WOOD AND WASTE BURNING IN INDUSTRIAL PLANTS

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ABSTRACT

This paper describes design considerations, recent industrial operating experiences, and new product developments in the field of waste burning in industrial boilers.

Products covered include the stoker, stoker accessory hardware and furnace/boiler considerations.

Emphasis is placed on the burning of various waste fuels in conjunction with coal, especially with respect to wood or wood-related products. Also, some experiences on gaseous and liquid wastes are discussed. Plant operating histories are developed for cases where refuse was fired initially in the unit and where refuse firing is a retrofit procedure. Applications involve both moving and stationary stokers.

INTRODUCTION

Waste burning offers several advantages to the potential industrial company or municipality. These include some or all of the arguments in the list below, depending on the economics of fossil fuels, environmental situation, etc. of the particular application.

1. Guaranteed long-term waste disposal site
2. Lower long-term waste disposal costs
3. Reduced weight and volume of ash for final stage disposal
4. A reliable source of fuel
5. Improved public relations
    - Reduced environmental hazards
    - Combined industrial and municipal waste disposal
    - Reduced public energy cost
6. Extra bonuses
    - Steam for process heat or power
    - By-product recovery, recycle or sale
    - Reduced on-site energy costs

Fuel burning equipment has been proven to be acceptable and to have reasonable availability and reliability to provide continuous refuse burning service, provided equipment is designed and operated in the appropriate manner, commensurate with the refuse fuel being burned.

SOME DESIGN CONSIDERATIONS IN BURNING WASTE FUELS

1. Stoker Considerations

Refuse solids can usually be burned best on a spreader stoker rather than in a pulverized coal furnace. As an example, some utilities have tried to burn prepared municipal refuse in suspension in existing P. C. units. Results have been disappointing from the standpoint of the percentage of unburned fuel which reaches furnace bottom and boiler hoppers.

Some of the equipment and operating variables in spreader stoker firing include:

- Total air quantity (excess air) - sensitive to fuel types.
- Proportioning of overfire to underfire air and location of overfire air ports relative to adequate flame turbulence and burnout of combustion products versus prevention of grate clinkers.
- Design of grate air openings and number of zones to give proper flow of air through fuel bed, adequate air distribution, and proper cooling of grate surface.
- Selection of grate speed to meet combustion demand, promote non-volatiles burnout and provide proper ash/fuel depth for grate protection and good combustion on grate.
- Selection of undergrate air pressures to maintain positive flow through ash/fuel bed and prevent excessive fuel carryover to air stream.
- Even feed rate from each feeder to maintain even fuel distribution on the grate.
- Fuel feed trajectory angle to maintain adequate front to rear grate coverage.
- Parallel angle adjustment for proper side to side coverage.
- Grate surface area selection, given fuel type and peak loads.
- Method of ash removal.

Grate heat release rate is an especially important consideration. Spreader stokers operate at a higher heat release rate per foot of grate area than mass burning systems due to combination suspension burning/thin bed burning. Based on past experience, the industry has established a desirable range as guidelines as shown in Table I. Heat release rates are maintained in this range in order to minimize the amount of flyash, carbon loss, and carryover.

As shown in the table, when firing cellulose fuels with grate heat release rates up to 3,155,000 W/M^2 (1,000,000 $Btu/hr/ft^2$), good combustion efficiencies can be achieved, as demonstrated in recent years. This is done by using several levels of overfire air nozzles with quantities approaching 50 percent of combustion air. High grate heat releases can be achieved when firing coal by increasing the amount of overfire air introduced at higher levels in the furnace.

Some operator aspects in stoker firing include the need to maintain a constant vigilance of the grate surface to discover clinkering build-ups and to detect unevenness in fuel feed. These in turn result in changes as necessary in air proportioning and pressures, grate speed and fuel feeder positioning, etc.

2. Furnace Considerations

There are many parameters involved in the selection of furnace configurations. It would seem that the logical tendency is to select an oversized furnace that will provide the highest degree of conservatism. If this is the case, however, it would be an uneconomical design and we would be faced with a system that has inadequate heat content in the flue gas. Sufficient heat is necessary to achieve desired superheat. On the other hand, too small a furnace can present major adverse conditions such as too much slag accumulation on furnace walls and convection section, tube burn-outs, excessive particle carryover, carbon loss, and short component life.

Table I depicts recommended boiler design parameters employed when firing solid fuels on traveling and stationary grates. One of the most important indicators as to whether or not the furnace has been properly sized is the effective projected radiant surface heat release. The ranges shown are only guidelines;

PARAMETERS IN METRIC UNITS

	Furnace Exit Gas Temp. °C	Velocity m/s	Volumetric W/M³	Radiant Surface W/M²	Heat Releases – Grate Surface: Traveling	Heat Releases – Grate Surface: W/M² Water Cooled	Heat Releases – Grate Surface: Hopper Fed
Bituminous Coal	926.66	17.06	186,424.03-279,636.04	236,625.4-268,175.46	2,050,753.5-2,366,254	---	1,419,752.4
Sub-bituminous Coal and Lignite	926.66	16.76	155,353.36-258,922.26	220,850.38-252,400.43	2,050,753-2,366,254	---	1,340,877.3
Cellulose Fuel (Bagasse, Wood Low Sand Content)	898.88	15.24	186,424.03-279,636.04	283,950.48	3,155,005.4	3,155,005.4	---
Cellulose Fuel High Sand Content	885	12.19	258,922.26	252,400.43	3,155,005.4	3,155,005.4	---

PARAMETERS IN U. S. CUSTOMARY UNITS

	Furnace Exit Gas Temp. °F	Velocity ft/sec	Volumetric Btu/hr ft³	Radiant Surface Btu/hr ft²	Heat Releases – Grate Surface: Traveling	Heat Releases – Grate Surface: Btu/hr ft² Water Cooled	Heat Releases – Grate Surface: Hopper Fed
Bituminous Coal	1700	56	18,000-27,000	75,000-85,000	650,000-750,000	---	450,000
Sub-bituminous Coal and Lignite	1700	55	15,000-25,000	70,000-80,000	650,000-750,000	---	425,000
Cellulose Fuel (Bagasse, Wood Low Sand Content)	1650	50	18,000-27,000	90,000	1,000,000	1,000,000	---
Cellulose Fuel High Sand Content	1625	40	25,000	80,000	1,000,000	1,000,000	---

Note: The values and ranges shown above are maximum limit guidelines and some deviations can occur without adverse effects in the unit operation.

Table I Recommended Grate and Furnace Parameters

some deviations can occur without any adverse effect on boiler operation. It is necessary to increase the size of the furnace to accommodate higher fuel rates, caused by lower heating values and higher moisture contents in order to properly fire lignite fuels.

This concept is represented in Table I by a lower range of heat releases when firing sub-bituminous coal as compared to the bituminous coals. Lignitic fuels also have slagging tendencies which are more severe than most bituminous coals; consequently, more cooling surface is recommended. Because of the low ash content and slagging tendencies, higher heat releases are permitted when cellulose fuels are fired.

The large amount of flue gas due to the low heating value and high moisture content of the cellulose results in approximately the same furnace exit gas temperature even though the furnace envelope has substantially reduced. The different radiation flame characteristics play important roles on the furnace exit gas temperature.

COMBINED COAL/REFUSE BURNING EXPERIENCES ON RILEY UNITS

Over the past years, Riley Stoker has had experience burning several types of wood waste alone or in combination with conventional fossil fuels. Some of the wastes being burned in the Riley boilers include:

general wood waste	other industrial plant solid waste
bark	sunflower seed hulls
bagasse	rice hulls
furfural residue	nut hulls
paper wastes	corncobs
cork	coffee grounds
leather scrap	paraffin
cellophane	sludges
rubber waste	blast furnace gas
municipal refuse	coke oven gas
	refinery CO gas

In this section, a few varied applications will be discussed in detail, including:

1. Combined coal and manufacturing plant solid wastes.
2. Combined coal and manufacturing plant gaseous waste.
3. Combined coal and municipal refuse.

Also, some applications involving only wood waste will be presented.

1. General Motors Corp. Truck and Coach Division, Plant No. 2

Riley Unit No. 8 was initially designed for combined coal and refuse firing. In its first three years of operation, 1973-1976, only coal was fired. Since 1976, both coal and refuse have been fired.

Raw Refuse Handling, Preparation and Processing

The refuse fuel is industrial solid waste collected from various GM plants in the vicinity of Pontiac, Michigan. The characteristics of the prepared refuse-derived fuel (RDF) and the coal are given in Table II. (The refuse has remained relatively constant in its constituent make-up over the refuse firing years.) The processing plant has a capacity of 224 short tons (200) tons per day and provides RDF to Riley Unit No. 8 as well as to another unit at the plant site. Approximately 112 short tons (100) tons of coal per day, on an equivalent heat basis are saved year round by burning combined coal and refuse in a single-shift operation. On a yearly basis, this amounts to approximately 22,400-28,000 short tons (20,000-25,000 tons) per year of coal.

