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Presented at
POWER-GEN '99 International
New Orleans, Louisiana
November 30 - December 2, 1999

RST-159

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ABSTRACT

With the advent of enhanced petroleum refining technologies, a new class of refinery byproducts, generically referred to as asphalts, are available for use as steam generator fuels. The composition and properties of asphalt fuels dictate the need for special handling and design considerations in terms of both the combustion and boiler systems.

This paper presents an overview of asphalt fuel characteristics as well as some of the combustion and boiler system design considerations necessary for successful utilization of residual asphalt fuels in steam generators. Field experience obtained from two European installations is presented.

INTRODUCTION

Steam generators within and in close proximity to petroleum refineries are typically fueled with the byproduct streams from the various refining processes. As such, these boilers and their associated firing systems must be designed for a large range of fuel compositions and quality. Economic pressures over the last two decades have forced the petroleum refining industry to develop enhanced refining processes in order to maximize the yield of high revenue product streams.

With the improvement in refining capability, the quality of residual byproduct streams available as fuel for the refinery power boilers and steam generators has decreased dramatically, presenting boiler and firing systems designers with significant challenges. The lowest quality streams can have a variety of names based on the specific refining process from which they are generated, but can be generally referred to as asphalts. One of the most

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distinguishing characteristics of asphalt fuels is that they typically must be heated to temperatures in excess of 300°F (150°C) to ensure that they can be pumped and in excess of 500°F (260°C) for proper atomization. Under these extreme operating conditions, asphalt fuels have a high propensity for coking in the fuel delivery and combustion system components. In addition, these fuels can contain large amounts of carbon residue, fuel bound nitrogen, sulfur and heavy metals, which together make fuel handling, control of emissions and prevention of boiler related problems extremely challenging.

Combustion and boiler systems utilizing asphalt fuels have been designed, and successfully implemented in Europe by Babcock Borsig Power. This paper provides an overview of the fuel characteristics and design experience gained from these installations.

ASPHALT FUEL CHARACTERISTICS

As is the case with all petroleum derived fuels, the chemical and physical properties of asphalt can vary based on the crude oil source and the specific refining process from which it is generated. In comparison to normal heavy fuel oil, asphalt fuels typically contain increased amounts of sulfur, fuel bound nitrogen and heavy metals making control of corrosion and emissions challenging. However, high carbon residue content and/or asphaltine content combined with extremely high viscosity are the two most distinguishing characteristics of asphalt fuels and indicate that they are likely to be difficult to handle and burn. Table 1 provides a comparison of fuel characteristics for several residual fuels ranging from heavy fuel oil (HFO) to asphalt (HSC-R).

Carbon residue content can be determined by Conradson (ASTM D-189) or Ramsbottom (ASTMD-524) methods and is a relative indicator of the tendency of a fuel to coke under vaporizing conditions. Carbon residue values in excess of 15% indicate the potential for difficult combustion. Asphaltines are the heaviest fractions found in oil and are defined as the weight percent of asphalt sample insoluble in a solution of n-heptane (ASTM D-3279). Fuels having greater than 7-8% asphaltine content are generally considered difficult to burn. However, since combustion performance is a function of many different factors such as excess air level, fuel/air mixing, atomization quality, as well as fuel quality, no single fuel characteristic can accurately predict actual combustion performance.

Generally speaking, fuel oils are heated to a viscosity of 4500-9000 SSU (1000-2000 cSt) for pumping and 75-150 SSU (15-30 cSt) for atomizing. Figure 1 shows the viscosity vs. temperature profile for fuels shown in Table 1. It can be seen from these profiles that the fuel temperature for a given viscosity can vary substantially between HFO and asphalt fuels. In fact, the required temperature for atomizing HFO can be significantly less than the temperature required for pumping asphalt fuel, which can produce problems when multiple fuels are fired in the same firing system.

Fuels with high carbon residue and/or asphaltine content tend to produce higher levels of carbonaceous particulate matter. This tendency can be offset by operating at lower than normal viscosity levels to provide improved atomization and smaller droplet size. However, operating at lower than normal viscosity level with high viscosity fuels requires extremely high atomizing temperatures, which in turn tend to promote coking of the firing system. Special attention must be given to firing system design to ensure minimum particulate levels and minimal coking problems with asphalt fuels.

