69 PAGES
4 Copies

THE JACKSONVILLE ELECTRIC AUTHORITY
600 MW COAL-FIRED POWER PLANTS
REFUSE CO-FIRING SYSTEM STUDY

TASK NO. 001225

Ebasco Services Incorporated
145 Technology Park/Atlanta
Norcross, Georgia 30092

June, 1980

THE JACKSONVILLE ELECTRIC AUTHORITY
600 MW COAL-FIRED POWER PLANTS
REFUSE CO-FIRING SYSTEM STUDY

TABLE OF CONTENTS

Section Title Page

I EXECUTIVE SUMMARY

III DISCUSSION

LIST OF TABLES

I EXECUTIVE SUMMARY

III DISCUSSION

THE JACKSONVILLE ELECTRIC AUTHORITY
600 MW COAL-FIRED POWER PLANTS
REFUSE CO-FIRING SYSTEM STUDY

TABLE OF CONTENTS (Continued)

LIST OF TABLES (Continued)

LIST OF FIGURES

JACKSONVILLE ELECTRIC AUTHORITY
600 MW COAL-FIRED POWER PLANTS
REFUSE CO-FIRING SYSTEM STUDY

TABLE OF CONTENTS (Continued)

LIST OF FIGURES (Continued)

JACKSONVILLE ELECTRIC AUTHORITY
600 MW UNITS
REFUSE CO-FIRING SYSTEM STUDY

I EXECUTIVE SUMMARY

1.0 PURPOSE

The purpose of this study was to assess the technical and environmental feasibility of co-firing refuse-derived solid fuel (RDSF) with coal in the new Jacksonville Electric Authority 600 MW Coal Fired Power Plants. The study did not consider the feasibility of collection of the refuse, delivery to the plant site, nor the separation of combustible and noncombustible materials, as these considerations are beyond the contractual scope of this investigation.

2.0 SCOPE

This study is concerned with the co-combustion of small percentages of refuse derived solid fuel (RDSF) with coal. This solid fuel is derived from raw garbage by (1) removing the majority of the noncombustible material and (2) shredding the remaining combustible material to a maximum particle size of about 1-1/2 inches. This version of RDSF is designated RDSF-3 in accordance with ASTM Interim Procedure E38.

To provide the basis for the study, the results of a number of previously operational, currently operational, and proposed utility power plants co-firing RDSF were reviewed. A preliminary fuel specification was developed based on this experience. Information was obtained on current refuse collection in the Jacksonville area.

The above information was used to assess the potential impacts of co-firing RDSF on boiler and Air Quality Control System (AQCS) performance and operations. The equipment required for RDSF handling and storage was sized and priced as were the required boiler and AQCS modifications. Anticipated operating costs and fuel savings associated with co-firing RDSF were projected and gross and net fuel fees were calculated.

3.0 RESULTS

3.1 Design Parameters for RDSF System

RDSF normally has a heating value from 4500 to 6500 Btu/lb. and is relatively high in chlorides, ash, and moisture but relatively low in sulfur when compared to coal. However, through proper processing, employing technology which has been developed only in recent years, it should be possible to achieve a fairly high grade of RDSF at Jacksonville.
Table 3.1-1 compares the anticipated range of certain RDSF properties against those of the range of coals to be burned at the new JEA plants.

Table 3.1-1 Coal and RDSF Properties

Properties	Coal			RDSF		
	Max.	Perf.	Min.	Max.	Avg.	Min.
Heating Value (BTU/LB)	13,250	12,500	10,500	6500	6100	5100
Moisture %	15.0	8.0	4.0	25.0	18.4	18.0
Ash %	18.0	9.0	6.0	15.0	9.6	6.0
Sulfur %	4.0	0.6	0.5	0.2	0.2	0.1
Chlorides %	0.3	0.1	0.1	0.5	0.2	0.2
Ash Fusion Temp.(Soft)°F	-	2300	-	-	2150	-
Ash Fusion Temp.(Fluid)°F	-	2350	-	-	2220	-

The amount of raw refuse that will be available for conversion to RDSF for co-firing at the new power plant is 1950 tpd. This will convert to 1460 tpd of RDSF at a conversion ratio of 75 percent and would result in an average firing rate on two boilers of approximately 50 tph, each, when normal load factors are considered. Although boiler manufacturers normally permit a maximum RDSF firing rate in coal fired boilers of 30 percent of the total heat input, it is recommended that the firing rate be conservatively limited to 20 percent of the total heat input, which is equivalent to a maximum firing rate for RDSF of approximately 99.9 tph per boiler at 100 percent load. For design purposes, a nominal capacity of approximately 100 tph has been selected for the RDSF feed system to each boiler. This will permit greater flexibility in operations, and allow for future growth in the waste stream.

Since it will not be possible to burn RDSF continuously due to factors such as low boiler load or equipment maintenance, there will be days when it will be necessary to fire the RDSF at maximum rates to catch up with the processing operation. Therefore, all assessments of the impact of co-firing RDSF on boiler operations are based on RDSF supplying a maximum of 20 percent of the heat input.

3.2 Impact of Co-firing RDSF on Boiler Design and Operations

In order to burn RDSF in a semi-suspension firing mode,it will be necessary to modify the boiler to incorporate nozzles for the RDSF and to install a dump grate in the bottom ash hopper. The dump grate has been found to be necessary to catch particles that fall out of suspension. These particles will then complete their combustion on the grate. The grate is left open when burning only coal.

Some boiler thermal efficiency is sacrificed when burning RDSF. Efficiency reductions as high as 3 percent have occurred when firing 20 percent RDSF. Higher excess air is not necessarily required to burn RDSF.

Experience indicates that the amount of bottom ash produced may increase by a factor of as much as 6 to 8 times when up to 20 percent of inadequately prepared RDSF is co-fired. This may require pulling bottom ash 3 to 4 times more frequently with a substantial increase in load on the ash settling pond.

