Technical Publication

Source Test and Evaluation of a Riley Gas Producer Firing North Dakota Lignite

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"SOURCE TEST AND EVALUATION OF A RILEY GAS PRODUCER FIRING NORTH DAKOTA LIGNITE"

In 1979, American Natural Service Company commissioned the Riley Stoker Company to perform a full scale test of the low Btu gasification of North Dakota lignite in the Riley coal gasifier. Co-sponsors of the test were the Riley Stoker Company, The Hanna Mining Company and the Environmental Protection Agency through a contract with Radian Corporation. This report summarizes the results of that test and more specifically the environmental assessment of the Riley gas producer carried out by Radian Corporation.

PROCESS DESCRIPTION

The Riley gasifier is a modern, modified version of the Morgan gas producer, workhorse of the steel, glass, lime, pulp and chemical industries during the first fifty years of this century. Of the nearly 1,100 of these first generation units manufactured, at one time installations could be found on every continent in the world.

Since 1974, Riley Stoker Corporation has been operating a commercial sized demonstration unit at its Worcester, MA., R & D facility, the primary goal being the refinement of the successfully established first generation technology to the standards imposed by both environmental and operational constraints of the synfuels industry. A secondary, but no less important goal, has been the gaining of hands on experience in an area long treated as more an art than a science, and in which hard data is generally lacking.

During this time, a total of twenty-two demonstration runs with various eastern coals was carried out on the gasifier, together with an equal amount on a smaller one-fifth scale gasifier. Results of this program, together with a summary of practical operating experiences have been presented before other bodies (References 1, 2, 3).

THE GASIFIER

The Riley gasifier is depicted in Figure 1. This unit is an example of that group of gas producers classified as thin-bed, atmospheric. The entire fuel bed, including ash, never exceeds 140 cm. (55 inches), and slowly rotates, at a speed of one revolution in six and one-half minutes.

The height of the active fuel bed, 76 to 91 cm. (30-36 inches), differentiates this gasifier from moderately deep bed gasifiers (Wellman-Galusha, Lurgi), and very deep bed gasifiers (two-stage units). This design resulted from the need to accommodate swelling bituminous coals in the steel

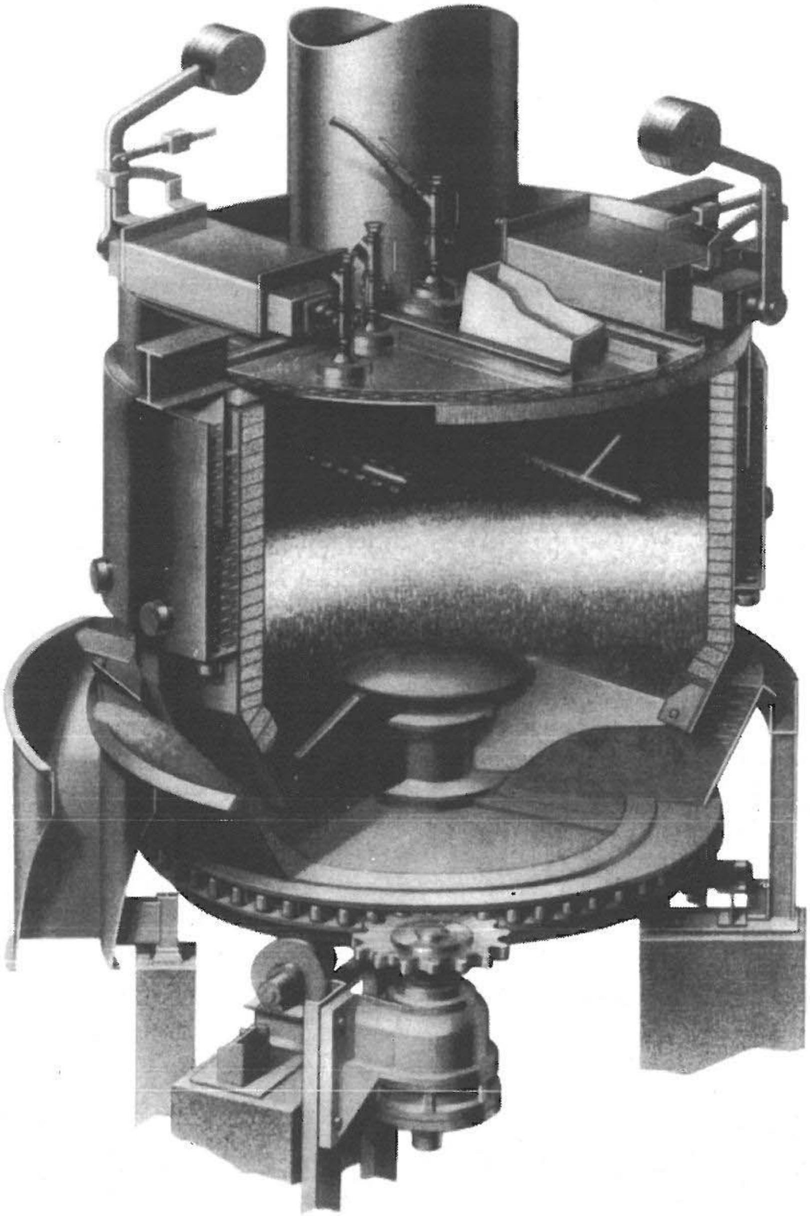

Figure 1. The Riley Gasifier

industries of the United States and the United Kingdom.

As has been found (Reference 1), coal particle heating rate is the controlling factor in managing swelling coals, and the ability to vary bed height allows the time-temperature history of the individual coal particle to be preselected and governed, resulting in minimal swelling. In general, thin-bed gasifiers operate with considerably higher exit temperatures than do the other classes of gasifiers, so that the distillation/pyrolysis environment which is first seen by the coal is more severe. This difference must be kept in mind in comparisons of yields and distribution of some of the minor families of compounds evolved from different gasifiers. Ash retention characteristics may also be influenced.

Continual rotation of the entire 3.2 meter (10'-6") I.D. unit accomplishes a number of purposes. Primarily, it is to assure even coal distribution across the entire fuel bed, a crucial factor in thin-bed management. This is accomplished without the use of an internal distributor by means of a slot drum feed across an entire radius of the unit. Thus, a continuous curtain of the fuel is evenly laid upon the advancing fuel bed.

Second, two horizontally fixed but vertically moveable water-cooled bars perform the function of fuel bed agitation, another requirement for swelling coals.

Third, ash is removed intermittently thru the use of a plow mechanism which is periodically stopped, scooping ash from the integral pan and discharging it over the ash pan lip. Some of the seal water will be carried over with this ash, and means for its treatment must be considered.

The Riley gasifier utilizes a blast hood for air/steam admission, rather than a grate, the ash bed acting as the diffuser.

THE SYSTEM

The demonstration facility at Riley Stoker is shown schematically in Figure 2. Coal is fed to the unit from a 60 ton nitrogen sealed bunker thru a three-valve lock hopper system, and is gasified by the countercurrent air/steam mixture. Gas exits thru a .9 meter (36 inch) insulated line, is cleaned of particulate in a high efficiency cyclone and transported to a 300 million Btu/hour test furnace where it is combusted. Char is removed from the cyclone dry, thru a lock hopper arrangement. A photograph of the installation is shown in Figure 3.

DESIGN FOR EMISSIONS

Much of the work at RSC during the past seven years has been devoted to design improvements of those parts of the system responsible for fugitive emissions. Historically, most gas producer manufacturers paid scant attention to the two areas most responsible for such emissions of raw gas: the coal feed system and access ports.

