July 2015
Interim Revision January 2021

FLUIDIZED BED BOILERS

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1.0 SCOPE

This data sheet describes the hazards associated with the combustion of fuel in fluidized bed boilers. The descriptions and recommendations are applicable only to atmospheric-type fluidized bed boilers. Fluidized bed combustors, pressurized fluidized bed units (2 to 10 atmospheres, 200 kPa to 1.0 MPa), fluidized bed gasifiers, and chemical process equipment are not addressed, but the recommendations in this data sheets may be applied with judgment where appropriate.
Additional guidance for fluidized bed boilers is contained in the following data sheets:

Data Sheet 6-12, *Low-Water Protection for Boilers*
Data Sheet 6-23, *Watertube Boilers*
Data Sheet 12-2, *Vessels and Piping*
Data Sheet 12-43, *Pressure Relief Devices*

1.1 Changes

January 2021. Interim revision. Contingency planning guidance was updated.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Equipment and Processes

2.1.1 Firing Equipment and Flame Supervision

Use FM Approved equipment and devices, such as fuel safety shutoff valves, supervisory switches, combustion safeguards, etc., when available and suitable for the application.

2.1.1.1 Fluidized Bed

2.1.1.1.1. When units are designed such that a minimum bed temperature must be reached before the main and lance fuels are introduced, provide a bed temperature interlock. Auxiliary startup burners or heaters are used to bring the bed up to temperature. (Figs. 2, 3, 4)

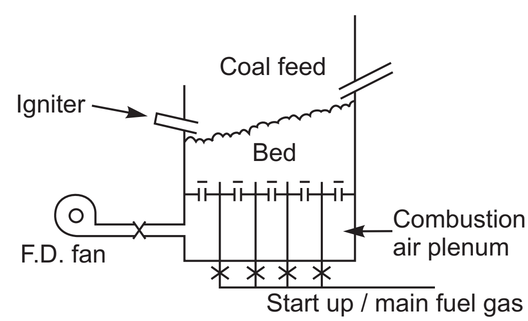

Fig. 1. Burn-in bed, surface ignitor

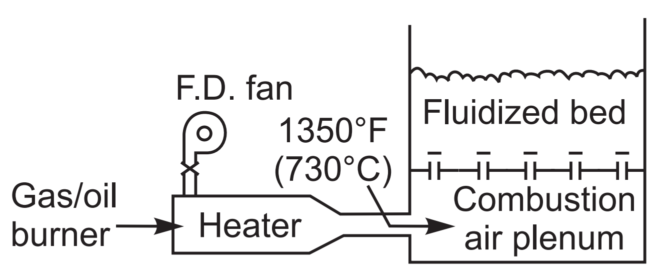

Fig. 2. External air heater

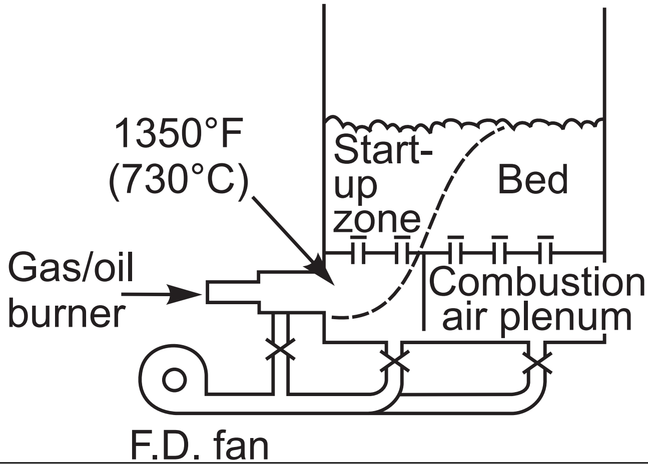

Fig. 3. Internal plenum heater

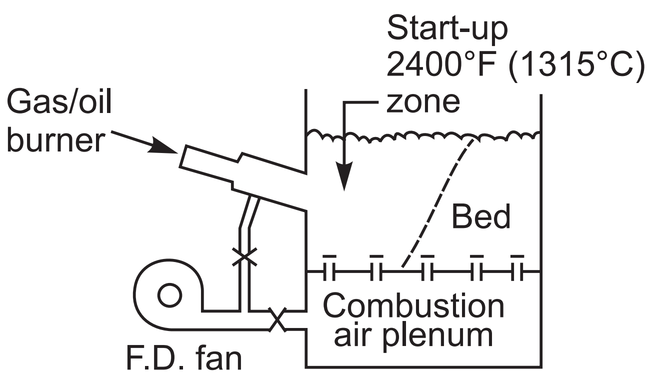

Fig. 4. Internal bed heater

When units are designed to be started with partial bed or zone temperature of 600° to 800°F (315° to 425°C), the bed may be charged with an initial quantity of solid fuel introduced at a minimum firing rate to bring the bed zone up to the operating temperature.