The high glass content which is often present in inadequately processed RDSF has contributed to increased slagging problems in those older, higher heat release boilers which have been retrofitted with RDSF co-firing capability. The slagging tendency can be reduced by proper processing to remove as much glass as possible from the RDSF. In the opinion of at least one boiler manufacturer, the limitations placed on heat release in modern coal-fired boilers should minimize, if not preclude the slagging problem if the boiler is designed with RDSF co-firing in mind (Ref. 11).

Induced draft fan and forced draft fan power requirements may increase by as much as 17 percent when burning RDSF. This is a result of the increased mass flow of flue gases and the increased pressure drop due to the higher flue gas velocities. The net increase in fan power could be as much as 2650 horsepower per boiler at full boiler load when firing 20 percent RDSF.

3.3 Impact of Co-firing RDSF on Air and Water Quality Control Systems

There is very little directly applicable data available to support a quantitative assessment of the effects of co-firing RDSF on precipitators. Based on the limited data available, however, precipitator efficiency generally deteriorates when RDSF is burned. This effect may be attributed primarily to the higher resistivity of the ash which is believed to follow from the lower sulfur content of the RDSF and the greater difficulty in collecting carbon particles from the combustion of paper, etc. Efficiency losses up to 2 percentage points have been reported when firing 20 percent RDSF. This much efficiency loss could not be tolerated due to the low allowable particulate emission rate of 0.03 $lb/10^6$ Btu. To avoid this potentially unsatisfactory situation the precipitator on each 600 MW unit will have to be enlarged by a minimum of 10 percent to insure that it develops the required efficiency.

SO_2 and NO_x emissions both tend to decrease when RDSF is burned and thus should not present any problems. It should be pointed out that the unpredictable nature of RDSF may make it difficult, if not impossible, to obtain monetary penalties for non-performance of the Air Quality Control System while firing RDSF. However, this is subject to confirmation during the actual AQCS acquisition process.

3.4 Corrosion and Erosion

Due to the bad experiences with corrosion and erosion that many water wall incinerators have experienced, there is cause for concern about corrosion and erosion in the boiler, precipitator, and scrubber. The corrosion mechanisms in incinerators have been traced to the formation of metal chloride deposits on tube surfaces and refuse is typically higher than coal in chloride content. The erosion problems are attributable to the higher refuse ash content. However, contrary to incinerator experience, there have been no reports of serious corrosion or erosion in co-fired high pressure utility boilers.

3.5 RDSF Handling and Firing Equipment

It is assumed that all processing of the RDSF will be done at another facility operated by the Jacksonville Department of Sanitation and not on the power plant site. Therefore some means must be provided to transport the RDSF to the power plant. If the processing plant is within about a mile of the power plant, one large overhead conveyer could be used. If much further than a mile, then some means of road transport, such as 75 cu. yd. transfer trailers will be required. In either case, storage systems should be provided on the power plant to provide storage of approximately one day's processing of RDSF (1500 tons). An order-of-magnitude conceptual estimate of the total installed cost of the RDSF equipment and the boiler and precipitator modifications in 1985 dollars is $49,129,000.

3.6 Economic Analysis

Electric power generation costs should not be subsidized by the sanitation department, nor should the JEA subsidize refuse disposal. For this reason, the value of the RDSF has been calculated based on the assumption that JEA will "break even." The maximum "gross fuel fee" which would be paid by the JEA for the energy provided (less additional operating costs) would be \$36.60/ton (\$3.03/10^6Btu), if the costs of installing and operating the RDSF facilities at the power plant site are directly assumed by the City of Jacksonville. For comparison the cost of coal in 1985 is projected to be approximately \$77.72/ton (\$3.11/10^6Btu).

If the cost of installing and operating the RDSF facility at the power plant are assumed directly by JEA, a maximum "net fuel fee" of \$25.51/ton (\$2.07/10^6Btu) results. This represents the net revenue available to the City of Jacksonville from operations at the power plant. On an annual basis, a net revenue of almost $13,593,000 results in the first year, 1985. Projected revenues increase every year, and result in a levelized net revenue of $66,890,000.

4.0 RECOMMENDATIONS

Based on the experiences of other RDSF facilities and considering the anticipated operating conditions of the new power plant, there do not appear to be any insurmountable barriers to the co-firing of RDSF. However, as pointed out above, there are significant costs as well as potential risks that must be assumed. Since boiler and precipitator modifications are required to accomodate the environmentally acceptable co-combustion of RDSF, a decision on the RDSF question should be made as soon as possible.

The success of such a venture is largely dependent on the quality of the RDSF supplied by the processing plant. Consequently, before a decision is made on whether to proceed with incorporating this equipment into the power plant design, an in-depth conceptual study must be made of the impact of resource recovery on the overall economics of refuse collection, transportation, and disposal in the City of Jacksonville, including the economics associated with the proposed RDSF processing plant. This study should be completed expeditiously to support boiler and precipitator procurement.

A decision to proceed with the RDSF system should only be made:

a - If the overall system economics are favorable, after consideration of all factors including fuel savings, power plant costs, processing plant costs, landfill savings, transport economics, etc.,

b - If the JEA and the Jacksonville Department of Sanitation can agree on a design of the processing facility, on fuel specifications and quality controls and on responsibilities for costs,

c - If the JEA is willing to accept the risk of potential operating problems associated with co-firing RDSF,

d - If an assessment of the various environmental impacts (both favorable and unfavorable) has acceptable results, and

e - If all affected parties agree that the undertaking is in the best interest of the City of Jacksonville.

Once an agreement is reached, it should be embodied in a simple contract which would clearly delineate the responsibilities of the JEA and the City of Jacksonville.