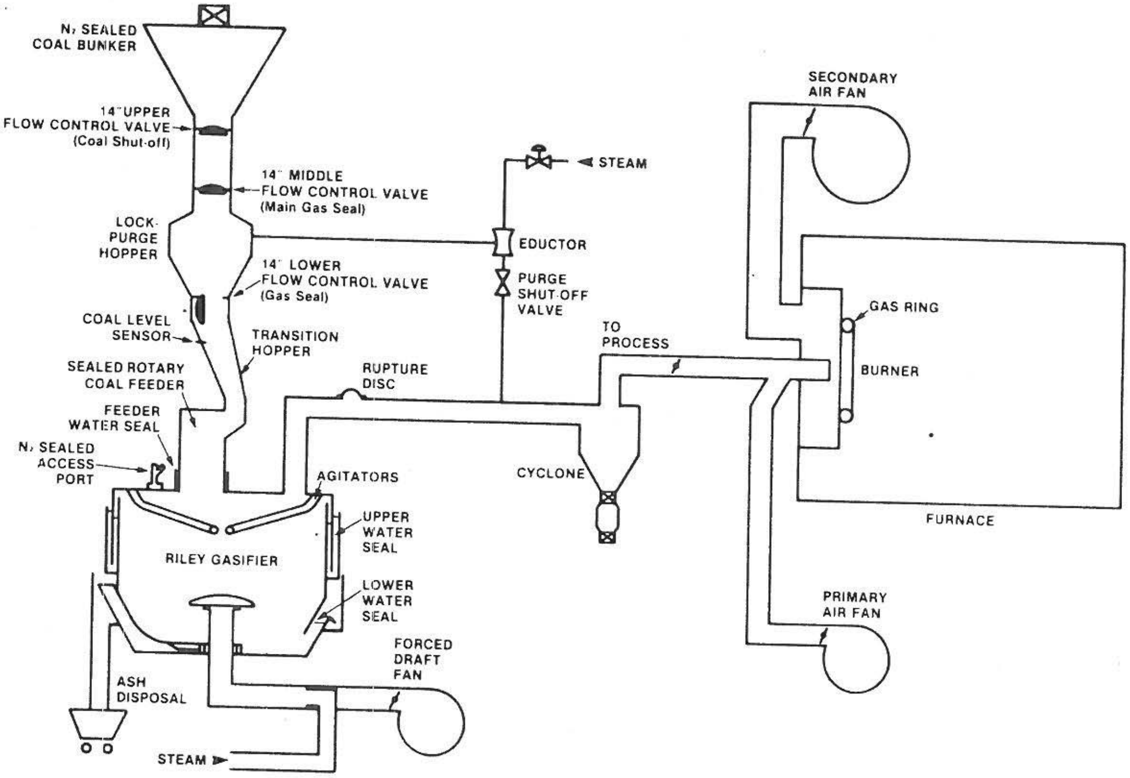

Figure 2 Schematic of the Test Facility

Figure 3. Riley Installation

Coal Feed System

In the Riley Stoker lock-purge coal feed system as shown in Figure 2, fuel is inventoried up to a level just below the middle valve, with the valves positioned as shown. The top valve must support a head of coal up to 6.4 meters (21 feet). The middle valve is closed to contain system gases. The lower valve is open to admit lock hopper coal to the gasifier feeder. All valves are of a semi-ball type, with ground seats.

As gasification proceeds the fuel in the lock hopper falls to a level just below the lower valve, where its absence is detected by means of a sonar device. This triggers a sequence as follows: following closure of the lower valve, a short burst of steam is admitted into the line from the eductor to the lock hopper cleaning that line of any residual tar or dust from the previous cycle. After an interval, the purge shut-off valve opens, and the steam eductor begins evacuating the lock hopper of gas and discharging it into the downstream gas piping system. The pressure in the lock hopper eventually becomes sub-atmospheric (660 mm. Hg. or less). At this time, the steam and purge shut-off valves close, and the upper two flow valves open, admitting coal from the main storage bunker to the lock hopper. These valves remain open until the lock hopper is filled to the previous level (approximately 1 ton). At this time the upper valve closes, interrupting coal flow, followed by the middle valve closing, creating a gas tight seal. The lower valve opens with middle valve closure, and the cycle is completed. Total elapsed time for this entire cycle is approximately one minute.

Throughout this sequence, gasifier feed has been maintained continuously, from the inventory of coal located between the coal feeder and the lower lock valve.

By the maintenance of a nitrogen blanket just slight above atmospheric pressure in the storage bunker above this system, together with the eductor system, migration of gases is always toward the gasifier, and never from it.

Access Ports

After a number of trials, RSC has perfected a nitrogen-sealed (any inert will do), universal joint access port, to be used during those times when access to the gasifier bed is a necessity. This unit is shown in Figure 4. Mounted atop a machined ball that moves within a gland seal fixed to the gasifier deck is another ball valve, a packing gland and a flexible hose conveying inert gas at approximately 1.4 kg/cm^2 (20 psig).

Insertion of a rod thru the upper gland to the ball valve is followed by opening the inert gas line. The ball valve is then opened and the rod inserted into the gasifier thru the assembly, inert gas flowing into the gasifier, and also around the upper gland to the environment.

