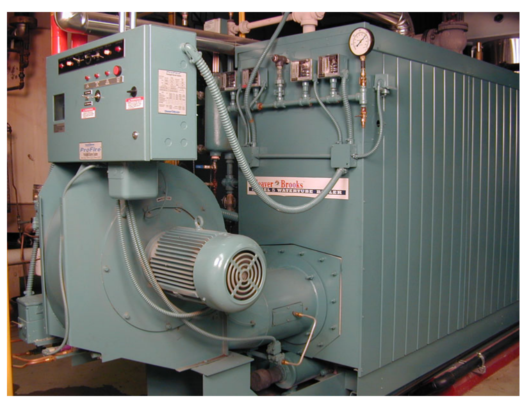
Track: Commercial Natural Gas I
Unit #2: Boilers

An overview of Boiler Components and Controls

Eric, Burgis, Energy Solutions Center

Presentation Outline

- Boiler Configurations
- Steam System Design and Components
- Burner and Controls
- Flue Gas Heat Recovery/Economizers
- Resources



2

Boiler

noun boil·er \ˈbȯi-lər\

Full Definition of *boiler*

1 : one that boils

2 a : a vessel used for boiling

b : the part of a steam generator in which water is converted into steam and which consists usually of metal shells and tubes

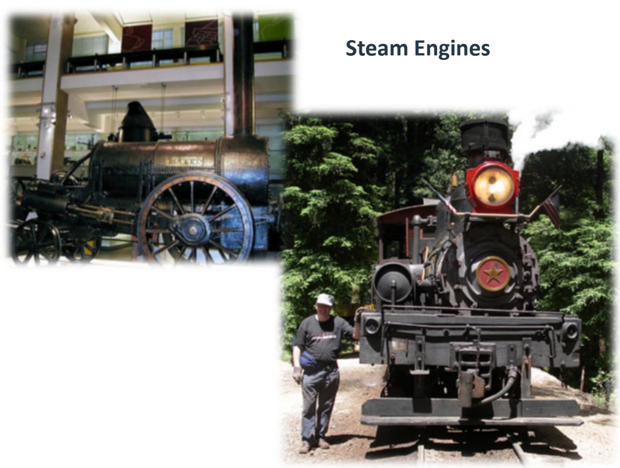
c : a tank in which water is heated or hot water is stored

http://www.merriam-webster.com/dictionary/boiler

Where It All Started

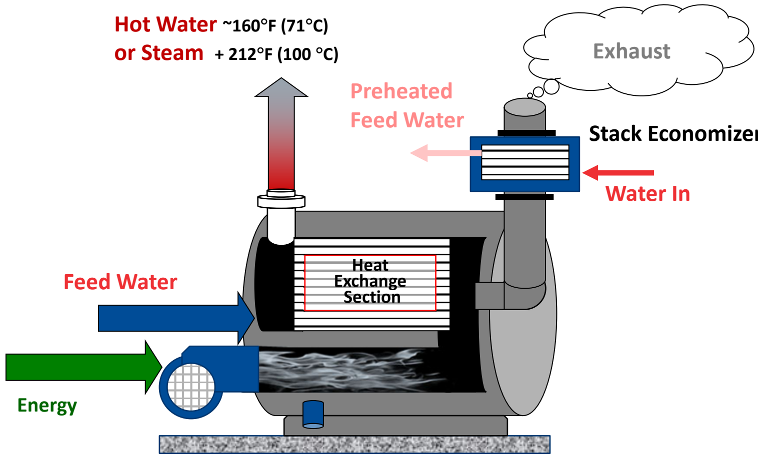
Haystack Boiler, 1700's

Steam Engines



Images Courtesy of
Cleaver Brooks

Typical Boiler Schematic



What Are Some Boiler Uses?

- Building heat
- Water heating
- Process heat or consumption
- Food Processing, Sterilization, etc.
- Driver for steam turbines or engines
- Energy source for absorption cooling

Boiler Terminology

- Horsepower (HP) – How a boiler is sized
- One boiler horsepower equals 33,475 Btu/hour (Energy rate required to evaporate 34.5 lb (15.6 kg) of water at 0 psig and 212°F (100°C) in an hour)
- Or Steam Production Rate: i.e. 10,000 lb/hr boiler
- Note: HP is the output of the boiler

Boiler Terminology

- Pony Boiler:
  - When a smaller, compact boiler is added to a large capacity boiler so that the large boiler can be shut down in the shoulder months
- Modular Boiler Systems
  - Common term used today when two or more compact boilers are used to replace the capacity of an older large boiler

Boiler Operating Pressures and Temps

- Boilers are constructed to meet ASME Boiler and Vessel code requirements
- Low Pressure Boilers:
  - Limited to a maximum working pressure of 15 psig for steam and 160 psig for hot water

Note that hot water boiler temperatures are limited to 250°F (121.1°C)

Boiler Configurations

- Water Tube
- Fire Tube
- Other
  - Coiled -tube
  - Fin-tube
  - Cast iron sectional
  - Condensing

Note: Stoker/Grate boilers for wastes, biomass, and coal fuels are not covered

Boiler Configurations

- Water Tube
- Fire Tube
- Coiled –tube
- Fin-tube
- Cast iron sectional
- Condensing
- Heat recovery steam generator (HRSG)

