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## 7.2 CONDENSATE AND FEEDWATER SYSTEM

**Learning Objectives:**

1. State the purposes of the condensate and feedwater system.

2. Describe the major differences between the condensate and feedwater systems of the AP1000 and currently operating Westinghouse plants.

### 7.2.1 Introduction

The purposes of the condensate and feedwater system are as follows:

1. To transfer water from the main condenser to the steam generators and to preheat it,
2. To collect and distribute heater drains, and
3. To purify secondary water and to maintain secondary chemistry control.

The condensate and feedwater system provides feedwater at the required temperature, pressure, and flow rate to the steam generators. Condensate is pumped from the main condenser hotwell by the condensate pumps through the low-pressure feedwater heaters to the deaerator. The condensate (now feedwater) is then pumped by the feedwater pumps through the high-pressure feedwater heaters to the steam generators.

### 7.2.2 System Description

The condensate and feedwater system supplies the steam generators with heated feedwater as part of a closed secondary cycle using regenerative feedwater heating. The condensate and feedwater system is composed of the condensate system, the main feedwater system, and portions of the steam generator system. The condensate system collects condensed steam from the condenser and pumps condensate forward to the deaerator. The feedwater system takes suction from the deaerator storage tank and pumps feedwater forward to the steam generator system utilizing high-pressure main feedwater pumps. The steam generator system contains the safety-related piping and valves that deliver feedwater to the steam generators. The condensate and feedwater systems are located within the turbine building, and the steam generator system is located within the auxiliary building and containment.

The main portion of the feedwater flow originates from condensate pumped from the main condenser hotwell by the condensate pumps. The main condenser hotwell receives makeup from the condensate storage tank. The condensate passes in sequence through: the condensate polishing system or condensate polishing bypass; the gland steam condenser; three strings of low-pressure heaters, each string consisting of No. 1 and No. 2 low-pressure heaters; two strings of low-pressure heaters, each consisting of No. 3 and No. 4 heaters; the No. 5 open low-pressure heater (deaerator); the three parallel booster/main feedwater pumps; and two strings of high-pressure heaters, each consisting of No. 6 and No. 7 heaters. Feedwater is pumped to each of the plant's two steam generators through a flow element, control valve, feedwater isolation valve, and check valve. The balance of the plant's feedwater flow is provided by drains from the main steam system moisture separator reheaters, drains from the No. 6 and No. 7 feedwater heaters, and steam condensed in the deaerator. These flows are collected in the deaerator storage tank and pumped forward into the feedwater system. A portion of the condensate flow downstream of the condensate polishers is diverted to provide cooling to the steam generator blowdown system heat exchangers before it is returned to the main condensate flow at the deaerator.

During plant startup, three recirculation paths to the condenser facilitate system cleanup and adjustment of water quality prior to initiating feed to the steam generators. These cleanup loops are designed for approximately 33 percent of design condensate flow and include a hotwell recirculation loop, a deaerator recirculation loop, and a third recirculation loop originating downstream of the No. 7 feedwater heaters. Steam is provided to the deaerating feedwater heater from the auxiliary steam supply system to preheat the feedwater to over 200°F during the initial cleanup and startup recirculation operations. This preheating action, along with chemical addition, minimizes the formation of iron oxides in the condensate system.

The condensate polishing system may be in service or bypassed.

The turbine island chemical feed system (CFS) is provided to inject an oxygen-scavenging agent and a pH control agent into the condensate pump discharge downstream of the condensate polishers, and an oxygen-scavenging agent and pH control agent upstream of the feedwater booster pump suction. During normal power operation, the addition of an oxygen-scavenging agent and a pH control agent to the condensate system downstream of the condensate demineralizers is automatically controlled, with manual control available. The added chemicals control pH according to the condensate and feedwater system chemistry requirements and establish a residual oxygen-scavenging agent concentration in the feedwater system. The oxygen-scavenging agent and pH control agent will be selected by the Combined License applicant.