General Characteristics of Raw Refuse: (Design)	**From various GM manufacturing plants: wood (42%), paper (33%), cardboard (23%), rubber and plastics (2%)**
Analyses of Prepared Refuse (Design):	**C - 41.5%, 0 - 34.2%, S - 0.5%, H - 5.9%, ash - 6.7%, water - 11.2%, 1,890 kcal/kg (7500 Btu/lb) as fired.**
Analyses of Coal (Design):	**C - 71.44%, 0 - 12.6%, S - 0.98%, H - 5.21%, N - 1.69%, ash - 8.08%, 3,061.8 kcal/kg (12,150 Btu/lb) as fired. Ash fusion temp. = 1482.22 °C (2700°F). 45 Hardgrove grindability.**
Prepared Refuse: (Actual)	**176.4 kcal/kg (700 Btu/lb) as fired.**
Coal: (Actual)	**0.8% Sulfur (Present Allowable Limit)**

Table II G. M. Truck and Coach Fuel Characteristics

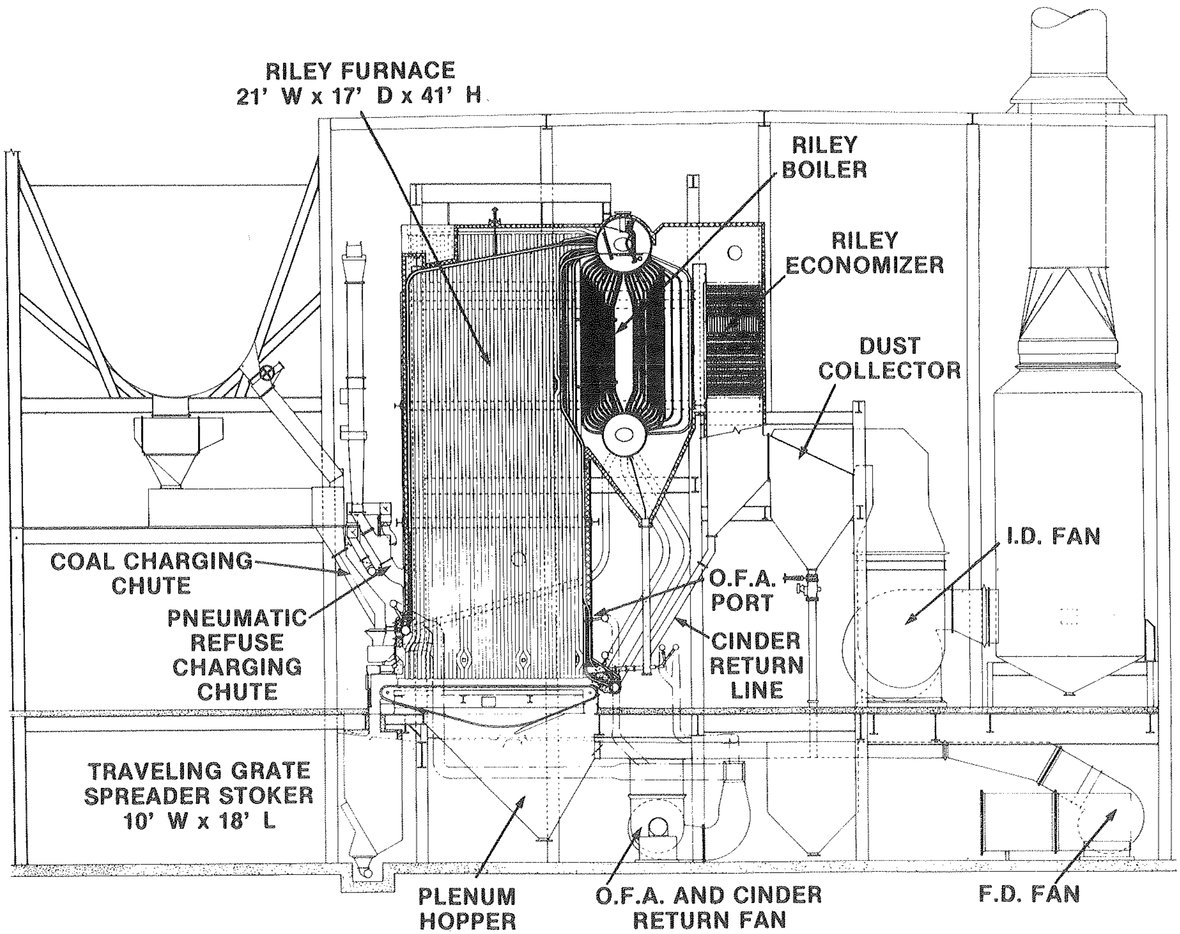

Figure 1 Riley Unit #8, Plant #2, GMC Truck and Coach Division

Fuel Burning Equipment Design

As shown in Figure 1, Riley Unit No. 8 was originally designed to handle either coal firing or combined refuse/coal firing. It includes a traveling grate spreader stoker with front ash discharge, with a design provision to burn a 70/30 refuse-to-coal ratio, on a heat input basis.

Fuel Burning Operating Experience

At no time is firing on 100% refuse allowed, since a sudden loss of refuse feed would result in a drastic loss of steam and incapability to meet continuous steam demand. Experience has shown that the optimum ratio of refuse-to-coal is 60/40 by weight (46/54 by heat input). This allows for a safe operating margin, i.e., if refuse feed is lost, coal feed rate can be moderately increased without a drastic loss of steam output. The 60/40 refuse-to-coal weight ratio is used during weekend operation and a 50/50 refuse-to-coal ratio is maintained during weekday operation as an additional conservative measure when there is a higher average steam demand.

Steam Generating Operating Features and Experiences

The summary of design process conditions at MCR steam load are given in Table III. A unit is operated continuously, 18-20 hours per day (as average refuse burning hours availability), in generating steam. There has been a steady increase in operating time per year on refuse. Last year the goal of 65% of working days for refuse firing was met, at an average of 112 short tons (100 tons) per day per unit. On Riley Unit No. 8, there have not been any appreciable slagging problems (especially in the upper firing chamber), since refuse firing was initiated in 1976. Screen tube section cleaning, by water-blasting method, has been required at an average rate of only once per year on this unit. Flue gas flow paths are appropriately sized for refuse firing and the furnace chamber is sized properly such that the products of combustion and any refuse carry-over do not have time to cool below their fusion temperatures and subsequently, fuse before reaching the upper tubes.

	GM TRUCK & COACH		GM FISHER BODY		AMES	
	Refuse Coal	Coal	Coal and Oven Gas	Coal	Refuse Coal	Coal
Steam Flow (kg/hr)	90,718.47	90,718.47	65,770.89	81,646.62	43,091.27	43,091.27
Sat. Steam Press. (KPa)	1110.09	1110.09		1206.62	4895.45	4895.45
Outlet Superheater Pressure (KPa)					4343.85	4343.85
Sat. Steam Temp. (°C)	188.33	188.33		219.44	443.33	443.33
Fuel Flow (tons/day)	300 (R) 75 (C)	120		213	175 (R)[1] 91 (C)	182.4
(tons/hour)	12.5 (R) 3.2 (C)	10		8.9	7.3 (R) 3.8 (C)	7.6
(kg/hr)	11,339.80 (R) 2,834.95(C)	9,071.84	6,441.01 (C)	8,051.26	6622.44 (R) 3,447.30 (C)	6,894.60
Air Flow (kg/hr)	127,459.46	114,305.28	61,234.97 (gas) 40,823.31 (air)	103,872.65	59,692.75	
Excess Air (%)	50	38	60	30	50	
Heat Input (MW)	55.95 (R) 22.45 (C)	71.80	54.22	67.41	21.39 (R) 21.39 (C)	42.79
Fuel Heat Content (kcal/kg) (As fired)	1,890 (R) 3,087 (C)	3,087	0 (gas) 3,276 (C)	3,276	1,260 (R) 2,404 .33(C)	2,404.33
Furnace Heat Release (W/M^3)	181,245.58	177,102.83	190,566.78	238,208.48	285,228.76	285,228.76
Furnace Heat Release (W/M^2)	239,780.41	235,363.4				
Grate Heat Release (W/M^2)	2,303,153.9	2,192,728.7	1,700,547.9	2,126,473.6	1,858,298.2	1,858,298.2
Overall Unit Efficiency	75.64	80.88		80.4	60	80

1: R - Refuse
C - Coal

Table III Design Conditions at Maximum Continuous Rating (Metric Units)

Since refuse is fired, the unit is rated as an "incinerator", thereby requiring a mechanical collector plus a wet scrubber for emission control. In comparison to coal burning, flyash from refuse/coal is lighter and finer (similar to talcum powder). Flyash escaping capture in the mechanical collector has previously resulted in I.D. fan wear, including erosion to the fan wheel and blades and abrasion to the I.D. fan inlet box.

The fan housing has been rebuilt three times, most recently with the addition of a ceramic-type tile welded to the housing to deter abrasion. The latest retrofit of tile has been very successful in minimizing expenditures for metal replacement in the fan housing and no further material changes have been made to the fan housing in the past three years.

A stainless steel stack was retrofitted, following initiation of refuse burning. The stack remained intact for five years before needing replacement. GM personnel estimate an improvement to 8-10 years life of the second stainless steel stack, since operating know-how has been gained.

