AP42 Section 1.2
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Reference 6

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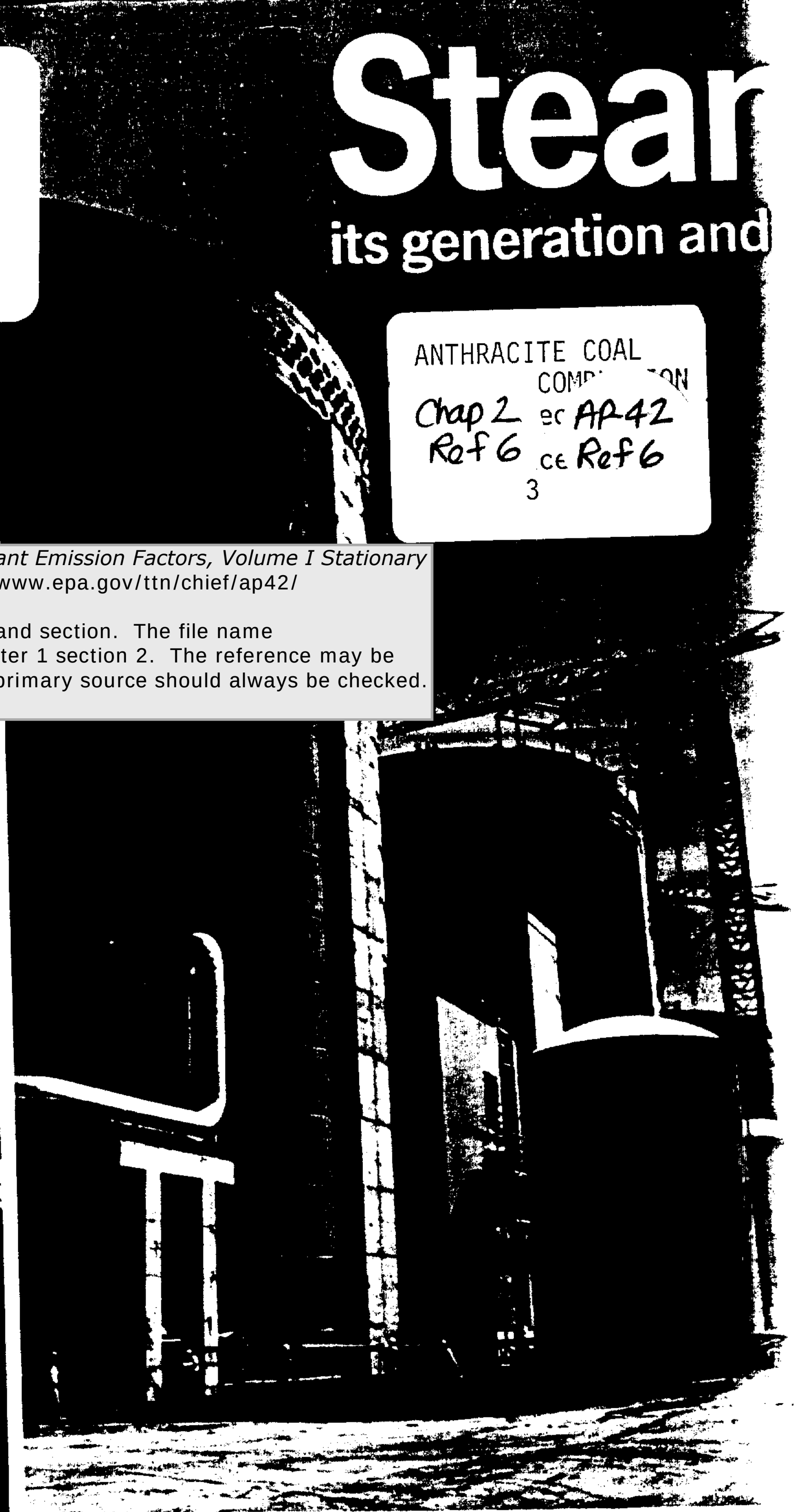

Steam

Babcock & Wilco

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Table 15
Classification of coals by rank[a] (ASTM D 388)

Class	Group	Fixed Carbon Limits, % (Dry, Mineral-Matter-Free Basis): Equal or Greater Than	Fixed Carbon: Less Than	Volatile Matter Limits, % (Dry, Mineral-Matter-Free Basis): Greater Than	Volatile Matter: Equal or Less Than	Calorific Value Limits, Btu/lb (Moist,[b] Mineral-Matter-Free Basis): Equal or Greater Than	Calorific Value: Less Than	Agglomerating Character
I. Anthracitic	1. Meta-anthracite	98	—	—	2	—	—	Nonagglomerating
	2. Anthracite	92	98	2	8	—	—	
	3. Semianthracite[c]	86	92	8	14	—	—	
I. Bituminous	1. Low volatile bituminous coal	78	86	14	22	—	—	Commonly agglomerating[e]
	2. Medium volatile bituminous coal	69	78	22	31	—	—	
	3. High volatile *A* bituminous coal	—	69	31	—	14,000[d]	—	
	4. High volatile *B* bituminous coal	—	—	—	—	13,000[d]	14,000	
	5. High volatile *C* bituminous coal	—	—	—	—	11,500	13,000	
						10,500[e]	11,500	Agglomerating
II. Subbituminous	1. Subbituminous *A* coal	—	—	—	—	10,500	11,500	Nonagglomerating
	2. Subbituminous *B* coal	—	—	—	—	9,500	10,500	
	3. Subbituminous *C* coal	—	—	—	—	8,300	9,500	
V. Lignitic	1. Lignite *A*	—	—	—	—	6,300	8,300	
	2. Lignite *B*	—	—	—	—	—	6,300	

This classification does not include a few coals, principally non-anded varieties, which have unusual physical and chemical prop-rties and which come within the limits of fixed carbon or calorific alue of the high-volatile bituminous and subbituminous ranks. All f these coals either contain less than 48% dry, mineral-matter-ree fixed carbon or have more than 15,500 moist, mineral-matter-ree British thermal units per pound.

[b] Moist refers to coal containing its natural inherent moisture but ot including visible water on the surface of the coal.

[c] If agglomerating, classify in low-volatile group of the bituminous class.

[d] Coals having 69% or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of calorific value.

[e] It is recognized that there may be nonagglomerating varieties in these groups of the bituminous class, and there are notable exceptions in high volatile *C* bituminous group.

Table 16
Seventeen selected U.S. coals arranged in order of ASTM classification

No.	Coal Rank: Class	Coal Rank: Group	State	County	*M*	*VM*	*FC*	*A*	*S*	Btu	Rank *FC*	Rank Btu
1	I	1	Pa.	Schuylkill	4.5	1.7	84.1	9.7	0.77	12,745	99.2	14,280
2	I	2	Pa.	Lackawanna	2.5	6.2	79.4	11.9	0.60	12,925	94.1	14,880
3	I	3	Va.	Montgomery	2.0	10.6	67.2	20.2	0.62	11,925	88.7	15,340
4	II	1	W.Va.	McDowell	1.0	16.6	77.3	5.1	0.74	14,715	82.8	15,600
5	II	1	Pa.	Cambria	1.3	17.5	70.9	10.3	1.68	13,800	81.3	15,595
6	II	2	Pa.	Somerset	1.5	20.8	67.5	10.2	1.68	13,720	77.5	15,485
7	II	2	Pa.	Indiana	1.5	23.4	64.9	10.2	2.20	13,800	74.5	15,580
8	II	3	Pa.	Westmoreland	1.5	30.7	56.6	11.2	1.82	13,325	65.8	15,230
9	II	3	Ky.	Pike	2.5	36.7	57.5	3.3	0.70	14,480	61.3	15,040
10	II	3	Ohio	Belmont	3.6	40.0	47.3	9.1	4.00	12,850	55.4	14,380
11	II	4	Ill.	Williamson	5.8	36.2	46.3	11.7	2.70	11,910	57.3	13,710
12	II	4	Utah	Emery	5.2	38.2	50.2	6.4	0.90	12,600	57.3	13,560
13	II	5	Ill.	Vermilion	12.2	38.8	40.0	9.0	3.20	11,340	51.8	12,630
14	III	1	Mont.	Musselshell	14.1	32.2	46.7	7.0	0.43	11,140	59.0	12,075
15	III	2	Wyo.	Sheridan	25.0	30.5	40.8	3.7	0.30	9,345	57.5	9,745
16	III	3	Wyo.	Campbell	31.0	31.4	32.8	4.8	0.55	8,320	51.5	8,790
17	IV	1	N.D.	Mercer	37.0	26.6	32.2	4.2	0.40	7,255	55.2	7,610

(Coal Analysis, Bed Moisture Basis: *M*, *VM*, *FC*, *A*, *S*, Btu)

Notes: For definition of Rank Classification according to ASTM requirements, *see Table 15*.