Table 1 Characteristics of Residual Fuels

	Unit	Residual Fuels			
		Heavy Fuel Oil	Visbreaker-Residue	Vacuum-Residue	HSC-R
Lower Heating Value	Btu/lb (MJ/kg)	17,325 (40.2)	17,070 (39.6)	17,240 (40.0)	16,680 (38.7)
Specific Gravity	20°C/4°C	0.955	1.02 - 1.04	1.01 - 1.02	1.06 - 1.07
Viscosity					
120°F/(50°C)	SSU (cSt)	1725 (380)			
212°F/(100°C)	SSU (cSt)	150 (32)	900 - 2700 (200 - 600)	3500 - 9000 (800 - 2000)	
300°F/(150°C)	SSU (cSt)		138 - 225 (29 - 50)	270 (60)	
500°F/(260°C)	SSU (cSt)				75 - 140 (15 - 30)
535°F/(280°C)	SSU (cSt)				60 - 75 (10 - 15)
Approx. Pumping Temperature	°F (C°)	95 (35)	165 - 195 (75 - 90)	200 - 230 (95 - 110)	290 - 380 (145 - 195)
Approx. Atomizing Temperature	°F (°C)	255 (125)	280 (195)	390 (200)	500 - 535 (260 - 280)
Flash Point	°F (°C)	280 - 390 (140 - 200)	335 -445 (170 - 230)		535 (280)
Ultimate Analysis					
C	%	85.0	86.5 - 87	85.5 - 86.0	87.0 - 87.5
H	%	11.0	9.3 - 9.8	10.1 - 10. 6	8.3 - 8.8
S	%	3.0	2.7 - 3.4	2.7 - 3.3	2.8 - 3.4
N	%	0.6	0.6 - 0.9	0.6 - 0.8	0.7 - 1.3
Ash	%	0.1	0.1	0.08	0.1
Vanadium	ppm	130 - 190	150 - 260	130 - 220	300 - 410
Nickel	ppm	60 - 90	50 - 90	75- 80	100 - 135
Conradson Carbon Residue	%	17	21.0 - 23.5	17 - 20	35 - 38

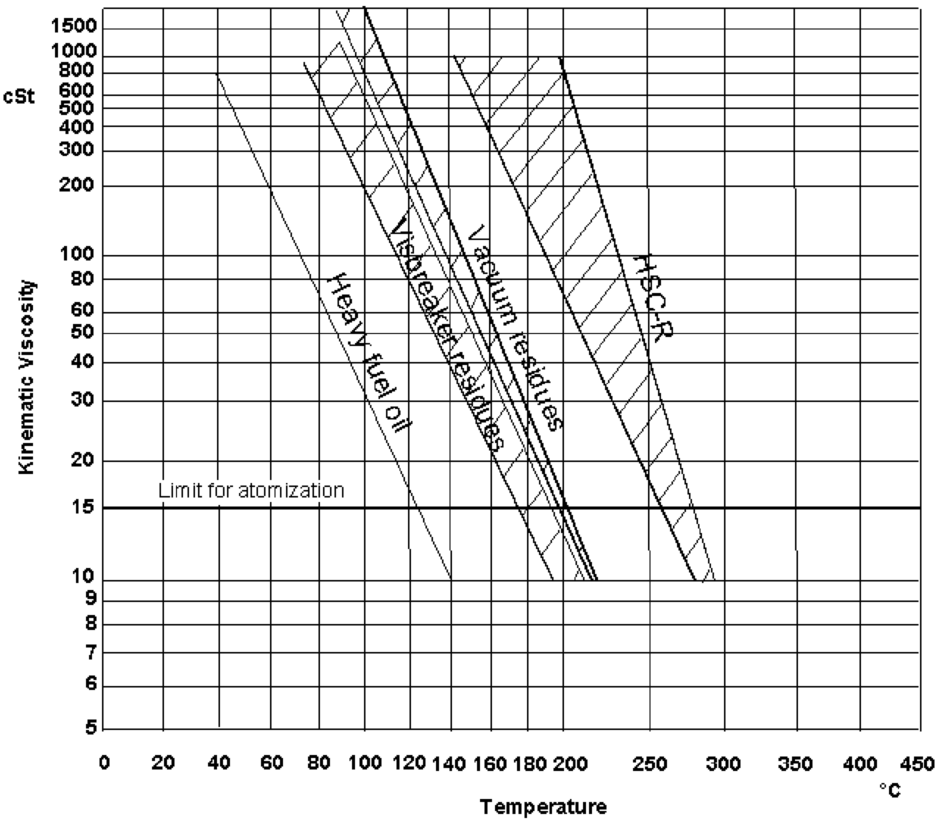

Figure 1 Viscosity vs. Temperature Profile for Residual Fuels (PCK/Schwedt)

EUROPEAN EXPERIENCE

DB Riley's parent company, Babcock Borsig Power, has successfully demonstrated retrofit and new boiler applications for asphalt fuels. Operations and data evaluation from these installations have confirmed the boiler and fuel burning design basis for firing this difficult fuel. A description of those projects follows:

Ingolstadt IV

This is a 400 MW Benson boiler design which saw original service in 1971 (See Figure 2). The unit was designed to fire oil, natural gas, and refinery gas in burners located on the furnace bottom (bottom fired boiler). Being a Benson design, the boiler is once through but subcritical. Final steam conditions are:

• Steam flow	2,750,000 lb/hr
• HP Steam pressure	2,700psig
• HP Steam temperature	995°F
• Reheat steam temperature	995°F

A two-phased retrofit approach was used on the Ingolstadt project. For Phase 1, the focus was on burner and fuel delivery system redesign to fire the asphalt fuel and operate within maximum plant NO_x emission guidelines. That value was 225ppm at 3% 0_2 and could be achieved up to a boiler operating load of 82% MCR.

