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**IMPORTANCE OF TEMPERATURE OF BYPASS STEAM ADMITTED INTO A  
STEAM SURFACE CONDENSER IN A COMBINED CYCLE PLANT**

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**ABSTRACT:**

The past decade has witnessed the commissioning of hundreds of large and small combined cycle plants worldwide. In a combined cycle plant, the steam surface condenser must condense the turbine exhaust steam (normal operation) as well as the bypass steam (steam turbine bypass operation). Bypass operation is encountered when the gas turbines are in service and the steam turbine is out of service (startup, shutdown, trip, etc.). With only the gas turbines in operation, high-pressure steam from the HRSG is attemperated in a pressure reducing/desuperheating (PRD) valve and then admitted into the condenser. The total bypass steam flow can be as high as 150%-200% of the design turbine exhaust flow and the duration of bypass operation can vary from a few hours to a few weeks.

The enthalpy of the steam exiting the PRD valve is selected anywhere between 1190 Btu/lb to 1225 Btu/lb and the pressure downstream of the PRD valve is established anywhere between 40 psia to 250 psia. In certain low-pressure bypass application, the PRD valve is altogether eliminated and bypass steam at relatively high temperature is admitted into the condenser. The current industry standards set a limit on the degree of superheat in the bypass steam but do not define the control strategy or set a limit on the temperature of the bypass steam admitted into the condenser. Elevated or low bypass steam temperature can cause structural damage to condenser internals.

This paper examines the effect of bypass steam temperature on the condenser performance, structural members, and the pressure boundary. The interaction with spray curtain is also discussed. Recommended limits on temperature of bypass steam are provided.

## **INTRODUCTION:**

Hundreds of combined cycle plants have been commissioned in the past decade. The principal function of the steam surface condenser in a combined cycle plant is to condense the steam exiting the turbine. One of the secondary functions is to condense the high and low pressure bypass steam.

In a combined cycle plant when the steam turbine is out of service the HP and LP steam from the HRSG is attemperated in a Pressure Reducing Desuperheating (PRD) valve and then admitted into the condenser. HP steam from each HRSG is attemperated in a PRD valve and then admitted to the condenser through a HP bypass header. In applications with multiple HRSGs the low-pressure steam lines are combined, attemperated in a PRD valve and then admitted to the condenser through a LP bypass header.

The HEI standards [1] state that the maximum pressure and enthalpy of bypass steam admitted into the condenser should be 250 psia and 1225 Btu/lb respectively. The standards [1] also state that the superheat in the bypass steam should be between 25°F – 75°F. Although the pressure, enthalpy, and superheat are enveloped, guidelines for selecting the proper temperature are not outlined.

Typically, the exhaust hood of the steam turbine is equipped with a spray curtain. In the event of overheating of the exhaust hood, the spray curtain sprays cold condensate and cools the hood. The above is applicable whether the steam turbine is in service or not.

A few of the turbine suppliers advocate a redundancy. When the steam turbine is not in service, a separate spray curtain is required to be incorporated in the steam surface condenser to prevent high temperature bypass steam from migrating into the steam turbine thereby heating the exhaust hood. The spray curtain is typically located downstream of the expansion joint and sprays a fine mist of condensate that covers the entire area of the steam inlet. Any high temperature steam migrating towards the turbine exhaust is cooled. Stainless steel expansion joints are more resistant to fluctuations in temperature, but rubber expansion joints especially neoprene rubber expansion joints are vulnerable to higher temperatures. The spray curtain protects the turbine exhaust hood, rubber expansion joint, and the steam dome internals from excursions in bypass steam temperatures. Typically, the spray curtain is turned on automatically when the bypass operation commences.

## **BYPASS OPERATION:**

Damage to the condenser internals from bypass steam with excessive spray water has been well documented [3]. Pockets of bypass steam with excessive spray water traveling at high velocities can cause severe damage to the condenser internals. Sheared tubes, damage to bypass headers and internal structural members have been frequently encountered during in bypass operation. Excessive temperature as well as excessive moisture in the bypass steam has a potential to cause damage to the condenser internals. For safe and reliable operation the temperature of the bypass steam must be controlled within a finite range.

