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Project Summary

Co-Firing of Solid Wastes and Coal at Ames: Pulverized Coal

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The objectives of this research were to conduct an in-depth evaluation of the environmental, economic, and technical aspects of the resource and energy recovery system in Ames, Iowa. The system includes recovery of ferrous metals, preparation, storage, and cofiring of the refuse-derived fuel (RDF) with coal in the power plant owned by the City of Ames to produce electric power.

The evaluation period was three years, and this report covers the third year of research. It includes evaluations of the refuse processing plant operation, economics of the total system and individual subsystems, flow stream characterization, and performance and environmental emissions of the suspension-fired steam generator. Data acquired during the first year's evaluation were previously reported in "Evaluation of the Ames Solid Waste Recovery System, Part I-Summary of Environmental Emissions: Equipment, Facilities, and Economic Evaluations" (EPA-600/2-77-205).

This Project Summary was developed by EPA's Hazardous Waste Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The Ames solid waste recovery system is a continuously operating system that processes municipal solid waste (MSW) to produce a shredded RDF that is burned with Iowa-Western coal mixtures in the tangentially fired steam generator in the Ames municipal power plant. This system consists of a nominal 136-Mg/day (150-ton/day) process plant, a 454-Mg (500 ton) Atlas storage bin, pneumatic transport systems, and the power plant boiler. The process plant incorporates two stages of shredding, ferrous metal recovery, and an air classification (density) separator.

The full report presents results and conclusions of the third-year effort of an evaluation of the Ames solid waste recovery system, including the process plant studies and boiler environmental and thermal performance characterizations. The detailed study objectives are listed in the following section.

This evaluation is a major research program funded by the Environmental Protection Agency (EPA) and the Department of Energy (DOE). Project tasks are being performed jointly by the City of Ames, Iowa, the Engineering Research Institute (ERI) of Iowa State University, the Ames Laboratory/DOE, and MRI. The EPA funding was used to provide for all manpower, major field equipment purchases, power plant and process plant modifications, laboratory analyses of process plant stream characterization, and other supplies used in the evaluation of both the power plant and process plant. The DOE funding was used to provide laboratory analysis of all field samples procured from the power plant testing. Additional financial support was provided by ERI, the City of Ames, and the American Public Power Association.

System Description

The Ames solid waste recovery system consists of three major subsystems: the process plant, the Atlas storage bin, and the existing steam generators of the municipal power plant which were modified to burn RDF. A general flow diagram is shown in Figure 1. The MSW enters the 45.4 Mg/h process line where primary shredding, ferrous removal, and second stage shredding occurs. The RDF produced from the air density separator (ADS) is transported 152.4 m to the 454-Mg Atlas storage bin through a 36 cm diameter pneumatic transport line. Rejects are subjected to further ferrous removal and are then trucked to the municipal landfill.

The RDF is reclaimed from the storage bin by four bucket sweeps which drop the material into two infeed conveyors for the pneumatic transport 61 m to the power plant through two, 20 cm diameter pipes. The RDF is injected into the two opposite corner burners of the 35-MW tangentially fired steam generator. The RDF is burned as a supplemental fuel along with the Iowa-Western coal mixture in suspension, and RDF dropout material is burned on a bottom hopper dump grate installed in 1978.

The tangentially fired boiler (No. 7) is a Combustion Engineering Company, Type VU-40S steam generator using balanced draft operation with a Ljungstrom regenerative air heater and an ESP but no economizer. The two-drum unit operates at 5,860.8 kPa and 485°C steam quality and 163,296 kg/h of steam flow.

Combustion air is drawn from the upper part of the building, passed through the forced draft fan through the air heater, and enters the furnace through the corner burner assemblies via two main windboxes. Flue gases produced by the fuel combustion in the furnace pass over the primary and secondary superheater tube banks through the convection bank, the air heater, and then through the American-Standard ESP and the induced draft fan (both located outside the building). The flue gases are discharged out the 61-m chimney or stack. Boiler pump discharge feed water is used for superheated steam temperature control, and this spray water is injected between the primary and secondary superheater sections.