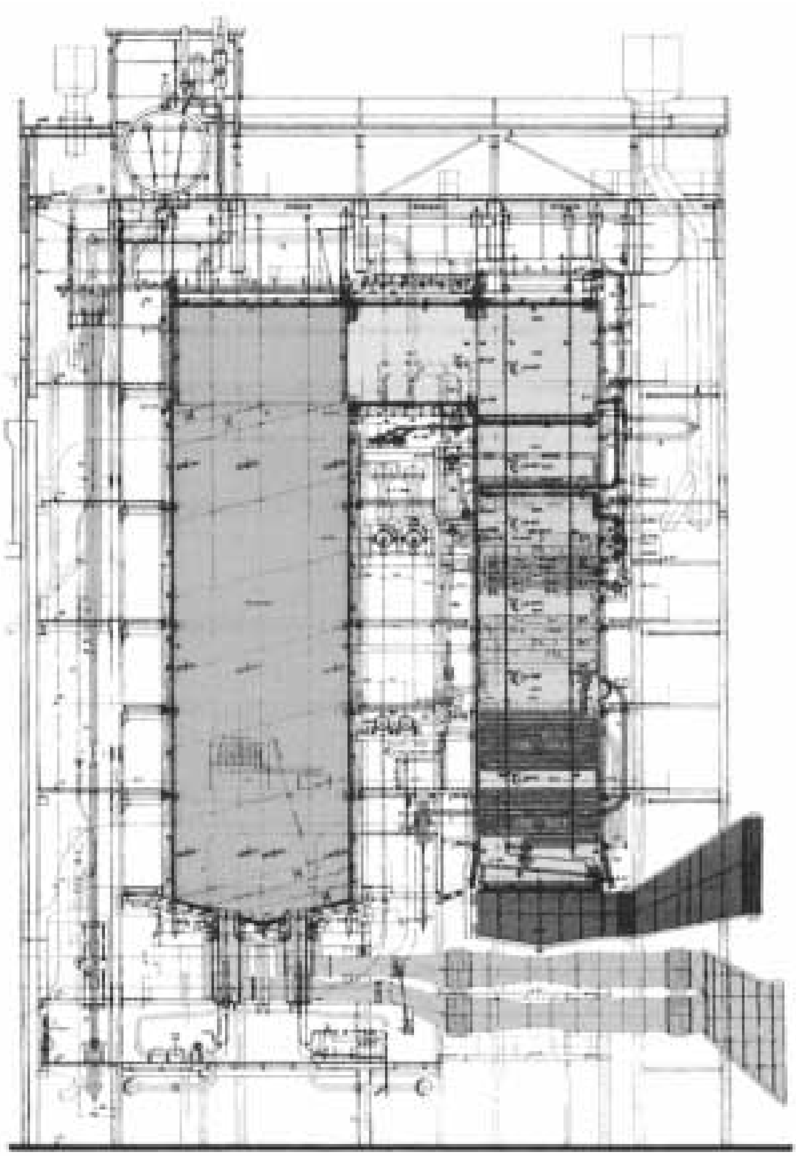

Figure 2 Ingolstadt IV 400 MW Retrofit

Phase 2 required extensive modifications to allow boiler operation at the original maximum continuous rating. Wet scrubbers, electrostatic precipitators and SCR were added to meet all environmental requirements.

No modifications were required on the boiler surfaces as a result of asphalt firing. Ferritic high chrome alloy materials were used in superheaters and reheaters and proved adequate. Additional convective pass soot blowers were installed because of the heavier dust/soot deposits.

Upon completion of Phase 1 and Phase 2, the retrofit was demonstrated to be extremely successful meeting all environmental and steaming conditions required and operating continuously on asphalt fuels.

Schwedt Power Plant

The PCK Raffinerie GmbH is a large oil processing facility in the town of Schwedt, Germany. Crude oil has been refined in the plant since 1964. Most of the crude oil processed is delivered from western Siberia through a 2,000 mile pipeline. Tanker facilities for unloading crude also exist at the refinery.

