Steam Association of Manitoba

Course Notes for Steam Traction Engine Steam School

Revision1: April 2017

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Contents

1. Preamble

1.1 Scope

The program is aimed at entry-level engineers.

Steam school is a key part of providing important information about steam traction engines, their safe operation and management along with an overview of the role of agencies, steam organizations, inspectors and licensed shops that need to be part of a new engineer's frame of reference today.

1.2 Licensing Requirements

Licensing of Steam Traction Engineers in Manitoba requires:

- steam school organized and presented by the Steam Association of Manitoba (SAM) with instructors who are members of SAM. SAM might invite members from steam associations in other provinces or states to help instruct.
- one hour experience credit for each steam school hour (20 hours in total) plus…
    - at least 80 hours with a variety of hands-on experience signed off by licensed Steam Traction Engineers.
    - An ITS affidavit specifying steam experience activities
    - written exam
    - driver's test

1.3 Hands-on Experience

The type of practical experience is important. The qualified engineer signing off a candidate's hours should be ensuring that a wide variety of practical experience in steam traction engine operation and maintenance. Student engineers should be able to:

1. check for water in boiler and reservoir tank/s prior to startup
2. conduct a complete walk around (inspection) of the engine prior to fire up
3. inspect and install an ASME fusible plug
4. install hand holes
5. clean tubes, grates, smoke box and ash pan
6. lubricate the whole steam traction engine with the appropriate lubricants.
7. set valves and controls in appropriate positions before firing
8. bring engine up to operating pressure from a cold start
9. prove a water gauge glass with a boiler under pressure
10. operate try cocks
11. control fire to maintain appropriate pressure
12. operate injectors and/or pumps to maintain appropriate water level
13. know governor operation, lubrication, adjustment and belt maintenance
14. start, stop and maneuver the steam traction engine on level and sloping ground
15. belt up to a pulley
16. conduct an emergency shutdown
17. conduct a safe blow down
18. drain, wash and prepare boiler for storage
19. prepare boiler for inspection: internal, hydrostatic

1.4 Cautions and Competence

The accumulated hours along with steam school and a licensing exam is not enough. The licensed engineer providing the practical training must make a judgment with his/her signature testifying not just to the candidate's hours of experience, but that the candidate would make for a competent engineer.

2. Course Outline

2.1 Parts of a Steam Traction Engine

A steam traction engine is built from a set of major systems that work together to generate steam, convert it into motion, and transmit that motion to the wheels. The exact layout varies by maker, but the core architecture is consistent across full-size and scale engines.

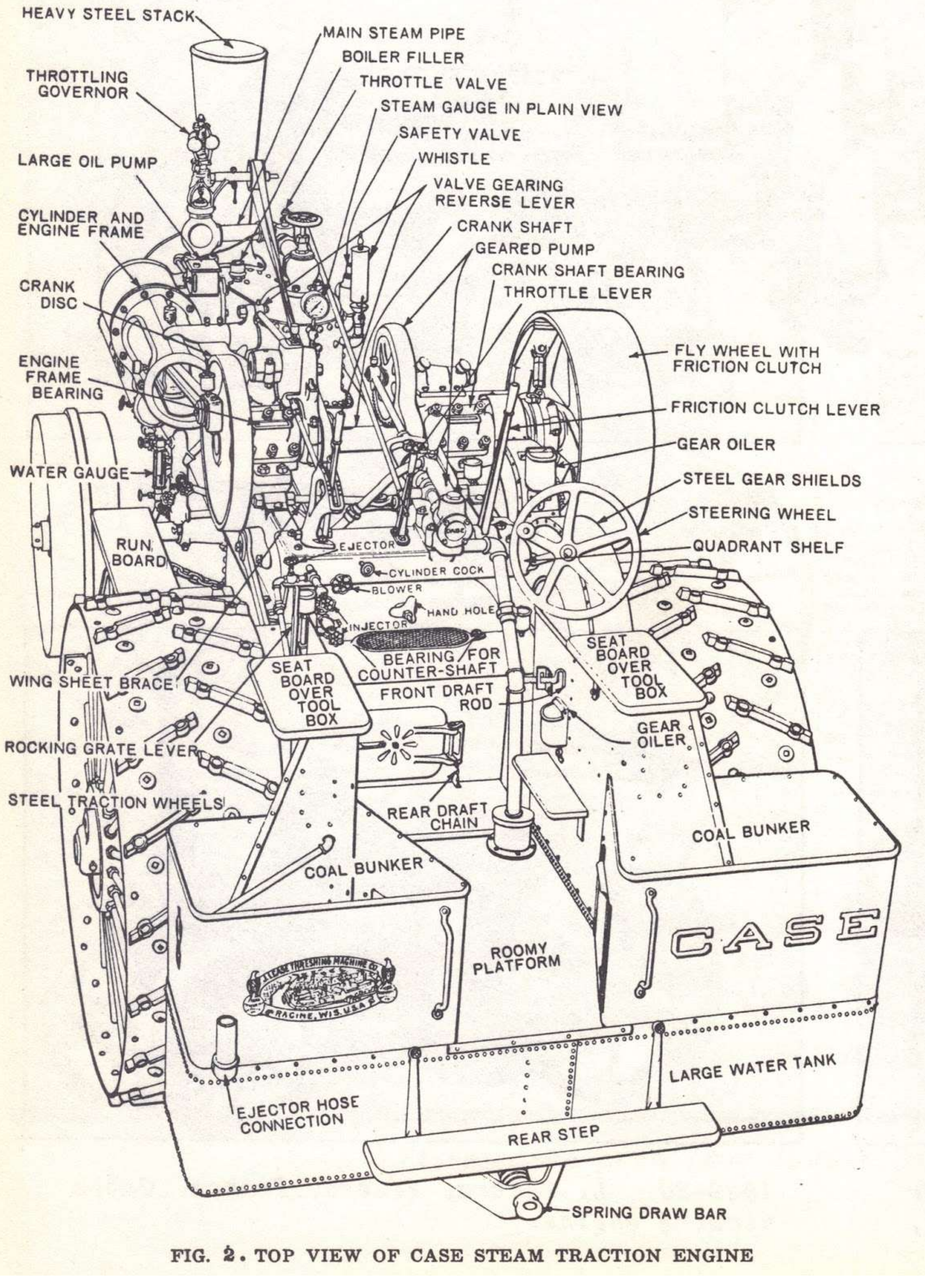


FIG. 2. TOP VIEW OF CASE STEAM TRACTION ENGINE

2.1.1 Boiler and Steam-Raising Components

These parts generate and manage steam pressure.

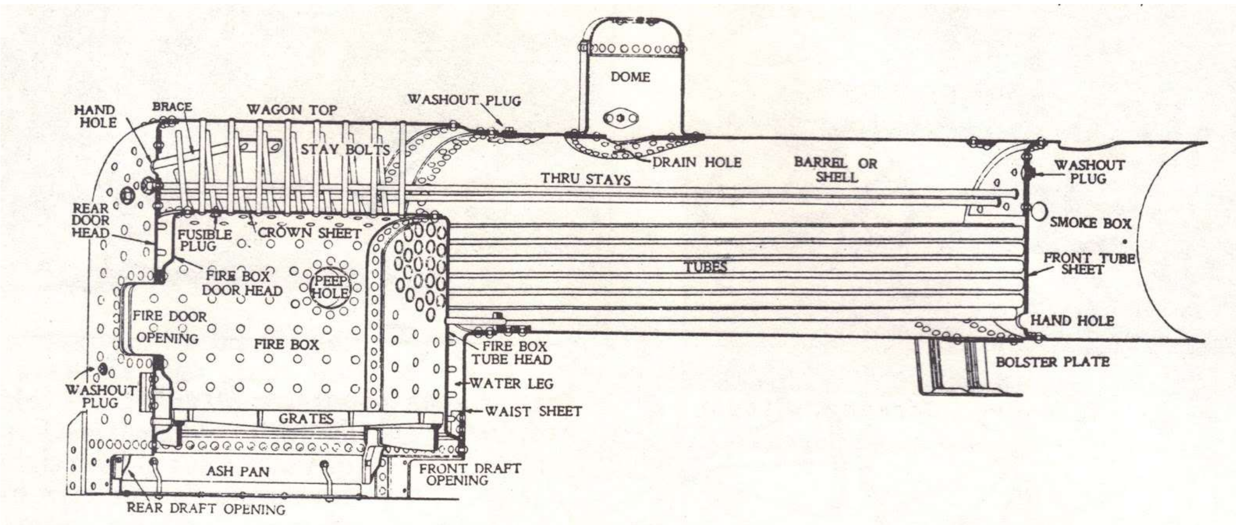


FIG. 1. SECTIONAL VIEW OF BOILER

- **Boiler shell** — The main pressure vessel where water is heated into steam.
- **Firebox** — Enclosed chamber where solid fuel (coal/wood) burns.
- **Grate** — Supports the burning fuel and allows air flow from below.
- **Ashpan** — Collects ash and regulates air intake.
- **Fire tubes / flue tubes** — Carry hot gases through the boiler to heat the water.
- **Smokebox** — Collects exhaust gases before they exit the chimney.
- **Chimney / stack** — Provides draft to pull air through the fire.
- **Dome** — High point on the boiler where the driest steam is collected.
- **Safety valves** — Prevent over-pressure by releasing excess steam.
- **Water gauge glass** — Shows boiler water level.
- **Blowdown valve** — Removes sludge and scale from the boiler.
- **Injector / feed pump** — Forces water into the boiler against pressure.
- **Check valves** — One-way valves for boiler feedwater.

2.1.2 Engine and Motion Work

These convert steam pressure into mechanical rotation.