A cross-connection from the main feedwater pump discharge header to the startup feedwater header allows any booster/main feedwater pump to supply feedwater to the steam generators via the startup feedwater control valves. Thus, feedwater from the deaerator storage tank can be supplied by the booster/main feedwater pumps through the startup feedwater connections to the steam generators during hot standby, plant startup, and low-power operations. A check valve in the cross-connection piping prevents the startup feedwater pumps from supplying the main feedwater header, and a non-safety-related isolation valve in the cross connection piping automatically closes in response to the feedwater isolation signal that trips the main feedwater pumps.

Events which produce an increase in feedwater flow or a decrease in feedwater temperature result in increased heat removal from the reactor coolant system, which is compensated for by control system action. Events which produce the opposite effect (i.e., decreased feedwater flow or increased feedwater temperature) result in reduced heat transfer in the steam generators. Normally, automatic control system action is available to adjust feedwater flow to prevent excess energy accumulation in the reactor coolant system, and an increasing reactor coolant temperature provides a negative reactivity feedback, reducing reactor power. In the absence of normal control action, either the high-outlet-temperature or the high-pressure trip of the reactor protection system provides reactor safety.

The bulk of the condensate and feedwater system is shown in Figures 7.2-1, 7.2-2, and 7.2-3. The steam generator system portion is shown in Figure 7.2-4.

### 7.2.3 Component Descriptions

#### 7.2.3.1 Feedwater Isolation Valves

One main feedwater isolation valve (MFIV) is installed in each of the two main feedwater lines outside of containment and downstream of the feedwater control valve. The MFIVs are installed to prevent uncontrolled blowdown from the steam generators in the event of a feedwater pipe rupture. The downstream main feedwater check valves provide backup isolation. In the event of a secondary-side pipe rupture inside of containment, closure of the MFIVs limits the quantity of high energy fluid that enters the containment through the broken loop and limits the cooldown of the reactor coolant system (RCS). The main feedwater control valves (MFCVs) provide backup isolation to limit the RCS cooldown and high-energy fluid addition to containment.

Each MFIV is a bidirectional wedge-type gate valve with a valve body that is welded into the system pipe. The MFIV gate valve is provided with a hydraulic/pneumatic actuator. The valve actuator is supported by the yoke, which is attached to the top of the body. The valve actuator consists of a hydraulic cylinder with a stored energy system to provide emergency closure of the isolation valve. The energy to operate the valve is stored in the form of compressed nitrogen contained in one end of the actuator cylinder. The MFIV is maintained in a normally open position by high-pressure hydraulic fluid. For emergency closure, redundant solenoids are energized resulting in the high-pressure hydraulic fluid being dumped to a fluid reservoir. To provide safety function actuation, the redundant actuation solenoid valves are powered from separate Class 1E power divisions. Redundant control and indication channels are provided for each of the isolation valves.

#### 7.2.3.2 Feedwater Control Valves

The MFCVs are air-operated control valves with the dual purpose of controlling the feedwater flow rate as well as providing backup isolation of the feedwater system. The valve body is a globe design.

The MFCVs automatically maintain the water level in the steam generators during operational modes. Positioning of each main feedwater control valve during normal operation is the function of an automatic feedwater level control system, which uses a refinement of a standard three-element control scheme. The three-element control system maintains feedwater flow equal to the steam flow, and steam generator water level is used as an input to trim feedwater flow and maintain programmed water level. Refinements on the standard control are made by varying the flow demand of the valve based on the actual stem position.

In the event of a secondary-side pipe rupture inside the containment, the main feedwater control valves provide a redundant isolation to the MFIVs to limit the quantity of high energy fluid that enters the containment through the broken loop. For emergency closure of the MFCV, a solenoid is de-energized to close the valve in sufficient time to limit the mass and energy release to containment.