In the mid 90's, the refinery starting development of a new boiler project for power generation at the facility and for steam supply to the city for district heating during the winter.

Both CFB's and conventional boilers were considered with asphalt being the principal fuel. Asphalt produced at the plant was literally considered a waste product, so effective utilization of this fuel for energy would provide plant expansion requirements and eliminate costly disposal.

Although CFB technology was very attractive from a fuels flexibility standpoint, PCK elected conventional wall fired boiler designs because of the following advantages from their perspective:

- Less complicated
- PCK's experience was wall firing
- Lower power consumption
- More simple process control
- More rapid system response
- Lower maintenance
- Small use of refractory
- Smaller arrangement plot plan

Two identical boilers were purchased and startup was in 1998. The units were balanced draft designs and used low-NOx burners, SCR, electrostatic precipitators, and wet scrubbers for environmental control. The boiler MCR steam conditions were:

- Steam Flow 1,408,000 lb/hr
- Steam Pressure 1,310 psig
- Steam temperature 970ºF

Figure 3 shows a cross section of the tower type boiler design offered. Many European boiler manufacturers prefer tower designs for what they believe are better flue gas flow characteristics across heating surfaces. USA boiler designers believe the design to be costly and the technical performance merits too marginal when compared to two-pass boilers.

Because of the high fuel sulfur, vanadium, and sodium, the design of pressure parts was very critical to control tube metal temperatures to the lowest possible level. Parallel flow superheaters were used where possible to help keep metal temperatures low even at the detriment of optimal heat transfer.

In addition, two locations of superheater sprays were provided as added flexibility in controlling superheater metal temperature for widely varying operational conditions such as fouling or fuel combinations.

