CONSISTENT COKE QUALITY FROM SUN COKE COMPANY'S HEAT RECOVERY COKEMAKING TECHNOLOGY

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Summary: Sun Coke Company's heat recovery coke technology has been continuously improved over its 40 years of development. All of the improvements that have been made have been directed at three criteria that are essential to good blast furnace operations, namely; (1). Coke Quality, (2). Coke Quality Consistency, and (3). Coke Supply Reliability. This paper will give basic background information about the technology, its development, and specific data about coke quality, consistency, and reliability. Data will be presented from both of Sun Coke's operating plants which together produce 2 million tons per year of blast furnace coke.

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Introduction

The Sun Coke heat recovery coke making technology has been developed over the last 41 years. The objectives of this presentation are to provide you with a basic understanding of the technology, its operation, and the benefits of this method of coke making.

Technology Development History

□ The 1960s

The first ovens built were in 1960 (see Figure 1). Three test ovens were built at Vansant VA., to determine if local Southwestern Virginia coals could be used to make suitable blast furnace coke. The results from this four month test oven operation were successful and an aggressive oven building program was initiated. By 1963, 250 Mitchell type non-recovery ovens were in production, producing 250,000 tons per year (TPY) (see Figure 2). Several technical advances were made on the initial 250 oven plant including but not limited to: (1)

- □ Automated tripper belt system for charge coal delivery
- □ Hot coke pushing, & external oven coke quenching
- □ Mitchell ovens at Vansant were 15% larger than conventional Mitchell ovens
- □ One piece oven door, handled hydraulically
- □ Refractory sill plates in place of cast iron

Because of the success of the produced coke in blast furnaces, additional Mitchell ovens were built throughout the late 1960s until a total of 527 were in operation producing over 500,000 TPY.

□THE 1970s

During the late 1960s and early 1970s, test ovens were built incorporating sole flue systems and after burner chambers (stacks). These two advancements led to higher oven production and substantially eliminated air pollution emissions. In 1972, 16 large Jewell-Thompson ovens were built for production tests. While the Mitchell ovens had inside coking chamber dimensions of 6 Ft wide X 34 Ft long, the newer Jewell-Thompson ovens had inside coking chamber dimensions of 11 Ft wide X 55 Ft long. With the larger coking chamber, sole flue system and higher natural draft, the newer Jewell-Thompson ovens could produce over 5000 TPY per oven compared to the Mitchell oven production of 1000 TPY per oven. During the 1970s maximum coke production was paramount. Ovens were operated at very high (2900-3000□F) temperatures with little regard for coke quality and oven life. It should be noted during these times of high production, the machinery that supports the coke oven operations was refined and pushed to its limits. The machinery includes the pusher/charger machine (PCM), the coke guide/utility car and the hot car/quench system. During this period the machinery design was perfected, especially since each oven was pushed and charged every 24 hours.

□THE 1980s

The technological advancements of the 1980s can best be characterized by (a) improved combustion control (b) enhanced coke quality and (c) improved oven construction techniques. All of these improvements led to lower air emission (best in the industry), improved coke quality (going from 25th out of 26 to near No. 1), and lower oven repair costs. The advances made during the early 1980s culminated in 1988-1989 with total oven temperature control through continuous temperature modulation, and finally with the advent of the 48 hour coking cycle.

□THE 1990s

Although the technological advancements made during the 1990s do not appear to be as significant as the 1980s, when taken in total, the advancements of the 1990s have led to a mature, robust coke oven technology that was poised to take its place on the world market. The full impact of the fine tuning of the Sun Coke Heat Recovery Oven (HRO) technology is best demonstrated in Figures 3, 4, 5, and 6. Noteworthy is that even as the Sun Coke (HRO) technology was achieving world class recognition regarding capital cost efficiency, operating cost efficiency, and coke quality, in 1990 it was designated as Maximum Achievable Control Technology (MACT) for coke making, by the US Environmental Protection Agency. When taken in total, these attributes lead to the decision of Inland Steel (now Ispat-Inland) to contract with Sun Coke to build and operate a 1.3 million TPY coke plant to service Inlands coke needs at Indiana Harbor. Sun Coke currently operates two plants, one at Vansant VA producing 700,000 TPY (Figure 7) and one at Indiana Harbor producing 1.3 million TPY (Figure 8). Current plans are to build and operate on-site or merchant plants at appropriate locations throughout the world.

□The Future (2000 to 2010)

The Sun Coke HRO Technology is obviously mature as evidenced by the successes detailed above. Sun Coke Company has a very active ongoing technology development plan. The Sun Coke Company currently has five U.S. and International patents in force covering the HRO technology and has filed three (US and International) patent applications over the last 1 ½ years.

Technology development projects include:

- □ Stamp charging for use of lower quality coals (Completed)
- □ Oven modifications for increased oven throughput (Completed)
- □ Per oven yield enhancements (On-Going)
- □ CSR enhancement (On-Going)

The Sun Coke Company is firmly committed to assisting steel production facilities world wide in the production of the highest quality steel at the lowest possible cost.

Process Description

The basic processes at both the Jewell Coal and Coke (JCC) Plant and the Indiana Harbor Coke Company (IHCC) Plant are identical. The only major difference is that at IHCC the waste heat is recovered in waste heat boilers, electricity is generated, and the coke oven flue gas is dry scrubbed for SO_2 removal. At JCC some waste heat is used directly in a thermal coal dryer, but most is vented to the atmosphere. It should be noted that the original oven design was developed to operate under natural draft (no heat recovery). This design feature is useful in heat recovery plants because if a boiler has to be taken out of service, the bypass stack can be opened and the ovens can continue to operate under natural draft. The basic process description presented below is for the 1.3 million TPY IHCC plant.

PROCESS DESCRIPTION

A detailed inventory of the plant equipment is shown in Table 1, and an overall description is presented below.

Each oven chamber can accept a coal charge of 45 T. The current nominal charge is 43-44 T and the cycle time is 48 hours. The pushing/charging machine (PCM) is different than a conventional pusher or charger machine in that it includes the functions of both, in a single machine.

To push the oven, the pushing ram is spotted in front of the oven to be pushed, the manual door latches are released, the door is then lifted above the ram by hydraulic cylinders and the ram enters the oven.

At the same time a utility car operator removes the coke side door, spots up the coke guide and calls out the oven is ready to be pushed. The utility cars are electric powered hydraulic drive units, one unit for each battery.

The hot cars that receive the hot coke are powered by 45 ton diesel locomotives modified to fit the coke side track and quench stations at the facility.

The hot coke is received in the hot car and carried to the quench stations. The station utilizes conventional quench sprays designed to fit the hot car to maximize the even distribution of the quench water. The coke is dumped in specific locations to provide maximum residence time. There are two wharves in the facility, one for each row of batteries. The wharves are connected to a central conveyor system that delivers the coke to the screening station.

Oven charging is accomplished by replacing the coke side door, and spotting the PCM in front of the recently pushed oven. Simultaneously, charge coal is metered onto the coal conveyor tripper belt at a rate of 1200 TPH. A false door is extended into the oven opening below the

PROCESS DESCRIPTION (continued)

charging conveyor to eliminate coal spillage. As the charge coal is received at the PCM machine, the leveling conveyor begins to convey coal into the empty oven. The leveling conveyor is a water cooled, hydraulically driven flight conveyor that moves into the oven as the coal is received. The leveling conveyor actually transfers coal to the leading edge of itself and the conveyor rides on top of the charge coal bed that has been laid down. Once the entire coal charge bed is laid down, the leveling conveyor is retracted from the oven, the pusher side door is replaced and the coking process is started. There are two inherent advantages of this charging method when compared to by-product oven charging methods. The leveling conveyor action provides some coal compaction such that charge coal bed bulk densities are higher and the coal bed is very level.

OVEN OPERATION

Process control of the Sun Coke HRO is accomplished by:

- ☐ Monitoring crown temperature
- ☐ Monitoring sole flue temperatures
- ☐ Adjusting sole flue induced air ports
- ☐ Adjusting door induced air ports, and
- ☐ Adjusting flue gas uptake dampers

This monitoring and control is accomplished by a coke oven operator (burner) and the temperature monitoring and uptake damper position DCS system. (2) A burner can easily control over 70 ovens. Temperature monitoring/damper movements are controlled from a centralized control room. Manual adjustments to the induced air ports are made during regularly scheduled once every four hours "walk around". (3) These adjustments are very predictable and repeatable since every oven is operated on a 48-hour cycle. The repeatable variation in coal gassing rate and hence induced air requirements are shown in Table 2. The temperature profile for an individual oven as a result of gassing rate variation and appropriate burner adjustments is also very repeatable. The DCS data collection system not only monitors instantaneous temperatures but also calculates an average temperature throughout the cycle. Several schematic views of the Sun Coke HRO System are presented in Figures 9, 10, 11, and 12, which will help the reader understand the oven operational aspects. Shown in Figure 13 are the typical crown and sole flue temperatures throughout a 48 hour cycle.

Relationships between coal blends and coke qualities

During the last decade, upwards of 30 different coal blends have been tested and/or used in coke production in Sun Coke's Heat Recovery Ovens. Presented in Tables 3 and 4 are coal blend properties and resultant coke quality for 24 individual blends. These blends constitute a wide variety of test coals with the volatile matter (VM) ranging from 19% to 31%, numbers of coals in blend ranging from one (single seam tests) to seven (7 coal blend), and reflectance values ranging from 1.09 to 1.65.

Relationships between coal blends and coke quality (continued)

Oven operating parameters were fairly consistent for all tests with the exception of the single seam low volatile coal tests. All tests were conducted following standardized production procedures including charging technique, oven temperature control practices, and pushing and quenching procedures. A more thorough discussion regarding each test is presented in references (3), (4), and (5).

The coke quality parameters presented in Table 4 show high values for stability, CSR and size. Excluding single seam tests, the coke stabilities range from 61.0 to 66.9 and CSR values range from 61.9 to 71.8. Coke size for all the tests (excluding single seam coal tests) show somewhat more test to test variability with +2" values ranging from 33% to 70%. Note that coke size parameters (+2", and mean size) are for coke that has been crushed (top size either 3" or 4") and screened (bottom size either 3/4" or 1").

Based on the data presented in Tables 3 and 4 and outside research (6) (7) several general trends regarding coke produced by the Heat Recovery Process are evident as listed below:

(a) The actual coke stability is greater than predicted coke stability from industry recognized coke stability models.
(b) The actual coke CSR values are substantially greater than predicted coke CSR values from industry recognized CSR models.
(c) The actual coke stabilities for heat recovery coke are consistently greater than coke stabilities produced in either slot type recovery ovens or movable wall test ovens.
(d) The actual coke CSR values for heat recovery coke are consistently greater than coke CSR values from slot type recovery ovens and movable wall test ovens.
(e) Both the coke mean size and the coke +2" size percentage for the heat recovery coke are greater than the coke produced in either slot type by-product ovens or movable wall test ovens.

Several theories and some scientific data are available to explain the enhanced quality of heat recovery coke.

CSR: H.S. Valia states "The interactions among the various coal parameters and their combined influence on CSR are complex but it appears that coal rheology, rank, sulfur and ash chemistry are of greatest importance" (8). The German research group DMT (6) has studied the carbon forms, most notably pyrolytic carbon deposition in by-product coke and heat recovery coke and has concluded that, there is a significantly higher amount of pyrolytic carbon deposition in heat recovery coke which inherently increases the CSR value of heat recovery coke compared to by-product coke. Intuitively this theory makes sense because in the heat recovery process, the maximum coke bed depth and hence the bed gas path length is over two times as long as the bed gas path length in thin bed by-product ovens. Other factors such as coal bed bulk density homogeniaty in the heat recovery process as well as resultant average cell wall

CSR (continued)

thickness, porosity, pore size and fissuring may also explain the phenomenon of enhanced CSR in heat recovery coke.