This arrangement assures no leakage of producer gas into the environment,

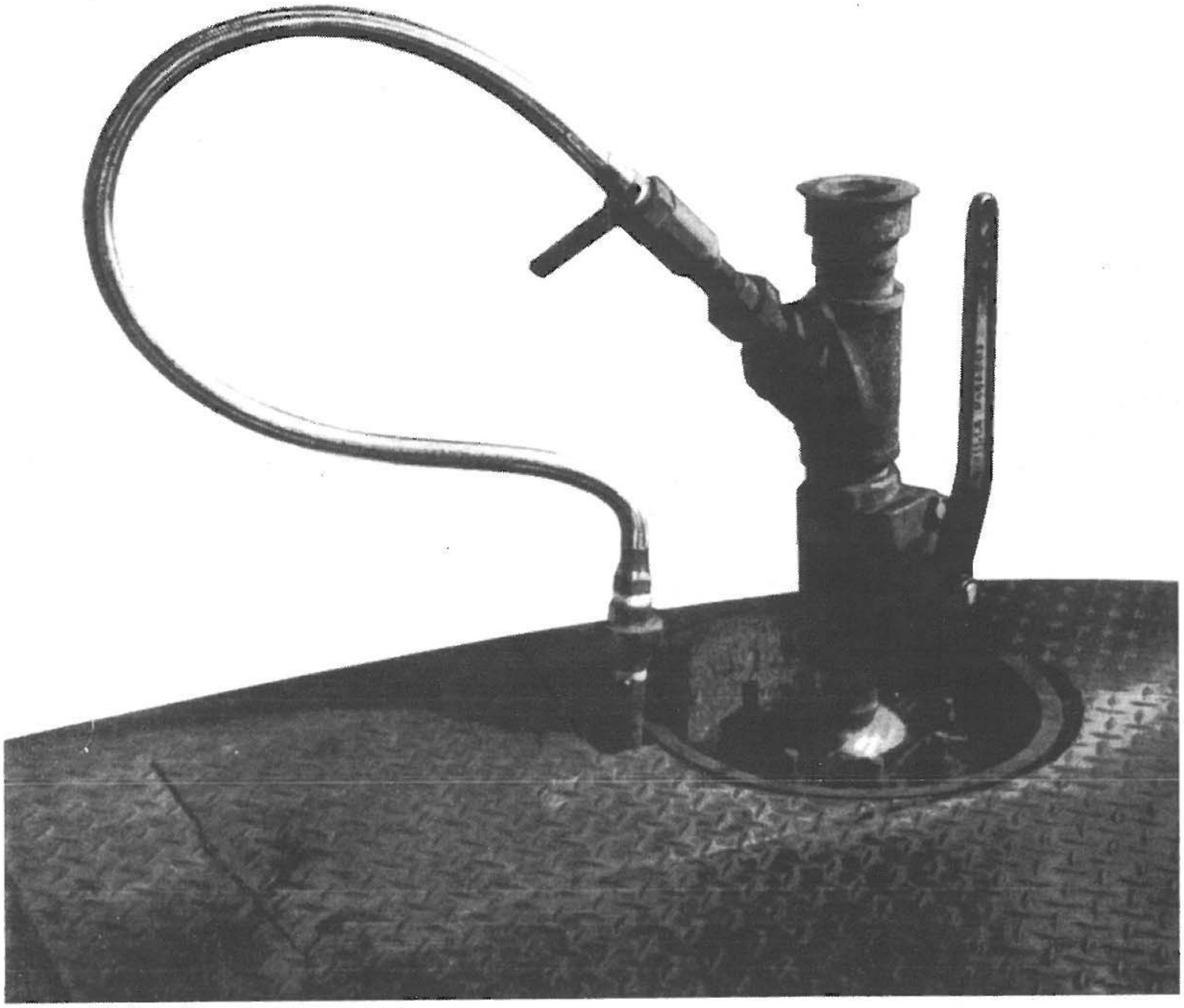

Figure 4. Nitrogen-sealed Universal Joint Access Port

and also makes possible viewing of the fuel bed by the substitution of a plexiglass plate for the rod or other device.

ABSTRACT OF RUN

The gasifier test facility was operated from December 4 to 15, 1979. During this period a total of 374 metric tons of North Dakota lignite was gasified. Because of some non-gasifier problems, two interruptions caused shutdowns early in the test. The major portion of the test fuel was processed in the last five days of operation, and the results presented herein represent data taken from this continuous period. More specifically, data for the environmental assessment were taken over a 25 hour period extending from 0900 hours on December 13 through 1000 hours December 14.

Tables I and II present the heat and material balance around the gasifier at a time near the end of the 25 hour period. Table III shows a summary of the concentrations of the major species of the product gas over the 25 hour operating period. Table IV summarizes the chemical compositions of the feed coal, tar and cyclone dust.

Over the total two week test period, the gasifier was operated at feed rates up to 4550 Kg/hr (10,000 lb/hr) of coal, and produced a high quality low Btu gas with a heating value of approximately 160 Btu/cubic foot. A summary of process conditions during the 25 hour sampling period is given in Figures 5 and 6.

ENVIRONMENTAL RESULTS

For the purposes of a source analyses model evaluation, five effluent or process streams are considered coming from the gasifier: product gas vapors; product gas particulates, tars and oils; gasifier ash; cyclone dust; and ash pan water. Product gas vapors are distinguishable from product gas particulates, tars and oils by a characterization temperature of 115 C (240 F). The product gas is separated into two fractions at this temperature by the sampling procedure. The separation makes it possible to assess the potential health and ecological effects of fugitive emissions. It also allows an evaluation of appropriate control technologies. The phase condensed and collected at 115 C (particulates, tars and oils) was collected in an electrostatic precipitator. The remaining portion of the product gas (vapors) was collected in a condenser at approximately 15 C (60 F), followed by an organics absorption resin for organics collection, or an impinger train for trace elements, ammonia or hydrogen cyanide.

The results of the source analysis model (SAM/1A, Reference 4) evaluation of the five effluent or process streams are presented in Figure 7. By this evaluation procedure there are potentially harmful health and ecological effects for all total discharge severity (TDS) and total weighted discharge severity (WDS) values above 1. Each of the five streams exhibited potentially harmful health and ecological effects. The SAM/1A approach indicated that potential health and ecological effects were primarily due to organic compounds. However, the total DS for the streams (except gasifier ash and product gas vapors) include significant contributions from "worst case assump-

TABLE 1. OVERALL HEAT & MATERIAL BALANCE

	Mass Flow Rate		Temperature		Type of Heat	Enthalpy*			Heat Flow Rate	
	kg/s	(lb/hr)	°C	(°F)		kJ/kg	(Btu/lb)	KW	(1000 Btu/hr)	Percent
Inputs										
Coal	1.045	(8,292)			Potential	16,205	(6,967)	16,932	(57,700)	96.0
			-2	(29)	Sensible	-33	(-14)	-34	(-116)	-0.2
Net Stream	0.274	(2,174)	164	(328)	Sensible	2,847	(1,224)	780	(2,661)	4.4
Air	1.554	(12,334)	-2	(29)	Sensible	-28	(-12)	-43	(-148)	-0.2
Total	2.837	(22,800)						17,635	(60,167)	100.0
Outputs										
Dry Gas	2.299	(18,245)			Potential	6,020	(2,588)	13,840	(47,218)	78.5
			270	(518)	Sensible	265	(114)	609	(2,080)	3.5
Moisture	0.440	(3,492)	270	(518)	Sensible	2,910	(1,251)	1,280	(4,368)	7.3
Tars and					Potential	26,193	(11,261)	566	(1,926)	3.2
Oils	0.0215	(171)	270	(518)	Sensible	205	(88)	4	(15)	---
					Potential	20,139	(8,658)	86	(294)	0.5
Cyclone Dust	0.0043	(34)	270	(518)	Sensible	205	(88)	1	(3)	---
					Potential	8,806	(3,786)	952	(3,248)	5.4
Ash	0.108	(858)	93	(200)	Sensible	58	(25)	6	(21)	---
Heat to Cooling Water								128	(437)	0.7
Unaccounted for Losses								163	(557)	0.9
TOTAL	2.873	(22,800)						17,635	(60,167)	100.0

* Enthalpy is 25°C (77°F) and H_2O liquid. Potential heats are based on higher heating value (HHV).

TABLE II. POTENTIAL ENERGY FLOWS BY LOWER HEATING VALUE

	Mass Flow Rate kg/s	LHV kJ/kg	LHV Heat Flow Rate kJ/s
Lignite Feed	1.045	14,783	15,448
Dry Gas	2.299	5,636	12,957
Tars and Oils	0.0215	24,398	525
Cyclone Dust	0.0043	19,821	85
Ash	0.108	8,706	940

TABLE III. MAJOR GAS COMPONENTS

	Time	Volume Percent on Dry Basis					
	Hrs	CO	CO_2	H_2	O_2	N_2	CH_4
Dec. 13	1000	NA	NA	NA	NA	NA	NA
	1100	NA	NA	NA	NA	NA	NA
	1200	NA	NA	NA	NA	NA	NA
	1300	NA	NA	NA	NA	NA	NA
	1400	26.9	7.0	16.6	1.1	46.8	NA
	1500	24.1	8.6	16.6	1.1	48.2	0.6
	1600	26.1	7.2	16.5	1.0	47.3	1.0
	1700	28.0	6.8	16.7	1.2	45.8	0.7
	1800	27.1	6.6	16.7	1.1	46.5	1.2
	1900	27.4	6.7	26.9	1.2	46.4	0.7
	2000	24.6	8.3	16.5	1.1	47.6	1.0
	2100	25.3	8.0	16.5	1.1	47.5	0.7
	2200	27.3	7.1	16.8	1.0	45.7	1.2
	2300	27.4	7.2	16.9	1.0	45.6	1.1
Dec. 14	2400	27.6	7.1	16.6	1.1	45.3	1.4
	0100	26.6	7.7	16.0	0.9	46.6	1.4
	0200	27.0	7.1	17.1	1.0	45.6	1.3
	0300	27.7	6.4	18.0	1.1	44.5	1.5
	0400	28.2	6.2	17.4	1.2	44.8	1.5
	0500	28.9	6.3	17.3	1.2	44.7	0.9
	0600	25.7	7.7	18.3	1.3	45.4	0.9
	0700	28.8	6.3	18.7	1.3	43.3	0.9
	0800	29.2	5.9	19.0	1.1	43.2	NA
	0900	28.9	5.3	17.3	1.0	45.9	NA
	1000	26.4	8.9	17.2	1.2	44.8	NA

Notes: * Compositions are Radian process gas chromatograph readings normalized to 100 percent.

