HEAT RECOVERY BOILERS

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1.0 SCOPE

This data sheet covers heat recovery boilers. Heat recovery boilers are units that recover sensible heat from industrial processes and combustion products; such units include fired and unfired heat recovery steam generators (HRSGs) used in combined cycle power generation. Firetube boilers are covered in Data Sheet 6-22, *Firetube Boilers.* Watertube boilers are covered in Data Sheet 6-23, *Watertube Boilers.*

1.1 Changes

January 2021. Interim revision. Updated contingency planning guidance.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Operation and Maintenance

2.1.1 Operation

A. Train operators on standard and emergency operating procedures. See Data Sheet 10-8, *Operators*, for guidance on developing operator programs. Ensure operators are properly trained in the operation of the boiler and well-versed in standard and emergency operating procedures. Ensure they also have an understanding of the overall process so as to recognize the effect of boiler operation. Give operators full authority to shut down the heat recovery boiler in case of emergency.

B. Provide written emergency operating procedures and have them readily avalable in the boiler control room.

C. Establish a training program designed to review boiler standard and emergency operating procedures. Plant management is responsible for this training program and scheduling periodic retraining.

D. Provide proper feedwater treatment at all times. Consult water treatment specialists and/or the boiler manufacturer to establish a proper feedwater treatment program. Boiler manufacturers should also be consulted to aid in the establishment of proper blowdown and chemical cleaning procedures.

E. Have heat recovery boilers cleaned (mechanically or chemically) by authorized/trained personnel.

F. Control dust loading by maintaining low velocities, and provide proper maintenance to curtail the buildup of dust and minimize erosion. Large quantities of dust in waste gases can be controlled by installing dust collectors, pockets and hoppers, or conveyors.

G. To minimize corrosion from low temperatures, operate boilers above the dew point.

H. Ensure a maximum heat input is established to prevent excessive heat from entering the heat recovery unit.

I. To prevent fatigue problems, do not cycle load firetube heat recovery boilers.

J. Perform more frequent inspections at combined cycle plants that were designed for base load operation but are cycled due to market conditions. Base load operation sees fewer starts and stops and therefore fewer fluctuations in temperature, pressure, and water chemistry. Cycling can cause additional concerns, such as creep and thermal fatigue.

K. Conduct a process hazard analysis to determine the possible consequences of a leak from the water side to the process side and vice versa.

2.1.2 Inspection, Testing and Maintenance

Establish and implement a heat recovery boiler inspection, testing, and maintenance program. See Data Sheet 9-0, *Asset Integrity*, for guidance on developing an asset integrity program.

Tube erosion should be monitored at installations that operate with high dust loading. Tube metal thickness readings should be taken at least once a year. Where applicable, readings should be taken more frequently to provide a clearer picture of potential problem areas.

The recommendations in this section are intended to supply the user with some additional inspection, testing, and maintenance guidelines. Use these recommendations in conjunction with those in Data Sheets 6-22, *Firetube Boilers,* and 6-23, *Watertube Boilers.*

2.1.2.1 General

Check for sagging tubes in a firetube boiler, and bulged or distorted tubes in a watertube boiler, indicating overheating.

Pitting of tube surfaces is an indication of corrosion and can occur on both the water and gas sides of the boiler. Waterside corrosion is an indication of an inadequate water treatment program. Gas-side corrosion may occur from operating at too low a dew point for the composition of the heat recovery gas. Dew point is especially critical in installations that are recovering heat from processes with high sulfur content.

2.1.2.2 Cold End Corrosion

A. Examine any fireside metal surfaces that have been or are coated with ash or slag for wasting. Wasting may be in the form of pits, grooves, or uniform thinning of the material. This can happen due to the presence of sulfur in gas-fired or fuel oil-fired units.

B. Remove surface deposits and examine metal surfaces for a light, shiny appearance. This may be an indication of acid etching.

C. Remove deposits on welded seams and stay bolt ends. Deposits can take on the shape of welds, thereby hiding severely wasted weld metal.

2.1.2.3 Boiler Heating Surface Erosion

A. Check all furnace and convection pass tubing for erosion as a result of fly-ash impingement. Tubing in the area of a change in direction of gas flow is especially susceptible.

B. Examine exposed U-bolts and any other projections into the gas stream for wear caused by eddy currents. Welded-on studs may be used in place of U-bolts for baffle tile support.

C. Check the boiler casing for cracks that would allow gas to penetrate. Check baffles and refractory cracks, voids, or widened joints that could allow high-velocity dust-laden gas to bypass, cutting the tubing or shell surfaces.

D. If excessive polishing and tube erosion is discovered, it may be necessary to change the original baffling arrangement or install deflector plates. Sleeves may also be placed over tubing to protect the tubes from fly-ash erosion.

Note: When attaching any type of shielding to tubes, care should be taken that the method of attachment permits expansion of the shielding independently of the tubes.

E. Take tube metal thickness readings at least annually in areas where erosion has taken place. When a tube bank becomes partially plugged, the cross-sectional area of the bank is decreased. This will increase gas velocities and could cause “polishing” of the unplugged section of the tube bank.

F. Examine areas around sootblowers for tube wastage resulting from impingement of high-velocity steam from improperly adjusted sootblowers. Steam from sootblowers, if not properly directed, can cut completely through tubes and drums.

2.1.2.4 Firetube Boilers

A. Check tubes, tubesheets, and tube-to-tube sheet attachments for signs of cracking as a result of thermal expansion differences. Rolled or rolled and seal-welded tubes are more susceptible to thermal expansion problems than full penetration welded tubes. Figure 1 shows an example of tube distortion that is a result of thermal expansion.

If allowance is not made for expansion, or if the thermal differences between tube sheet and tube exceed the tolerances, then the compressive forces will exceed the yield strength of the tube and cause a gap as shown in Figure 1. When the unit cools, water and any solids will be trapped in the gap. When the unit is reheated, the trapped water will vaporize, creating a pressure that could lead to cracking.

Insulated ferrules may be used to protect tube ends from overheating. Ferrules could also be used to guard against the condition shown in Figure 1, although the best way to protect the tube ends in this case would be to use a full penetration weld, or butt weld the tube to the back of the tube sheet.

B. Check refractory for breakdown that could lead to overheating.

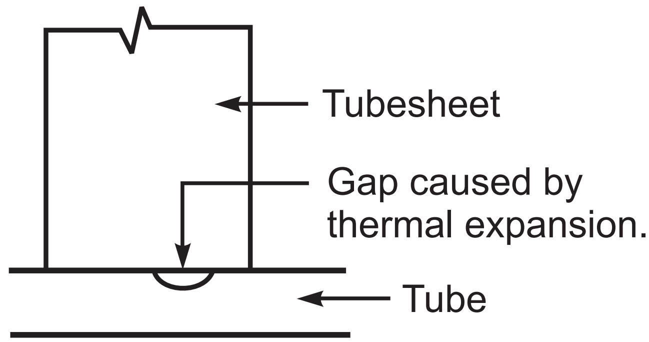

Fig. 1. Effects of thermal expansion

2.1.2.5 Repairs

The method of repairing tubes or any pressure part of the boiler affected by erosion depends on the degree of damage and, to a certain extent, the location. Tube sections with 50% of the wall thickness eroded should be replaced. See guidance in Data Sheet 6-23 for watertube boilers. Small eroded tube areas may be overlaid and reinforced by either gas or arc welding. Welding should not be done on sections of tube where enough of the wall thickness has been eroded to allow burn-through when applying weld overlay. With larger tube defects, it may be necessary to remove a section of tube or, in some cases, the entire tube.

