3.1 Deaerator Systems

3.1.1 Design & Operational Considerations

System Overview

The primary function of a deaerator system is to protect the boiler and condensate system from corrosion by removing oxygen and carbon dioxide from feedwater. It also serves to raise the temperature of feedwater to the boiler.

Basic System Flow Path

The following illustrations represent basic deaerator circuitry. Deaerator systems may vary with respect to component and circuit design. Any variation may impact how the guidelines are employed. The boundaries for this system begin with the steam control valve and the water into the deaerator and end with feedwater leaving the deaerator storage tank.

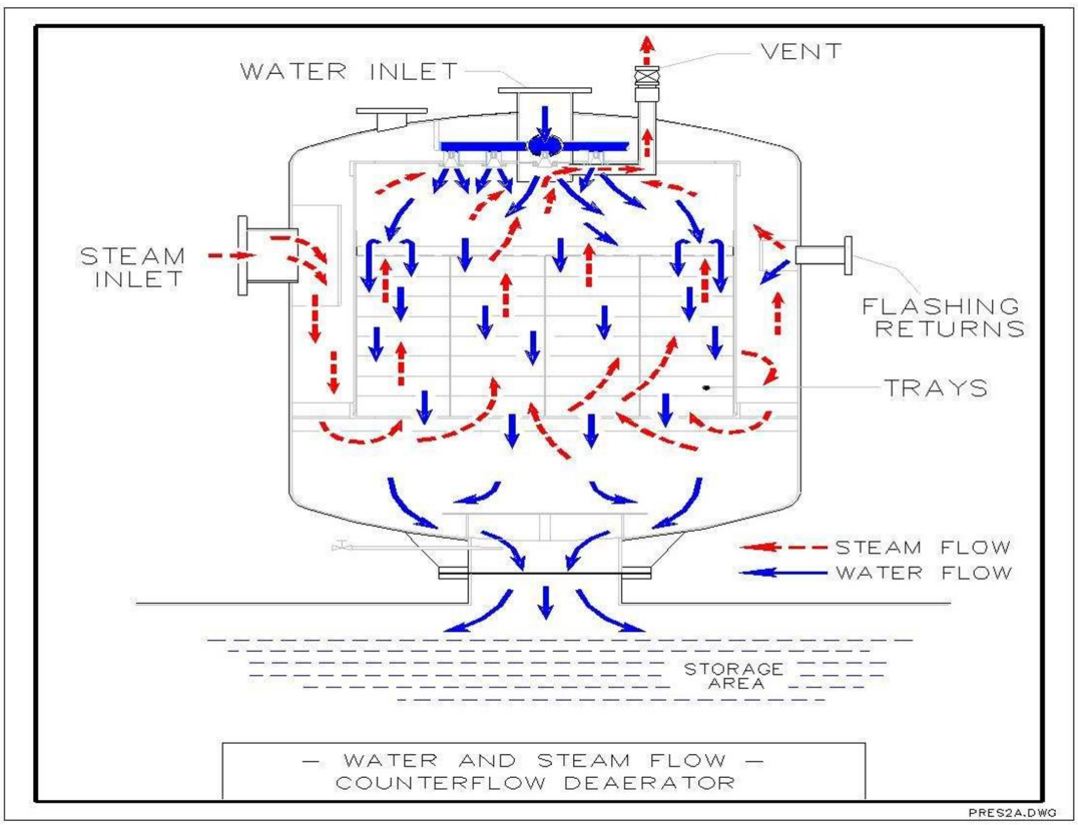


Illustration 3.1 - Typical counterflow deaerator flow path.

