Recover heat from waste incineration

Improved waste-heat boiler design criteria enhance thermal energy recovery, reduce unit size and increase heat transfer efficiency

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Using these guidelines, engineers can address critical design problems associated with burning processwaste streams and select cost-effective waste-heat boilers. Incinerating contaminant streams is a *win-win* situation: 1) Complete destruction of pollutant(s) is attained and 2) Valuable thermal energy is recovered as steam and returned to process, thus conserving energy. However, recovering thermal energy from incinerated flue-gas streams contains some caveats. This treatment method creates a large high-temperature flue gas from which valuable thermal energy is recovered as saturated or superheated steam. Unfortunately, because a processwaste stream is used as feed, this stream will have variations in contaminant and component concentrations which influence the load on the boiler. Also, burning contaminants may create acid gases which will accelerate corrosion problems for the boiler at elevated temperatures. The following guidelines and checklist clarify the *do's* and *don'ts* when designing waste-heat boilers. Packaged boilers are not designed for waste-incineration purposes. Therefore, plant engineers must supply boiler designers important operating parameters such as gas-stream analysis, steam parameters, gas flowrates, etc. Developing a better understanding of the waste stream can reduce boiler size and cost, and improve its operability.

Profit from waste. Incineration is a widely accepted technique to dispose of various types of chemical and refining solid, liquid and gaseous wastes. Due to stricter federal and state regulations and the need for cleaner environment, incineration has been under much criticism. During incineration, large amounts of flue gases are generated at temperatures ranging from 1,400°F to 2,400°F depending upon the wastes incinerated, destruction levels desired and equipment used. Energy from these gas streams can be recovered as saturated or superheated steam, which can be used for process or power generation.

Gas stream nature affects boiler design. The starting point when evaluating a suitable boiler type for incineration-heat recovery is the nature of the gas stream, whether it is clean, dirty, dusty, corrosive, etc. If fumes, VOCs or gaseous pollutants are incinerated which is often done in refineries, the gas stream will be usually clean; thus, finned tubes can be used for heat-transfer surfaces such as