The predicted collection efficiency of the mechanical collector at MCR steam load is 94% when firing coal and 92% when firing a 60/40 refuse to coal ratio by weight. Actual tests performed in recent years indicate an

	GM TRUCK & COACH		GM FISHER BODY		AMES	
	Refuse Coal	Coal	Coal and Oven Gas	Coal	Refuse Coal	Coal
Steam Flow (lb/hr)	200,000	200,000	145,000	180,000	95,000	95,000
Sat. Steam Press. (psi)	161	161		175	710	710
Outlet Superheater Pressure (psi)					630	630
Sat. Steam Temp. (°F)	371	371		427	830	830
Fuel Flow (tons/day)	300 (R) 75 (C)	120		213	175 (R)[1] 91 (C)	182.4
(tons/hour)	12.5 (R) 3.2 (C)	10		8.9	7.3 (R) 3.8 (C)	7.6
(lb/hr)	25,000 (R) 6,250(C)	20,000	14,200 (C)	17,750	14,600 (R) 7,600 (C)	15,200
Air Flow (lb/hr)	281,000	252,000	135,000 (gas) 90,000 (air)	229,000	131,600	
Excess Air (%)	50	38	60	30	50	
Heat Input (Btu/hr)	187.5×10^6 (R) 76.6×10^6 (C)	245×10^6	185×10^6	230×10^6	73×10^6 (R) 73×10^6 (C)	146×10^6
Fuel Heat Content (Btu/lb) (As fired)	7,500 (R) 12,250 (C)	12,250	0 (gas) 13,000 (C)	13,000	5,000 (R) 9,541 (C)	2,404.33
Furnace Heat Release (Btu/ft³/hr)	17,500	17,100	18,400	23,000	27,540	27,540
Furnace Heat Release (Btu/ft²/hr)	76,000	74,600				
Grate Heat Release (Btu/ft²/hr)	730,000	695,000	539,000	674,000	589,000	589,000
Overall Unit Efficiency	75.64	80.88		80.4	60	80

1: R - Refuse
C - Coal

Table III Design Conditions at Maximum Continuous Rating (U. S. Customary Units)

actual efficiency at 75% of MCR steam load of 93% on coal firing and 87% on 60/40 refuse/coal (by weight) firing. In summary, the mechanical collector provides nearly maximum efficiency in removing coal burning particulate and does quite well when firing a refuse/coal mix. However, as the refuse/coal ratio increases, collector efficiency may decrease.

In summary, the mechanical collector provides nearly maximum efficiency in removing coal burning particulate and does quite well when firing a refuse/coal mix. However, as the refuse/coal ratio increases, collector efficiency may decrease.

GM Truck and Coach Future Plans

GM plans to continue with this refuse burning practice. It should be emphasized that GM has evaluated the trade-offs of savings in fuel costs and landfill costs vs. increased capital and operating costs (caustic chemicals for wet scrubber, etc.) and has determined that a positive return exists with refuse firing based on existing fuel costs and landfill costs. This advantage could disappear should fuel and/or landfill costs decrease significantly and GM could easily return to coal firing only on the existing equipment.

Also, GM has a unique situation in that it has a captive supplier of refuse. Furthermore its refuse suppliers (other plants) are able to accept a varying demand for refuse by the GM Truck and Coach Plant based on the steam demand at the Truck & Coach Plant and the amount of refuse generated on site. GM Truck and Coach could probably not obtain a long term contract with an outside supplier of refuse, due to its rapidly varying seasonal and work load related quantity demand for refuse.

2. Waste Gas Burning at GM Fisher Body Division

In the late 1970's, the Fisher Body, Lansing, Michigan Plant was faced with a concern of disposal of exhaust gases from production plant paint ovens. The oven gases have some heat content (see Table IV) and therefore, have some energy recovery value. The primary issue, however, was the need to control in-plant and neighborhood air quality, from an odor emission consideration, relative to air compliance standards. It was determined that acceptable air quality could be obtained by incinerating a portion of the overall waste gases produced. The following paragraphs describe the retrofit effort on the two Riley units at Fisher body to allow for burning of the oven off-gases in the furnace chamber and the subsequent operating experiences.

Original Fuel Burning Equipment

These Riley units were originally installed in the mid 1970's. The original equipment for each unit included a Riley Traveling Grate Spreader Stoker with Model "B" Riley feeders to distribute the coal (partly burned in suspension) over the grate.

Underfire air supplied from the forced draft fan was distributed through three air zones to the stoker grate surface. There was also a connection from the forced draft fan to supply overfire air to several ports above the grate surface. This allows for proper furnace turbulence and burnout of the combustion products.

Retrofit Fuel Burning Equipment

In order to maximize air quality, it was ideally desirable to incinerate all of the oven off-gases. However, the boilers were able to accept only approximately 40% of the total off-gas production as com-

General Characteristics of Oven-off Gas	**Product of Plant Paint Ovens:** **68.03 kg/min (150 PPM) Hydrocarbons, 22.67 kg/min (50 PPM) Methane, 90,71 kg/min (200 PPM) Solids** **Oxygen Content 14 - 16%**	
Analysis of Coal (Original Design)	**Proximate:**	**Ohio High Sulfur** **Moisture - 5.6%, Volatiles 36.1%** **Fixed Carbon - 52.4%, Ash 5.9%** **2,772 kcal/kg (11,000 Btu/lb) (As Received)**
	Ultimate:	**H_2O - 10%, C - 62.2%, H - 4.5%** **O - 7.6%, N - 1.2%, S - 2.5%, Ash - 12%**
Analysis of Coal (Present Day Usage)	**East Kentucky and West Kentucky**	
	Proximate:	**5 - 10% Moisture, 30% Volatiles** **50 - 55% Fixed Carbon, 5% Ash, and 1% Sulfur** **3,150 - 3,402 kcal/kg (12,500 - 13,500 Btu/lb) (As Received)**

Table IV GM Fisher Body Fuel Characteristics bustion air, based on the boiler maximum continuous rating. It was determined that this would be acceptable in terms of the net improvement in air quality.

Each unit had a second forced draft fan installed. This was used solely to extract oven off-gases and by damper control, supply the combustion air required by the grates and bypass the remaining oven gases directly to the flue gas ducts to the stack. Oven gas temperatures vary from as low as − 17.8°C (0°F) to as high as 176.7°C (350°F), with normal temperature of 104.4°C (220°F).

From the forced draft fan, the oven gases used for combustion were conveyed via ducting to the undergrate plenum area to mix with ambient air supplied from the originally installed forced draft fan. No special materials were required for the forced draft or induced draft fans to handle the waste gases. A schematic of this process is shown in Figure 2.

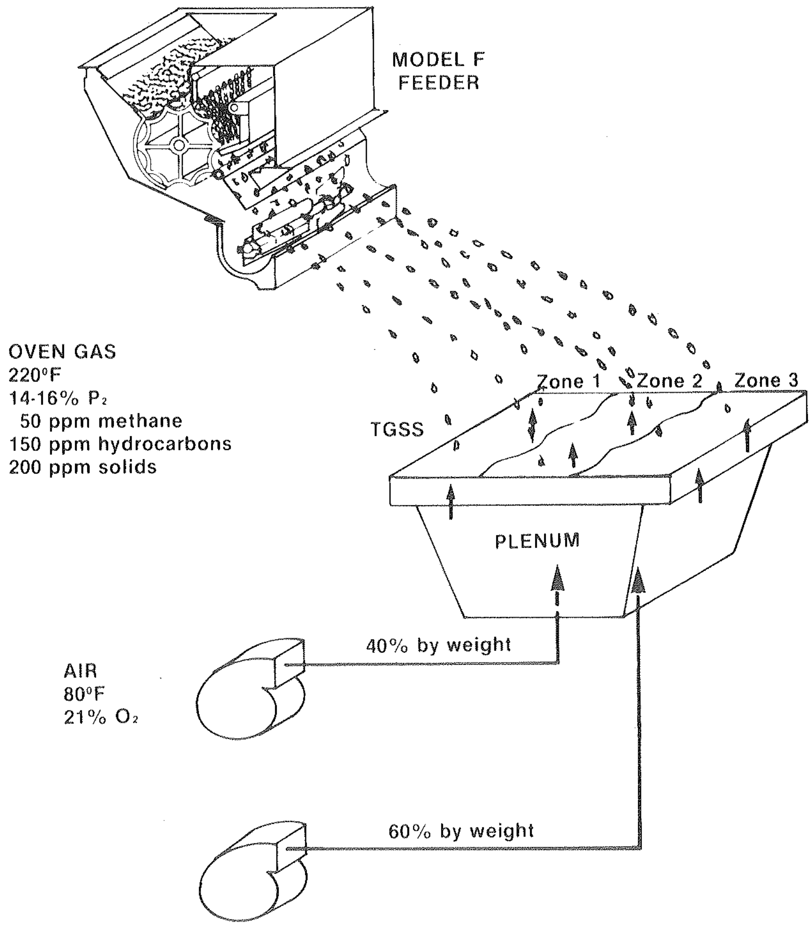

Figure 2 GM Fisher Body, Waste Gas Burning

Fuel Burning Operating Practices

The ratio of oven gas to air on a weight basis with respect to the air mixture to the undergrate plenum averages 80/20 in the summer and 60/40 in the spring, fall and winter. The oven gases with 14-16% O_2 mix with air at 21% O_2 to provide combustion air at 17-19% O_2.

To maintain proper turbulence and adequate oxygen for final burnout, the overfire air portion, as a percent of total combustion air, has been increased somewhat. Total excess air has been increased from approximately 30% prior to oven gas burning to 60% with oven gas burning to assure adequate oxygen for combustion stability. This in turn has resulted in a 20% de-rating of the unit. (In the summer months the large Riley units are often shut down, due to a lack of steam demand which can be met by operating other smaller units at the Plant.)

A summary of operating parameters is given in Table III.

Fuel Burning Operating Experiences

There have been a few expected operational problems. The most considerable one has been some erosion and abrasion in the area of the economizer tube bends due to the high velocity created by the requirement to go to higher excess air. Special shields have been installed and the problem has been significantly reduced, with no tube leaks reported in the past six months.

Initially, there also was a problem with condensing of the oven gas/flue gas on the economizer tubes. A fireside treatment was injected at the boiler outlet, which mixed with the flue gas and effectively eliminated the tendency of the gas to adhere to and condense on the economizer tubes.

Future Fisher Body Division Plans

The incinerating of oven off-gases has been considered successful in the two Riley units, and in two other units at the Lansing plant for the 2-3 years of oven gas incineration. No changes in operating procedures or equipment are being planned and the waste gas burning process will be continued.