Note: Stoker/Grate boilers for wastes, biomass, and coal fuels are not covered

Water Tube Boilers

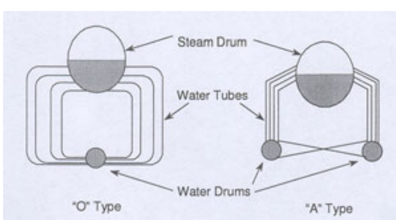
https://www.cleaverbrooks.com/Catalog/boilers/packaged-watertube-boilers/flx

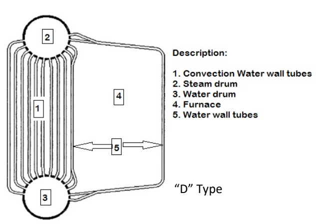
Water Tube Boilers

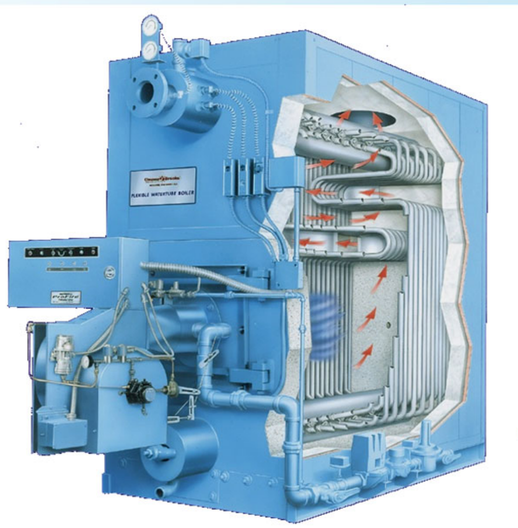
- Combustion gases circulate around water-filled tubes
- Pressure confined inside of the tubes
- Produces hot water, low or high pressure steam
- Efficiency ranges are typically from 75 to 85%
- Available as packaged systems or can be field erected
- Can be fabricated in large sizes (several million pound per hour systems) and very high pressures

13

Water Tube Boiler Schematics







Source: www.hurstboiler.com

14

Water Tube Boilers

- Typical Applications of Water Tube Boilers
  - Space heating
  - Water heating
  - Steam for process heating or consumption
  - Turbine power generation and prime movers
- Considerations
  - May have large space requirements
  - May require significant foundations and/or site preparation
  - Long life expectancy
  - Fuel flexibility

Water Tube Boilers

- Considerations – continued
  - System design
  - Integrated control systems
  - High turndown ratios
  - Water treatment essential
  - Fast startup for certain configurations

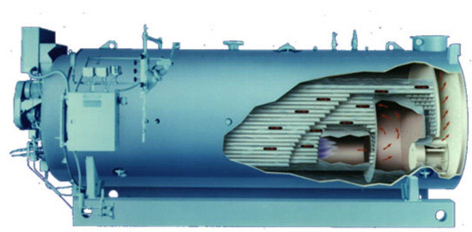
Courtesy Cleaver Brooks

Fire Tube Boilers

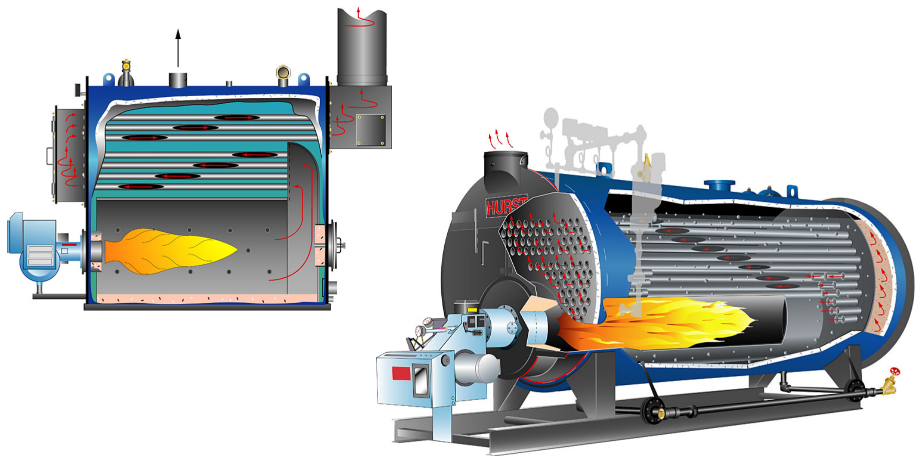
https://www.cleaverbrooks.com/Catalog/boilers/firetube/cbex

Fire Tube Boilers

- Combustion gases circulate through tubes
- Produce hot water, low or high pressure steam
- Efficiency ranges are also typically from 75 to 85%
- Small packaged systems up to over 100,000 lbs/hr