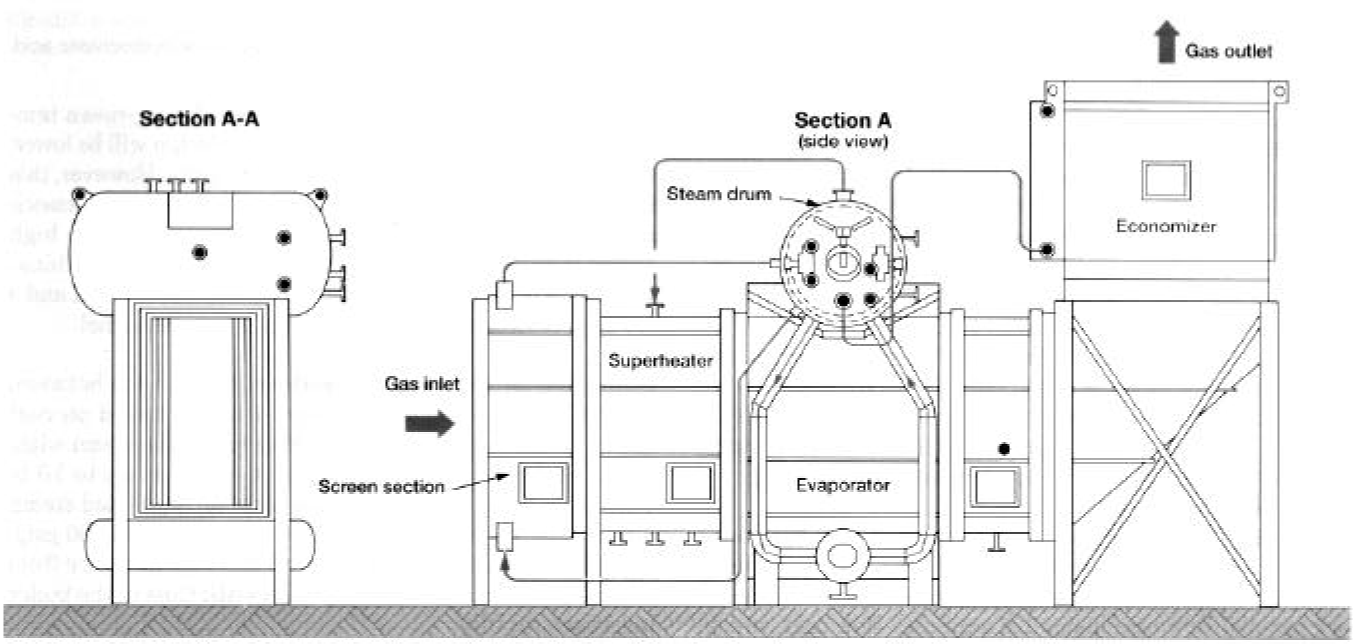

Fig. 1. Extended surfaces are used in this water-tube boiler for a fume incinerator because the flue gas is clean.

Table 1. Melting points of some salts and oxides present in incinerators[2]

Component, mole fraction	°C	°F	Remarks
P_2O_3	569[1]	1,056	
0.50 NaCl–0.26 Na_2SO_4 –0.24 Na_2CO_3	612[2]	1,134	tertiary eutectic
0.65 Na_2SO_4–0.35 NaCl	623[2]	1,153	binary eutectic
0.62 Na_2CO_3–0.38 NaCl	633[2]	1,172	binary eutectic
NaCl	801[3]	1,474	
Na_2SO_4	884[3]	1,623	
Ca_2O	1,236[3]	2,257	
Fe_2O_3	1,462[3]	2,664	decomposition
Fe_2O_3	1,560[4]	2,840	decomposition

[1] Fabian, H. W., P. Reher and M. Schoen, "How Bayer Incinerates Wastes," *Hydrocarbon Processing*, p. 185, April 1979.
[2] Bergnian, A. G., and A. K. Sementann, *The Tertiary Systems Na, Cl, SO_4, CO and K/Cl, SO_4, CO_4*, Zhur Neorg Khim, 3, (2), 388, 1958.
[3] Dean J. A. *Langes Handbook of Chemistry*, Ed. 12, McGraw-Hill Book Co., New York, NY, pp. 4–48–113, 1979.
[4] Kirk and Othime, *Encyclopedia of Chemical Technology*, Ed. 2, Vol. 12, p. 19, John Wiley and Sons, New York, 1964.

superheater, evaporator and economizer to make the boiler compact (see Fig. 1). In this boiler, the superheater is located behind a screen section, which shields it from hot gases and cavity radiation and which also helps to minimize the fluctuations in steam temperatures due to load. Gas velocities are limited only by gas pressure drop consideration and associated operating costs. In the boiler, gas velocities can be high, exceeding 80 to 100 ft/s; however, erosion is not a concern.

If a hazardous waste liquid or solid waste is incinerated, the composition of the waste-gas stream, ash concentration and its analysis must be known. Table 1 lists the melting point of a few eutectics containing salts of sodium and potassium which have a low melting point. These salts can form a molten deposit on boiler tubes if the local temperature is high enough. These salts can be cooled, forming a solid mass on the tubes. This mass deposit blocks the passage for gases and also attacks the protective oxide layer on the boiler tubes, thus causing corrosion. A large water-cooled radiant furnace may be required to cool gases below their ash-slagging temperatures, followed by a convection section and an economizer, all of bare tube construction (see Fig. 2). The resulting boiler will be *huge and costly*. Retractable soot blowers will be required to clean accumulated slag to keep the boiler surfaces reasonably clean. Wide-tube spacings may be necessary at the boiler front end to minimize plugging and blockage of tubes and ash hoppers may be needed.