When units are designed for startup by firing gas into the bed (Fig. 1), provide a flame-supervised igniter at the bed surface. When the igniter flame is proven, the interlocked main gas safety shutoff valve may be energized. The fluidized bed air and gas mixture is fed up through the bed and ignites on the surface. As the bed temperature increases the combustion zone expands down into the bed. Provide a temperature sensor interlocked so that when the bed has reached the design ignition temperature, the main fuel may be introduced.

2.1.1.1.2 Provide a bed temperature sensor interlocked to discontinue introduction of fuel into or onto the bed when the temperature is below the minimum temperature specified by the manufacturer (Typically, this temperature is 1200°F [650°C]).

2.1.1.1.3 Provide a bed temperature sensor interlocked to discontinue introduction of fuel into or onto the bed when the temperature is above the maximum temperature specified by the manufacturer. (Typically, this temperature is 1800°F [980°C]).

2.1.1.1.4 For bubbling fluidized bed boilers, provide controls for the fluidizing air velocity to prevent excessive carryover of partially burned fuel beyond the designed combustion zone and recirculation dust collectors.

2.1.1.1.5 Provide interlocks to discontinue fuel introduction upon inadequate induced draft, inadequate fluidizing air, inadequate distribution air for the fuel nozzles, and for excessive furnace pressure.

2.1.1.1.6 Operate the fluidized bed with excess combustion air at all firing rates.

2.1.1.1.7 Admit solid fuel fines only to furnaces that are designed for, and are being properly operated to burn, the quantity of fines being introduced.

2.1.1.1.8 Protect the igniters, startup burners, gaseous and liquid fuel lances, and solid fuel injectors from overheating and fuel burn-back into the supply system. Burner retraction, air or water cooling, and star valves may be applicable. Positive furnace pressure has caused problems on some units.

2.1.1.1.9 Provide a high-temperature interlock for a preheated air duct system (Fig. 2) to shut down the fluidizing air preheater and in-plenum burner (Fig. 3).

2.1.1.1.10 Ensure the fly ash removal system on cyclones and bag-type dust collectors is operated and interlocked to prevent excessive fly ash from building up in the hoppers. Also see Data Sheet 7-73, *Dust Collectors and Collection Systems.*

2.1.1.1.11 Provide the fluidized bed boiler with low-water cutoff devices that shut down all fuel and operate an alarm. See Data Sheet 6-12, *Low-Water Protection for Boilers.*

2.1.1.2 Gas-Fired or Oil-Fired Burners (Startup, Auxiliary and Air Preheaters) and Lances

2.1.1.2.1 Install safety shutoff valves for each gas-fired or oil-fired main burner, fuel lance and fuel-fired igniter in accordance with Data Sheet 6-4, *Oil and Gas Fired Single Burner Boilers,* and Data Sheet 6-5, *Oil and Gas Fired Multiple Burner Boilers,* as applicable. If burners or lances in a multiple-burner/lance arrangement are controlled separately follow the guidance for single burners in Data Sheet 6-4.

2.1.1.2.2 Provide permanent and ready means for making periodic tightness checks of the main gas safety shutoff valve.

2.1.1.2.3 Provide flame supervision for each fuel-fired igniter. Also provide flame supervision for each burner unless a continuous Class 1 igniter is provided.

2.1.1.2.4 Install igniters and flame sensing element(s) securely so their positions with respect to the main flame will not change. Provide observation ports so these positions can be easily observed when igniter and/or main burner are firing. Ensure these units are readily accessible for inspection and cleaning.

When a high-energy spark-igniter assembly is provided for the main oil-fired burner, the fuel-burning igniter and proof of igniter flame are omitted.

2.1.1.2.5 When an igniter is retractable, prove it is in the correct position for proper lighting-off of the main burner fuel before the ignition cycle proceeds.

2.1.1.2.6 When an igniter is proved by a combustion safeguard, provide supervision at a location where the igniter flame effectively ignites the main burner or burner unit. Ensure the main burner ignites immediately, even when the igniter is reduced to a minimum of flame capable of holding the flame sensing relay of the combustion safeguard in the energized (flame present) position. Ensure the safe-start check of the combustion safeguard is not nullified by the action of operating or limit controls.

2.1.1.2.7 Provide a nonrecycling flame supervisory combustion safeguard, arranged to first prove the existence of a reliable igniter flame before permitting the main burner safety shutoff valve to open.