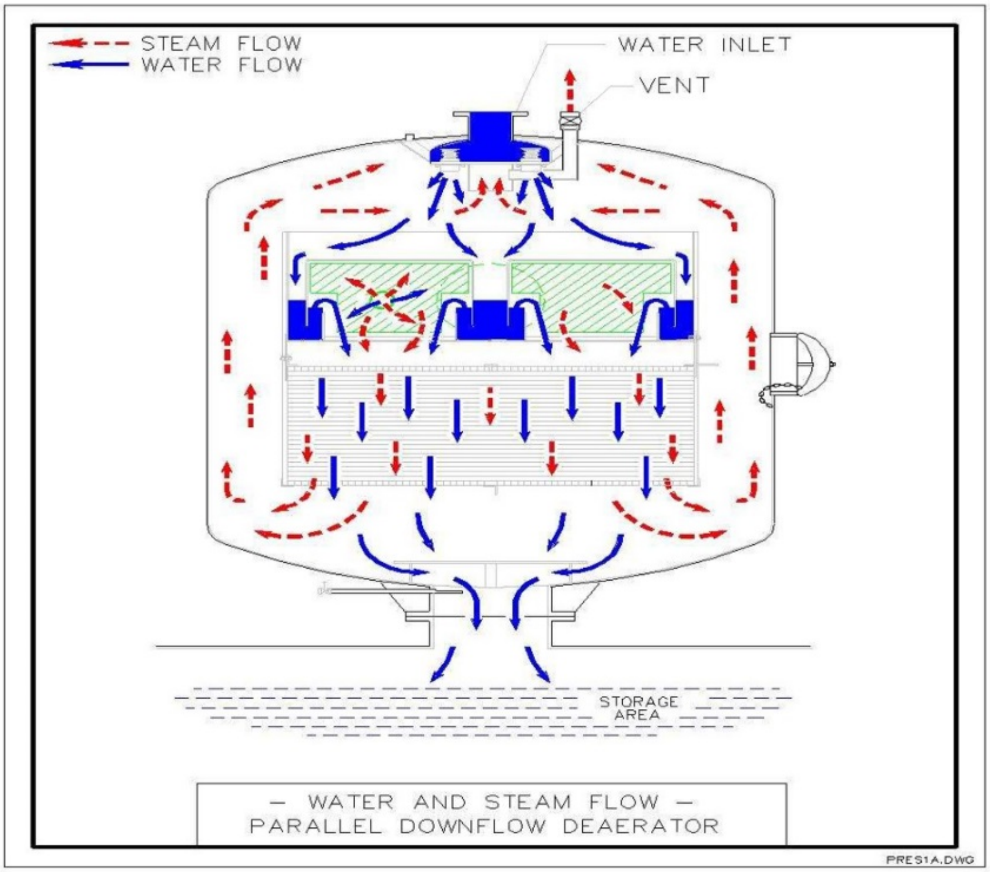


Illustration 3.2 - Typical parallel deaerator flow path.

Deaerator Systems

Basic System Component Design

A basic deaerator system may be comprised of some or all of the following:

- A steam control valve
- A steam check valve
- A steam desuperheater system
- A water flow control valve
- A vacuum breaker on the deaerator head
- A manual deaerator vent valve with a silencer
- Trays and/or spray nozzles to maximize contact of steam and water
- A heater box inside the deaerator head
- A dropleg to the storage tank.
- A chemical injection quill.
- Deaerator pressure, storage tank level, and storage tank temperature instrumentation
- Feedwater pump automatic recirculation valve (ARC) line penetrations into the tank.
- An overflow standpipe
- A high level dump valve
- Vortex breakers at the discharge of the tank.

Basic System Control Technology

Steam is regulated to the deaerator head to control pressure. The steam is sometimes desuperheated to eliminate excessive superheat. Non-condensible gases, such as oxygen and carbon dioxide, are vented via a manual vent valve which is set according to dissolved oxygen levels and/or generally accepted visual plume characteristics.

A water control valve is utilized to ensure an adequate level in the storage tank.

A high level automatic dump valve prevents high water levels in the deaerator.

3.1.2 Chemical Treatment & Control Considerations

Water/Steam Purity Impact Assessment

Oxygen and carbon dioxide that enters the deaerator must be substantially removed. Oxygen that is transported to the economizer can contribute to corrosion fatigue, stress-assisted corrosion, pitting and failure of economizer tubes. Carbon dioxide transported to the boiler will volatilize with the steam, increasing the potential for condensate system corrosion.

Deaerators are designed to provide less than 7 ppb of dissolved oxygen without chemical treatment. Sustained operating levels above that will damage the economizer.

	Key Chemical Control Variables
	Oxygen scavenger is typically added to the feedwater in the deaerator dropleg. If a neutralizing amine is added to the same quill, ensure the compatibility of the amine with the oxygen scavenger.

3.1.3 Key Maintenance Practices & Protocols

	System Reliability Impact Assessment
	Trays can become dislodged if storage tank level control is poorly managed or if steam pressure is abruptly changed. Operators should be particularly careful to decrease steam pressure on the deaerator slowly to prevent hot water from boiling out the vent valve. Failure of springs on the spray nozzles can affect oxygen removal efficiency.
	Inspection Techniques
	In addition to routine visual and NDE inspections. Ensure that trays are securely held down and that spray nozzles have adequate tension and are not plugged. Verify that steam box doors swing freely. Look for cracks in the steam box. (See NACE SP0590 – 2015 Standard Practice Prevention, Detection, and Correction of Deaerator Cracking for further information. Also reference National Board Inspection Code 2.3.1.6.) When possible, verify the integrity of the steam check valve. Visually inspect the chemical injection quill.
	Inspection Frequency
	Mill configuration will determine when there is an opportunity to inspect the deaerator. At a minimum, deaerator inspection intervals should not exceed five years. Whenever the deaerator is shut down cold, it is considered good practice to visually inspect the deaerator components.

3.1.4 SOPs

	3.1.4.1 - *SOP - Deaerator Operation* - An SOP for start-up, shutdown, normal operation, and response to high dissolved oxygen levels should be developed for the deaerator.