II INTRODUCTION

The subject of resource recovery and, in particular, energy recovery from the burning of municipal solid waste (MSW) has received increasing attention over the past decade. A practice in Europe for many years, energy recovery from MSW in the United States had been hampered by a number of factors in the past including:

a - Ready access to landfill sites,

b - Availability of relatively cheap primary fuels,

c - Lack of facilities for utilization of waste heat from municipal incinerators (for example, equipment for district heating has been installed in only a handful of cities),

d - Lack of willingness by utility companies to accept the risks of equipment damage and reduced availability from burning fuels derived from MSW,

e - Lack of willingness on the part of municipalities and private corporations to erect processing facilities without substantial commitments from utilities to accept the processed refuse

f - Concern over environmental regulations that place severe restriction on both air-borne and water-borne emissions from waste handling and burning systems.

Today, the situation is rapidly changing. Approved landfill sites are no longer readily available. Primary fuels are increasing in price day by day. The technology for processing, handling, and burning RDSF is developing rapidly. Finally, evidence is mounting that the environmental problems associated with energy recovery from refuse are not as severe as once thought.

The purpose of this study was to assess the technical and environmental feasibility of co-firing refuse-derived solid fuel (RDSF) with coal in the new Jacksonville Electric Authority (JEA) 600 MW Coal-Fired Power Plant(s). The study is organized into four main sections. The first section discusses the basic assumptions of the study including boiler operating parameters, coal properties, anticipated RDSF production rates and RDSF properties. The second section addresses the state-of-the-art in co-firing RDSF with coal in utility boilers. In this section relevant experience from previous RDSF experiments is introduced. The third section describes in detail the equipment required to enable RDSF to be co-fired in the proposed power plant and summarizes the capital costs. The fourth section presents the incremental capital and operating costs for the RDSF facility plus a calculation of the maximum "break-even" price that could be paid for the RDSF as a fuel.

III DISCUSSION

1.0 DESIGN CRITERIA FOR THE RDSF SYSTEM

The purpose of this section is to establish the basic assumptions for the conceptual design of the RDSF handling system and for the assessment of the impact of co-firing RDSF on power plant operations.

1.1 General Description of RDSF and Its Processing

Technology for energy recovery from MSW covers a broad range of final fuel products. At one end of the spectrum is the burning of raw garbage on a series of traveling grates in a waterwall incinerator. This is the predominant technology employed in Europe. The other end of the spectrum is occupied by pyrolysis gases and even chemical conversion to ethanol or methanol. The technology under consideration in this study is referred to as supplemental-firing or co-firing of refuse-derived solid fuel (RDSF) with coal.

Table 1.1.1 presents an analysis of typical raw MSW.

Table 1.1.1 Typical Analysis of Raw Municipal Solid Waste (MSW)

	Percent by Weight
Paper, Cardboard	51
Plastics	4
Food Waste (Natural Organics)	5
Yard Waste (Wood)	6
Other Combustibles (Cloth, Tar, Etc.)	2.5
Ferrous Metals	3
Other Non-Ferrous Metals	0.2
Glass	8
Ceramics and Other Materials	20

RDSF technology involves sufficient processing to carry the raw garbage through the following operations:

A. Removal of oversized objects (refrigerators, engine blocks, etc.),

B. Breaking up of all containers (bags, boxes, bottles, etc.),

C. Extraction of the metals,

D. Extraction of as much non-metallic inert material as possible (especially glass), and

E. Shredding of the combustible material to a size that can be semi-suspension fired in a boiler.

The result is a fluffy (but not powdered or pulverized) material with relatively little odor. The conversion rate from raw garbage to RDSF is normally about 70 to 80 percent by weight.

Because of its nature, MSW and the RDSF derived from it through the processes described above have highly variable properties. Table 1.1-2 presents typical ranges for the properties of RDSF as experienced at several recent demonstration plants (Ref. 1 and 2).

Table 1.1-2 Range of Properties of RDSF from Actual Demonstration Plants

Higher Heating Valve	4500-6500 BTU/lb
Bulk Density (Uncompacted)	2.5 - 8 lb/ft^3
Maximum Particle Size	1 1/2" - 4"
Ultimate Analysis	
Carbon	24-40 Percent
Hydrogen	4-6 Percent
Oxygen	20-45 Percent
Nitrogen	0.2-0.8 Percent
Sulfur	0.1-0.4 Percent
Chlorine	0.2-0.6 Percent
Moisture	15-30 Percent
Ash	6-30 Percent

A commercial brand of RDSF known as ECO-FUEL II, which is much more homogeneous as well as lower in moisture and higher in carbon, is now on the market. This RDSF goes through further chemical and mechanical processing to produce a dustlike material which is somewhat easier to burn from the fluff material. However, because of the additional processing, the cost of ECO-FUEL II is very near that of oil (Ref. 3). ECO-FUEL II is mentioned here only to distinguish it from fluff RDSF which is described in the previous paragraphs and which is the only type of RDSF under consideration in this report.

1.2 Predicted RDSF Characteristics for JEA

One of the longest running, perhaps most successful, and certainly the most thoroughly documented, demonstrations of co-firing RDSF and coal has been conducted by the City of Ames, Iowa under several grants from the EPA. Through continual refinements in their processing facility Ames has succeeded in making the highest quality RDSF yet produced using purely mechanical processing techniques. (Ref. 1 and 4).

For design purposes in this report the composition of the Ames RDSF is used as the average composition of the RDSF which is expected from the processing facility at Jacksonville. Unfortunately, RDSF composition can vary somewhat from city to city and from season to season. Before any detailed design work is done it is recommended that some attempt be made to analyze the MSW at Jacksonville to determine if there are any unusual characteristics that might impact on the design of the system.

For purposes of the present study it is assumed that all processing of the RDSF will be accomplished at a facility separate from the power plant. This processing facility will not be owned or operated by JEA. For this reason it is very important that JEA set definite specifications for what is and what is not an acceptable RDSF product.