#### 7.2.3.3 Feedwater Check Valves

Each main feedwater line includes a check valve installed outside containment. During normal and upset conditions, the check valve prevents reverse flow from the steam generator whenever the feedwater pumps are tripped. In addition, the closure of the valves prevents more than one steam generator from blowing down in the event of a feedwater pipe rupture. The check valve is designed to limit blowdown from the steam generator and to prevent slam resulting in potentially severe pressure surges due to water hammer. The valves are designed to withstand the closure forces encountered during the normal, upset and faulted conditions. Rapid closure associated with a feed line rupture does not impose unacceptable loads on the steam generator or the steam generator system.

#### 7.2.3.4 Condensate Pumps

The three 50-percent, vertical, multistage, centrifugal condensate pumps are motor driven and operate in parallel. Valving allows individual pumps to be removed from service. The pump capacity meets normal, full-power requirements with two of the three pumps in operation.

#### 7.2.3.5 Condensate Regulating Valves

The main condensate flow to the deaerator is regulated by two parallel, split-ranged, pneumatically operated control valves. Condensate is regulated to maintain the level in the deaerator storage tank. During startups and low-load operation, the smaller valve modulates to control flow while the larger valve remains closed. As the load increases, the larger valve modulates to control flow.

#### 7.2.3.6 Low-Pressure Feedwater Heaters

These heaters are shell-and-tube heat exchangers, with the heated condensate flowing through the tube side and the extraction steam condensing on the shell side. Parallel strings of low-pressure feedwater heaters No. 1 and 2 are located in each of three condenser necks. Feedwater heaters No. 3 and 4 are also parallel strings of heaters. Except for the No. 1 feedwater heaters, the closed low-pressure feedwater heaters have integral drain coolers, and each shell-side drain cascades to the next lower stage feedwater heater. The drains from each No. 1 heater are dumped to its respective condenser shell.

A drain line from each heater allows direct discharge of the heater drains to the condenser in the event that the normal drain path is not available or that flooding occurs in the heater.

### 7.2.3.7 Deaerator

The deaerator is a tray-type, horizontal-shell, direct-contact heater with a horizontal storage tank. Condensate enters the deaerator from the top. The heating steam flows upward and is condensed, thereby raising the temperature of the condensate to near saturation and liberating dissolved gases from the condensate. Condensate drains from the deaerator into the storage tank. Noncondensable gases are vented from the top of the deaerator and flow through an orifice and valve assembly to the main condenser.

Auxiliary steam from the auxiliary steam supply system is supplied to the deaerator during recirculation conditions and maintains the pressure in the tank above atmospheric pressure. The steam heats the condensate during cleanup and recirculation for liberation of noncondensable gases. Auxiliary steam is also automatically supplied to the deaerator following a turbine trip to assist in maintaining deaerator pressure above atmospheric pressure.

A high-level dump line and control valve provides overflow protection for the deaerator storage tank. During high-level conditions, water from the deaerator storage tank is drained to the main condenser.

### 7.2.3.8 High-Pressure Feedwater Heaters

The main feedwater pumps discharge into a parallel string of No. 6 and No. 7 high-pressure feedwater heaters. These heaters are shell-and-tube heat exchangers. Heated feedwater flows through the tubes and extraction steam condenses in the shell. Each No. 6 and No. 7 heater drains into low-pressure heater No. 5 (the deaerator).

A drain line from each heater allows direct drain discharge to the condenser in the event that the normal drain path is not available or that flooding occurs in the heater.

### 7.2.3.9 Feedwater Booster Pumps

The feedwater booster pumps are horizontal, centrifugal pumps located upstream of the main feedwater pumps. Each feedwater booster pump takes suction from the deaerator storage tank and pumps forward to its associated main feedwater pump. An electric motor drives both the booster pump and the main feedwater pump. The booster pump is driven by one end of the motor shaft, and the main pump is driven by the other end through a mechanical speed increaser. The booster pump, operating at a lower speed than the main feedwater pump, boosts the pressure of feedwater from the deaerator to meet the net positive suction head requirements of the main feedwater pump.