Data on Coal (Bed Moisture Basis)

M = equilibrium moisture, %; *VM* = volatile matter, %;
FC = fixed carbon, %; *A* = ash, %; S = sulfur, %;
Btu = Btu per lb, high heating value.

Rank *FC* = dry, mineral-matter-free fixed carbon, %.
Rank Btu = moist, mineral-matter-free Btu per lb.
Calculations by Parr formulas.

Table 21
Study of the suitability of other criteria in the classification of coals

Coals Table 16 No.	Btu Lord's *H* Value	Perch & Russell Ratio	Btu per lb VM_{pc}	Coal Analysis, Dry, Ash-Free Basis: *VM*	*FC*	C	H_2	O_2	N_2	Btu	Grind-ability
1	14,950	—	—	2.0	98.0	93.9	2.1	2.3	0.3	14,850	37
2	15,180	2520	25,685	7.3	92.7	93.5	2.6	2.3	0.9	15,100	26
3	15,410	1358	23,330	13.6	86.4	90.7	4.2	3.3	1.0	15,325	83
4	15,765	907	21,750	17.7	82.3	90.4	4.8	2.7	1.3	15,670	100
5	15,840	834	21,155	19.8	80.2	89.4	4.8	2.4	1.5	15,615	112
6	15,765	688	19,785	23.5	76.5	88.6	4.8	3.1	1.6	15,540	105
7	15,930	611	19,570	26.5	73.5	87.6	5.2	3.3	1.4	15,630	95
8	15,500	445	17,230	35.2	64.8	85.0	5.4	5.8	1.7	15,265	88
9	15,460	389	16,930	39.0	61.0	85.5	5.5	6.7	1.6	15,370	56
10	15,230	322	15,430	45.8	54.2	80.9	5.7	7.4	1.4	14,730	57
11	14,800	320	14,875	43.8	56.2	80.5	5.5	9.1	1.6	14,430	60
12	14,359	318	14,200	43.2	56.8	79.8	5.6	11.8	1.7	14,260	50
13	14,830	300	14,690	49.3	50.7	79.2	5.7	9.5	1.5	14,400	61
14	14,170	295	13,885	40.8	59.2	80.9	5.1	12.2	1.3	14,110	55
15	13,145	229	11,435	42.8	57.2	75.9	5.1	17.0	1.6	13,100	43
16	13,055	181	11,570	49.0	51.0	74.0	5.6	18.6	0.9	12,970	52
17	12,400	170	9,945	45.3	54.7	72.7	4.9	20.8	0.9	12,330	45

Notes:
For calculations of Lord's *H* Value and the Perch & Russell ratio, and the heating value of the volatile matter (pure-coal basis) refer to equations 7 to 12, inclusive, this chapter.

The subscript *pc* means on a "pure coal" basis. The dry, ash-free *VM* may be used, instead of the VM_{pc}, without appreciable error. Grindability is determined by ASTM Method D 409.

in order to establish reasonably accurate heating values for volatile matter. The only difference in the conversion used for this method and the conversion used in the ASTM Standard D 388 is that half the sulfur is assumed to be pyritic on the pure-coal basis. The assumption that only half the sulfur is pyritic and the remainder organic is in closer agreement with the average for a large number of U.S. coals. The formulas for converting the analyses and coal heating values to the "pure coal" basis and for calculating the heating value of the volatile matter are as follows:

$$(9)\quad VM_{pc} = \frac{VM - (0.08A + 0.2\,S)}{100 - (1.08A + 0.2625\,S + M)} \times 100,\ \%$$

$$(10)\quad FC_{pc} = \frac{FC - 0.0625\,S}{100 - (1.08A + 0.2625\,S + M)} \times 100,\ \%$$

$$(11)\quad Btu_{pc} = \frac{Btu - 26.2\,S}{100 - (1.08A + 0.2625\,S + M)} \times 100,\ Btu/lb$$

$$(12)\quad Btu/lb\ VM_{pc} = \frac{Btu_{pc} - \left(\frac{14{,}460}{100} FC_{pc}\right)}{VM_{pc}} \times 100,\ Btu/lb$$

where:
VM, *FC*, *A*, *S*, *M*, and Btu are the same as noted previously for the Parr formulas. Subscript *pc* denotes "pure coal" basis.

The Btu per lb volatile matter, calculated from the above formulas, is given in Table 21 for 16 of the 17 coals listed, covering the entire range of rank. The order of these values follows generally the ASTM classification of the coals, although the correlation is not as good as with the Perch and Russell ratio. The range of values of Btu per lb volatile matter, from about 8000 to 28,000 (Fig. 6), is large and may serve as a useful classification.

The relation of the heating value of the volatile matter and the heating value of the pure coal is shown in Fig. 6 for a large number of coals. It is evident that a fair line could be drawn, without serious error, to indicate the path of this relationship.

Commercial sizes of coal

Bituminous. Sizes of bituminous coal are not well standardized, but the following sizings are common:

Run of mine. This is coal shipped as it comes from the mine without screening. It is used for both domestic heating and steam production.

Run of mine (8 in.). This is run of mine with oversize lumps broken up.

Lump (5 in.). This size will not go through a 5-in. round hole. It is used for hand firing and domestic purposes.

Egg (5 in. × 2 in.). This size goes through 5 in. and is

Chapter 16 Boiler enclosures, insulation and casing

Boiler settings

The term *boiler setting* was originally applied to the brick walls enclosing the furnace and heating surface of the boiler. As the demand grew for larger capacity steam generating units, the brick walls gave way to air-cooled refractory walls and then to water-cooled tube walls. The water-cooled wall progressed in turn through the Bailey-block-covered tube, the tube with flat studs backed with refractory and the tangent tube, to the present membrane wall construction. The term *boiler setting* comprises all the walls that form the boiler and furnace enclosure, and includes the insulation and lagging of these walls. The term *enclosure* may refer either to the entire setting or to a section of it.

Casing is sheet or plate attached to pressure parts for the purpose of supporting insulation or forming a tight closure.

Lagging is an outer covering over a wall for the purpose of protecting insulation or improving appearance.