Fire Tube Boiler Schematics



Source: www.hurstboiler.com

19

Fire Tube Boilers

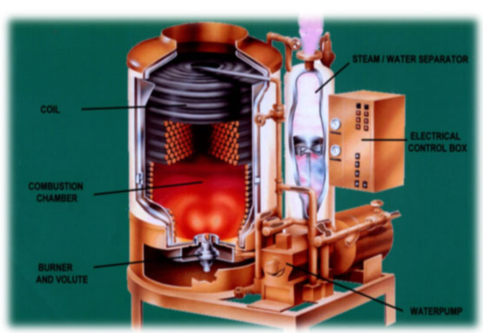
- Typical Applications of Fire Tube Boilers
  - Space heating
  - Water heating
  - Process steam or hot water
- Considerations
  - Space requirements
  - Minimal foundation or site preparation
  - Long Life Expectancy

20

Fire Tube Boilers

- Considerations – continued
  - Easy to design system: pre-packaged units
  - Integrated control systems
  - High turndown ratios
  - Water treatment recommended to prevent scaling

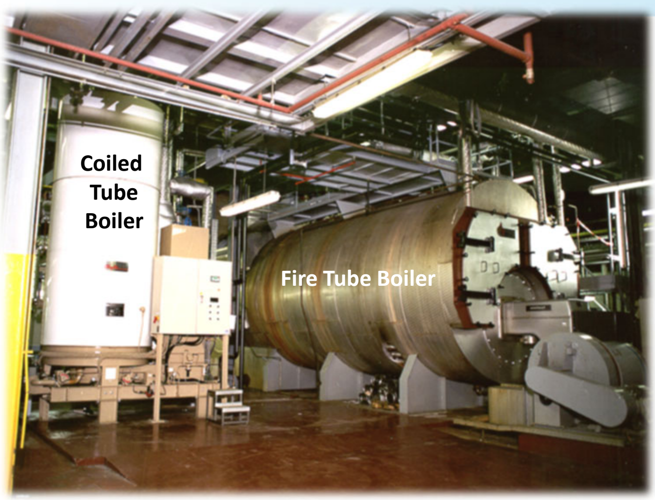
Coiled Tube Boilers



Coiled Tube Boilers

- As in a water tube boiler, water passes through boiler tubes while combustion gases remain in the shell side, passing over the tube surfaces
- Unlike conventional water tube boilers the tubes in a coiled tube boiler form a coil allowing for a more compact vertical configuration and very low water inventory.

The Size Advantage



Fin Tube Boilers

25

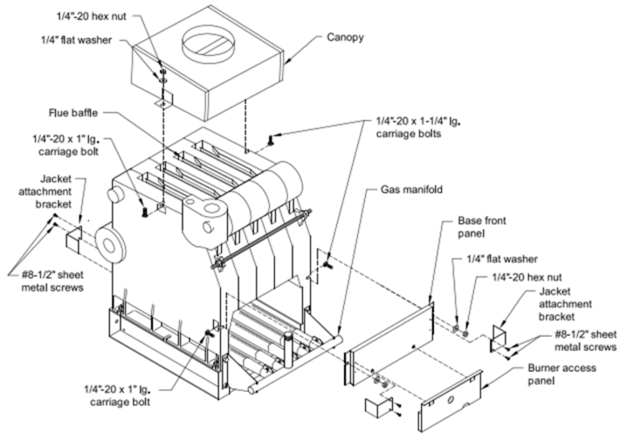
Fin Tube Boilers

- As in a water tube boiler, water passes through boiler tubes while combustion gases remain in the shell side, passing over the tube surfaces
- Unlike conventional water tube boilers the tubes in a fin tube boiler are fitted with fins, increasing the area available to transfer heat
- Primarily used in commercial hot water systems for domestic hot water and for space heating needs

https://www.lochinvar.com

26

Sectional Boilers



https://www.burnhamcommercial.com

27

Sectional Boilers

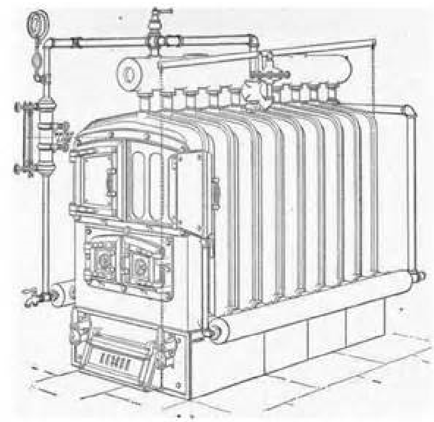
- Consist of multiple sections that are connected together
- Sometimes multiple sectional boilers are ganged together as a modular boiler
- Commercial size sectional boilers can come either prepackaged or assembled on-site

Sectional Boiler

28

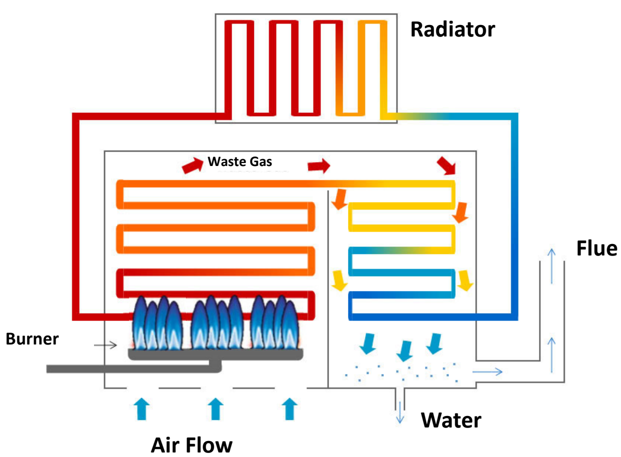
Sectional Boilers

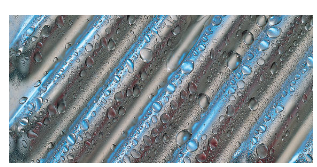
- Ideal for retrofit/replacement applications
- Small footprint (able to fit through doorways)
- Easily assembled or expanded