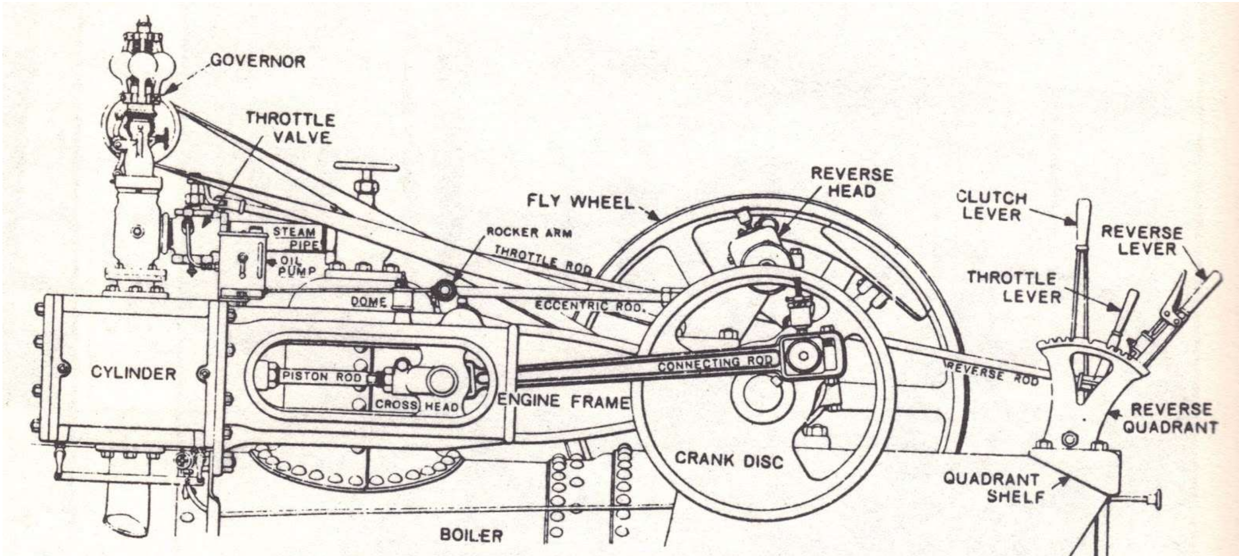


FIG. 3. SIDE ELEVATION OF ENGINE PROPER

- **Cylinder** — Where steam expands to push the piston.
- **Piston and piston rod** — Convert steam expansion into linear motion.
- **Crosshead** — Guides the piston rod in a straight line.
- **Connecting rod** — Transfers motion from piston to crankshaft.
- **Crankshaft** — Converts reciprocating motion into rotation.
- **Flywheel** — Smooths out power delivery.
- **Eccentrics and straps** — Drive the valve gear.
- **Valve gear** — Times steam admission and exhaust.
- **Slide valve or piston valve** — Controls steam flow into and out of the cylinder.
- **Governor** — Regulates engine speed automatically.

2.1.3 Transmission and Drive Components

These deliver power to the wheels and ground.

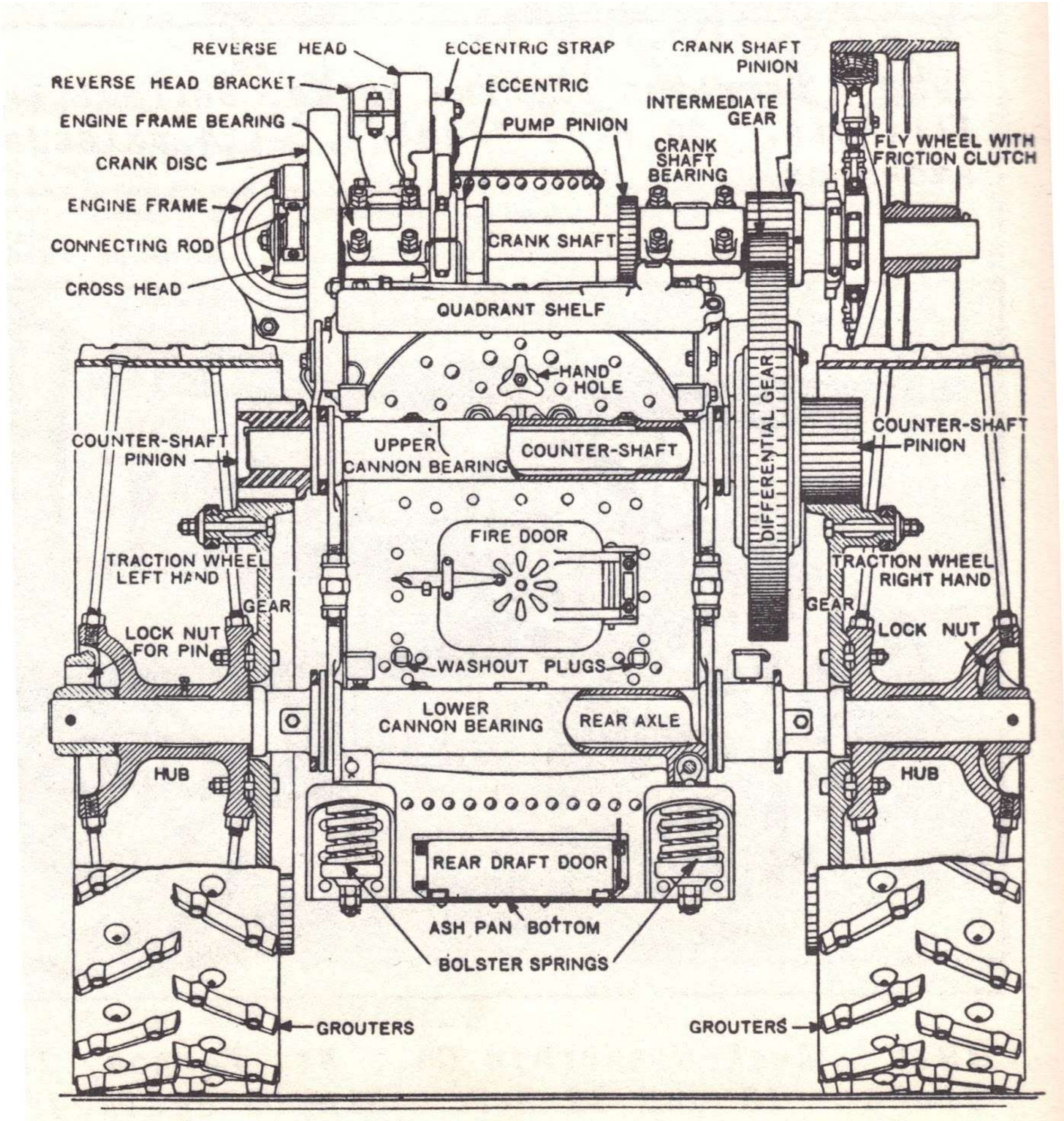


FIG. 4. CUT SHOWING CANNON BEARINGS AND GEARING

- **Gear train** — Provides selectable drive ratios.
- **Differential** — Allows wheels to turn at different speeds.
- **Final drive gears** — Transfer power to rear axle.
- **Rear axle and hubs** — Support and drive the rear wheels.
- **Front axle and steering gear** — Includes worm gear, chains, or steering shaft.
- **Wheels** — Typically large rear driving wheels and smaller front wheels.

2.1.4 Controls, Fittings, and Ancillaries

These support operation, lubrication, and safety.

- **Regulator (throttle)** — Controls steam flow to the cylinder.
- **Reversing lever / quadrant** — Sets direction and cutoff.
- **Cylinder drain cocks** — Remove condensate from cylinders.
- **Lubricators** — Feed oil to cylinder and bearings.
- **Whistle** — Steam-powered signaling device.
- **Pressure gauge** — Indicates boiler pressure.
- **Manifold / turret** — Distributes steam to auxiliary fittings.
- **Water lifter / hose** — Allows the engine to draw water from a source.
- **Toolboxes and footplate** — Operator's working area.

2.1.5 Structural Components

These hold everything together.

- **Wingsheets** — Heavy side plates supporting crankshaft and motion work.
- **Tender / bunker** — Stores coal and sometimes water.
- **Frame** — Supports boiler and running gear.
- **Bolster** — provides front axle support
- **Canopy (optional)** — Provides shade and weather protection.

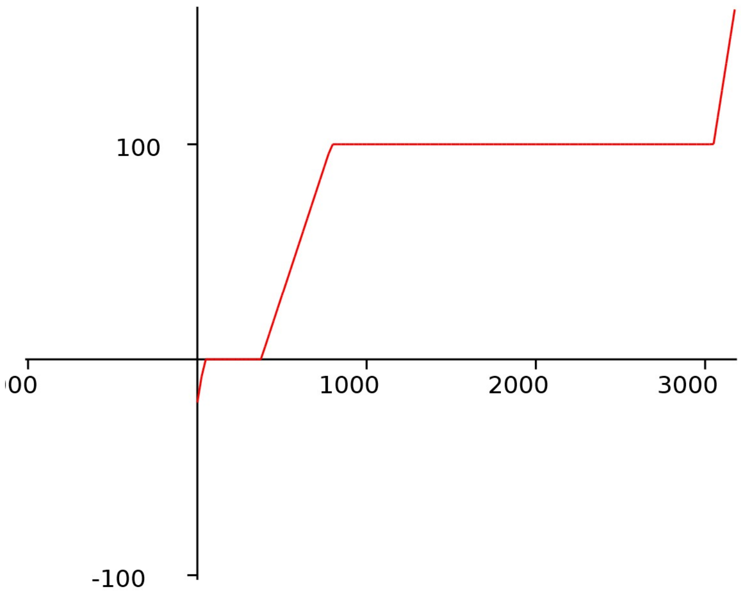
2.2 Properties of Water and Steam

2.2.1 Phases of water

Water's phase changes sit at the heart of how a steam traction engine produces power. The engine's entire job is to add enough energy to liquid water to push it through two major transitions—heating and vaporization—and then use the high-energy vapor to do mechanical work. The physics behind these transitions explains why steam engines need large fireboxes, heavy boilers, and constant water management.

Energy increases in **distinct, piecewise segments**

- **Sloped segments** — temperature rises because energy is increasing the *thermal motion* of molecules (specific heat applies).
- **Flat plateaus** — temperature stays constant because energy is going into *phase change*, not heating. This is latent heat:
- At 0 °C, energy breaks solid–liquid bonds (fusion).
- At 100 °C, energy breaks liquid–gas bonds (vaporization).
- **Piecewise nature** — each segment has its own equation:
- Phase changes consume enormous amounts of energy without raising temperature.



2.2.2 Heating water in the open vs. in a pressure vessel

- Heating in the open — Water boils at atmospheric pressure (≈100 °C / 212 °F). Once boiling begins, added heat only drives phase change; temperature does not rise further until phase change is complete.
- Heating in a pressure vessel — Confinement raises the boiling point. Water can be heated well above 100 °C before boiling begins, storing more sensible heat and producing higher-energy steam.
- "phase-change teaching pack."

2.2.3 Definition of BTU

- A **BTU** is the amount of heat required to raise **1 pound of water by 1 °F**.
- It's the standard unit for describing boiler output, fuel energy, and steam enthalpy.

2.2.4 Water to steam

  - latent heat of vaporization
  - wet steam
  - dry steam
  - superheated steam
- **Latent heat of vaporization** — The large amount of energy needed to break liquid-phase molecular bonds without raising temperature. At atmospheric pressure this is ~970 BTU/lb.
- **Wet steam** — Steam containing suspended water droplets; lower energy content and poor for efficient engine work.

- **Dry steam** — Steam with no entrained water; ideal for cylinders because it expands predictably and avoids water hammer.
- **Superheated steam** — Steam heated beyond its saturation temperature; contains extra energy and resists condensation during expansion, improving efficiency.