3. City of Ames, Iowa Municipal Power Plant

Unit No. 5 was originally designed for firing on high-sulfur (5-7%) Iowa coal. Riley Stoker supplied the fuel burning steam generating equipment for this unit, which was started up in 1951.

By 1972, the City of Ames was advised that the existing city sanitary landfill would soon be full and that it would be difficult to locate a new site. A feasibility study led to a recommendation to design and install a municipal solid waste recovery system which would provide:

A. An economic alternative and more environmentally acceptable method of disposal.

B. The ability to convert existing furnaces to burn solid waste (refuse-derived fuel) as a supplement to coal firing, at a reasonable cost and with no increased air pollution.

C. A readily available source of low sulfur power plant fuel, which when mixed with a current blend of Iowa/Western coal would result in a composite fuel having a lower sulfur content.

D. A way to recover valuable metals and other by-products.

Construction of the waste processing plant and retrofitting of the Riley Unit No. 5, as well as the other units at the Municipal Power Plant, began in 1974. Commercial operation began in November, 1975.

Raw Refuse Handling, Preparation and Processing

The characteristics of the prepared refuse-derived fuel (RDF) and the characteristics of the blended Iowa/Colorado coal are given in Table V. The processing plant has a capacity of 50 TPH or 200 TPD, based on a 2-5 hour operating phase, with the remaining shift hours used for maintenance and cleaning of the processing equipment. It services 3 units, including Riley Unit No. 5.

By-products of the processing phase include baled paper, recovery of magnetic metals as well as recovery of aluminum and other non-ferrous metals. Ferrous metals are sold to help defray operating costs.

Fuel Burning Equipment Design

Original equipment, supplied in 1951, includes twin Riley traveling grate spreader stokers and two rows of overfire air nozzles (Figure 3). The stokers are each 2.43 m (8 feet) wide by 5.18 m (17 feet) long, each having two 66.04 cm (26 inches) Model "B" feeders and a maximum rated speed of 4.27 m (14 feet) per hour.

Control of refuse firing rate is performed by automatic or manual variation of storage bin drag conveyor speed. This provides the desired fixed volume flow rate into pneumatic feeders and for a constant density refuse media, a fixed mass flow rate occurs. Generally the manual operating mode is used.

Retrofitting for refuse burning in 1975 included four steps (Figures 4 and 5). The four natural gas burners in the front wall were removed. Two Riley Pneumatic Distributors with air swept spouts were added at the elevation of the old gas burners. One row of overfire air nozzles was added in the rear wall, below the eleva-

General Characteristics	Corrugated cardboard, rubber and plastic products, aluminum foil and alumina sandpaper, carbon paper, wood chips, glass, sand, stones, other ferrous and non-ferrous metals, food waste, yard waste.
Analyses of Prep. RDF: (Actual)	Proximate (as received) 1/27/78 - Moisture - 21.3%, Volatiles - 59.9%, Ash - 14.5%, Fixed Carbon - 4.3%; 1601.46 kcal/kg (6,355 Btu/lb) 9/75 - Moisture - 18.7%, Volatiles - 59.4%, Ash - 14.5%, Fixed Carbon - 7.2%; 1775.59 kcal/kg (7046 Btu/lb) Ultimate 1/27/78 - (Dry) C - 45.9%, O + N - 29.3%, S - 0.4% H - 5.6%, Ash - 18.4%, Chlorine - 0.42% 10/75 - (Wet) C - 35.9%, O + Misc. - 23.5%, S - 0.3% H - 5.6%, Water - 24.9%, ash - 9.8% Ranges of Heating Values: 1237.32 - 2122.34 kcal/kg (4,910 - 8,422 Btu/lb) (8/75/6/76) (As received) Ranges of moisture content: 15-30% (8/75-6/76)
Analyses of Coal Blend: (Actual)	Proximate (As Received) 1/2778 - Moisture - 13.8%, Volatiles - 33.7% Ash - 12.4%, Fixed Carbon - 40.1%; 2695.64 kcal/kg (10,697 Btu/lb) 10/75 - Moisture - 18.76%, Volatiles - 34.99%. Ash - 8.37%, Fixed Carbon - 37.88%; 24.36.84 kcal/kg (9,670 Btu/lb) Ultimate 127/78 - (Dry) C - 68.5%, O - 7.7%, N - 1.5%, S - 3.6% H - 4.3%, Ash - 14.4%, Chlorine - 0.026% 10/75 - Moisture - 18.76%, C - 54.96%, O + Misc. -10.27%, S - 2.17%, H - 5.47%, Ash -8.37%

Table V City of Ames Fuel Characteristics

tion of the pneumatic distributors, to complement the existing nozzles. A larger overfire air fan was installed to allow for increased OFA flow rates. A larger OFA air duct was also installed.

The firing system was designed for a 50/50 refuse-to-coal ratio by heat input.

Fuel Burning Operating Experiences

The Riley unit burned coal and refuse for approximately 4 years in the 1975-1979 period. In general experiences were satisfactory, with the principal exception of furnace wall slagging and tube fouling due to a perceived undersized furnace for combined coal and refuse firing. (See Table III, where Ames is shown to have a high volumetric furnace heat release rate.)

This unit was started up in 1951 with the intention to burn bituminous coal only. Therefore, it had been designed with a high heat release rate. Also, due to sand and glass in the supplied RDF, there was some tendency for clinkering on the grate and this resulted in running at high excess air at certain times to avoid clinkering. This in turn caused load reductions during these intervals.

Grate clips performed well, with little maintenance and only a few clips required replacement in these years of operation. One difficult operating issue was to provide the optimum level of overfire air. It was desirable to keep overfire air low to minimize clinkering, i.e., to pass as much of the air as possible through the ash bed on

