Lecture 2.19

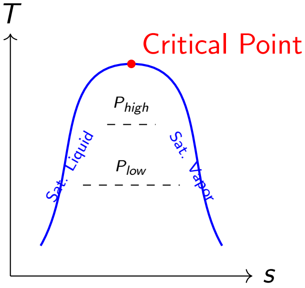
High-Pressure Boilers: Lamont, Benson, and Super-Critical Systems

Lecture Agenda

- 1. Necessity and Features of High-Pressure Boilers
- 2. Lamont Boiler: Forced Circulation Principle
- 3. Benson Boiler: Once-Through Technology
- 4. Modern Super-Critical Boilers: Thermodynamics & Design
- 5. Comparative Analysis: Super-Critical vs. Sub-Critical Boilers

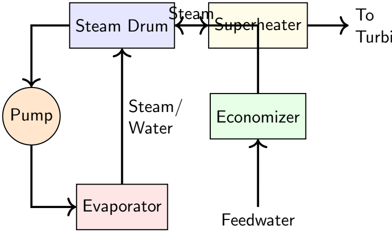
Need for High-Pressure Boilers

- **Thermodynamic Advantage:** Higher operating pressure and temperature increase the mean temperature of heat addition, directly improving Rankine cycle efficiency.
- **Natural Circulation Limits:** At high pressures (> 170 bar), the density difference between saturated water and saturated steam diminishes, making natural circulation sluggish and unreliable.
- **Forced Circulation:** To prevent tube overheating (DNB - Departure from Nucleate Boiling) at high pressures, pumps are employed to



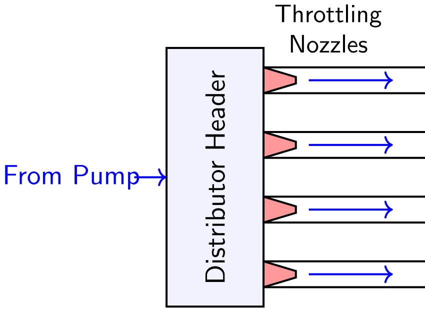
The Lamont Boiler: Operating Principle

- **Classification:** A forced-circulation, water-tube boiler equipped with a steam-separating drum.
- **Operating Range:** Typically operates at pressures around 130 to 170 bar with steam generation capacities of up to 50,000 kg/hr.
- **Circulation Mechanism:** Uses a motor-driven centrifugal pump to circulate water from the drum through the evaporator tubes.
- **Circulation Ratio:** The pump circulates about 10 to 15 times the mass of steam actually



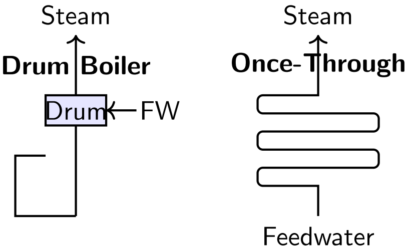
Lamont Boiler: Components and Advantages

- **Key Components:** Steam drum, circulating pump, distribution headers with throttling nozzles, and various heat exchanger surfaces (economizer, evaporator, superheater).
- **Throttling Nozzles:** Installed at the inlet of each tube in the evaporator section to ensure uniform flow distribution regardless of varying heat absorption.
- **Advantages:** High heat transfer rates, rapid steam generation, safe operation at high pressures, and less scale formation due to high water



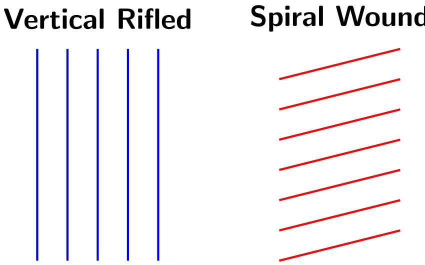
The Benson Boiler: Once-Through Technology

- **Classification:** A once-through, drum-less high-pressure boiler.
- **Operating Principle:** Feed water is pumped into one end of a continuous tube circuit and emerges as superheated steam at the other end.
- **Critical Pressure Capability:** Designed to operate at or above the critical pressure of water (221.2 bar).
- **No Bubble Formation:** At supercritical pressures, water



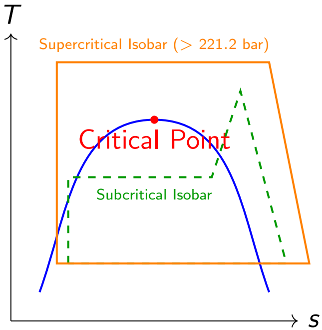
Benson Boiler: Key Characteristics

- **Absence of Steam Drum:** Significantly reduces the total weight, initial capital cost, and structural requirements of the boiler.
- **Rapid Start-up and Load Tracking:** Less water inventory and reduced thermal inertia allow for faster start-ups and excellent response to grid load fluctuations.
- **Water Quality:** Because there is no drum to blow down concentrated impurities, the feed water