2.1.3 Contingency Planning

2.1.3.1 Equipment Contingency Planning

When a heat recovery boiler breakdown would result in an unplanned outage to site processes and systems considered key to the continuity of operations, develop and maintain a documented, viable heat recovery boiler equipment contingency plan per Data Sheet 9-0, *Asset Integrity*. See Appendix C of that data sheet for guidance on the process of developing and maintaining a viable equipment contingency plan. Also refer to sparing, rental, and redundant equipment mitigation strategy guidance in that data sheet.

2.2 Equipment and Processes

2.2.1 Control and Instrumentation

A. Install pressure transmitters in furnace areas of watertube boilers. Also install them throughout the convection zone of the watertube and on the inlet and outlet sides of the firetube to monitor pressure increases due to fly-ash or dust blockage. Ensure proper spacing of tubes to prevent fly-ash and dust blockage.

B. Provide audible and visible alarms to indicate low water. Where applicable, protect installations against overheating by arranging to divert the heat recovery gases around the boiler through actuation of the low-water tripping devices or high-temperature sensors. Provide a standby feed pump for those installations that are not equipped with a means to bypass heat recovery gas.

2.2.2 Design and Installation

A. Ensure heat recovery boilers are designed and constructed in accordance with the ASME Boiler and Pressure Vessel Code or equivalent standard.

B. Ensure new boilers are designed and constructed with automatic heat recovery bypass systems arranged to bypass the heat recovery gas around the boiler in the event of high-temperature or low-water conditions.

C. Where dust collects:

1. Locate soot blowers to dislodge any accumulations.

2. Establish proper soot blower and hand-lancing procedures. Ensure soot blowers are aligned properly to avoid impingement.

3. To prevent condensate erosion, have soot blowers drained before they are operated.

D. In watertube boilers with finned tubes, ensure the gas temperature is not excessive, to avoid burning the fins. Where fin tubes are used, ensure the gas is clean. The buildup of solids (fouling) can lead to fire.

E. Provide low-water protection in accordance with DS 6-12, *Low-Water Protection.*

2.2.3 Gas Turbines

A. Provide draft gages to monitor draft loss through the heat recovery boiler. A minimum draft loss is necessary to avoid a buildup of back pressure that would affect turbine power output.

B. Do not use baffles in these units. Baffles could cause back pressures to be developed on the gas turbine.

2.3 Occupancy

2.3.1 Steel Mills

A. Because of the dust loading, carefully inspect tubes for signs of impingement and erosion. Ensure procedures for proper soot blower operation are followed.

B. Forced circulation may also be necessary for this application since positive and complete circulation is required in areas of high heat absorption.

C. Cleaning of blast furnace gas (BFG) is needed to extend and improve availability of equipment. Ensure BFG is cleaned prior to entering the boiler furnace.

2.3.2 Combined Cycle Plants

See Figure 2 for a typical single-unit combined cycle layout.

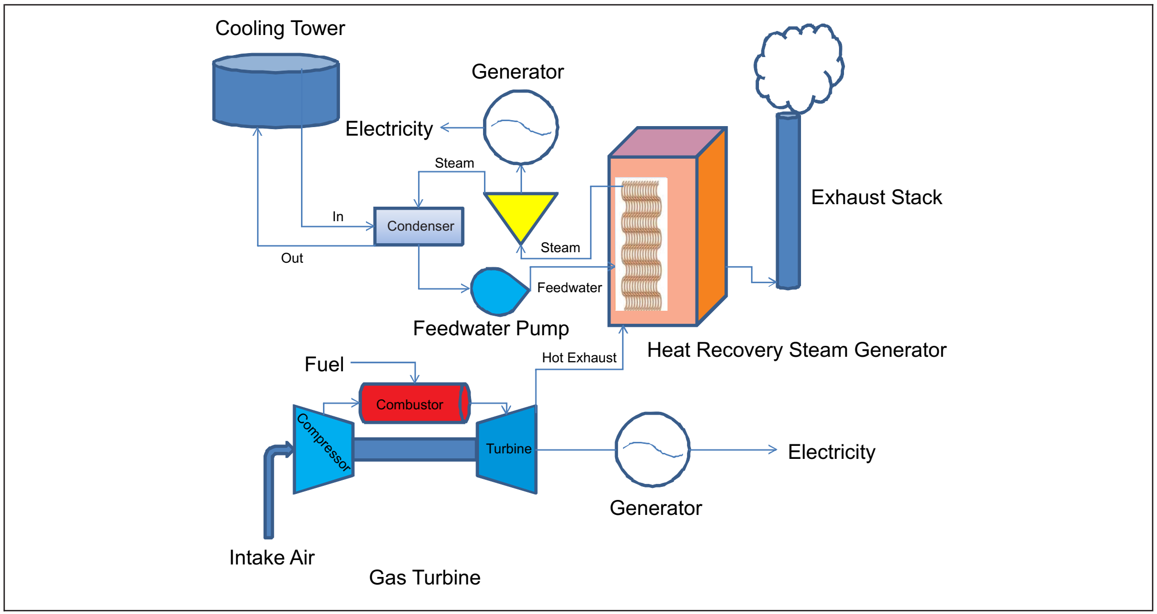

Fig. 2. A typical single-unit combined cycle layout

2.3.2.1 Inspection

Areas of concern due to cycling and/or swing loads are water chemistry, temperature differentials that can cause unequal expansion or contraction due to metal thicknesses, and spray attemperation, particularly at low load and startup.

A. Spray Attemperators

At each internal inspection, do the following:

1. Check for deterioration, broken liner welds, and worn or obstructed spray nozzles

2. Inspect and service block and control valves, including calibration of the control loop

B. Steam Drums

At each internal inspection, check the following for erosion or corrosion:

1. Steam separators, baffle plates/belly liners, and nozzle welds

2. Chemical feed line

3. Feedwater pipe

4. Piping supports and hardware

5. Perforated plates (located upstream of the first set of tubes in the hot end; they are subject to severe cracking because they are not cooled)

C. Review and comply with OEM technical bulletins.

D. Implement a high-energy piping inspection program. Include the following:

1. Hot and cold setting inspection for hangers

2. Periodic NDE of longitudinal seam welded piping

2.3.2.2 Low-Water Protection

Provide low-water protection for once-through units, and for the high-pressure steam drum on units with natural or forced circulation, in accordance with Data Sheet 6-12, *Low-Water Protection.*

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Loss History

There are several general causes of boiler loss. They are abnormal temperature, physical weakness, fatigue (stress concentration), abnormal pressure, and inadequate supports, including insufficient clearance and misalignment. Abnormal temperature is by far the most common cause of boiler failure.

Abnormal temperature can result from a number of scenarios, including failure of controls, scale buildups that insulate heat transfer surfaces, and faulty designs that cause circulation problems.

Physical weakness is usually caused by corrosion (both internal and external) or erosion.

Oxygen corrosion usually occurs as small pits on the water sides of tubes or drums. Its occurrence is spotty and it is often difficult to explain why the attack takes place where it does.

Low water velocity may cause sludge or scale particles in suspension to settle out on the lower half of the tube wall. This may form a porous coating that permits some water to reach the tube surface but not enough to keep the inside tube-wall temperatures at or near saturation temperature. An atmosphere of superheated steam then exists at the metal surface. Metal temperatures of perhaps 100°F to 200°F (47°C to 94°C) above saturation temperature occur, and a direct attack of steam on the metal follows. The corrosion products formed further thicken the deposit, which again raises the metal temperature and accelerates attack. Sodium hydroxide in the boiler water is concentrated at the metal surface. This also greatly accelerates the corrosion rate.