2.2.5 Pressure

- atmospheric pressure
- pressure gauge
  - psi and PSIG
- velocity and pressure (venturi)
- temperature and pressure

- **Atmospheric pressure** — The external pressure exerted by the air (~14.7 psi at sea level). It defines the boiling point of water.
- **Pressure gauge** — Measures pressure relative to atmosphere.
- PSI vs. PSIG —
  - **PSI**: pounds per square inch (can be absolute or gauge).
  - **PSIG**: pounds per square inch *gauge*, meaning pressure above atmospheric.
  - A gauge reading of 150 PSIG means the boiler is at ~165 PSIA (absolute)
- **Velocity and pressure (Venturi effect)** — As fluid velocity increases through a restriction, static pressure drops. This principle helps create draft and influences injector operation.
- **Temperature and pressure** — In saturated steam, temperature is fixed by pressure. Higher boiler pressure means higher steam temperature and higher stored energy.

2.2.6 Expansive properties of steam

Steam expands dramatically when pressure is released. This expansion converts internal energy into mechanical work. The piston harnesses this expansion, and cutoff timing determines how much of the expansion energy is used.

2.2.7 Flashover

When hot pressurized water is suddenly released to a lower pressure, part of it instantly flashes into steam. This occurs because the water contains more heat than is needed to remain liquid at the new pressure. In steam systems this is useful (flash steam recovery) but can also be hazardous if uncontrolled.

2.3 Boiler Design and Construction

2.3.1 Types of Boilers

- Fire tube

    - Vertical Tube Boiler
        - Wet top
        - Dry top
    - Return Flue
    - Locomotive
        - Wet bottom
        - Dry bottom
- Water tube
    - e.g. Bryan Tractor

Steam-era boiler designs fall into two big families—fire-tube and water-tube—and each subtype reflects a different way of moving heat from combustion gases into water. North American traction engines overwhelmingly used fire-tube boilers, but a few experimental and late-era tractors (like the Bryan) used water-tube designs. The following gives a condensed but technically accurate explanation of each type and subtype.

2.3.1.1. Fire-tube boilers

Fire-tube boilers route **hot combustion gases through tubes** surrounded by water. They are simple, rugged, and store a large volume of water—ideal for traction engines that see variable loads.

2.3.1.2. Vertical-tube boilers

A compact boiler with vertical fire tubes rising from the firebox to the top of the shell. Common on small portables, early tractors, and steam launches.

- **Wet Top** — The top of the furnace is covered by water.
    - Better heat transfer.
    - More steam space above the tubes.
    - Slightly safer because the crown sheet is water-cooled.
- **Dry Top** — The top of the furnace is exposed metal, not water-jacketed.
    - Simpler construction.
    - Less efficient heat absorption.
    - More vulnerable to overheating if water level drops.

2.3.1.3. Water-Tube Boilers

Water-tube boilers route **water through tubes** while hot gases flow around them. They heat rapidly, store less water, and can generate steam at high pressures.
Example: Bryan Tractor Boiler
The Bryan steam tractor used a **flexible water-tube** design with closely spaced, curved tubes.

- Very fast steaming.
- High efficiency due to large heating surface.
- Much safer under low-water conditions because tubes contain small water volumes.
- More complex and expensive to build.
- Less thermal inertia—requires steadier firing.

Water-tube boilers were rare in traction engines because farmers preferred the forgiving nature of large-water-capacity fire-tube boilers.

2.3.1.4. How these designs differ in practice

A few key distinctions help explain why certain types dominated:

- **Fire-tube = stability and simplicity** Large water volume smooths out firing irregularities and load swings.
- **Water-tube = responsiveness and efficiency** Rapid steam generation but less margin for operator error.
- **Wet vs. dry construction** "Wet" designs place more surfaces in contact with water, improving heat transfer and safety.
- **Return flue vs. locomotive** Locomotive boilers offer far more heating surface and draft control, which is why they became standard.

2.3.2 Five safety features on a boiler:

Every boiler has five safety devices built into its design. Each of these safety devices protects the boiler from a different failure mode. Together they form a layered system that lets an operator see what the boiler is doing, control it, and—if something goes wrong—prevent catastrophic damage. The explanations below are concise but still capture how each device works and why it matters on a traction engine.

Water-level and water-verification devices exist to answer one question: *Is the crown sheet safely covered?* Each device approaches that question differently, and together they give the operator redundancy and cross-checks.

2.3.2.1. Water gauge glass

A transparent tube connected to the boiler above the maximum water line (steam space) and below the minimum water line (water space).

- Shows the **actual water level** inside the boiler in real time.
- Lets the operator keep the crown sheet covered—*the single most important safety requirement*.
- If the water drops out of sight, the operator must immediately add water or drop the fire.

The gauge glass is the primary indicator of boiler water level. It shows the actual water level because it is connected to both the steam space and the water space.

Components

- **Top gauge cock (steam cock)** — Connects the upper end of the glass to the steam space.
- **Bottom gauge cock (water cock)** — Connects the lower end of the glass to the water space.
- **Gauge glass tube** — The transparent tube showing the water level.
- **Protective guards** — Metal rods or shields to contain glass fragments if the tube breaks.
- **Drain cock / blowdown valve** — Clears sediment and verifies the glass is reading correctly.

A correctly mounted gauge glass will have the bottom nut located 3 inches above the crown sheet. The gauge glass may be mounted to a water column or directly to the boiler, but the principle is the same.

Checking water with no boiler pressure

With **zero pressure**, the gauge glass cannot show a true level because there is no pressure differential to keep water in the glass.

The correct method is:

- Open the top and bottom gauge cocks briefly
- Water should flow from the bottom cock
- Steam or air should escape from the top cock
- If both produce water, the boiler is full
- If both produce air, the boiler is empty

This is a *static* check, not a running indication.

2.3.2.2. Try cocks

Try cocks are small test valves mounted at fixed heights on the boiler or water column. They provide a direct, mechanical confirmation of water level. Two try cocks are required but many boilers have three.

What the try cocks do

Each cock tells you whether its height is in **water** or **steam**:

- Open a cock briefly
- If **water** comes out, the water level is above that cock
- If **steam** comes out, the water level is below that cock

Their purpose is to:

- Verify the gauge glass is truthful
- Provide a backup if the gauge glass is clogged or broken

- Give a quick safety check during firing or under load

Try cocks are deliberately simple: no glass, no moving parts except a valve stem, and no dependence on pressure balance. They are the final, most reliable way to confirm crown-sheet coverage.

Try cocks may be mounted to the water column or directly to the back head. On some boilers they are mounted in both locations.

Safety valve

A safety valve is a spring-loaded device that opens automatically when boiler pressure reaches its set point. It prevents over-pressure by venting steam faster than the boiler can generate it and serves as the final fail-safe against explosion.

- **MAWP compliance** — The valve must be set and certified to open at or below the boiler's Maximum Allowable Working Pressure.
- **Relief and regulating functions** — These valves are for over-pressure protection only; they are not throttling or control valves.
- **ASME requirements** — Construction, lift capacity, and set-pressure accuracy must meet ASME standards.
- **Piping arrangement** — The valve must have a direct, unobstructed connection to the boiler with discharge piping that does not restrict flow or create back-pressure.
- **Certified servicing** — Periodic testing, sealing, and documentation by qualified personnel ensure correct operation and opening pressure.

2.3.2.3. Steam pressure gauge

Steam pressure gauge

- Measures boiler pressure using a Bourdon tube that flexes in response to internal pressure.
- Shows how close the boiler is to the safety-valve setting and reflects firing rate, load changes, injector action, and draft quality.
- Essential for safe operation; the engine is managed by the gauge, not by subjective feel.

Operating pressure range

- Gauge range must cover the boiler's full working pressure.
- Should provide clear resolution near normal operating pressure and the safety-valve setting.

Siphons

- Protect the gauge from live steam by trapping a water pocket that absorbs heat.
- **Pigtail siphon** — curled loop that holds water and reduces vibration.
- **U-tube siphon** — compact vertical loop used where space is limited.

Gauge shutoff valve

- Allows isolation of the gauge for maintenance or replacement.
- Must provide a clear visual indication of open or closed position to avoid operating the boiler with the gauge unintentionally isolated.

PSI and PSIG

- **PSI** — pounds per square inch; may refer to absolute or gauge pressure depending on context.
- **PSIG** — pressure above atmospheric pressure.
- A reading of **150 PSIG** corresponds to roughly **165 PSIA**, accounting for atmospheric pressure.

2.3.2.4. Fusible plug

A bronze plug with a low-melting-point metal core (usually tin).

- Installed in the **crown sheet**, the hottest part of the firebox.
- If water drops below the crown sheet, the plug melts and vents steam into the firebox.
- This creates a violent but controlled warning that forces the fire to die down and alerts the operator.
- Its purpose is to **prevent crown-sheet overheating**, the most common cause of boiler explosions.
- Fusible plugs must be replaced after 500 hours of service or within 10 years of initial installation.

2.3.2.5. How these devices work together

A traction engine's boiler is safest when multiple indicators agree:

- The **gauge glass** shows the water level continuously.
- The **try cocks** verify the gauge glass.
- The **pressure gauge** shows how hard the boiler is working.
- The **safety valve** prevents runaway pressure.
- The **fusible plug** protects the crown sheet if water level is lost.

This layered design reflects 19th- and early-20th-century engineering philosophy: assume components can fail, and provide redundant, simple, mechanical safeguards

2.3.3 Boiler Construction

The construction described here is for a conventional locomotive-style boiler.

2.3.3.1. Firebox, barrel, smoke box

- Firebox: the furnace where fuel burns, surrounded by water on the sides, rear, and top.

- Barrel: the cylindrical boiler shell containing water space, steam space, and fire tubes.
- Smoke box: the front chamber receiving hot gases from the tubes and directing them up the stack. Components: exhaust pipe, exhaust nozzle or jet, blower pipe, stack, spark arresters or screens.

2.3.3.2. Side sheets, throat sheet, back head, wagon top

These components have atmosphere on one side and pressure on the other. Collectively, they are referred to as the external shell.

- Front tube sheet: contains tube holes
- Side sheets: vertical water-jacketed walls of the firebox.
- Throat sheet: sheet supporting the connection between firebox and barrel.
- Back head: rear boiler sheet holding the fire door and fittings.
- Wagon top: raised upper shell providing increased steam space.
- The wagon top and side sheets are formed from a shingle sheet of steel with a constant radius bend starting above the side row of staybolts.