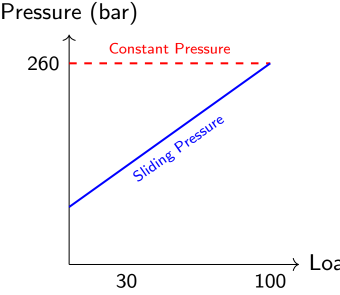
Modern Super-Critical Boilers: Thermodynamics

- **Critical Point Parameters:** Water reaches critical state at a pressure of 22.12 MPa (221.2 bar) and temperature of 374.15°C.
- **Single-Phase Heating:** In a supercritical boiler, the fluid acts as a single phase. The specific volume of water and steam become identical.
- **Continuous Expansion:** The transformation from dense supercritical fluid to high-pressure steam is continuous, bypassing the wet steam region entirely during heat addition.
- **Efficiency Gains:** By operating at pressures around 240-300 bar and temperatures of 560-600°C



Modern Super-Critical Boilers: Design & Metallurgy

- **Furnace Wall Construction:** Utilizes once-through spiral or vertical rifled tubes to maintain fluid mass flux and cooling efficiency under extreme heat loads.
- **Sliding Pressure Operation:** Supercritical once-through boilers are highly adaptable to sliding pressure operation, allowing high efficiency even at partial loads.
- **Advanced Metallurgy:** High pressures and temperatures dictate the use of advanced creep-resistant alloys.
- **Material Examples:** Austenitic stainless steels, T91, P91, P92, and advanced nickel-based superalloys (Inconel) are critical for superheater

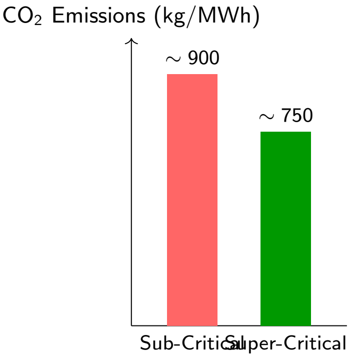


Comparison: Sub-Critical vs. Super-Critical Boilers (Part 1)

Parameter	Sub-Critical Boiler	Super-Critical Boiler
Operating Pressure	$<$ 221.2 bar (typically 130-170 bar)	$>$ 221.2 bar (typically 240-300 bar)
Phase Change	Distinct boiling phase (water and steam co-exist)	Single-phase continuous transition
Boiler Type	Uses heavy, thick-walled steam separating drum	Once-through technology (no drum)
Thermal Efficiency	Limited to $\sim 34-38\%$	Achieves $40-45\%$ (Ultra-supercritical $\sim$

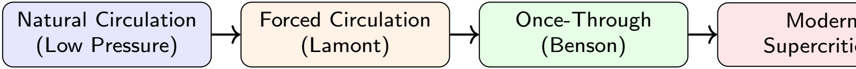
Comparison: Sub-Critical vs. Super-Critical Boilers (Part 2)

- **Fuel Consumption:** Super-critical requires less coal per MWh of electricity generated due to higher efficiency.
- **Environmental Impact:** Reduced fuel consumption directly translates to lower CO_2, SO_x, NO_x, and particulate emissions per unit of power.
- **Operational Flexibility:** Super-critical (once-through) systems offer much faster start-up times and better sliding pressure load tracking.



Summary

- High-pressure operation increases Rankine cycle efficiency but necessitates forced fluid circulation to prevent tube failure.
- Lamont boilers use a circulation pump and throttling nozzles to manage forced flow across a drum boiler system.
- Benson boilers operate on the once-through principle, eliminating the heavy steam drum and allowing supercritical operation.
- Modern super-critical boilers operate above 221.2 bar, bypassing the two-phase region, achieving superior efficiency and lower emissions, albeit requiring advanced metallurgy.



Preview of Next Lecture

Next Topics

- **Draught Systems:** Forced draft (FD) and induced draft (ID) fans.
- **Cooling Towers:** Design and thermodynamics of heat rejection.
- **Environmental Control:** Understanding the operation of Electrostatic Precipitators (ESPs) for particulate matter removal.

Reading Assignment

Review Chapter 3 on Draft Systems and Heat Exchangers.