External corrosion in watertube boilers is prevalent in areas that are subject to constant or occasional dampness combined with the presence of soot and other corrosion-producing chemicals. Minor leaks or even sweating of cooler boiler parts during idle periods in humid weather will enhance the rate of this corrosion.

External erosion of boiler tubes has been one of the leading causes of forced shutdowns. Erosion is of particular concern in boilers that are recovering heat from “dirty gases.”

Fatigue is the most common cause of cracking without accompanying overheating and is defined as the action that takes place in material, especially metals, causing deterioration and failure after a repetition of stress. A repetition of stress can be caused by restriction of proper expansion in the boiler setting, foreign material lodging under drums and headers closing the expansion gap, and by steam and other line connections that have inadequate expansion facilities.

The change of pressure and temperature in boilers produces a “breathing action” that may result in fatigue cracking after several years of service. Cracking may result in areas of high stress where localized from general expansion and contraction. A crack from fatigue may grow faster in the presence of corrosive water. The combined deteriorating effect of fatigue and corrosion are greater than the sum of their individual consequences.

Safety valves can be the cause of a loss due to overpressure if they are of improper size. Improper setting and broken and jammed parts of safety valves can also lead to losses from overpressure.

Inadequate supports include broken or collapsed supports and columns, loosened nuts on suspension bolts, loose or broken pipe hangers, inadequate room for expansion of pipes, misalignment, and excessive external loading on piping.

4.0 REFERENCES

Data Sheet 6-12, *Low-Water Protection*
Data Sheet 6-22, *Firetube Boilers*
Data Sheet 6-23, *Watertube Boilers*
Data Sheet 7-72, *Reforming and Cracking Furnaces*
Data Sheet 9-0, *Asset integrity*
Data Sheet 10-8, *Operators*

APPENDIX A GLOSSARY OF TERMS

Augmented air: Fresh air required by the duct burner for proper operation and stable combustion.

Brayton cycle: A thermodynamic cycle that describes the workings of a constant pressure heat engine.

Cold start: When more than 48 hours have elapsed since the combustion turbine was last fired and synchronized.

Duct burner: A burner mounted within the HRSG enclosure used to heat the combustion turbine exhaust flow to a temperature required for desired steam generation flow, temperature, and/or pressure.

Heat recovery boiler: A power plant subsystem used to capture energy that would otherwise be lost.

Heat recovery steam generator (HRSG): A heat exchanger that uses a series of heat transfer sections (e.g., superheater, evaporator, and economizer) positioned in the exhaust gas stream to recover heat and supply a rated steam flow at a required temperature and pressure.

Hot start: When less than 8 hours have elapsed since the combustion turbine was last fired and synchronized.

Rankine cycle: A thermodynamic cycle that converts heat into work. The heat is supplied externally to a closed loop, which usually uses water as the working fluid.

Warm start: When between 8 and 48 hours have elapsed since the combustion turbine was last fired and synchronized.

APPENDIX B DOCUMENT REVISION HISTORY

The purpose of this appendix is to capture the changes that were made to this document each time it was published. Please note that section numbers refer specifically to those in the version published on the date shown (i.e., the section numbers are not always the same from version to version).

January 2021. Interim revision. Updated contingency planning guidance.

January 2014. This document has been completely revised. Significant changes include the following:

A. Changed the title from *Waste Heat Recovery Boilers* to *Heat Recovery Boilers.*

B. Changed the term “waste heat recovery boiler” to “heat recovery boiler” throughout the document.

C. Added recommendations for heat recovery steam generators (HRSGs) and combined cycle plants.

D. Added information on HRSGs and combined cycle plants to Section 3.0, *Support for Recommendations.*

E. Added terms to Appendix A.

June 1999. Reformatted the document to be consistent with other data sheets.

May 1998. The content of DS 12-14C was added to this document.

APPENDIX C SUPPLEMENTAL INFORMATION

C.1 Introduction

Rising fuel costs have made the recovery of heat from a given process economically feasible. Heat recovery can also be important from a pollution standpoint. Most waste gases are characterized by a high inert gas content and by a solid carryover content. The degree to which the inerts are present, and the quality, size, and character of the solids, strongly influence the boiler design for a given application. With proper design, all or part of the plant's steam requirements may be supplied by a heat recovery boiler.

Heat recovery is economically practical wherever a process waste product or gas is continuously discharged at a temperature of 1,000°F (538°C) or higher (Table 1). In addition to producing useful steam, the lowering of the flue gas temperature may reduce maintenance of flues, fans, and stacks. Process material may often be more completely recovered from the cooled gases.

Table 1. Temperature of Waste Heat Gases

Source of Gas		*Temperature, °F*	*Temperature, °C*
Ammonia oxidation process		1,350-1,475	732-801
Annealing furnace		1,100-2,000	593-1093
Black liquor recovery furnace		1,800-2,000	982-1093
Cement kiln (dry process)		1,150-1,350	621-732
Cement kiln (wet process)		800-1,100	427-593
Coke oven	beehive	1,950-2,300	1066-1260
	by-product	up to 750	up to 379
Copper refining furnace		2,700-2,800	1482-1538
Copper reverberatory furnace		2,000-2,500	1093-1371
Diesel engine exhaust		550-1,200	288-649
Forge and billet heating furnace		1,700-2,200	927-1204
Garbage incinerator		1,550-2,000	843-1093
Gas benches		1,050-1,150	562-621
Glass tanks		800-1,000	427-538
Heating furnace		1,700-1,900	927-1038
Malleable iron air furnace		2,600	1427
Nickel refining furnace		2,500-3,000	1371-1649
Petroleum refinery still		1,000-1,100	538-593
Steel furnace, open hearth	oil, tar or natural gas	800-1,100	427-593
	producer gas-fired	1,200-1,300	649-704
Sulfur ore processing		1,600-1,900	871-1038
Zinc fuming furnace		1,800-2,000	982-1093

The heat transfer from the process waste gases is accomplished primarily through convection. There is very little radiative heat in process waste gases. As a result, gas velocities in heat recovery boilers tend to be high. In gases that carry a substantial amount of particulate matter, the velocities cannot be too high or erosion of heating surfaces will become a problem.

There are basically two types of heat recovery boilers: firetube and watertube. When heat must be removed or recovered from a process gas supplied above atmospheric pressure, firetube units are usually the choice. Watertube heat recovery boilers are useful when heat must be removed from flue gases at near-atmospheric pressure.

C.2 Watertube Waste Heat Boilers

The watertube heat recovery boiler (Figure 3) is the most frequently used for the following reasons:

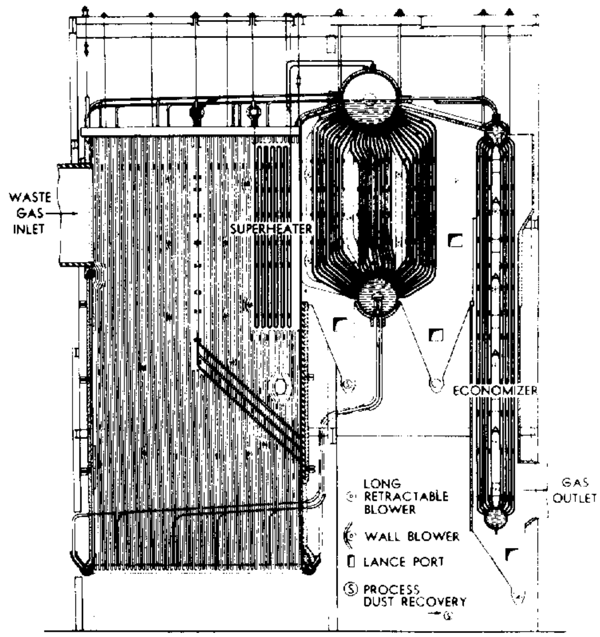

Fig. 3. Heat recovery boiler unit suitable for high-temperature gases carrying sticky or semi-molten particles

A. Larger sizes at higher pressures are readily available.

B. Dust may be recovered and collected into hoppers.

C. Tube size and spacing may be varied to minimize slagging and erosion.

D. Damage from wide fluctuations in gas temperature is not so likely.

E. The water side of the tube is more readily cleaned and is not susceptible to damage from poor feedwater. (Note: Proper boiler feedwater treatment must protect piping, feedwater heaters, economizers, and the deaerator). The most common causes of corrosion are oxygen pitting and acidic attack due to low pH.