The three components of RDSF that can have the greatest influence on the design of a co-firing system are chlorides, ash, and moisture content. A maximum percentage has been assumed for each of these three components. For ash the maximum has been estimated at 15 percent based on experience at Ames (the limit set for ash is explained in subsequent paragraphs). The maximum for moisture is estimated to be 25 percent again based on Ames' experience. The maximum amount of chlorides is estimated to be 0.5 percent based on a survey of data from a number of incineration and co-firing systems.

Using these maximums and adjusting the percentages of the other elements (C, H, O, S, N) for the high moisture and ash content, the "worst case" composition, which is shown in Table 1.2-1 was generated. Also shown in the Table is the average expected composition of the RDSF as well as the composition of the performance coal for the new JEA power plant. It can be seen that the "worst case" RDSF is lower in carbon and sulfur content but higher in oxygen, chlorine, ash and moisture content than the performance coal.

A power plant normally retains the option of refusing coal that does not meet contract specifications. Likewise, a power plant should have the option of rejecting RDSF that does not meet certain specifications. Probably the only component of the RDSF that the processing plant has any direct control over is the ash content. Moreover, as discussed in Section III paragraph 2.3.1, the amount of ash and its composition can have a major impact on boiler performance. Ash content should be controlled as much as is possible.

Through proper processing, it has been demonstrated that the ash content of RDSF can be maintained in the range of 10 percent (Ref. 4). Therefore, it is not unreasonable for JEA to reserve the right to reject RDSF if the ash content exceeds 15 percent. It is recommended that grab samples be taken and analyses run of the RDSF processed each day in accordance with ASTM Interim Procedure E38. If a significant number of samples reveal ash contents in excess of 15 percent, then that day's RDSF production should be set to landfill rather than to the power plant. The ash analysis is similar to the ASTM procedure for coal, and it is assumed that the same laboratory equipment would be used.

Table 1.2-1 Expected Compositions of RDSF Versus the JEA Coal

	RDSF		Coal	
	Worst Case	Average	Performance	Maximums
Higher Heating Value (Estimated) Btu/lb (As Fired)	5100	6100	12,400	-
Ultimate Analysis (%)				
Carbon	30.4	36.7	68.9	78.0
Hydrogen	4.5	5.4	4.4	5.8
Oxygen	24.2	29.2	7.8	9.8
Nitrogen	0.2	0.3	1.2	1.9
Sulfur	0.2	0.2	0.6	4.0
Chlorine	0.5	0.2	0.1	0.3
Ash	15.0	9.6	9.0	18.0
Moisture	25.0	18.4	8.0	15.0
	100.0	100.0	100.0	
Ash Fusion Temp. (Soft) °F	-	2150	2300	
Ash Fusion Temp. (Fluid) °F	-	2200	2350	

In addition to the limits on ash, specifications should also be set on the particle top-size of the RDSF. The processing facility should be designed to shred the RDSF to a nominal 1 1/2" x 0" (or minus 1 1/2") size. This leads to a size distribution similar to that shown in Table 1.2-2. To achieve this size distribution, which has been found to allow adequate burnout of combustibles in a semi-suspension firing system, the processing facility should include at least two stages of shredding or a flail mill and a shredder. If it becomes obvious that the top-size of the RDSF exceeds 1 1/2 inch, then the material must be rejected by the JEA and returned for reshredding. RDSF top-size is controlled by adjustment of the shredder grates.

Heat content of the RDSF stream should also be tested on a regular basis. While heat content will not be used as a basis for accepting or rejecting RDSF, it will provide data to use in periodically checking the fuel fee calculation to insure that a fair price is being paid for the RDSF.

Table 1.2-2 Typical Size Distribution for 1 1/2" x 0" RDSF (Ref. 1)

	Percent by Weight
Larger than 63mm (2 1/2")	3.4
38.1 mm (1 1/2") to 63 mm (2 1/2")	9.2
19 mm (3/4") to 38.1 mm (1 1/2")	43.3
9.5 mm (3/8") to 19 mm (3/4")	14.2
4.8 mm (3/16") to 9.5 mm (3/8")	11.5
2.4 mm (3/32") to 4.8 mm (3/16")	7.2
Smaller than 2.4 mm (3/32")	11.2
Total	100.0

1.3 RDSF System Design Criteria

The amount of raw refuse that will be available for conversion to RDSF for co-firing of the new power plant is 1950 tpd. This raw garbage will in turn yield an amount of RDSF equal to roughly 1460 tpd. Using the average RDSF heating value of 6100 Btu/lbm, the average amount of energy available from the RDSF is determined below:

$$\text{Energy From RDSF/Day} = \underline{1460 \text{ tons/day} \times 2000\ \#/\text{ton} \times 6100\ \text{Btu}/\#}$$

$$= 17{,}812 \times 10^6\ \text{Btu/Day}$$

Due to the variability of the heating value of RDSF and the instability of a coal flame at reduced loads, it is recommended by the boiler manufacturers that RDSF not be fired unless boiler load exceeds 70 percent of design load.

Based on historical availability and load data the load profile shown in Table 1.3-1 has been established for each JEA boiler:

Table 1.3-1 JEA Load Regimen

Hours Per Year	Load Percent of Maximum Continuous Rating (MCR)
500	100 Percent
3700	92 Percent
1300	75 Percent
950	50 Percent

Assuming that RDSF is not fired unless boiler load is 75 percent of design load or greater, then RDSF can only be burned for 5500 hours per year, roughly 63 percent of the time, or about 15 hours per day. This leads to an average energy contribution by RDSF of:

$$\text{Energy From RDSF/Hour} = 17{,}812 \times 10^6/15 = 1{,}187 \times 10^6 \text{Btu/Hr}$$

The design energy input to each boiler is approximately $6{,}096 \times 10^6$ Btu /hr. Therefore, the RDSF would initially provide the following minimum fraction of energy input to the two boilers:

$$1{,}187 \times 10^6 \;/\; 2 \times 6{,}096 \times 10^6 = \sim 10 \text{ Percent}$$

