CONDENSING COSTS

Bill Kubik, Graham Corp., USA, shows how steam turbine operating costs depend on surface condenser performance, and why condenser operations have a direct effect on plant utility costs.

Fertilizer plants commonly use steam turbines to drive process air compressors, synthesis gas compressors, refrigerant compressors, electric generators and other mechanical devices. The cost of producing steam to operate the plant's turbines is significant. Any adjustments in operation that can improve turbine performance will lead to reduced energy consumption and cost. Unfortunately, the equipment that is used to support the turbine is often overlooked. This article will explore the important relationship between operation of the steam surface condenser and its venting ejectors, and how their performance directly affects the fuel costs associated with operating a steam turbine.

Steam turbines are mechanical devices that use thermal energy from high pressure steam and convert it into mechanical work to drive a rotating shaft. With a focus on energy savings, considerable efforts have been expended to improve steam turbine efficiencies to the levels seen today. Many of these developments have logically focused on the turbine itself, leading to blade, casing and other design improvements.

Turbines can be manufactured using the backpressure design, where steam exits the turbine at a pressure higher than atmospheric. Backpressure turbines are typically employed when the plant has a requirement for process steam. In these cases, the discharge steam is used for an application such as heating or drying.

This discussion will focus on condensing turbines, which discharge to pressures below atmospheric. They operate in accordance with the thermodynamic Rankine cycle, which is based on the transfer of energy through phase changes in a fluid. The Rankine cycle consists of four steps.

- A boiler generates steam at high pressure through the addition of heat, which can be supplied using fossil fuels, biomass, nuclear, concentrated solar or another energy source.
- In the turbine the high pressure steam is expanded and the potential energy of the steam is converted to high velocity kinetic energy that drives the turbine blades and output shaft. The rotating turbine shaft is used to power the pump, compressor, generator or other items using the work generated by the expansion of the steam through the turbine.
- Steam then exits the turbine into the surface condenser, where the steam is condensed into liquid. Heat is rejected through the condenser's cooling water, which is often sent to a cooling tower to be cooled and returned in a closed-loop system.
- The liquid condensate (water) formed in the condenser is then pumped back to the boiler where it is reheated to create a new supply of steam and the cycle repeats.

The major components of the Rankine cycle are shown in Figure 1.

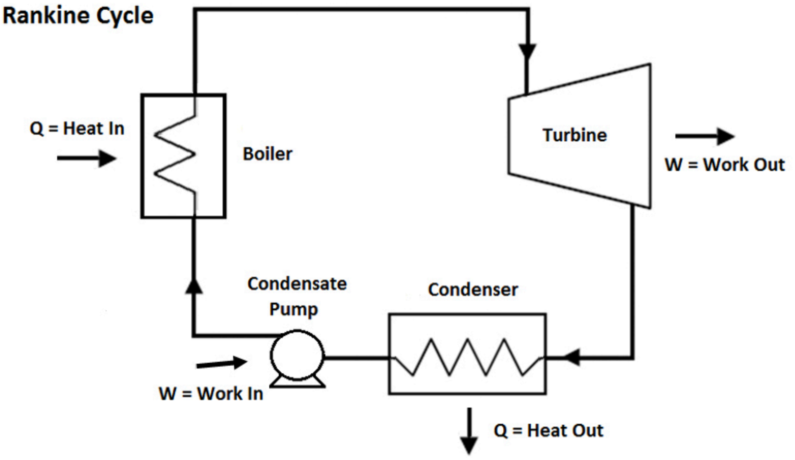

Figure 1. Major components of the Rankine cycle.