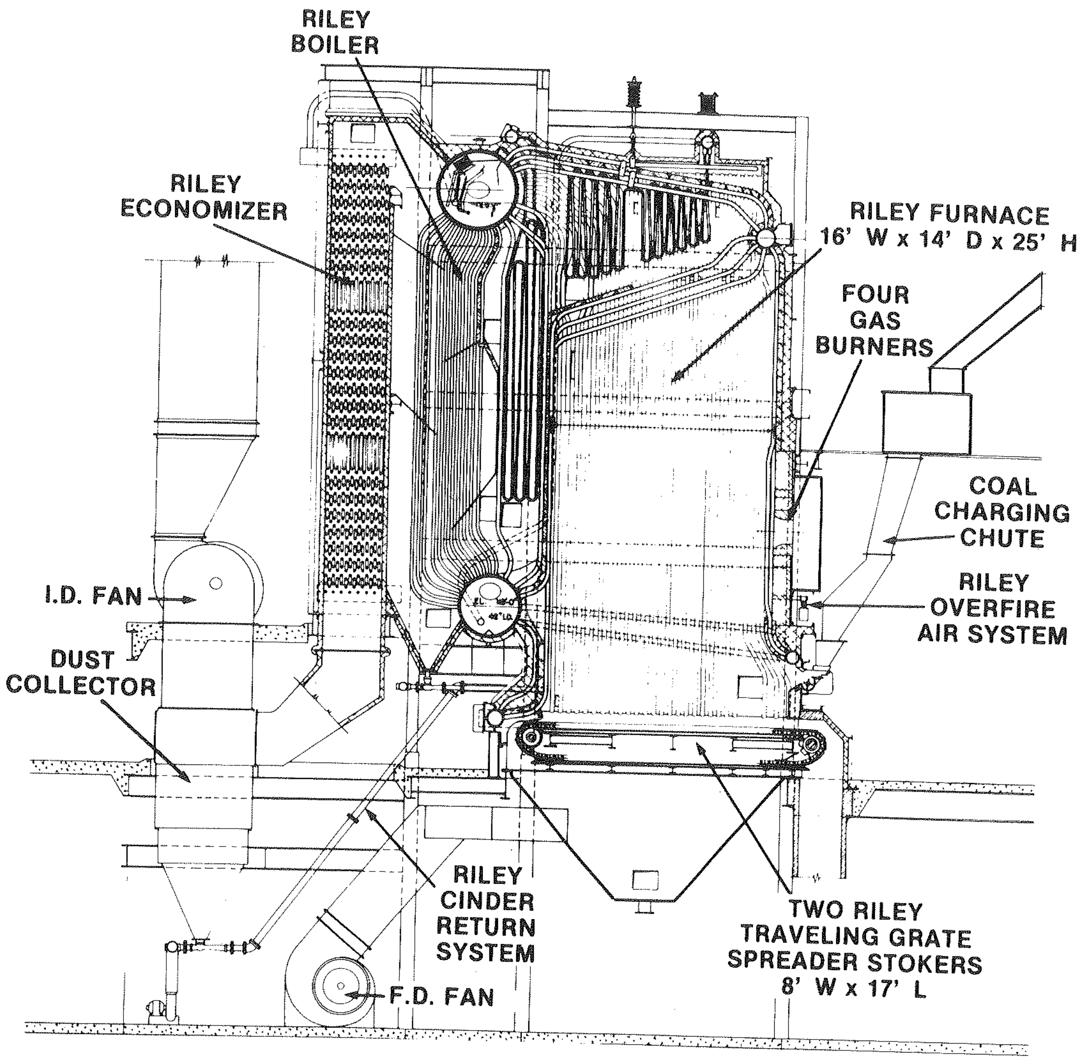

Figure 3 Riley Unit #5 (Original Unit) City of Ames, Iowa Municipal Power Plant

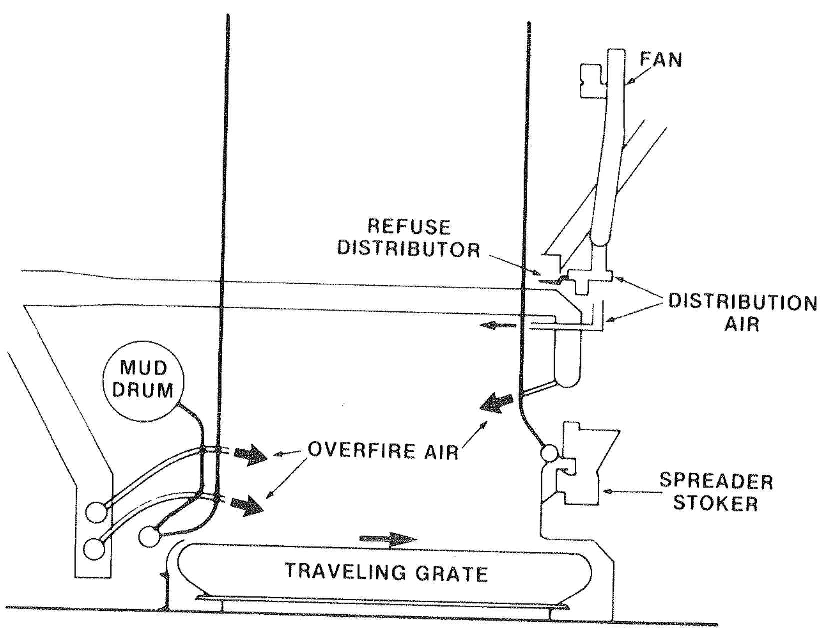

Figure 4 Modified Fuel Burning System, Riley Unit #5, City of Ames, Iowa

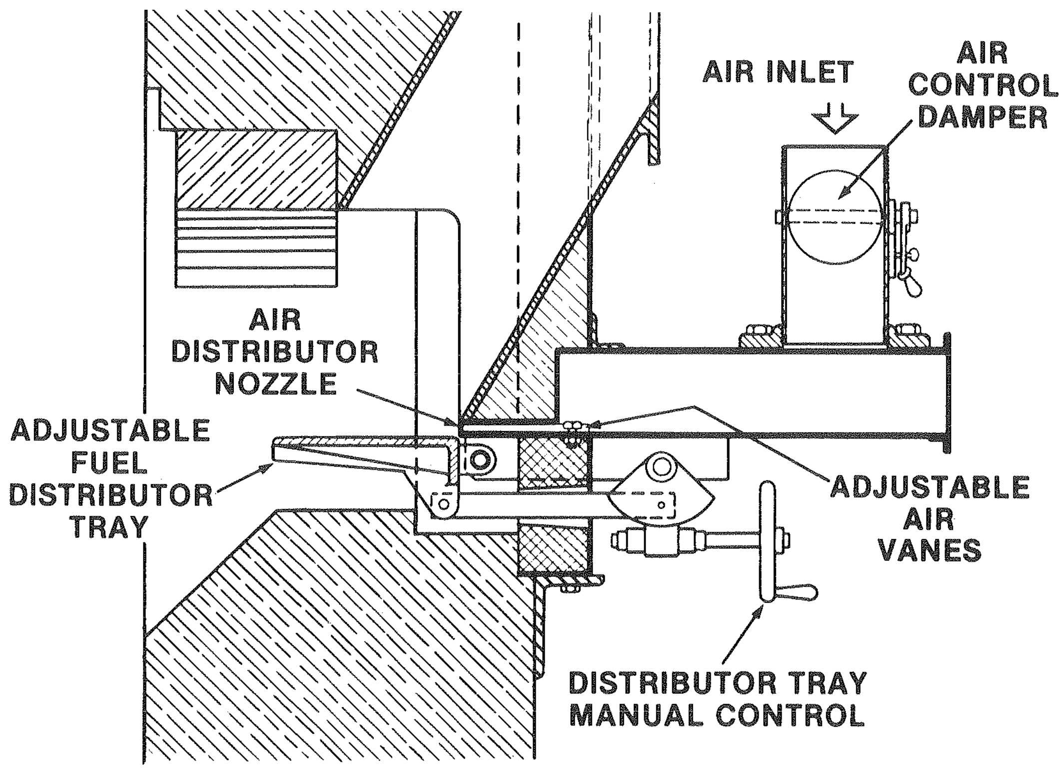

Figure 5 Riley Pneumatic Refuse Fuel Distributor

the grate. However, too little overfire air lowers flame turbulence and in turn lowers combustion efficiency. If too low, it also would result in uneven distribution of fuel/ash on the grate surface.

With a 50/50 refuse/coal ratio typically used, Ames did not experience any problem with flyash handling overloading in the boiler hopper. Experimental efforts showed that refuse/coal ratio could be increased to 70/30 (Btu/basis) without ash loading problems. Also, no corrosion problems were encountered despite the refuse averaging approximately 0.50% chlorine.

In 1979, Ames was forced to discontinue refuse burning on the Riley unit. The original outdated mechanical dust collector (1951 installation date) could not effectively collect partculates to meet the new stricter federal and state limits on particulate emissions. In addition, Ames was forced to burn a lower ash coal and reduce capacity to meet particulate and opacity limits when burning coal only. This small Riley unit was placed in cycling service since load demand could be met with two larger base-loaded units on site. Presently, the load demand is essentially base-load. This unit will soon be retired due to nature of load and age of the unit.

4. Wood Waste Burning Applications

A summary of recent wood waste burning experiences is given in Table VI. Each of these applications includes a Riley water-cooled grate. It is a stationary grate with no moving parts, supported by floor tubes in the furnace. During operation, accumulated ash is periodically removed by steam jets from nozzles located within certain of the grate segments. The motive energy provided by the jets propels the ash down the sloping grate surface into the ash pit. Control of steam flow into the jets is accomplished by a piping network equipped with remotely actuated valves which can be hand operated or can be programmed to automatically clean the grate surface at predetermined intervals.

Analysis of Table VI reveals that design steam flow rates have been achieved or exceeded burning a variety of waste wood fuels having a considerable moisture range. An adequate fuel distribution over the grate and a sufficient depth of fuel bed have been achieved.

	ITT Rayonier	US Plywood	Plum Creek Lumber
Design MCR (kg/hr Steam) (PPH Steam)	90,718 200,000	72,574.77 160,000	54,431 120,000
Maximum Achieved (kg/hr Steam) (PPH Steam)	104,326 230,000	72,574.77 160,000	68,038.85 150,000
Operating Pressure (KPa) (psig)	2,920.37 425	4,137 600	2,068.5 300
Fuel(s) (normal)	Hogged Wood, Hogged Bark, Sander Dust	Hogged Wood, Sander Dust, Plywood Shavings	Hogged Wood, Hogged Bark, Sander Dust, Plywood Shavings
Fuel(s) (emergency)	No. 6 oil	Natural Gas	Natural Gas
% Sand in Fuel	5-6%	2%	2%
Moisture in Fuel	Range: 35-75% Average: 60%	Average: 35%	Average: 55%
Distributed Air Tray Adj.	Const. Setting of 5° Below Horizontal	Const. Setting of 5° Below Horizontal	Const. setting of 5°Below Horizontal
Distributed Air Pressure	45.72 cm Static 18-20" Static	Approx. 30.48 cm Static Approx. 12" Static	25.4 - 38.1 cm Static 10-15" Static
Overfire Air Pressure Front	30.48 - 38.1 cm Static 12-15" Static	5.8 - 12.7 cm Static 2-5" Static	No Front OFA
Pressure Rear	17.78 - 25.4 cm Static 7-10" static	17.78 - 25.4 cm Static 7-10" static	17.7 cm Static 5" Static
Type of Refuse Feeding	Belt and Screw Conveyors	Belt and Screw Conveyors	Belt and Screw Conveyors
Fuel Distribution	Complete Coverage to 2/3 The Grate Length	Complete Coverage to 2/3 The Grate Length	Complete Coverage to 2/3 The Grate Length
Fuel Bed	5.08 - 7.62 cm 2-3" During Normal Operation 0 - 1.27 cm 0-½" Bed With Sander Dust	1.27 - 2.54 cm ½-1" During Normal Operation	2.54 - 7.62 cm 1-3"
% Hogged Fuel Fired in Suspension	30%	30-40%	30%
Ash Bed	1.27 - 2.54 cm ½-1"	0 - 1.27 cm 0-½"	1.27 - 2.54 cm ½-1"
Ash Handling	Manual Hoe	Screw Conveyor (No Problems)	Screw Conveyor (Minor Problems Due to Rocks and Tramp Metal)
Flyash Reinjection	One Nozzle in Each Sidewall	One Nozzle in Each Sidewall	One Nozzle in Each Sidewall
Reinjection Problems	Minor Plugging on Sander Dust Firing	Minor Plugging on Sander Dust Firing	Minor Plugging on Sander Dust Firing
Carryover Problems	Tube First Pass Blockage (Minor) When Firing Large Mounts of Sander Dust		
Sootblowers Used	Yes	Yes	Yes
Grate Cleaning	Hand-operated Steam Lance	Steam Cleaned Grates with Minor Hand Lancing To Clear Large Clinkers	Steam Cleaned Grate with Minor Hand Lancing To Clear Large Clinkers
Grate Steam Pressure KPa (psig)	2758 400	1034.25 - 1379 150 - 200	1723.75 250
Steam Cleaning Sequence	Once Every 8-12 Hours Fuel and Air Left On	Once Every 8-12 Hours Fuel and Air Left On	Once Every 8-12 Hours Fuel and Air Left On

Table VI Wood Waste Burning Experiences

5. Burning of Liquid Wastes

Liquid wastes are burned in suspension after being atomized by air, steam or mechanical burners. In a midwestern Riley unit, spent sulfite liquor has been burned in combination with pulverized coal, oil or gas.