** Argon was not measured and is assumed to be 0.54 volume percent for all periods.

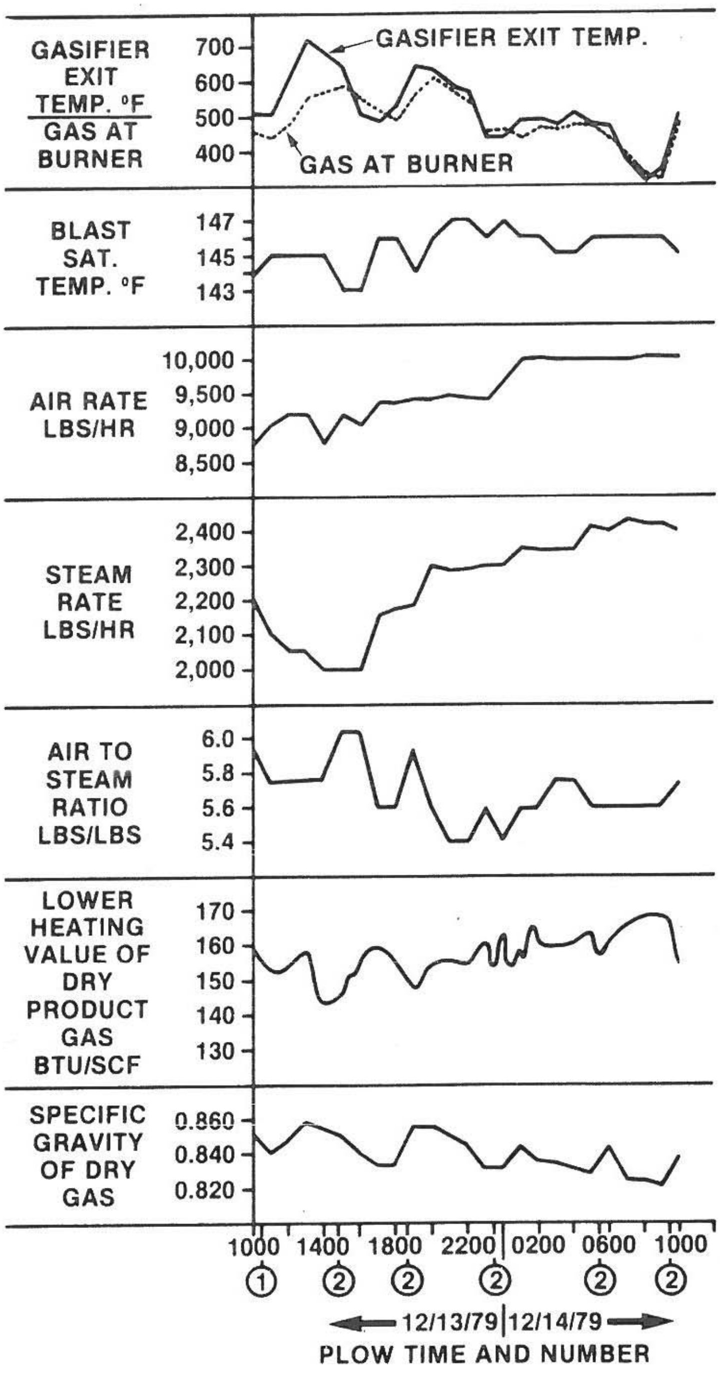

Figure 5. *Process Variable for 24 Hour Period*

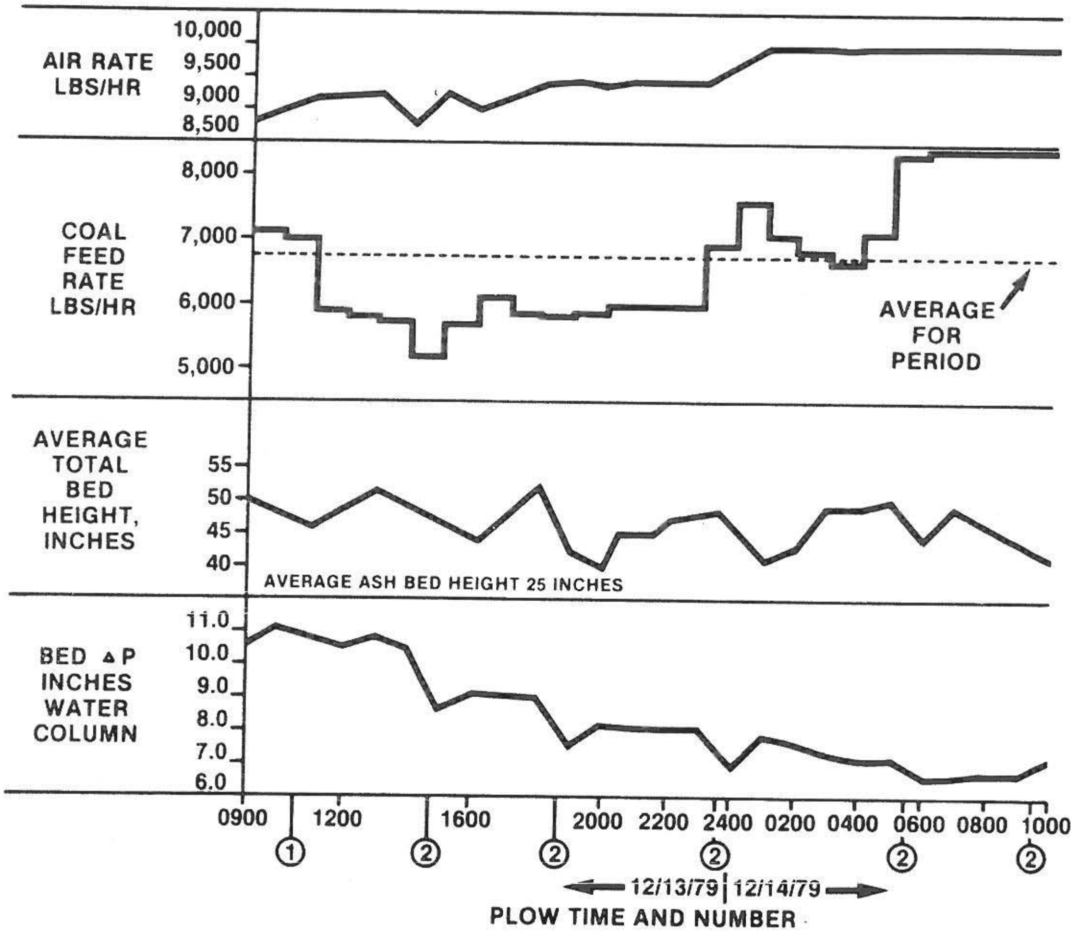

Figure 6. *Bed Related Process Variable Plots for 25 Hour Lignite Run*

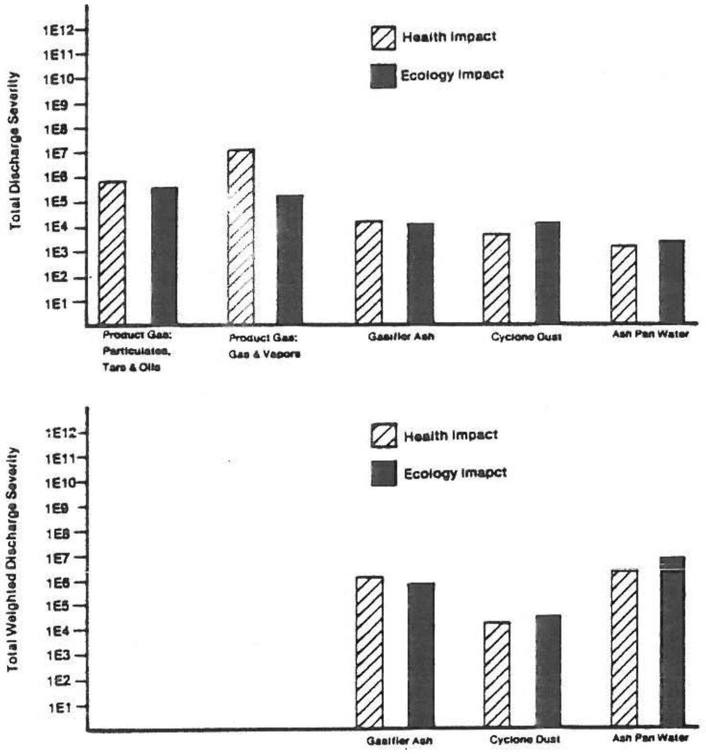

Figure 7. Total Discharge Severities and Weighted Discharge Severities of Effluent Streams

TABLE IV. SELECTED CHEMICAL ANALYSES

	Feed Coal (as received)%	Cyclone Dust WT.%	Tar WT.%
Moisture	34.10	0.59	--
Ash	7.54	38.21	0.20
Carbon	41.82	54.48	59.57
Hydrogen	2.83	1.48	8.40
Oxygen	12.70	2.82	30.75
Nitrogen	0.70	0.83	0.69
Sulfur	0.31	1.59	0.33
V.M.	30.68	--	--
F.C.	27.68	--	--
HHV, Btu/lb	6,967		
HHV, kJ/kg	16,205	8,607	11,261
LHV, kJ/kg	14,669	20,020	26,193

TABLE V. CONTRIBUTIONS TO TOTAL DS AND TOTAL WDS BY WORST CASE ASSUMPTIONS GC/HECD DATA, AND EXPERIMENTALLY DETERMINED RESULTS

	Health				Ecology			
EFFLUENT STREAMS	WCA*	GC/HECD	EXP.	ORG./INORG.	WCA*	GC/HECD	EXP.	ORG./INORG.
Product Gas: Particulates, Tars and Oils	~97%		~3%	99.9%/0.1%	~99%		1%	99.7%/0.3%
Product Gas: Gas and Vapors	~100%	<1%	<1%	100%/0%	<1%		~100%	100%/0%
Gasifier Ash	~1%	~2%	~97%	18%/82%	<1%	~4%	~95%	5%/95%
Cyclone Dust	~83%		~17%	83%/17%	~23%		~77%	23%/77%
Ash Pan Water	~74%	~5%	~21%	99.9%/0.1%	~76%	~3%	~21%	79%/21%

*Worst Case Assumptions

tions" for the organics, which should be greatly reduced by more extensive analysis for specific organics (Table V).

Inorganic elements, on the other hand, had the most significant contribution to the health and ecological impacts of the gasifier ash stream, with iron having the most significant health impact and phosphorus the most significant ecological impact. Inorganic elements did not contribute significantly to total DS or WDS for product gas or ash pan water health effects. However, phosphorus did make a significant contribution to the ecological effects of the ash pan water.

The findings in this source test evaluation indicate that the potential health and ecological effects of the ash pan water are significant. Even though the organic loading of the ash pan water was very low, the health and ecological DS and WDS of the stream were the result primarily of organics, other than the contribution of phosphorus to ecological impact. During the test program, ash pan water was continuously purged. Therefore, the concentrations of many parameters of concern in the stream were possibly held below anticipated levels of design operation using recycle, thereby reducing the total DS. However, continuous purging of the ash pan water provided a flow rate higher than design operation flow rate for the ash pan water and thereby raised the total WDS values to a level representative of commercial operation of the gasifier (Table VI).