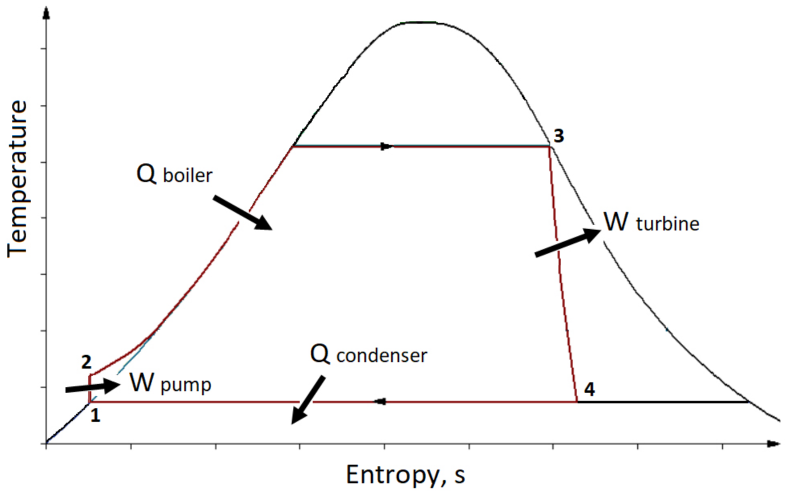

Figure 2. Temperature-entropy (T-s) diagram.

Figure 3. Surface condenser.

Energy transfer

The transfer of energy throughout the Rankine cycle is best depicted using a temperature-entropy (T-s) diagram (Figure 2). Only in an ideal world does Energy In = Energy Out. Therefore, the goal is to obtain the required work output from the turbine while minimising heat input to the boiler.

Turbine design considerations

Turbine efficiency improvements often target the physical characteristics of the turbine. However, it is important to realise that a properly operating steam surface condenser is required to allow the turbine to operate to its full potential. Alternatively, a poorly performing surface condenser or its venting system will result in more steam required to give the same power output, with a resulting increase in operating fuel costs.

Surface condenser operation

A steam surface condenser is most often of the shell and tube design. Hot steam from the turbine enters the shell side of the condenser, while cold water is circulated inside the condenser tubes. When the hot steam comes into contact with the cold tube surfaces, the steam cools and condenses. As it condenses, the steam collapses into a much smaller volume. It is this change in volume that creates vacuum conditions (low absolute pressure) in the condenser. Typical operating pressures are in the range of 10 – 20 kPa absolute (3 – 6 in. Hg absolute). Special design features are used in the condenser to promote efficient condensing and allow for the removal of any air in-leakage into the system. A typical surface condenser is shown in Figure 3.

Turbine power output

Enthalpy is the thermodynamic measure of a system's internal energy plus the product of its pressure and volume. The power produced by a turbine is a function of the change in enthalpy between the turbine's inlet and discharge conditions. The greater the pressure (and enthalpy) differential across the turbine, the greater the amount of power is produced. Stated another way, it can be seen that with greater pressure differential, less steam is needed to produce the required power. Thus it follows that a means to improve turbine power output is to increase the steam enthalpy entering the turbine, or to decrease the enthalpy exiting the turbine. The process that will next be examined is the effect of deeper vacuum (reduced absolute pressure) at the turbine outlet.

Operating example

Consider a turbine designed to produce 20 MW of power when supplied with steam at 6.3 MPa and 480°C. The turbine discharges to a surface condenser designed to operate at 10.2 kPa absolute. Under these conditions, the turbine requires 73 700 kg/hr of steam to produce 20 MW. However, if the surface condenser does not perform to design and instead operates at 13.5 kPa absolute (abs), 3% more steam will be needed. If it operates at 16.9 kPa abs, 5.4% more steam is required (Table 1).

The next step is to evaluate the added cost of operation at these off-design conditions. Actual power output required and the local cost of steam should be used when doing a plant evaluation; however, for illustrative purposes, an assumed cost of US$9/1000 kg of steam (US$4.08/1000 lbs) can be used:

Added cost per year = added kg/hr steam required x US$9/1000 kg x 8760 hr/yr

The results are tabulated in Table 2 for this 20 MW plant.

Thus, if the condenser was designed to operate at 10.2 kPa abs, but instead is discharging to 16.9, the plant is spending an additional US$316 500/yr in OPEX.

If a lower pressure boiler is used to supply steam to the turbine the effect is more pronounced. For example, with steam inlet at 1.8 MPa abs and 260°C, a turbine will require 4.3% more steam when discharging to 13.5 or 8% more if at 16.9 kPa abs.