F. The water-cooled furnace wall is easily applied.

G. “Sticky” flue gases can be handled easier in a watertube boiler.

H. A more economical arrangement is possible.

Specific process requirements have resulted in the design of various types of watertube heat recovery boilers, which are described in the following sections.

C.2.1 Bent-Tube Boiler

The bent-tube boiler is used for heat recovery for the following reasons:

1. Greater flexibility in diameter, spacing, and arrangement of tubes.
2. Vertical tubes collect less dust.
3. Less space is needed for tube removal.
4. More positive circulation minimizes tube damage.
5. Pendent superheater installation is possible.

Bent-tube boilers have a relatively low steam generating rate per square foot of heating surface. As a result, more tubes are needed for a given steaming rate, and the number of drums is determined according to the area necessary for tube attachment.

C.2.2 Forced Circulation Boilr

The forced circulation boiler (Figure 4) is suitable for use with clean, low-temperature gases. Its extremely small tubes can be arranged without regard for natural circulation requirements because circulation is provided by pumps, a design flexibility that results in a lighter, more compact boiler.

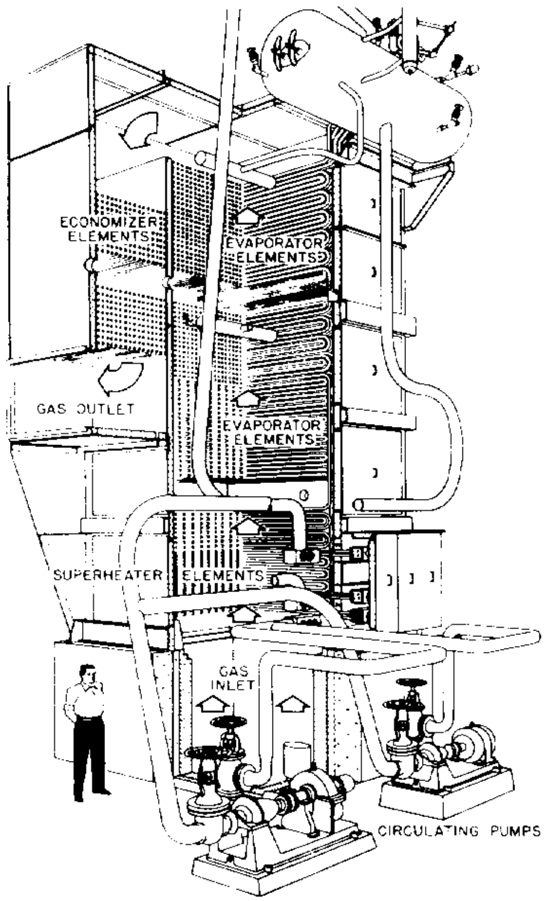

Fig. 4. Forced circulation LaMont heat recovery boiler

C.2.3 Horizontal Straight-Tubular Header

The horizontal straight-tubular box header and sectional header heat recovery boilers were occasionally used for relatively clean waste gases, although their comparatively low gas temperature required deep tube banks with multiple passes. Generally, they have been superseded by other types that are more economical to build and operate.

C.2.4 Vertical Boiler

The vertical boiler is used to save floor space (Figure 5). It is limited to a shell diameter of about 96 in. (2.4 m) because of shipping limitations and drum attachments. The top inlet arrangement is used in sulfur-burning furnaces.

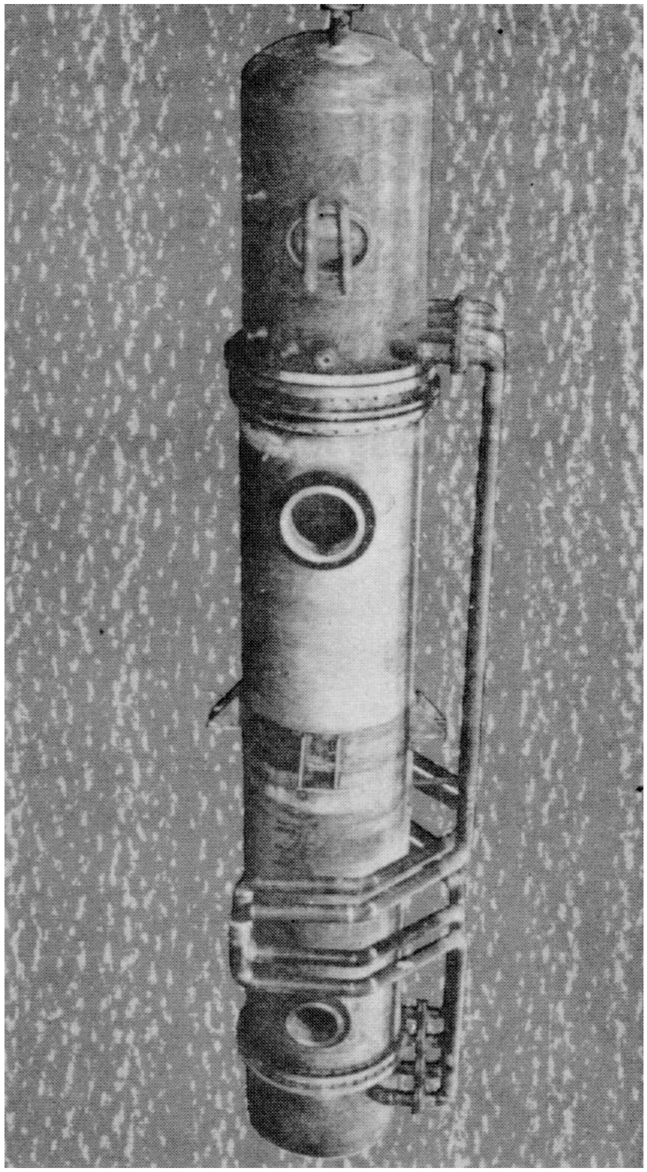

Fig. 5. Vertical water tube heat recovery boiler with external downcomers (steam generated at 50 psi [345 kPa] recovering heat from sulphur-bearing gases; the top channel serves as steam disengaging drum)

Watertube boilers are equipped with plain or finned tubes (Figure 6). Plain tubes are useful only for small volumes of gas, or for high-temperature gases (above 1400°F, 760°C). Plain tubes are also used on units where gases have large amounts of solids.