One can easily hypothesize that a liquid waste is relatively free of ash or solids, but this is not necessarily the case. Some operating units have reported high particulate emission levels when burning liquid wastes and design problems can be as complex as with solid waste fuels.

RECENT PRODUCT OFFERINGS

Shop Assembled Modular Boiler

A recent Riley new product offering is the Shop Assembled Modular Boiler. It is essentially a package boiler teamed with a traveling grate spreader stoker. Its application is for small industrial-sized units ranging in size from 18,144 - 68,039 kg (40,000 - 150,000 pounds) of steam per hour. Coal as well as waste fuels can be burned in this unit. Superheater outlet temperatures and pressures up to 482.22°C (900°F) and 11,032 KPa (1600 psig), respectively, can be attained.

The design arrangement maximizes the number of integral parts to be shop-assembled, thereby minimizing field erection time and associated installation costs. There are four major components completely assembled in the shop: the stoker, furnace, superheater, and boiler bank modules. For unit capacities exceeding 31,751 kg (70,000 pounds) of steam per hour, the furnace module is shipped in large assembled modules rather than a complete unit. See Figure 6.

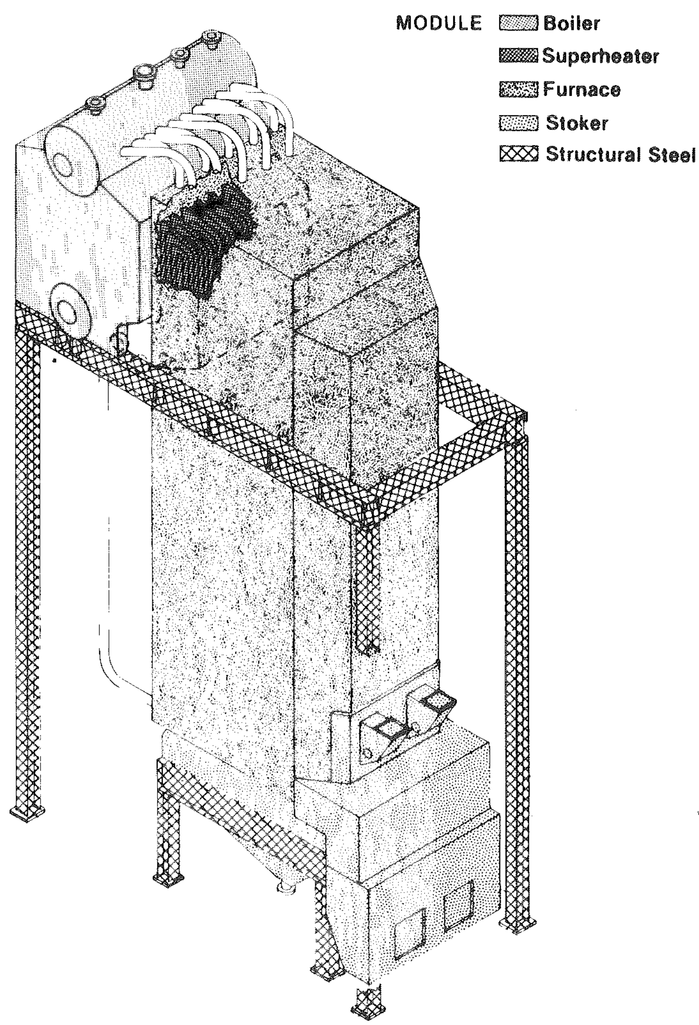

Figure 6 Isometric View of Shop Assembled Modular Boiler

The sequence for erection of these components is as follows: structural frame, stoker, furnace, superheater and boiler bank. Downcomers, feeders, and releasers are installed last. The furnace module is of welded wall construction with all headers attached, observation doors installed and all integral buckstays welded in the shop to comply with code requirements (See Figures 7, 8 and 9).

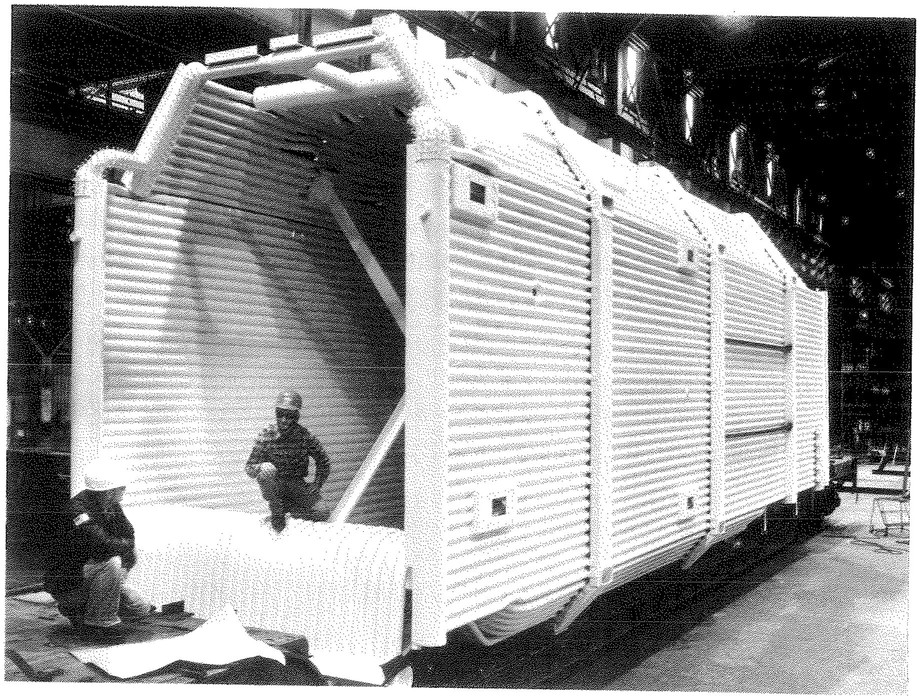

Figure 7 View From Rear of Furnace Module Ready for Shipment

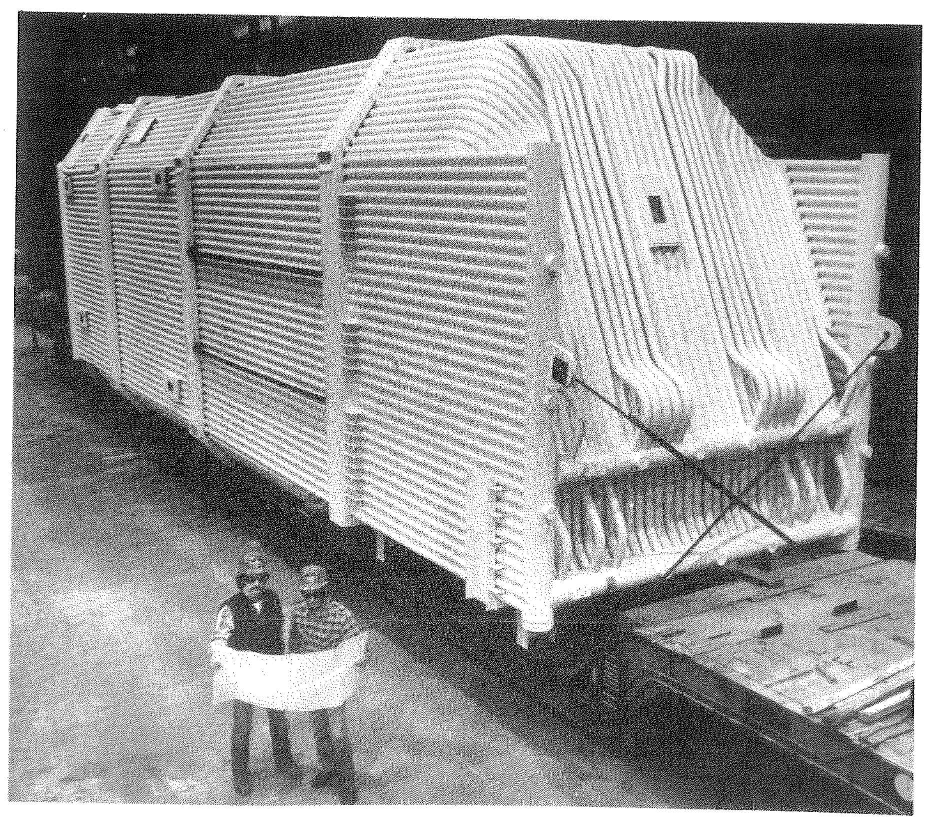

Figure 8 View From Top of Furnace Module Ready for Shipment

Figure 9 Internal View of Furnace Module and Boiler Opening

Special fixtures are built to support the main drum and the mud drum in the shop to allow for complete assembly before shipment. The same concept applies to the superheater module. In summary, this modular concept allows for lower overall cost, reduced overall time to completion and improved quality control.

Figures 10 and 11 show, respectively, two typical arrangements of a water-cooled grate and a hopper-fed traveling grate coupled to a Shop Assembled Modular Boiler. The water-cooled grate is utilized when burning bagasse and many types of hogged woods. The hopper-fed traveling grate has been used for many years to fire fuels with a wide range of coking, caking, and ash fusion temperatures (fine sizes of anthracite, coke breeze, lignite, bituminous and sub-bituminous coals). Also, the traveling grate spreader stoker can be readily used with the Shop Assembled Modular Boiler for fuels which readily burn in suspension.