29

Condensing Boilers





30

Condensing Boilers

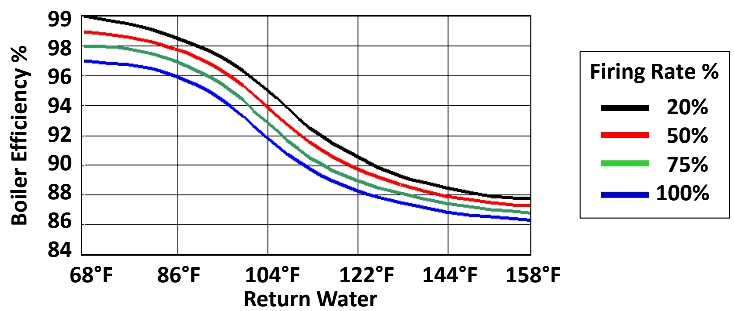
- Condensing boilers recover some of the heat from water vapors created by the boiler combustion process.
- Return water temperature is critical with this type of boiler system (need water at 130°F (55 °C) or cooler)
- The boiler extracts additional heat from the waste gases by condensing the water vapor thus recovering its latent heat.

Condensing Boilers

- About 9% of the BTU content in each ft^3 of natural gas burned leaves the stack as latent heat of vaporization in the water vapor
- By condensing the water vapor and lowering the stack temperature 98% efficiency levels can be reached
- For natural gas water vapor will only condense if the flue gas temperatures are cooled below 137°F (58.3°C)

Condensing Boilers

- Higher efficiency than conventional boilers
- Controls and low feed water temperatures are essential to achieving high system efficiencies

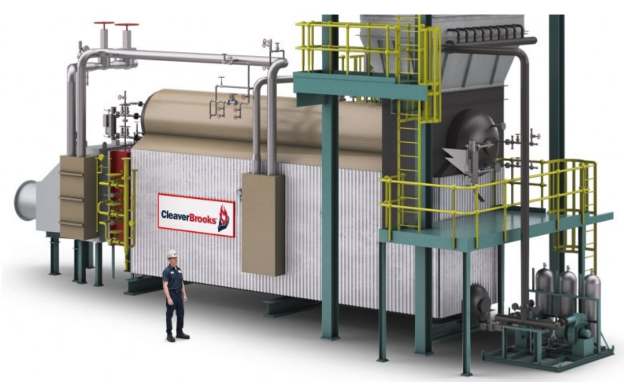


Source: Cleaver Brooks ClearFire-C

33

Heat Recovery Steam Generator

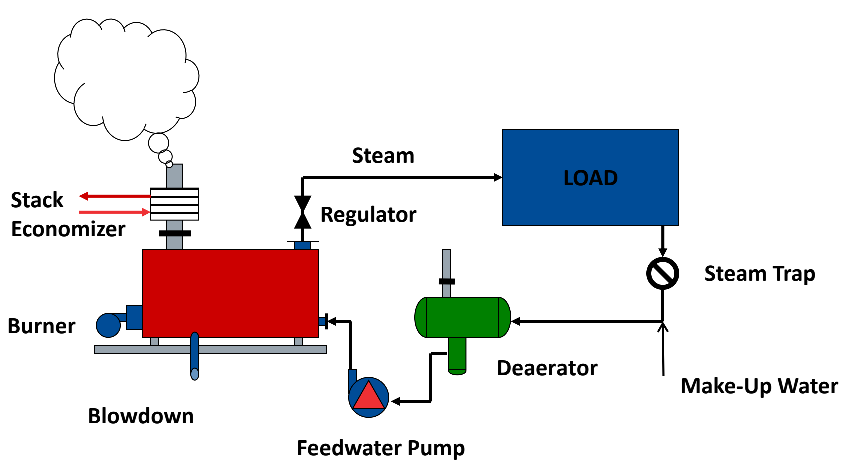
- Steam generators are comprised of four major components. These components are an economizer, an evaporator, a superheater and a water preheater.
- Most typically used with CHP waste heat to create usable steam.
- Acts a lot like a fire tube boiler but uses direct products of combustion from CHP system in the tubes to heat water.