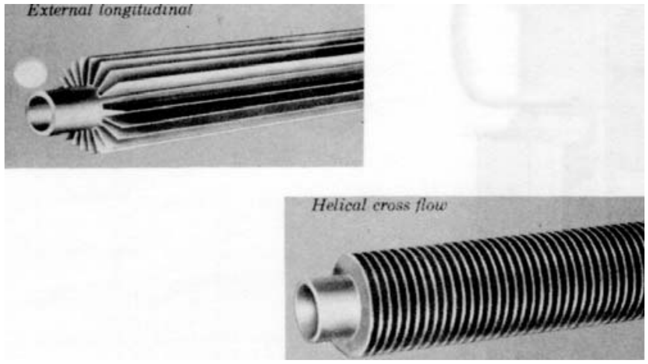

Fig. 6. Finned tubes used on watertube boilers

Nearly all other watertube boilers are equipped with finned tubes. Finned tubes provide greater heating surface; as much as 10 times more than bare tubes of the same tube diameter and length.

C.3 Firetube Heat Recovery Boilers

A direct-fired firetube boiler that has part of its shell exposed to the furnace absorbs heat both by radiation and convection and therefore makes more efficient use of its surfaces. In heat recovery applications, the firetube boilers usually have a single-pass arrangement that absorbs only convection heat from the gases. The exterior shell is not used as a heating surface. The boiler is suitable for pressures as high as 500 psi (3447 kPa) and an entering-gas temperature as high as 1,800°F (982°C).

The boiler is inherently tight under pressure and may be used with pulsating gases, such as diesel engine exhaust, where no refractory lining or setting is used but where the exterior is insulated.

The tubes are of smaller diameter and more closely spaced than in direct-fired applications. They are kept clear of deposits by a rotating-arm soot blower, with the nozzles directed toward the tube ends. For heavier incrustations, hand lances are inserted through lance doors in the wall of the connecting flue (there is less tendency for flue dust to clog the vertical tubes). The firetube boiler should be used only with heat recovery streams having light dust loadings.

The firetube boiler is usually of the horizontal type (Figure 7). Practically the entire space within the shell of the horizontal boiler is filled with tubes; steam space is minimized and a steam drum used instead. All tubes are submerged to minimize the stresses that occur when dry tubes are used. The manhole provided near the bottom for inspection and cleaning limits the number of tubes installed in the lower part of the drum. The access may be in the shell or in the head at the gas outlet end.

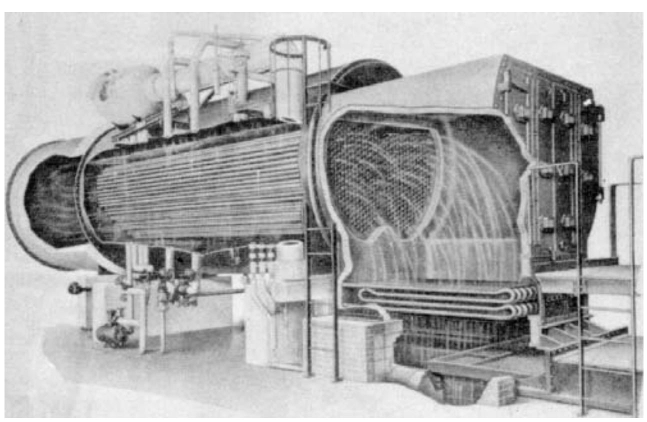

Fig. 7. Open hearth horizontal gas tube heat recovery boiler

C.4 Typical Heat Recovery Boiler Applications

C.4.1 Steel Mills

Open hearth, forge, and continuous heating furnaces are usually equipped with heat recovery boilers. As a general rule, it is impractical to attempt recovery of heat from single-batch furnaces or those in which a large portion of the combustion gases are lost through the doors. A common arrangement is for two or more furnaces to discharge through a common heat recovery boiler. Boilers used in steel mills include horizontal and vertical firetube as well as the horizontal straight-tubular and bent-tube types.

Steam demands in a steel mill make the use of heat recovery boilers a practical means of reducing the temperature of waste gases to around 600°F (316°C). This permits the use of electrostatic precipitators capable of removing dust particles as required by increasingly stringent air pollution laws. Because these gases are dirty and offer only sensible heat, they present special requirements. Heating surfaces must be arranged so as to minimize deposits and the plugging of gas passages. At the same time, positive circulation is essential to provide stability of boiler operation and ensure good steam quality.

Figure 8 shows a controlled circulation boiler for the recovery of heat from open hearth furnace gas. Tube spacing at the inlet section near the bottom of the unit is comparatively wide to prevent slag adherence and to minimize abrasion. As the gas is cooled in passing through the boiler, the tube spacing is decreased. The boiler circulating pumps not only permit flexibility in the choice of tube size and spacing but also ensure positive and stable circulation under steady and variable load conditions.

C.4.1.1 Basic Oxygen Process

In the basic oxygen process for steel making, oxygen is top-blown into a vessel similar to a Bessemer converter, and the products of this reaction (mainly CO gas) are collected in a fume hood (Figure 9). The primary function of the fume hood is to reduce the temperature of the dust-laden gases and direct them to the cleaning equipment before they are discharged to the atmosphere. The unit designed for this service uses controlled circulation principles and can be combined with a convection surface to constitute a heat recovery boiler. The unit is fabricated of smaller diameter tubing with fillet welds between adjacent tubes on the outside perimeter to form a continuous wall that is gas-tight. The vessel cover is placed directly above the converter vessel and located in such a manner as to control entering ambient air through the induced draft fan. The amount of air allowed to enter is related to the quantity required to oxidize the carbon monoxide gas that is generated in the basic oxygen process.

Feedwater is discharged into the steam drum where it mixes with circulated water from the unit. This water mixture enters the downcomers, connected to circulating pumps which deliver water to a discharge manifold. The water then flows through supply tubes to the inlet headers of the fume hood and through the waterwalls to the outlet header. Risers from the outlet header to the steam drum complete the circuit. The unit has complete water cooling with convection surface located in the upper furnace area.

C.4.2 Lead and Zinc Smelters

One way to process lead and zinc is by smelting in fuming furnaces where pulverized coal and air are injected into the molten slag. The lead and zinc are boiled out from the slag as metal vapor and then reoxidized above the slag bed in an atmosphere free of impurities. The gaseous products leave the fuming furnace at about 2,200°F (1204°C) carrying solids in a semi-molten or sticky form. As the gas passes through a combustion chamber, the zinc vapor is completely oxidized. The waterwalls of the combustion chamber cool the products to about 1,400°F (760°C) prior to their entry into the superheater and convection passes so the solids may be removed from the surfaces in the form of dust.

The suspended dust is precipitated into a water-cooled, hopper-shaped furnace bottom and removed by screw conveyors. Rotating wall soot blowers (using air or steam) periodically remove accumulations of dust from the waterwalls. Long, retractable automatic soot blowers are used in the convection zone. Occasional hand-lancing is necessary. Figure 10 shows a typical heat recovery boiler for use with a fuming smelter.