3.1.5 Monitoring

	3.1.5.1 - *Monitoring - Storage Tank Temperature* - Monitor storage tank temperature to ensure that the water is within 5°F of saturation, based on deaerator section pressure.

	3.1.5.2 - *Monitoring - Steam Pressure* - Steam pressure instrumentation to control steam to the deaerator. A low pressure indication and alarm should be in place.
	3.1.5.3 - *Monitoring - Storage Tank Level* - Low level and high level alarm are required.
3.1.6 Inspection/Documentation	
	3.1.6.1 - *Inspection/Documentation - Pressure Vessel Inspections* - The deaerator and storage tank should be inspected at a frequency in conformance with NACE SP0590 – 2015 or National Board System Design, Operation and Inspection of Deaerators requirements. All inspection data should be documented.
	3.1.6.2 - *Inspection/Documentation - Trays* - Trays and traybox should be inspected at every scheduled cold outage. Ensure that they are secure and aligned properly.
	3.1.6.3 - *Inspection/Documentation - Spray Nozzles* - Spray nozzles should be inspected at every scheduled cold outage to ensure they are tight and are not obstructed.
	3.1.6.4 - *Inspection/Documentation - Steam Check Valve* - The steam check valve should be inspected to verify integrity on a mill-determined frequency.
	3.1.6.5 - *Inspection/Documentation - Feedwater Chemical Delivery Systems* - A chemical feed injection quill is recommended when introducing oxygen scavenger. This quill should extend to the center of the dropleg. If oxygen scavenger is added to the storage tank, scavenger should be injected via a quill or pipe away from the wall of the storage tank. The quill should be inspected at every opportunity.
	3.1.6.6 - *Inspection/Documentation - Compatibility of Chemicals* - When multiple chemicals are injected in the same point, compatibility of the chemicals should be verified. It is not recommended to add scavengers and amines in the same quill to avoid pluggage and compatibility concerns.

Condensate System

5.1 Condensate System

5.1.1 Design & Operational Considerations

System Overview

The condensate system is designed to reclaim heat and high purity water for reuse as boiler feedwater. An added benefit is the recycle of a portion of the condensate treatment chemicals into the boiler feedwater.

Basic System Flow Path

Condensate system designs vary depending on processes utilized at a mill and the system designer's preferences. Major sources of condensate include paper machine dryers, pulp dryers, digesters, evaporators, and turbine condensers. It is important to understand the individual mill design so that proper water chemistry is maintained throughout the system. The boundaries for the system start with the locations where steam is first condensed and end at the point of entry into the deaerator.

Basic System Component

Condensate Flash Tanks - The flash tank allows the temperature of condensate to be reduced while capturing the steam that flashes off in the process. This reduces the likelihood of flashing when condensate is returned to an atmospheric flash tank.

Condensate Dump Systems - The system diverts condensate based on contaminated water.

Turbine Condensers - A shell and tube heat exchanger that may be installed on the exhaust of a steam turbine generator, converting all steam routed through the turbine exhaust into condensate.

Steam Traps - Devices that segregate condensate from steam by either mechanical or thermostatic control.

Condensate Filters - An electromagnetic or cartridge filter. It is used in lieu of, or in conjunction with, condensate polishers. Removes particulate iron and a portion of copper in a condensate system.

Condensate Polishers - Resin-based ion exchange polishers may be used to remove both particulate and dissolved impurities. Units are typically limited to cation resin polishers, due to typical condensate temperatures which exceed the capability of anion resin. Polishers may be used as stand-alone devices or following a magnetic filter.

Heat Exchangers - Condensate streams are frequently routed through heat exchangers for energy efficiency reasons.

Condensate Receivers - In most applications these are atmospheric tanks. They collect multiple individual condensate streams and integrate them into a single combined stream. The receivers may be preceded by a heat exchanger to collapse steam. In some mills makeup and condensate streams are blended in a common tank.

Paper Machine Condensate Separators & Vacuum Receivers - Condensate separators are designed to separate the steam and condensate from the paper machine dry end and typically operate under pressure. Condensate, or a mix of steam and condensate, is passed through these vessels. The level in these tanks is typically controlled by level control loops. One or more pumps on each tank maintains level and pumps the condensate back for reclaim. A vent on the top of the tank allows blow-through steam to go to a lower pressure dryer group or into a thermocompressor. Vacuum receivers are sometimes utilized on the lowest pressure steam in the paper machine.

Dryer Drainage Systems - These can either be rotating or stationary siphons within the dryer cans. They are designed to remove condensate and blow-through steam from the inside of the dryer cans.

Condensate Pump Seals - API 682 details over 30 pump seal designs; several of them are applicable to condensate pumps; of these, some have a potential for condensate contamination due to the source of seal water or a failure in a heat exchanger. Pump packing material also has a potential to contaminate condensate.