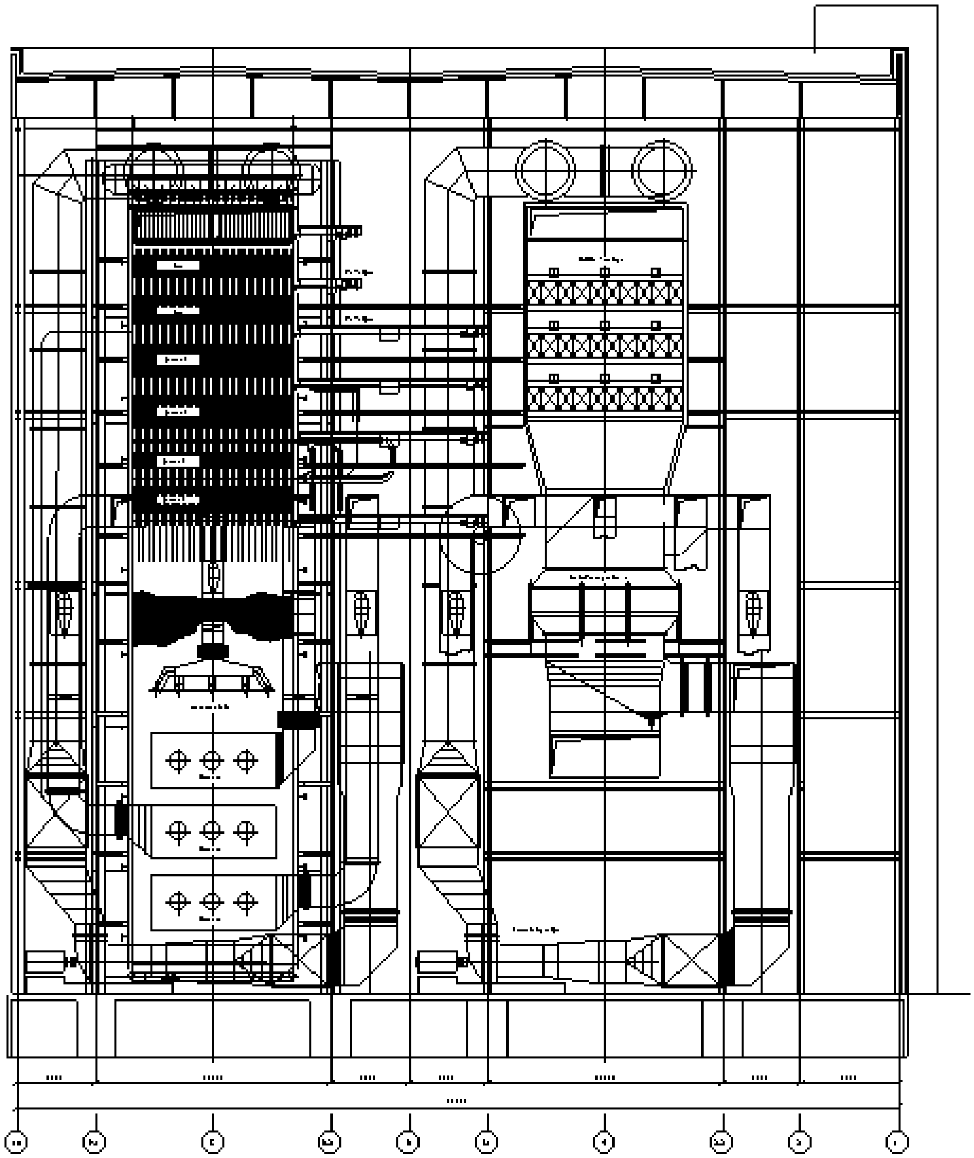

Figure 3 PCK Refinery, Schwedt Power Plant

Carbon steel and ferritic alloys were used for all pressure part tubing. It would be expected that for steam temperature designs higher than Schwedt, high chrome materials would be necessary to provide the corrosion resistance necessary for finishing superheaters and reheaters.

Fuel additives are not used with asphalt at Schwedt. Final steam temperature is controlled from 60% to 100% through the use of excess air.

Control of NO_X emissions with the combustion process was done with nine low-NO_X burners and a single level of overfire air, which will described in much more detail later.

Performance of the two boilers has been excellent. Predicted versus actual data are as follows:

		Predicted	Actual
1.	Steam Flow, lb/hr	1,408,000	1,420,000
2.	Steam Temp,°F	970	970
3.	Steam Pressure, psig	1,310	1,320
4.	Excess Air, %	10	9
5.	Airheater Exit Gas Temp., °F	355	315
6.	Boiler Efficiency, %	88.01	89.05
7.	Fuel Flow, lb/hr	91,376	90,300
8.	Fuel	Asphalt	Asphalt
9.	Steam Temp. Control	60%	57%
10.	Fuel HHV, Btu/lb	17,444	17,581

One of the ironic disappointments of early operation, from PCK's standpoint, has been the high boiler efficiency on asphalt firing. Since asphalt is a waste product, the plant relied on maximum incineration using these two boilers.

To combust more asphalt in the boilers, Babcock Borsig Power studied actual operation and confirmed substantial system and component margins. The boilers were re-rated to 1,540,000 pounds of steam per hour allowing 10% additional asphalt to be combusted. The only change needed to the boiler to accommodate the extra flow was increased safety valve relieving capacity.

Another aspect of Schwedt power plant operation that was somewhat unexpected was catalyst condition in the SCR. After two years service, the catalyst activity has literally increased from its original condition because of the high vanadium content of asphalt fuel.

PCK/SCHWEDT FIRING SYSTEM DESIGN ASPECTS AND RESULTS

Design Aspects

The power boilers at PCK/Schwedt are designed to fire a range of liquid fuels including Heavy Fuel Oil (HFO), Visbreaker Residue (VBR), Vacuum Residue (VR) and High Soaker Conversion Residue (HSC-R), with HSC-R being the design fuel. The viscosity vs. temperature profiles for these fuels are presented in Figure 1 (chemical and physical characteristics of these fuels are presented in Table 1). It is the design fuel, HSC-R, that falls into the classification of asphalt fuel and presents the greatest challenge in terms of fuel preparation and combustion. Initial NO_X and CO targets for the combustion system were set at 0.41 lb/10^6 Btu and 140 ppm at 3% O_2 (650 and 175 mg/Nm^3) respectively for all liquid fuels.

To control NOx emissions, the furnace is fitted with a separate OFA system consisting of five front wall ports located one burner elevation (approximately 15 feet) above the top burner row to control NO_X. Furnace stoichiometry is controlled to 0.95 with a final stoichiometry of 1.1 after the OFA ports. Each unit features nine low-NO_X burners arranged in a 3 x 3 matrix with separate windboxes for each elevation. Design burner draft loss is 10 iwc (25 mbar) for a combustion air temperature of 550°F (290°C). The burners are rated for a full load capacity of 160 10^6 Btu/hr each (46 MW) and feature total air slides for balancing as well as three separate air zones to control fuel/air mixing and NO_X formation in the burner near field. The middle elevation of burners is also designed to fire refinery gas when available. A cross sectional view of the burner is provided in Figure 4.