34

Steam System Design and Components

System Design Considerations



36

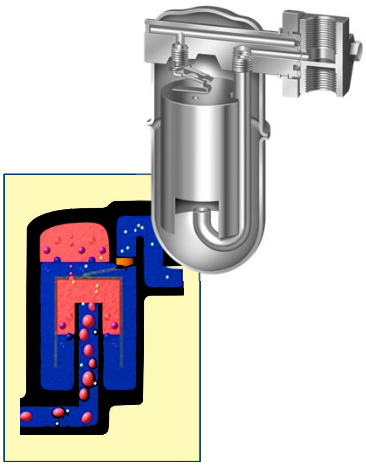
Steam Traps

- Steam traps are automatic valves
- They open, close or modulate automatically
- The three important functions of steam traps are:
  - Discharge condensate as soon as it forms
  - Ensure negligible steam losses
  - Have the capability of discharging air and other non-condensable gases

Mechanical Steam Trap

- Has a float that rises and falls in relation to condensate level
- Has a mechanical linkage attached that opens and closes the valve
- Operates in direct relationship to condensate levels present in the body of the steam trap: **Inverted bucket** and **float traps** are examples of mechanical traps

Inverted Bucket Steam Trap



- The most robust type of mechanical trap – resistant to water hammer and with a check-valve can be used with superheated steam
- Steam enters under the "bucket" causing it to float thereby closing the discharge valve
- Condensate entering the trap causes the "bucket" to sink and discharge the condensate
- A vent opening in the bucket allows for the discharge of air and non-condensable gases

ESC

39

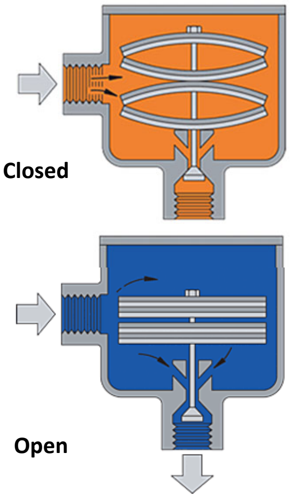
Temperature Traps

- A valve that is driven on/off the seat by either expansion / contraction caused by temperature change
- Design requires them to hold back some condensate waiting for it to cool allowing the valve to open
- Normally not desirable as condensate needs to be removed as soon as it is formed

ESC

40

Bimetallic Steam Trap

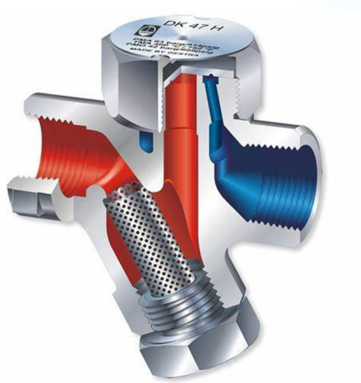


Closed

Open

- Uses two strips of dissimilar metals welded together into one element
- Elements deflect when heated
- Operation of the trap takes place at a certain fixed temperature. Not recommended for steam systems operating at varying pressures and temperatures

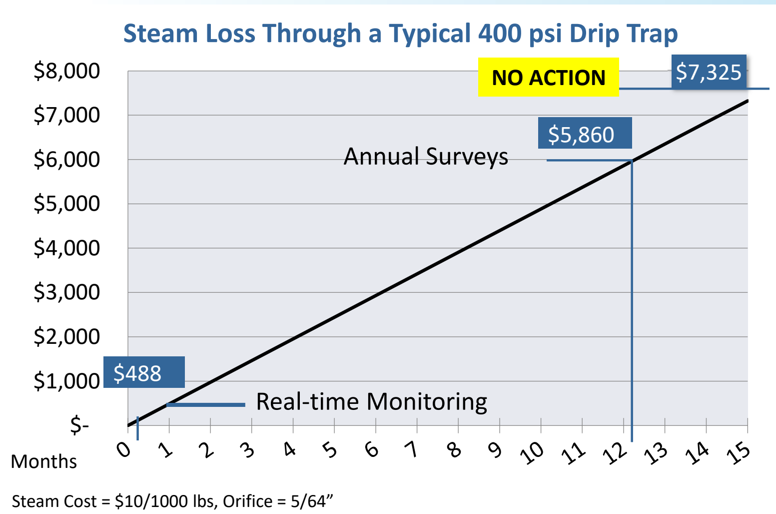
Thermodynamic (TD) Traps



https://www.ibhs.co.uk/dk47h-thermodynamic-steam-trap-1-2-bsp-screwed.html

- Work on the difference in dynamic response to velocity change in flow of compressible and incompressible fluids.
- Compact, simple, lightweight and have a large condensate capacity for their size
- As steam enters, static pressure above the disk forces the disk against the valve seat
- As steam starts to condense, the pressure against the disk lessens and the trap cycles
- A TD trap is a "time cycle" device: it will open even if there is only steam present

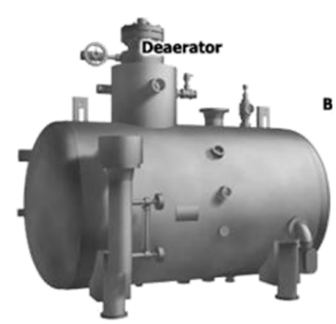
Steam Trap Maintenance



43

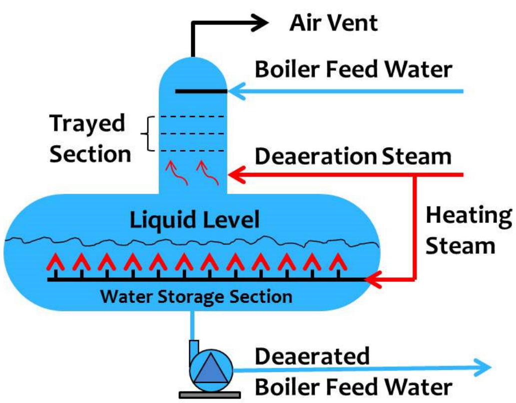
Deaerator Tank

- Found in larger steam systems
- Heats return condensate to 200-215°F (93.3-101.6°C)
- Removes air and other dissolved gases from boiler feed water.
- Air and gases released from the condensate are vented off