Since organics provide the most significant contribution to the total DS of the product gas, these values would be reduced for the product gas combustion effluent due to the vast reduction in organic content following combustion. It should be noted that the SAM/1A approach treated the product gas as an effluent stream, which it is not, other than as a fugitive emission.

The SAM/1A results for gasifier ash and cyclone dust also showed potentially harmful health and ecological effects. On the other hand, bioassay tests conducted on the solid gasifier ash and cyclone dust indicated little or no health hazard. A neutral leaching of the two solid streams provided a liquid for bio-assay testing that showed a high level of ecological hazard. However, subjecting the gasifier ash and cyclone dust to (RCRA) leaching procedures (Reference 5) resulting in the solids being classified as non-hazardous (Tables VII, VIII).

EMISSIONS FOLLOWING COMBUSTION

Presently, the main concern about the utilization of coal and coal-derived fuels in industry centers above emissions of oxides of sulfur, oxides of nitrogen, and particulates. While the actual emissions of SO_2 and NO_x due to low Btu gas combustion are dependent on application, the Riley test provided some indication of what the expected levels of these emissions might be.

During the two week test period, product gas from the gasifier was passed through a single stage cyclone for clean-up and transported directly to the large kiln burner. Because the temperature of the gas was maintained very close to that observed at the gasifier exit, not one gallon of product

TABLE VI. COMPARISON OF LIQUID STREAMS TO DRINKING WATER STANDARDS*

	NIPDWS*** µg/1	NSDWR**** µg/1	ASH PAN WATER** RANGE µg/1	ASH PAN WATER** AVERAGE µg/1	ASH PAN CARRY-OVER WATER µg/1	SERVICE WATER µg/1
As	50		11 - 30+	21+	9+	<10
Ba	1,000		91 - 230	170	250	100
Cd	10			<1	≤10	<10
Cl-		250,000	48,000-110,000	78,000	2,000	300
Cr	50			<1	<1	≤30
Cu		1,000	3 - 10	6	<1	70
F-	1,800		300 - 710	530	~1,000	~20
Fe		300	540 - 3,400	1,900	910	3,000
Pb	50		<1 - 2	<1.3	300	<10
Mn		50	27 - 96	58	11	40
Hg	2			<0.5+	<0.5+	
Se	10		<5 - 10+	<7	<5+	<10
Ag	50		2 - 30	14	20	<10
Zn		5,000	<3 - 12	<5.3	<3	80
NO_3^- (as N)		10,000		<20		
$SO_4^=$ (mg/1)		250	540 - 1,870	1,260		6.1
pH		6.5-8.5	10.2 - 11.3	10.8	5.0	4.3
TDS (mg/1)		500	1,250 - 2,050	2,250		52

*ICPES analytical results unless noted otherwise. Analysis performed by SSMS.
**Samples RM-18, RM-23, RM-49
***National Interim Primary Drinking Water Standards (Federal Register, 8/27/80).
****National Secondary Drinking Water Regulations (Federal Register, 7/19/79).
+Analysis performed by AAS.