Table 1. Steam required to produce 20 MW based on condenser operating pressure

Operating pressure (kPa abs)	Steam required (kg/hr)	Steam used vs design
10.2	73 750	design
13.5	75 900	103%
16.9	77 750	105%

Table 2. Added cost per year based on condenser operating pressure

Operating pressure (kPa abs)	Additional steam (kg/hr)	Additional cost per year
10.2	design	design
13.5	4800	US$171 500
16.9	8850	US$316 500

Condenser operation

How can poor condenser operation be corrected? The following is a partial checklist that can be used for troubleshooting:

- Cooling water supply – Is the cooling water flow at design? Is the temperature at design or colder?
- Pressure drop – Check the pressure drop. If cooling water flow is per design and there is a high pressure drop, either the tubes are fouled or debris may be blocking some of the tubes.
- Tubes – What are the age and condition of the tubes? Tube leaks can often be found by checking condensate properties. Leaks may also affect the condenser operating pressure. When were the tubes last cleaned? Careful control of the cooling water chemistry can keep tubes performing well longer.
- Condensate removal – Are the condensate pumps and level controls working properly? If the liquid level is too high, some of the condenser tubes can be submerged in condensate, and will not be useful in condensing the steam.
- Air in-leakage – Must be kept to a minimum.

Steam jet ejectors

As previously mentioned, it is the surface condenser that produces a vacuum due to the collapse of the steam. The steam jet air ejectors are correctly referred to as 'venting equipment'. They must operate properly to allow the surface condenser to run at its best vacuum level. It is the surface condenser that should set the operating vacuum level. If the ejectors cannot handle the air in-leakage, the pressure will rise in the condenser and the entire system will be affected. In those instances, the ejectors cannot maintain the pressure that the surface condenser is capable of. Air will build up inside the condenser and the pressure will rise. Maintaining gaskets, flanged joints, turbine glands, expansion joints, valve packing and other items throughout the system is important to keep air in-leakage to a minimum.

Ejector packages are normally supplied with two 100% capacity two-stage ejectors using a common intercondenser and aftercondenser. A single stage hogging ejector is often provided which should be used for rapid startup of the turbine. The hogging ejector is only intended to be operated during system startup.

Items to check for proper ejector operation include:

- Motive steam – The motive steam supplied to the ejectors should be at the design pressure, with a typical tolerance of -0% to +20%. Motive steam must be dry, as wet steam can quickly erode ejector internals and lead to a loss in vacuum.
- Motive steam nozzles and diffusers – These items should be inspected during shutdowns and internal throats should be measured and compared to design. Wear of these items can cause significant capacity loss of the ejectors. If worn they should be replaced.
- Cooling water supply – Many of these units are cooled with condensate from the main surface condenser. The guidelines given above should be followed when evaluating the cooling water supply, temperature, pressure drop and tube condition.
- Condensate removal – To remove condensate, most often the intercondenser and aftercondenser drains will flow through condensate traps and then discharge to the main surface condenser before being returned to the boiler. Checking the condition of the traps and associated piping is recommended.

Case study

Graham's service team was dispatched to a site in the southeast US that was operating a 17 MW turbine. Upon arrival the unit was operating with the condenser at a very poor 40.6 kPa absolute. Several minor issues with the condenser were discovered and corrected without much effect on the operating pressure level. However, inspection of the off-brand venting ejectors uncovered a significant problem. In an effort to compensate for poor performance, both sets of 100% ejector trains were being operated. The problem was that the ejector manufacturer had designed the intercondenser and aftercondenser for 100% operation only. Running all the ejectors at 200% had overloaded the intercondenser, causing the performance of both first stage ejectors to degrade. The 'fix' consisted of isolating and shutting down one of the ejector trains. Shortly thereafter a more reasonable 27 kPa abs was reached. The difference in operating cost for this plant was over US$600 000/yr.

Ejector packages should not be overlooked when evaluating turbine performance. The company has seen many instances where the ejectors have not been functioning correctly, and were limiting the performance of the turbine.

Conclusion

Steam turbines play a vital role in plant operations. The energy cost to produce the steam needed to operate the turbines represents a significant cost for a plant. Although they are often ignored, special attention should be given to the surface condenser and venting ejectors. Proper operation of these units is needed to keep a turbine operating at its peak performance level, and a plant operating at its most efficient. WF