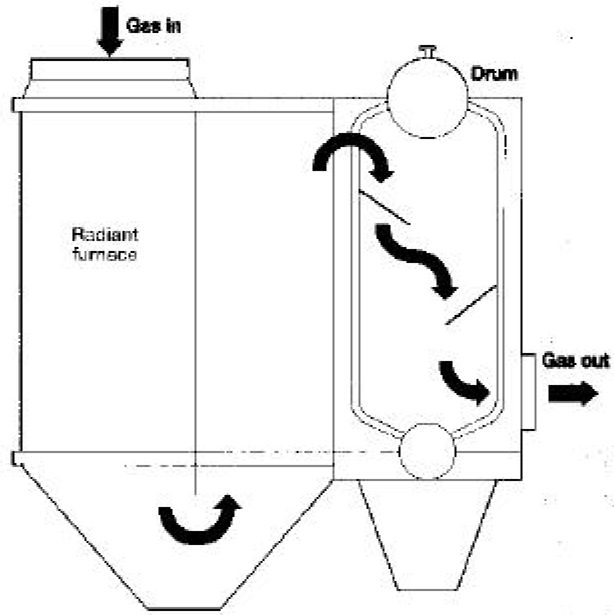

Fig. 2. Schematic of a bare-tube boiler with radiant furnace.

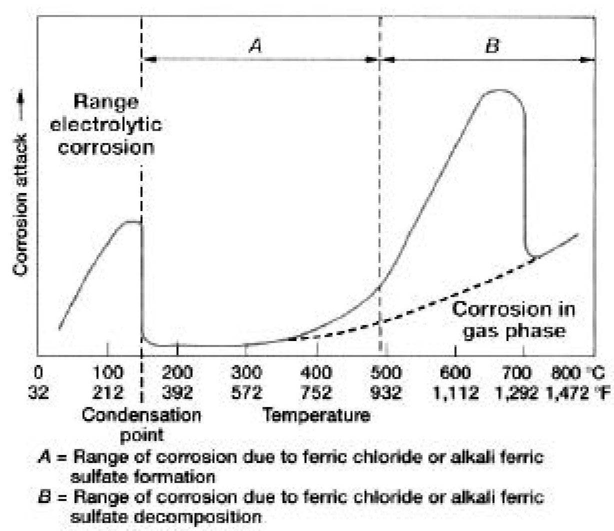

Fig. 3. High- and low-temperature corrosion due to hydrochloric acid.

Operating parameters. Gas analysis is also important when determining steam parameters. If the gas stream contains a large amount of hydrogen chloride, high-temperature corrosion may occur. This situation is accelerated at high tube-wall temperatures exceeding 800°F to 900°F (see Fig. 3). It is preferred to avoid superheaters in such cases or if they are used, then operate them at low tube-wall temperatures. To ensure lower tube-wall temperatures, select a lower steam temperature such as 650°F to 700°F instead of 850°F to 900°F. Also, the superheater can be located in a cool gas temperature zone (see Fig. 4), buried deep into the boiler.

A screen section shields the superheater from hot gases and also minimizes wild swings in tube-wall temperatures due to varying loads. The superheater can also be designed as a parallel-flow unit instead of a counter-flow unit, which has a higher tube-wall temperature due to the combination of higher gas and steam temperatures. The log-mean temperature difference with a parallel-flow design will be lower, resulting in larger surface area requirements. However, this is a consideration in contrast to handling problems associated with high temperature superheater design. If a high steam temperature is a must, then consider the combination of a waste-heat boiler generating saturated steam and a separately fired superheater, operating on clean fuel.

Fire-tube or water-tube boilers. The choice between fire-tube and water-tube boilers is often based on cost aspects and steam parameters. Fire-tube boilers can withstand high gas pressures, are cost-effective up to 70 to 100,000 lb/h gas capacity and are ideal for saturated steam generation. When steam pressure exceeds 600 to 700 psig, the tube thickness must withstand external pressure from steam increases and the weight. Result: Cost of the boiler increases rapidly.