STABILITY: It is generally recognized that coal blend petrography is the dominant factor in determining coke cold strength (stability).

As mentioned previously, heat recovery coke appears to have higher stabilities than equivalent coals coked in by-product ovens. The underlying inherent process conditions that lead to enhanced coke stability in heat recovery coke are not well understood at this time. Several researchers have postulated that the higher stabilities may be due to:

(a) More uniform spatial temperature distribution
(b) Slower coking rate
(c) Longer time at high temperature
(d) Less macro-fissuring
(e) More complete wetting in the plastic zone and hence improved carbon forms, and thicker cell walls
(f) Allowance for coal/coke bed expansion
(g) Higher and more consistent charge coal bulk density throughout the entire coal bed

COKE SIZE: One of the most dramatic features of heat recovery coke is its size and shape (prior to crushing and screening). When viewed on the wharf, heat recovery coke is noticeably larger, blockier, and has a greater length to width aspect ratio compared to by-product slot oven coke. Several outside researchers and end users (7), (9) have commented on the physical attributes of heat recovery coke.

While there are many factors that contribute to coke size, it is safe to say that all other things being equal, a deep (40-44") coal bed with consistent charge coal size distribution and consistent charge coal bulk density will inherently make larger coke than a thin (18") coal bed with macro-variations in coal size and bulk density. Ongoing internal research is continuing to determine the actual controlling parameters.

COKE CONSISTENCY: Notwithstanding the absolute coke quality parameters as outlined above, the blast furnace operator especially values coke quality consistency for long term maximum blast furnace production. Sun Coke recognizes this need and pays attention to those details that lead to consistent coke quality, namely:

(a) Coal Blend Selection
(b) Coal Blending and Pulverization
(c) Consistent Oven Operations
(d) Consistent Quenching
(f) Coke Crushing and Screening Operations

COKE CONSISTENCY (continued)

By way of example, pertinent long term coke quality parameters and production levels for the IHCC plant are shown in Figures 14, 15, 16, and 17.

The monthly coke production for 31 months (July 98-January 01 inclusive) is shown in Figure 14. The monthly production data are for furnace coke normalized to 4.5% moisture. The data will show that the IHCC plant was able to achieve production rates in excess of 100,000 tons/month within six months of start-up, and has consistently achieved an annual production rate in excess of 1.3m TPY over the last 17 months.

In addition to achieving high production levels, high and consistent coke quality parameters have been met. Shown in Figures 15, 16, and 17 are weekly average coke quality parameters, for the past 31 months. Also shown in Figures 15, 16, and 17 are the times when coal blend changes and coal pulverization changes were made. Inspection of these data show that for the last 31 months, in spite of plant startup, coal blend changes and pulverization changes, the coke quality for all coke quality parameters has been high and consistent. Over the 31 month period, coke ash values have averaged 8.6% with a minimum of 8.12% and a maximum of 9.78% while sulfur levels have averaged 0.56% and minimum and maximum values of 0.50% and 0.66% respectively. During the same period, coke VM has averaged 0.42% and ranging from 0.25% to 0.60%. The mean coke size has averaged 54mm (2.13 inches) with a range of 51mm (2.0 inches) to 61mm (2.4 inches). Coke CSR values have averaged 69.8 with a range from 67.4 to 71.6, while stability has averaged 61.9 and a minimum and maximum of 58 and 64 respectively. It should be noted that the lower stability cokes occured during a period when there was poor charge coal pulverization (i.e. minus 1/8" of 60 to 65%), see Figure 17.

- Seven different coal blends have been used over the past 31 months
- Coal blends have had as few as three coals and as many as six coals
- No non-coal additives (such as pet coke, coke breeze, etc.) have been used
- Blends have been made up using Eastern U.S. coals, Southern U.S. coals, Midwestern U.S. coals, and Canadian coals
- A wide range of coal blends has been used as is shown in Table 5.

In summary, it is fair to say that even with a wide variation in coal blend properties, that the IHCC plant has achieved excellent production and coke quality throughout the past 31 months of operation.

At the end of the day, the real proof of the coke produced lies in the performance of the blast furnace. The reader is directed to an excellent paper (9) regarding blast furnace performance utilizing heat recovery coke. This paper details the transition of Ispat-Inland's No.7 blast furnace from conventional to heat recovery coke. One salient point in the paper is that the No.7 blast furnace achieved a North American record tonnage in the 4^{th} quarter of 1999 while operating on 100% heat recovery coke.

Material and Energy Balance

By way of example, a simplified block flow diagram for the IHCC plant is presented in Figure 18. This figure shows the overall material and energy flows from coal recieving, coke making and energy production. A more detailed schematic diagram is shown in Figure 19. This diagram shows a more detailed view of major process streams for the 1.33 million TPY furnace coke facility, including the 94 MW's of power production and the 100,000 to 500,000 lb/hr of export steam.

ENVIRONMENTAL CONSIDERATIONS:

Waste Water: There are no waste water discharges from a Sun Coke Heat Recovery Plant. The plant is a net water consumer with machine cooling water reused to provide quench water.

Solid Wastes: There are no hazardous solid wastes or sludges from a Sun Coke Heat Recovery Plant. The only solid waste is non-hazardous $CaSO_4/CaSO_3$ from the spray dryer flue gas de-sulfurization (FGD) system which can be recycled to other industries or land filled.

Air Emissions: The comment we hear the most from first time visitors to our plant is, "there is no coke plant smell or odors". Obviously this is because there are no door leaks or fugitive emissions from a by-product recovery plant.

Sun Coke's heat recovery technology was designated as maximum achievable control technology (MACT) for coke making in the 1990 Clean Air Act Amendments. This designation came about due to extensive on site inspections and EPA emission testing of the Jewell Coke Plant with final U.S. EPA reports issued in 1992. (10,11).

Shown in Table 6 are the air emissions (plant-wide) for a Sun Coke Heat Recovery Plant, and a by-product coke plant each processing 2 million tons per year of coal. The substantially lower air emission rates for the heat recovery plant are a direct result of five factors:

(a) The ovens continuously operate under negative pressure (-0.30 to -0.50 in wc) so there are no door leaks of hazardous coke oven gas constituents.
(b) The Sun Coke Heat Recovery Plant has a state of the art pushing emission control system including a coke side shed and bag filter evacuation system.
(c) The Sun Coke Heat Recovery Plant has a state of the art close capture ventilation and bag filter system to capture and control charging emission, and
(d) Most importantly, the combustion system which is an integral part of the oven technology was designed with the dual purpose of in-situ process heat transfer and total combustion efficiency.
(e) SO_2 control is accomplished using a established and proven power plant FGD technology.

Air Emissions (Continued)

Inspection of Table 6 shows that the most dramatic reduction of air pollution emissions for the Sun Coke Heat Recovery Process are associated with the reduction of combustion related emission such as CO, NO x, VOC's, C_6H_6, CS_2, C_2H_4, H_2S, CH_4, $C_{10}H_8$, C_7H_8, C_8H_{10}, and Heavy Hydrocarbons (C10+).

Along with the substantial reduction in combustion related gases as outlined above, the overall combustion efficiency is best demonstrated by the extremely low values for CO (actual stack gas concentrations of less than 1ppm) and benzene with actual stack gas concentrations of 12 to 23ppb. The stack gas CO levels are actually lower than urban and rural background concentrations of CO at 5-50ppm and 1-3ppm respectively.

The efficiency of the in-process combustion system is simply a result of good combustion design practices incorporating the three T's and excess oxygen.

Time- The actual residence time from coal bed to exhaust point is over 6 seconds.
Temperature- The entire flue gas path operates in the temperature regions of 2000-2500 degrees F
Turbulence (mixing)- The coke oven gas experiences 15-90 degree turns in traveling from the coal bed to the exit point, and
Excess Oxygen- The common tunnel flue gas is typically at 6-8% by volume O_2.

Plant Economics: There is some debate in the literature over the actual capital cost requirements for coke making technologies. We offer the following published actual costs for the IHCC plant which is producing coke at a rate of 1.35 million TPY.

☐ Coke oven facility (Complete)		$190 Million
☐ Coal handling/blending (Complete)		$ 35 Million
☐ Energy facility (Complete)		$140 Million
	Total	$365 Million

Please note that this is for a new, fully operational plant complete from ground up. It should also be noted that this plant was fully operational within 18 months of notice to proceed. It should also be noted that for larger plants there are economies of scale.

Further to the question of investment costs we would offer the following: It is Sun Coke's stated mission to design, **finance**, build, own and operate heat recovery plants to supply the highest quality coke to blast furnace operators, thereby relieving the steel plant owners and operators from having to invest precious capital in coke plant operations. Under this arrangement the lower investment cost when compared to by-product plants is reflected as a reduced coke cost.

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Table 1 – Coke Oven Plant Equipment Inventory – IHCC	
Plant Statistics	
Coke Ovens	
Type	Sun Coke Heat Recovery
No. of Batteries	4 @ 67 ovens each
No. of Ovens	268
Heating Flues	Split Sole Flue Design
Downcomer Flues	6 per oven
Chamber Width	12 ft.
Chamber Length	47 ft. (between buckstays)
Chamber Height	9 ft. @ crown
Uptake Flues	2 per oven
Doors	2 per oven
Charging Method	Water Cooled Leveling Conveyor
Charge Weight	42 – 45 tons (6.5 – 8.5% moisture)
Charging sequence	Staggered
Coking Time	48 hrs.
Combustion Air	Induced
Combustion Air Ports	
Doors	3 ports and 2 doors = 6 ports/oven
Sole Flues	2 ports/oven
Temperature Control	Bailey – DCS System
Monitoring	Type B thermocouples – 3 per oven
Crown Temperature Control	Door Air Ports
Sole Flue Temperature Control	Sole Flue Air Port Dampers and uptake dampers (draft control)
Environmental Protection	
Door Leaks	None, ovens operate under negative pressure
Coke Oven Gas	Complete combustion in crowns, sole flues, and waste heat tunnels, over 6 seconds residence time at 2000 - 2500°F, with excess air.
Coke Oven Machines	
Coal Delivery	Tripper Belt Conveyor, 1/Battery, 1200 TPH
Pushing and Charging Machines	
Type	Combined, Sun Coke Company
Number	1/Battery
Charging Duration	2 ½ Minutes
Pushing Duration	1 ¼ Minutes
Total Oven Cycle Time	8 Minutes

Table 1 – Coke Oven Plant Equipment Inventory – IHCC Continued	
Drives	Hydraulic
Emergency Power	Yes
Environmental Protection	
Charging	Baghouse, onboard, 32,000 ft^3/min.
Pushing	Shed and baghouse, 170,000 ft^3/min.
Quench Cars	
Type	2 Sloped Bottom
	2 Tilt Box
Capacity	2500 ($ft^{3)}$
Locomotives	2 Hydraulic
	1Electric
Coke Guides	
Type	Sun Coke Company Design
Number	4
Drives	Hydraulic
Personnel Protection	Filtered/Air Conditioned Cab
Quench Towers	
Type	Sun Coke Company Design
Number	2
Size	60ft. L x 20ft. W x 60ft. H
Environmental Protection	Baffles + Quench Water TDS limit
Coke Wharves	
Type	Sun Coke Company Design
Number	2
Size	340ft L x 20ft. W
Discharge	Gates, Hydraulically Actuated

