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DESIGN AND CONTROL OF BYPASS CONDENSERS

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ABSTRACT

In waste to energy plants and certain genre of cogeneration plants, it is mandatory to condense the steam from the boiler or HRSG in a separate bypass condenser when the steam turbine is out of service. The steam from the boiler or HRSG is attemperated in a pressure reducing desuperheating valve and then condensed in a bypass condenser. To avoid flashing of condensate in downstream piping it is customary to subcool the condensate in the bypass condenser. Circulating water from the steam surface condenser is used to condense the steam in the bypass condenser.

Some of the challenges involved in the design of the bypass condenser are:

- High shellside design pressure and temperature
- Condensate subcooling
- Large circulating water (tubeside) flow rate
- Relatively low circulating water (tubeside) inlet temperature
- Large Log Mean Temperature Difference (LMTD)
- Large shell diameters
- Small tube lengths

The diverse requirements complicate the mechanical and thermal design of the bypass condenser. This paper highlights the complexities in the design and performance of the bypass condenser. Similarities with the design and operation of steam surface condensers and feedwater heater are reviewed. The uniqueness of the bypass condenser's design and operation are discussed and appropriate solutions to ensure proper performance are suggested.

INTRODUCTION

Waste to energy plants generate their revenues from the burning of waste and production of electricity. Waste is incinerated on a continuous basis and heat from incineration converts water to steam in a boiler. The high pressure steam from the boiler flows through a steam turbine generator producing electricity. The low pressure steam emerging from the steam turbine is condensed in a steam surface condenser. Continuous incineration mandates that the steam from the boiler must be condensed whether the steam turbine is operational or not. When the steam turbine is not in service, the steam from the boiler is condensed in a bypass condenser. Typically the pressure and temperature of steam from the boiler is reduced in a pressure reducing desuperheating valve. This steam, at relatively lower pressure and temperature, is condensed in a bypass condenser. The entire process is illustrated in a cycle diagram included in Figure 1.

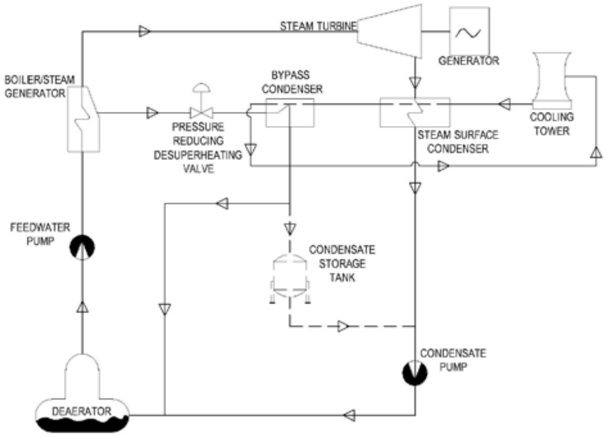

Figure 1: SERIES CYCLE DIAGRAM

From a design and operation standpoint, the bypass condenser resembles a steam surface condenser as well as a feedwater heater. On the shellside, the steam is condensed at pressures normally higher than atmospheric pressure. The condensate is subcooled to prevent flashing in downstream piping. Higher condensing pressures and subcooling of condensate are typical features of a two-zone feedwater heater. The circulating water on the tubeside is the same as that used in the steam surface condenser. The tubeside design of the bypass condenser is subject to the same restrictions as that for the steam surface condenser. These include lower temperature rises, large flow rates, tube velocities, pressure drop, and water chemistry tube material compatibility. The shellside design of the bypass condenser is similar to that of a feedwater heater whereas the tubeside design is similar to that of the steam surface condenser. There are also a number of unique differences. The similarities and differences must be carefully evaluated while formulating the thermal and mechanical design of the bypass condenser. The major issues to be considered while designing the bypass condenser are addressed in the following section.

SERIES OR PARALLEL ARRANGEMENT

The bypass condenser and the steam surface condenser use the same circulating water. The bypass condenser can be located in series or in parallel to the steam surface condenser. Each configuration has its own advantages and disadvantages. Locating the bypass condenser in parallel involves installation of large diameter fast acting automatic valves in circulating water line that can divert the circulating water from the steam surface condenser to the bypass condenser in the event of a turbine trip. The parallel configuration is illustrated in Figure 2. Circulating water either flows through the steam surface condenser or the bypass condenser. The pressure drop is limited to one piece of equipment.