Process Plant Particulate Emissions and Dust Evaluation

Particulate emissions from the roof ventilators of the refuse plant were evaluated by EPA Method 5 particulate sampling techniques. Extensions were added to each of the roof ventilators on the refuse plant to facilitate the samplng. Twenty-four sampling locations on each of two perpendicular traverses across the diameter of the roof ventilator ducts were used, for a total of 48 sample points. At each sample point, the sampling train was operated for 3 min, meaning that a total sample was collected over 144 min of operation. The amount of particulate collected was then determined on both a volume and a time basis. The results are reported later in this summary under Power Plant Emission Characterization.

In addition to sampling emissions from the roof ventilators, high volume ambient air samplers were placed in the plant to determine the dust concentration at specific locations.

The ambient air in the refuse processing plant was sampled at three general elevations in the plant by means of high volume samplers modified to contain 10 cm (4 in.) diameter quartz fiber filters on which the particulate matter collected as the sample train operated. Each sample train was operated for 15 min. The weight of sample was then determined for the time span of the test and recorded for each location in the plant.

The three levels sampled in the plant included the floor level in the general vicinity of the first and second stage shredders

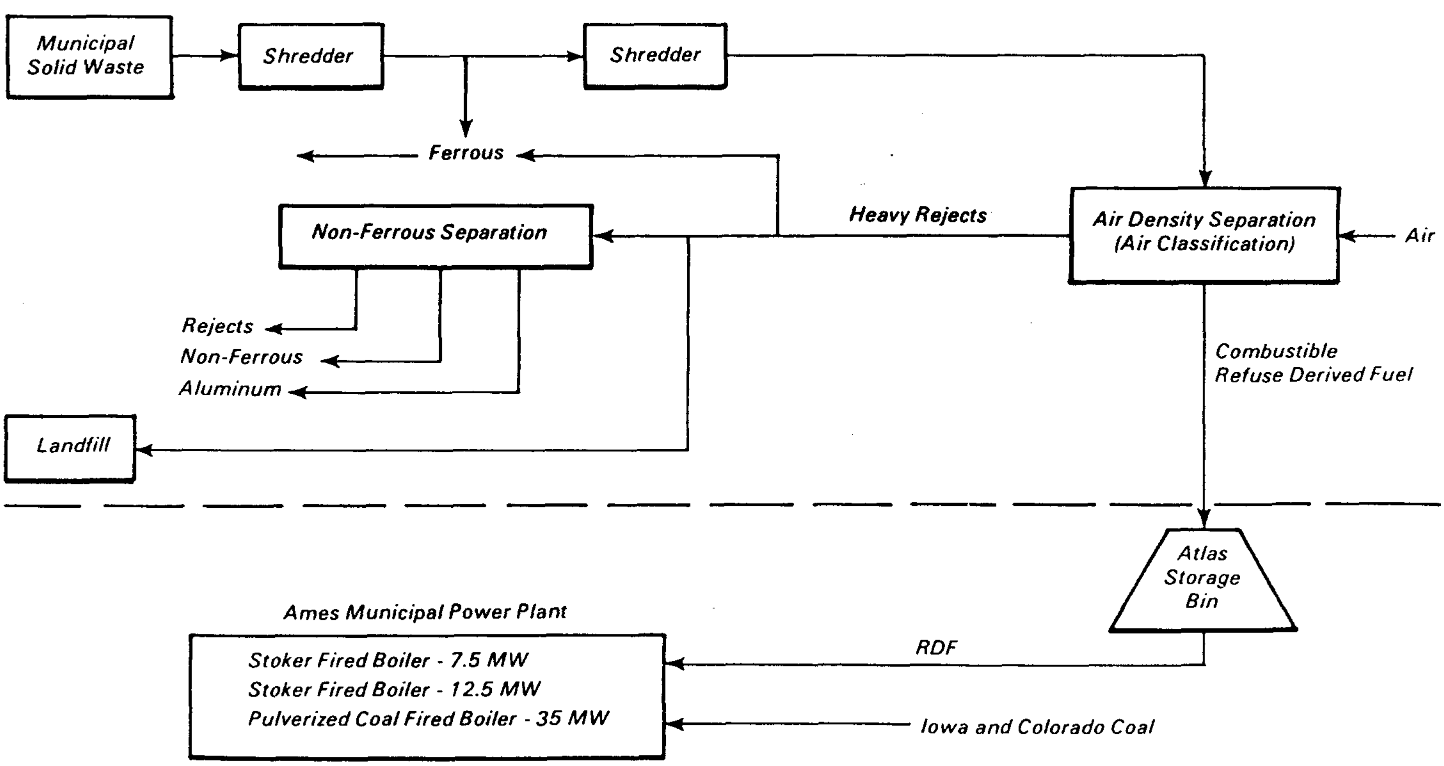

Figure 1. Flow diagram of the Ames solid waste recovery system.