Table 2 – Individual Oven Temporal Variation Over 48 Hour Coking Cycle			
Period	**Time**	**Gassing Rate**	**Comments**
Early Cycle	0 - 6 hrs.	1.4 x Average	Coal bed moisture and coal VM
Mid Cycle	7 – 36 hrs.	Average	Coal bed moisture gone after 10 – 12 hrs, thereafter coal VM only.
Late Cycle	37 – 48 hrs.	0.7 x Average	Gradually declining coal VM flow rate

Table 3: Coal Blend Test Results (Coal Data)

Test Description	Date	# of Coals	Additives	Moist. %	F.C. % Dry	V.M. % Dry	Ash % Dry	Sulfur % Dry	Reflect.	Pulv. (-1/8")	Fluidity dd pm	Inerts %
Bluestone Coal Test	10/1999	1	none	5.16	75.99	19.00	5.01	0.83	1.58	72.09		
Consol Coal Test	10/2000	1	none	8.35	75.44	19.18	5.38	0.74	1.65	81.42	30-60	22.20
Oak Grove Test	5/1998	1	none	5.86	70.75	20.37	8.88	0.50	1.50	74.34		
Oak Grove 75%, Jewell 25% Test	5/1998	6	none	7.53	70.23	20.91	8.86	0.54	1.46	77.25		
Jawbone/Tiller 56.82% & Red Ash 43.18%	5/1995	2	none	13.32	70.98	22.38	6.64	0.82	1.36	N/A	1,813	34.70
Jewell Coal Blend	2/1995	5	none	14.20	70.98	22.97	6.05	0.82	1.34	N/A	1,400	31.00
Jewell -Synfuels Tests (avg. of 12 tests)	4,5,6/2000	5	Syn Fuel	N/A	70.72	23.17	6.11	0.80	N/A	N/A	1,631	29.00
Jewell 60%, Bluestone 20%, & Powelton 20%	7/1997	7	none	8.35	69.78	23.52	6.70	0.82	1.26	N/A		
Jewell 84%, Pet Coke 16%	7/2000	6	Pet Coke	7.65	70.83	23.63	5.54	0.98	1.24	86.11	728	
Jewell 60%, Bluestone 20%, & Elk Run 20%	7/1997	7	none	5.77	69.81	23.88	6.31	0.82	1.26	N/A		
Jewell 75% & Race Fork 25%	4/1996	6	none	9.70	68.62	25.08	6.31	0.87	1.25	N/A	7,141	27.10
Jewell 75% & Powelton (Mossy) Eagle 25%	5/1996	6	none	11.78	68.87	25.22	5.91	0.83	1.26	N/A	4,531	30.50
Jewell 59% & Certified Coal 41%	5/1997	8	none	9.00	67.83	25.95	6.22	0.81	1.26	76.60		
Jewell 60%, Sanborn Crk. 20%, Pet Coke 20%	7/2000	7	Pet Coke	8.27	66.75	26.61	6.64	0.91	1.13	81.39		
Jewell 50% & Powelton (Mossy) Eagle 50%	4/1996	6	none	9.06	67.48	26.76	5.76	0.81	1.19	N/A	8,908	30.80
By-Product Coal Blend	5/1997	3	none	8.13	67.57	26.78	5.65	0.73	1.18	70.56	4,793	23.30
Jewell 50% & Race Fork 50%	4/1996	6	none	7.22	65.26	28.30	6.45	0.92	1.18	N/A	12,421	25.20
By-Product Coal Blend	2/1998	3	Pet Coke	6.88	65.85	28.36	5.79	0.98	1.18	79.48	2,392	23.60
Inland Steel Coke Test (Blend "C")	7/1997	5	none	6.17	63.94	29.68	6.38	0.88	1.14	86.47	2,738	19.80
By-Product Coal Blend	1/1996	n/a	none	8.62	63.58	30.04	6.38	0.94	1.24	73.14	11,800	23.90
Inland Steel Coke Test (Blend "B")	7/1997	5	none	8.82	62.88	30.50	6.62	0.87	1.13	87.45	7,325	22.30
Inland Steel Coke Test (Blend "D")	7/1997	5	none	6.03	63.26	30.70	6.05	0.83	1.11	76.93	3,097	22.50
Inland Steel Coke Test (Blend "E")	7/1997	5	none	10.71	62.69	31.03	6.28	0.82	1.06	87.51	2,322	18.90
Race Fork 100%	4/1996	1	none	5.39	61.58	32.38	6.04	0.94	1.05	N/A		

Table 4: Coal Blend Test Results (Coke Data)

Test Description	Date	Moist. %	F.C. % Dry	VM % Dry	Ash % Dry	Sulfur % Dry	Stab.	Hard.	CSR	CRI
Bluestone Coal Test	10/1999	12.91	93.50	0.53	5.97	0.69	58.7	64.8	48.9	
Consol Coal Test	10/2000	7.93	92.69	0.53	6.78	0.63	47.7	54.4	31.4	
Oak Grove Test	5/1998	6.65	88.83	0.30	10.87	0.48	65.6	69.5	75.6	14.1
Oak Grove 75%, Jewell 25% Test	5/1998	7.90	89.22	0.53	10.25	0.52	65.0	68.9	66.8	16.7
Jawbone/Tiller 56.82% & Red Ash 43.18%	5/1995	7.71	91.94	0.42	7.64	0.65	63.3	68.4	65.1	23.7
Jewell Coal Blend	2/1995	7.00	91.89	0.35	7.76	0.69	62.0	67.7	61.9	26.7
Jewell -Synfuels Tests (avg. of 12 tests)	4,5,6/2000	N/A	91.53	0.34	8.13	0.68	64.1	68.6	66.3	26.2
Jewell 60%, Bluestone 20%, & Powelton 20%	7/1997	10.31	91.80	0.42	7.78	0.63	62.7	67.1	64.7	26.1
Jewell 84%, Pet Coke 16%	7/2000	11.90	92.52	0.24	7.24	0.88	65.8	70.5	70.5	
Jewell 60%, Bluestone 20%, & Elk Run 20%	7/1997	9.39	91.86	0.67	7.47	0.63	66.0	69.9	69.1	25.3
Jewell 75% & Race Fork 25%	4/1996	3.67	91.27	0.26	8.46	0.68	62.8	67.9	66.8	22.6
Jewell 75% & Powelton (Mossy) Eagle 25%	5/1996	5.92	92.02	0.32	7.66	0.66	64.2	69.5	68.0	19.0
Jewell 59% & Certified Coal 41%	5/1997	7.11	91.27	0.78	7.95	0.65	65.8	69.4	69.6	
Jewell 60%, Sanborn Crk. 20%, Pet Coke 20%	7/2000	4.22	91.39	0.22	8.39	0.88	66.9	72.3	67.9	
Jewell 50% & Powelton (Mossy) Eagle 50%	4/1996	2.52	91.92	0.21	7.86	0.65	61.0	69.6	71.6	18.2
By-Product Coal Blend	5/1997	8.07	91.92	0.59	7.50	0.62	62.4	68.7	70.2	20.3
Jewell 50% & Race Fork 50%	4/1996	5.18	91.37	0.38	8.25	0.68	61.7	68.3	68.3	20.8
By-Product Coal Blend	2/1998	8.77	91.65	0.57	7.78	0.82	63.4	69.6	67.2	21.9
Inland Steel Coke Test (Blend "C")	7/1997	9.25	91.47	0.48	8.05	0.65	64.3	70.4	68.4	20.8
By-Product Coal Blend	1/1996	8.03	91.20	0.33	8.47	0.72	61.8	68.8	70.2	20.4
Inland Steel Coke Test (Blend "B")	7/1997	9.94	91.01	0.48	8.51	0.67	62.8	69.7	71.8	20.2
Inland Steel Coke Test (Blend "D")	7/1997	11.94	91.33	0.56	8.11	0.63	61.8	69.1	69.2	20.1
Inland Steel Coke Test (Blend "E")	7/1997	9.52	91.24	0.60	8.16	0.61	62.0	69.9	69.9	21.4
Race Fork 100%	4/1996	N/A	91.38	0.21	8.41	0.68	45.9	66.3	70.6	15.8

Table 4: Coal Blend Test Results (Coke Data)
Continued

Test Description	Date	Size +2"	Mean Size (mm)	Apparent S.G.	True S.G.	Coke Porosity	Cell Wall Thk (mm)	Pore Size (mm)	Pyrolytic Carbon %
Bluestone Coal Test	10/1999	45.56							
Consol Coal Test	10/2000	58.92							
Oak Grove Test	5/1998	63.59		0.91	1.98	54.00			0.2
Oak Grove 75%, Jewell 25% Test	5/1998	64.18		0.91	1.97	53.80			1.0
Jawbone/Tiller 56.82% & Red Ash 43.18%	5/1995	N/A							
Jewell Coal Blend	2/1995	N/A		0.92	1.95	52.80	134.00		
Jewell -Synfuels Tests (avg. of 12 tests)	4,5,6/2000	66.04	56.60	0.92	1.98	48.30	162.60		2.3
Jewell 60%, Bluestone 20%, & Powelton 20%	7/1997	59.24							1.0
Jewell 84%, Pet Coke 16%	7/2000	61.96	55.90	0.98					
Jewell 60%, Bluestone 20%, & Elk Run 20%	7/1997	48.92							2.0
Jewell 75% & Race Fork 25%	4/1996	33.36							
Jewell 75% & Powelton (Mossy) Eagle 25%	5/1996	39.10							
Jewell 59% & Certified Coal 41%	5/1997	69.78							
Jewell 60%, Sanborn Crk. 20%, Pet Coke 20%	7/2000	70.44	59.40	0.97					
Jewell 50% & Powelton (Mossy) Eagle 50%	4/1996	40.42							
By-Product Coal Blend	5/1997	61.31							
Jewell 50% & Race Fork 50%	4/1996	39.99							
By-Product Coal Blend	2/1998	53.60		1.07	1.96	45.50	152.00		2.3
Inland Steel Coke Test (Blend "C")	7/1997	47.72	51.50	0.99		52.00	182.10	25.8	3.3
By-Product Coal Blend	1/1996	42.94		1.07	2.00	46.50			4.4
Inland Steel Coke Test (Blend "B")	7/1997	45.65	47.50	0.97		53.00	132.70	28.1	4.5
Inland Steel Coke Test (Blend "D")	7/1997	44.12	49.40	1.00		49.00	199.50	29.3	2.6
Inland Steel Coke Test (Blend "E")	7/1997	42.84	50.30	0.96		52.00	180.30	34.9	2.9
Race Fork 100%	4/1996	33.36							

Table 5 – Variation in Coal Blend Properties Used at IHCC Over the Past 31 Months		
Charge Coal Properties	**Maximum**	**Minimum**
Volatile matter, % Dry	30	22.5
Fixed Carbon, % Dry	71	63
Ash, % Dry	6.8	6.4
Sulfur, % Dry	0.83	0.64
Moisture, %	7.11	6.0
Reflectance, Ro Max	1.34	1.09
Grind % - 1/8"	85	60

Table 6: Comparison of Overall Emissions By-Product and Non-Recovery Coke Ovens 2 Million Tons Coal Carbonized PerYear			
	Emissions (ton/yr) [A]		
Pollutant	**Non-Recovery**	**By-Product**	**By-Product v. Non-Recovery**
Total Suspended Particulate Matter [B]	728	664	-10%
Particulate matter smaller than 10 microns [B]	396	329	-20%
Sulfur Dioxide [C]	1,058	3,462	69%
Nitrogen oxides	722	1,121	36%
Carbon monoxide	133	1,234	89%
Volatile organic compounds	220	641	66%
Benzene	0.495	35.381	99%
Carbon Disulfide	0.002	0.011	83%
Ethylene	ND	27.488	100%
Heavy Hydrocarbons	ND	240.044	100%
Hydrogen Sulfide	ND	15.241	100%
Methane	ND	192.688	100%
Naphthalene	0.329	11.703	97%
Toluene	0.478	3.021	84%
Xylene	0.006	0.327	98%

Notes:
[A] - All ovens assumed to meet appropriate NESHAP (MACT) standards in 40 CFR 63.
[B] - Non-recovery particulate limits at Indiana Harbor Coke Plant.
[C] - Non-recovery spray dryer - 90% removal

Figure 1: Photograph of 3 Test Mitchell Ovens 1960 – Vansant, Va.

