Lecture 2.18

High-Pressure Boilers

Agenda

Topics to Cover

- Introduction to High-Pressure Boilers
- Lamont Boiler: Forced Circulation Principle
- Benson Boiler: Once-Through Concept
- Modern Supercritical Boilers
- Thermodynamics of Supercritical Generation
- Subcritical vs. Supercritical Boiler Comparison
- Summary and Q&A

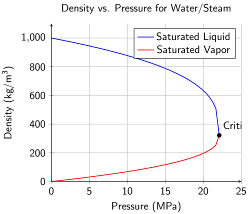
Introduction to High-Pressure Boilers

Why High-Pressure?

- High-pressure boilers typically operate at steam pressures exceeding 100 bar (often 130 to 170 bar in subcritical range).
- At high pressures, the density difference between water and steam decreases significantly, impairing natural circulation.
- Therefore, forced circulation using a centrifugal pump is employed to ensure adequate flow through the evaporator tubes.

Benefits

- Advantages include higher thermal efficiency, reduced boiler weight, improved heat transfer rates, and rapid response to load variations.
- They utilize forced draft and induced draft fans to manage high volumes of combustion gases.



Lamont Boiler: Principle & Circulation

Principle

- The Lamont boiler is a high-pressure, forced-circulation, water-tube boiler.
- It uses a centrifugal pump, known as the circulating pump, placed between the steam drum and the evaporator tubes.
- Water is pumped from the drum to radiant and convective evaporators at a pressure slightly above the drum pressure (approx. 2-3 bar higher).

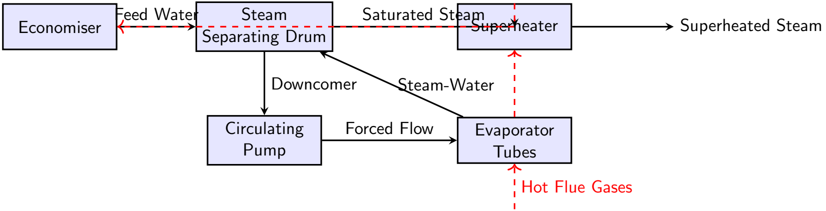
Circulation Ratio

- Circulation ratio is typically around 10:1; this means the pump circulates 10 times the amount of water actually converted to steam.
- A distribution header with regulating orifices ensures uniform water flow distribution to prevent tube overheating.

Lamont Boiler: Components & Diagram

Key Components

- 1. Economiser: Preheats feed water using flue gases.
- 2. Steam Separating Drum: Separates water and steam mixture.
- 3. Circulating Pump: Provides forced circulation.
- 4. Radiant and Convective Evaporators: Main steam generating tubes.
- 5. Superheater: Raises steam temperature above saturation point.



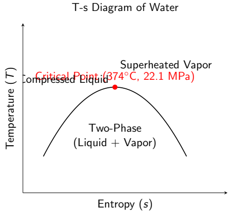
Benson Boiler: The Once-Through Concept

Once-Through Concept

- The Benson boiler is a high-pressure, drum-less, once-through water-tube boiler.
- Invented by Mark Benson in 1922 to operate at or above the critical pressure (221.2 bar).
- At supercritical pressure, there is no bubble formation; water flashes directly into steam because the latent heat of vaporization is zero.

Eliminating the Drum

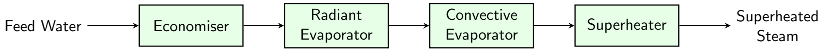
- This eliminates the need for a heavy, expensive steam separating drum.
- Feedwater enters at one end, passes through economiser, radiant evaporator, and superheater, and emerges as superheated steam in a single continuous path.



Benson Boiler: Operation & Layout

Operational Characteristics

- Lighter weight (up to 20% lighter than drum boilers of same capacity) and lower cost due to absence of steam drum.
- Requires extremely pure feedwater since impurities cannot be blown down from a drum and will deposit on tube walls.
- Extremely fast start-up times and rapid response to load fluctuations.
- Can be operated at both subcritical (with separators during startup) and supercritical pressures.