C.4.3 Gas Turbines and Combined Cycle

The combustion gas turbine has become an important element in the production of electrical and mechanical power throughout the world. By burning liquid or gaseous fuels at relatively high temperature and pressure, these machines extract the energy their burned fuel generates. A widely used combination of a gas turbine

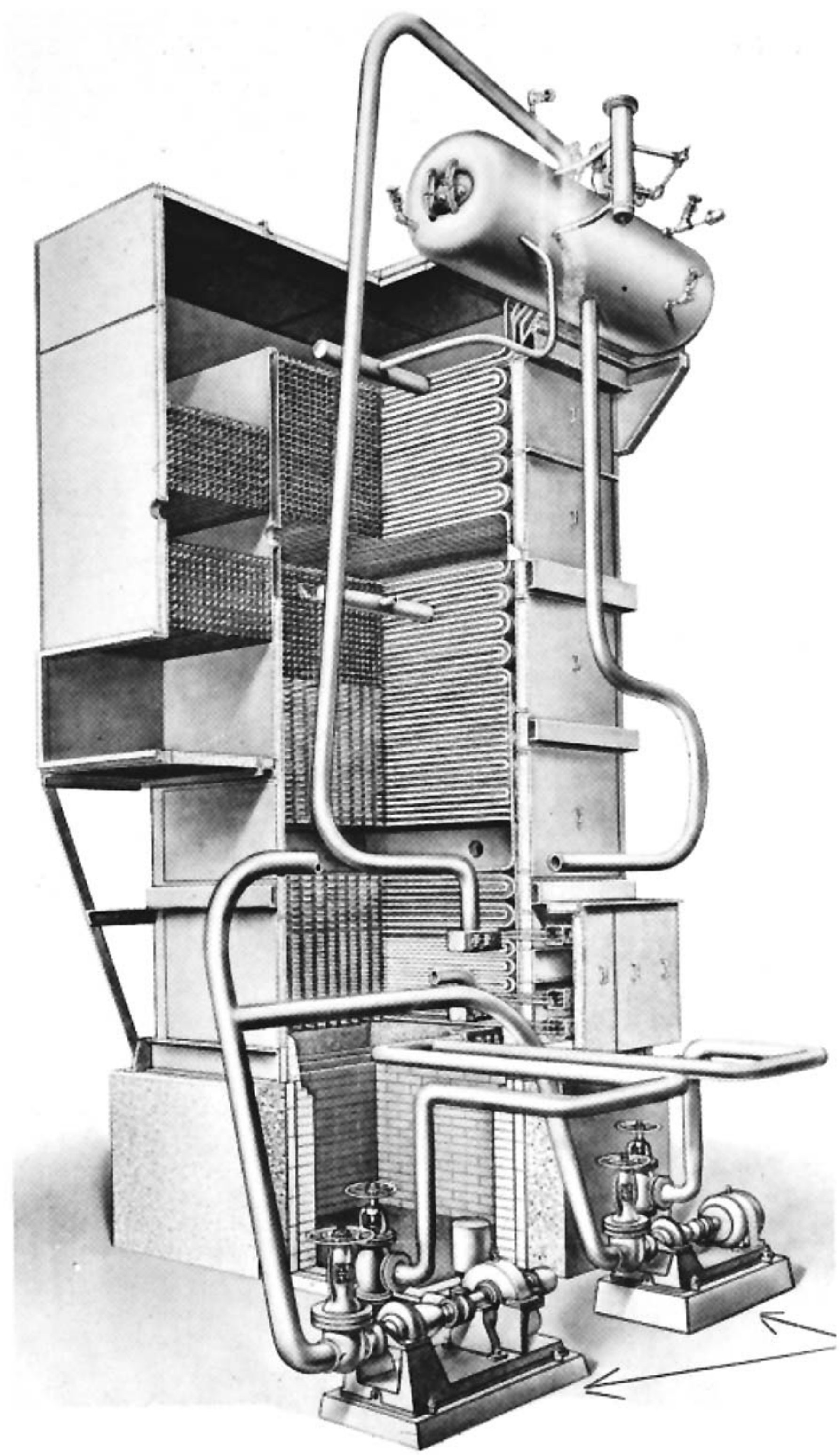

Fig. 8. Controlled circulation boiler for recovery of heat from open hearth furnace

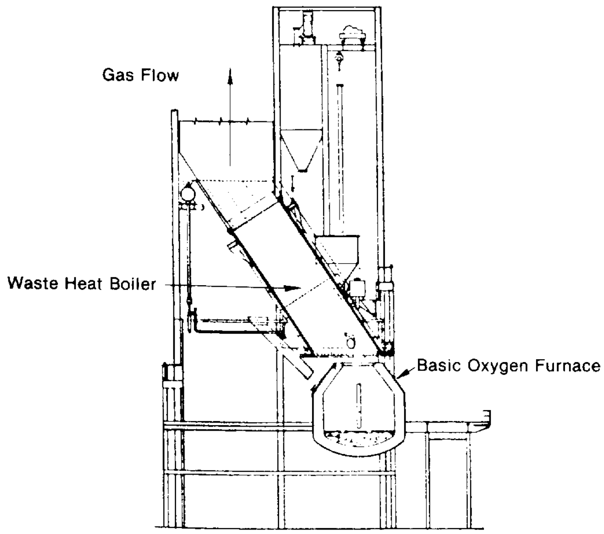

Fig. 9. Fume hood for heat recovery in the oxygen process for steel making

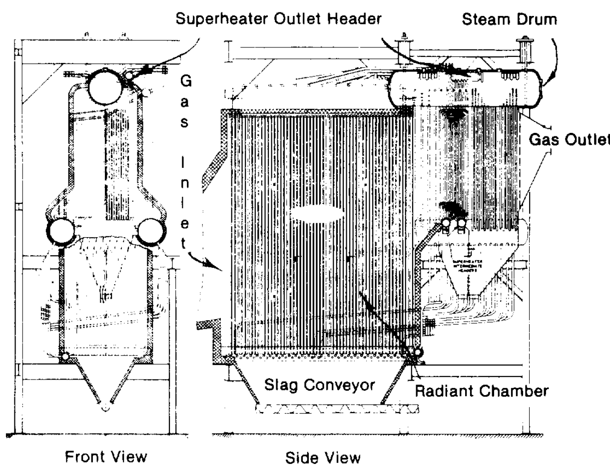

Fig. 10. Smelting and refining heat recovery boiler

(Brayton cycle) burns fuel, and the hot exhaust is ducted to a heat recovery steam generator that provides steam to a steam turbine (Rankine cycle) to increase the overall efficiency of the operation.

Gas turbines find wide application where power must be provided on a standby or peaking basis, and for unattended service in remote locations. In many cases the thermal efficiency of a gas turbine plant has been improved by adding heat recovery equipment comprising boilers, economizers, and regenerators, singly or in combination (Figure 11).

Gas turbines employ air-cooled stainless-steel combustion chambers operating at about 1500°F (815°C) on a continuous basis. To obtain this relatively low combustion temperature, excess air in quantities higher than 300% must be employed. With some gas turbines in which lower combustion chamber temperatures are used because of the nature of the fuel, the excess air may be as high as 500%. The exhaust gas temperature is about 600°F (315°C) below the combustion chamber temperature.

The large quantities of excess air and the 700°F to 900°F (371°C to 482°C) turbine exhaust gas temperatures have the following effects on the design of steam generating equipment:

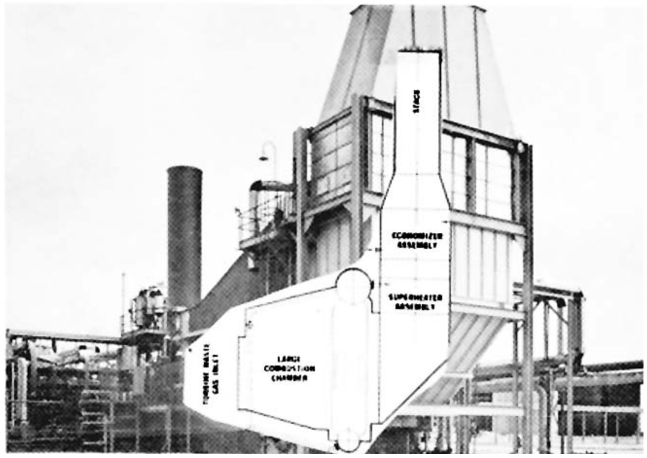

Fig. 11. Heat recovery equipment at a gas turbine installation

A. Straight waste-heat recovery of sensible heat in the turbine exhaust must be accomplished at lower thermal heads than is the case with waste gas from reverberatory furnaces and the like.