44

Tray Deaerator



- Section mounted above a horizontal boiler feedwater storage vessel
- Feedwater enters the vertical section above the perforated trays and flows downward
- Low-pressure dearation steam enters below the perforated trays and flows upward through the perforations
- The steam strips the dissolved gas from the boiler feedwater and exits via the vent at the top of the domed section.
- Deaerated water flows down into the horizontal storage vessel from where it is pumped to the boiler system

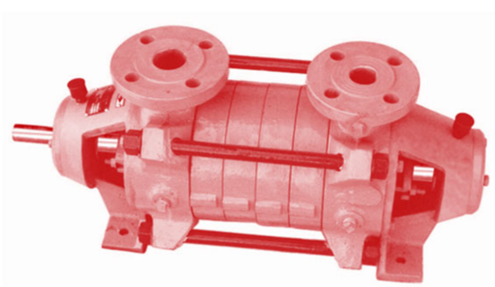
Water Treatment

- Due to evaporation in the boiler, dissolved impurities precipitate out of solution and adhere to the heat transfer surfaces forming boiler scale on boiler tubes and other heat transfer surfaces.
- Scale will reduces efficiencies and can lead to tube failures. Oxidation also leads tube failures
- Boiler feed water is chemically treated to reduce or remove impurities from water prior to entering the boiler

Feed Water Pumps

- Pumps feed water into a steam boiler
  - The water may be freshly supplied or returning condensate produced as a result of the condensation of the steam produced by the boiler. A float switch controls the operation.
- Pumps are normally high-pressure units that take suction from a condensate return system and can be of the centrifugal pump type or positive displacement type

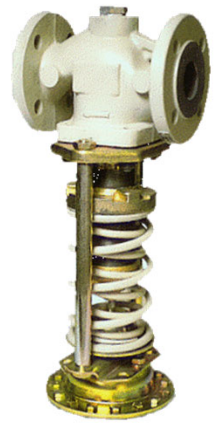
Feed Water Pump Specs



For high pressure steam systems with condensate returns these pumps operate at high pressures and temperatures requiring special seals and materials.

Pressure Regulator Valves

- Steam pressure regulators are mounted in the steam outlet line from the boiler
- Actuating energy is provided directly from the steam thus ensuring that a minimum upstream pressure is maintained
- If the upstream pressure falls below the set point the valve will throttle back or close until the minimum desired pressure is achieved



ESC

49

Blow down

- Removes impurities from the boiler such as suspended and dissolved solids
- Water is periodically discharged or "blown down" from the boiler
- Surface water blow down is often done continuously to reduce the level of dissolved solids
- Bottom blow down is performed periodically to remove sludge from the bottom of the boiler

ESC

50

Blow down Benefits

- Less water, fuel and treatment chemicals needed
- Less maintenance and repair cost (minimized carryover and deposits)
- Saves manual supervision for other tasks (with automatic control)
- Cleaner and more efficient steam production
- For larger systems heat recovery from the blow-down stream results in additional savings

Blow Down Valves

- Can be a manual valve or operated with automatic controls
- Various sizes and configurations
- Valve with adjustable stage nozzle, sample valve, and electric actuator used for automatically controlled continuous blow down

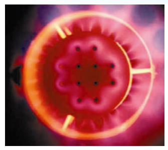
Burner and Controls

Burners

- Pre engineered on packaged boiler systems
  - Forced draft, pre-mixed burner provided with blower motor and controls
  - Variable combustion rates
- Typically provided by third party
- Separate name plate

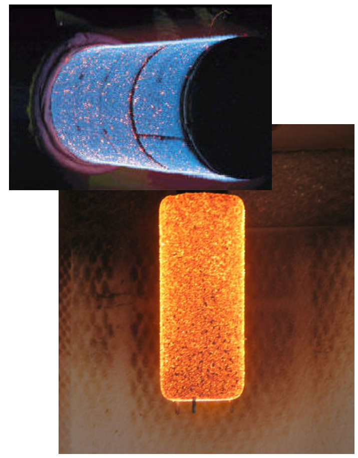
54

Ultra Low-NOx Burners (< 9 vppm)