Design requirements

Settings must safely contain high temperature gases and air. Leakage, heat loss and maintenance must be reduced to acceptable values. A number of factors require consideration in the design of settings:

1. Enclosures must withstand the effects of high temperature, ranging up to 3500F in some cases.
2. The action of ash and slag (molten ash) must be considered from the following viewpoints:
   a) Destructive chemical reactions between slag and metal or refractory can occur under certain conditions.
   b) Accumulations of ash on the water walls can significantly reduce heat absorption.
   c) Ash accumulations can fall from a height and cause injury to personnel or damage to apparatus.
   d) High-velocity ash particles can erode the pressure parts.
3. Provisions must be made for the expansion of enclosures and for differential expansion of component parts.
4. Supports must be designed to accommodate the effects of thermal expansion, temperature and pressure stresses, and wind and earthquake loadings appropriate to the plant site.
5. The effect of explosions must be taken into account to lessen the probability of injury and damage.
6. Vibrations caused by combustion pulsations and the flow characteristics of gas and air must be limited to acceptable values.
7. The insulation of the enclosures should limit the heat loss to an economic minimum.
8. The surface temperature or the ambient air temperature must not cause discomfort or hazard to the operating personnel.
9. Enclosures must be gastight to minimize leakage into or out of the setting.
10. The design must be adequate to meet the corrosive effects of ash and gases.
11. Settings of outdoor units must be weatherproof.
12. Settings must be designed for economical fabrication and erection.
13. Serviceability, including access for inspection and maintenance, is essential.
14. Good appearance, consistent with cost and maintenance requirements, is always desirable.

Tube wall enclosures

In modern units, water- or steam-cooled tubes are utilized as the basic structure of the enclosure in high temperature areas of the setting. Three important types of water-cooled enclosures are discussed in this section—membrane walls, membrane walls with refractory lining, and flat-stud-tube walls. Fig. 1 illustrates locations where two of these are used in the setting of a modern boiler.

Membrane walls

Fig. 2 illustrates a typical furnace wall using membrane construction. These membrane walls are water-cooled walls, constructed of bare tubes joined together by thin membrane bars. The walls thus formed are gastight and require no inner casing to contain the products of combustion. Insulation is provided on the outer side of the wall, and metal lagging to protect the insulation. Membrane wall construction is used for furnace walls and roof (Fig. 1).

Membrane walls with refractory lining

The lower furnace walls of cyclone-fired units consist of membrane walls with the tubes covered with refractory held in place by cylindrical (pin) studs on the hot side (Fig. 3). The studs are welded to the tubes at close intervals and covered with a slag-resistant refractory material.

The purpose of this construction, is to increase furnace temperatures to maintain the coal, peat or lignite ash in a liquid state. The external surface is insulated and lagged as in Fig. 2.

Flat-stud-tube walls

These walls consist of tubes with small flat bar studs welded at the sides (Fig. 4). These flat-studded tubes are backed by refractory and a welded inner casing are backed by refractory and a welded inner casing forming a gastight enclosure. This casing is supported

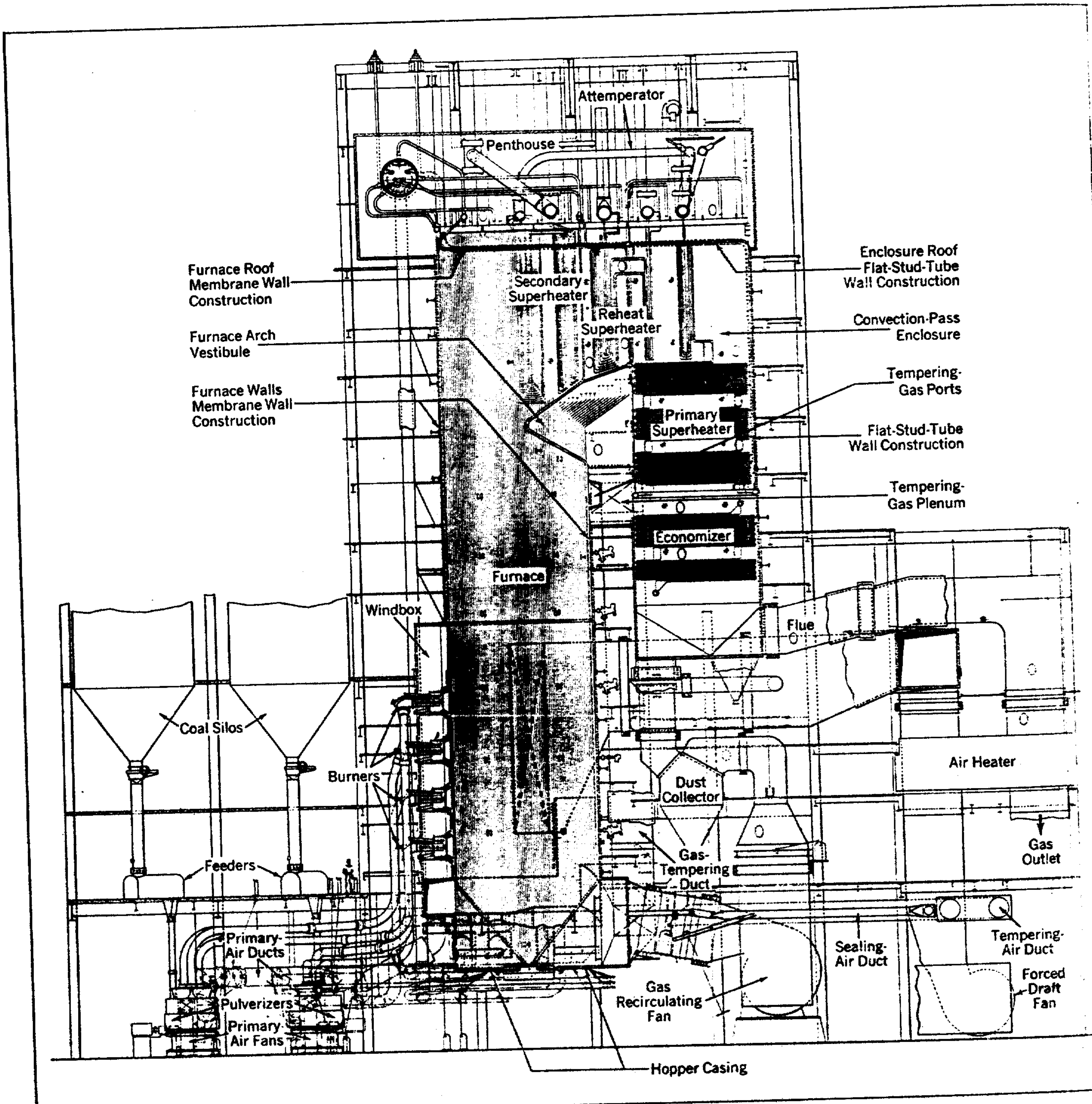


Fig. 1 Enclosure constructions—pulverized-coal-fired Radiant boiler.

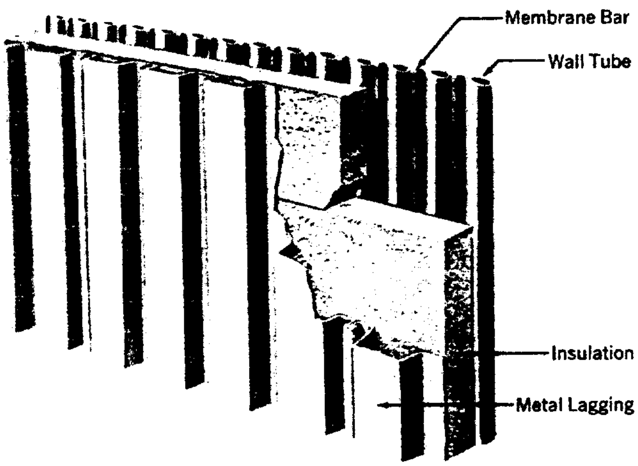


Fig. 2 Membrane wall construction.

from channel tie bars welded to tubes at each buckstay row. The walls are reinforced with buckstays and the inner casing is reinforced with stiffeners to withstand the design pressure of the walls between buckstays. Insulation is applied to the outer face of the inner casing and protected with a metal lagging. This construction is used in the area of the convection tube banks and the convection pass enclosure (*see Fig. 1*).