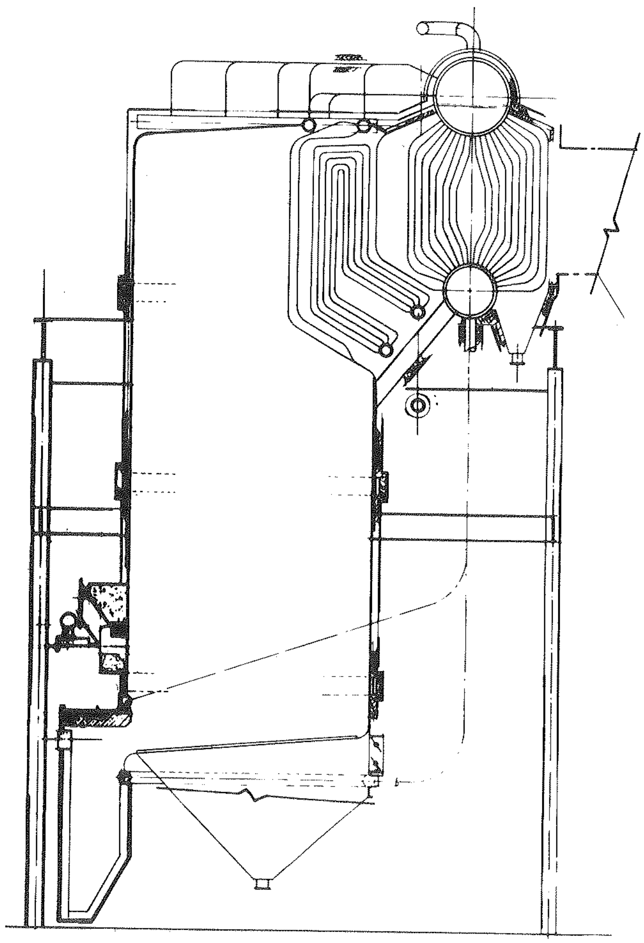

Figure 10 Shop Assembled Modular Boiler Fired by a Stationary Water Cooled Grate

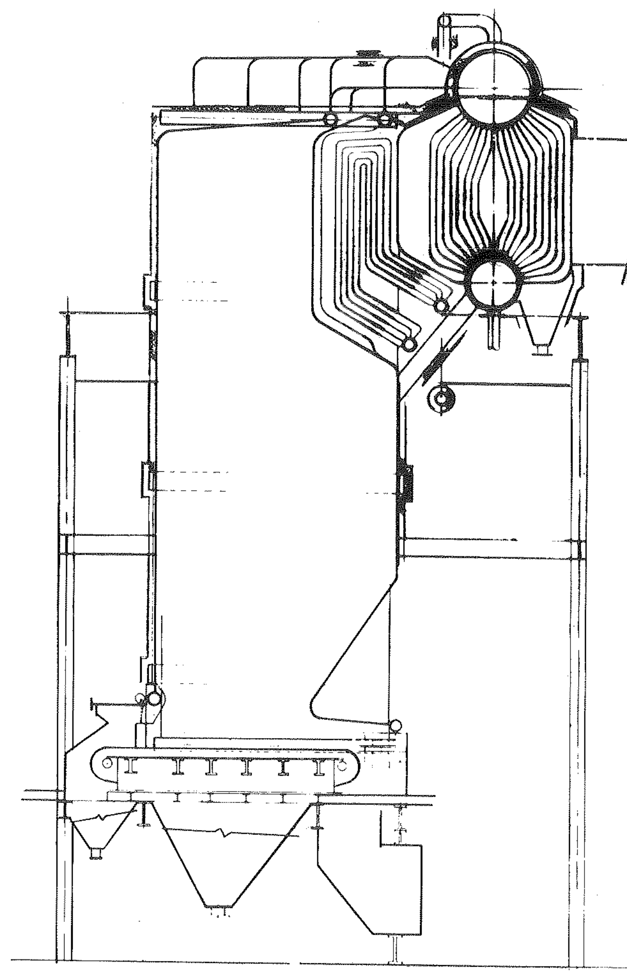

Figure 11 Shop Assembled Modular Boiler Fired by a Hopper Fed Traveling Grate Stoker

Recently, a Riley Shop Assembled Modular Boiler was shipped to the Georgia-Pacific Company, Fort Bragg, California, for a wood burning application. This is a unit rated at 63,503kg (140,000 pounds) of steam per hour, with superheater outlet conditions of 2,758 KPa (400 psig) and 385°C (725°F). A sectional view of this spreader stoker/boiler is shown in Figure 12. The fuel will consist of redwood and douglas fir bark and wood residues from a sawmill having a high, widely varying moisture content (40 to 70 percent by weight). Supplemental No. 5 oil fired in a burner above the grate, may be used to prevent furnace "flame out" on the high moisture wood fuels.

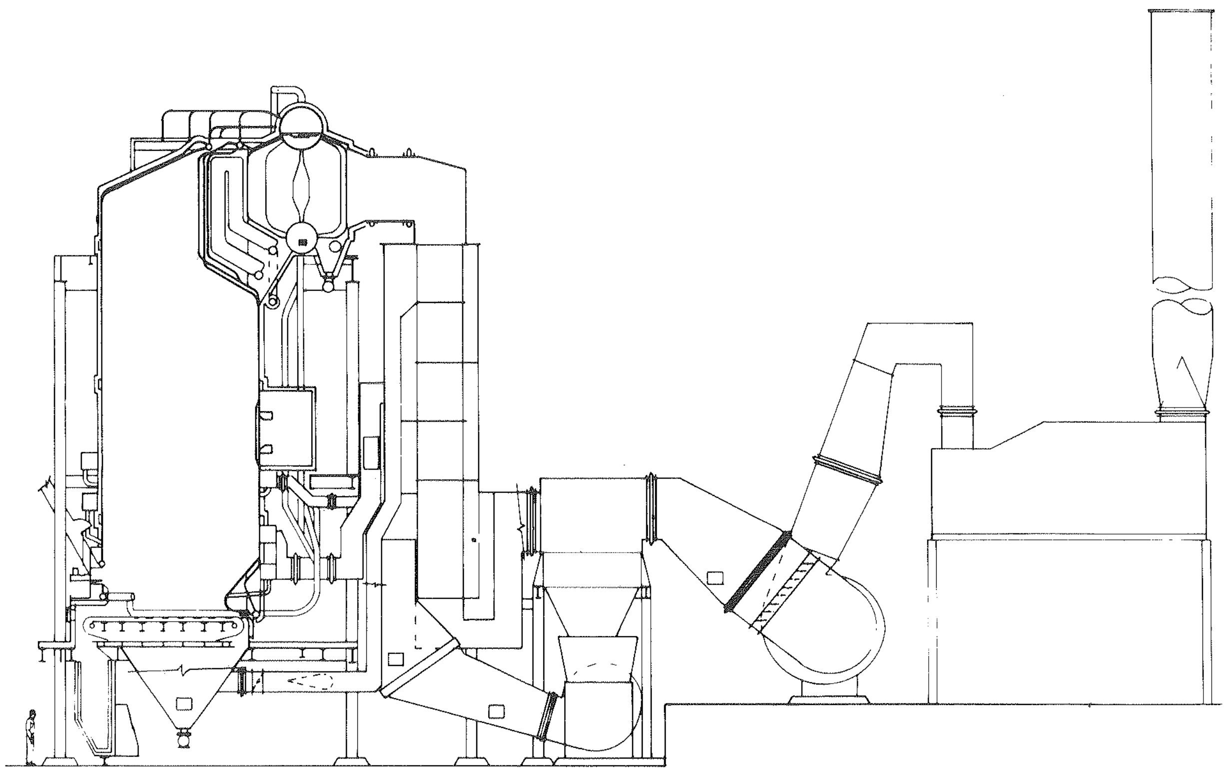

Figure 12 Sectional Side Elevation,
Shop Assembled Modular Spreader Stoker Boiler Firing Wood

Riley VR Boiler

As a complementing unit to the Riley Shop Assembled Modular Boiler, the VR Boiler is available in capacities up to 226,796 kg (500,000 pounds) of steam per hour at 12,066 KPa (1,750 psig) design and 510°C (950°F) superheat. It is a field-erected industrial boiler designed for stoker firing of coal or cellulose fuels. Standardization is the unique feature of the VR boiler. Basic design characteristics including customized economizer, air heater and super heater where required and major auxiliaries are completed on computer-generated drawings. A view of the VR Boiler is shown in Figure 13.

Multi-flex Feeder

For application where coal and wood are burned on a traveling grate and because of the density differences of the fuel, they should be conveyed through separate feed and spreading systems for optimum fuel distribution. A recent new Riley product offering is the Multi-flex combination Coal Feeder/Cellulose Distributor which provides for separate conveying and spreading in a single feeder. An illustration of this feeder is shown in Figure 14. This feeder has been installed and is operating at Molokai Electric in Hawaii.

Improved Water-Cooled Grate Design

Water-cooled grates are used for low ash, clean fuels. Grate cleaning is accomplished by steam jets periodically blowing down the slope of the grate to remove accumulated ashes. This is an option to the Riley traveling grate shown in Figure 17.

A recently improved design for more efficient and reliable steam cleaning systems has been tested. The separate stainless steel cleaning nozzle shown in Figure 16 provides better control over the grate cleaning pattern and eliminates grate block failure due to thermal shock and steam pressure stresses associated with integrally cast steam nozzles (Figure 15).