A superheater if used with a fire-tube boiler must be

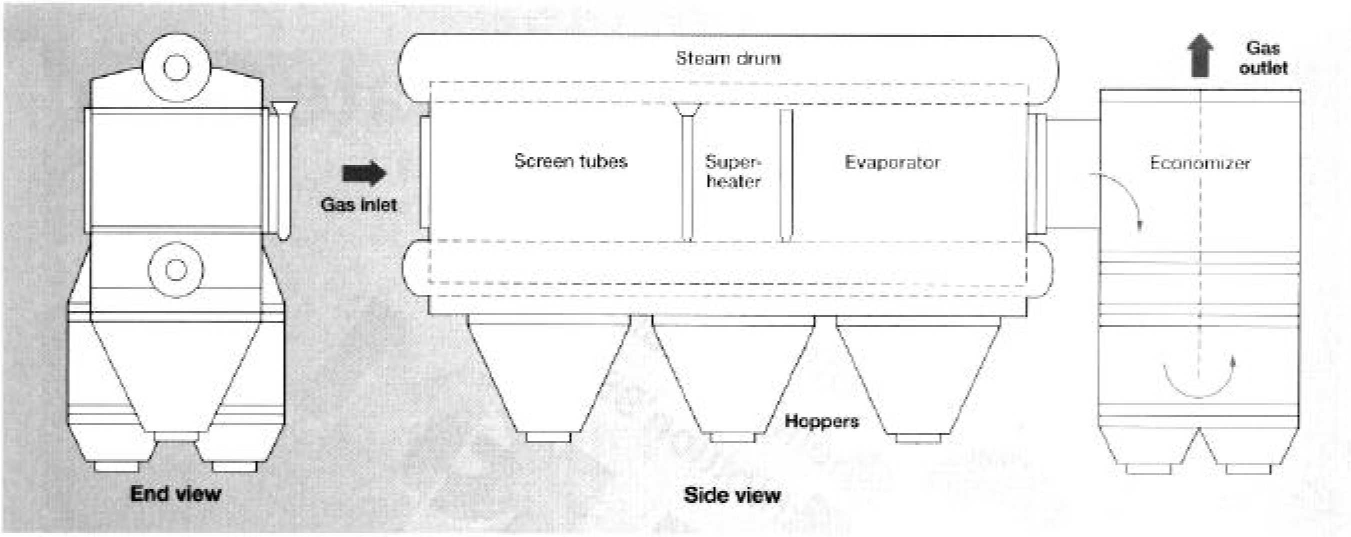

Fig. 4. In a water-tube boiler, the superheater can be buried between two evaporator sections.

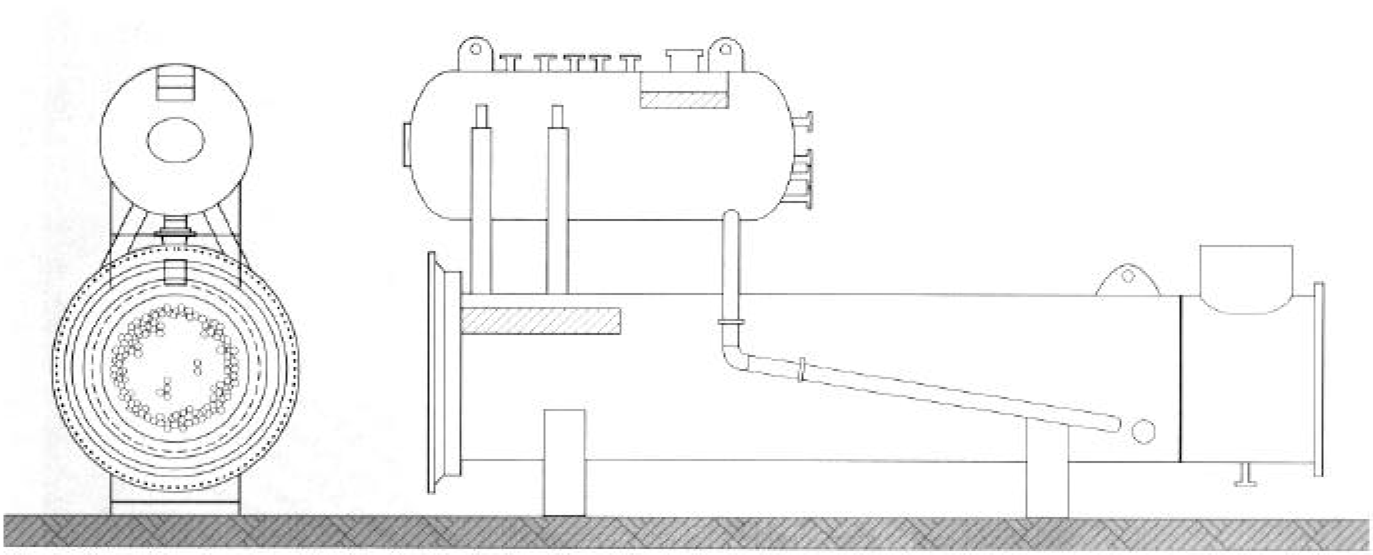

Fig. 5. Schematic of an elevated drum fire-tube boiler designed for high-temperature incineration plant.