Cased enclosures

A boiler unit contains many non-water-cooled or cased enclosures. These must be designed to withstand relatively high temperatures and at the same time to have external wall temperatures low enough to minimize heat loss and to be safe for contact by operating personnel. Important cased enclosures include (*see Fig. 1*):

Hopper casing

This casing forms the gastight enclosure at the bottom of the furnace for dry-bottom units. It also serves as an insulation retainer and generally improves the appearance of the steam generator in this area. The enclosure provided by the hopper casing may also serve as a flue for the recirculating gas which enters the furnace through openings between tubes.

Windbox

This is a reinforced cased enclosure housing the burners and functioning as a distributor of combustion air. The windbox may be located on one burner wall or on all furnace walls with a wraparound configuration. The top, outer side and bottom of the windbox are made of metal casing while the furnace tube wall forms the inner side. The attachment to the furnace wall must be gastight and also permit differential thermal expansion between the tubes and the casing.

Tempering gas plenum

This enclosure is similar to a windbox with economizer exit gas flowing through it instead of air. This gas is used to temper the furnace gases and thus control ash fouling of the heating surfaces. The construction of the plenum is similar to that of the windbox but the tempering gas plenum is much smaller. The reinforced casing construction is normally unprotected on the inside except for stainless steel shields located opposite the gas ports.

Penthouse casing

This casing forms the enclosure for all miscellaneous pressure parts located above the furnace and convection pass roofs. It is gastight, with the roof tubes forming the bottom of the enclosure. Many seals are used with this gastight enclosure, such as cylindrical bellows or flexible cans sealing the suspension hangers, or large fold (pagoda) seals around steam leads. This top enclosure, composed of a series of reinforced flat panels welded together, is normally pressurized with air to form a secondary seal for furnace and convection pass roof tubes.

Inner casing is used over wall surfaces that would not be gastight without this covering. The inner casing may be applied directly to the external face of the walls or remotely, as in the area between the convection pass and furnace rear wall, for economical insulation coverage. In general the casing consists of flanged panels seal welded to be gastight.

Casings are constructed of light gage sheet or thin plate, suitably reinforced with stiffeners to withstand the required pressure and temperature. When the casing is directly attached to the furnace walls, expansion elements are provided to accommodate differential thermal expansion of the tubes and casing.

Pressure-fired units require gastight construction. Each unit is considered tight when all welded joints are inspected visually and tested under pressure (*see "Leakage"*). Suction or negative-pressure-fired units are also of welded gastight construction.

Resistance to ash and slag

Ash has a tendency to shed from a cold metal surface, particularly when the temperature of the ash itself is well below its softening point. Wall-type blowers remove ash in high temperature areas, where it tends to adhere to the walls.

Extensive areas of exposed refractory should not be used because of the tendency for slag adhesion. Damage or injury from the falling of large slag accumulations into the furnace is thus avoided. Also, crotches formed by tubes bent out of the plane of the wall should be designed to prevent ash accumulation.

Erosion of pressure parts is reduced by limiting the gas velocity through the unit. However, low average gas velocities do not preclude local high velocities which can still occur in areas where gas bypasses baffles or heating surface. These high-velocity lanes must be eliminated by proper design, installation and maintenance.

Expansion

With the inner-cased unit, Fig. 4, small temperature differentials can occur between the casing and the tubes during start-up. Expansion of the wall in the horizontal direction is governed by the temperature of the tie channel. Since the casing and the channels are at the same temperature, they can be welded together. Vertical expansion differences are taken in the slight bending of

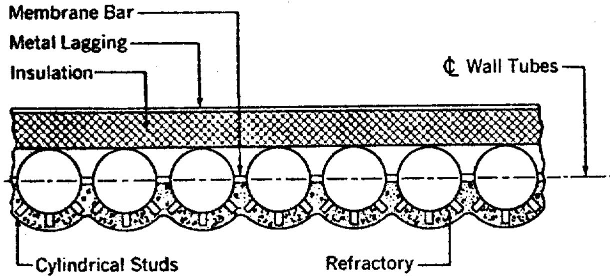


Fig. 3 Fully studded membrane walls.

the casing flanges at the top and bottom of each section of the casing.

With a bottom-supported unit, such as the type PFI Integral-Furnace boiler (Fig. 5), which is designed for pressure firing, the structure is fixed at a point at one end of the lower drum. Clearances, seals and supports are designed for known expansions in all directions.

With the top-supported unit, Fig. 1, the expansion occurs downwards from one elevation. Unless one of the walls is fixed to the building steel, the expansion will occur outwards from the center of the unit.

Flues and ducts, piping, ash tanks, and burner lines must be designed with expansion joints or seals to accommodate the relative movements involved. Flexible metal bellows are used in flues and ducts; metal hoses and sliding or toggling gasketed couplings in piping. Water seals are generally used between ash hoppers or slag tanks and the associated furnace. With large units, the expansion may be as much as 7 in. between adjacent parts, yet joints must be maintained pressure-tight.

Support

The support of steam generators is discussed in Chapter 30. It is generally more economical to support the smaller size units from the bottom and the larger units from the top. In either case the boiler setting is formed by the water walls where these are available (Figs. 2, 3 and 4).

For bottom-supported units, other parts of the enclosure are usually supported from a common foundation with the boiler (Fig. 5). For top-supported units, similar portions of the enclosure are supported from the pressure parts except that the cased enclosure at the top of the unit is supported directly from the structural steel by the hanger rods (Fig. 1).

Explosions

In the design of settings, the effect of possible explosions must be taken into account to eliminate the possibilities of injury and serious damage. Historically, the rupture of pressure parts in boilers was a serious menace. Such disastrous explosions have been largely eliminated by better understanding of the technical problems and the development of adequate design and operating codes. More recently the firing of large units with fluid or fluidized fuels has introduced a new hazard from the ignition of explosive fuel and air mixtures within the setting. Explosion pressures may range as high as 50 psi in some parts of the setting. It is not feasible to build structures to meet bursting pressures of this magnitude. The enclosure is normally designed to withstand common puffs and minor explosions which may develop pressures of about 2 psi. In the event of a major furnace explosion the design should provide for failure of studs, stud attachments, and welds rather than the tube walls themselves. This practice minimizes the danger of releasing large quantities of steam in the event of a furnace explosion.

The loading from furnace puffs and from normal operating negative or positive furnace pressure is contained by the use of bars and channels welded to tubes to form continuous bands around the setting. Beams, called buckstays, are attached to the tie bars with slip connections and keep the walls from bowing inward or outward.

Since the buckstays are outside the insulation, special corner connections are required (*see Fig. 6*) that will allow the walls to expand and at the same time tie together the corners, where the force of an explosion is concentrated. These corner connections must be tight during starting-up periods when the walls have not fully expanded, as well as at the normal operating fully expanded position. Furnace puffs caused by incorrect fuel-and-air mixtures are often associated with starting-up operations.

The tube span between the buckstays acts as a beam to resist the internal furnace pressure. The larger the tube diameter and the heavier the tube wall, the farther apart the buckstays may be spaced. The size of the buckstay beam usually is determined by the permissible deflection.

Explosion doors are now seldom used to relieve excessive internal furnace pressure. Except in very small furnaces, they cannot fulfill their purpose, because the internal pressure from a fuel explosion is not significantly relieved by the opening of a door. Actually, explosion doors may be more of a hazard than a safety feature because, in the event of a puff, they may discharge hot gases that would otherwise be completely contained within the setting.

