

# KEEPING THINGS CONDENSED

**Mason Battaglia, Graham Manufacturing,** analyses the effects of intercondenser operation on vacuum distillation unit performance.

**A** well operating vacuum distillation unit (VDU) is key to keeping a refining tower disruption free. Most vacuum systems will be comprised of ejectors, condensers, and sometimes vacuum pumps in series. Of the three, condensers seem like a very simple piece of equipment, making them easy to overlook. However, a poorly maintained condenser can lead to many issues in a vacuum system, and ultimately, costly disruptions in tower operation.

## **How condensers control interstage pressure**

Condensers work by turning a vapour into a liquid. When the vapour hits a cold surface, such as a tube full of cooling water, it rapidly collapses into a liquid. This sudden collapse greatly decreases the volume of the vapour, creating low pressure in

**Table 1. Comparison of operating changes**

|                                | Q          | U                          | A               | Cooling water in | Cooling water out | Pressure |
|--------------------------------|------------|----------------------------|-----------------|------------------|-------------------|----------|
|                                | Btu/hr     | Btu/hr-ft <sup>2</sup> -°F | ft <sup>2</sup> | °F               | °F                | inHgA    |
| Design                         | 35 320 000 | 219.9                      | 3859.4          | 70               | 91                | 3.75     |
| High load                      | 40 618 000 | 219.9                      | 3859.4          | 70               | 94                | 4.65     |
| High cooling water temperature | 35 320 000 | 219.9                      | 3859.4          | 85               | 106               | 5.59     |
| Fouled condenser               | 35 320 000 | 186.9                      | 3859.4          | 70               | 91                | 4.57     |

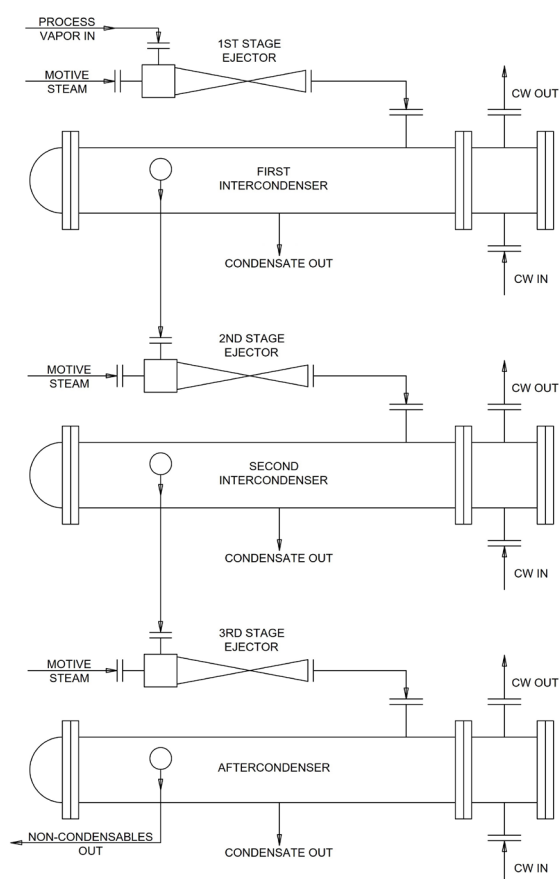
is entering the condenser. U is the total heat transfer coefficient, which combines the heat transfer rates for the condensing gases to the tubes, the transfers through the walls of the tube, and the transfer from the tube to the cooling water. This number is mostly fixed, but will be lowered if there is a build-up on the tube

or if the percent of non-condensables increase. A is the total condensing area of the tubes and is fixed, but it can be reduced if tubes have been plugged. LMTD takes into account the cooling water temperatures and the condensing temperature.  $LMTD = [(T_1 - t_2) - (T_2 - t_1)] / \ln[(T_1 - t_2) / (T_2 - t_1)]$ , where T<sub>1</sub> is hot vapour in, T<sub>2</sub> is condensed vapour out, t<sub>1</sub> is cooling water in, and t<sub>2</sub> is cooling water out.

Now to relate this back to condenser operating pressure. In a hydrocarbon application, there are different condensing temperatures for the different hydrocarbons, but the theory is still the same as when operating with steam only. In the field, most of this formula becomes a constant. Q is the given load from the ejector motive steam and condensable load from the tower. U is a fixed coefficient that is determined by the condenser manufacturer. A, the area is fixed. That means the only thing that can change is LMTD. Assuming the cooling water inlet temperature to be fixed, there are only two variables that can be changed: cooling water outlet temperature (t<sub>2</sub>) and condensing temperature (T<sub>1</sub>). These two temperatures are linked together, meaning that if the cooling water outlet rises, so does the condensing temperature. Condensing temperatures can then be used to find the resulting condensing pressure.

What happens when refiners change one of the constants assumed from before? If Q goes up, A and U stay the same, then LMTD will increase. The result is the cooling water outlet temperature and the condensing temperature will rise. The rise in condensing temperature will correspond with a rise in condenser pressure. Table 1 shows the outcome of changes in operation.