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NOVEMBER, 1962

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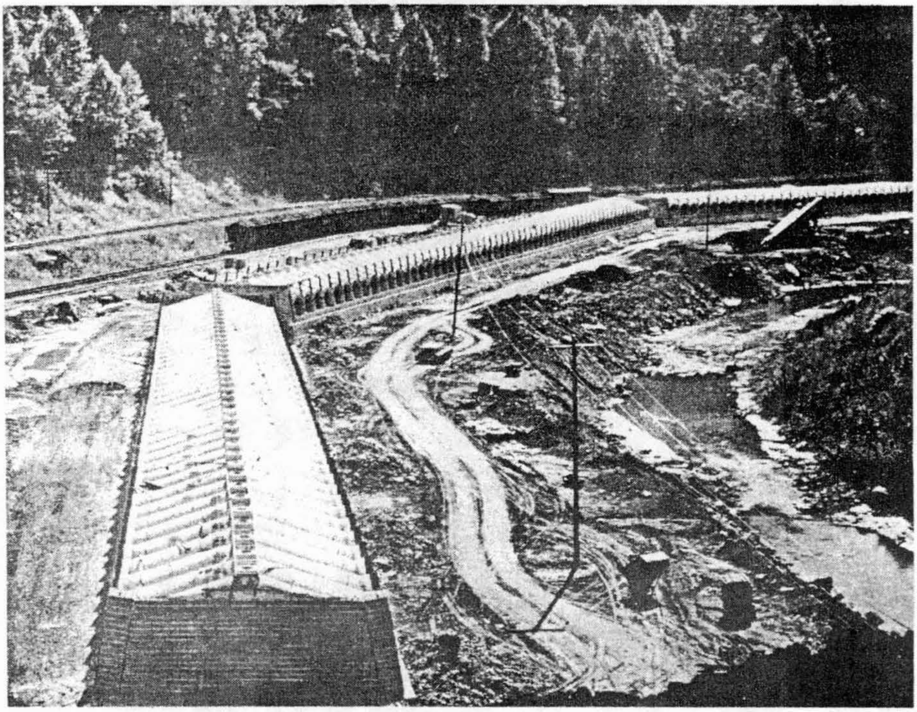

Figure 2: Cover of Coal Age Magazine, Nov. 1962 Showing Construction of 250 Mitchell Ovens at Jewell Coal and Coke Company, Vansant, Va.

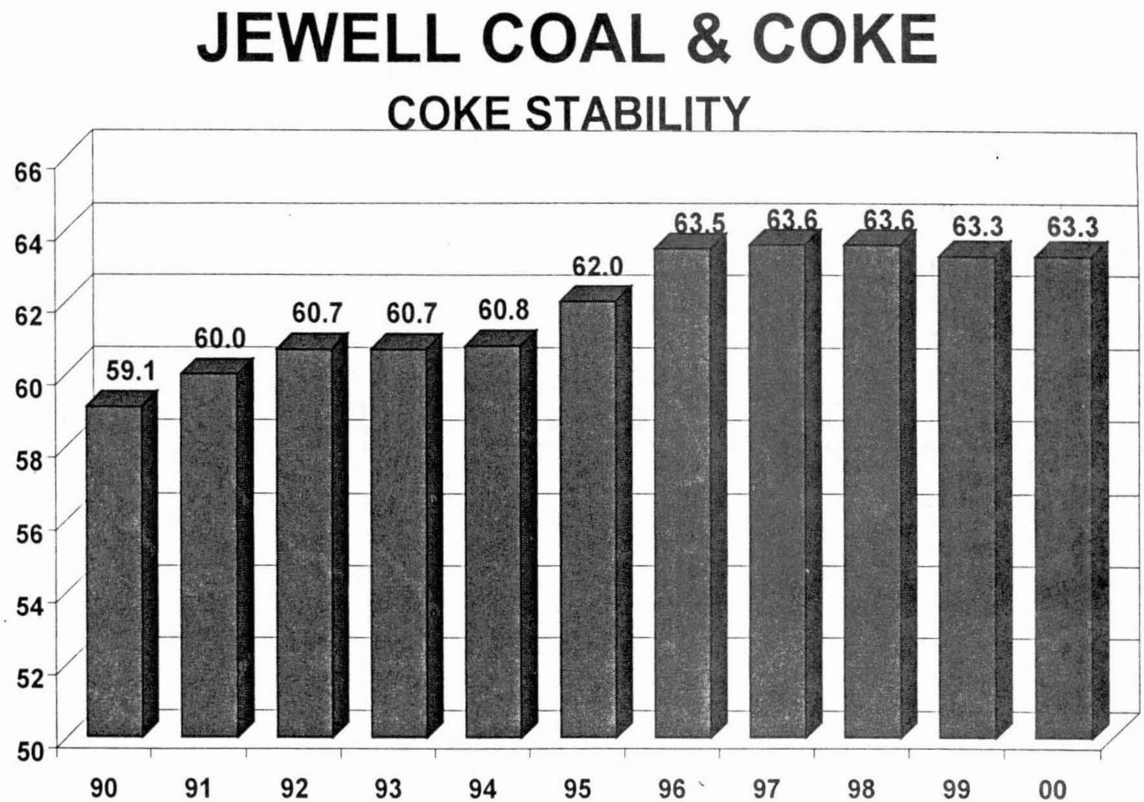

Figure 3: Annual Average Coke Stability for Jewell Coal and Coke, 1990- 2000.

JEWELL COAL & COKE

COKE YIELD

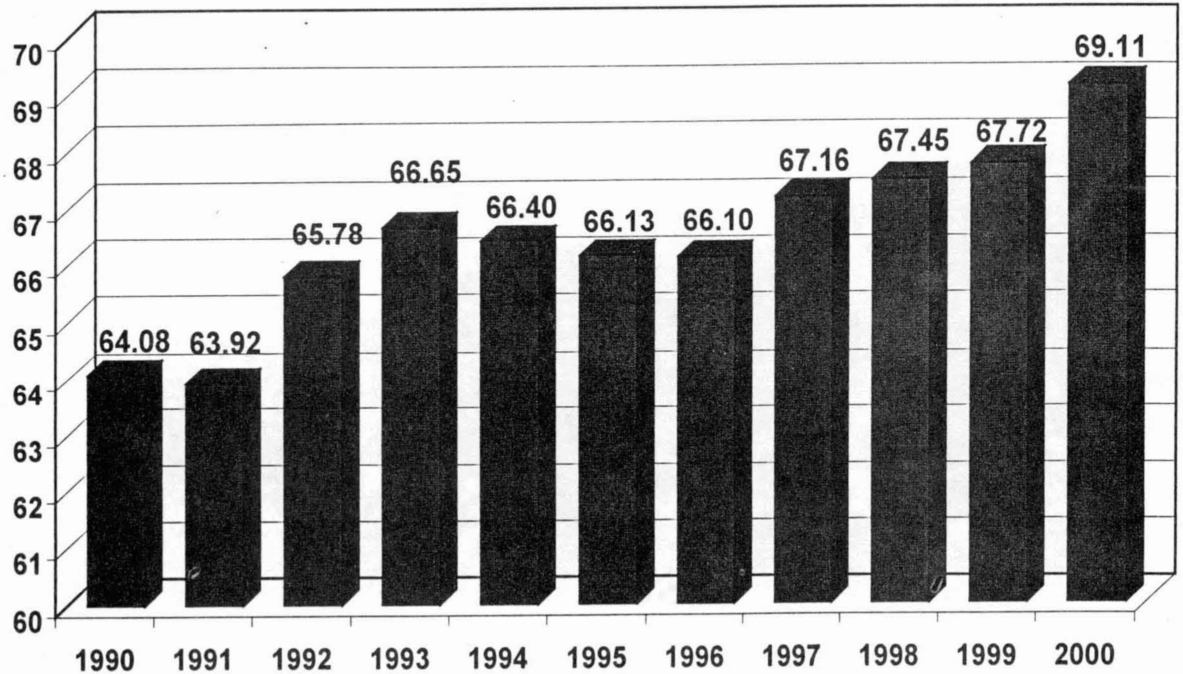

Figure 4: Annual Average Furnace Coke Yield forJewell Coal and Coke, 1990-2000.

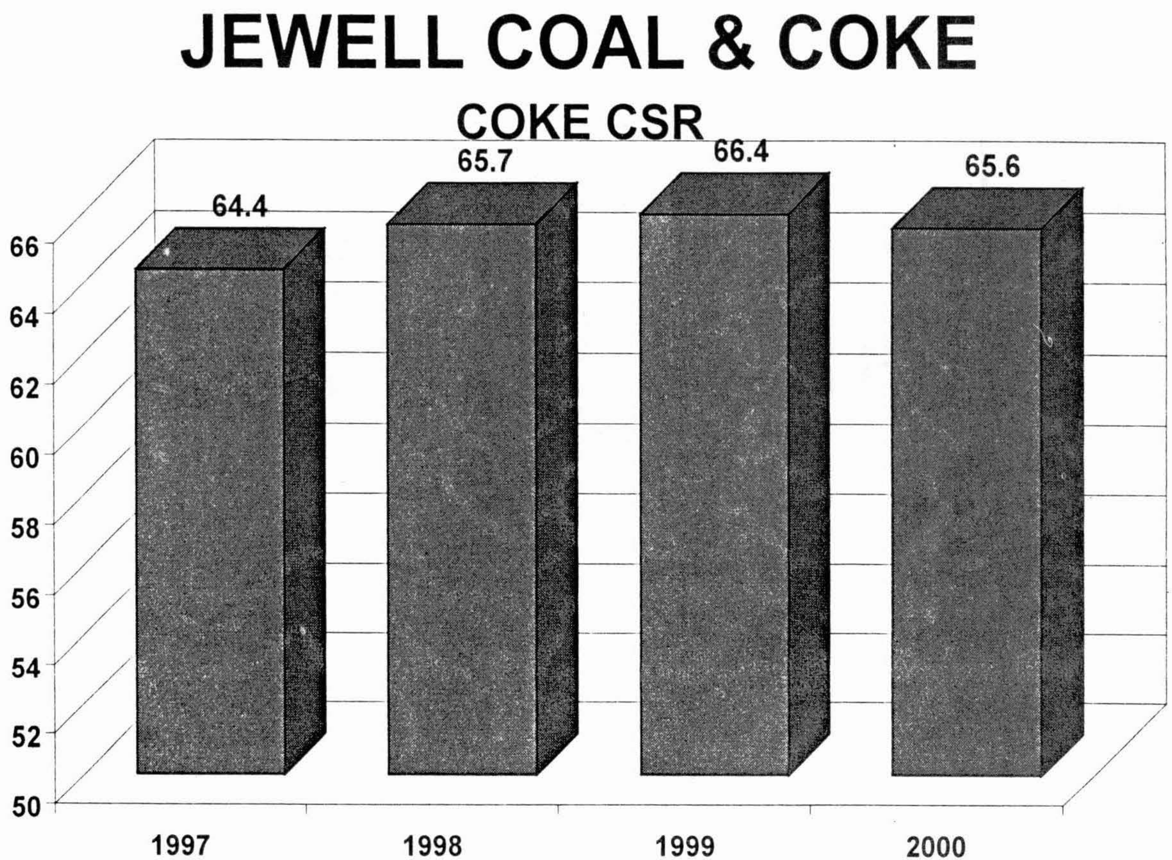

Figure 5: Annual Average Coke CSR for Jewell Coal and Coke, 1997-2000.