#### 7.2.3.10 Main Feedwater Pumps

The three main feedwater pumps operate in parallel; each takes a suction from its associated feedwater booster pump. The combined discharge from the main feedwater pumps is supplied to the high-pressure feedwater heater strings and then to the steam generator system. Each main feedwater pump is a horizontal, centrifugal pump driven, through a mechanical speed increaser, by the motor that drives the associated feedwater booster pump. Isolation valves allow each of the booster/main feedwater pumps to be individually removed from service while power operations continue at reduced capacity.

#### 7.2.3.11 Pump Recirculation Systems

Minimum flow control systems automatically protect the pumps in the condensate and feedwater system from pumping below minimum flow rates to prevent pump damage. The condensate pumps recirculate to the main condenser. The booster/main feedwater pumps recirculate to the deaerator storage tank.

### 7.2.4 System Operation

#### 7.2.4.1 Power Operation

One operating condensate pump supplies sufficient condensate flow to the deaerator during initial power operation and at low-power levels. As power escalates, a second condensate pump is started prior to exceeding approximately 50-percent of full-load condensate flow. The third condensate pump is in standby.

The condensate regulating valves to the deaerator automatically maintain the level in the deaerator storage tank. If condensate flow to the deaerator drops below the minimum required flow for operation of the gland steam condenser or the condensate pumps, the hotwell recirculation valve to the condenser opens to provide the minimum flow. Noncondensable gases are removed by the deaerating section of the main condenser and by the deaerator. Condensate polishing, chemical feeding, and condensate sampling are performed, as needed, to maintain water quality.

For normal operating conditions between 0- and 100-percent load, system operation is primarily automatic. Automatic level control systems control the water levels in the feedwater heaters and the condenser hotwell. Feedwater heater water levels are controlled by modulating flow control valves. Level control valves in the makeup line to the condenser from the condensate storage tank and in the return line to the condensate storage tank control the level in the condenser hotwell.

During reactor startup and at very low power levels, feedwater is supplied to the steam generators through the startup feedwater control valves either by the startup feedwater pumps drawing from the condensate storage tank, or by a booster/main feedwater pump drawing from the deaerator storage tank. If the startup feedwater pumps are initially in use, a transfer is made to a booster/main feedwater pump prior to exceeding the capacity of the startup pumps. As power increases, startup feedwater continues to be supplied through the startup feedwater control valves until control of feedwater is automatically transferred from the startup feedwater control valves to the main feedwater control valves. The startup feedwater control valves close and the main feedwater control valves open to supply main feedwater to the steam generators and maintain steam generator level (see section 8.5.7 for feedwater control discussions). Position indication is available in the main control room for the main and startup feedwater control valves. As power escalates, booster/main feedwater pump minimum flow recirculation automatically decreases as the forward flow to the steam generators increases. The second and third booster/main feedwater pumps are placed into service as required.

Condensate flow to the steam generator blowdown heat exchangers is normally automatically controlled. In the automatic mode, condensate flow is regulated to control the steam generator blowdown outlet temperature from the blowdown heat exchangers.

Ten-percent step load and five-percent/minute ramp changes are accommodated without major effect on the condensate and feedwater system. The system is capable of providing the necessary feedwater flow to the steam generators with the steam pressure increase resulting from a 100-percent load rejection.

Positioning of each main feedwater control valve during normal operation is the function of an automatic feedwater level control system using a refinement of a standard three-element control scheme. For each steam generator, the three-element control system maintains feedwater flow equal to the steam flow, and steam generator water level is used as an input to trim feedwater flow and maintain programmed water level. Refinements on the standard control are made by varying the valve flow demand based on actual stem position, dynamic line losses and feedwater temperature. A flow venturi is located in each feedwater line to provide the feed-flow input to the three-element feedwater control system. Feedwater control is further described in subsection 8.5.7.1.