located either at the front or at the exit of the evaporator, which affects the superheater's performance and metallurgy. When gas inlet temperatures are high, exceeding 1,600°F to 1,900°F, do not locate the superheater at the gas inlet zone due to the higher tube wall temperatures and the large fluctuations of steam temperature with load. Locating it behind the evaporator would result in a *very large superheater* because of the lower gas temperature. Also, a high steam temperature may not be achievable. Water-tube boilers are very flexible in design, and

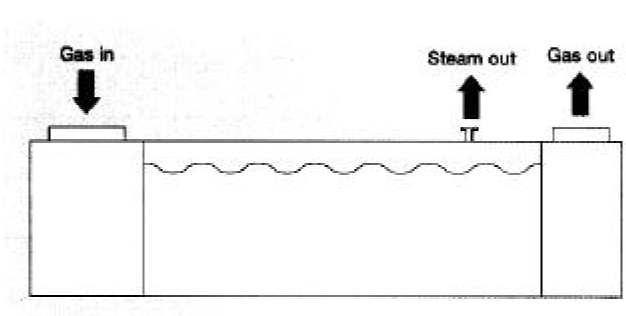

Fig. 6. Single shell fire-tube boiler flow diagram.

are suitable for large gas and steam flows and high steam pressures. They can be made compact by using extended surfaces which can transfer energy at much lower pinch points (difference between saturation steam temperature and gas temperature exiting evaporator) compared to firetube boilers. Superheater location is very flexible, often in between evaporator modules and hence can result in better designs with lower tube-wall temperatures. Water holdup is also less compared to fire-tube boilers, resulting in quicker transient performance. Due to compact designs, they often have lower gas pressure drop, thus reducing operating costs. With gas temperatures exceeding 1,800°F to 2,000°F, an elevated fire-tube boiler (Fig. 5) is preferred because the tube sheet at the front can be completely cooled by a circulating steam-water mixture. Often refractory is also used at the tube sheet with ferrules to protect the tube sheet and minimize the temperature drop across it. An elevated-drum design enables using better steam drum internals, hence improving steam purity.

A single shell-fire tube boiler (Fig. 6) is inexpensive and may be used when gas temperature is less than 1,600°F. Typically, these boilers operate at heat fluxes of

Table 2. Dew points of acid gases'

Hydrobromic acid:

$1,000/T_{DP} = 3.5639 - 0.1350 \ln (P_{H_2O}) 0.0398 \ln (P_{HBr}) + 0.00235 \ln (P_{H_2O}) \ln (P_{HBr})$

Hydrochloric acid:

$1,000/TDP = 3.7368 - 0.1591 \ln (P_{H_2O}) - 0.0326 \ln (P_{HCl}) + 0.00269 \ln (P_{H_2O}) \ln (P_{HCl})$

Nitric acid:

$1,000/T_DP = 3.6614 - 0.1446 \ln (P_{H_2O}) 0.0827 \ln (P_{HNO_3}) + 0.00756 \ln (P_{H_2O}) \ln (P_{HNO_3})$

Sulfurous acid:

$1,000/TDP = 3.9526 - 0.1863 \ln (P_{H_2O}) + .000867 \ln (PSO_2) - 0.000913 \ln (PH_2O) \ln (PSO_2)$

Sulfuric acid:

$1,000/TDP = 2.276 - 0.0294 \ln (P_{H_2O}) 0.0858 \ln (P_{H_2SO_4}) + 0.0062 \ln (P_{H_2O}) \ln (P_{H_2SO_4})$

Where: T_DP is dew point temperature oK and P is partial pressure, mmHg.
Compared with published data, the predicted dew points are within about 6°K of actual values except for H_2SO_4 which is within about °K.