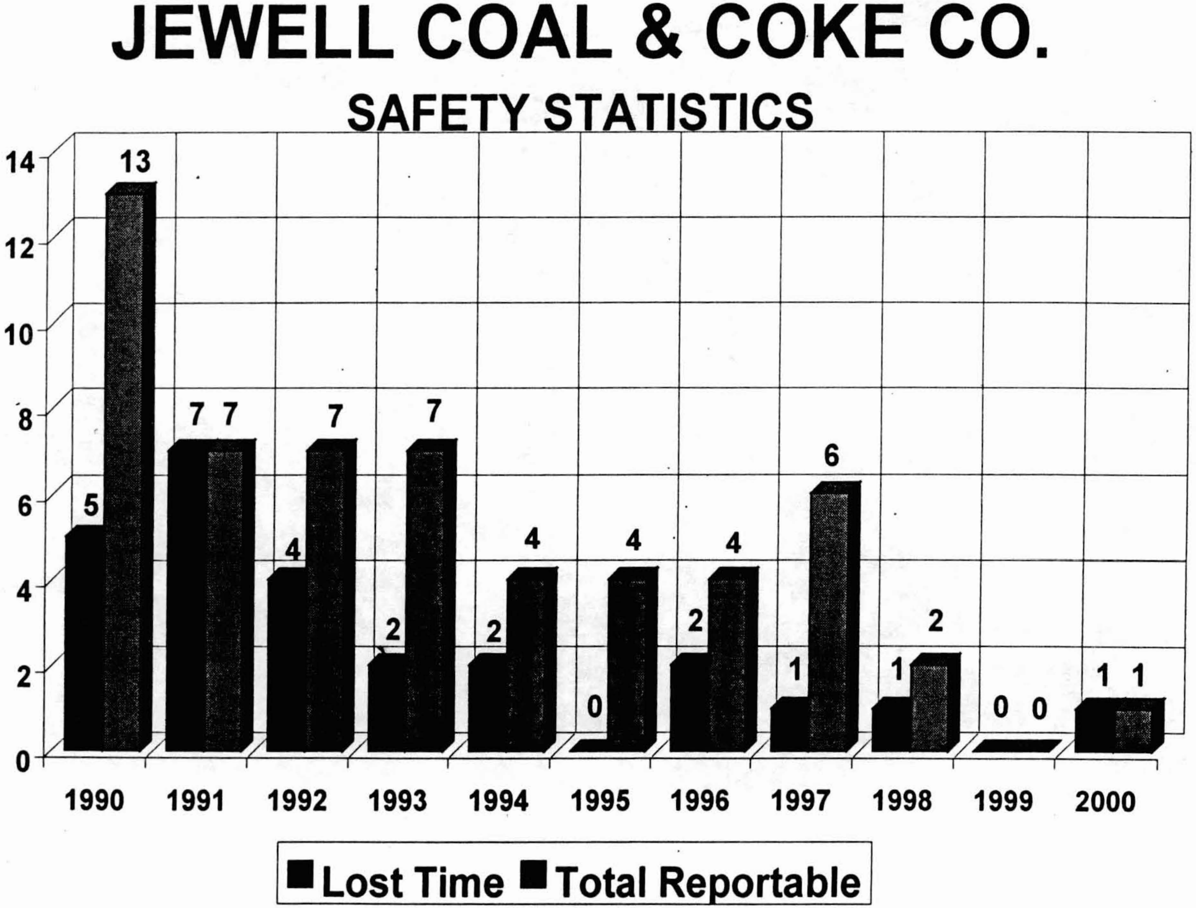

Figure 6: Annual Safety Statistics for Jewell Coal and Coke, 1990-2000.

1. Coke Ovens
2. Waste Heat Boilers
3. Waste Heat Common Tunnel
4. Pusher Charger
5. Quench Tower
6. Coke Conveyor to Blast Furnace
7. Coal Stockpiles
8. Power Facility

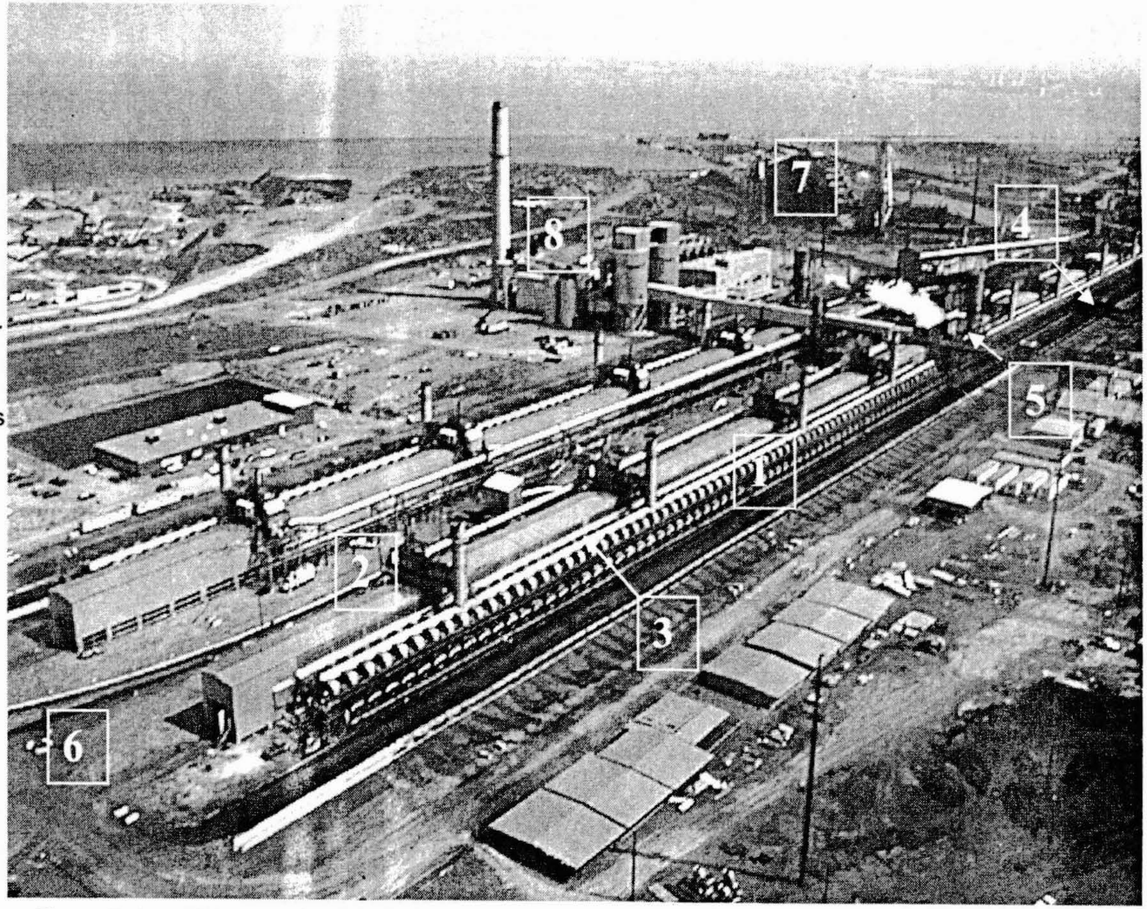

Figure 7: Aerial Photograph of the Indiana Harbor Coke Company Plant – East Chicago, IN.

1. Coke Ovens
2. Waste Heat Stacks
3. Waste Heat Common Tunnel
4. Pusher Charger
5. Quench Tower
6. Coke Stockpile
7. Coal Thermal Dryer
8. Coal Transfer

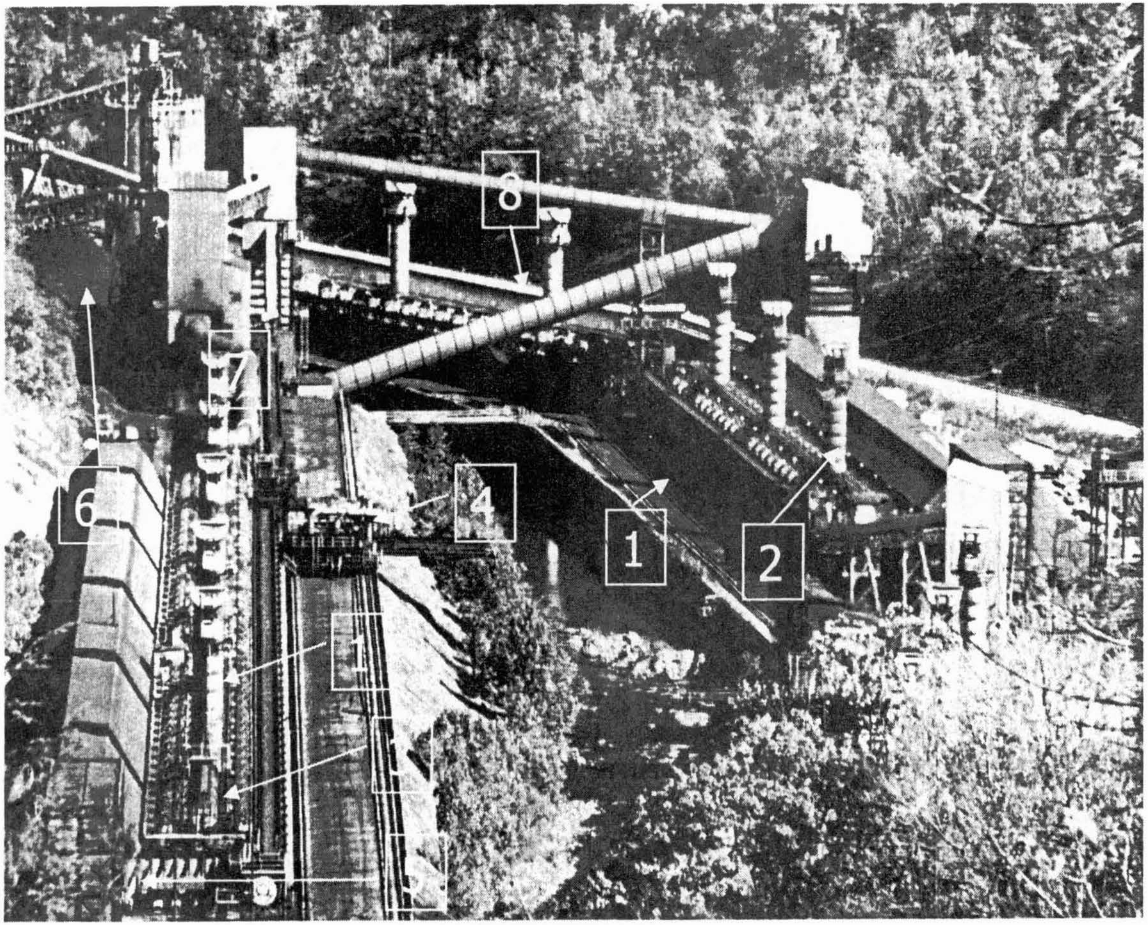

Figure 8: Aerial Photograph of the Jewell Coal and Coke Plant – Vansant, VA.