It is important to note that condensers are unique pieces of equipment. Although condensers and shell and tube heat exchangers share many similarities, a shell and tube will not function as well as a condenser in vacuum service, if it has been designed for liquid-to-liquid heat transfer. This means that the hot liquid needs to contact the cold tubes for as long as possible to lower the temperature of the hot liquid. However, in a condenser, the vapour only needs to hit a cold tube once. After it has condensed, any further contact with a cold tube is not needed. This changes how a condenser is designed when compared to a shell and tube heat exchanger. A well-designed condenser will allow the vapour to reach all the tubes as directly as possible, minimising pressure drop. A heat exchanger

**Figure 1. A typical three stage vacuum system.**

the area where the vapour had been. The vapour surrounding the newly formed liquid rushes into this low-pressure zone, and the cycle continues.

A condenser, free of any non-condensables such as air, will maintain its own vacuum level. As long as the downstream ejectors remove non-condensables, the pressure the condenser maintains will be based on the condensing surface area, heat load, cooling water flow rate, and cooling water temperature. Frequently, a condenser's operating pressure will rise in the hotter months, due to the elevated temperature of the cooling water. This can cause disruptions in the vacuum system and lead to tower pressure fluctuations.

When designing and evaluating a condenser,  $Q = U \cdot A \cdot LMTD$  is the driving formula, where Q is the heat load, U is the overall heat transfer coefficient, A is the condensing area, and LMTD is the log mean temperature difference. Q, heat load, is the Btu/hr that

will have many baffles, creating a long path for the shellside vapour to travel before it exits the unit. This will create a much larger pressure drop, causing a rise in operating pressure.

## High interstage pressure effects on upstream ejectors

When a vacuum system is designed, the steam ejectors are built to operate at a given suction and discharge pressure. The suction pressure of an ejector is a function of the load it is handling, and ejectors can handle changes in load quite well. However, the ejector has no control over the discharge pressure; the condensers and downstream equipment hold this responsibility. The ejector is designed to overcome a maximum discharge pressure, any higher, it is likely to break operation or begin backfiring. When a condenser is operating at higher than design pressure, it causes a higher backpressure on the upstream equipment. This can cause disruptions to the tower immediately, as a broken ejector can more than double its operating pressure.

The first intercondenser is not the only one that can cause tower upsets. If any condenser in the system is operating at a higher than designed pressure, it can cause the upstream ejector to break. When, for example, the second stage ejector breaks, it will not be able to remove non-condensables from the upstream condensers at the rate they are entering. This will cause a build-up of non-condensables in the condenser. The built-up non-condensables start to cover tubes, preventing condensables from reaching them. This blanketing effect reduces the effective condensing area, and the condensing pressure will rise. Eventually, the pressure will rise to a point where the backpressure on the first stage ejectors is too high, and they break, causing a tower disruption. Every condenser in the system needs to be properly maintained to ensure uninterrupted tower operation.

When an ejector breaks, raising the motive pressure may help to stabilise it; however, it can also exacerbate the problem. The increased motive pressure will cause a greater heat load on the condenser. An added heat load can cause the operating pressure for the condenser to rise even further, increasing the backpressure on the ejector.

## Reducing condenser pressure

In order to keep a VDU operating properly, the condensers will need to run at their design pressures. When possible, installing test connections before and after every piece of equipment can prove to be very helpful in the trouble shooting process. There are several common ways to reduce the condensers' operating pressure:

### Changing loading to the vacuum system

The condenser pressure can be lowered by reducing the heat load into it. Reducing the load from the tower will lower the heat load to the first intercondenser, allowing

it to operate at a deeper vacuum. Although this will reduce the backpressure on the first stage ejectors, allowing them to operate properly, the tower may have a lower production.

### Clean or retube the condensers

A more involved solution is to clean or retube the condensers. Cleaning or retubing both have the effect of lowering the resistance to heat transfer of the tubes, allowing the condenser to return to the designed operating conditions. A well-designed condenser will have a built-in fouling factor, but once this is exceeded, the condenser will also operate at a higher pressure.

### Increase cooling water flow or decrease temperature

If possible, increasing cooling water flow rate or decreasing cooling water temperature can lower the condenser operating pressure. Changing the cooling water is not always an easy task, but if there have been changes to the cooling water loop over the years, the condensers may not be getting the water they need. Before making any major changes to the condensers, it is critical to work with the original equipment manufacturer (OEM) to ensure that they are receiving enough cooling water at the correct temperature.

### Replace ejector with a higher efficiency ejector

With older vacuum systems, there may be ejector improvements that have been developed. Companies must reach out to OEMs and see if there is a way to reduce ejector motive steam consumption. For example, Graham Manufacturing has developed the NextGen Nozzle. This is a drop-in nozzle replacement for existing long compression first stage ejectors that can decrease motive steam consumption. Less motive steam consumption will lower the heat load to the downstream condenser, lowering operating pressure.

### Vacuum system revamp for current conditions

A full system revamp may be an option if there have been changes in the crude and the process over the years. If the vacuum system needs to handle a larger load or needs to operate at a deeper pressure, it most likely is the best option. Companies must work with the OEM to meet the new conditions while reusing as much of the existing equipment as possible. Often, even if higher loading is required, the first intercondenser can be used as the second, so only one set of condensers will need to be purchased. The ejectors might be able to be reused with only new nozzles as well.

## Conclusion

Condensers are a complex piece of static equipment. Like any industrial equipment in a plant, they require maintenance and may cause problems if left unattended. However, many issues can be easily identified and fixed. 