B. As gas turbine combustion chamber temperatures are lowered, the exhaust stream becomes larger in quantity for a given gas turbine output at such a low-temperature level that the recovery of heat recovery may become uneconomical.

C. The use of gas turbine exhaust as highly preheated combustion air for a steam generating unit fired with any fuel, and without restriction as to steam conditions, becomes attractive. Many of the combined gas-steam turbine applications in operation involve both straight heat recovery by boilers or economizers and the use of turbine exhaust as the source of oxygen for fuel burning.

Heat recovery steam generators for the recovery of sensible heat from gas turbine exhaust can be of either the natural or controlled circulation design. Such boilers can be built inside of what amounts to a continuation of the turbine exhaust duct. Gas velocities through these units are limited to about 100 ft/s (30 m/s) by reason of excessive backpressure on the gas turbine.

C.4.3.1 Classification of HRSGs

Classification of HRSGs is based on application, design, or operation.

A. Fired and Unfired

Normally, HRSGs do not have any heat input other than exhaust heat. The performance and output of the HRSG is dependent on the exhaust heat of the gas turbine. At partial electrical loads, this lower heat exhaust leads to reduced output from the HRSGs. Ambient conditions also affect the gas turbine performance, lowering exhaust heat. This could affect the downstream process where the steam is used. To avoid such situations, supplemental firing of oil or gas takes place within the HRSG. While this may not be an efficient process, it avoids costly production disturbances. Duct burner fuel trains should be reviewed in accordance with Data Sheets 6-4 or 6-5 as appropriate.

Supplemental firing takes place in burners within the transition or near the gas duct at HRSG inlets. Oil or gas is the supplementary fuel. At low loads, the flue gas at exhaust of a gas turbine is high in oxygen content, and additional air is not required for combustion. This eliminates the need for forced draft or induced draft fans. Since the oxygen in the gas flow decreases as the firing temperature of the gas turbine get higher, supplementary air may be required for the duct burners.

B. Multiple Units

Where multiple HRSGs are located in a facility, adequate separation should be provided between adjacent trains to permit access for cranes and other maintenance equipment.

C. Vertical and Horizontal

The construction or design of the HRSG is based on the gas flow. The unit can be either vertical or horizontal.

C.4.4 Diesel Engine Exhaust

Either the gas-tube or the positive circulation watertube boiler may be used for recovery of 30% to 40% of the heat from diesel engine exhaust gases. These boilers are constructed to withstand the pulsations of the gas as it is discharged from the engine. When the four-cycle engine with solid injection operates at maximum load, it has a discharge temperature of about 800°F (426°C) (400°F [204°C] at half load). The two-cycle engine, which uses more scavenging air, has a lower exhaust temperature (sometimes not over 550°F, 289°C). From 12 to 18 pounds of gas/hour per boiler horsepower is available from a fourcycle diesel, and twice this quantity from a two-cycle engine. Exhaust gases from two 3,000 hp (2235 kw) diesel engines, at a temperature of 550°F (289°C) are capable of generating 3,000 pounds (1361 kg) steam an hour at 100 psi (689 kPa) pressure in a heat recovery boiler. See Figure 12.

C.4.5 Copper Ores

The reverberatory furnaces used for smelting copper ore concentrates are fired by pulverized coal, oil or gas. Impurities float to the top and are skimmed off as slag. The products of combustion, leaving at about 2,300°F (1260°C), are heavily contaminated with slag particles and solids, some of which may be in a pasty or semi-fused state.

To cool these slag particles to about 1,700°F (926°C), a large water-cooled furnace area is used. Platens spaced on about 18 in. (46 cm) centers prevent bridging and provide additional heat-absorbing surface for cooling the gases prior to their entry into the superheater and convection zones. Figures 14 and 14 show a typical heat recovery boiler designed for use with a copper reverberatory furnace.

C.4.6 Chemical Process Industries

In many chemical installations the use of heat recovery boilers, often known as heat recovery systems, are used as a means of efficiently and economically obtaining steam for process. In the chemical process industry the heat recovery boilers are designed primarily to extract heat from waste process gases. In many cases the steam is of secondary interest. The primary purpose of the heat recovery boiler is the cooling of the gases for the purpose of combining with a catalyst. This is done, for example, in sulfuric acid plants and ammonia process plants to obtain other byproducts.

Where elemental sulfur is burned with air inside a combustion chamber, the heat resulting from the chemical reaction is used for steam generation. The exhaust gases containing SO2 are cooled to a controlled temperature and combined with oxygen in a catalyst bed to produce SO3 for further process in the manufacture of acid (Figure 15).

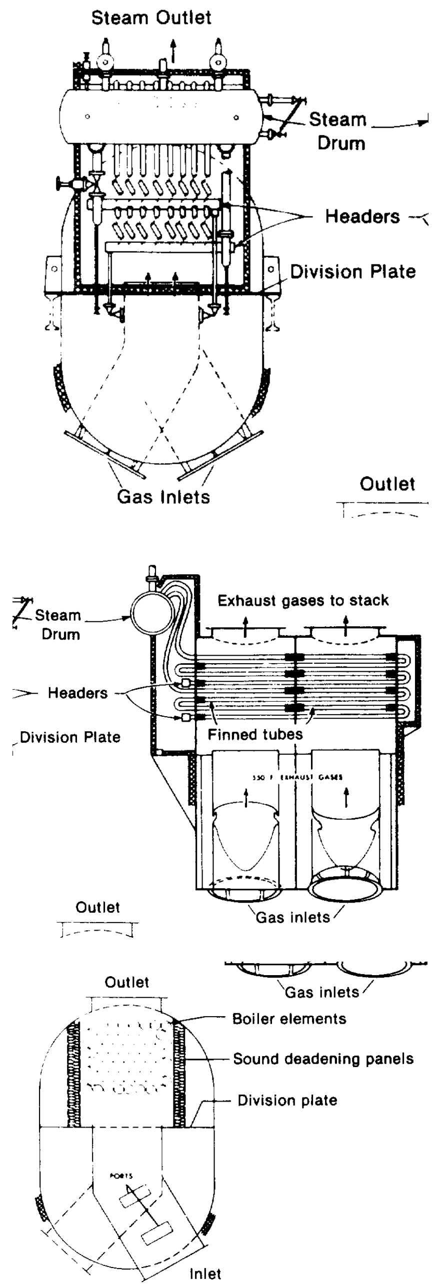

Fig. 12. Diesel engine waste-heat steam generator (U.S. Maritime Commission Liberty ship "Thomas Nelson")

In the ammonia process the waste recovery system may be used to accomplish two or more objectives. Steam is produced for processing, but the main use of the heat recovery system is to cool the gas in process so it can then be passed over a catalyst bed in the conversion process to obtain ammonia. A special type of boiler, the bayonet type, is used in the ammonia process. For information about this special application, refer to Data Sheet 7-72, *Reforming and Cracking Furnaces.*

In chemical plants today the conversion of heat recovery in process systems is a custom job and needs careful study and evaluation for the process involved. When sulfur is burned under a boiler, as in the commercial production of sulfuric acid, the temperature of all metal surfaces should exceed the dew point