2.1.2 Interlocks

2.1.2.1 Purge and Firing Sequence

2.1.2.1.1 Provide a mandatory preventilation period to purge the fluidized bed, boiler combustion chamber, gas passes, air preheaters (if provided), the components of the exhaust gas system, and stack. Ensure the purge consists of at least five volume changes of fresh air for a continuous period of not less than five minutes. Ensure the purge airflow rate is at least 25% of that required for firing at maximum output.

2.1.2.1.2 Control the purge period by a time delay that will prevent activation of the ignition system opening of the safety shutoff valves and introduction of fuel(s) before the purge has been completed.

2.1.2.1.3 Provide interlocks to prove the following purge requirements are satisfied. If any permissive interlock is lost during the purge timing, a reinitiation of the purge is required.

A. All fuel safety shutoff valves are closed.

B. All required burner registers or dampers are open to the purge position. (Interlock not necessary with manual burner front operation.)

C. All required induced draft, combustion, fluidizing air, cooling, and preheater fans are running.

D. Purge airflow is established (not less than 25% of the full load volumetric airflow).

2.1.2.1.4 Provide basic interlocks as follows for starting up and firing protection to ensure properly sequenced operation.

A. Prove induced draft fans and other required fans in operation. Ensure failure of the induced draft fan or other required fans shuts down any fan following it in the order of actuation, and shuts off and locks out all fuel and ignition systems.

B. When purge airflow rate is in excess of 25% of the full load volumetric air flow, provide an additional minimum air flow interlock set at 25% of the full load volumetric air flow. This allows reduction of the air flow to a minimum level for low load operation (and for light-off, if required by the manufacturer's start-up procedure).

C. Provide high and low fuel-gas pressure interlocks and low fuel-oil pressure interlocks for main burner, fuel lance, and igniter fuel supplies.

D. Provide atomizing-medium interlocks for steam or air-atomized fuel oil burners to prevent the introduction of fuel oil to the burners or lances upon loss of, or impairment of, the atomizing medium.

E. Limit the igniter flame-establishing period to the shortest practical interval, generally not exceeding 10 seconds. Upon completion of the main burner trial-for-ignition period, arrange the nonrecycling, flame supervisory combustion safeguard for direct supervision of the main flame only. Limit the trial-for-ignition for the main burner to the shortest practical term, generally not exceeding 10 seconds for gas and light oil and 15 seconds for heavy oil.

F. Ensure the loss of flame causes the fuel safety shutoff valve for the igniter or burner to trip.

G. Provide a low bed temperature interlock for fuel lances.

H. Ensure main fuel feed rate is initiated at the equivalent of a low-fire start as defined by the manufacturer.

I. Where an electrostatic precipitator is provided, provide alarms and interlocks in accordance with DS 7-73, *Dust Collectors and Collection Systems*.

2.1.2.2 Implosion Protection

Apply recommendations for implosion protection in accordance with DS 6-6, *Boiler Furnace Implosions.*

2.1.2.3 Tripping Interlocks

2.1.2.3.1 Provide “First Out” indication for all safety interlocks that will initiate a unit trip. (Refer to 2.1.1.1.)

2.1.3 Indicators and Alarms

2.1.3.1 Provide adequate means for communication between operators in the control room and operators at the fluidized bed boiler. This is particularly important during critical operating situations such as lighting-off, bringing the unit up to temperature, and during upset operating conditions.

2.1.3.2 Install instrumentation to provide the operator with adequate information concerning the status of operating equipment, position of valves, burner registers, vital damper settings, and other conditions that will permit ready evaluation of the operating situation.

2.1.3.3 Provide alarm systems that give both audible and visual indication of abnormal conditions. Means may be provided to silence the audible alarm, but ensure the visual indication remains until the condition has returned to normal.

2.1.3.4 Provide oxygen and combustibles analyzer-recorders to monitor the exit flue gas. When measurable combustibles (exceeding 1%) are indicated, provide an alarm to warn the operator of a possible hazardous condition. Because of the flue gas composition, the analyzer probe may have to be installed downstream of the dust collector, baghouse, or electrostatic precipitator.

2.1.4 Electrical Installations

2.1.4.1 Ensure electrical installations conforms to the National Electrical Code.

2.1.4.2 Ensure both ac and dc safety control circuits are two-wire, one side grounded. Ensure all safety control switching is in the hot, ungrounded conductor, and overcurrent protection is provided. In addition to circuit grounds, also ground noncurrent-carrying metal parts, such as equipment enclosures and conduit.

2.1.4.3 In unusual cases where an ungrounded dc power supply cannot be avoided, locate all switching in one conductor and provide ground fault protection.