The temperature of the bypass steam entering the condenser should be carefully monitored. Temperature settings for “High-High”, “High”, “Normal”, “Low” and ‘Low-Low” scenarios should be established. Typical settings would appear as:

High-High:	70°F Above Saturation Temp.	Increase Spray Water Flow to PRD Valve
High:	60°F Above Saturation Temp.	High Alarm
Normal:	50°F Above Saturation Temp.	
Low:	20°F Above Saturation Temp.	Low Alarm
Low-Low	10°F Above Saturation Temp.	Reduce Spray Water Flow to PRD Valve

Assuming the inlet pressure to be 100 psia, the settings would result in:

High-High:	100 psia; 397.8°F; 1226.6 Btu/lb	Increase Spray Water Flow to PRD Valve
High:	100 psia; 387.8°F; 1221.2 Btu/lb	High Alarm
Normal:	100 psia; 377.8°F; 1215.9 Btu/lb	
Low:	100 psia; 347.8°F; 1199.2 Btu/lb	Low Alarm
Low-Low	100 psia; 337.8°F; 1193.4 Btu/lb	Reduce Spray Water Flow to PRD Valve

The above provides an example for the temperature settings for a given pressure. The actual pressure and temperature settings would be governed by the plant design, design of the PRD valve, the control logic, and the characteristics of the instruments selected.

The pressure and temperature settings should be selected such that the thermodynamic properties are within the envelope advocated by the client specification and industry guidelines. Care must be exercised when allocating temperature limits between various settings. Furthermore the temperature difference must be high enough to prevent “hunting”.

In certain applications the pressure and temperature of the low-pressure bypass steam is fairly close to the industry guidelines. In such cases, the PRD valve is eliminated and the temperature and pressure of low pressure bypass steam is not monitored at all. Excursions in temperature of low-pressure bypass steam have caused damage to condenser internals on numerous occasions. It is always prudent to monitor the pressure and temperature of low-pressure bypass steam admitted into the condenser. The temperature settings should include high-high, high, normal, low, and low-low settings as noted above.

For reliable operation in bypass mode, in the PRD valve the spray water must be added to the bypass steam in the form of a fine spray to ensure uniform mixing. In addition adequate pipe length must be maintained between the PRD valve and the condenser to ensure proper mixing. Any mixing must occur before the bypass steam enters the condenser. It should be noted that the condenser designer do not make provisions for mixing spray water and the high temperature bypass steam within the condenser. The bypass lines between the PRD valve and condenser must be sloped and equipped with proper drainage (outside the condenser) to remove the excess condensate from the bypass steam.

The bypass header should extend along the entire length of the tubes to distribute the steam along the entire length of the condenser. Uniform distribution along the entire length of tubes avoids high-localized steam velocities. The bypass headers must be equipped with the smallest diameter orifices. It should be noted that the smaller the diameter of the orifice the smaller the safe distance. Safe distance is defined as the distance within which the expanding bypass steam causes damage to structural members. Structural members should not be located within the safe distance. Provisions must be made for impingement protection for structural members located within the safe distance.

It has been a standard industry practice to include impingement protection for the tubes. Typical industry practice has been to increase the wall thickness and or change the material of the tubes in the impingement zone. In condensers with bypass operation, additional impingement protection is included. Typically two rows of carbon steel dummy tubes are included (installed above the impingement tubes) to protect the tubes. The dummy tubes extend from the first to the last support plate and are located such that they prevent a direct line of sight between the impinging steam and the active tubes.

Steam surface condenser internals are made from carbon steel. The allowable stress for carbon steel is constant up to 650°F. The stainless steel bellows expansion joints can tolerate maximum operating temperatures of 400°F – 500°F. EPDM rubber expansion joints can withstand a maximum intermittent temperature of 330°F. Neoprene rubber expansion joints can withstand a maximum temperature of 250°F. The external paint, depending on the selection, can withstand temperatures anywhere between 150°F – 1000°F. The differential thermal expansion between the shell and the tubes is of prime importance. The maximum operating temperature of various condenser internals and the tube stresses due to differential thermal expansion must be carefully considered while establishing the maximum temperature of bypass steam entering the condenser. Admission of bypass steam at elevated temperature has resulted in cracked steam dome welds, “cooked” expansion joints, “burnt” outside paint, and tube damage.

## **CONCLUSION:**

It is important to establish limits on the temperature of bypass steam entering the condenser. The High-High, High, Normal, Low, Low-Low temperature settings for the HRH, IP and the LP bypass steam permits the control room operators to monitor the temperature of the bypass steam entering the condenser and the performance of the PRD valve. Fluctuations in the temperature of bypass steam and associated alarms offers the control room operator an opportunity to adjust the flow of spray water to the PRD valve and control the temperature of the bypass steam within the specified guidelines. Additional design features such as distribution of steam along the entire length of the tubes, carbon steel dummy tube impingement protection, selecting the lowest recommended orifice diameter in the bypass header, and draining of the bypass headers outside the condenser are mandatory for ensuring reliable performance in bypass mode. Frequently encountered damages in bypass operation such as “blown” end caps of bypass headers, cracked bypass headers, sheared tubes, cracked structural welds, burnt or cracked expansion joints, among others can be avoided. Costly repairs and the vast expense of down time can be eliminated.

## **REFERENCES:**

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