2.3.3.3. Firebox parts

These components have hot fire and gases on one side and pressure on the other. Collectively, they are referred to as the internal shell

- Side sheets: vertical firebox walls cooled by surrounding water.
- Crown sheet: top plate of the firebox directly above the fire.
- Side sheets and crown sheets are formed from a single sheet bent at shoulders and crown
- Back sheet: rear firebox wall supporting the fire door.
- Rear or back tube sheet: plate separating firebox and barrel, containing tube holes.
- Tubes: transmit heat products of combustion from firebox to smoke box

2.3.3.4. Firebox doors

- Wood and coal fuel doors: hinged doors for solid fuel firing and airflow control.
- Straw chutes and arches: special doors and refractory arches for straw firing.
- Inspection doors either above fuel door or on side wall
- Some boilers have 2-inch air ports through the upper rear side walls
- Rear draft and front cleanout doors below grates above ashpan

2.3.3.5. OG ring or mud ring

- Heavy ring joining the bottom edges of firebox sheets to the outer wrapper, forming the water space and collecting sediment.

2.3.3.6. Barrel

- Uniform diameter barrel: straight cylindrical shell of constant diameter.

- Variable-diameter barrel: constructed from multiple rings to optimize steam space and strength.

2.3.3.7. Barrel segments

- Smoke box and shell ring: front ring supporting the smoke box.
- First course: main cylindrical section behind the smoke box.
- Conical ring: tapered ring transitioning between diameters.
- Dome course: ring containing the steam dome.
- Throat sheet connection: rear end where barrel meets throat sheet.
- Roof sheet (wagon top): raised upper shell providing additional steam space.

2.3.3.8. Dome

- Single riveted vertical seam
- Circular dome seam
- Optional diagonal stays
- Barrel is reinforced by inner plate whose shape conforms to the saddle
- Large openings for steam line reinforce by riveted backing plate

2.3.3.9. Seams and joints

- Riveted lap seam: one plate overlaps another; single, double, or triple riveted.
- Riveted butt strap: plates meet edge-to-edge with one or two internal straps; single, double, or triple riveted.
- Welded seams: fusion-welded joints eliminating rivet holes.
- Joint strength: determined by rivet pattern, plate thickness, and construction method.

2.3.3.10. Tensile strength of boiler sheets

- Sheet thickness and tensile strength determine allowable working pressure.

2.3.3.11. Front and rear tube sheets (flue sheets)

- Tubes or flues: carry hot gases from firebox to smoke box.
- Flue size: chosen for heat transfer and draft characteristics.
- Tube sizing: measured on outer diameter.
- Ferrules: sleeves reinforcing tube holes.
- Rolling: expanding tube ends into sheets for a tight seal.
- Beading: rolling a lip on the firebox end of tubes.
- Prossering: mechanical method of expanding and sealing tubes.

2.3.3.12. Smoke box

- Usually a simple extension of the barrel past the front tube sheet
- Collects hot gases after they pass through tubes and directs them up the stack.

- Components: exhaust pipe, exhaust nozzle or jet, blower pipe, stack, spark arresters or screens.

2.3.3.13. Hand hole, gaskets, washout plug

- Hand hole: access opening for internal inspection and cleaning.
- Gaskets: sealing rings used with hand hole plates.
- Washout plug: removable plug for flushing sediment.

2.3.3.14. Stays

2.4 Items attached to the boiler

2.4.1 Safety features

- Water gauge glass
- Try cocks
- Safety valve
- Steam Pressure Gauge
- Fusible plug

See **Error! Reference source not found.**

2.4.2 Boiler features

- Devices to put water into the boiler
    - Injectors
        - designed to pickup over a pressure range
        - swing check valves
        - how injectors work
        - how to operate injectors
        - troubleshooting injector problems
    - Feed water Pumps
        - mechanical pumps
            - driven by engine motion
                - gear pump
                - eccentric pump
                - crosshead pump
            - move water only when engine is turning
            - valves control water flow direction
                - recirculate to tender
                - deliver to boiler
        - independent pumps
            - steam powered pump
        - heaters
        - top check valves

- Nipples and shutoff (isolation) valves off the boiler
    - as opposed to control valves
    - short length Schedule 80 to the first shutoff valve
- Dome Valve
    - what it does
    - when to use it
- Blower
    - what it does
    - caution – chilling tubes with air coming through holes in a fire
- Blow down Valve
    - helps control level of total dissolved minerals
    - planning for a blow down
    - valve design
- Fusible Plug
    - Indicates to the engineer a low water condition
- Whistle
    - purpose of a whistle
        - whistle codes
    - use around people and animals
    - piping and shutoff valve
- Hand Holes
    - purpose of hand holes
    - installing hand hole gaskets
        - tools required
        - gaskets
            - size varies with different steam traction engines
            - gaskets must be steam service rated (temperature and pressure)
- Ash Pan
    - purpose
    - maintenance
    - not present on wet bottom boilers
- Grates
    - purpose
    - types appropriate to fuel
- Dampers
    - purpose
    - front and rear dampers
    - use of dampers when using arches

- Water column is a vertical chamber mounted beside the boiler or on the backhead that the gauge glass attaches to. It provides:
- A stable, less turbulent water level
- Space for try cocks
- A safer location for fittings away from the boiler shell
- Reduced risk of scale blocking the gauge connections

2.4.3 Devices to put water into the boiler

Devices that deliver water to a traction-engine boiler fall into two families—injectors and pumps. Both must push water **against boiler pressure**, but they do it in completely different ways.

2.4.3.1. Injectors

Injectors use **steam pressure itself** to force cold water into the boiler. They have no moving mechanical parts other than check valves.

Components

- **Steam cone**: Admits high-velocity steam.
- **Combining cone**: Where steam mixes with incoming water.
- **Delivery cone**: Narrows the flow and increases pressure.
- **Overflow**: Discharges water/steam if the injector is not “picked up.”
- **Swing check valves**: One-way valves preventing boiler pressure from pushing back into the injector.

Designed to pick up over a pressure range

Each injector is built to operate within a **specific steam-pressure window**.

- Too little pressure → steam cannot accelerate water enough to exceed boiler pressure.
- Too much pressure → injector may “break” because the steam jet cannot condense properly.

How injectors work

The injector uses the **velocity energy** of steam to create pressure:

1. Steam expands through the steam cone, reaching very high velocity.
2. The steam jet entrains cold water in the combining cone.
3. The steam condenses instantly, transferring its velocity to the water.
4. The resulting water jet exits the delivery cone at **higher pressure than the boiler**, opening the top check valve and entering the boiler.

This is a direct application of the **Bernoulli principle** and the **latent heat of condensation**.

How to operate injectors

- Open the water valve first.
- Crack the steam valve until the injector “picks up” (steady, smooth sound).
- Adjust steam and water for a stable delivery.
- Ensure the overflow stops discharging—overflow means it is not injecting.
- Shut off steam first when stopping.

Troubleshooting injector problems

- **Won’t pick up**: Water too hot, insufficient steam pressure, air leaks in suction line, insufficient water in tender.
- **Overflows constantly**: Steam valve opened too far or water supply restricted.
- **Intermittent delivery**: Scale in cones, worn cones, or fluctuating water supply.
- **Stops when boiler pressure rises**: Injector not sized for the new pressure range.

2.4.3.2. Feedwater Pumps

Pumps are mechanical devices that physically push water into the boiler. They work whenever the engine is turning or when powered independently.

Mechanical pumps (engine-driven)

These pumps move water only when the engine rotates.

- **Gear pump**: Uses meshing gears to push water; steady and reliable.
- **Eccentric pump**: Driven by an eccentric on the crankshaft; common on traction engines.
- **Crosshead pump**: Driven by the piston crosshead; stroke-matched to engine motion.

How mechanical pumps move water

- Pump stroke or gear rotation draws water from the tender.
- Check valves ensure one-way flow.
- Water is either delivered to the boiler or recirculated.

Valves controlling water direction

- **Recirculate to tender**: Allows pump to run without forcing water into the boiler (useful during warm-up).
- **Deliver to boiler**: Opens the line to the boiler’s top check valve.

Independent pumps (steam-powered)

A **steam-powered pump** operates even when the engine is not turning.

- Useful for raising water level during warm-up or emergencies.

- More complex but very reliable.

Heaters

Feedwater heaters warm incoming water using exhaust steam.

- Reduces thermal shock to boiler plates.
- Improves efficiency by preheating water before injection.

Water inlet check valves

These are the final one-way valves on the boiler shell and are required for both injectors and pumps.

- Prevent boiler pressure from pushing water backward.
- Must seal perfectly for injectors and pumps to work.

Nipples and isolation valves at the boiler outlet are treated differently from downstream control valves because they sit in the hottest, highest-pressure, highest-stress part of the entire piping system. The points below give a condensed explanation of what matters and why.

2.4.3.3. Nipples and isolation valves at the boiler

These are the **first components attached directly to the boiler nozzle**. Their job is to provide a short, safe transition from the boiler shell to the rest of the piping system.

- They must withstand full boiler pressure and temperature at all times.
- They experience the greatest thermal cycling and vibration.
- They form the boundary between the boiler proper and the external piping system.

Because of this, they must be built to a higher standard than ordinary line valves.

Isolation valves vs. control valves

Isolation (shutoff) valves

- Used to completely open or completely close flow.
- Must be able to hold full boiler pressure without leaking.
- Installed as close to the boiler nozzle as physically possible.
- Required for safety, maintenance, and emergency shutdown.

Control valves

- Used to regulate flow, not isolate it.
- Installed downstream, after the isolation valve.
- Not designed to withstand continuous full boiler pressure at the boiler outlet.

The code distinction is simple: the first valve must be a shutoff valve, not a throttling or regulating valve.

Short Schedule 80 nipple to the first shutoff valve

A short, heavy-wall nipple is required between the boiler and the first valve.

- **Schedule 80** is required because of its thicker wall and higher pressure rating.
- The nipple must be **as short as practical** to minimize bending stress and vibration.
- This section sees the highest temperature and pressure, so seamless Schedule 80 is strongly preferred.
- After the first shutoff valve, piping may step down in schedule only if permitted by code and pressure rating.

This short heavy-wall section ensures that the most critical part of the piping system has the greatest safety margin.

2.4.3.4. Dome valve

The dome valve is the **main steam isolation valve** mounted at the steam dome outlet. It controls the flow of dry steam from the boiler into the engine's throttle and auxiliary systems.

- The dome valve isolates or opens the boiler's steam supply. Because it sits at the dome—where steam is driest—it provides the cleanest, driest steam to the engine. It also serves as a safety boundary: closing it isolates the boiler for maintenance or emergencies.
- **I**t is used when placing the engine in service, shutting it down, or isolating the boiler for repairs. It is not a regulating valve; it should be either fully open or fully closed to avoid wire-drawing and seat erosion.

2.4.3.5. Blower

The blower is a small steam jet in the smokebox that creates artificial draft by pulling hot gases through the tubes and up the stack.