Forced Internal
Circulation Burner

Induced FGR and FGR Modulating Valve



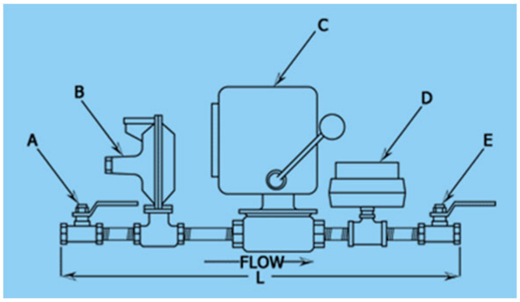
Fiber Burners

Controls

- Traditional gas safety valve arrangement
- Integrated electronic ignition systems
- Flame Detection
- Linkage-less controls are now the norm
- FM (Factory Mutual) and IRI (Industrial Risk Insurers) certification

https://www.cleaverbrooks.com/Catalog/controls/boiler-controls/hawk-boiler-controls

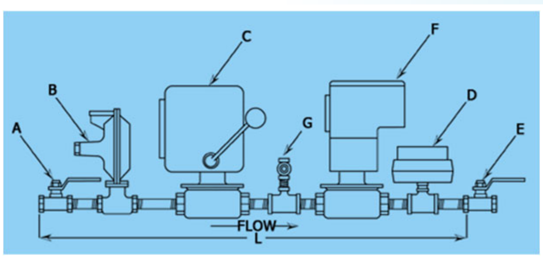
F-M (Factory Mutual Gas Train)



A	MANUAL GAS COCK
B	GAS PRESSURE REGULATOR
C	MANUAL RESET SAFETY VALVE
D	HIGH/LOW GAS PRESSURE SWITCH
E	MANUAL GAS COCK
L	OVERALL LENGTH IS APPROX. 36"

- Includes an F-M approved gas cock
- Gas pressure regulator
- Manual reset safety shut-off valve
- High/low gas pressure switches
- Approved gas cock.

IRI (Industrial Risk Insurers)



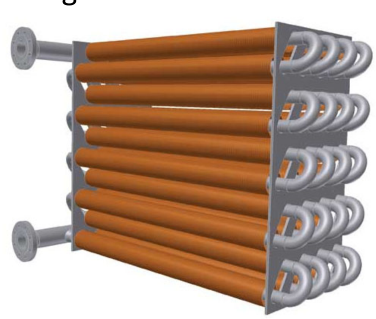
A	MANUAL GAS COCK
B	GAS PRESSURE REGULATOR
C	MANUAL RESET SAFETY VALVE
D	HIGH/LOW GAS PRESSURE SWITCH
E	MANUAL GAS COCK
F	MOTORIZED SAFETY VALVE
G	SOLENOID VENT VALVE
L	OVERALL LENGTH IS APPROX. 48"

- Includes an F-M approved gas cock,
- Gas pressure regulator
- Manual reset safety shut-off valve
- Normally open "vent" solenoid valve
- Motorized safety valve
- High/low gas pressure switches
- An additional, approved manual gas cock.

Flue Gas Heat Recovery/Economizers

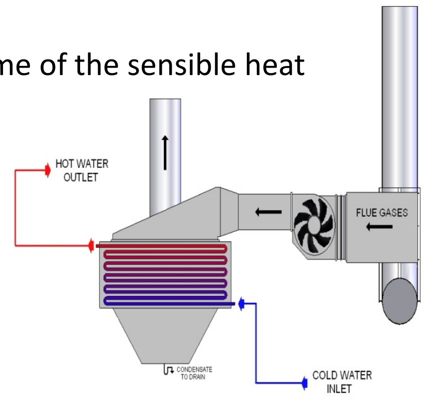
Stack Economizers

- Heat exchangers that recover heat from flue gases that would otherwise be wasted
- Heat is used to raise boiler feed water temperature prior to entering the boiler
- Rapid changes in load demands can be met faster due to higher feed water temperature
- Reduced fuel-firing rates for any given steam output helps reduce NOx emissions



The Drivers for Economizers

- Flue gas temperatures exiting large boiler chambers typically are at 450 to 650°F (232.2 to 343.3°C)
- Standard stack economizers can be used to recover some of the sensible heat from boiler flue gases
- These standard economizers thus increase combustion efficiencies and are used to preheat boiler feed water streams



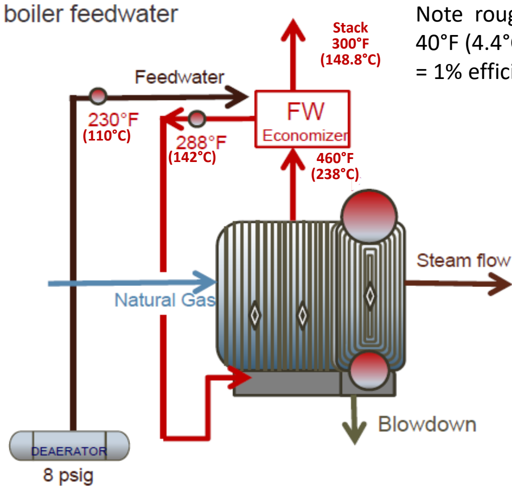
CONTINUED

The Drivers for Economizers

- Condensing stack economizers can further increase efficiencies and should be considered when large amounts of make-up water are used (result of large amount of live steam use in the plant) or when large quantities of hot process water are needed concurrently within the plant, such as seen in food processing plants.
- Cools stack gases below 137°F (58.3°C) for natural gas boilers fired to maintain 3% oxygen in the flue gas