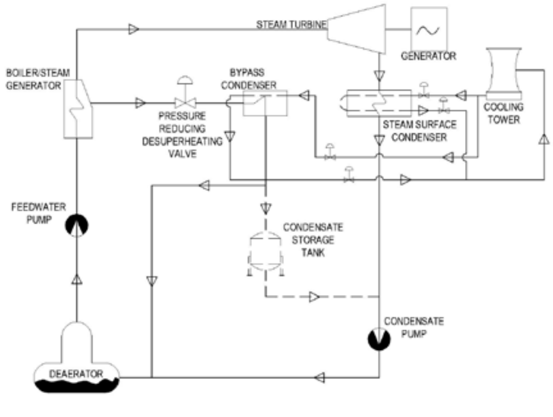

Figure 2: PARALLEL CYCLE DIAGRAM

An alternate solution is to place the bypass condenser in series with the steam surface condenser. This configuration is shown in Figure 1. The disadvantage is the pressure drop through the bypass condenser. Circulating water pumping power cost during the lifetime of the plant must be accounted for. The flow of water through the bypass condensers is guaranteed at all times. The advantage of a series configuration is the elimination of the large valves in the circulating water lines from steam surface condenser to bypass condenser. To assure simplicity and reliability it has become a common practice to place the bypass condenser in series with the steam surface condenser. The lifetime pumping power cost through the bypass condenser is lowered by specifying a lower allowable tubeside pressure drop typically in the range of 4 psi to 5 psi. In general, the increased capital cost of lowering the tubeside pressure drops in the steam surface and bypass condensers is smaller than the lifetime pumping cost of the plant.

FOULING OR CLEANLINESS FACTORS

Cleanliness factors in the range of 75% to 90% are used in the design of steam surface condensers. Typical fouling factors used in the design of feedwater heaters and heat exchangers are as follows:

- Tubeside = 0.0002 Btu/hr-ft^2-°F
- Shellside-Condensing Zone = 0.0000 Btu/hr-ft^2-°F
- Shellside-Subcooling Zone = 0.0003 Btu/hr-ft^2-°F

The condensing zone fouling factor of 0.0002 Btu/hr-ft^2-°F (tubeside) and 0.0 Btu/hr-ft^2-°F (shellside) correspond to cleanliness factor of approximately 85%. Cleanliness or fouling factors can be specified for bypass condensers. Fouling factors are preferred for bypass condensers with subcooling zone.

Care must be exercised not to over specify the cleanliness factor or the fouling factors. In winter months lower circulating water inlet temperatures and clean tubes can lower the shellside condensing pressure. In certain cases, the shellside operating pressure may dip below atmospheric pressure leading to air in-leakage. This will have a detrimental effect on condensation heat transfer. In such instances, condensate may not flow out of the bypass condenser and will start to accumulate in the bypass condenser. With the rise in the condensate level, the tube surface will start to submerge thereby decreasing the heat transfer surface. Lowering the heat transfer surface will result in an increased shellside operating pressure. The condensate level will keep rising until an equilibrium pressure is reached that is high enough to drive the condensate out of the bypass condenser. In certain cases the operating pressure may oscillate between a range which is above or below atmospheric pressure. Prolonged accumulation of air inside the bypass condenser combined with elevated temperatures can corrode the carbon steel shell internals and compromise the life of the equipment. The problem can be avoided by selecting a relatively high shellside operating pressure and ensuring that in the worst case operating scenario (clean tubes, lowest steam flow rate, and lowest circulating water inlet temperature) will result in a shellside operating above atmospheric pressure. If the shellside operating pressure is below atmospheric pressure for prolonged periods, then an evacuation package (steam jet air ejectors or vacuum pumps) must be deployed to remove the non-condensable gases. In any event, it is prudent to place the critical connections, especially the steam inlet, well above the maximum water level to ensure that they are not submerged in any unforeseen operating scenario.

SUBCOOLING OF SHELLSIDE CONDENSATE

The condensate from the bypass condenser can be directed to a deaerator, storage tank, steam surface condenser hotwell, or an equivalent reservoir. The condensate should be subcooled to prevent flashing in the piping downstream of the bypass condenser. The degree of subcooling depends on the operating pressure of the bypass condenser, length of downstream piping, associated pressure drop, and the pressure in the downstream reservoir. Typically subcooling in the range of 50 °F to 60 °F avoids the problems associated with flashing in the piping downstream of the bypass condenser. For reliable subcooling, the condensate must be subcooled in a separate subcooling zone. Guidelines for design of subcooling zone in feedwater heaters with subcooling zone must be invoked. The subcooling zone components such as subcooling zone shroud, longitudinal baffle, seal ring, end plate, and snorkel must be carefully designed to obtain the required condensate subcooling.