Oven Schematic

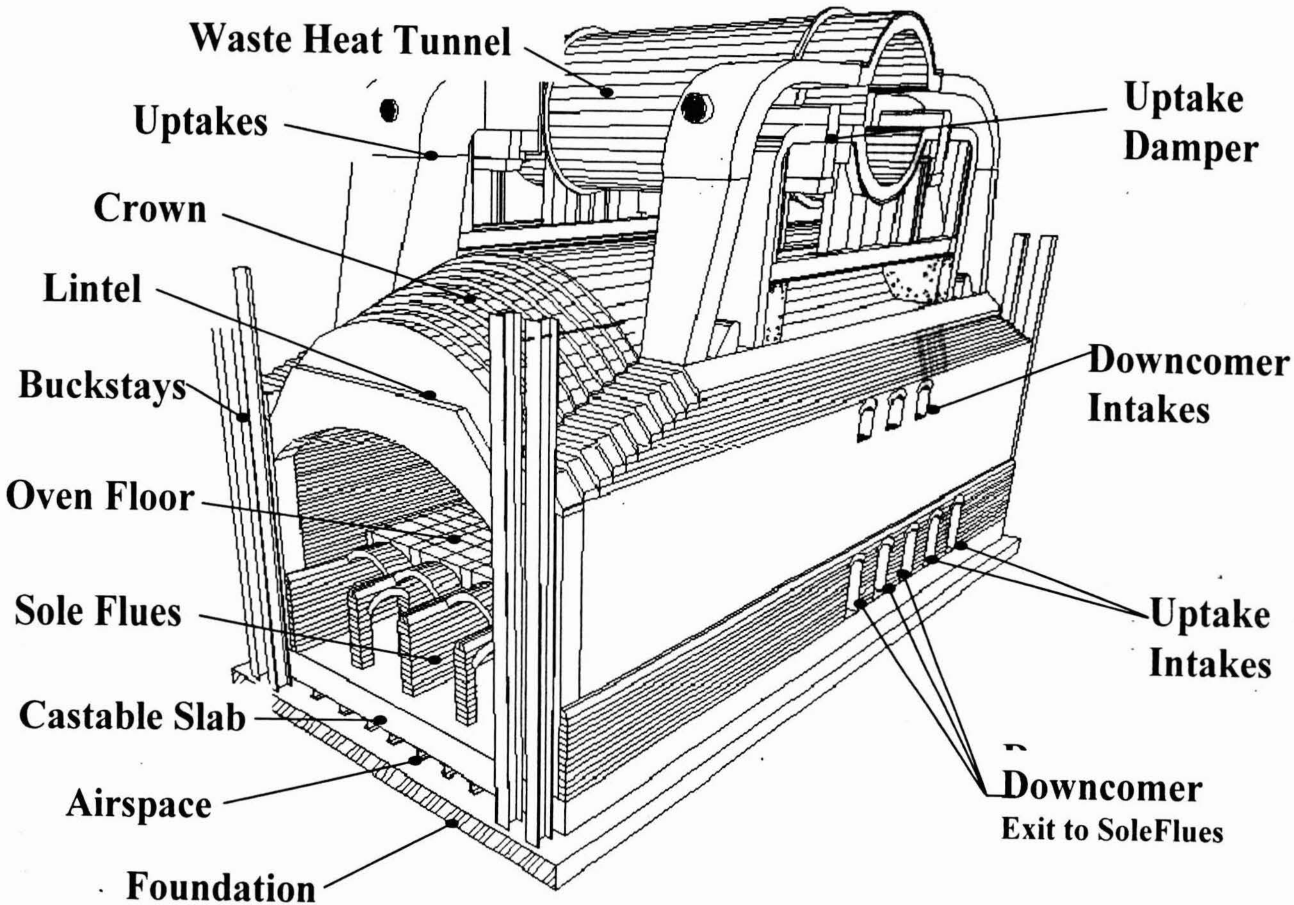

Figure 9: Schematic Diagram of the Sun Coke Heat Recovery Coke Oven.

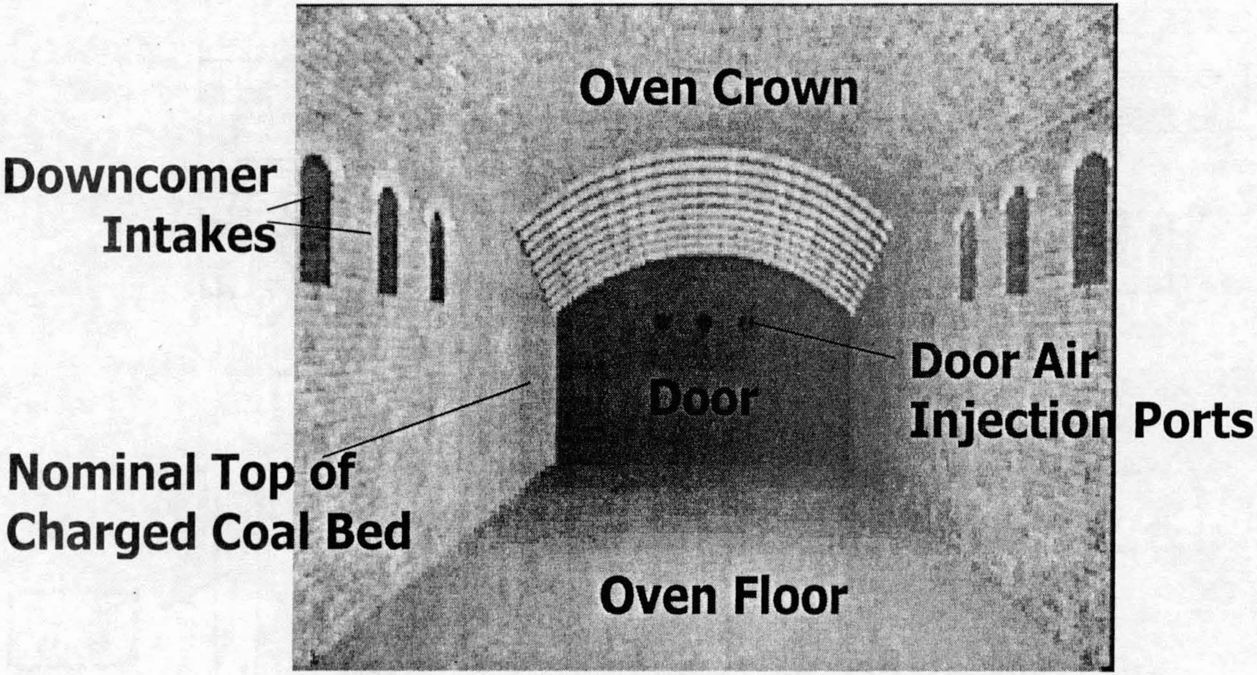

Figure 10: Interior View of a Sun Coke Heat Recovery Oven.

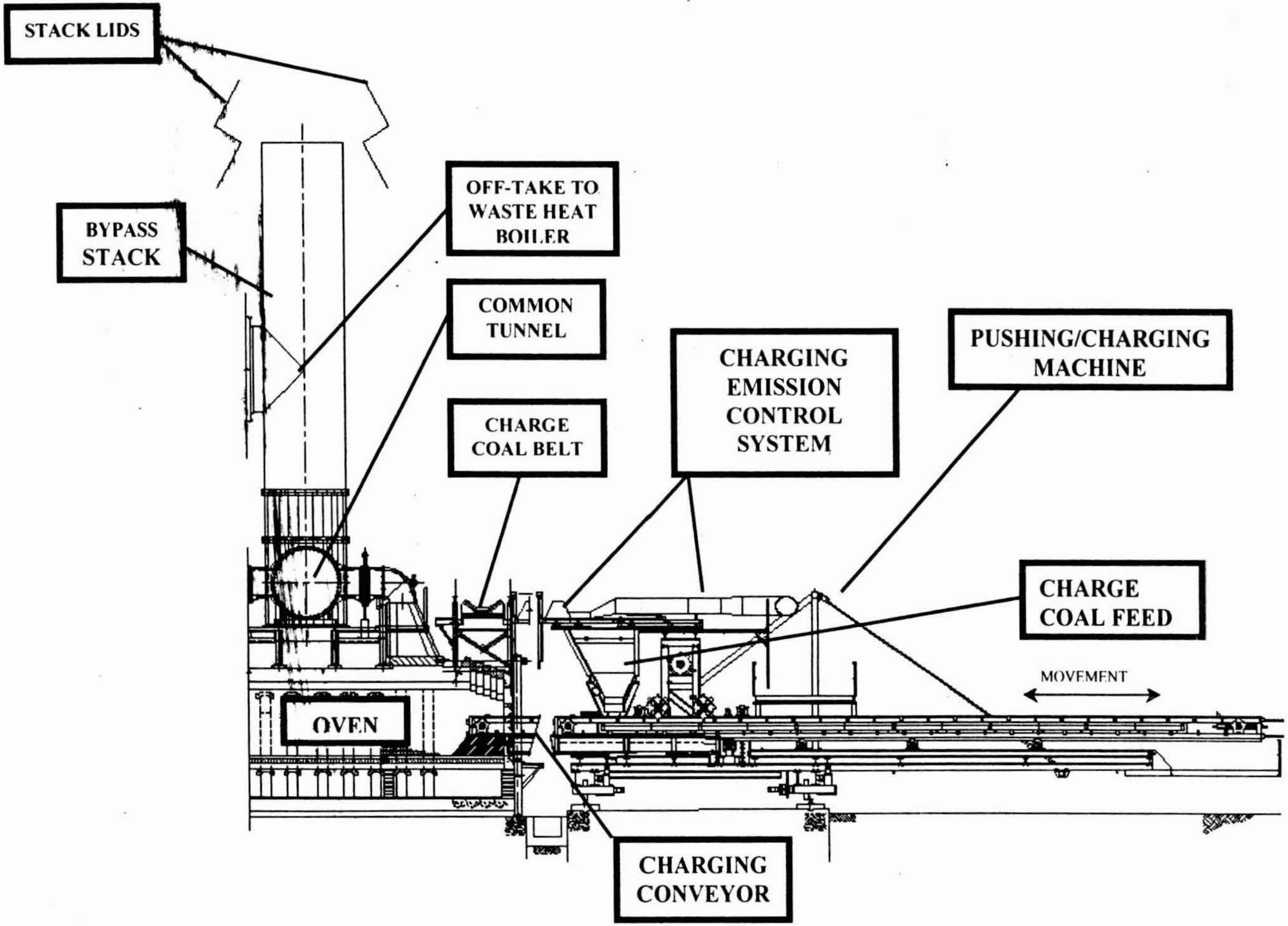

Figure 11: Side Elevation View of Pusher/Charger Machine – View Shows Charging Operation.