TABLE VII. BIOASSAY TEST MATRIX

	Ames* (Health)	CHO** (Health)	RAM*** (Health)	RAT**** (Health)	Fresh-water Alga***** (Ecology)
Cyclone Dust	Negative	Low Toxicity	No Detectible Toxicity		
Gasifier Ash	Negative	No Detectable Toxicity	Low Toxicity		
Gasifier Ash Neutral Leachate	Negative	Low Toxicity		Not Toxic	Toxic
Cyclone Dust Neutral Leachate	Negative	No Detectable Toxicity		Not Toxic	Toxic

*Salmonella Mutagenesis Assay (Ames)
**Chinese Hamster Ovary Clonal Toxicity Assay (In Vitro Cytotoxicity Assay)
***Rabbit Alveolar Macrophage Assay (In Vitro Cytotoxicity Assay)
****Rodent Acute Toxicity (Acute in Vivo Toxicological Test)
*****Freshwater Alga (Selenastrum capricornutum) Toxicity Assay

TABLE VIII. COMPARISON OF SOLID EFFLUENT EXTRACTS AND RCRA EXTRACT LIMITS

	RCRA Extract Limits* (5/19/80)	Gasifier Ash Leachate*	Cyclone Dust Leachate*
As	5,000	33	4
Ba	100,000	680	390
Cd	1,000	<0.5	<0.5
Cr	5,000	<1	<1
Pb	5,000	<2	<2
Hg	200	<0.5	<0.5
Se	1,000	6	2
Ag	5,000	<0.5	<0.5
Endrin	20	<2.0	<2.0
Lindane	400	<0.2	<0.2
Methoxychlor	10,000	<2.0	<2.0
Toxaphene	500	<100	<100
2,4-D	10,000	<0.8	<0.8
2,4,5-TP Silvex	1,000	<0.3	<0.3

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*Concentrations in μg/liter.

gas tars and oils was condensed from the gas, nor was any significant amount of water-based condensate produced. With the exception of a light coating of dust which formed on the inside of the gas main, all product gas effluents leaving the gasifier cyclone outlet proceeded to the gas burner for combustion.

Combustion of the product gases was achieved in a low pressure baffle burner operating with combustion in the primary air zone at 33% of theoretical air and 213% of theoretical air overall. The theoretical adiabatic flame temperature for this mixture was 1077 C (1970 F). The flame produced was a long diffusion flame, ranging from 1.2 to 2 meters (4-7 feet) in diameter and 9 to 12 meters (30-40 feet) in length. Figure 8 illustrates several temperature profiles measured in the flame using a suction pyrometer.

No measurements of actual stack emissions were made. However, by analyzing the composition of the product gas being fed to the combustor, it was possible to make the following correlations.

The North Dakota (Indian Head) lignite gasifier feedstock for the 24 hour test period had an average sulfur concentration of $0.44 g/10^6 J$ (1.02 lb $S/10^6$ Btu). Some 53% of the sulfur being fed to the gasifier was being converted to reduced sulfur species in the product gas, with the majority of the remainder being retained by the gasifier ash stream. If 100% of the reduced sulfur species in the product gas were converted to sulfur dioxide during combustion, the resulting SO_2 emission level would be $0.49 g/10^6 J$ (1.10 lb $SO_2/10^6$ Btu) based on the heat value of the lignite feed. The New Source Performance Standards emission limit for SO_2 is $0.52 g/10^6 J$ (1.20 lb $SO_2/10^6$ Btu) for coal-fired boilers (Reference 6, Subpart D: Fossil Fuel Fired Steam Generators).

The average ammonia content of the product gas was 7.8×10^5 µg/Nm^3 and the average HCN concentration was 1.8×10^5 µg/Nm^3. About 26% of the nitrogen in the lignite feedstock was converted to reduced nitrogen species. Assuming that 100% of the reduced nitrogen species in the product gas was converted to NO_x during combustion, the resulting NO_x emission (as NO_2) would be $0.36 g$ $NO_2/10^6 J$ ($0.84 lb$ $NO_2/10^6$ Btu) based on the heat value of the lignite feedstock. The NSPS emission level (Subpart D) for NO_x is $0.26 g$ $NO_2/10^6 J$ (0.60 lb $NO_2/10^6$ Btu) for coal fired boilers. While estimated NO_x emissions may be biased high, assuming 100% conversion of reduced nitrogen species to NO_x, it does not provide for the additional NO_x created due to thermal reaction of nitrogen and oxygen during combustion, which for many applications may be a significant contribution. For the specific test described here, the low combustion temperatures observed would likely minimize thermal production of NO_x, but high excess air levels would likely favor conversion of reduced nitrogen species to NO_x.

The particulate loading of the product gas stream was 4.76×10^5 µg/Nm^3 downstream of the cyclone. Particulate was assumed to be of the same composition as the cyclone dust, and the cyclone dust ash content was used for calculations to determine the particulate emissions after combustion. Basing the adjusted particulate loading upon the heat value of the lignite feedstock, the particulate emission after combustion would be 0.026g particulate/

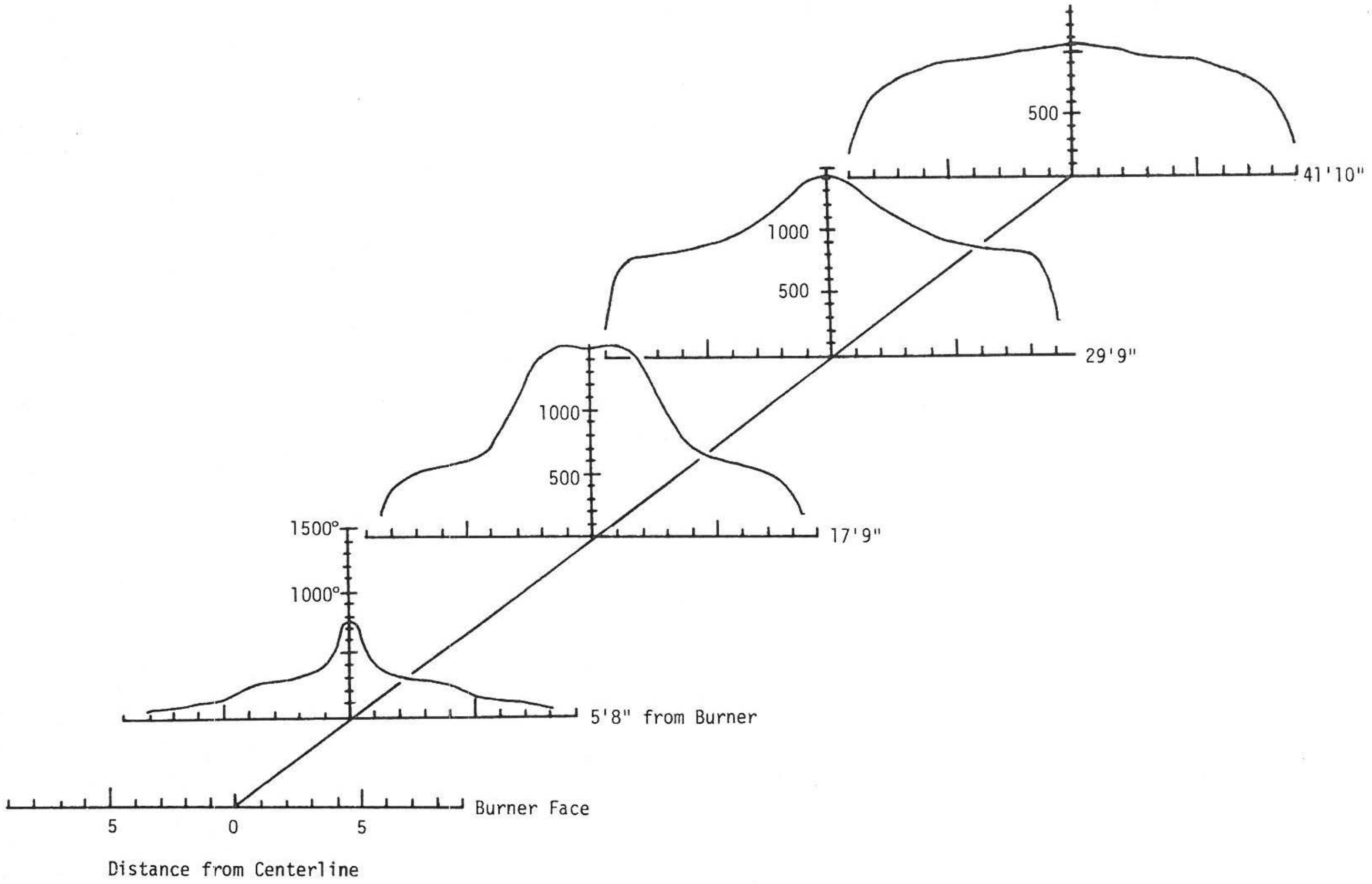

Figure 8. LOW BTU GAS FLAME TEMPERATURE PROFILE
(9300 lb/hr rate)

10^6J (0.06 lb particulate/10^6 Btu). This particulate emission estimate does not consider particulate resulting from incomplete combustion of tars and oils. The NSPS (Subpart D) for particulate is 0.043g particulate/10^6J (0.10 lb particulate/10^6 Btu) for coal-fired boilers.