2.1.4.4 Set all controls and interlocks so that if they fail, they will fail in the fail-safe mode.

2.2 Protection

2.2.1 Arrange protection for fuel supplies as outlined in Data Sheet 7-76, *Prevention and Mitigation of Combustible Dust Explosions and Fires,* Data Sheet 7-32, *Ignitable Liquid Operations;* Data Sheet 7-88, *Ignitable Liquid Storage Tanks;* Data Sheet 7-54, *Natural Gas and Gas Piping;* Data Sheet 7-55, *Liquefied Petroleum Gas (LPG) in Stationary Installations;* and Data Sheet 8-10, *Coal and Charcoal Storage.*

Keep gaseous and liquid fuels free from all foreign matter. Remove welding beads, chips, scale, dust, and debris from both newly installed fuel piping and that which has been opened for alteration or maintenance. Install suitable strainers, filters, drip legs, etc.

2.2.2 Provide each oil-fired or gas-fired burner and lance with a manually operated fuel shutoff valve for emergency closing in case of fire. Ensure the valve is prominently marked and accessibly located, preferably outside the firing building.

2.2.3 Address the fire hazards imposed by leakage or rupture of piping near the boiler. Particular attention must be given to flexible connections, hoses, swivel joints, etc. Provide automatic sprinkler protection, deluge systems, small hose stations, or other methods for fighting burner front fires. Good housekeeping is a must.

2.3 Operation and Maintenance

2.3.1 Train operators on standard and emergency operating procedures. See Data Sheet 10-8, *Operators*, for guidance on developing operator programs. This includes training in the proper operation of the fluidized bed boiler and its ancillary equipment and in the specific functions of the various safety controls. Provide documented standard and emergency operating procedures and have them readily available in the boiler control room.

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

Inspect and test safety controls and perform other maintenance required by the manufacturer's instructions to ensure proper functioning when emergencies arise. Failure to make these periodic checks may not only result in fire or explosion damage or mechanical or electrical failure, but also may contribute to accidental shutdown and loss of production.

For pressure part inspections, follow the guidelines in Data Sheet 6-23, *Watertube Boilers*.

2.3.3 Maintain all equipment in good condition. Maintenance details and schedules depend on the equipment and the operating conditions. Follow a specific routine recommended by the manufacturers of the various components.

Some aspects of the inspection, testing, and maintenance programs for various components of fluidized bed boilers and ancillary equipment are discussed in other data sheets, listed below:

Data Sheet 6-4, *Oil- and Gas-Fired Single-Burner Boilers*
Data Sheet 6-12, *Low-Water Protection*
Data Sheet 6-23, *Watertube Boilers*
Data Sheet 7-73, *Dust Collectors and Collection Systems*
Data Sheet 12-43, *Pressure-Relief Devices*

2.4 Contingency Planning

2.4.1 Equipment Contingency Planning

When a fluidized bed 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 fluidized bed 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.

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Illustrative Losses

3.1.1 Accumulated Flammable Gases Exploded

A hog fuel (chipped wood) combustor, 18 ft (5.5 m) dia. by 28 ft (8.5 m) high, with a 4 ft (1.2 m) deep sand bed, supplied a 110,000 lb (31.4 MW) per hour waste heat boiler. The bed temperature dropped 500°F (from 1600°F to 1100°F) [260°C to 593°C] when the wet hog feeder plugged. The fluidizing bed fan and ID fan were stopped to maintain bed temperature. Approximately two hours later the hog feeder was operated briefly. Fifteen minutes later the feeder was finally unplugged and the fluidized bed fan was started. Before the ID fan could be started, an explosion damaged the refractory at the top of the combustor. Unburned gases from the hog fuel on top of the bed mixed with the bed air, ignited, and exploded.

3.1.2 Tube Rupture Followed by Steam-Water Explosion

A 400,000 lb/hr (180,000 kg/hr) watertube circulating fluidized bed boiler firing coal, sludge and wood waste (bark and sawdust), sustained a ruptured waterwall screen tube at a kraft pulp and paper mill. The sudden release of 1,500-psi (100 bar) water caused the water to flash to steam, which over pressurized the boiler and electrostatic precipitator.

Damage to the boiler was limited to the one ruptured tube, which sheared off near the screen wall header. However, the electrostatic precipitator had its south wall bulged out approximately 10 ft (3 m) and its north wall approximately 4 ft (1.2 m). There was also damage to support beams, and extensive sheet metal damage, and the precipitator shell was moved off its structural supports.