A flow element in the discharge piping from each main feedwater pump provides a flow signal for control of the associated minimum flow recirculation valve.

Level transmitters, located at the deaerator storage tank, control deaerator level. Condensate flow to the deaerator is regulated by two split-ranged control valves upstream of the deaerator. During normal power generation, the valves are regulated by a three-element control system; total feedwater flow is used as a feed-forward demand signal, and the control is trimmed by measured feedback of total condensate flow and deaerator storage tank level.

The total water volume in the condensate and feedwater system is maintained through automatic makeup and rejection of condensate to the condensate storage tank. The system makeup and rejection are controlled by the condenser hotwell level controller. Level transmitters are provided at the condenser hotwell for use by the hotwell level controller. The system water quality requirements are automatically maintained through the injection of an oxygen-scavenging agent and a pH control agent into the condensate system. The pH control agent and oxygen-scavenging agent injection is controlled by the system pH level and the residual concentration of oxygen-scavenging agent in the system, which are continuously monitored by the secondary sampling system.

#### 7.2.4.2 Plant Shutdown

Operation during a power descent is largely the reverse of that during a power ascent. As power is decreased, one of the two operating condensate pumps may be stopped; one or two booster/main feedwater pumps may be stopped as well. At low feedwater flow, control of feedwater is automatically transferred from the main feedwater control valves to the startup feedwater control valves.

Following a reactor trip or other reactor shutdown, feedwater is supplied through the startup feedwater control valves to maintain steam generator inventories. Decay heat and sensible heat are removed by steam release via the steam dump system to the condenser to cool the plant and bring it to safe shutdown. During this time, startup feedwater is supplied either by an operating booster/main feedwater pump drawing from the deaerator storage tank, or by the startup feedwater pumps drawing from the condensate storage tank.

#### 7.2.4.3 Emergency Operation

During a design-basis event (with or without normal ac power supplies available), feedwater isolation signals are generated as required. The MFIVs and MFCVs automatically close on receipt of the isolation signals. The condensate and feedwater system is not required to supply feedwater under accident conditions to effect a plant shutdown or to mitigate the consequences of an accident. However, the startup feedwater system is expected to be available as a nonsafety-related system to provide feedwater to the steam generators. Also, the condenser may be available to accept turbine bypass steam for secondary-side heat removal. Coordinated operation of the startup feedwater system, if available, and the main steam supply system removes the primary-loop sensible heat and reactor decay heat.

- For a main feedwater line break inside the containment or a main steam line break, the MFIVs and the MFCVs automatically close upon receipt of a feedwater isolation signal.

- The MFIVs are provided with solenoids supplied by redundant power divisions. Failure of either of the power divisions or solenoids does not prevent closure of the MFIV. Releases of radioactivity from the condensate and feedwater system, resulting from a main feedwater line break, are minimal because of the negligible amount of radioactivity in the system under normal operating conditions. Following a steam generator tube rupture, isolation of the main steam system and the operation of the passive residual heat removal heat exchanger limit accidental releases. Detection of radioactive leakage into and out of the system is facilitated by area radiation monitoring, process radiation monitoring, and steam generator blowdown sampling.

- For a steam generator tube rupture event, positive and redundant isolation is provided for the main feedwater system (MFIVs and MFCVs) with isolation signals generated by the protection and safety monitoring system (PMS).

The main feedwater pumps are tripped by manual actuation or feedwater isolation.

If a feedwater heater experiences a sizable tube leak or a feedwater heater water level control valve fails closed, the main turbine is protected from failure resulting from flooding on the shell side of a feedwater heater and subsequent water introduction into the moving turbine blades.  This is accomplished by the automatic closure of the isolation valve in the steam extraction line to that heater and the opening of the high-level dump control valve that dumps the heater excess drains to the condenser.  For heaters that do not have extraction line isolation valves, condensate isolation valves are automatically closed to isolate condensate flow to the heater tubes.