The boiler manufacturers have recommended that the maximum heat input from RDSF be kept below 30 percent of the total heat input of the boiler. Since the majority of the demonstration plants that have co-fired RDSF have held the RDSF firing rate to below 20 percent, this value has also been conservatively selected as the maximum percentage of RDSF for the present system. At 20 percent of the heat input to one boiler, the required rate of RDSF firing is calculated as follows;

$$\begin{aligned}\text{Maximum RDSF Firing Rate} &= 0.20 \times (6{,}096 \times 10^6 \text{ Btu/Hr})\\ &= 1{,}219 \times 10^6 \text{ Btu/Hr}\end{aligned}$$

or in tons per hour,

$$\begin{aligned}\text{Maximum RDSF Firing Rate} &= \frac{1{,}219 \times 10^6 \text{ Btu/Hr}}{6100 \text{ Btu/lb} \times 2000 \text{ lb/tons}}\\ &= 99.9 \text{ tph}\end{aligned}$$

There will be occasions when only one boiler is operating, and it will be necessary to fire the boiler at its maximum RDSF rate of 20 percent total heat input in order to keep up with RDSF production. This leads to the conclusion that all the equipment feeding RDSF to the boiler and all predictions concerning the impact of co-firing RDSF on the boiler, its auxiliaries, and its AQCS system must be based on providing 20 percent of the boiler heat input with RDSF. This, in turn, leads to a design firing rate of approximately 100 tph of RDSF at the design load of each boiler. Table 1.3-2 summarizes the basic RDSF system design parameters.

Table 1.3-2 Summary of RDSF System Design Data

RDSF Heating Valve	6,100 Btu/lbm
Coal Heating Valve	12,400 Btu/lbm
MSW collection rate for Jacksonville,	1,950 tpd
Processed RDSF Production Rate	1,460 tpd
Minimum Percent Heat Input from RDSF	10 Percent of 2 Boilers
Design Percent Heat Input from RDSF	20 Percent of 2 Boilers
Calculated Maximum RDSF Firing Rate (per boiler)	99.9 tph
Nominal Design RDSF Firing Rate (per boiler)	100 tph

2.0 IMPACT OF CO-FIRING RDSF ON POWER PLANT OPERATION

When RDSF is co-fired with coal in a power plant, there are several areas of the boiler and air quality control system (AQCS) operation that may be affected. The purpose of this section is to explore these areas and assess the magnitude of these impacts. The discussion will cover each of the following major subjects:

a - Boiler Physical Modifications

b - Boiler Thermal Efficiency

c - Boiler Operations and Auxiliary Equipment

d - Air and Water Quality Control Systems (AQCS)

e - Corrosion of Boiler and AQCS

2.1 Boiler Physical Modifications

In the last few years a large amount of experience has been gained with co-firing RDSF in pulverized-coal boilers. The sizes of these boilers range from 35 MW to 358 MW with steam conditions up to 2400 psia and 1050°F.

RDSF is typically pneumatically conveyed or hauled in transfer trailers to the power plant. There it is unloaded into a storage or surge bin. From the surge bin it can either be fed through a rotary lock feeder and pneumatically conveyed into the boiler or fed to a live-bottom hopper with metering screw conveyors that control the feed rate to the boiler.

In early demonstration tests, the RDSF nozzles were either located between or above the coal nozzles. It was thought that this location would reduce dropout and improve combustion of the RDSF by introducing it directly into the fireball. This location for the RDSF nozzles was also initially chosen for the Ames installation. However, subsequent testing at Ames revealed that injection of the RDSF below the coal nozzles reduced particulate emissions and did not increase dropout of material to the bottom ash hopper (Ref. 1). This effect will be discussed further in connection with performance of the AQCS equipment.

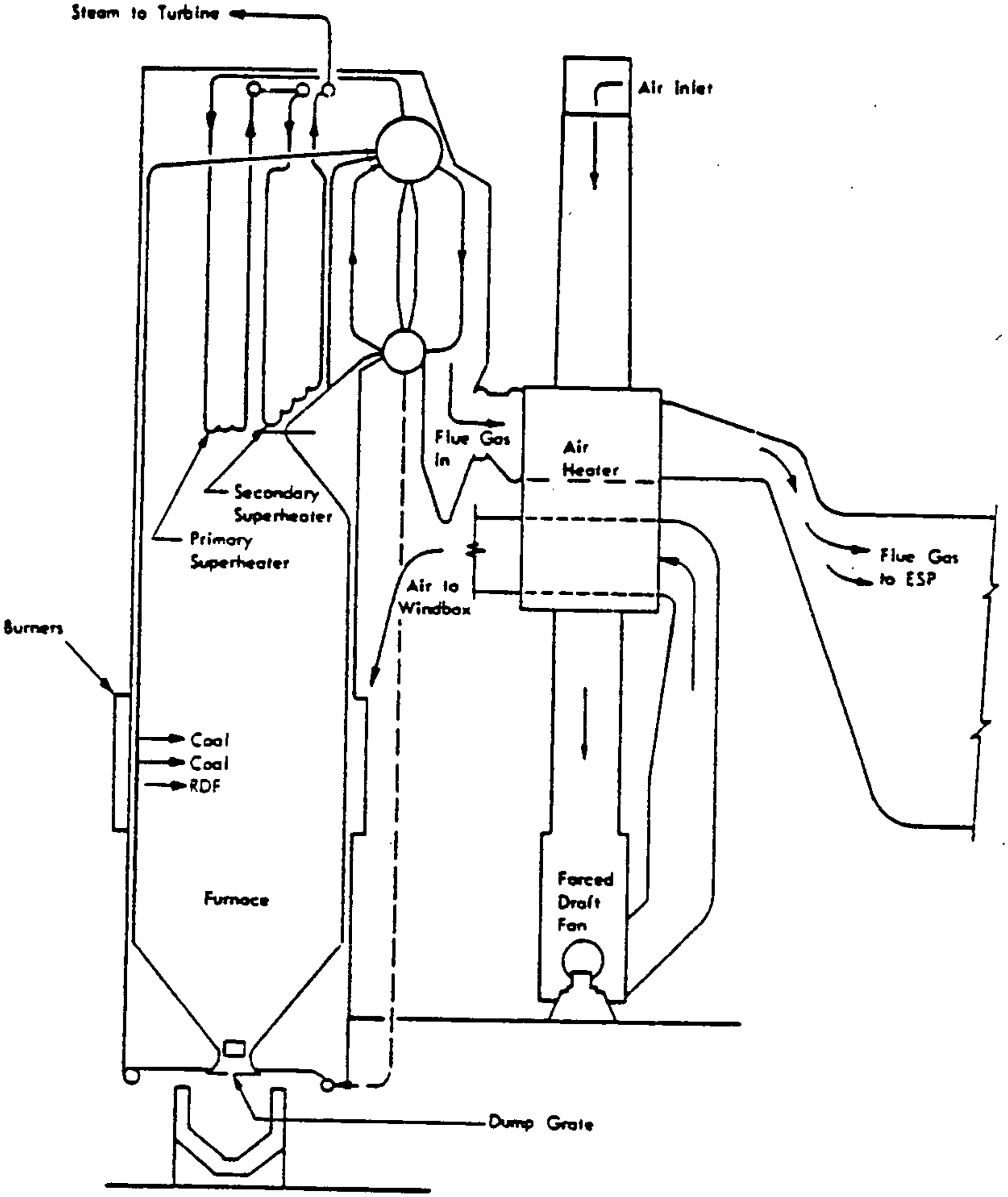
Early attempts to burn RDSF in a pulverized coal boiler also met with major problems from dropout of unburned material into the bottom ash hopper. Because of the large particle size of RDSF compared to pulverized coal, it is just not possible to burn RDSF in a full suspension firing mode. This experience has led to the installation of dump-grates similar to those used in bark boilers at the throat of the bottom ash pit. The elevation view in Figure 2.1-1 shows a typical pulverized coal boiler modified to burn RDSF. Note the location of the RDSF nozzles and the dump grate.