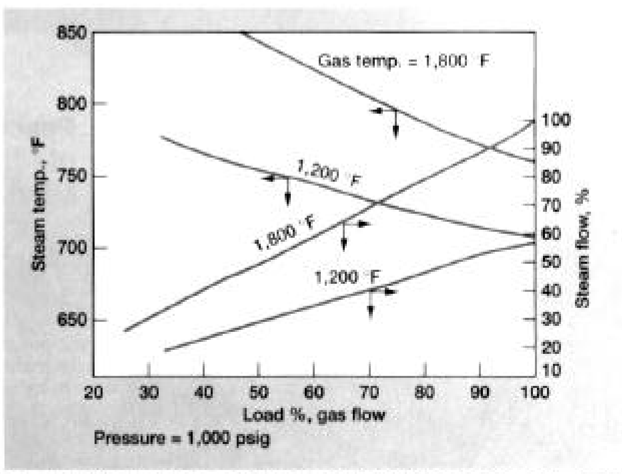

Fig. 7. Performance diagram for waste-heat boilers at various gas flowrates and temperatures.

less than 25,000 Btu/ft^{2}h. Heat fluxes up to 100,000 Btu/ft^{2}h can be tolerated by steam at low to medium pressures.[1] If the gas stream does not contain hydrogen and large amount of water vapor, which is the case of reformed gases in hydrogen plants, the heat flux is not a concern.[2]

Boiler performance. As with any boiler, lowering the exit gas temperature increases energy recovery. But if the gas stream contains acid vapors such as hydrochloric acid, hydrobromic acid, sulfuric acid, etc., one must evaluate dew points so that the lowest tube-wall temperature at the economizer is close to or above the stream's dewpoint. Table 2 shows dew point correlations for several common acid vapors. Since the tube-side heat transfer coefficient in the economizer is very high compared to the gas-side coefficient, the feedwater temperature will determine the tube-wall temperature and not the gas temperature.

Incinerators typically operate at high gas temperatures with the mass flow changing due to load. Hence boiler performance is different from a conventional packaged steam generator. Fig. 7 shows the effect of mass flow and gas temperature on the performance of the waste heat boiler. It appears that the superheater steam and tubewall temperatures increase at lower loads from a combination of lower steam generation and high gas inlet temperature. This result differs from a packaged boiler, where the steam temperature falls with load.

Table 3. Engineering data or checklist to design waste-heat boiler[2] (or aspects to be considered while developing specifications)

1. Application: Describe process; give flow diagram for gas/steam; source of deaeration steam; distribution of process and superheated HP, IP and LP steam.
2. Space limitations: Describe or provide drawings. Is a site visit required?
3. Gas stream parameters:
   a. Gas flow, pph: (at different loads/ambient conditions). b. Inlet gas temperature, °F: (associated with gas flow)
   c. Analysis, % volume: CO_2, H_2O, N_2, O_2, SO_2, HCL, SO_3, H_2S, CL_2; etc., corresponding to each gas flow condition
   d. Gas pressure, psig
   e. Suggested gas pressure drop: (at a given gas flow and inlet condition) or the maximum value.
   f. Nature of gas: dirty/clean; particulate concentration in grains/scf; ash analysis to indicate slagging tendencies.
4. Duty or suggested steam generation/temperature profile or exit gas temperature: Part load conditions; % of time in each operating mode; steam temperature control if any; provide flow diagram showing HP/IP/LP steam, makeup water, condensate returns at various loads.
5. Auxiliary fuel data: Fuel analysis, augmenting air for burners if any.
6. Emission data: NO_x and CO at boiler inlet and outlet; Contribution by burner (from burner vendor); Emission control equipment suggested.
7. Feedwater or makeup water analysis: % condensate returns if any. Is demineralized water available for spray temperature control? Injection water TDS should be very low.
8. Cost of fuel, electricity and steam: In addition, the % of time in each operating point in order to optimize life cycle cost.
9. Steam purity requirements: Drum holdup time criteria if any. Quick startup or load change requirements.
10. Other special requirements, if any.

Influential design factors. Since several variables influence boiler type and its design features, plant engineers involved in design or operation of an incineration facility should provide proper information to boiler designers. Table 3 lists important parameters that should be furnished to boiler vendors. Of particular importance are the gas analysis, ash analysis (if present), steam parameters and gas flow in mass units.

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The author

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