Standard Economizers in Boilers

Purpose: Preheat boiler feedwater



Note roughly each
40°F (4.4°C) drop in the flue gas
= 1% efficiency improvement

Courtesy: Enbridge Gas - Industrial Group

Feed Water (FW) Economizers Configurations

Associations & Resources

Associations & Resources

- The American Boiler Manufacturers Association (ABMA)
  - Located in Vienna, VA
  - National, nonprofit trade association founded in 1888 by boiler manufacturers and end users
  - www.abma.com

Associations & Resources

- American Society of Mechanical Engineers (ASME)
  - Located in Vienna, VA
- National, nonprofit trade association founded in 1880 providing a forum for the engineering community
  - www.asme.org

ASME
SETTING THE STANDARD

Web Resource

www.CleanBoiler.org

ESC Home Page Other Industrial

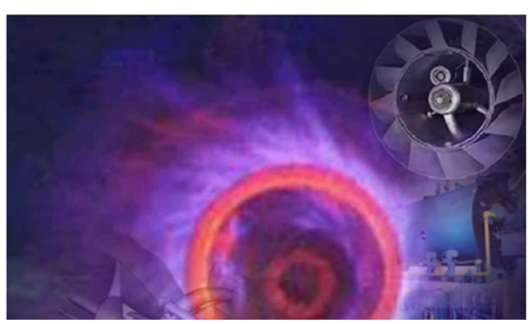
Boiler Technologies | ESC Energy Solutions Center

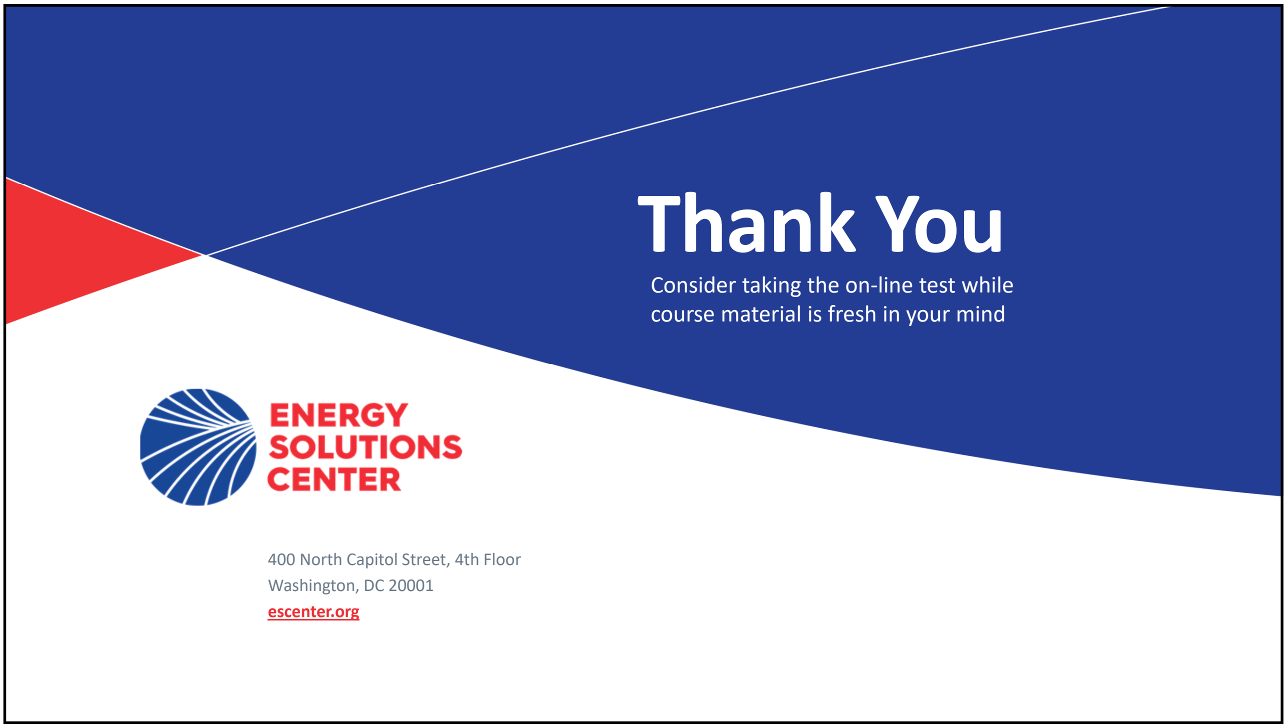
Home Learn About Sales Tools About Us

Boiler Consortium – A Resource of the Energy Solutions Center

The Energy Solutions Center Inc. is a non-profit organization of energy utilities and equipment manufacturers that promotes energy efficientnatural gas solutions and systems. Through a consortium of members, ESC created this educational website, marketing materials, case studies, training manuals, and other tools and resources designed to enhance the success of utility customer service professionals.

ESC makes no representations about the reliability, accuracy, suitability of the information, software, products, services provided on this website. For more information visit our Terms of Use.




Thank You
Consider taking the on-line test while
course material is fresh in your mind
ENERGY
SOLUTIONS
CENTER
400 North Capitol Street, 4th Floor
Washington, DC 20001
escenter.org