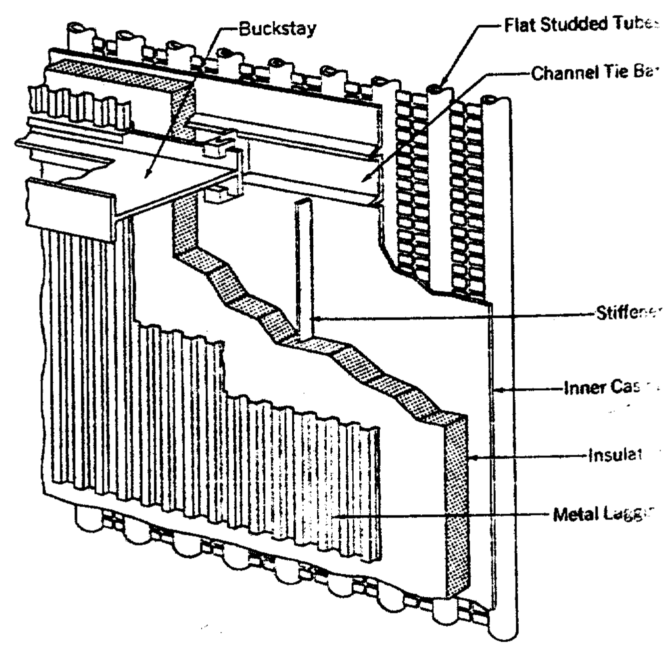


Fig. 4 Flat-stud-tube wall construction.

Vibration

Excessive vibration in boiler settings can cause failures of the insulation, casing and supports. This vibration can be produced 1) by external rotating equipment, such as turbines and fans, and transmitted to the setting through building steel, piping, flues or ducts; 2) by furnace pulsations from the uneven combustion of the fuel; and 3) by turbulence in the flowing streams of air or gas in flues, ducts and tube banks.

The walls, flues and ducts are designed to limit vibration to low values for normal operating conditions. For the walls, the section modulus of buckstays is usually selected to limit wall deflection at its midpoint to $\frac{1}{16}$ in. with a pressure change of 1 in. of water. Flues, ducts and casings are similarly stiffened by bars or structural shapes to prevent excessive vibration. This stiffening is particularly necessary in sections of flues and ducts where the flow is highly turbulent as in the fan-discharge connecting piece. Every effort should be made to eliminate the sources of severe vibration, such as unbalanced rotating equipment, poor combustion, and highly turbulent air or gas flow.

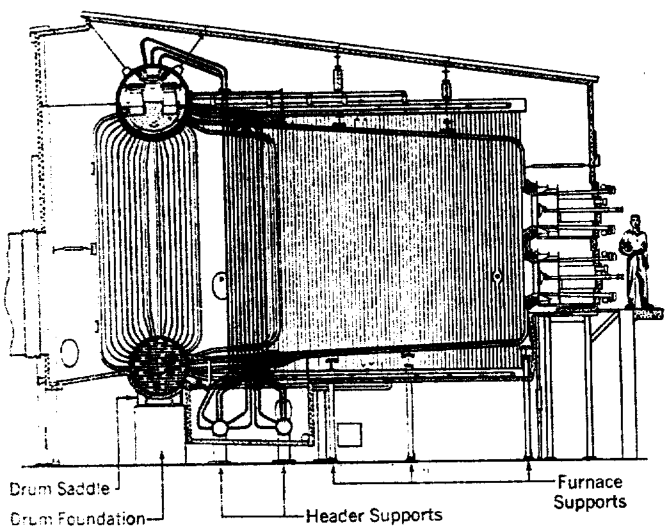


Fig. 5 Bottom-supported unit.

Heat loss

Heat loss from a boiler setting is reduced by the installation of insulation, usually as an integral part of the boiler enclosure (Figs. 2, 3 and 4). From the standpoint of heat loss there is an economic balance between the value of the heat lost and the cost of insulation and its installation.

For steam generating units located outdoors it is customary to install the amount of insulation required for maximum economy, since natural ventilation is normally adequate to remove the heat losses without discomfort to operating personnel.

For indoor units ventilation is required for operator comfort, and the heat losses must be removed from the boiler room by means of the ventilating air. This generally requires more insulation than could be justified by the heat loss criterion alone.

The basic materials most frequently used in heat insulation for steam generators are listed below together with some of the commercial forms of insulation made from these materials and their limitations.

1. *Diatomaceous-earth-base blocks.* A silica composed of the skeletons of simple organisms, this material may be used uncalcined or calcined, with asbestos fiber and clay molded under heat and pressure. Its principal application is for boiler walls behind firebrick, in temperature zones from 1200 to 1800F.
2. *Mineral wool.* This material comprises molten slag, glass or rock, blown into fibers by steam or air jet or spun by high-speed wheels.
   - (a) *Mineral-wool-base block.* Mineral-wool fibers and clay, molded under heat and pressure, are used to insulate membrane tube walls and boiler casing up to a temperature limit of 850, 1200 or 1800F depending upon the grade.
   - (b) *Mineral-wool blanket.* Mineral-wool fibers compressed into blanket form, and held in shape by retention between hexagonal wire mesh or expanded metal lath, are used on all types of enclosures with external metal lagging or casing and for piping inside cased enclosures. The temperature limit is normally 1000 or 1400F.
3. *Calcium silicate block.* Reacted hydrous calcium silicate block is used on enclosures and piping, generally below 1200F.
4. *High temperature plastic.* Insulating cement made of mineral-wool fibers processed into nodules and then dry-mixed with clay forms a tough fibrous monolithic insulation in final dried condition. Drying shrinkage is as much as 40% and there is a tendency to crack upon drying. This material is used principally on boiler walls, irregularly shaped valves and fittings, and heated tanks up to a temperature of 1500F.
5. *Ceramic fiber.* High purity ceramic fibers with melting points above 3000F are used for expansion joint packing up to 2300F where resiliency is required, and up to 2800F where resiliency is not required.

Heat loss calculations

Calculations of the heat flow through a composite wall are discussed in Chapter 4 (Fig. 3 and related text). Thermal conductivities of a wide range of commercial

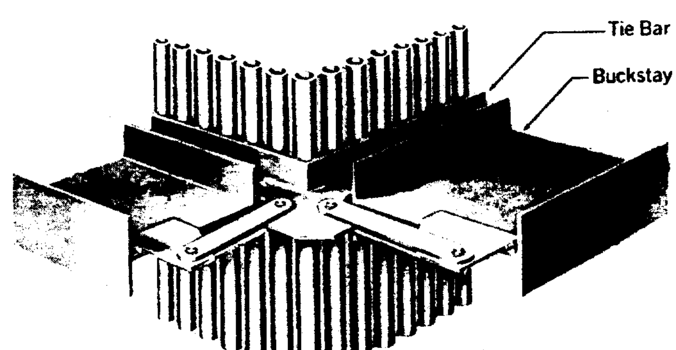


Fig. 6 Tie bar and buckstay arrangement at corner of furnace.

refractory and insulating materials, at the temperatures for which they are suitable, are given in Fig. 7. Combined heat losses (radiation plus convection) per sq ft of outer wall surface are given in Fig. 8 for various ambient air velocities and various temperature differences between surface and air. The ABMA radiation loss chart (Fig. 27, Chapter 4) provides a quick approximation for radiation loss, expressed as a percentage of gross heat input.