3.1.3 Dry Fire Caused Tube and Refractory Damage

A solid waste fuel-fired 125,000 lb/hr (56 t/hr) fluidized bed boiler at an industrial manufacturing facility was being restarted following a maintenance outage. Drum water level was determined to be adequate by visual inspection of the drum gage glass and boiler light-off was commenced. The boiler operated approximately eight hours with drum level control/remote level indication showing high drum level. As a result, no feedwater make-up occurred during this time. When the low water condition was recognized, water was added to the boiler and the sudden quenching of boiler waterwall tubes caused severe warping of a number of waterwall tubes with consequent refractory damage.

The false high drum level indication was the result of having little or no condensate in the constant head legs of the three differential pressure drum level transmitters.

Production at the facility was maintained by operating other boilers at the facility, but extra costs were incurred for purchasing fuel and electric power.

4.0 REFERENCES

4.1 FM

Data Sheet 6-2, *Pulverized Coal-Fired Boilers*
Data Sheet 6-4, *Oil- and Gas-Fired Single-Burner Boilers*
Data Sheet 6-5, *Oil- or Gas-Fired Multiple Burner Boilers*
Data Sheet 6-6, *Boiler Furnace Implosions*
Data Sheet 6-12, Low-Water Protection
Data Sheet 6-23, *Watertube Boilers*
Data Sheet 7-32, *Ignitable Liquid Operations*

Data Sheet 7-54, *Natural Gas and Gas Piping*
Data Sheet 7-55, *Liquefied Petroleum Gas (LPG) in Stationary Installations*
Data Sheet 7-73, *Dust Collectors and Collection Systems*
Data Sheet 7-88, *Ignitable Liquid Storage Tanks*
Data Sheet 7-109, *Fuel-Fired Thermal Electric Power Generation Facilities*
Data Sheet 8-10, *Coal and Charcoal Storage*
Data Sheet 9-0, *Asset Integrity*
Data Sheet 10-8, *Operators*
Data Sheet 12-43, *Pressure-Relief Devices*

4.2 NFPA

NFPA 85, *Boiler and Combustion Systems Hazards Code*
NFPA 30, *Flammable and Combustible Liquids Code*
NFPA 54, *National Fuel Gas Code*
NFPA 70, *National Electrical Code*

4.3 Other

ASME B31.3, *Power Piping*

APPENDIX A GLOSSARY OF TERMS

FM Approved: References to ‘‘FM Approved’’ in this data sheet mean the product and services have satisfied the criteria for FM Approval. Refer to the *Approval Guide*, a publication of FM Approvals, for a complete listing of products and services that are FM Approved.

Fuel lance: A device without its own air supply or combustion safeguard (flame scanner) that injects fuel directly into the combustor section of a circulating fluidized bed boiler. A lance can be used to inject any gaseous or liquid fuel and can include fuel atomization (mechanical, steam, air, etc.).

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. Contingency planning guidance was updated.

January 2019. Interim revision. Minor editorial changes were made.

July 2015. The following changes were made:

A. Changed the title and scoped of the data sheet to address only fluidized bed boilers. The previous title was *Fluidized Bed Combustors and Boilers.*

B. In the scope section added a note that recommendations in this data sheet can be applied with judgment to fluidized bed combustors, pressurized fluidized bed boilers, fluidized bed gasifiers, and chemical process equipment, when applicable. Also added a list of data sheets that address hazards in fluidized bed boilers that are not within the scope of this data sheet.

C. Revised recommendations for safety shutoff valves by referencing Data Sheet 6-4, *Oil and Gas-Fired Single Burner Boilers,* and Data Sheet 6-5, *Oil or Gas-Fired Multiple Burner Boilers.*

D. Added definition and recommendations for fuel lances.

E. Added guidance for implosion protection.

F. Added guidance recommending controls and interlocks be fail-safe.

G. Updated loss information.

H. Updated supplemental information in Appendix C.

April 2012. Terminology related to ignitable liquids has been revised to provide increased clarity and consistency with regard to FM Global’s loss prevention recommendations for ignitable liquid hazards.

May 2010. Minor editorial changes were done for this revision.

May 2006. Minor editorial changes were done for this revision.

May 2003. Minor editorial changes were made for this revision.

January 2000. This document was reorganized to provide a consistent format.

APPENDIX C SUPPLEMENTAL INFORMATION

Fluidized bed boilers burn fuel in a turbulent bed of particles kept in suspension by the combustion air. The bed can consist of fuel, chemically reactive solids (limestone), inert solids, and ash. High combustion efficiencies at relatively low furnace temperatures can be achieved. Other advantages include the ability to burn low Btu fuels, such as low-grade coal, wood wastes, agricultural wastes, municipal sludges, and other wastes.