and below the air density separator (ADS). The mid-level location sampling was adjacent to the ADS and underneath the bucket elevator in the processing plant. Upper level samples were taken at a walkway in the plant and at the top of the bucket elevator.

Following the weighing of the samples, several representative filters were analyzed to ascertain the typical elements present in the dust and the amounts. The amount of dust in the ambient air of the processing plant and the results of the trace element analysis are also presented under Power Plant Emission Characterization.

Table 1. *Test Matrix for Unit No. 7 Experimental Runs*

Percent Load	*Percent RDF*		
	0%	*10%*	*20%*
60%	*3 runs (1976)*	—	—
80%	*3 runs (1976)*	*2 test runs (1977)*	—
100%	*3 runs (1976)*	—	—
80% (Wyoming coal)	*3 runs (1978)*	*3 runs (1978)*	*3 runs (1978)*
100% (Wyoming coal)	*3 runs (1978)*	*3 runs (1978)*	*3 runs (1978)*
100% (Wyoming coal)	—	—	*Compliance tests[a] 4 runs (1978)*

[a]RDF injection nozzles relocated to below the coal injection nozzle.

Power Plant

In this study, it was determined that two major factors could be controlled at various levels. These factors were the steam generator load, based either on steam flow generated or megawatts of power generated, and the amount of RDF, based on heat energy input to the boiler. The levels chosen were 60, 80, or 100% nominal steam generator load, and 0, 10, or 20% RDF. To obtain sufficient data for statistical analysis, a factorial experimental design with three replications was devised for the steam generators, as summarized in Table 1. The statistical design was a 3 by 3 (three loads, three values of EDF, and three replications) full factorial experiment with 27 runs. To ascertain compliance with Iowa's Environmental Quality rules, additional miscellaneous testing was done. During these tests, the location of the RDF injection point was changed.

To satisfy the objectives of the environmental emission study, all appropriate input and output streams associated with the operation of the steam generator unit were sampled. A block diagram showing the sample locations of entering and leaving streams is included as Figure 2. The tests on unit No. 7 are summarized in Table 1. All inputs to and outputs from the steam generator were evaluated, including fuel, combustion air, bottom ash, steam, fly ash, and stack gas. All the sampling was conducted on a regular basis except the organic species, which were sampled on intermittent days as manpower, instrumentation, and equipment would allow.

Economic Evaluation

For 1976, 1977, and 1978, total annual expenses remained relatively constant in that the decreasing principal and interest were approximately balanced by the increasing operating and maintenance costs.

Table 2 shows the relative percentages of operating and maintenance costs allocated to salaries, contractual expense, commodities, and principal and interest. Contractual expenses were higher than salaries during all three years. Principal and interest accounted for nearly half of the operating and maintenance costs. Total operating cost per megagram averaged $27.82 in 1976 and $23.87 in 1977. Net cost per megagram averaged $12.47 in 1978, compared with $15.73 in 1976 and $12.61 in 1977. These data are summarized in Table 3.

Process Plant Emission Characterization

The particulate effluent from the ventilator ducts on the refuse plant and the particulate in the ambient air of the process plant were sampled by appropriate methods.

Table 4 summarizes the particulate emissions from the three roof ventilators in operation during this study. Over the 144-min sampling period, the sampling train filters collected particulate effluent in the amounts shown. It should be noted that the emission levels were very low and, in fact, were virtually invisible to observers.