Ventilation, surface temperature, and working conditions

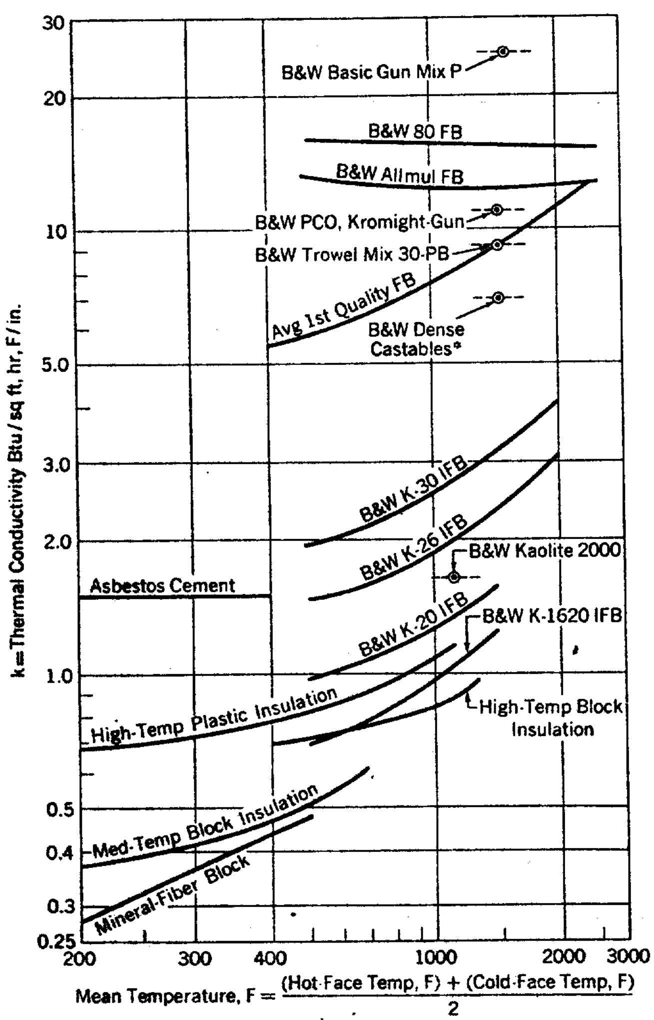
To maintain satisfactory working conditions around a boiler installed indoors, the insulation must be thick enough to keep the outside surface temperature of the wall reasonably low, and to prevent excessive increase in the boiler room temperature by heat loss through the wall. A cold face temperature of 130 to 160F is usually considered satisfactory for an indoor installation. Heat losses, corresponding to these surface temperatures, range between 70 and 180 Btu/sq ft, hr, which can be readily absorbed by the air circulation generally provided in present day boiler rooms.

Insulating a boiler to reduce the heat loss to a value that can readily be absorbed by the total volume of room air does not in itself assure comfortable working conditions. Good air circulation around all parts of the boiler is also necessary to prevent the accumulation of heat in the areas frequented by the operating personnel. This can be aided by the substitution of grating for solid floors, by ample aisle space between adjacent boilers, by the location of fans to assist the circulation of air around the boiler, and by the addition of ventilating equipment to assure adequate air change.

Fortunately on modern units good ventilation does not greatly increase the overall heat loss. Air velocity affects the surface conductance ($q/S \div$ temperature difference); this can be verified by data from Fig. 8. However, surface conductance is only a small part of the total resistance to heat flow. For example, an increase in air velocity from 1 to 10 fps, for the conditions given in Fig. 9, will increase the heat loss rate through the wall only 3 Btu from 144 to 147 Btu/sq ft, hr. This is approximately 2% for a tenfold increase in air velocity.

Unlike heat loss, outer surface temperature is affected considerably by the surrounding conditions. In a situation such as that shown in Fig. 10 where two walls of similar temperature are close together, the radiant heat transfer from either wall is negligible. The natural circulation of air through such a cavity is inadequate to cool the walls to a temperature suitable for personnel working in the vicinity. From Fig. 11 it will be seen that a considerable change in surface film resistance will cause an appreciable change in lagging or surface temperature while not affecting the heat loss through the wall to any extent.

Increased insulation thickness would not significantly reduce the surface temperature in the cavity in Fig. 10. Cavities should therefore be avoided in areas where operators work. Ventilating ducts can be installed, if necessary, to reduce the air temperature in such a cavity.



*Average of Kaocast and Kaocretes A, B, D and HS.

Fig. 7 Thermal conductivity of various refractory materials.

Leakage

Continuing efforts have been made over the years to reduce air infiltration into boiler settings. Such leakage increases gas flow and the heat rejected to the stack, thus lowering the boiler efficiency (*see Combustion Calculations, Chapter 6*) and increasing induced draft fan power.

With the advent of water-cooled walls and welded outer casings, leakage was reduced to approximately 10% of the theoretical air required for combustion. By using a plastic finish with an asphalt mastic seal coat, an enclosure is obtained which is almost as tight as a steel-cased unit. Units enclosed with welded outer casings or seal coats require maintenance to assure setting tightness. As an indication of the savings that can be effected by proper maintenance, setting repairs on one large utility unit reduced air infiltration 10%, lowered exit gas temperature 20F, and cut the fuel bill by 1%.

The constant goal of higher efficiency has led to the development of pressurized firing. With this system leakage is reduced to a minimum, the induced draft fan is eliminated, and the cost of fans and fan power is lowered considerably (*see Pressure Furnaces, Chapter 17*). The all-welded casing, directly behind the tube enclosures with the insulation on the outside of the casing (Fig. 4), and the membrane wall (Figs. 2 and 3) were developed for pressurized firing. The casing tem-

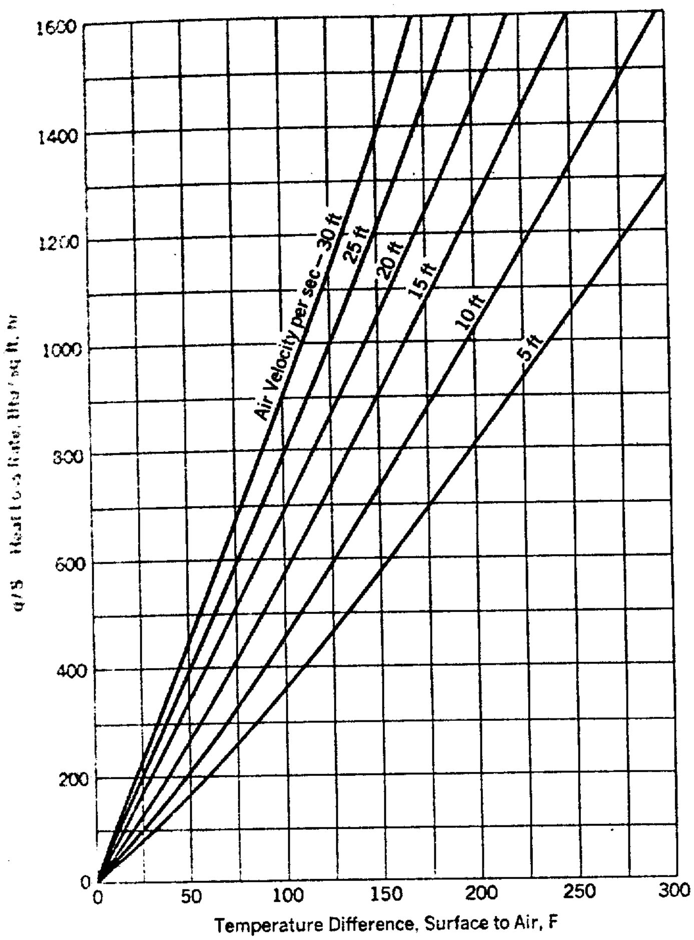


Fig. 8 Heat loss from wall surfaces (radiation + convection). *(Source—ASTM Standards, Part 13, 1969)*

perature is approximately the same as the temperature of the tube walls so that all-welded seals can be used around openings. For rotating sootblowers and some inspection doors, seal air, from the forced draft fan, at a pressure higher than internal, is provided to prevent gas leakage and to furnish some cooling. This seal air usually amounts to 1 or 2% of the theoretical air required for combustion.

The same type of inner casing is also used for many suction-fired boilers to obtain the benefits of minimum leakage. This amounts to about 1 to 2% of the theoretical air required.