5.1.2 Chemical Treatment & Control Considerations

Water/Steam Purity Impact Assessment

Condensate can serve as a conduit for contaminants, such as liquor, iron, starch, fiber, caustic, acid, copper, hardness, and others, to reach the boiler and deposit within the boiler tubes. Condensate typically contains some oxygen and, under low pH conditions (< 8.3), carbon dioxide. The concentration of oxygen and/or CO_2 can be localized within the system or widespread. Component venting practices can impact the concentration levels in various system components. The resulting corrosion not only affects the condensate piping itself, but has the potential to transport iron into the recovery boiler.

In all cases, consult with water treatment SMEs for water treatment program recommendations.

Condensate System

	Key Chemical Control Variables

There are a number of factors that can influence condensate chemical treatment program and control. The program should be selected based upon:

Mechanical Factors -

- **Presence of copper alloys for equipment in the steam or condensate systems.** If copper is utilized for equipment in the steam or condensate systems, particular focus must be placed on pH control and the levels of specific contaminants that may react with copper.

- **Deaerator performance.** Sub-optimal condition of the deaerator can/will cause economizer corrosion. In addition, the gases that remain in the feedwater could carry through to the steam system, consuming scavengers and amines in the condensate system. The level of gases, specifically CO_2, that remain in the feedwater system may be influenced by the pH of the deaerated water. The presence of oxygen will tend to drive the corrosion rates of the feedwater metallurgy higher when oxygen is present in a low pH environment.

- **Air inleakage.** Any portion of the condensate system vented to atmosphere or operating under a vacuum has a potential to draw in air and increase corrosion. This corrosion can transport red iron to the recovery boiler.

Design & Operational Factors -

- **Boiler feedwater water quality.** Any design modification to the pre-treatment or external treatment system (equipment or procedures) can create a discernable and sustainable change in feedwater quality which will carry through to the steam and condensate. It may require a change in treatment selection and/or control to meet corresponding ASME guidelines based upon the conditions encountered.

- **Condensate system complexity.** In systems where there are a number of operating pressures and/or extensive piping, consideration should be given to treatment chemistry selection. In most paper mill applications, a blend of amines is utilized to elevate the pH throughout the condensate system.

- **Condensate return rates.** A sustained change in the proportion of return condensate will change the amount of treatment chemicals that are recycled back to the feedwater system. Any change in the ratio of condensate returns to makeup water will alter the feedwater chemistry.

- **Boiler operating pressure.** The volatilization and decomposition of some amine products present in the boiler water will be a function of boiler operating pressure.

- **Boiler internal tube condition.** Overall economizer and boiler waterside tube surface conditions as determined by DWD and deposit composition could merit a change in the condensate treatment program.

- **ASME guidelines for the feedwater and boiler water.**

- **Site-specific water quality guidelines.**

  In all cases, consult water treatment SMEs when a change in water quality has taken place or when a change in the makeup of the mechanical condensate treatment processing system(s) is being considered.

Other Factors that Affect Chemical Treatment Program Selection & Performance -

- **Presence of known deposits within the recovery boiler circuitry.** The presence of deposits in boiler circuits and headers increases the concerns regarding the condensate treatment program selection.

- **Historical information.** Collection and consolidation of condensate quality data and condensate system upset incidents can be beneficial for historical review of recovery boiler operations.

  Note: In all cases, provide the water treatment SME with a historical overview of past water treatment-related anomalies.

Program Selection Options - Program selection is dependent on factors such as feedwater quality, condensate system design, boiler steam temperature, and boiler deposit history. Current available treatment options for condensate systems are:

- Neutralizing amines
- Filming amines
- Oxygen scavengers/metal passivators.

Treatment can consist of a combination of the above options.

In all cases, provide your water treatment SMEs with a historical overview of past water treatment-related anomalies.

Chemical Feed & Condensate Monitoring Practices -

- Care must be taken in selecting chemical feed points and delivery systems. Improperly designed chemical delivery systems can compromise the ability to control water chemistry.

- Intermittent or highly variable flows from condensate streams that have their own corrosion treatment injection, such as filming amines, should be reviewed to ensure that the treatment does not overfeed or underfeed during periods of variable condensate flow.

- Condensate sampling points should be located in close proximity to the source of potential contamination to allow for the condensate dump systems to function in a timely manner and to provide accurate/representative sample monitoring results. An example of suggested sample points can be found in TAPPI TIPs #0416-03 (water quality and monitoring requirements for high purity water) and #0416-14 (water quality and monitoring requirements for softened water).

- Condensate sample streams shall have proper flow to ensure that they are representative of the water returning from a given source. The temperature of the samples should be conditioned to 25°C. Variation from this temperature will affect turbidity, particle count, and pH meters. The sample stream shall flow continuously. It should be noted that restrictions in sample flow will alter the response time in automated dump systems and can generate non-representative data.