FUGITIVE EMISSIONS

The North Dakota lignite gasification test provided an opportunity for testing the effectiveness of the unique Riley coal feed and poke hole designs for minimizing fugitive emissions from the gasifier. Fugitive emissions of hydrocarbons were measured in the vicinity of the gasifier by several methods. Hydrocarbon concentrations, reported as methane, were less than on part per million as summarized in Table IX. Hydrocarbons were also measured in the off-gases from the nitrogen-pressurized coal bin. Concentrations here were 5-6ppm as methane. Readings of two carbon monoxide monitors maintained by Riley Stoker were recorded during the sampling period, and are summarized in Table X. The maximum recorded CO concentration was 24 ppm with readings generally below this value. The Occupational Safety and Health Administration (OSHA) permissable exposure limit for CO is 50 ppm (see Reference 7). There is no OSHA regulation for hydrocarbons as a compound class. Propane is the lightest hydrocarbon regulated by OSHA and has a permissable exposure limit of 1,000 ppm.

Radian Corporation has performed STE's for a Chapman low Btu gasifier with a bituminous coal feedstock and a Wellman Galusha gasifier with an anthracite coal feedstock. The Chapman STE Report (Reference 8) presents coal feeder vent gas hydrocarbons concentrations of 2.5×10^6 μg/Nm^3. Similar measurements at the Wellman Galusha facility (Reference 9) resulted in coal hopper gas hydrocarbon concentrations of 1.4×10^6 μg/Nm^3 as methane. Related values measured at the Riley gas producer are many orders of magnitude less. These data demonstrate the relative reduction of fugitive emissions achieved by the controls employed on the coal bin at the Riley gas producer.

A sample was taken of the poke hole gas discharge during a simulated poking operation on the gasifier, to determine the effectiveness of the Riley poke hole design in keeping product gas sealed within the gasifier. Table XI summarizes the results of that test, and shows the high degree of effectiveness of the Riley poke hole.

TRACE ELEMENTS

Trace elements enter the gasification process with the lignite feedstock and are subjected to the high temperatures of the process. Many elements, especially the more volatile ones, undergo volatilization in the hot areas of the system, and may either remain a vapor in the product gas, condense homogeneously, or condenses upon aerosol particles. Other elements are chemically transformed into gaseous species and are emitted in the product gas. Most trace elements remain in the coal solids and are emitted in the gasifier ash. Even though the majority of most elements are emitted with the solid effluent streams, RCRA extraction procedures analyses result in the classification of these solids as non-hazardous.

TABLE IX. ORGANIC VAPORS ANALYSIS

DATE	TIME	LOCATION	CONCENTRATION (ppm as CH_4)
12/13	1100 hrs	Gasifier Building --all walkways	1.5 ppm
12/13	2200 hrs	Gasifier Building --all walkways	1 ppm
12/13	2200 hrs	Gasifier Building --top of gasifier during poking operation	1 ppm
12/13	2223 hrs	Coal Bin --2-inch gate on top	5-6 ppm

TABLE X. CARBON MONOXIDE MONITOR READINGS

Date	Time	Monitor 1*	Monitor 2**
12/13	1100		20 ppm
12/13	1500	1 ppm	
	1502		12 ppm
	1506		15 ppm
	1750	1 ppm	24 ppm
	1808		1 ppm
	2213		<0 ppm
12/14	0035		<0 ppm
	0235	1 ppm	<0 ppm

*Located in gasifier building on ground level, west wall.

**Located in gasifier building on gasifier poke hole level, north wall.

TABLE XI. POKE HOLE DISCHARGE DURING SIMULATED POKING OPERATION

DATE: 12/14

TIME: 0645 hours

FLOWRATE: 0.022 m^3/sec (actual)

GAS ANALYSIS:

N_2	95.4%
H_2	1.1%
O_2	0.2%
CO	Below detection limit
CH_4	Below detection limit
CO_2	Below detection limit

Minor and trace elements can be grouped according to the mechanism by which each is emitted. The elements primarily in the product gas can be considered highly volatile or transformed into gaseous compounds. Moderately volatile elements are predominately in the cyclone dust or product gas particulate and can be evaluated on the basis of volatilization and recondensation. Elements emitted predominately in the gasifier ash can be considered to be non-volatile elements.

For this source test evaluation, an element was considered to be highly volatile if 25% or more of its total mass was found in the gas and vapors portion of the product gas. These highly volatile elements were: bromine, cesium, chlorine, fluorine, gallium, iodine, selenium, silicon, sulfur and tellurium. An element was classified as moderately volatile if 25% or more of its total mass was found in the cyclone dust and particulates, tars and oils portion of the gas. These elements were: antimony, arsenic, chromium, germanium, lead, tin, and zinc.

The following elements were possible volatile and will acquire additional data to characterize their behavior definitively: beryllium, bismuth, cadmium, dysprosium, erbium, europium, gold, holmium, iridium, neodymium, osmium, palladium, platinum, praseodymium, radium, rhodium, ruthenium, silver, tantalum, terbium, thallium, thulium, uranium and ytterbium.

Figures 9 and 10 graphically present the elemental distribution in the effluent streams. The elements are listed in the order of increasing boiling points. In general, as the elemental boiling points increase, the predominance of elemental distribution shifts from the product gas to the gasifier ash. Although a general trend is evident, there is no direct correlation between elemental boiling point and distribution. The distribution of individual elements in the system is dependent not only on elemental boiling point, but also on much more complex properties, including chemical reactions within the gasifier, the volatility of compounds containing the elements, and solubility of compounds in the tars and oils.

Most of the elements classified as highly volatile from their distribution in the effluent streams were depleted in both the gasifier ash and cyclone dust. Cesium and gallium were exceptions and were enriched in both solids. This behavior is more characteristic of non-volatile elements.

Those elements considered to be moderately volatile from distributions fell into two major categories. Lead, chromium and zinc follwed the expected behavior of being depleted in the gasifier ash and enriched in the cyclone dust. Arsenic and antimony, however, were depleted in both solids. The distribution results show that both of these elements were found in the particulates, tars and oils fraction of the product gas. This indicates somewhat greater volatility than that of other moderately volatile elements. The behavior of germanium and tin was more characteristic of non-volatile elements, for germanium was enriched in both solids, and the enrichment ratios for tin were very close to the ash contents.