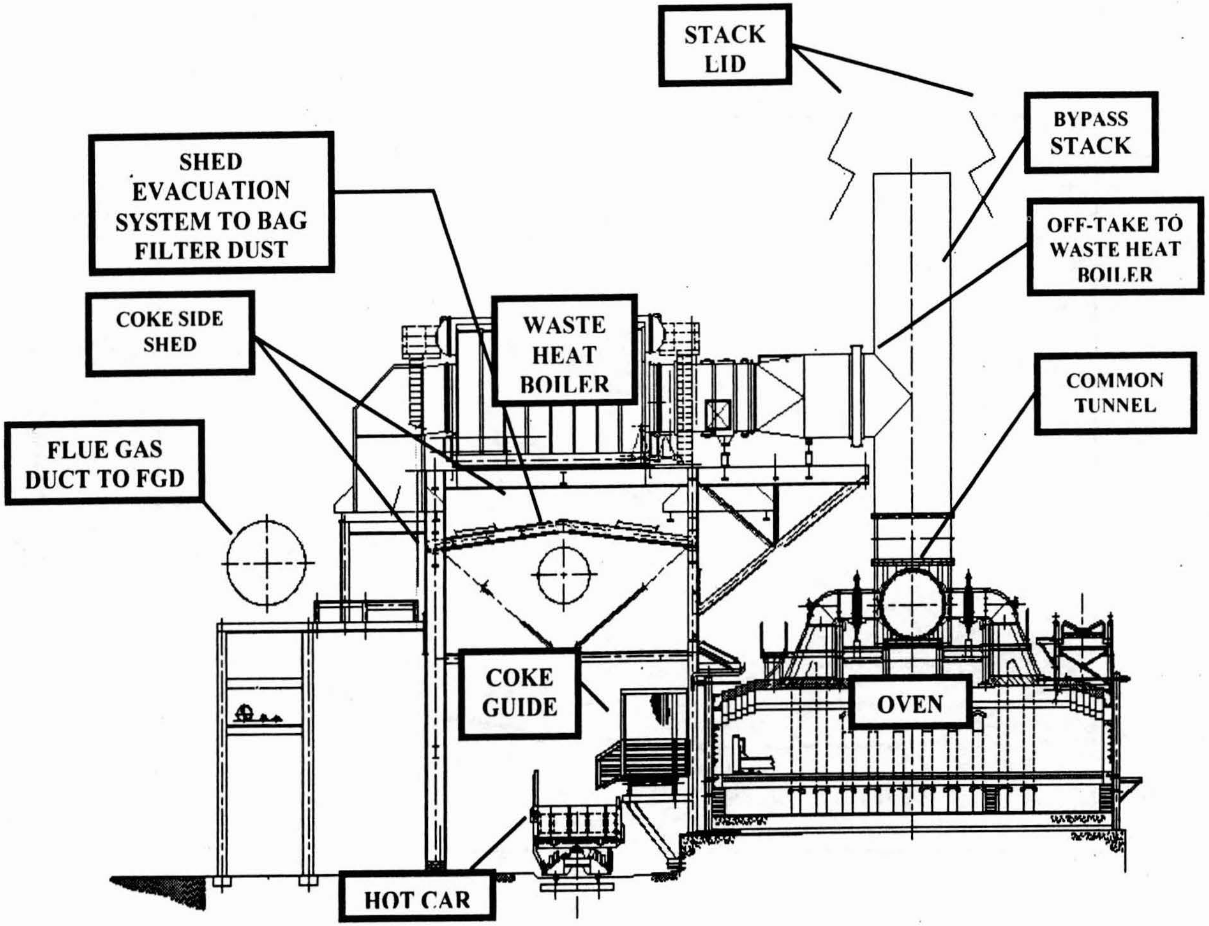

Figure 12: Side Elevation View of Coke Side – Pushing Operations.

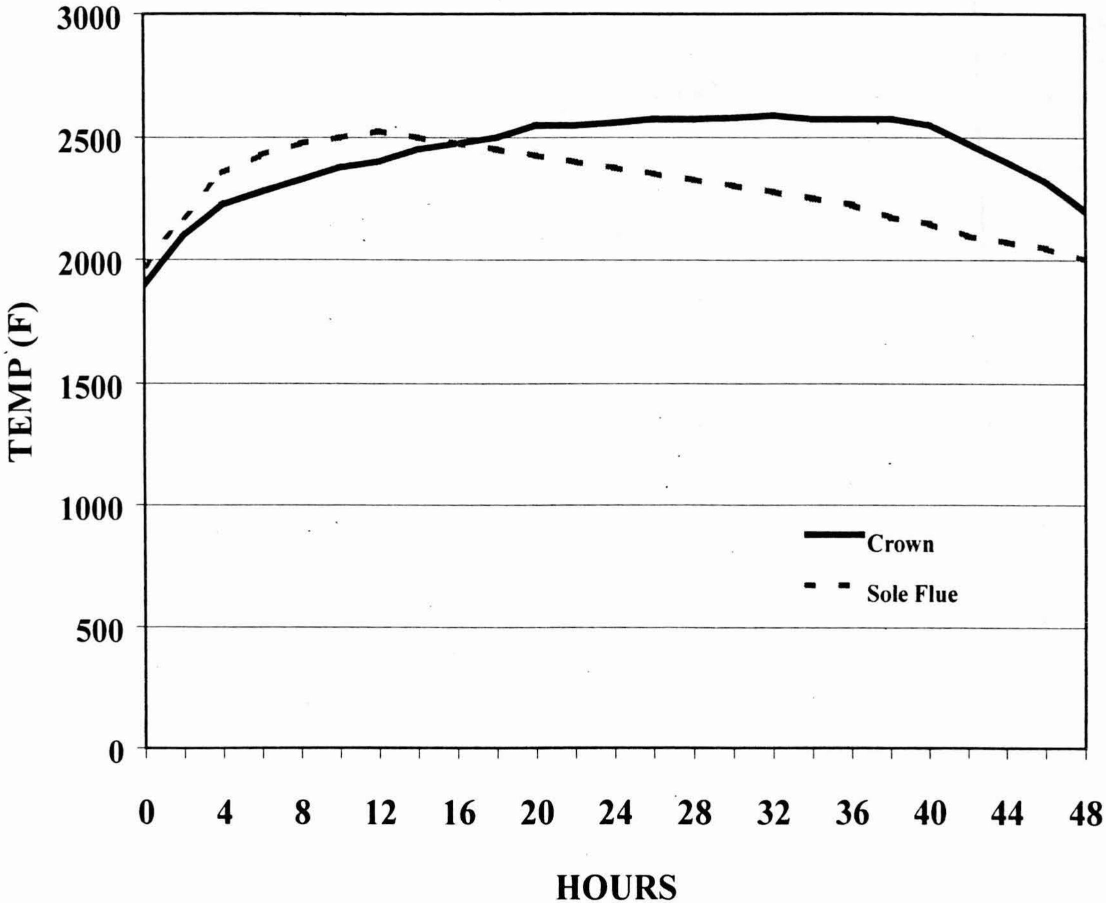

Figure 13: Typical Crown and Sole Flue Oven Temperature Profile for 48 hour Coking Cycle.

Consistency & Reliability

Indiana Harbor Furnace Coke Production

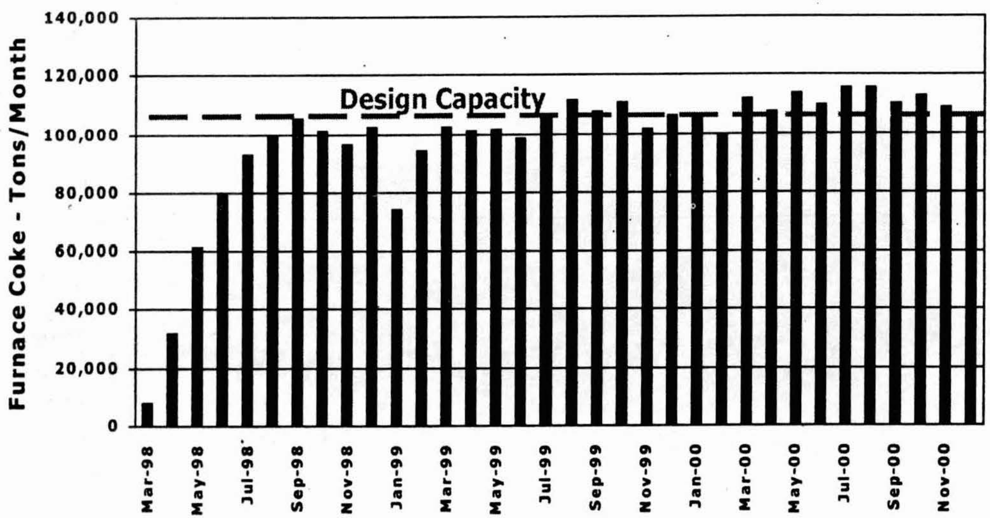

Figure 14: Furnace Coke Production for the Indiana Harbor Coke Plant.

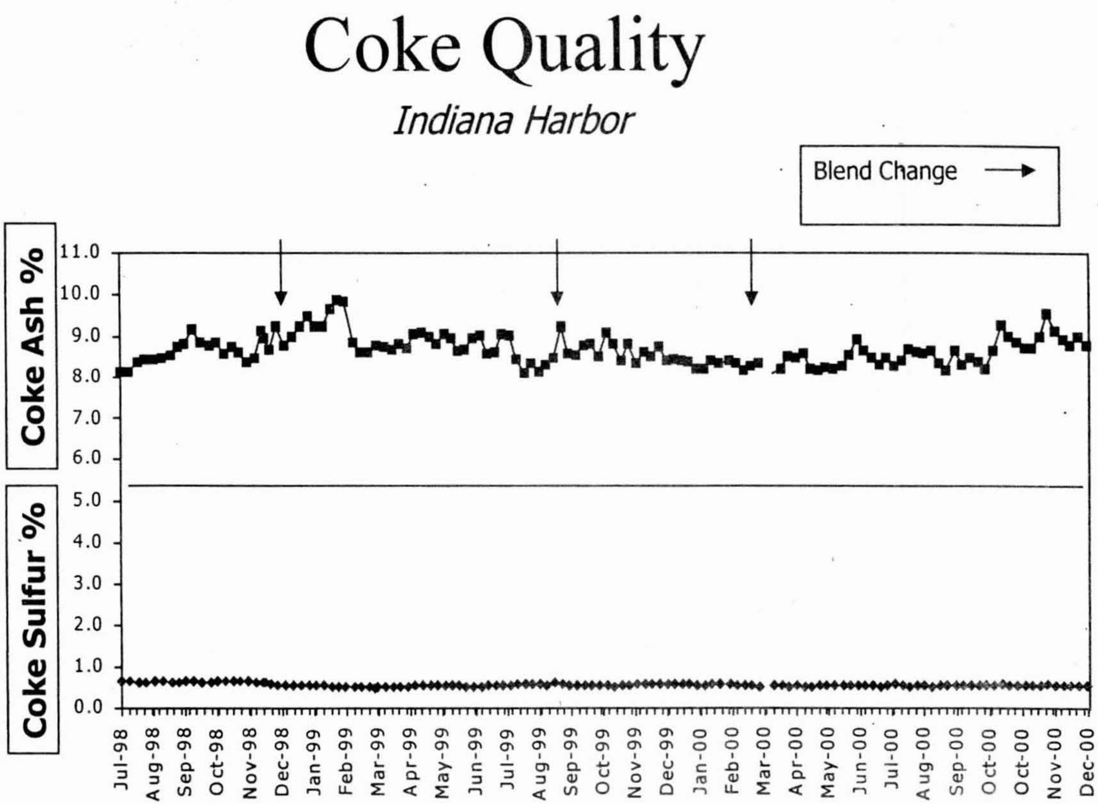

Figure 15: Weekly Average Coke Quality Parameters (% Sulfur and % Ash) for the Indiana Harbor Coke Plant.