The two main types of fluidized-bed boilers are bubbling fluidized bed (BFB) and circulating fluidized bed (CFB). (See Figures 5, 6, 7, and 8). In BFB boilers the velocity of the combustion air is low enough that the fluidized particles remain in the lower furnace; in a CFB unit the velocity is greater and hot particles are circulated through the entire range of the boiler combustion zone with larger particles collected in the cyclone and recirculated back to the combustor.

Bubbling fluidized bed boilers typically range in sizes up to 150,000 lb/hr, although a few larger units with steaming capacities as large as 375,000 have been built both as new units and where a fluidized bed has been retrofitted into an existing watertube stoker or chemical recovery boiler. Circulating fluidized bed boilers range in size up to 300 MW (approximately 2,000,000 lb steam/hr.

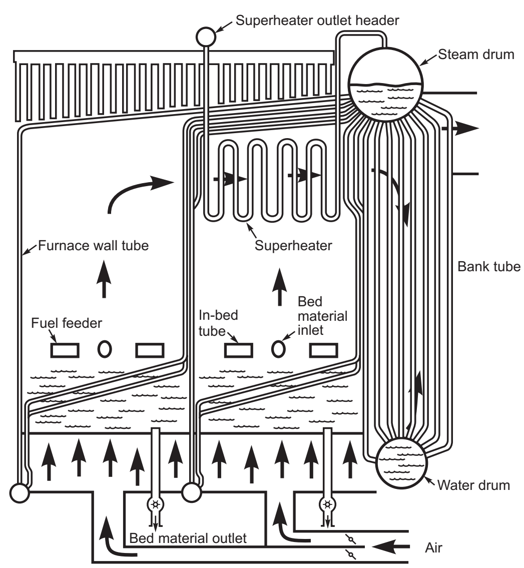

Fig. 5. Bottom-supported bubbling fluidized bed boiler

For bubbling bed boilers, the bed operating temperatures range from 1500°F to 1750°F (816°C to 954°C). Water tubes in the bed, the lower wall tubes, and multi-bed separation tubes have direct contact with the fluidized bed. The use of multi-interconnected beds or zones, each capable of being operated independently, provide a broader range of firing rates when compared with single bed units.

Similar operating temperatures exist in the combustor section of circulating fluidized bed boilers. Most combustor sections are constructed of refractory covered membrane waterwall tubes. Heat transfer to the waterwall tubes occurs through the refractory.

With either type of fluidized bed boiler, for fuels such as crushed coal and lignite, a bed of crushed limestone or dolomite, ash, and the fuel is kept in suspended fluid motion by combustion air being forced up from

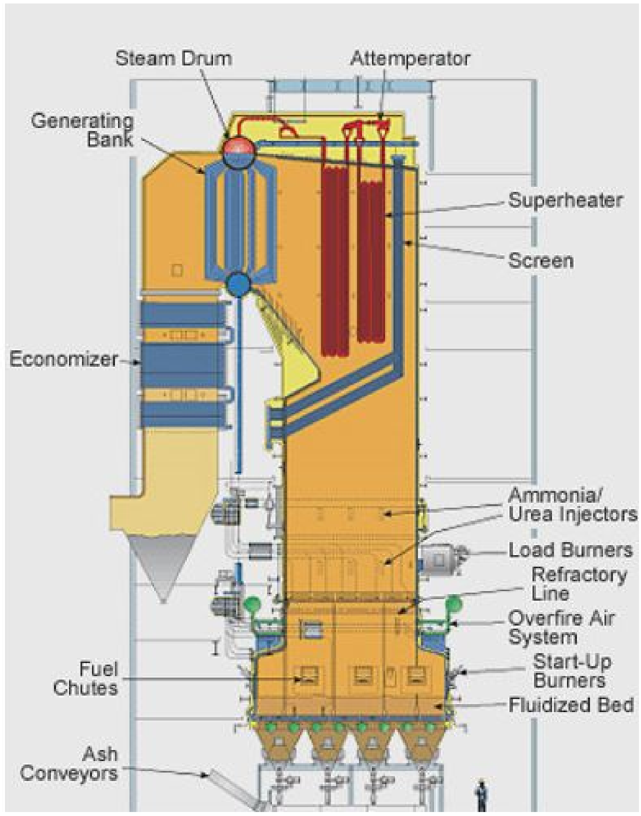

Fig. 6. Top supported bubbling fluidized bed boiler (courtesy of the Babcock & Wilcox Co.)