- The blower increases draft when the engine is not exhausting steam—during lighting up, low-load operation, or when the engine is stopped. It keeps the fire bright and prevents smoke from rolling out the firedoor.
- **Caution: chilling tubes with air through holes in a fire** Excessive blower use with a thin or patchy fire can pull **cold air** through gaps in the fuel bed. Cold air striking hot tubes can cause thermal shock, tube leakage, or cracking. The blower should be used lightly and only when needed, with a well-covered firebed.

2.4.3.6. Blowdown valve

The blowdown valve removes concentrated boiler water from the lowest point of the boiler to control mineral buildup and sediment.

- **Helps control total dissolved minerals** As water boils, minerals stay behind and concentrate. Periodic blowdown removes high-TDS water and sediment, slowing scale formation and protecting the crown sheet and tubes.

- **Planning for a blowdown** Blowdown should be done when the boiler is hot and steaming, but not at peak pressure. The operator should ensure: adequate water level before opening the valve
    - people and equipment are clear of the discharge area
    - the valve is opened fully and briefly (cracking it open erodes the seat)
    - the boiler is refilled afterward with fresh water
- **Valve design** Blowdown valves are heavy, quick-opening valves—usually a straight-through quarter-turn or angle globe design—with a robust seat and a short, direct discharge path. They are designed to withstand erosion from high-velocity, high-temperature water and sediment.

2.4.3.7. Whistle

A whistle is both a safety-related signaling device and a communication tool for people and animals around a working traction engine.

- provides an audible signal that carries over long distances and through ambient noise.
- Used to alert bystanders, communicate intentions, and signal engine movements where visibility is limited.
- Serves as a courtesy and safety device when operating near people, livestock, or other equipment.

Whistle codes

- One short blast: engine stopped; finished with engine
- Two short blast: engine is about to start
- Three short blasts: sheaves needed
- 1 long blast, 3 short blasts: need water immediately
- Many short blasts: emergency, fire or accident
- Codes help coordinate with ground crews and reduce the chance of miscommunication.
- Around animals used to engines, brief and predictable signals reduce the risk of startling them.
- Whistle use should be assessed before using it around animals unaccustomed to engines

Piping and shutoff valve

- The whistle is supplied by a dedicated steam line with a small isolation valve for maintenance.
- The shutoff valve must clearly indicate open or closed position to avoid unintentionally disabling the whistle.
- Piping should be direct, properly supported, and sized to deliver a clean, responsive whistle tone.

2.4.3.8. Hand holes

- Provide access to the boiler's internal surfaces for washing, scale removal, and inspection of sheets, stays, and seams.
- Located at low points and washout locations where sediment accumulates. Optionally located higher on the back head or on the barrel shoulder
- Sealed by flanged plate with integrated bolt, external bridge and nut
- Must seal reliably because they sit directly in the pressure boundary.

Installing hand-hole gaskets

- Surfaces must be clean, smooth, and free of scale or debris to ensure proper seating.
- Gasket is positioned on the flanged hand-hole plate and drawn tight against the boiler sheet using the nut.
- Even tightening is essential to avoid distortion and ensure a uniform seal.
- After steaming up, joints should be checked for weeping and retightened if needed.
- May loosen after the first heat cycle because cooling reduces pressure and a new gasket compresses as it beds in.

Tools required

- Scrapers or wire brushes for cleaning seating surfaces and cover-bolt threads
- Wrenches sized for the nuts
- Vice grips for use on bolts to rotate or reposition the internal plate
- Wire for securing bolt ends when there is a risk of dropping the plate into the boiler.
- Flashlight or inspection light for internal visibility.
- Gloves and protective equipment for handling hot components during checks.
- Paint marker for numbering covers and locations when fit varies between openings

Gaskets

- Sizes vary by manufacturer and model; traction engines do not use a universal standard.
- Must be rated for steam service, meaning they can withstand boiler temperature and pressure without softening, extruding, or degrading.
- Common materials include steam-rated fiber, graphite, or composite gaskets designed for curved hand-hole plates.

2.4.3.9. Ash Pan

The ash pan collects falling ash and embers beneath the grates, keeping them from dropping onto the ground and maintaining proper airflow through the firebed. It also protects the area under the engine from fire hazards.

- **Purpose** — Holds ash, prevents ground fires, and maintains a controlled air path through the grates.

- **Maintenance** — Must be emptied regularly to prevent ash buildup from choking primary air. Warped or corroded pans should be repaired or replaced to maintain safe clearance and airflow.
- **Not present on wet-bottom boilers** — Wet-bottom fireboxes have a water-cooled lower sheet instead of an ash pan; ash falls into a pit or must be managed externally.

2.4.3.10. Grates

Grates support the fuel bed and allow controlled airflow from below, shaping how the fire burns and how heat is delivered to the boiler.

- **Purpose** — Hold the fuel, admit primary air, and allow ash to fall away so the firebed stays active and even.

Types appropriate to fuel

- **Coal grates** — Narrow bars with air gaps sized to admit strong under-fire air and shed clinkers.
- **Wood grates** — Wider spacing or heavier bars to support larger fuel pieces and reduce excessive under-fire draft.
- **Straw or light-fuel grates** — Often use finer spacing or special patterns to prevent fuel from falling through and to moderate draft.

Matching grate type to fuel improves combustion efficiency and reduces clinker formation.

2.4.3.11. Dampers

Dampers regulate the amount of air entering the firebox and the flow of hot gases through the boiler, directly affecting draft strength and firing rate.

- **Purpose** — Control draft by adjusting how much air enters beneath the grates and how quickly gases move through the tubes. Proper damper use stabilizes steam pressure and prevents over- or under-firing.
- **Front and rear dampers** — Many traction engines have both:
  - **Front damper** controls air entering under the grates.
  - **Rear damper** controls gas flow at the base of the smokebox or uptake. Using both allows fine control of fire intensity and heat distribution.
- **Use with arches** — When a brick arch is installed, dampers help maintain the correct gas path over and around the arch. Reduced under-fire air and increased over-fire circulation help complete combustion and protect the tubes from cold-air impingement.

2.5 Piping, Fittings and Valves

2.5.1 Pipe

2.5.1.1. Types and construction

- **Rolled and welded pipe** — Formed from a steel strip rolled into a cylinder and longitudinally welded. Suitable for many steam applications when properly rated.
- **Seamless pipe** — Manufactured without a weld seam; stronger and more uniform under pressure and thermal cycling. Preferred for high-stress boiler piping.
- **No galvanized pipe** — Zinc coatings degrade at steam temperatures, producing zinc oxide and potentially toxic fumes; flakes can also contaminate valves and injectors.

2.5.1.2. Pipe names and sizes

- Pipe is specified by **nominal size** and **schedule**, which defines wall thickness.
- **Schedule 40** — Standard wall; adequate for low-pressure service but not recommended near the boiler.
- **Schedule 80** — Heavy wall; higher pressure rating and better resistance to erosion and vibration.
- **Schedule 160** — Extra-heavy wall; used where very high pressure or mechanical stress is present.

2.5.1.3. Material specifications

- **SA-53 Grade A or B, Type E or S** — Welded or seamless pipe made from rolled steel strip; acceptable for many steam lines when properly rated.
- **SA-106 Grade A, B, or C** — Seamless carbon-steel pipe specifically intended for high-temperature, high-pressure service; preferred for traction-engine steam piping.

2.5.1.4. Code requirements

- **Schedule 80 from the boiler to the first shutoff valve** — This section sees the highest temperature and pressure and must have maximum strength.
- **Schedule 80 seamless pipe and fittings recommended throughout** — Provides superior durability under vibration, thermal cycling, and long-term steam exposure.

2.5.2 Fittings

2.5.2.1. Types

- Includes elbows, nipples, bushings, bell reducers, solid plugs, couplings, and unions, all selected for steam-service pressure and temperature.

2.5.2.2. Requirements

- **Steam-service class** — Fittings must be rated for saturated-steam temperature and the boiler's MAWP.
- **NPT threads** — Boiler piping uses **National Pipe Taper (NPT)** threads to ensure a pressure-tight mechanical seal.
- **Sealants** — Use steam-rated pipe dope or Teflon tape applied sparingly; excessive sealant can extrude into the line and obstruct valves or injectors.

2.5.3 Valves

2.5.3.1. Valve types

- **Globe valves** — Best for throttling and fine flow control; common for auxiliary steam lines.
- **Gate valves** — Designed for full open/full closed isolation; not suitable for throttling.
- **Ball valves** — Quick-acting isolation valves; must be explicitly steam-rated to avoid seat degradation.

2.5.3.2. Identifying steam-rated valves

- Markings should indicate pressure-temperature rating, material, and steam service approval.
- Non-steam valves (e.g., water or air service) may fail rapidly under boiler conditions.
- Identifying marks on tag under handle correlate to design and CRN documentation

2.5.3.3. Check valves

- **Swing check** — Hinged flapper; good for horizontal lines with steady flow.
- **Top check (lift check)** — Vertical lift design; suitable for injector delivery lines and vertical runs.
- **Ball check** — Simple ball-and-seat design; commonly used in water-glass service where small, clean flow paths are required.

2.5.3.4. Documentation

- All pipe, fittings, and valves should be purchased with **material certifications**, **pressure-temperature ratings**, and **traceable documentation** to verify suitability for boiler service.
- Valves used for service in Canada must have a Canadian Registration Number and documentation valid for the date of purchase.

2.6 Boiler Water Treatment

Water treatment protects the boiler from oxygen attack, mineral scale, corrosion, and unstable water conditions.

2.6.1 Purpose of water treatment

- Water treatment maintains boiler health by controlling oxygen, dissolved minerals, and pH. Proper treatment reduces corrosion, prevents scale, stabilizes water chemistry, and extends boiler life.

2.6.2 Boiler water and water tank testing

- **Test kits and labs** — Portable kits measure hardness, alkalinity, sulfite, and pH; laboratory testing provides more accurate mineral analysis when needed.
- **Chemical selection** — Treatment chemicals should be chosen with professional guidance to match local water chemistry and boiler design.
- **Safe handling** — Chemicals must be stored in labeled containers, kept dry, and handled with gloves and eye protection.
- **Record keeping** — Maintain logs of test results, chemical additions, and blowdown events to track trends and adjust treatment.

2.6.3 Oxygen in water

- **Corrosion risk** — Untreated, unheated water causes the most oxygen damage in the first 24 hours, leading to pitting and “necking” of steel surfaces.
- **Oxygen scavengers** — Chemicals such as sulfite bind dissolved oxygen and prevent corrosion; they must be maintained at proper residual levels.

2.6.4 Minerals in water

- **Scale formation** — Hardness minerals (calcium, magnesium) precipitate on hot surfaces, reducing heat transfer and causing overheating.
- **Sludge benefits** — Proper treatment converts hardness into soft sludge that stays suspended and can be removed by blowdown rather than forming hard scale.