Coke Quality

Indiana Harbor

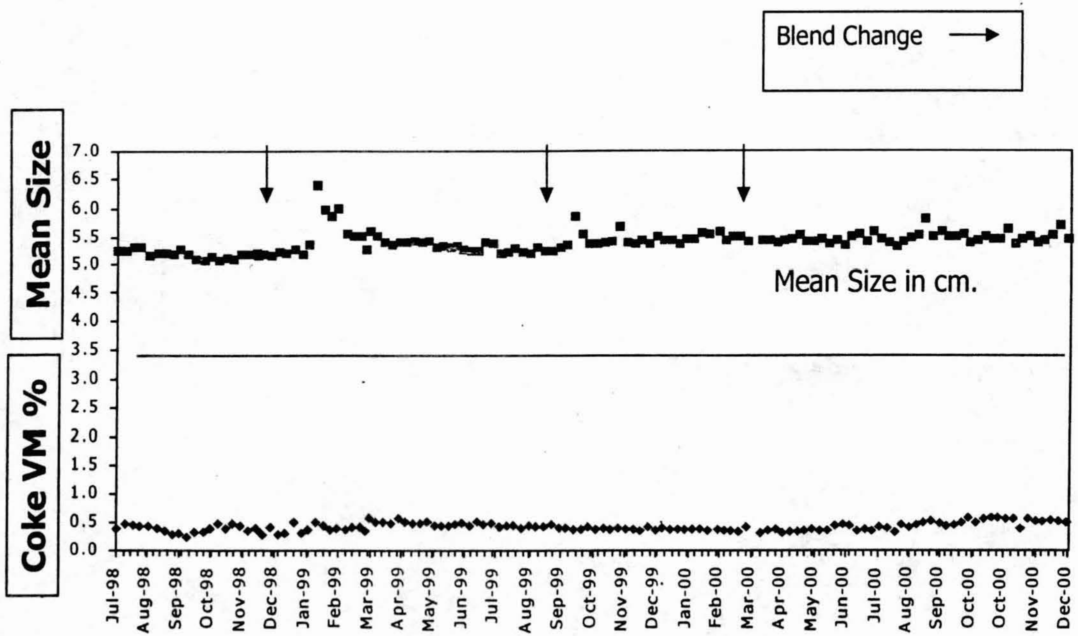

Figure 16: Weekly Average Coke Quality Parameters (% VM and Mean Size) for the Indiana Harbor Coke Plant.

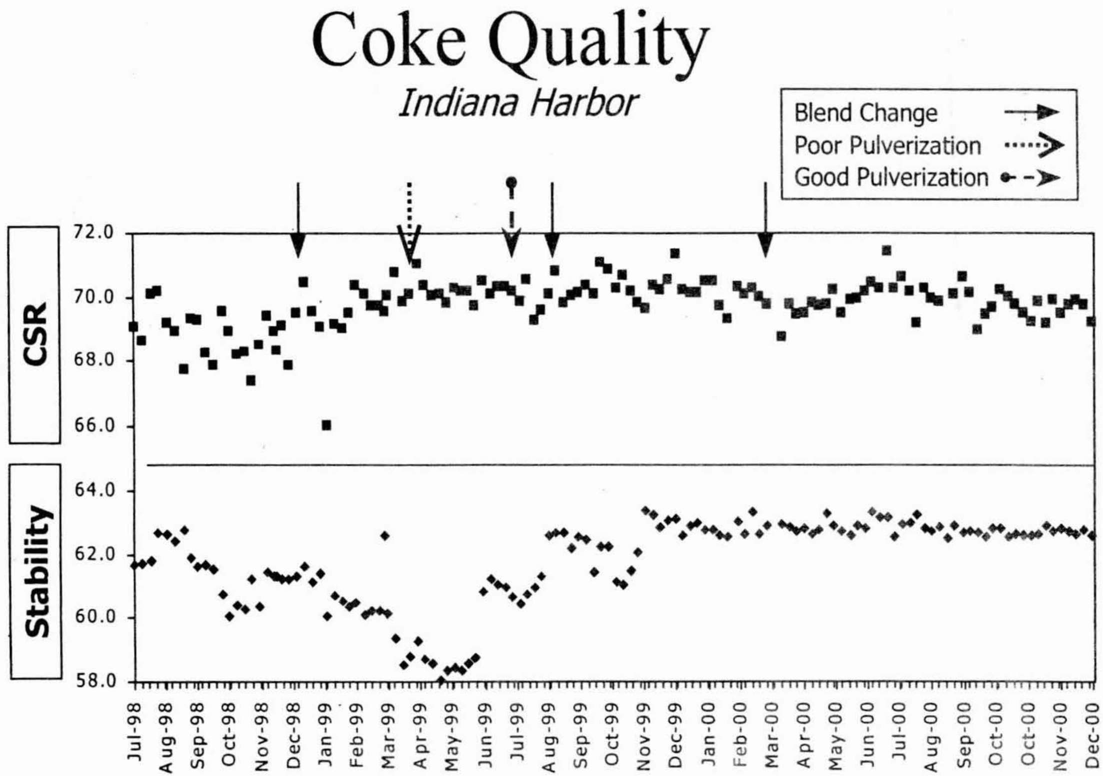

Figure 17: Weekly Average Coke Quality Parameters (Stability and CSR) for the Indiana Harbor Coke Plant.

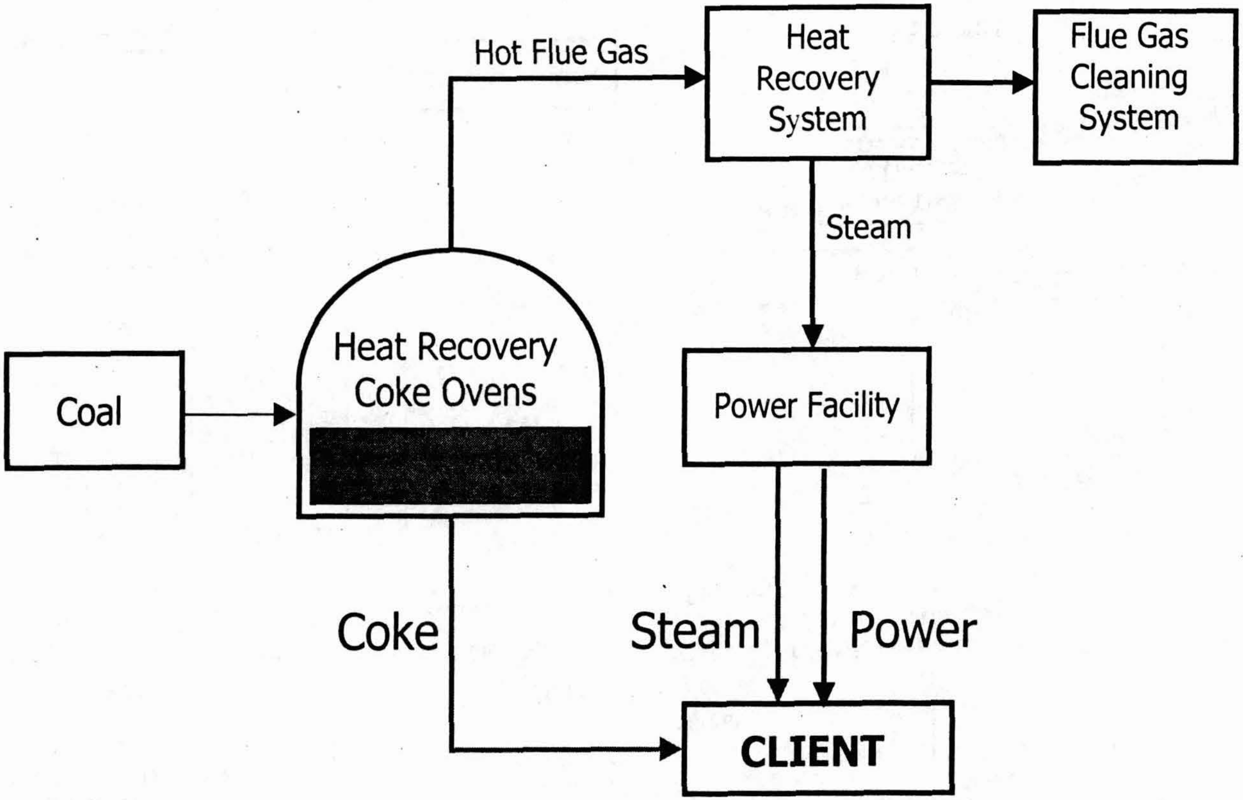

Figure 18: Simplified Block Flow Diagram for the Indiana Harbor Coke Plant.

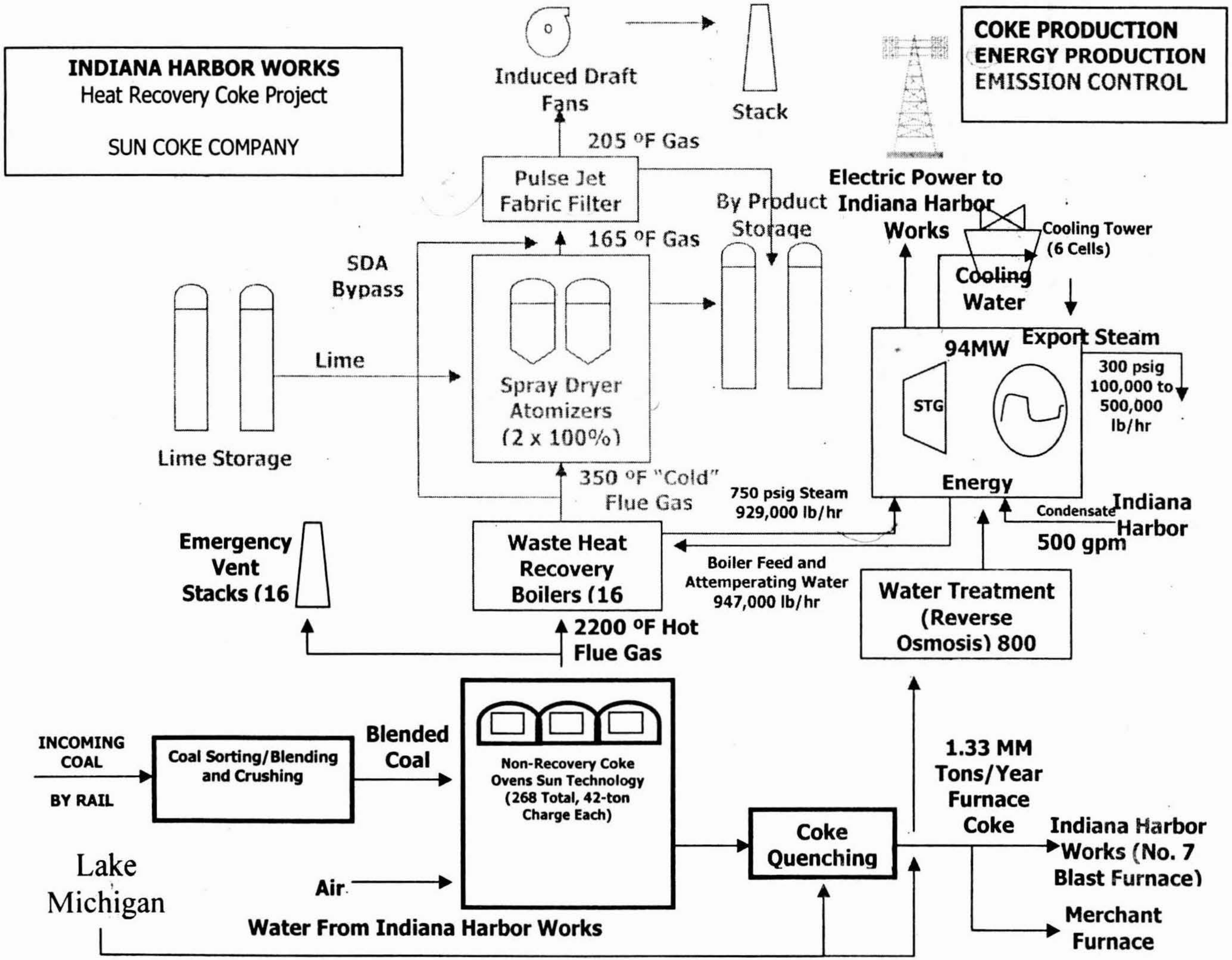

Figure 19: Detailed Block Flow Diagram for the Indiana Harbor Coke Plant.