A rigorous test is made to check the tightness of the inner casing of a pressurized unit. All inlets and outlets to the boiler setting are sealed temporarily with welded closures, and the setting is pressurized to 20 in. of water or 1.5 times the design pressure, whichever is the lower. Welds are examined for air leakage, and the rate of pressure drop within the setting is noted. A rate of 5 in. of water pressure drop in 10 minutes is usually considered acceptable depending upon the size of the unit. Leakage tests of negative-pressure-fired units are made by visual inspection with the unit under pressure from the forced draft fan.

Gas leakage through walls separating zones of different pressure must be prevented. Such leakage can overheat inner or outer casings as well as other structural parts. Walls that become saturated with ash and sulfur may undergo corrosion of outer casings. Enclosures around headers and drums may accumulate large quantities of troublesome ash. A good seal directly behind or in line with the tube wall prevents these difficulties (Fig. 2). All openings through walls must be sealed by tight sleeves. Barriers in walls may be necessary to prevent gas flow through insulation between zones of different pressure.

Corrosion

One of the advantages of the membrane wall is that it eliminates flue-gas corrosion in the enclosure walls.

Most flue gases contain sulfur, and metal parts of the setting must be kept either above the dew point of the gases or out of contact with the gases if the metal is below the dew point (Chapter 13). The dew point generally ranges between 150 and 250F and is dependent on the fuel, its sulfur content, and the firing method.

Flues carrying low-temperature spent gases should be insulated on the outside to inhibit corrosion. This is particularly necessary on outdoor units. Water-cooled doors and slag-tap coils require water temperatures above 150F to keep the cooling coils above the dew point.

When casing is located outside of insulation or refractory, it is still subject to the action of the flue gases. When this type of casing is subjected to temperatures below the dew point, an asphalt mastic coating is required to protect the casing from corrosion on the inside. The same is true of the metal in a cased enclosure. This problem requires special attention in the design of outdoor installations where temperatures may at times be low.

With the use of inner casing, corrosion problems are greatly reduced, since the flue gases are completely contained by a metal "skin" that is well above the dew point. Even with the inner casing, however, care must be exercised to insulate seals and expansion joints properly to avoid cold spots and the consequent corrosion.

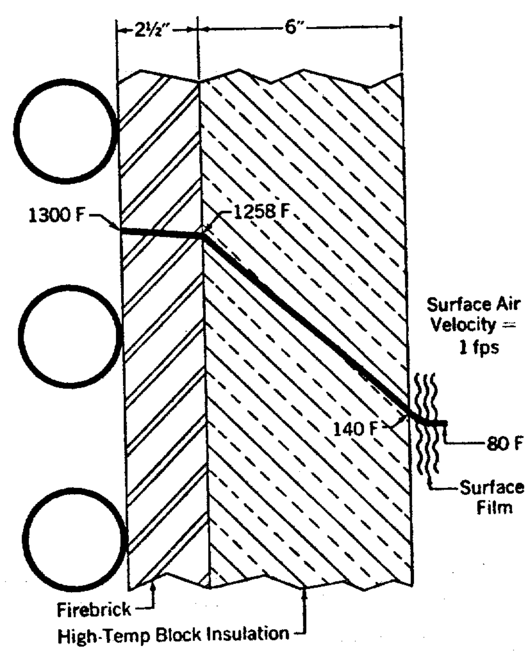


Fig. 9 Temperature gradients through tube-and-brick wall.

Resistance to weather

In recent years, outdoor boiler installations have gained in popularity, particularly in mild climates. Although the initial cost of the plant is reduced, maintenance of the boiler and auxiliary equipment must be considered. Severe weather can extend outage time and increase maintenance expense. These units must have sufficient reinforcement to withstand the pressure and suction forces of the wind.

It is relatively simple to make a metal-lagged unit rainproof. Joints and flange connections are overlapped, and flashings are used around openings. Welding of joints or the use of mastic compounds is necessary in areas difficult to seal.

Sloping roofs are required and are particularly important on aluminum lagging as pockets of water would eventually stain the surface. Direct contact between aluminum and steel must be avoided to prevent galvanic corrosion of the aluminum in the presence of moisture. Copper lines or roof flashings should be so designed that water runoff does not wet the aluminum.

All outdoor jobs should have the connections between the water-gage assembly and the drum insulated, except for approximately 4 ft of the upper connection adjacent to the assembly. This area is left uninsulated to assure circulation of the condensate. Water columns must also be insulated. In climates where freezing weather is experienced, the drain lines for the water-gage assembly must be insulated and protected. The water gage and its illuminator will provide ample warmth within the water-gage housing.

Weather hoods should be used to keep rain, snow and ice from contact with outdoor safety valves. Nozzles and valve necks must be insulated and protected with sheet metal or other waterproof covering.

Outdoor control lines containing air or flue gas, drain and sampling lines, and intermittently operated steam and water lines should be insulated and protected by electric-resistance-heating wires. Steam pipe tracer lines may be substituted in some cases. Dry air should be supplied for control lines and sootblowers. Steam and water lines outside the setting must be completely drainable.

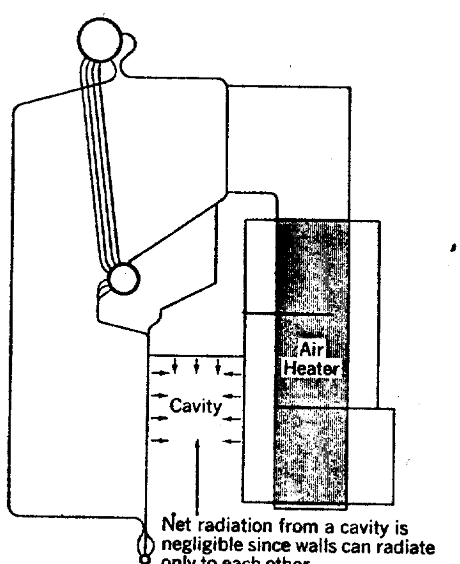


Fig. 10 Cavities tend to raise wall-surface temperature.

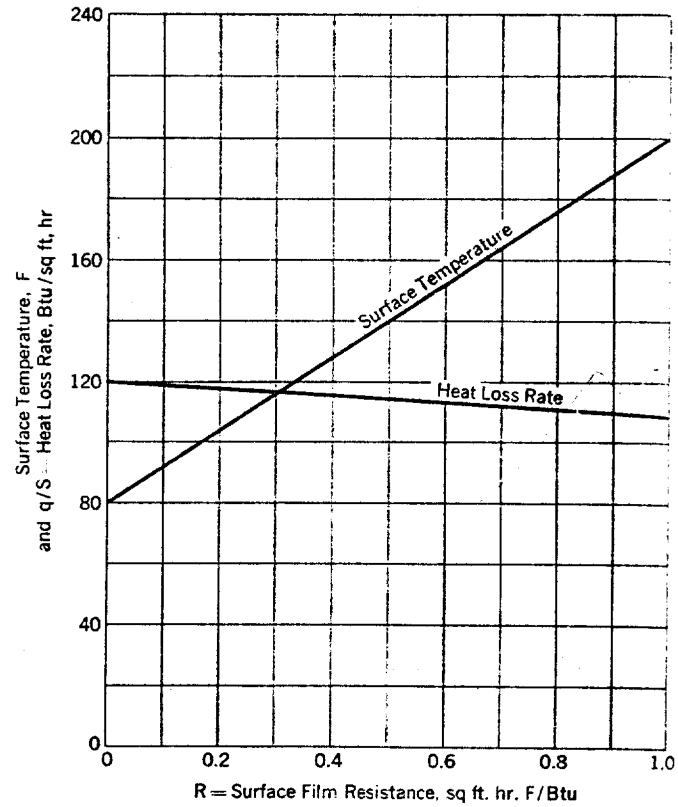


Fig. 11 Effect of surface film resistance on surface temperature and heat loss rate.

Fabrication and assembly

The setting must be designed for economical fabrication and field assembly. This requires integration of all shop and field methods and practices. Small units can be completely shop-assembled. For larger units the trend has been toward shop subassembly of large components.