2.6.5 Blowdown

- Removes concentrated minerals and sludge from the boiler.
- Controls total dissolved solids (TDS), removes sludge, and prevents scale and foaming.
- Performed when the boiler is hot and steaming but not at peak pressure.
- Ensure safe discharge, adequate water level, and full-open/short-duration operation to avoid seat erosion.
- Frequency depends on water quality and treatment program.

2.6.6 pH levels

- Boiler and tank water should be maintained around **pH 10**, which minimizes corrosion and supports proper chemical reactions.
- Low pH causes acidic corrosion; high pH increases foaming and caustic embrittlement risk.

2.6.7 Foaming

- **What it is** — Formation of stable bubbles on the water surface caused by high TDS, oils, or organic contamination.
- **How to deal with it** — Reduce TDS through blowdown, correct chemical balance, and eliminate contamination sources.

2.6.8 Priming

- **What it is** — Carryover of water droplets into the steam line, often caused by high water level, sudden load changes, or foaming.
- **How to deal with it** — Lower water level to normal range, stabilize firing rate, correct foaming, and ensure proper boiler water chemistry.

2.7 Engines

2.7.1 Types of steam engines

Steam engines differ in how many cylinders they use and how steam is expanded.

- **Simple engines** — Expand steam once in each cylinder.
  - **Single-cylinder** — One cylinder drives the crankshaft; simplest design but less smooth and less efficient.
  - **Double-cylinder (simple double)** — Two identical cylinders receive full-pressure steam; smoother running and better traction.
- **Compound engines** — Expand steam in stages for higher efficiency.
- **Tandem compound** — High-pressure and low-pressure cylinders arranged in line on a common axis.
- **Cross compound** — High-pressure and low-pressure cylinders placed on opposite sides of the engine, each driving its own crank.

These configurations balance efficiency, smoothness, and mechanical simplicity depending on the engine's intended work.

2.7.2 Determining power output

Power can be expressed in several ways depending on whether it is theoretical, measured at the engine, or delivered to the ground.

- **Horsepower (indicated horsepower)** — Calculated from cylinder dimensions, boiler pressure, and engine speed; represents the theoretical power developed inside the cylinders.
- **Drawbar horsepower** — The usable power delivered to the ground through the drawbar; accounts for mechanical losses in gears, bearings, and traction.
- **Torque** — The twisting force applied to the crankshaft and wheels; determines pulling ability at low speeds and under heavy load.

- **Prony brake** — A mechanical device that measures torque and rotational speed directly from the flywheel to determine actual horsepower.
- **Dynamometer** — A rolling or stationary device that measures drawbar pull and speed to calculate real-world drawbar horsepower under load.

2.7.3 **Typical** components **of traction engines**

2.7.3.1. Water and controls

- **Water tanks** — Located on the rear deck, side tanks, or saddle tanks depending on engine design.
- **Throttle** — Regulates steam flow to the engine.
- **Governor** — Automatically maintains engine speed under changing load.
- **Reverse gear** — Sets direction and valve cutoff; includes a **reverser quadrant** with **notches** for adjusting steam expansion.

2.7.3.2. Engine structure

- **Engine bed** — Main structural casting supporting the crankshaft, cylinder, and gearing.
- **Crankshaft** — Converts reciprocating motion into rotation.
- **Main bearings** — Support the crankshaft and carry engine loads.
- **Flywheel** — Smooths power pulses and stores rotational energy.
- **Crank disc and crank pin** — Transfer motion from connecting rod to crankshaft.

2.7.3.3. Motion components

- **Connecting rod** — Transfers piston motion to the crank pin.
- **Crosshead** — Guides the piston rod in a straight line; includes **guides**, **wrist pin**, **shoes**, and **lubricator**.
- **Piston rod** — Connects piston to crosshead; includes **packing** to prevent steam leakage.
- **Piston** — Converts steam pressure into linear motion.
- **Cylinder** — Houses the piston and steam passages.

2.7.3.4. Valve gear and steam distribution

- **Valve chest** — Chamber supplying steam to the valve.
- **Valve rod** — Operates the valve; includes **packing** to maintain a steam-tight seal.
- **Eccentrics** — Drive the valve gear to time steam admission and exhaust.

2.7.3.5. Exhaust and heating

- **Exhaust** — Releases spent steam to the stack to create draft.
- **Exhaust heater** — Preheats feedwater using exhaust steam to improve efficiency.

2.7.3.6. Clutch and drive

- **Clutch** — Engages or disengages the engine from the drive train.

- Includes clutch lever, shoes, and pins.
- **Direct drive** (e.g., Buffalo Springfield road rollers) uses a fixed engagement without a friction clutch.

2.7.4 Controlling motion and power in a reciprocating steam engine

2.7.4.1. Throttle

- Regulates how much steam enters the cylinder, directly controlling engine power and speed.
- Smooth throttle use prevents wheel slip, priming, and sudden load shocks.

2.7.4.2. Governor

- Automatically maintains a steady engine speed by adjusting steam admission as load changes.
- Typical traction-engine flywheel speeds fall within a narrow, manufacturer-specified range for safe operation.
- A **sawyer's lever** allows the operator to override the governor temporarily for short bursts of power.
- Governor belts must be properly tensioned and aligned; slipping belts cause erratic speed control.

2.7.4.3. Valve and cylinder steam cycle

Steam events

- **Admission** — Steam enters the cylinder at boiler pressure.
- **Expansion** — Steam continues to push the piston as pressure drops.
- **Release** — Exhaust port opens and spent steam leaves the cylinder.
- **Compression** — Remaining steam is compressed before the next admission stroke, cushioning the piston.

Cutoff and lead

- **Cutoff** — The point in the stroke where steam admission stops; earlier cutoff improves efficiency, later cutoff increases power.
- **Lead** — A small amount of steam admitted just before the piston reaches dead center to ensure smooth reversal.

Valve types on traction engines

- **D-valve** — Common slide valve; simple, durable, and easy to maintain.
- **Gould (balanced) valve** — Reduces friction and operating force by balancing steam pressure across the valve.

Valve gear types

- **Woolf** — Early, simple gear with fixed characteristics.

- **Stephenson** — Widely used; provides smooth reversing and adjustable cutoff via shifting eccentrics.
- **Marsh** — A refinement of Stephenson with improved geometry.
- **Baker** — Uses links and levers instead of sliding blocks; reduces wear and maintains consistent valve events.

2.7.4.4. Setting the valve quadrant (forward/reverse)

- The quadrant positions the valve gear for direction and cutoff.
- Correct placement predicts the initial movement of the crank disc, ensuring the engine starts in the intended direction.

2.7.4.5. Single-cylinder dead centers

- **Top and bottom dead centers** are positions where the crank, piston, and connecting rod align, producing no turning force.
- To move off dead center safely, the operator rocks the flywheel gently or uses the reverse gear to shift the crank away from alignment.

2.7.4.6. Hooking up

- Moving the reverser toward shorter cutoff improves efficiency by using more expansion and less steam per stroke.
- Engines should be hooked up only after the load is steady and the engine is running smoothly.

2.8 Startup Routine Procedures

2.8.1 Crew preparation for a new engine

Water-glass reference to the crown sheet

- Determine the vertical distance between the top of the crown sheet and the top of the bottom gauge-glass nut.
- Mark this crown-sheet height on the **backhead** with chalk or paint so every crew member knows the minimum safe water level.

Try-cock reference

- Confirm the height of each **try cock** relative to the crown sheet so their readings can be interpreted correctly during low-water checks.

2.8.2 Crew preparation for the day's operation

Standard items for operators

- Appropriate clothing for engineers and firemen
  - non-synthetic, close-fitting, protective
  - CSA approved safety boots
  - Welder's gauntlets

- Engineer’s logbook
- Manitoba class ST power-engineers license.
- Flashlight and basic hand tools such as a crescent wrench or pliers.

Tools carried on the engine

- A basic onboard kit for routine adjustments, inspections, and emergencies.

Water checks

- Verify all water sources: main tanks, head tanks, saddle tanks, and rear tanks.
- Verify external water sources: stand pipes, water wagons, pumps, hoses
- Prove the gauge glass (and water column if fitted) **with no pressure on the boiler**.
- Cross-check water level using the try cocks.

Boiler integrity

- Confirm each hand hole is tight and steam-tight.
- Avoid over-tightening; crushing a gasket reduces sealing reliability.
- Never adjust a hand hole when the boiler is hot or under pressure—movement of the plate or gasket can cause severe injury.
- Inspect for leaks at hand holes, nipples, fittings, and valves.

Valve and control settings

- Set all valves and controls to their correct starting positions before raising steam.

Valve operation practices

- When opening a valve: open fully, then close **one flat** to prevent binding when hot.
- When closing a hot valve: leave slight clearance to allow contraction as it cools.
- When closing a cold valve: allow for expansion as it heats.
- Admit steam gradually to cold engine parts (especially through the dome valve) to prevent thermal shock.

Cleaning and ash handling

- Clean tubes, smokebox, grates, and ash pan before firing.
- Dispose of hot ashes safely in a designated, non-combustible area.

Fire lighting

- Lighting the fire is **the final step** after all inspections, water checks, and valve settings are complete.

2.9 Lubrication

Lubrication on a traction engine follows a simple rule: any place where two parts move against each other requires lubrication.

2.9.1 Lubrication types

- **Steam-cylinder oil** — Heavy, high-temperature oil that survives saturated steam; used in cylinders, valves, and valve gear.
- **Journal or bearing oil** — Medium-weight oil for crankshaft bearings, crosshead guides, and other rotating or sliding parts.
- **Grease** — Used where slow, high-load motion occurs (crank pins, wheel hubs, steering gear).

2.9.2 Lubrication delivery methods

- **Oil cups and waste** — Gravity-fed cups with felt or waste to meter oil slowly.
- **Mechanical lubricators** — Gear-driven pumps delivering measured oil to cylinders and valve chests.
- **Hand-pump oilers** — Manual pumps for bearings or parts needing periodic attention.
- **Sight-glass oilers** — Allow visual confirmation of oil flow to critical components.
- **Screw-type grease cups** — Turned down gradually to force grease into bearings (e.g., Case crank pin).
- **Grease cups** — Simple reservoirs that push grease as the cap is tightened.
- **Grease nipples** — Accept grease-gun pressure for quick, positive lubrication.
- **Hydrostatic lubricator** — Uses steam pressure and condensation to meter cylinder oil through sight glasses.

2.9.3 Checking bearings

- **Dry or tight bearings heat up** — Lack of lubrication or excessive preload causes rapid temperature rise.
- **Back of the hand** — A traditional, quick check; if it's too hot to touch, lubrication or adjustment is needed.
- **Infrared thermometer** — Provides accurate, non-contact temperature readings and helps track trends over time.

