and returned to acceptable condition, the bundle was reinstalled in the condenser, and the condenser taken up to the vacuum unit for re-hook up. When the system was brought in service, the tower top pressure was maintained at approximately 10 torr and system performance was stable.

Conclusion

Ejector systems provide extremely reliable performance, but they do require periodic maintenance. It is recommended that routine surveys be performed to document actual behavior and performance of the ejector system. An ejector system may be performing at less than optimal conditions for a variety of reasons, such as improper utilities, fouled condensers, mechanical damage, excessive process load, excessive non-condensible load or improper installation.

A skilled vacuum technician, most often from the ejector system manufacturer, should conduct the routine surveys and issue performance reports. The performance surveys may be conducted on line without affecting the process. The performance reports will document actual performance at a point in time, discuss corrective action where applicable and offer preventative maintenance suggestions.

If performance problems arise, the original supplier of the vacuum system should be consulted. If necessary, a request should be made for a service engineer to be dispatched to offer support on site. Actual corrective action to take is situation dependent and requires a thorough understanding of variables that influence ejector system performance.

References

1 LINES J R and SMITH R T, Ejector system troubleshooting, Hydrocarbon Engineering, Part 1 January/February 1997 pp. 69 - 78 , Part 2 March/April 1997 pp 35 - 40
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