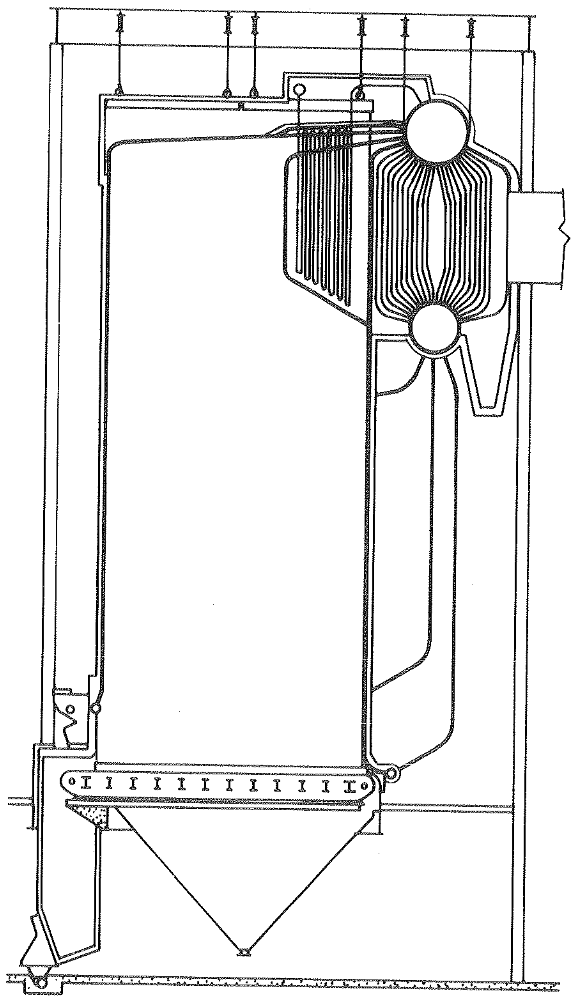

Figure 13 Riley VR Boiler

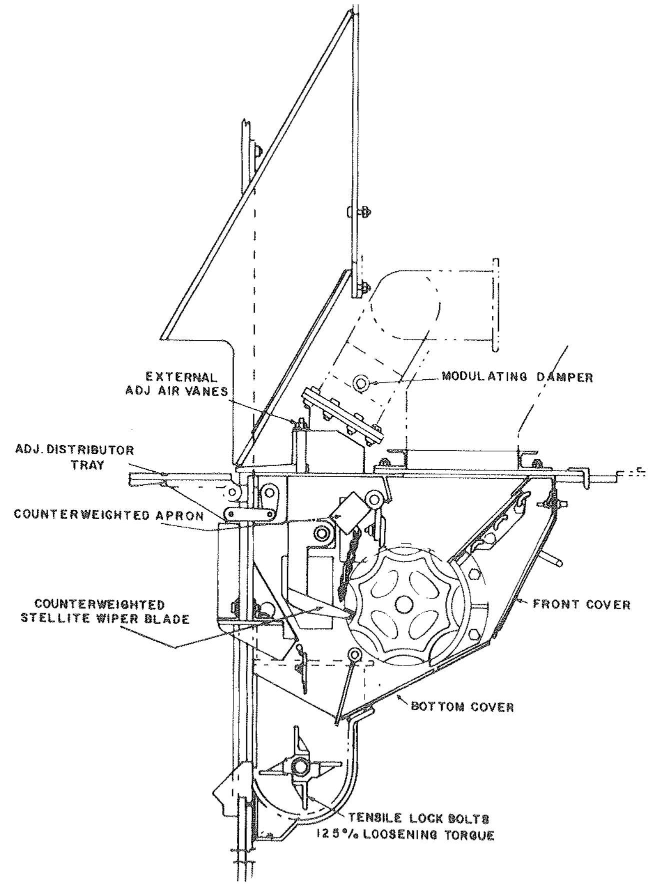

Figure 14 Riley Multiflex, Combination Coal Feeder, Cellulose Distributor

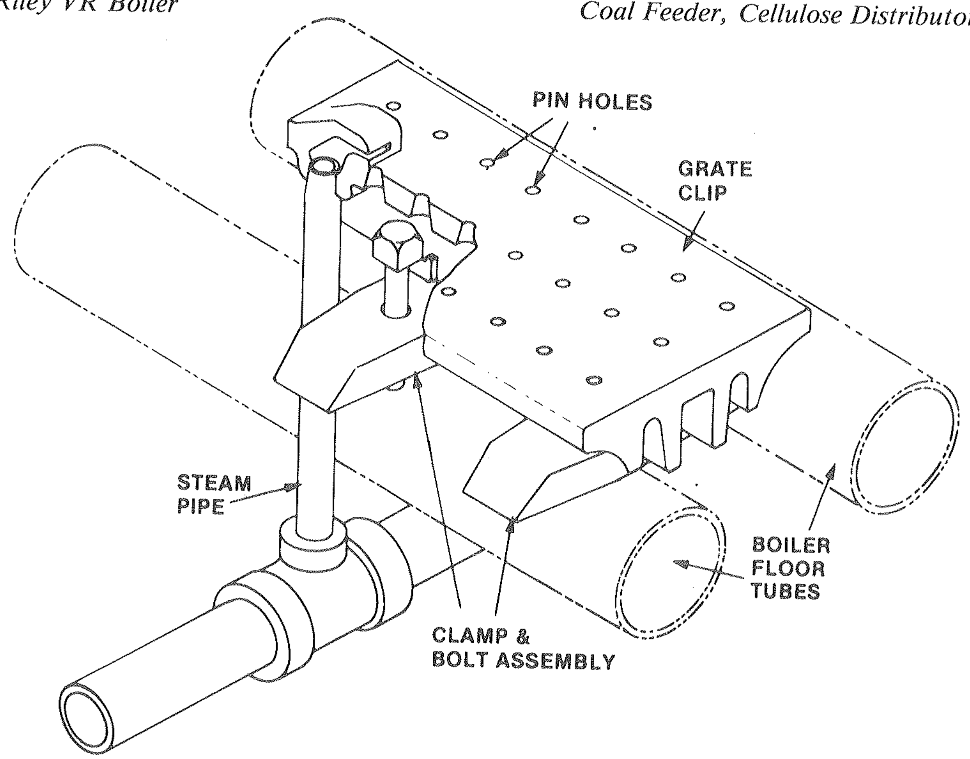

Figure 15 Water-Cooled Grate Clip With Integrally Cast Steam Jet Nozzle

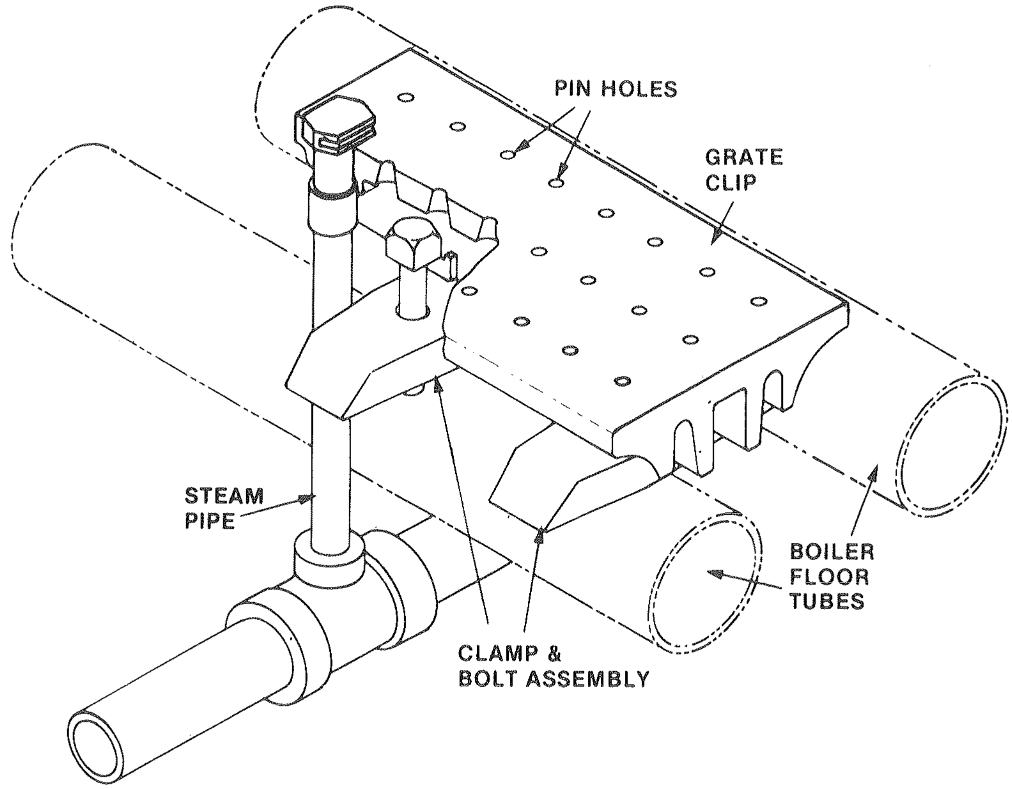

Figure 16 Water Cooled Grate Clip With Stainless Steel Steam Jet Nozzle

Figure 17 Shop Assembled, Modular Riley Traveling Grate

CONCLUSIONS

As energy costs continue to rise, waste burning applications will increase. With the downturn in the utility market sector, Riley Stoker as well as other boiler manufacturers will continue to place greater engineering and marketing emphasis on industrial boilers, including waste burning applications. This will include new product developments such as discussed in this paper, as well as expanded product lines and products with cost economy in mind.

The technological experience is presently available, as shown here by the diversified applications and many years of waste burning experience. Initial design effort is important, given the individualized characteristics of waste fuels, to assure proper operating performance and long life from fuel burning and boiler components.