Power Plant Emission Characterization

The average of heating values, ultimate analysis, and trace elements analysis for both coal and RDF used during the tests on unit No. 7 are as follows: The ash content of the RDF was higher than that of the coal used during 1978, and both the heating values and the amount of sulfur in the RDF were lower than that of the coal for the comparison runs made during this study. The significance of these observations is that as the amount of refuse used in the boiler unit is increased an increased amount of ash will be generated due to the use of refuse. The additional amount of ash was expected to show up partially as fly ash and partially as bottom ash. Consequently, as the RDF increased, the amount of particulate emissions was expected to increase. This was also in agreement with the previous data obtained on traveling grate stoker unit Nos. 5 and 6 during 1976 and 1977 studies on the traveling grate units.

Because the sulfur content in the RDF was lower than that in the coal, it was also expected that the oxides and sulfur emitted from the smokestack would decrease significantly with increases in RDF.

Based on the tabulation of trace elements from the fuel samples, the RDF contained significantly more copper, lead, titanium, and zinc than coal used as a fuel. As a consequence, the emissions of these four elements were expected to increase significantly. The most important of the three elements would be the lead because of its toxicity. Therefore, some additional ambient air sampling was performed on a random basis during the 1978 experiments. Germanium, iron, and sulfur were found in smaller concentrations in the RDF than in the coal, but there did