The dump grate is supplied with unheated combustion air from an auxiliary air fan. The air is introduced both above and below the dump grate as shown in Figure 2.1-2. The dump grate is typically made in four sections (2 pairs). Each pair of sections can be manually dumped by the operator (See Figures 2.1-3 and 4). Typical dumping frequency is about every 1-1/2 hours. The RDSF flow is interrupted briefly each time before the dump grates are opened.

The controls for firing RDSF are relatively simple. Typically, the feedrate of RDSF to the boiler is set by the operator and is held constant. Boiler load must be in the range of 70 percent of design load in order to introduce RDSF. If boiler load drops below this threshold, the RDSF feed is tripped off in order to insure that flame stability at low load is not impaired by the variable quality of the RDSF.

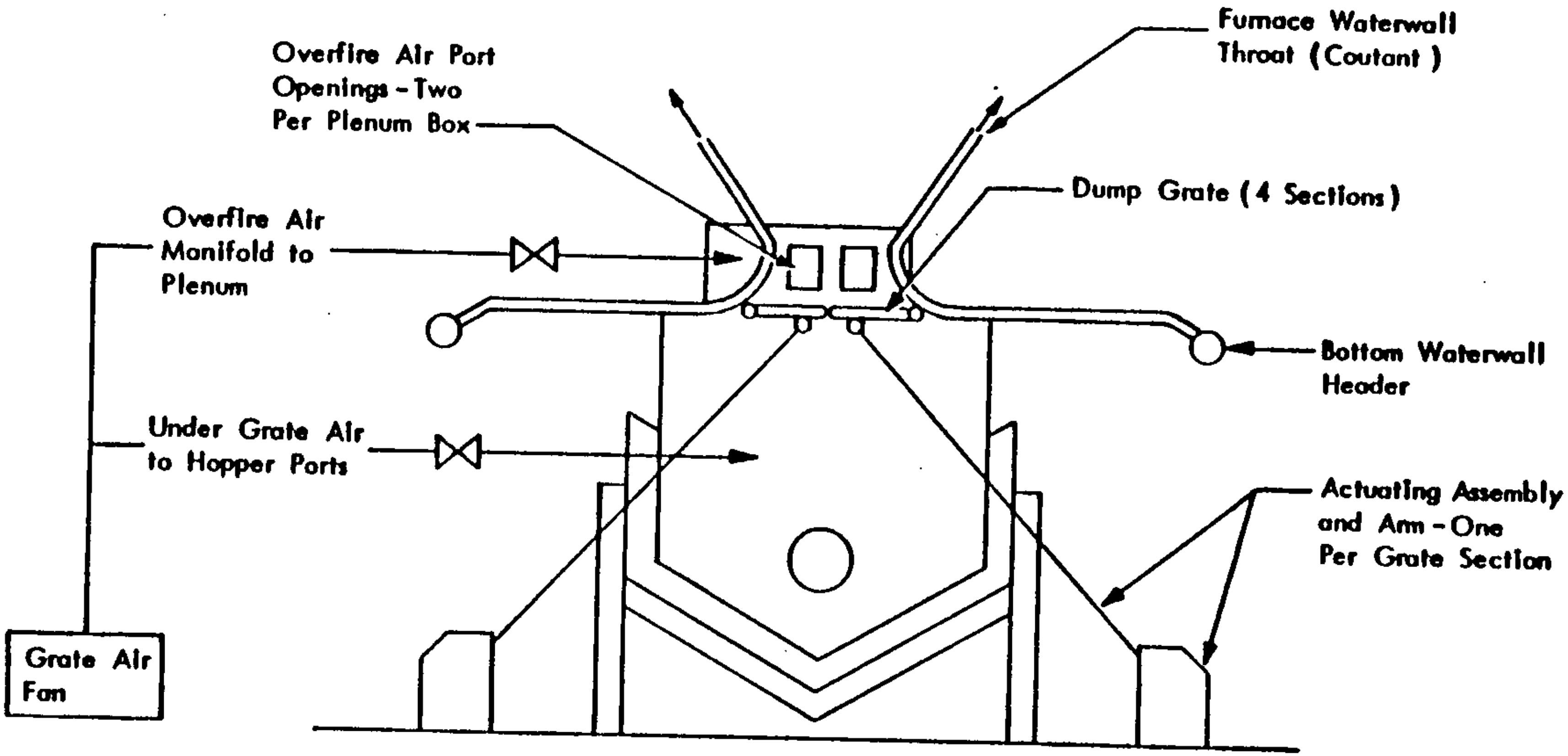
2.2 Boiler Thermal Efficiency

There is no question that boiler thermal efficiency is reduced when RDSF is co-fired. The magnitude of the efficiency reduction depends primarily on the amount of moisture contained in the RDSF and on what fraction of the total heat input is supplied by RDSF. In general, it can be stated that as the moisture content of the RDSF increases, boiler efficiency will decrease. Likewise, as the percentage of RDSF input to the boiler increases, efficiency will decrease. These effects are expected and can be predicted by a heat-loss balance on the boiler.