  Any stream servicing an instrument that could potentially be contaminated with liquor has a potential to plug or foul. Best practice would be an insertion-style probe in a large diameter continuous flowing stream.

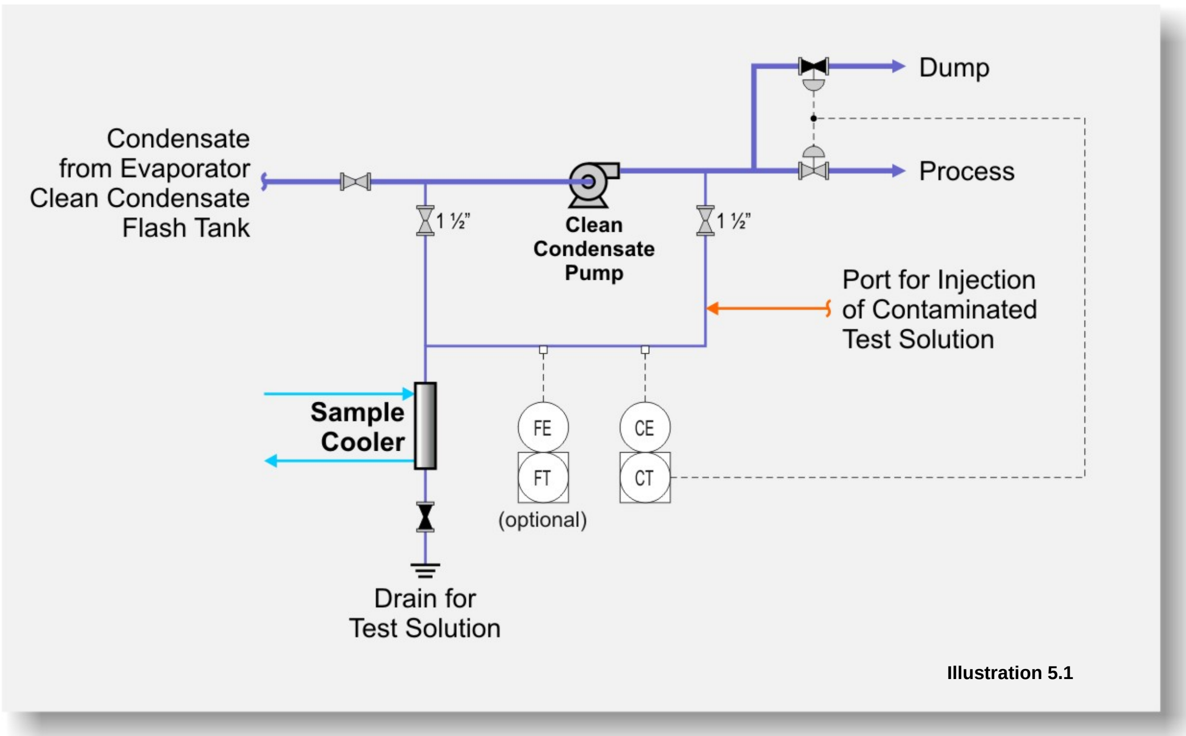


Illustration 5.1 - Recommended configuration for condensate conductivity sampling of a condensate stream with the potential for liquor contamination.