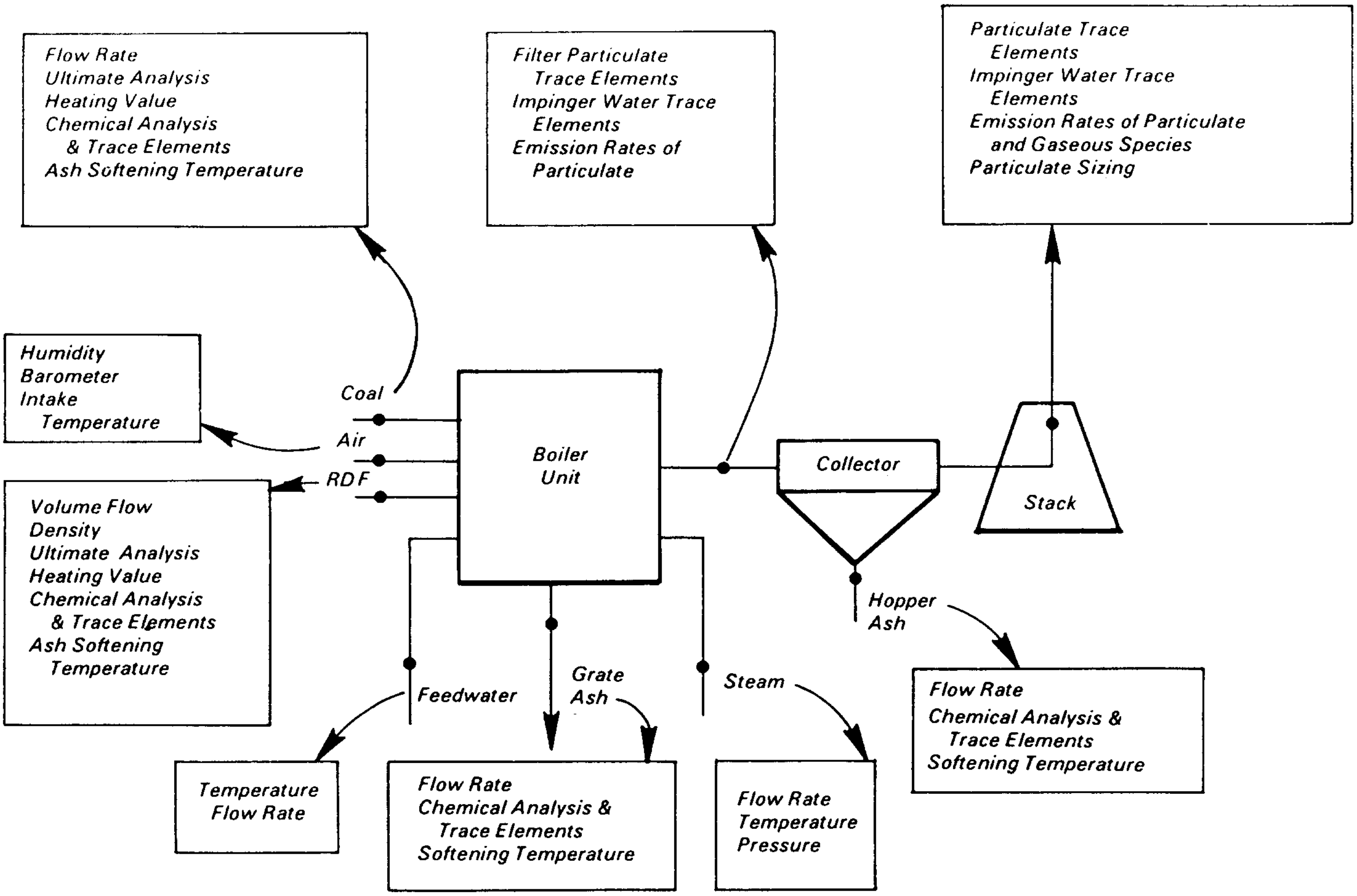

Figure 2. *Sampling locations.*

Table 2. ***Solid Waste Plant Operating Expense Distribution, 1976-1978***

Year	Operating and maintenance: Labor (%)	Contractual (%)	Commodities (%)	Principal and interest (%)	Total (%)
1976	13.91	29.16	6.50	50.43	100
1977	18.91	24.40	9.21	47.48	100
1978[a]	16.73	29.25	9.98	44.04	100
Average		53.52		46.48	100

[a]*January to September data only.*

Table 3. ***Total Operating Expenses and Revenues for the Ames Solid Waste Recovery Processing Plant, 1976-1978***

Year	Total operating expense ($)	Total revenue ($)	Total net cost ($)	Refuse processed (Mg)	Total cost/Mg ($/Mg)	Net cost/Mg ($/Mg)
1976	1,033,186	448,721	584,465	37,137	27.82	15.73
1977	1,047,734	494,309	553,425	43,890	23.87	12.61
1978[a]	784,740	411,190	373,550	29,958	26.19	12.77

[a]*January through September only.*

not appear to be a significant difference between RDF and coal in the relative amounts of the other elements.

The uncontrolled emissons generally increase with RDF except for the 100% load data using coal only. Otherwise all the runs show significant increases in particulate emissions as the amount of RDF increases. It is also apparent from this plot that the initial data obtained using coal only on this boiler in 1976 and 1977 indicate a reverse trend in terms of particulate emissions. The expected particulate would be higher at 100% load than at 60% load as was the case for the 1978 data. This reversed trend in the 1976 data is believed to be related to difficulties in operation of the particulate collector on unit No. 7 during 1976 and 1977. However, it should be emphasized that the scale for the emissions is significantly expanded and that all the emissions with 100% coal as the only fuel are within 2.8 to 3.9 g/MJ of heat energy input.

Table 4. Ames Refuse Processing Plant Particulate Emissions

EPA Run No.	Roof ventilator No. 1	Roof ventilator No. 2	Roof ventilator No. 3	Total	Roof ventilator No. 1	Roof ventilator No. 2	Roof ventilator No. 3	Total
	mg/std m³				g/s			
350	32.16	18.94	20.85	71.95	0.516	0.209	0.449	1.174
351	29.77	36.14	25.27	91.18	0.422	0.453	0.538	1.413
352	37.19	53.80	31.14	122.13	0.518	0.629	0.632	1.779
353	23.26	31.35	9.798	64.41	0.343	0.368	0.201	0.912
Average standard deviation				87.42 ± 25.74				1.320 ± 0.368

The controlled emissions generally increased with increases in RDF. This result was expected, since the amount of ash in the RDF was proportionally larger than that in the coal. For the 100% coal runs (0% RDF), the decrease in the emissions at 80 and 100% load for the 1978 data was a result of the repair of the ESP late in 1977. Difficulty was experienced with the ESP during 1976 and 1977. Some of the plate retainers in the ESP had failed, which rendered them ineffective during the test runs in 1976 and 1977. This is one reason why the emissions for the 60, 80, and 100% loads in 1976 and 1977 appear to be significantly higher than the emissions for the corresponding loads in 1978. Thus, the data obtained in 1978 are much more representative of the usual performance of unit No. 7. Furthermore, the data of 1978 show very consistent trends in the direction anticipated based on the fuel input analysis.