2.10 Firing

2.10.1 Preparing the fire

- Start with **clean tubes, a clean ash pan, and clean grates** so draft is unobstructed and heat transfer is efficient.
- Build the fire **slowly and gently** to warm castings, sheets, and stays evenly and avoid thermal shock.

2.10.2 Fuel types

- **Wood** — Lights easily, burns fast, produces light ash; good for starting.

- **Coal** — High heat output, forms a stable fire bed; requires proper draft and clinker management.
- **Straw** — Burns quickly with high volume; needs fine grate spacing and careful draft control.
- **Oil** — Provides steady heat when equipped; requires proper burner adjustment.

2.10.3 Early-morning condensation

- A cold boiler produces **condensation that mimics leaking tubes** until metal temperatures rise and moisture evaporates.

2.10.4 Firebed management

Holes in the fire

- Gaps in the firebed disrupt airflow, reduce steam production, and can cause cold-air impingement on sheets; patch with fresh fuel and level the bed.

Grates

- Grates **hold the fire** while allowing air to rise through the fuel.
- Air-space size varies by fuel type to balance draft, fuel retention, and ash shedding.

Arches

- Arches improve combustion by lengthening the flame path and protecting tubes from direct flame.
- **Brick arches** retain heat and stabilize combustion; **metal arches** are simpler but less durable.

2.10.5 Draft control

Types of draft

- **Natural draft** from the exhaust nozzle and stack.
- **Forced draft** from blowers when starting or maintaining fire at low engine speed.

Managing draft with arches

- Arches require **strong, even draft** to pull flame over the arch and complete combustion.
- Excess under-fire air can short-circuit the flame path; balance with over-fire air if needed.

Draft regulation

- **Front dampers** admit air under the grates; used to control fire intensity.
- **Rear dampers** regulate gas flow through the tubes; used to fine-tune draft and heat distribution.
- Dampers should be adjusted gradually to avoid upsetting the fire.

Back draft

- **Causes** — Poor chimney draft, sudden wind changes, blocked tubes, or excessive blower use.
- **Hazard** — Hot gases and flames can exit the firedoor, posing burn and fire risks.

2.10.6 Banking and shutting down

Banking a fire

- Build a deep, compact bed with reduced air to hold heat for short periods.
- Advisable only when the engine will be restarted soon; prolonged banking leads to clinker formation and uneven heating.

Letting a fire die

- Spread the fire thin, reduce draft, and allow fuel to burn out evenly.
- Remove large pieces of fuel (wood) if fire reduction is required. Remove hot ashes safely to a non-combustible area and ensure no embers remain near the engine.
- Boiler is safe to leave when
    - Fire is dying
    - No fresh fuel in firebox
    - Pressure under one-half MAWP and decreasing
    - Valves have been placed in shutdown position

2.11 Handling an Engine

2.11.1 Water, steam, and motion checks during operation

Routine water checks

- Water levels in all tanks must be checked frequently because traction engines consume water quickly under load.
- Tanks, saddle tanks, and rear tanks should be confirmed full before and during operation.

Proving the gauge glass under pressure

- The gauge glass must be “proved” by opening and closing the top and bottom gauge-cock valves one at a time to confirm the water level is accurate.
- This follows the NBIC method: isolate, drain, re-open, and verify that water returns instantly to the correct level.

2.11.2 Using the try cocks

- Try cocks provide a direct reading of water level independent of the gauge glass.
- Color and sound:
    - Water discharge is clear and heavy.
    - Steam discharge is white and sharp.

- For the most accurate reading, open each cock briefly in sequence from lowest to highest, allowing pressure to stabilize between checks.

2.11.3 Engine and motion controls

Cylinder drain cocks

- Open during startup and low-speed maneuvering to remove condensate and prevent water hammer.
- Close once the engine runs smoothly with dry exhaust.

Clutch and pins

- Engage the clutch only when engine is stopped or engine speed is low and steady.
- Ensure clutch pins or dogs are fully seated before applying load.

Throttle control

- Use gentle throttle openings when starting to avoid wheel slip and shock loading.
- Increase steam gradually as the engine begins to move.

Hooking up the reverse lever

- Once moving steadily, shorten cutoff by moving the reverser toward the center of the quadrant.
- This improves efficiency and reduces steam consumption.

2.11.4 Stopping and speed control

Normal stopping

- Close the throttle smoothly.
- Open cylinder drain cocks to clear condensate.
- Place the reverse lever in neutral.
- Disengage the clutch if it was engaged.

Braking without brakes

- Control downhill speed with a **low fire**, **closed damper**, and careful use of the reverse lever.
- A slight throttle opening against reverse gear provides controlled braking without locking the wheels.

2.11.5 Steering

Chain steering

- Steering wheels are turned by a chain wound around a drum; response is slower and requires anticipation.

Power steering

- Some engines use power-assist systems that reverse steering direction when the engine is reversed, requiring operator awareness.

2.11.6 Belt operation with governor control

- Align the engine carefully before engaging the belt.
- Bring the belt up to speed gradually using the governor to maintain steady RPM.
- When stopping, reduce load slowly and let the governor bring the engine down without throwing the belt.

2.12 Belting up, Hitching and Maneuvering

2.12.1 Positioning and maneuvering

- Approach the work area slowly with the clutch engaged and the engine at low throttle.
- Align the engine squarely with the load, belt line, or hitch point to avoid side pull or belt tracking problems.
- Use small throttle changes to make fine adjustments.

2.12.2 Belting up

Operator procedure

- Position the engine so it aligns with the belt path laid out from the driven pulley.
- Approach slowly while the ground crew pulls back the engine-end of the belt, keeping the remainder straight on the ground.
- Stop when the engine's pulley has moved just past the original belt position.
- Close the throttle and disengage the clutch.
- Take the belt from the ground crew and place it around the engine pulley.
- Engage the clutch and set the reverse lever. Confirm clearance behind the engine.
- Use light throttle to back slowly into the belt. Expect initial slip until the belt lifts and friction takes hold.
- Watch belt tracking carefully, especially on the engine side where it must not fall into the pulley gears.
- Continue backing until the belt is fully taut. Hold tension with the throttle until the ground crew chocks the wheel.
- Close the throttle and disengage the clutch.
- After receiving the signal from the driven equipment, roll the engine over slowly to confirm stable belt alignment.

Ground-crew duties

- Place a wheel block near the expected final position of the rear wheel.

- Lay the belt straight from the driven pulley and pull back the engine-end as the engine approaches.
- Signal the operator when the correct alignment and distance are reached.
- Hand the belt up to the operator and assist in positioning it on the pulley.
- Lift the belt so it clears the front wheel and tracks cleanly.
- Guide the belt as the operator backs into it, watching for misalignment.
- Chock the rear wheel when the belt reaches proper tension.
- Signal the operator to close the throttle.

2.12.3 Operating on the belt

- Maintain steady governor speed and avoid sudden throttle changes.
- Watch belt tracking, tension, and heat.
- Keep hands, clothing, and tools away from the moving belt at all times.
- Watch the equipment crew at all times an be prepared to stop the engine immediately on receiving a stop signal

2.12.4 Hitching to pull equipment

- Back toward the implement at the slowest possible speed.
- Align the drawbar directly with the tongue or hitch point.
- Ensure the pin is fully seated and secured before applying any pull.

2.12.5 Maneuvering near objects

- Move at walking speed when close to buildings, fences, crowds, or other engines.
- **Parading:** smooth throttle, wide turns, and constant awareness of spectators. Stop well back and give right of way to animals and handlers unfamiliar with steam engines.
- **Parking:** approach slowly and leave enough clearance for firebox heat and exhaust.

2.13 Emergency Procedures:

Emergency actions focus on isolating the boiler, stopping motion, removing heat, and protecting the crew.

2.13.1 Isolating the boiler from the engine

- **Close the throttle fully** to stop steam flow to the cylinders.
- **Open cylinder drain cocks** to vent residual steam and prevent the engine from turning.
- **Place the reverse lever in neutral** so no valve events can drive the crank.
- **Disengage the clutch** to separate the engine from the drivetrain.
- **Shut injector and pump valves** to prevent unintended feedwater flow.

2.13.2 Control settings to stop the engine

- Throttle closed.
- Reverse lever in neutral.
- Clutch out.
- Cylinder drains open.
- Dampers closed to reduce draft and slow the fire.
- Firedoor cracked open if needed to break draft and reduce firing rate.

2.13.3 Killing a fire safely and quickly

- **Close dampers** to choke under-fire air.
- **Open the firedoor slightly** to break draft and collapse the firebed.
- **Pull the fire** only if absolutely necessary, using proper tools and PPE.
- **Never throw water on the fire**—thermal shock can damage sheets and cause dangerous steam flashes.
- **Remove hot ashes** to a safe, non-combustible area once stable.

2.13.4 Specific emergency situations and actions

2.13.4.1. Broken or blown water glass

- Use a shovel and gloves when approaching the gauge cocks
- Close the water first, then the steam
- Use try cocks to verify water level.
- Maintain safe water level until the glass can be replaced.

Runaway engine or governor overspeed

- Close the throttle instantly.
- Open cylinder drains.
- Disengage the clutch.
- If throttle linkage has failed, pull the sawyer's lever if safe.
- Close the come valve

Injector trouble

- Switch to the second injector or pump if available.
- Check water temperature, steam supply, and injector overflow.
- Reduce firing rate until feedwater is restored.

Foaming or priming

- Reduce firing and close dampers.
- Open the throttle slightly to steady steam flow.
- Blow down briefly to reduce dissolved solids.
- Restore proper chemical balance when safe.

Hand-hole gasket blowout

- Move away from the leak path immediately.
- Reduce firing and draft.
- Maintain water level if possible.
- Shut down as soon as conditions allow; do not attempt tightening.

Tube or flue burst

- Loud roar or jet of steam from smokebox or firebox.
- Kill the fire immediately by closing dampers and opening the firedoor.
- Maintain water level above the crown sheet.
- Shut down and evacuate the area if visibility or heat becomes unsafe.

Leaking valve

- Close the valve fully, then open one flat to prevent binding.
- If leak persists, isolate the line if possible and reduce pressure.

Broken pipe

- Isolate by closing upstream valves.
- Move away from the steam jet.
- Reduce boiler pressure and shut down.

Safety-valve problems

- **Not opening at set pressure:** reduce firing immediately; open firedoor; close dampers; pull the fire if pressure continues to rise.
- **Opens but won't close:** reduce firing; maintain water level; allow pressure to fall naturally; do not attempt to force the valve shut.

Leaking pipe plugs

- Reduce pressure and isolate the affected line.
- Do not attempt tightening under pressure.

Melted grates

- Caused by extreme firing or restricted airflow.
- Kill the fire, close dampers, and let the boiler cool.
- Do not operate until grates are replaced.