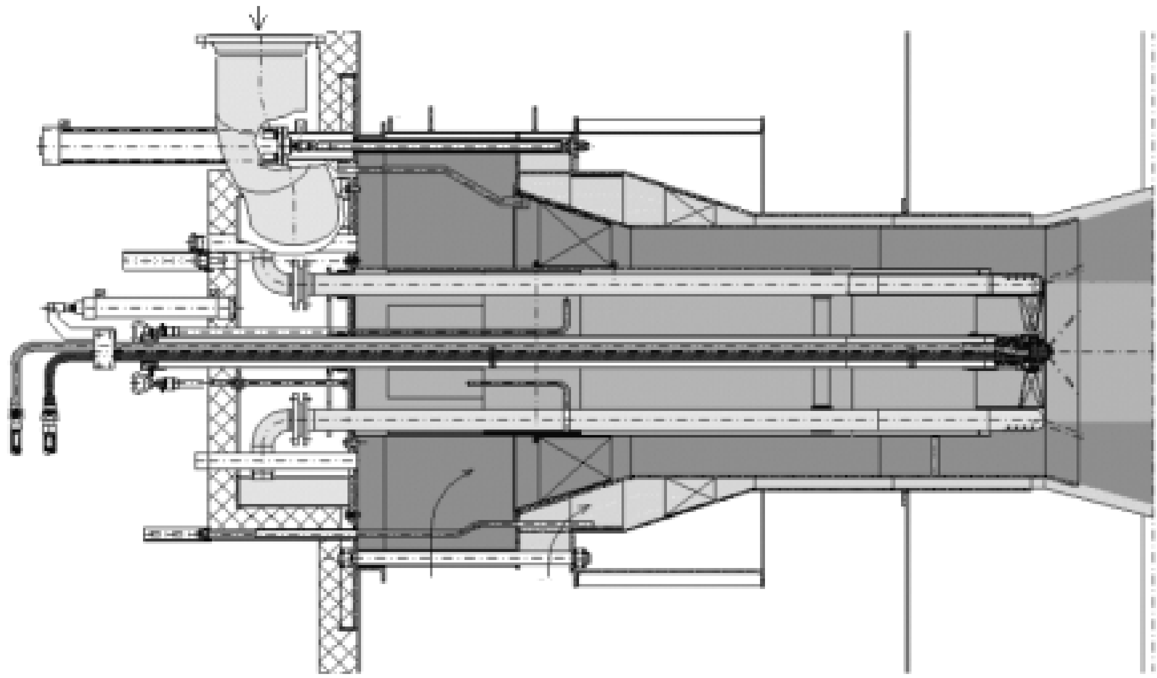

Figure 4 PCK/Schwedt Low-NO_X Burner

The liquid fuels are atomized using parallel tube, internal mix type atomizers with a design atomizing mass ratio of 6% at full load. The fuel and steam pressure is operated in a cross over mode with design pressures of 100 and 115 psig (7 and 8 barg) at full load respectively. The atomizers are designed for a viscosity of 75 SSU (15 cSt), which translates to a supply temperature of 500 - 535°F (260 - 280°C) for the HSC-R fuel. This fuel has a tendency to coke not only at high temperature but also at low pressure. The liquid fuel trains incorporate the following design features to ensure proper fuel preparation without coking:

- operation of oil heaters based on viscosity control rather than temperature control to ensure lowest possible fuel temperature while maintaining optimum atomization,
- installation of individual oil heaters at each burner to ensure shortest possible fuel residence time at high temperature, and
- installation of individual oil flow control valves at each burner to ensure shortest possible fuel residence time at low pressure.

In addition, progressive fuel sequencing is employed (i.e., HFO → VBR or VR → HSC-R at start up and the reverse order during shutdown) to avoid the possibility of low temperature HFO coming in contact with residual amounts of HSC-R and causing solidification. Removal of all HSC-R fuel from the valve trains is imperative because it cannot be liquefied once it has solidified. The fuel train is designed such that one burner on each boiler can burn slop oil when a unit is taken off line. The fuel trains are also configured such that change over from one fuel to another can be done on individual burners, which provides a high degree of operational flexibility.

Results

The combustion system demonstrated the capability of successfully firing the range of design fuels. Numerous atomizer tip configurations were tested with varying effects on emissions. Burner air biasing by elevation also provided a slight reduction in overall NO_X emissions with a corresponding increase in CO emissions. Figure 5 shows the effect of excess air on NO_X and CO emissions at full load when firing the HSC-R fuel under optimized conditions. Although the data shows a fair amount of scatter, it confirms that the NO_X and