The effect of RDF on ESP collector efficiency drops consistently with increases in RDF. These trends were very consistent for the data obtained in 1978 and showed the ESP efficiency to be higher at 80% load than at 100% load. The effect of the repair between 1977 and 1978 data is also apparent in this figure. For example, for the coal-only runs, the collector efficiency increased from 93.4 to 94.4% at 100% load and from 94.9 to 96.8% at 80% load, thus demonstrating the effect the repair of the ESP had on its performance.

The oxides of sulfur (SO_x) emitted from the boiler decreased significantly with increases in RDF. This decrease amounted to about 50% for 80 and 100% boiler loads in going from 0 to 20% RDF. Thus, an advantage of using RDF with coal is that relatively high-sulfur coal can be used and EPA standards can still be met.

The oxides of nitrogen (NO_x) generally decreased with increases in RDF at all boiler loads. The decrease was in the range of 10 to 20% and was somewhat dependent on boiler load as the RDF was increased up to 20%. The NO_x emissions generally decreased less for the 1978 data than for the 1976-1977 data. This might represent better operation of the boilers and better control of the combustion zone temperatures for the experimental runs of 1978.

Except for the 100% load, 20% RDF data point, the chloride emissions for the suspension-fired boiler increased linearly and significantly with increases in RDF. The boiler experienced as much as a tenfold increase in chloride emissions as the RDF increased from 0 to 20% for all boiler loads in 1978. The chlorides in the stack emissions are believed to have come from the chlorinated hydrocarbons in the RDF. The chlorides dropped in the 1976-1977 data because of the dropout of RDF into the bottom hopper; the bottom grates had not yet been installed.

A series of 19 trace elements were sampled from all input and output streams associated with the operation of steam generator unit No. 7. Table 5 lists the trace elements detected in the input fuels of coal and RDF used during the test. The elements selected for analysis are listed by rank order, and the ranking was determined by the concentration given in parts per million (ppm). The standard deviations are also listed. Another column shows the amount of the trace element listed on the basis of mass per unit of energy input to the boiler. The values listed in Table 5 are overall averages for both coal and RDF. The trace elements with higher proportions of concentration in coal than in RDF are identified in this table as strontium, beryllium, nickel, and germanium. The elements that were not detected based on the detection limit of the analytical instrumentation are also indicated. Elements relatively high in concentration in the RDF were zinc, lead, copper, manganese, and vanadium.

Conclusions

The major result of this project is that RDF can be burned successfully when combined with coal in both stoker-fired and suspension-fired boilers to produce electric power. The net cost per megagram to produce this RDF fuel was $15.73 in 1976, $12.61 in 1977, and $12.47 in 1978. The yearly reduction in these net costs was due to plant improvements and increased value of the energy contained in RDF.

Major improvements which were made in the Ames solid waste recovery system

***Table 5.** Trace Element Content of Coal and RDF Used as Fuel in Boiler Unit No. 7*

Coal Element	Coal Level[a] ppm	Coal Level[a] ng/J	RDF Element	RDF Level[a] ppm	RDF Level[a] ng/J
Strontium[b]	86 ± 28	2.92 ± 1.15	Zinc	763 ± 345	4.65 ± 2.13
Vanadium	83 ± 16	2.92 ± 1.15	Lead	613 ± 289	3.89 ± 2.27
Manganese	76 ± 23	2.92 ± 0.52	Copper	572 ± 854	3.58 ± 5.74
Zinc	66 ± 41	2.39 ± 1.46	Manganese	194 ± 47	1.18 ± 0.33
Beryllium[b]	37 ± 12	1.55 ± 0.49	Vanadium	154 ± 32	0.94 ± 0.19
Lead	36 ± 13	1.26 ± 0.48	Strontium	46 ± 11	0.28 ± 0.04
Tin	20 ± 5	0.71 ± 0.17	Chromium	34 ± 8	0.28 ± 0.04
Chromium	19 ± 7	0.74 ± 0.35	Tin	27 ± 8	0.17 ± 0.06
Nickel[b]	18 ± 5	0.63 ± 0.17	Antimony	25 ± 17	0.15 ± 0.11
Copper	15 ± 3	0.52 ± 0.08	Gallium	16 ± 3	0.10 ± 0.02
Germanium[b]	5.3 ± 0.9	0.19 ± 0.04	Nickel	14 ± 4	0.09 ± 0.03
Gallium	2.5 ± 0.5	0.09 ± 0.02	Selenium	8 ± 1	0.05 ± 0.01
Antimony	BDL	BDL	Cadmium	6.4 ± 8.1	0.04 ± 0.05
Selenium	BDL	BDL	Germanium	1.7 ± 0.3	0.01 ± 0.00
Thallium	BDL	BDL	Thallium	BDL	BDL
Mercury	BDL	BDL	Mercury	BDL	BDL
Arsenic	BDL	BDL	Arsenic	BDL	BDL
Cadmium	BDL	BDL	Beryllium	BDL	BDL
Cobalt	BDL	BDL	Cobalt	BDL	BDL