Thrown drive belt

- Close throttle immediately.
- Disengage clutch.
- Wait for all motion to stop before approaching the belt.
- Inspect for damage before re-belting.

2.14 Shutdown

2.14.1 Blowdown procedure

- Perform blowdown only when the boiler is hot and under pressure, but not at peak pressure.
- Ensure the blowdown will be directed into a clear area.
- Open the blowdown valve **fully and briefly** to remove concentrated solids and sludge from the lowest point of the boiler.
- Close the valve cleanly to avoid wire-drawing the seat.
- Repeat short blows if needed until discharge runs clear.
- Never leave the blowdown valve cracked open; it must be either fully open or fully closed.

2.14.2 Valve and control positions

- **Throttle** fully closed.
- **Cylinder drain cocks** open to release residual condensate as the boiler cools.
- **Reverse lever** in neutral on the quadrant.
- Dome valve closed
- **Clutch** disengaged.
- **Dampers** open slightly to allow natural cooling and prevent back-drafting into the firebox.
- Injector and pump valves closed.
- Injector steam and feedwater isolation valves closed.
- **Water column** isolation and **gauge glass** valves open **so** water level can be checked during walk by.
- Any other valves that might release hot water or steam onto an untrained and unsuspecting bystander should be open for drainage.

After the boiler has cooled to 0 indicated pressure but is still warm

- Open the blower or top try cock to allow pressure to equalize until startup.

2.14.3 Short-term boiler lay-up

Short-term lay-up covers periods of **hours to a few days** when the boiler will be restarted soon and must be protected from oxygen attack and condensation.

- Leave the boiler **full of hot, treated water** to minimize air space and oxygen exposure.
- Close all valves except water column and gauge-glass cocks. The gauge glass must remain connected to the boiler volume; otherwise vacuum formation in the glass itself could lead to cracking, implosion, distortion of gauge-glass rubbers and an incorrect reading.
- Keep the firebox and ash pan clean and dry to prevent corrosion.

- Inspect for leaks as the boiler cools; correct minor issues before the next firing.

2.14.4 Long-term boiler lay-up

Long-term lay-up applies when the boiler will sit **weeks or months**. The goal is to prevent corrosion, scale hardening, and freeze damage.

Boiler washing procedure

- Allow the boiler to cool completely and relieve all pressure.
- Remove hand holes and washout plugs.
- • Wash the boiler thoroughly with clean water, directing flow across sheets, stays, and the mud ring to remove sludge and loose scale.
  - Start at the upper rear handhole to wash scale and sediment off the crown sheet and around the firebox door ring.
  - Wash the belly of the boiler from the front handhole back toward the throat sheet, sweeping across the lower sheets.
  - Wash across the mud ring using the handholes in the bottom of the water legs, flushing sediment toward the washout openings
- Inspect tubes, seams, and stays for scale or pitting.
- Allow the boiler to **dry completely**, using warm air or fans if needed.

Screens and wicking

- Install **screens** over hand-hole and washout openings to keep debris and animals out while allowing airflow.
- Use **wicking materials** (such as dry rags or desiccant packs) in the firebox or smokebox to absorb moisture and reduce condensation.
- Replace wicking periodically if storage is extended.

Special considerations for freezing conditions

- Drain all water tanks, injector lines, pumps, and low points where water can collect.
- Open all valves to ensure trapped water can escape.
- Use **non-corrosive antifreeze** only in external tanks if absolutely necessary—never inside the boiler. Never introduce antifreeze into the boiler itself, and never use it in any tank or line that cannot be completely drained and flushed before the next startup.
- Ensure the boiler is completely dry; even small pockets of water can freeze and damage sheets or fittings.
- Protect exposed piping with insulation or heat if the engine is stored outdoors.

2.15 Inspection

2.15.1 Types of tests and examinations

- **Visual / internal inspection** — Full internal examination of sheets, stays, seams, tubes, mud ring, and fittings.
- **Hydrostatic test** — Performed with clean water at the required test pressure.
  - **Water temperature** must be warm (typically 70–120 °F) to avoid thermal shock.
  - **Pressure level** is set by the inspector, normally 1.25× MAWP unless otherwise directed.
- **Operational (under-pressure) examination** — Conducted under steam to verify safety-valve function, controls, feedwater systems, and general operation.
- **Non-Destructive Examinations (NDE)** — Ultrasonic thickness testing and other methods required every five years.

2.15.2 Frequency of inspections

- NBIC requires **annual inspections**, rotating through a **three-year cycle** of:
  - Internal/visual
  - Hydrostatic
  - Operational
- -If a boiler is out of service and an annual inspection is missed, the requirement does not disappear. Missed inspections accumulate, and when the boiler returns to service after three years or more, all three inspections must be completed before operation is permitted.
- **NDE** is required every **five years**
- replacement of safety (pop) valves is required every five years.

2.15.3 Preparations for inspection

Internal inspection

- Wash the boiler thoroughly and remove all handholes and washout plugs.
- Clean tubes, firebox, smokebox, and all mud-ring areas.
- Ensure all fittings, valves, and openings are accessible for visual and mechanical examination.
- Remove plugs from tees, water columns, and gauge-glass connections to provide straight-through access into the boiler.
- Prepare the engine for safe internal entry when required, including ventilation, lighting, and lockout of all steam sources.

Hydrostatic inspection

- Install all handholes and washout plugs, close isolation valves, and fill the boiler completely to the highest point.

- Remove safety valves and regulating valves; install test plugs, including one fitted for the hydrostatic pump connection.
- Warm the boiler gradually using tiger torches or equivalent heat in the firebox to bring the shell to a safe, uniform temperature before applying pressure.

Operational (under-pressure) inspection

- Prepare the boiler exactly as for normal steaming.
- Verify that injectors, pumps, and feed systems are functional.
- Ensure sufficient fuel is available to raise pressure and demonstrate proper safety-valve operation.

Requirements common to all inspections

- Provide documentation of previous inspections, repairs, alterations, and MAWP records.

2.15.4 Determination of Maximum Allowable Working Pressure (MAWP)

- MAWP is based on the **lowest ultrasonic thickness reading** from the NDE cycle.
- If the new NDE shows a **decrease in the minimum thickness** compared to the previous cycle, MAWP must be recalculated.
- Any change in MAWP is recorded as an **alteration to the boiler's CRN** (Canadian Registration Number or equivalent jurisdictional record).
- Updated MAWP must be stamped or documented according to the jurisdiction's requirements.

2.16 Repairs and Modifications

2.16.1 SAM QA program

- Operated by the Steam Association of Manitoba (SAM).
- The **QA Manual** defines the types and scope of repairs permitted under the program.
- The QA Manual is **reviewed every three years** to maintain compliance with NBIC and jurisdictional requirements.
- The **QA Manager** oversees preparation of repair plans and submits them to the boiler inspector for approval.

2.16.2 Repair plans

- Describe the **procedures** to be used for the repair, including sequence and method.
- Reference **ASME, NBIC, and other applicable standards** to confirm the repair is permitted and to determine the correct procedure.
- Track **Material Test Reports (MTRs)** for all materials used in the repair.
- Include preheat and post-heat requirements when applicable.

- Record the **credentials of pressure welders**, ensuring all welding is performed by qualified personnel

2.16.3 Approval process

- The owner submits a repair request to SAM.
- SAM forwards the request to the **QA Manager** for evaluation.
- If the repair is deemed viable:
  - SAM issues an **invoice** to the owner.
  - The QA Manager prepares the **formal repair plan** and submits it to the boiler inspector for approval.

2.16.4 Certification of service providers

- Welders performing work on boilers must hold a **valid pressure-welder ticket** recognized by the jurisdiction.
- The selected welder must be **identified on the repair plan** before the plan is submitted for approval.

2.16.5 Pre- and post-repair inspection

- A **pre-repair inspection** is performed by the QA Manager or designate to confirm the repair is viable, identify required materials, and provide cost guidance of service providers.
- A **post-repair inspection** may include NDE, depending on the nature of the repair and inspector requirements.
- The boiler inspector will **review and accept the repair** either immediately upon completion or during the next scheduled inspection, depending on jurisdictional practice and owner preference.

2.17 Log Books

2.17.1 Personal logbook

- Records the **date and time** of each session with an engine.
- Includes engine identification, owner, and a description of the work performed.
- For **operational sessions**, documents the period from **light-off to shutdown**, or the duration of cameo sessions, and specifies the **type of work** (parading, threshing, plowing, demonstrations, etc.).
- For **work sessions**, records the nature of the work (piping, cleaning, riveting, startup, lay-up, maintenance tasks).
- For **student operators**, records the **name of the operator-in-charge** for affidavit and certification purposes.

2.17.2 Engine logbook

- Maintains a continuous record of **engine-specific information**.

- For **operational sessions**, records the period from **light-off to shutdown** and any notable events.
- For inspection sessions, documents the type of inspection and the results.
- For **repair sessions**, records the **repair plan number** (if applicable) and a description of the work performed.
- For all sessions, lists the **personnel involved** including ticketed and student operators.
- Tracks hours of operation on the fusible plug.
- Tracks **gauge calibration** dates and results.
- Tracks pop-valve replacement intervals.
- Records **hand-lifting of the pop valve**, including date, pressure at lift and reset points, and operator.

2.18 Boiler Law and Regulations

2.18.1 ASME

- **American Society of Mechanical Engineers**
- Establishes the ASME Boiler and Pressure Vessel Code (BPVC), which governs the design, construction, materials, and fabrication of boilers and pressure vessels.
- Provides the standards under which new boilers are built and stamped, including historic-boiler restorations that involve code-level alterations.

2.18.2 NBIC

- **National Board Inspection Code**
- Governs the **inspection, repair, and alteration** of boilers after they are placed in service.
- **NBIC Parts 2 and 3, Section 6** specifically address the inspection and repair of **historic boilers**, including requirements for internal inspection, hydrostatic testing, operational testing, and acceptable repair methods.

2.18.3 CSA

- **Canadian Standards Association**
- Provides Canadian standards for **pressure equipment design, fabrication, and operation**, including CSA B51 (Boiler, Pressure Vessel, and Pressure Piping Code).
- Establishes requirements for registration, stamping, and certification of pressure equipment used in Canada.

2.18.4 ITS

- Office of the Fire Commissioner / Inspection and Technical Services Manitoba (ITS)
- The **authority having jurisdiction** for boilers and pressure vessels in Manitoba.
- Oversees inspections, issues operating certificates, enforces compliance with ASME, NBIC, CSA, and provincial regulations, and approves repairs and alterations.

3. History of Steam Traction Engine Development (optional)

- major technical developments
- influence of “the Alberta or Canadian Boiler”
- companies and mergers
- interesting features that worked/failed to work