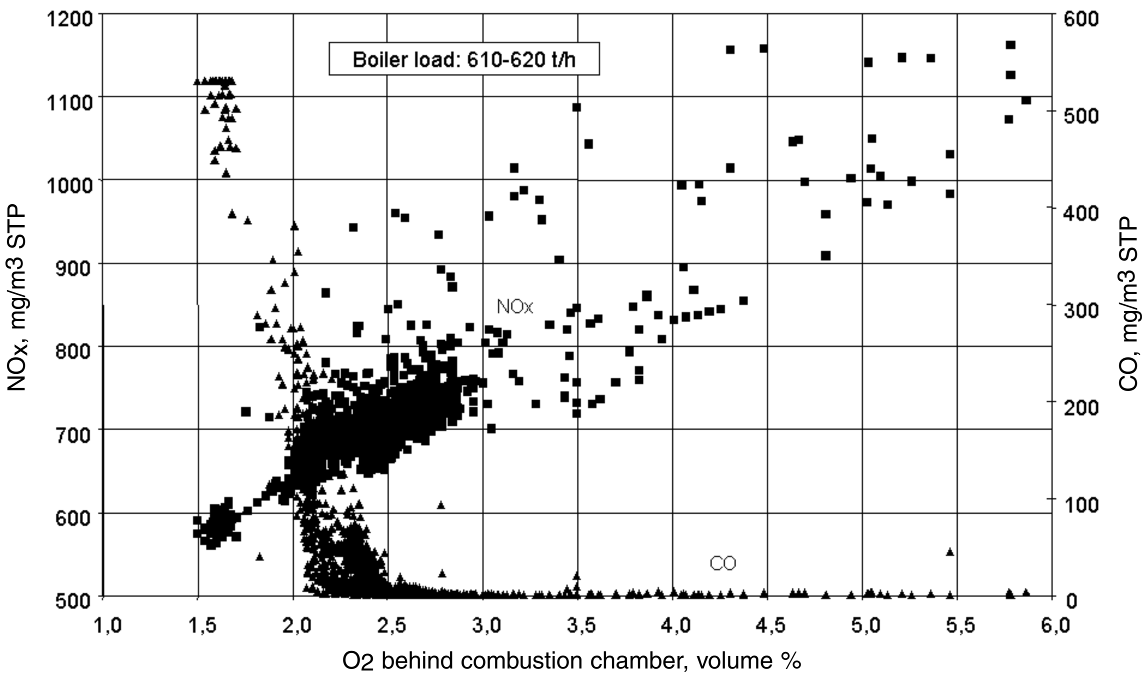

Figure 5 PCK/Schwedt NO_X and CO vs. O_2 at Full Load Firing HSC-R

CO targets can be met simultaneously when reasonable care is exercised in establishing operating conditions. Figure 6 shows NO_X, CO, and O_2 variation over the boiler load range following the 10% boiler uprate condition.

The atomizers were later redesigned to accommodate coke particles in the fuel supply up to 0.20 inch (5 mm) in diameter, which resulted in a NO_X increase of 25-30%.

Boiler Design Consideration

Babcock Borsig Power design expertise on asphalt firing is now being used by DB Riley for proposals on new boilers from 250 to 500 MW in size.

One such design is shown in Figure 7. The unit is a typical oil fired design utilizing the so called "box" arrangement . Burners are all located on the front wall of the furnace. The unit is a 2,400 psig design using superheat and reheat for 1005 ºF final steam temperature. Steam temperature is controlled by means of gas recirculation introduced through the furnace bottom. Specific boiler design parameters developed for asphalt firing and used for this proposal are shown in Table 2.