Note: BDL signifies the element is below the analytical instrumentation detection limit.

[a]Values listed are overall averages for the coal and RDF used during 1978 tests.

[b]Trace elements with higher proportions in coal than in RDF.

during the three-year comprehensive study are as follows:

- Addition of dump grates to the 35-MW suspension-fired steam generator
- Relocation of RDF fuel input nozzles on the 35-MW suspension-fired steam generator to feed RDF below instead of above the coal nozzles
- Addition of a grit removal system at the processing plant to improve the quality of the RDF
- Addition of a dust control system at the processing plant to decrease the occurrence of failure of electric motors and mechanical equipment, as well as to improve the worker environment
- Addition of two crew conveyors at the Atlas storage bin to allow two pneumatic transport lines to pick up RDF from all four drag conveyors and thus reduce the speed of the pull-ring buckets and the wear on the storage bin floor
- Replacement in 1979 of mechanical collectors with new ones for emissions control of the two stoker-fired steam generators to meet environmental regulations and permit cofiring of RDF and coal in the stoker boilers

The study of boiler performance showed the necessity to improve the quality of RDF in order to reduce slagging and increase boiler performance. A grit removal system was added in the processing plant which achieved a 24.5% increase in heating value of the RDF, from 11,408.7 to 14,209.1 kJ/kg, and a 54.5% decrease in ash, from 20.99 to 9.55%. Additionally, the boiler fouling impact of RDF was reduced.

The addition of the dump grate was the most significant change. This facilitated the successful cofiring of RDF with coal in the suspension-fired steam generator. The relocation of the RDF injection nozzle to a point below the coal injection was found to be important in its effect on lowering emissions.

Suspension-fired boiler efficiency decreased 3.3 percentage points when operating at 80% steam load with 20% heat input from RDF and decreased 1.33 percentage points at 100% steam load with 20% heat input from RDF. This decrease was attributed to an increase in moisture loss when RDF is fired. Some furnace slagging was encountered during the period prior to installation of the grit removal system but was reduced after the quality of the RDF was improved by the addition of the grit removal system.

Stack particulate emissions increased slightly with corresponding increases in RDF as a fraction of the fuel input and was due to the presence of lighter RDF particles and increased mass flow. Stack particulate emissions decreased after the RDF injection nozzle was relocated below the coal burners.

Oxides of nitrogen (NO_x) and oxides of sulfur (SO_x) both decreased while chlorides increased with an increase in RDF burning. No discernible trends within the data scatter were noted concerning formaldehyde or hydrocarbon emissons. Increased emissions of the trace elements — zinc, copper, lead, and gallium — corresponded to increases in RDF.

The two stoker-fired boiler units, used as backup to burn RDF, were modified with new mechanical collectors in 1979. These units previously had difficulty meeting particulate emission standards while only firing coal. Subsequent tests conducted on these units by the City of Ames indicated that coal plus RDF can be successfully burned and meet particulate emission standards as a result of this modification along with the grit removal system at the process plant.

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The complete report, entitled "Co-Firing of Solid Wastes and Coal at Ames: Pulverized," (Order No. PB 85-183 044/AS; Cost: $28.00, subject to change) will be available only from:
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