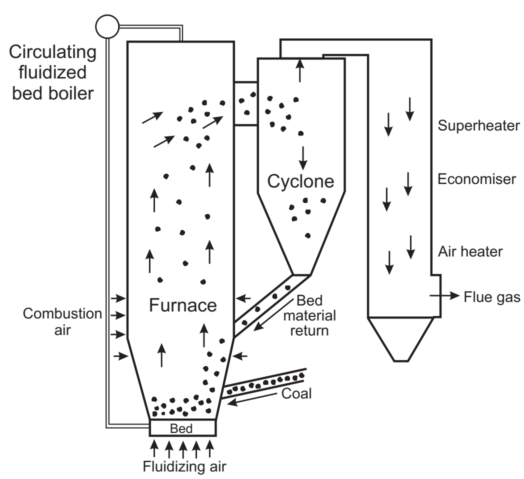

Fig. 7. Circulating fluidized bed boiler with hot cyclone

underneath. Generally, solid fuels consist of less than 5% of the bed contents. Crushed coal used with limestone interacts so that the sulfur, lime, and oxygen form relatively inert compounds, such as calcium sulfate. Optimum sulfur retention occurs with an operating temperature of approximately 1550°F (843°C). The low combustion temperatures and limestone additive appreciably reduces the generation of oxides of

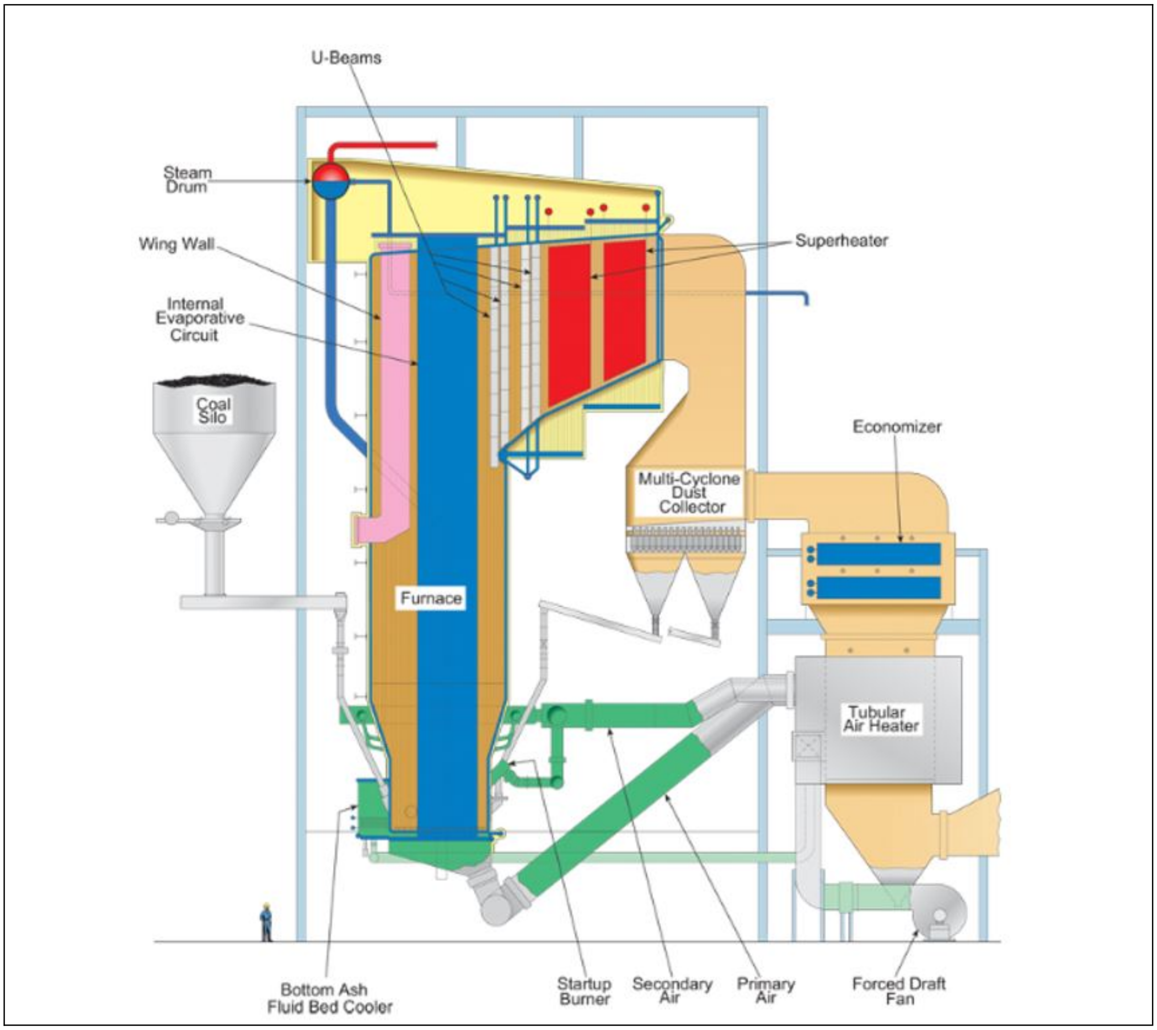

Fig. 8. Circulating fluidized bed boiler with U-Beam bed recirculation system (courtesy of the Babcock & Wilcox Co.)

nitrogen and sulfur dioxide emissions. Because of the small percentage by volume of the bed fuel content, the available fuel is consumed within minutes after the fuel input has been discontinued. The bed may be cooled by continued fan operation.