Drum-less Once-Through Continuous Flow

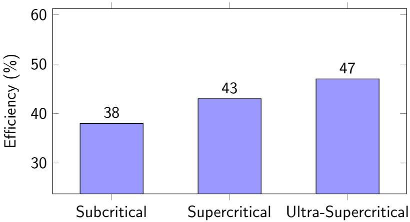
Modern Supercritical Boilers

Supercritical Generation

- Supercritical boilers operate above the critical point of water: P ¿ 22.1 MPa (221 bar) and T ¿ 374 °C.
- Typically operate at pressures of 240-300 bar and steam temperatures of 540-600 °C.
- They utilize the once-through principle (like the Benson boiler).

Advantages

- Significant improvement in Rankine cycle efficiency due to higher mean temperature of heat addition.
- Reduced fuel consumption and consequently lower greenhouse gas (CO2) emissions per MW generated.



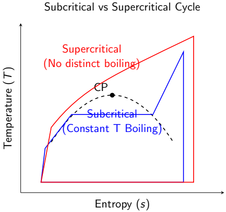
Thermodynamics of Supercritical Operation

Thermodynamic Benefits

- In a supercritical cycle, heating fluid passes directly from a compressed liquid state to a superheated vapor state without a two-phase isothermal boiling region.
- The heat addition curve on a T-s diagram slopes continuously upward, raising the average temperature of heat addition (Tm1).
- Thermal Efficiency = 1 - (T2 / Tm1). Higher Tm1 yields higher cycle efficiency.

Material Challenges

- Requires advanced metallurgy (like T91, P92 steels) for superheater and reheater tubes to withstand high creep and oxidation at elevated temperatures.



Supercritical vs. Subcritical: Operational Differences

Feature	Subcritical Boiler	Supercritical Boiler
Pressure	$<$ 22.1 MPa (Typically 170 bar)	$>$ 22.1 MPa (Typically 250+ bar)
Steam Drum	Essential for steam/water separation	Completely absent (once-through)
Circulation	Natural or forced (pumped)	Once-through forced flow only
Water Chemistry	Standard treatment	Absolute purity required
Part Load Eff.	Lower at part loads	High (sliding pressure operation)

Supercritical vs. Subcritical: Economics & Environment

Economics & Environment

- Capital Cost: Supercritical units have higher initial costs due to the requirement for advanced, high-temperature alloy steels and massive feed pumps.
- Running Cost: Supercritical units consume 5-8% less coal for the same power output, leading to lower lifetime fuel costs.
- Emissions: Higher efficiency directly translates to reduced CO2, SOx, NOx, and particulate emissions per kWh.
- Plant Footprint: Supercritical boilers are physically more compact and have less thermal inertia, allowing faster start-ups.
- Future Trend: Transition towards Ultra-Supercritical (USC) and Advanced USC operating above 300 bar and 700 °C.

Subcritical
Base Efficiency
Baseline Emissions

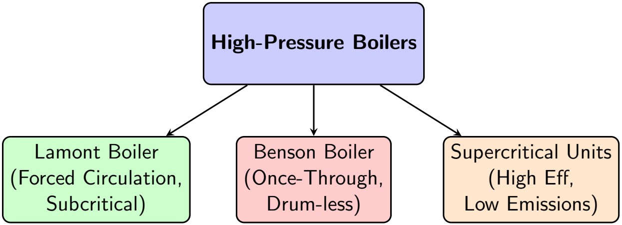
Upgrade →

Supercritical
+5% Efficiency
-5 to 8% Fuel/CO_2

Summary

Key Takeaways

- High-pressure boilers require forced circulation due to reduced density differences at elevated pressures.
- Lamont Boiler utilizes a circulating pump and drum for forced circulation at subcritical pressures.
- Benson Boiler pioneered the drum-less, once-through design suitable for critical and supercritical pressures.
- Modern Supercritical Boilers offer superior thermal efficiency and reduced emissions by operating above 22.1 MPa.
- The shift from subcritical to supercritical entails higher metallurgical costs but delivers significant operational and environmental benefits.



Preview of Next Lecture

Next Session

- Next Lecture: Draught Systems and Boiler Performance
- Understanding Natural, Forced, Induced, and Balanced Draughts.
- Calculation of chimney height and draught losses.
- Boiler efficiency testing and heat balance sheets.
- Please review the basic fluid mechanics regarding flow through ducts.