Condensate System

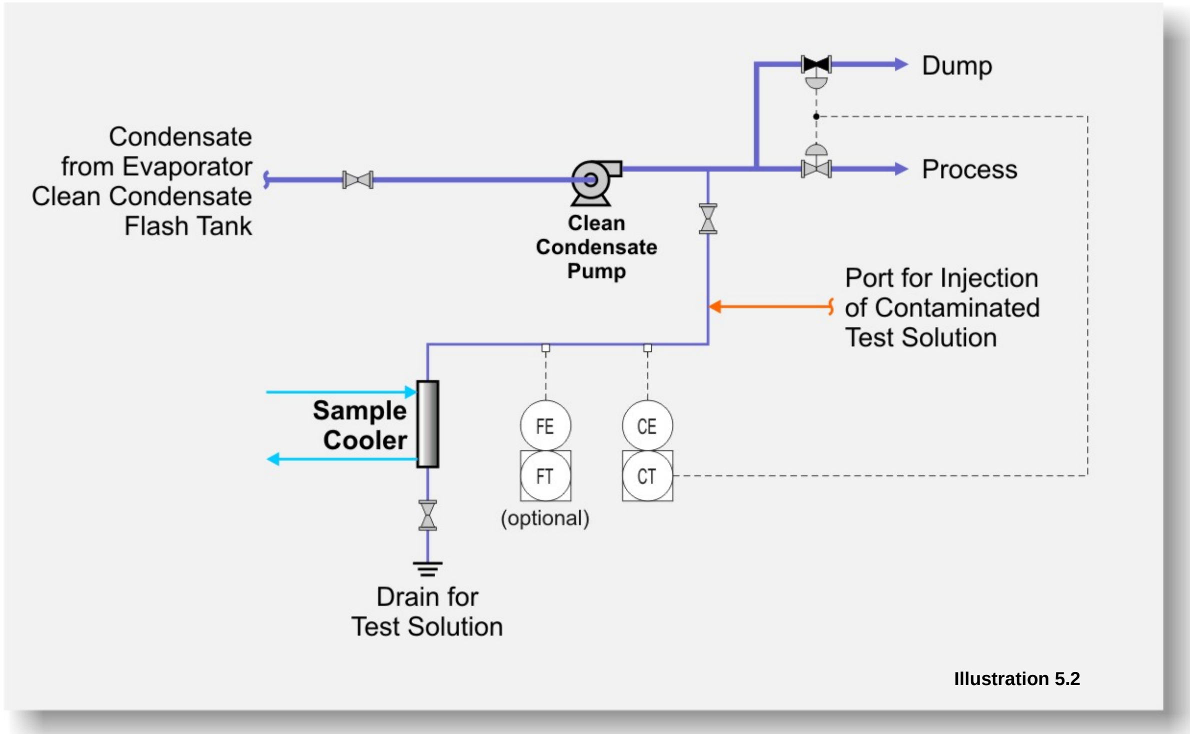


Illustration 5.2 - Alternate configuration for condensate conductivity sampling of a condensate stream with the potential for liquor contamination.

- Instruments to protect feedwater from condensate upsets should be located to provide adequate time for dump or divert valves to actuate and prevent contamination of all condensate.

- Sample streams should be located to enable testing of condensate while it is being dumped or diverted in order to determine acceptability for reintroduction into the condensate collection system.

- Flow monitoring is recommended for all sample streams:
    - Flow measurements that are alarmed in the DCS are the preferred method of verifying flow.
    - On recirculation loops, if flow meters are not utilized, the sample line should be opened to sewer and the positioning of the conductivity meter should be such that dump valves will actuate in a timely manner even if the recirculation loop is plugged and the flow is only traveling through the sample line to sewer.
    - If the alternate sample system is utilized as shown in Illustration 5.2, in the absence of an alarmed flow measurement, there should be a managed system for visually verifying flow on a routine basis.

Condensate System

5.1.3 Key Maintenance Practices & Protocols

System Reliability Impact Assessment

A properly maintained condensate system will prevent oxygen and CO_2 contamination. It will also prevent many process contamination events.

Inspection Techniques

Qualified individuals should perform visual piping and condenser inspections in conjunction with appropriate nondestructive examination. In addition, qualified individuals should perform polisher resin analysis, spark testing of liners, instrumentation PMs and calibrations of key instruments, control valve PMs, check valve PMs, and steam trap PMs.

Inspection Frequency

The frequency of inspection for the piping and check valves is mill location specific. It will typically correlate with a steam system cold outage.

Piping inspections will depend on the piping materials, corrosion history, water quality, and chemical treatment efficacy.

Condensers are a common source of raw water infiltration. Pressure testing and/or other nondestructive testing frequencies should be established.

A representative condensate polisher resin sample should be analyzed as history and performance dictates, but should be done not more than three years after installation/rebedding.

Lined polisher bodies should be spark tested at a frequency consistent with the ASME required interval for the pressure vessel. Laterals should be inspected when the vessel is open for spark testing. A visual inspection should be performed on laterals any time all of the resin is removed from the unit.

All test instrumentation and their associated collection/dump valves should be functionally tested weekly.

Benchtop and field instrumentation should receive regular PMs at an established interval to ensure reliable operation.

5.1.4 SOPs

5.1.4.1 - *SOP - Returning Condensate from Processes Returning to Service* - For processes such as paper machines or evaporators that are returning to service, the mill should establish a procedure to field-verify adequate condensate sample flow and quality prior to bringing that source back into the collection stream.

Condensate System

	5.1.4.2 - *SOP - Condensate Testing* - Condensate samples should be tested at intervals not to exceed six hours. Intervals between tests can be longer where continuous monitoring is utilized. Manual entry test data should be retained in accordance with mill document retention policies. Tests should include pH, conductivity, hardness, and iron. Silica may be a suitable surrogate for hardness to detect mill water contamination.
	5.1.4.3 - *SOP - Condensate pH* - Condensate in systems where copper is present in some portion of the metallurgy should be maintained at a pH appropriate for this metallurgy to minimize corrosion potential. If no copper is present in the condensate system, a wider recommended pH range will typically be permitted. Regardless of metallurgy, an established SOP should indicate acceptable ranges for condensate pH.
	5.1.4.4 - *SOP - Condensate Outside Normal Control Boundaries* - All condensate streams tested should include an SOP for all test results outside specified control ranges.
	5.1.4.5 - *SOP - Polisher Operation* - A written procedure should exist to define operation, backwash, and regeneration intervals and criteria.
	5.1.4.6 - *SOP - Double Block & Bleed* - A written procedure should exist to explain proper operation of double block and bleed steamout lines in all departments where steam is utilized to purge or clear a process line.
	5.1.4.7 - SOP - *pH Meter Calibration, Use & Storage* - A written procedure should exist for all departments testing the pH of condensate streams with a benchtop unit. The procedure should detail the calibration procedure, sample test protocol including sample temperature range, and proper storage of the pH probe.