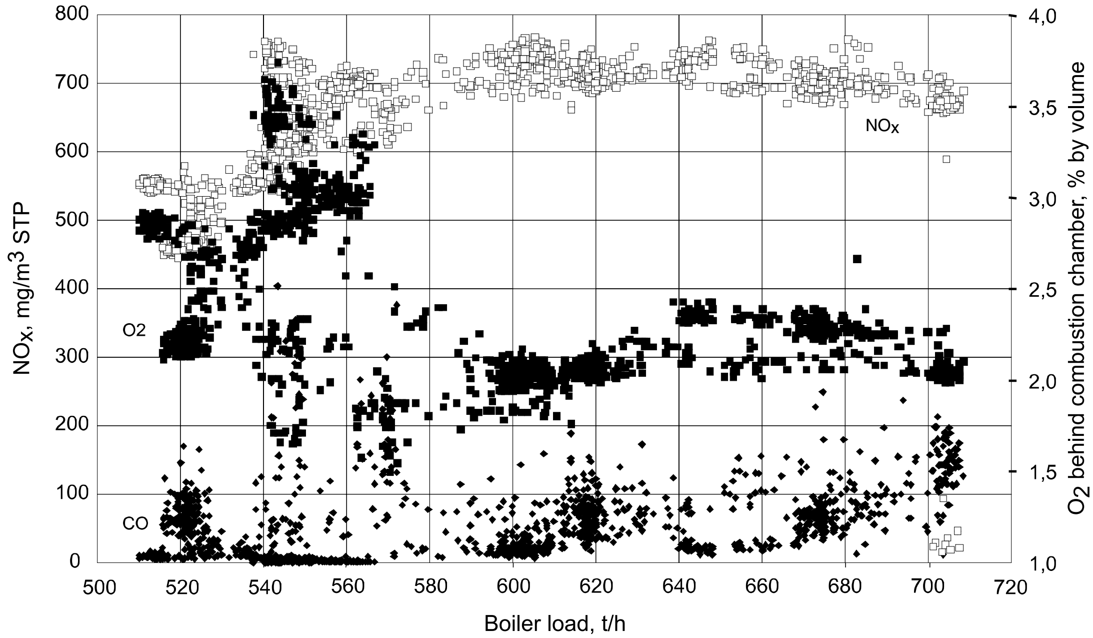

Figure 6 PCK/Schwedt NO_X, CO and O_2 vs. Boiler Load Firing HSC-R

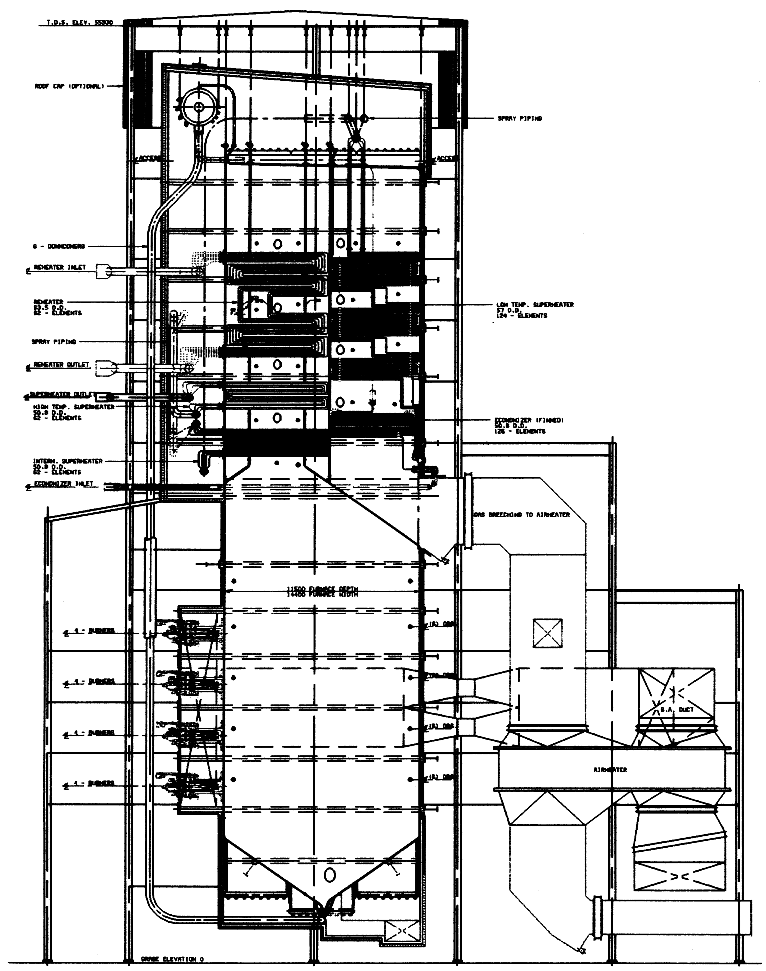

Figure 7 550 MW Design

Table 2 Design Parameters for Asphalt

1.	Furnace Area Heat Release	150-170,000 Btu/hr/ft^2
2.	Furnace Volume Heat Release	15-17,000 Btu/hr/ft^3
3.	Furnace Gas Retention Time	1.75 sec. Min.
4.	Need For Additives	Yes For 1005°F Steam Temp.
5.	Tube Materials	Below 970ºF Ferritic, Above 970ºF Austenitic
6.	Convection Surface Arrangement	Parallel Flow In HTSH and HTRH
7.	Soot Blowers	Upper Furnace and Convection Passes
8.	FEGT	2300ºF - 2400ºF max.
9.	Steam Temperature Control	Gas Recirculation and Spray
10.	Furnace refractory	None
11.	Arrangement	Two Pass, Box
12.	Cold End Protection	Yes, 235ºF, CET
13.	Finned Surface	Yes, But Inline
14.	Combustion NO_X Control	OFA, GR, LNB
15.	Airheater Exit Gas Temp.	310ºF - 330ºF
16.	Excess Air	8 to 10%

Conclusions

Conventional flat walled furnace systems have been demonstrated both on retrofit and new boiler applications for firing of asphalt fuels.

Burning of asphalt requires individual burner control of viscosity and stringent attention to operational parameters at the burners.

Boiler designs for asphalt must consider the highly corrosive aspects of the combustion products. Low tube metal temperature, the use of fuel additives, proper tube material selections, and good surface cleaning capabilities will result in installations performing excellently on this difficult fuel.

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