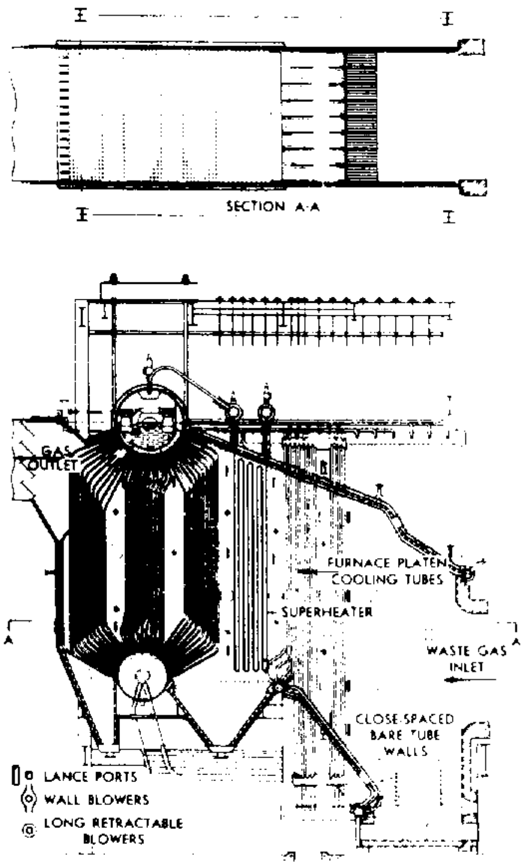

Fig. 13. Copper reverberatory furnace heat recovery boiler

temperature of 450°F (232°C) if they are to have a reasonably long life. The quantity of acid present is small, about 0.005% by volume in dry gas. Figure 16 is a sketch of a combination watertube/firetube heat recovery boiler for use in a chemical plant.

Gases in contact with tubes and plates reach the dew point sooner than gases in the main stream. The gases leaving the boiler proper are not all the same temperature. Corrosion usually is most noticeable at the cold end of the economizer or air heater.

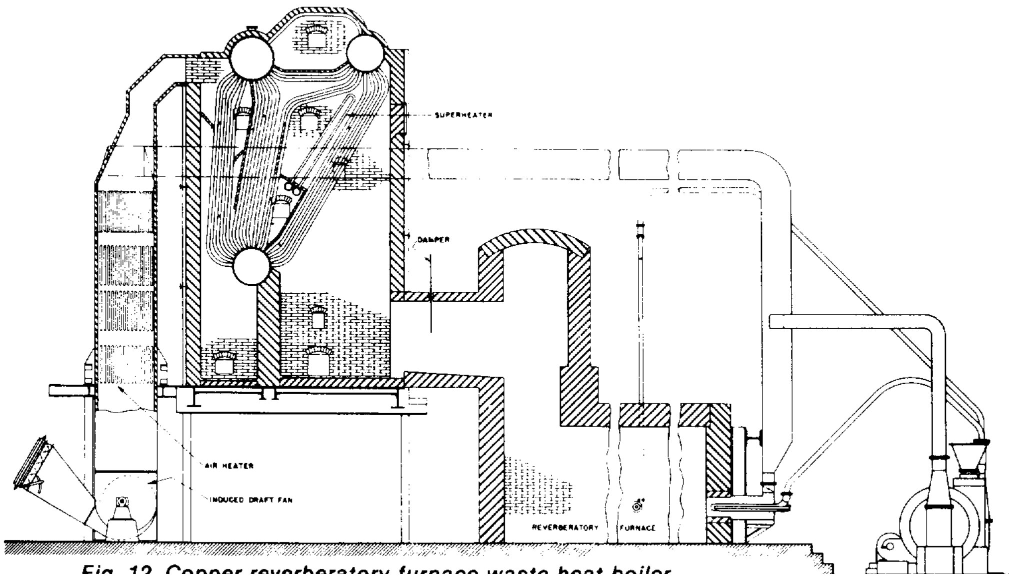

Fig. 14. Copper reverberatory furnace heat recovery boiler

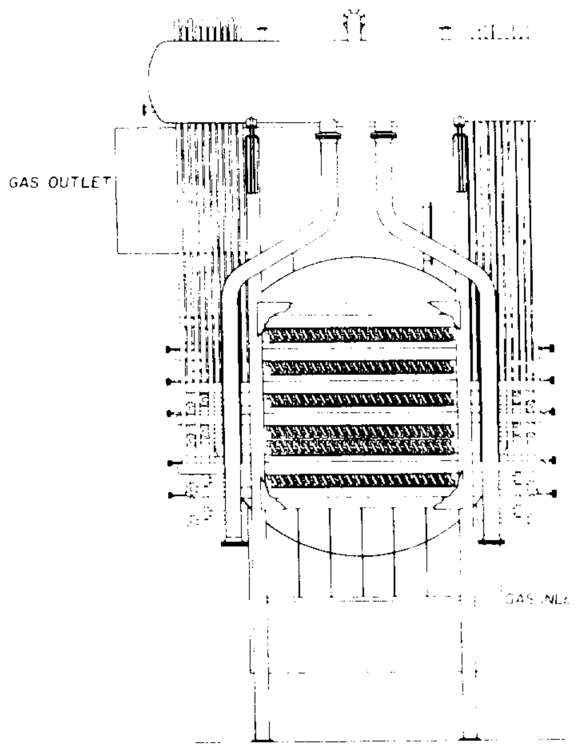

Fig. 15. Watertube boiler for sulfur recovery plant with cast iron extended surface tube elements

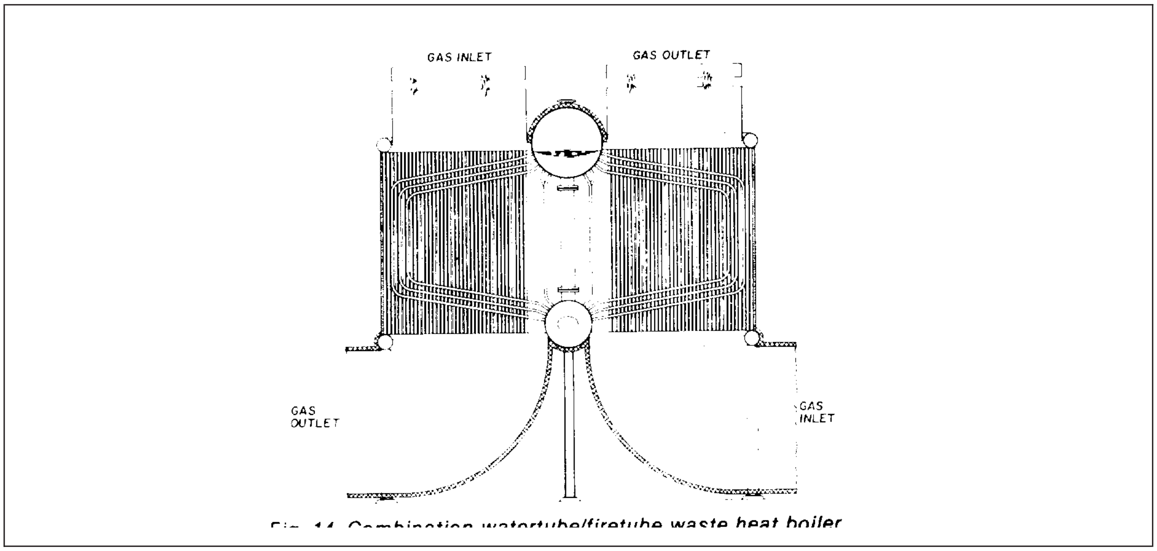

Fig. 16. Combination watertube/firetube heat recovery boiler