5.1.5 ESOPs	
	5.1.5.1 - *ESOP - Condensate Emergency Conditions* - All of these ESOPs should include the following elements: • A troubleshooting decision tree that delineates action steps to be taken • A list of likely contaminant sources for the given excursion • A call list of upstream condensate suppliers to contact for troubleshooting contamination questions • A list of water treatment SMEs to be contacted in the event of an emergency • A list of feedwater consumers downstream to be contacted • Which condensate samples are to be retained for future analysis • Which water tests should be performed at increased frequency • Specification of test intervals for specified parameters • A description of water support system component bypass capabilities (if any exist).
	5.1.5.2 - *ESOP - High/Low pH* - An ESOP should exist for high and low pH excursions in condensate. In addition to the common elements, this ESOP should include: • A check and confirmation of condensate conductivity relative to normal operating range.
	5.1.5.3 - *ESOP - High Condensate Conductivity* - An ESOP should exist for high condensate conductivity. In addition to the common elements, this ESOP should include: • A check and confirmation of pH relative to normal operating range • A check of cation conductivity relative to normal operating range.
	5.1.5.4 - *ESOP - Condensate Silica* - If silica is tested, an ESOP should exist for silica excursions.
	5.1.5.5 - *ESOP - Condensate Hardness Excursions* - If hardness is tested, an ESOP should exist for hardness excursions.
	5.1.5.6 - *ESOP - High Condensate Iron Levels* - An ESOP should exist for high condensate iron levels.
	5.1.5.7 - *ESOP - Starch Contamination* - For mills that cook starch, an ESOP for identifying starch contamination is recommended. Establish a chemical oxygen demand (COD) baseline test to compare against upset conditions (depressed boiler water pH and increased boiler water conductivity with no apparent feedwater contamination).

5.1.6 Monitoring

5.1.6.1 - *Monitoring - Representative Samples -* Samples shall be representative of the source. Sample lag time should be minimized to prevent contaminants from traveling past the dump valves. Sample velocities should be sufficient to maintain particulate contaminants in suspension (5 ft/s is recommended). Maintain adequate sample bottle supply to collect and retain samples in the event of an upset. Refer to ASME CRTD - Vol. 81 Consensus on Operating Practices for the Sampling and Monitoring of Feedwater and Boiler Water Chemistry in Modern Industrial Boilers for specifics on proper sampling technique.

5.1.6.2 - *Monitoring - Evaporator Conductivity* - Evaporator condensate streams shall be equipped with conductivity meters that are alarmed in a control room.

These meters shall be tied to automatic condensate divert valves located downstream of the meter. A redundant conductivity meter is recommended for each evaporator stream. Configuration of evaporator clean condensate stream meters should be in-line, in a continuously flowing recirculating side stream (see Illustration 5.1), or a probe upstream of a sample cooler.

5.1.6.3 - *Monitoring - Evaporator Conductivity Sample Stream Flow* - Evaporation condensate sample streams should have means of verifying flow.

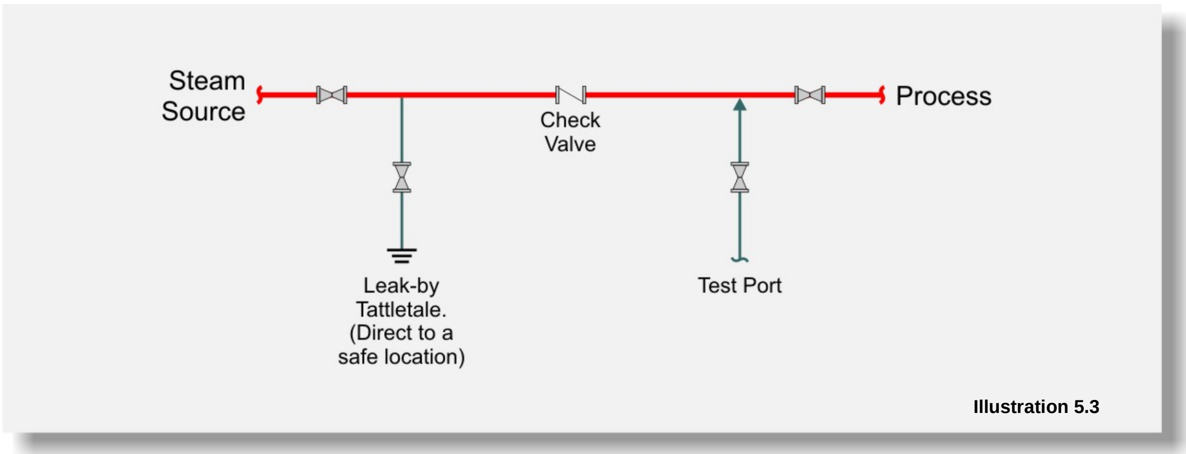
- Flow measurements that are alarmed in the DCS are the preferred method of verifying flow.
- On recirculation loops, if flow meters are not utilized, the sample line should be opened to sewer and the positioning of the conductivity meter should be such that dump valves will actuate in a timely manner even if the recirculation loop is plugged and the flow is only traveling through the sample line to sewer.
- If the alternate system is utilized as shown in Illustration 5.2, in the absence of an alarmed flow measurement there should be a managed system for visually verifying flow on a routine basis.