In bubbling bed boilers, coal and other solid fuels may be fed by a spreader stoker distributing the fuel over the bed surface. Fuel may also be pneumatically fed through open capped pipes extending through the bottom plate (Fig. 9). In circulating bed boilers, solid fuel is typically added through one or several pipes near the bottom of the combustor.

Limestone feed is customarily through separate pipes into the sides of the bed. Some are designed to mix the crushed coal and limestone before injection into or onto the bed. The proportion of limestone needed with the coal varies with the coal composition; approximately one part limestone and three parts coal have been effective in some installations.

Air is supplied from a bottom plenum up through the perforated bottom plate. The perforations usually have tee or caps to prevent backflow of the bed material when the bed is slumped and the combustion air blower is not operating. Where multi-bed designs are used, the plenum is divided into chambers for control of the air to each bed.

In bubbling bed boilers, combustion air velocities for fluidizing the bed vary due to the coal particle size, bed depth, and whether or not ash reinjection from cyclone-type collectors located at the boiler exit are provided. Small coal sizes, below ¼ in. (6.4 mm), and coal with a lot of fines require lower velocities to prevent excessive unburned coal and ash carryover into the flue gas cleaning system. Larger coal sizes, 1¼ in.

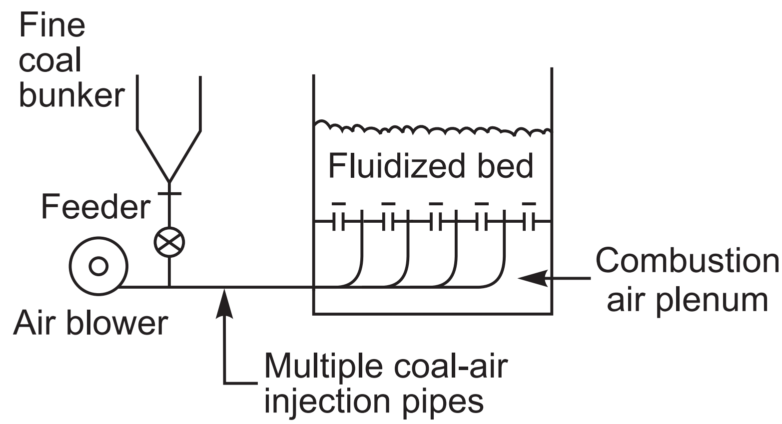

Fig. 9. In-bed solid fuel feed, pneumatic injection

(32 mm) or less, with few fines are more effective for spreader-stoker-fed units. For bed injection, 1/8 in. (3.2 mm) size and smaller is common and few fines are released from the bed. In the case of the in-bed feed, the quantity of fuel in the combustor is usually less than the top-fed spreader-stoker type. The reduced air velocity in the free-board zone above the bed allows for return of solids onto the bed and for combusting the released volatiles and flammable gases.

Ash does not deposit as slag on the convection tube surfaces; instead, fine ash forms on the tubes and the need for soot blowers is limited. Slagging does not occur in the combustion zone when the temperatures are below 1600°F (871°C), lower than the ash-softening temperature. Bottom ash and fly ash removal in bubbling bed boilers are of nearly equal proportions and total 20% by weight of the initial coal-limestone input. All ash is removed as flyash in circulating bed boilers.

Pressure parts, drums, and tubes are constructed of materials commonly used for conventionally fired boilers; carbon steel is used for water-wall and bed tubes. Arrangement of bed tubes is designed to avoid stratification or bypassing the fluidizing process. These tubes need to be secured to resist the dynamic forces from the fluidized bed movement.

APPENDIX D OTHER STANDARDS

1. Additional information concerning fuel explosion prevention in fluidized bed boilers may be found in NFPA 85 Boiler and Combustion Systems Hazards Code. It is recommended that this standard be consulted for a more detailed explanation of system requirements and operating philosophy. (Also see Section 2.1.)

2. Other related standards include NFPA 54, *National Fuel Gas Code;* NFPA 30, *Flammable Liquids Code;* NFPA 70, *National Electrical Code;* and ASME B31.1, *Power Piping.*