CIRCULATING WATER FLOW

The temperature rise in a once through cooling system with a surface condenser is in the neighborhood of 10.0°F. In cooling tower applications the circulating water rise is about 20.0°F. A low temperature rise requires large quantities of circulating water and therefore large number of tubes. Lower Terminal Temperature Difference (TTD = Difference between shellside saturation temperature and circulating water outlet temperature) yields a relatively low Log Mean Temperature Difference (LMTD) which translates into a high heat transfer surface area and longer tube lengths. Large number of tubes with relatively long length is a common feature of the steam surface condenser.

The bypass condenser uses the same circulating water as the steam surface condenser. The restrictions that apply to the tubeside design of surface condenser also apply to the bypass condenser. Higher circulating water flow rates require large number of tubes. However, a higher shell side operating pressure leads to a higher TTD and LMTD and therefore a lower heat transfer surface. Lower heat transfer surface combined with large number of tubes results in a small tube length. The problem is severely compounded in a two pass unit. The low aspect ratio leads to an entirely new set of design and performance issues.

HOTWELL

Steam surface condensers are equipped with a condensate hotwell. The condensate storage time can vary anywhere between one minute to ten minutes. From a dimension standpoint the hotwell occupies a small portion of the steam surface condenser. The hotwell condensate, at sub-atmospheric pressure, is pumped by condensate pumps into equipment downstream of the condenser. In the bypass condenser, the pressure gradient drives the condensate to the deaerator or condensate storage tank. Except in certain unique cases, hotwells are not required for bypass condensers. Hotwells can sometimes exceed the size of the bypass condenser. Hotwell with limited capacity, if required, should be designed as a separate storage tank as commonly found in deaerators.

ASME CODE ISSUES

The tubeside of the bypass condenser are subject to the same design pressure and temperature as the steam surface condenser and do not require code stamping per ASME (Section VIII, Division 1). The shellside design pressure and temperature will be substantially higher than that for the steam surface condenser and will require a code stamp.

CONSTANT PRESSURE OR CONSTANT LEVEL OPERATION

In the steam surface condenser the condensate level is maintained at the normal water level (NWL) by level controllers that modulate the flow through the condensate pumps. In the bypass condenser, the condensate level can be maintained at a specified level by modulating the flow through a valve in piping downstream of the bypass condenser (similar to a feedwater heater). This is possible so long as the lowest pressure in the bypass condenser is sufficient to drive the condensate into the downstream equipment. Alternatively, the condensate level in the bypass condenser can be allowed to float freely. The condensate will seek a level in the bypass condenser that

creates sufficient pressure to drive the condensate into the downstream equipment.
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STARTUP

In the event of a turbine trip, the steam from the boiler is diverted through a pressure reducing desuperheating valve into the bypass condenser. The bypass condenser has to be on a standby mode ready to accept the steam should the turbine trip. When placed in series with the steam surface condenser, the circulating water flows through the tubeside of the bypass condenser guaranteeing a heat sink at all times. In the standby mode the shellside of the bypass condenser is typically filled with water. A small amount of heating steam is admitted to keep the shell components warm. In the event of a turbine trip, an emergency drain empties the condensate thereby exposing the heat transfer surface. The increase in steam flow rate and increase in exposure of heat transfer surface occur simultaneously. Steady state operation begins once the entire heat transfer surface is exposed and the steam flow rate has reached its design value. The condensate removal rate must be comparable to the bypass steam ramp up rate. A disparity between the two rates, or a transient condition, could result in a spike in the operating pressure. These variations in pressures can be accounted for by specifying a higher margin between the shellside operating and design pressure. A shell side relief valve can be deployed to eliminate the pressure spikes.

CONCLUSION

Bypass condensers have unique design and operating requirements which are similar, yet different, from that of a steam surface condensers and feedwater heaters. These requirements depend on the plant configuration and are different for each project. The generic guidelines for design of steam surface condensers or feedwater heaters should not blindly be applied to the bypass condensers. Certain condenser and heater design concepts can yield unfavorable results if applied to the bypass condenser without thought. The plant design requirements along with selective heater and condenser design principles must be carefully applied to arrive at an optimized bypass condenser that serves its intended purpose.

REFERENCES

1. Heat Exchange Institute Standards for Steam Surface Condensers, 10th Edition

2. Heat Exchange Institute Standards for Closed Feedwater Heaters, 8th Edition.