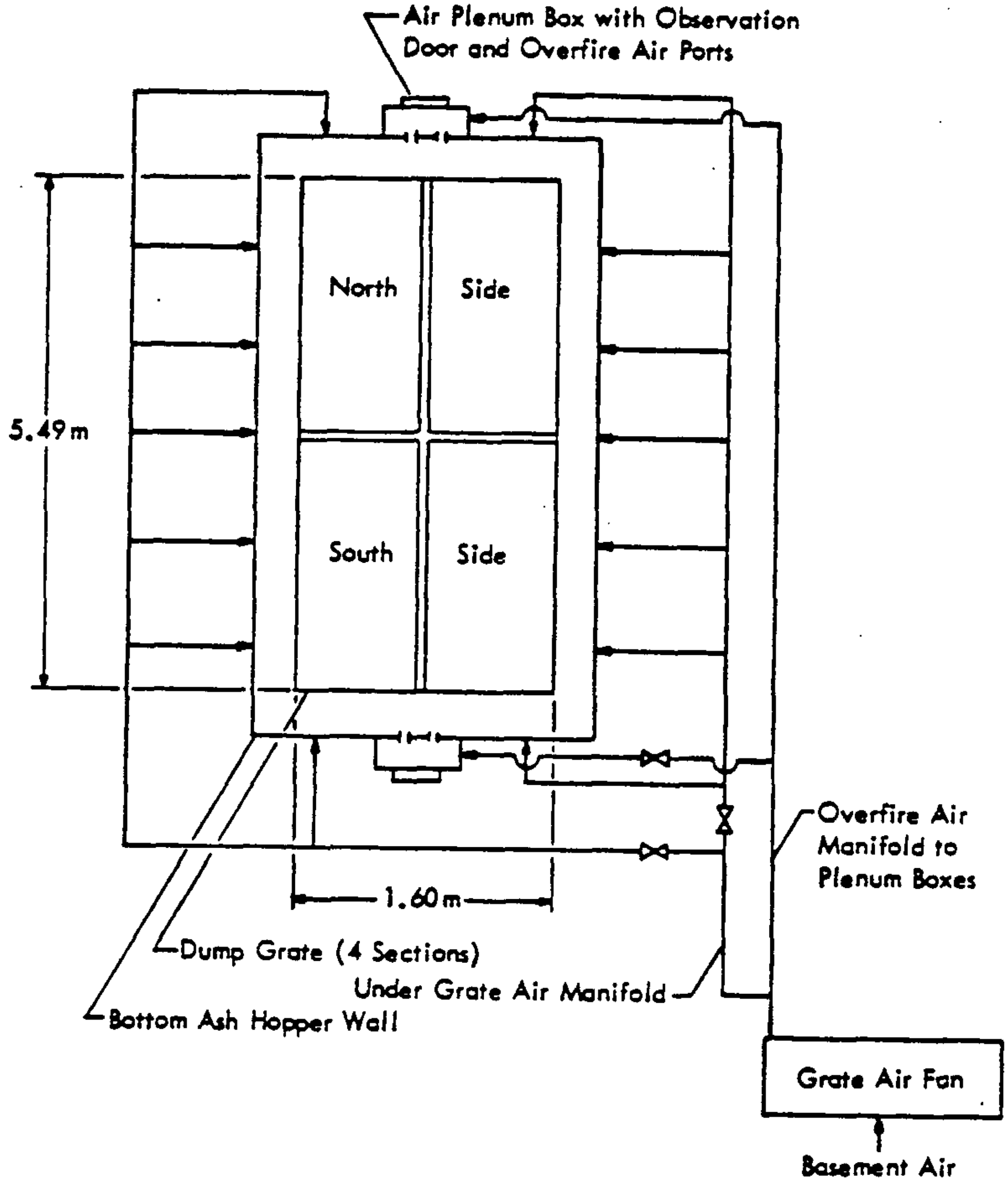
ELEVATION VIEW OF TYPICAL RDSF CO-FIRED PULVERIZED COAL BOILER

FIGURE 2.1-1



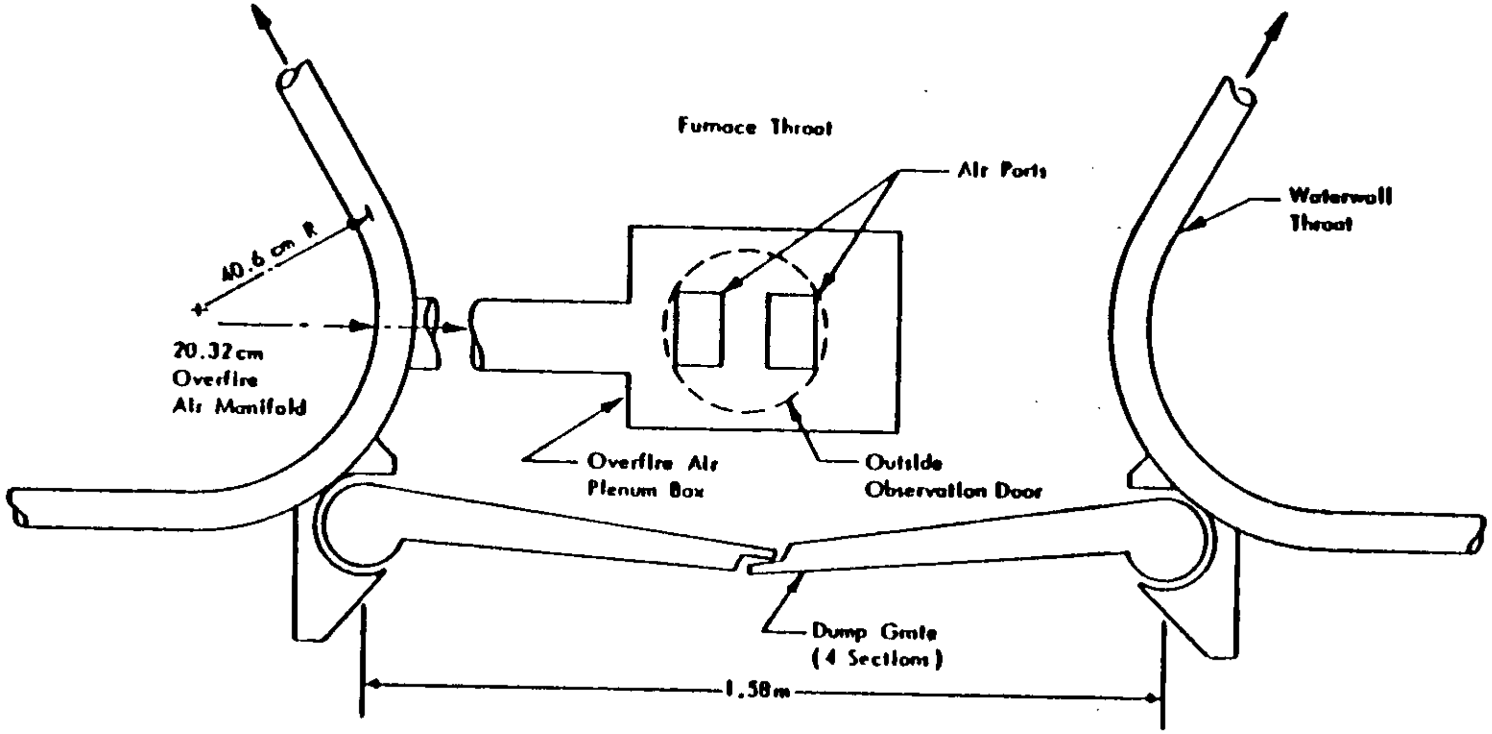
ELEVATION VIEW OF TYPICAL DUMP GRATE INSTALLATION

FIGURE 2.1-2



PLAN VIEW OF TYPICAL DUMP GRATE INSTALLATION

FIGURE 2.1-3



CROSS SECTIONAL VIEW OF TYPICAL DUMP GRATE AND OVERFIRE AIR PORT

FIGURE 2.1-4

Heat-loss due to the sensible heat contained in the flue gases exiting the regenerative air heater is always one of the most singificant losses from a boiler. The greater the percentage of moisture in the flue gas becomes, the larger will be the boiler heat loss due to moisture, assuming that stack temperature does not vary significantly.

Table 2.2-1 presents an estimate of flue gas composition based on two different fuel compositions. The first fuel is 100 percent performance coal and the second fuel is a mixture of 62 percent performance coal and 38 percent "worst case" RDSF. The 62%/38% mixture is in the proportions required to obtain 20 percent of the total heat input from the RDSF. The data in Table 2.2-1 is for complete combustion with 20 percent excess air. It can be seen that the percent by volume of H_2O in the flue gas increases from 8.9 percent to 11.1 percent. This means that the heat loss due to all sources of moisture could increase approximately 25 percent over its value with coal only.

Table 2.2-1 Estimated Flue Gas Compositions for Coal Vs. Coal/RDSF Mixture

	Flue Gas Composition (% by Vol.)	
	Performance Coal	62% Coal/ 38% RDSF