Shipping clearances limit the size of shop-assembled wall panels to approximately 10 ft wide and 65 ft long. Shop assembly of components permits better quality control of the more complicated parts such as burners and Cyclone Furnace throats.

Advances in welding methods and the development of shop machinery have greatly influenced the design of enclosures. Flues, ducts, expansion joints and inner casings are welded. Tube connections to headers, tie bars, doors and other attachments are generally welded. New and improved materials and attachment methods reduce the man-hour requirements for insulating boilers and installing metal lagging.

Serviceability

Many setting design details must be resolved to simplify operation and maintenance. Working areas around the unit should have adequate lighting and comfortable temperatures. Clearances for servicing and removing parts should be provided. Access through the setting is necessary for inspection of boiler internals. Suitable platforms for access doors, sootblowers, instruments and controls are essential.

Inspection doors permit observation of combustion conditions and the cleanliness of heat-absorbing surfaces. They facilitate good operation and should be safe and easily opened. Fig. 12 illustrates an inspection door for a pressurized setting. Safety is provided by two types of interlocks which assure that compressed air is properly aspirating the aperture before the door is opened. A feature of this door is that the aspirating jet does not restrict the comparatively wide view angle.

The tube bends that form openings in high-duty furnaces must be of the smallest possible radius. In some cases die-formed tube bends are used. The length of the stud-plate closures around the opening is thus minimized, so that the plates can be adequately cooled by welded contact to the tubes.

Appearance

The setting should present a good appearance initially and be designed so that the good appearance can be retained indefinitely with a minimum of housekeeping. The outer surface should be easily cleanable. Equipment handling flue gas, coal, ash, or oil should be designed to contain these materials without leakage.

Light-gage metal lagging is generally used for outer covering. This is particularly true for outdoor units, where it is relatively simple to make the metal lagging watertight. Many types of covering are still found in older installations. These include plastic insulation, cement finishes, canvas and asbestos cloth, welded steel casing, and asbestos lumber.

Figs. 2, 3 and 4 show metal-lagged units. Light-gage galvanized-steel or clad-aluminum sheets are commonly used for lagging. Galvanized steel is generally less expensive than the aluminum, but for outdoor units it may be necessary to paint the galvanized steel after weathering, unless the climate is dry. If much painting is required, the clad aluminum may be preferable, since it does not require painting except under the more severe conditions. Since the lagging is fabricated at the job site, the cost is less than it would be for metal casings shop-manufactured from drawings.

For indoor units a plastic insulation finish, made from high-temperature plastic insulating cement, makes an acceptable surface when low first cost is important. The relatively rough surface is a dirt catcher unless painted. It is more easily damaged than metal lagging, and random cracks sometimes detract from its appearance.

For outdoor units, asphalt mastic seal coats reinforced by hexagonal wire mesh or glass cloth have been used. However, maintenance is high, particularly in areas where the mastic must seal against metal parts, such as door frames and buckstays. The cost of mastic seal coat is not sufficiently below that of metal lagging to justify its use for large areas.

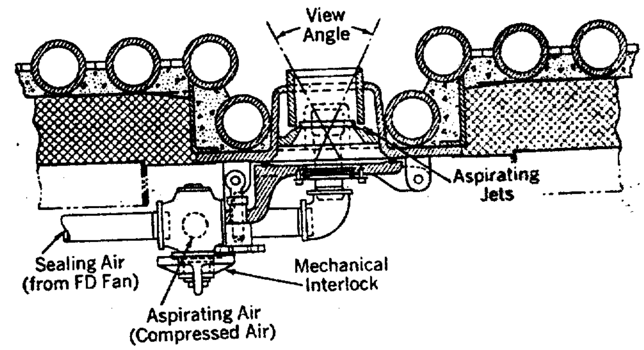
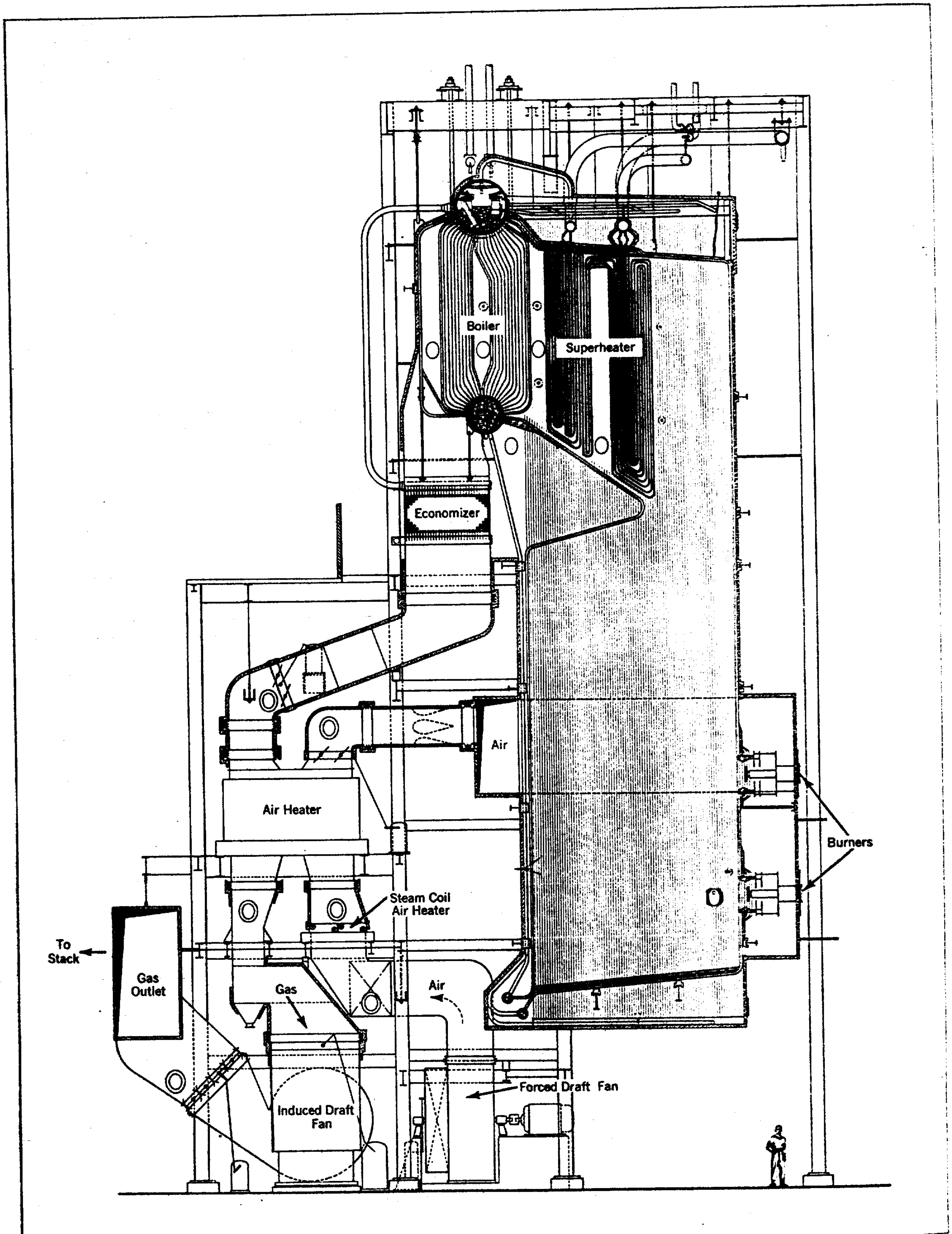


Fig. 12 Inspection door for pressurized furnace.



Arrangement of forced and induced draft fans for a boiler unit of 325,000 lb of steam per hr capacity.