5.1.6.4 - *Monitoring - Other Major Condensate Streams Conductivity* - Major condensate streams should be equipped with online conductivity meters.

Online conductivity meters are recommended on every condensate storage tank or on the combined condensate return line.

Any condensate stream with the potential for contamination that imparts conductivity and could shut down the recovery boiler shall have an online conductivity meter and an automatic dump system at some point between the contaminant and the recovery boiler feedwater.

	5.1.6.5 - *Monitoring - Turbidity* - Online turbidity meters/particle monitors are recommended for all paper machine condensate streams to trend and alarm iron throw levels. Time-based dumping with manual verification, while not as effective as continuous monitoring, is an acceptable alternative. Where meters are used, they should be interlocked to condensate dump valves, especially if there is no downstream filtering or polishing of the condensate. Sample lag time is particularly important in this application.
	5.1.6.6 - *Monitoring - Condensate Sample Locations* - All steam traps immediately upstream of any direct steam injection processes should have a sample collection tap to facilitate troubleshooting in the event of a process upset.
	5.1.6.7 - *Monitoring - pH of High Purity Streams* - High purity streams should have a dedicated laboratory pH probe. Calibration according to manufacturer's recommendations.
5.1.7 Inspection/Documentation	
	5.1.7.1 - *Inspection/Documentation - Presence of Copper Alloys* - The mill should consult with their water treatment SMEs for proper control parameters when copper alloys are present.
	5.1.7.2 - *Inspection/Documentation - Surface Condensers* - Turbine condensers should be pressure and/or nondestructively tested to ensure cooling water is not entering the condensate.
	5.1.7.3 - *Inspection/Documentation - Evaporators* - Any equipment in the black liquor evaporation train that uses live steam should be hydro-tested with every major shutdown to ensure that the potential for black liquor contamination is minimized.
	5.1.7.4 - *Inspection/Documentation - Black Liquor Heaters* - Black liquor heaters should be hydro-tested or nondestructively tested at an interval not to exceed five years.
	5.1.7.5 - *Inspection/Documentation - Flash Tanks* - Any flash tanks with vacuum break lines should be inspected to ensure that the lines do not extend to sewers where the pipe has the potential to be submerged. Drains should not be positioned such that they could be submerged in a sewer, as this creates the potential to draw sewer streams back into the system if subjected to vacuum.

	5.1.7.6 - *Inspection/Documentation - Check Valves in Steam Systems -* Any process where steam is directly injected into a process should have a minimum of one check valve. Check valves should be inspected for proper function at designated intervals (to be determined by the mill). It is recommended that check valve systems be designed such that they can be visually inspected, borescoped, acoustically tested, or functionally tested.  Illustration 5.3 - Example of a check valve functional verification system in a non-pressurized application. Pressurized applications may eliminate the test port.
	5.1.7.7 - *Inspection/Documentation - Polisher Resin -* If equipped with condensate polishers, samples of condensate resin should be drawn every three years and analyzed. Resin volume, specifications, and manufacturer should be recorded. Resin should be extracted such that the sample is a representation of the entire resin bed for a given polisher. Note the condition (exhausted, regenerated, or mid-run) of the resin upon extraction.
	5.1.7.8 - *Inspection/Documentation - Polisher Liner -* Each polisher equipped with liners should be spark tested at intervals not to exceed ASME intervals for testing the pressure vessel.
	5.1.7.9 - *Inspection/Documentation - Condensate Dump/Divert Valves -* Condensate dump and divert valves should be exercised as a part of regular documented condensate conductivity functional testing. Functional testing should include: • Introduction of a conductivity contaminant to the conductivity element • Visual verification of dump valve operation, including time to open and close • Verification of control room alarm or valve state change on operator panel.

Condensate System

	5.1.7.10 - *Inspection/Documentation - Condensate System Flow Diagram* - A one page drawing showing all dump systems should exist from the receiver to termination in the dump system. Drawing should be verified annually for accuracy.