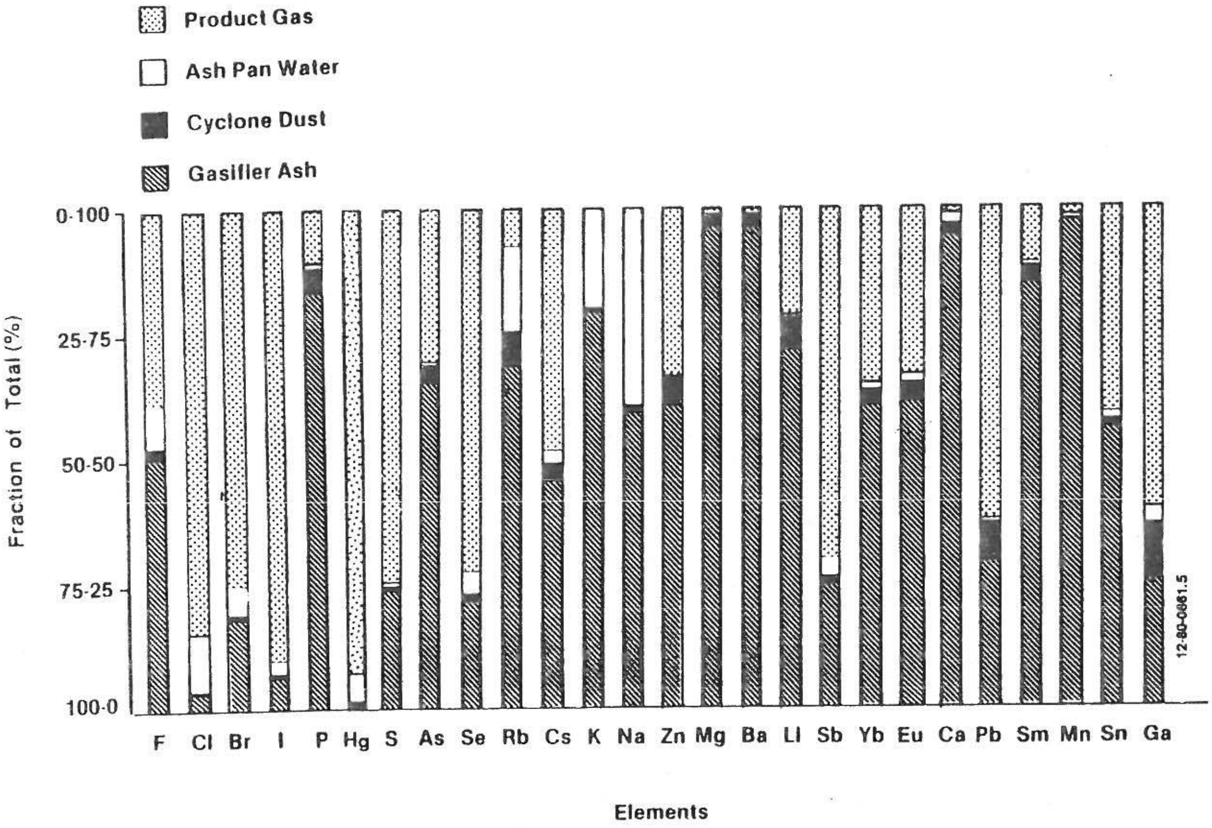

Figure 9. Stream Elemental Distributions as Percentage of Combined Effluent Streams Emission (Ordered by Increasing Elemental Boiling Points)

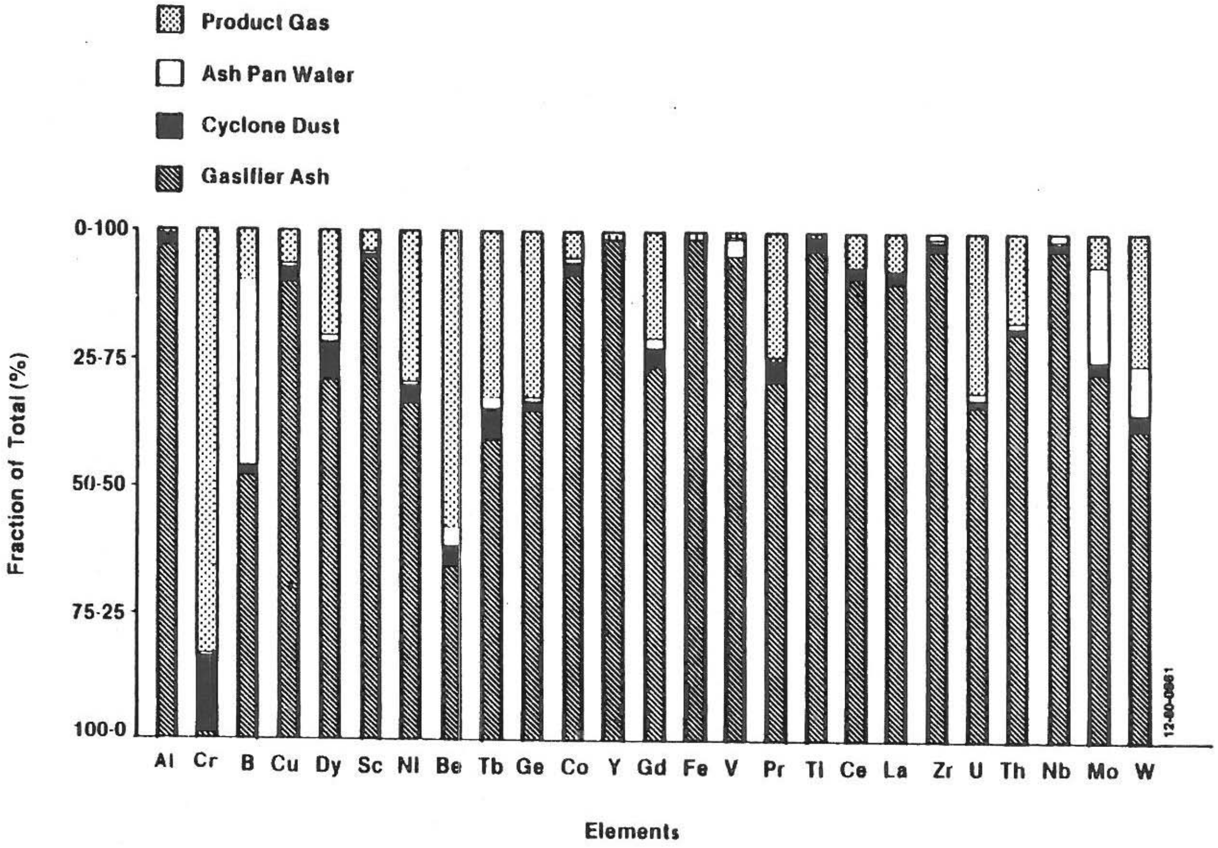

Figure 10. Stream Elemental Distributions as Percentage of Combined Effluent Streams Emission (Ordered by Increasing Elemental Boiling Points)

CONCLUSIONS

The major findings of this program are summarized below.

- Acute bio-assay tests of the gasifier ash and cyclone dust solids and neutral leachates of the gasifier ash and cyclone dust indicated no adverse health effects. Environmental bio-results of neutral leachates of the gasifier ash and cyclone dust showed significant toxic effects.

- Leaching studies conducted on the gasifier ash and cyclone dust to determine the effects of solid waste disposal, indicated that the materials are non-hazardous according to Resource, Conservation and Recovery Act (RCRA) protocol and standards.

- Although the gasification process emits over 50% of the lignite sulfur in the product gas, it will not require additional sulfur removal to meet New Source Performance Standards for coal fired boilers.

- Assuming that 100% of the ammonia and HCN present in the product gas are converted to NO_x during combustion, and not considering the contribution of thermally created NO_x in the boiler, additional NO_x controls will be necessary to meet the New Source Performance Standards for coal fired boilers.

- Additional particulate control measures will not be necessary to meet NSPS for particulate. This conclusion is based upon the particulate loading of the product gas downstream of the cyclone and the heat value of the lignite feedstock.

- Enclosed and pressurizing the coal bin, together with the nitrogen purge poke hole mechanism developed by Riley Stoker significantly reduce fugitive emissions.

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