CO_2	14.2	13.9
H_2O	8.9	11.1
SO_2	.05	.04
N_2	73.6	71.8
O_2	3.3	3.2

NOTE: Assumes complete combustion and 20 percent excess air.

Another area where some efficiency is lost when co-firing RDSF is the regenerative air heater. Total flue gas volumetric flow is increased when RDSF is introduced. This occurs for two reasons. First, even though less air is required to burn a pound of RDSF than a pound of coal, the total flow of fuel (by weight) increases when RDSF is introduced. This in itself increases flue gas flow. Secondly, the greater percentage of moisture in the flue gas reduces the density of the flue gases (water vapor is less dense than nitrogen, carbon dioxide, or oxygen). This increase in volumetric flow reduces the effectiveness of the air heater. Moreover, with an increased percentage of moisture, the flue gas has a slightly higher specific heat capacity (i.e., less temperature drop is required to give up the same amount of heat). The net result of all this on the air heater is a rise in flue gas outlet temperature (as much as 12-15°F) with a corresponding loss in boiler efficiency. If an attempt were made to oversize the preheater to lower the flue gas temperature when RDSF is burned then flue gas tempertures may dip below the sulfuric acid dew point when 100 percent coal is burned. For this reason, consideration should be given to the incorporation of an air heater or economizer bypass control to hold air heater flue gas outlet temperature within acceptable limits.

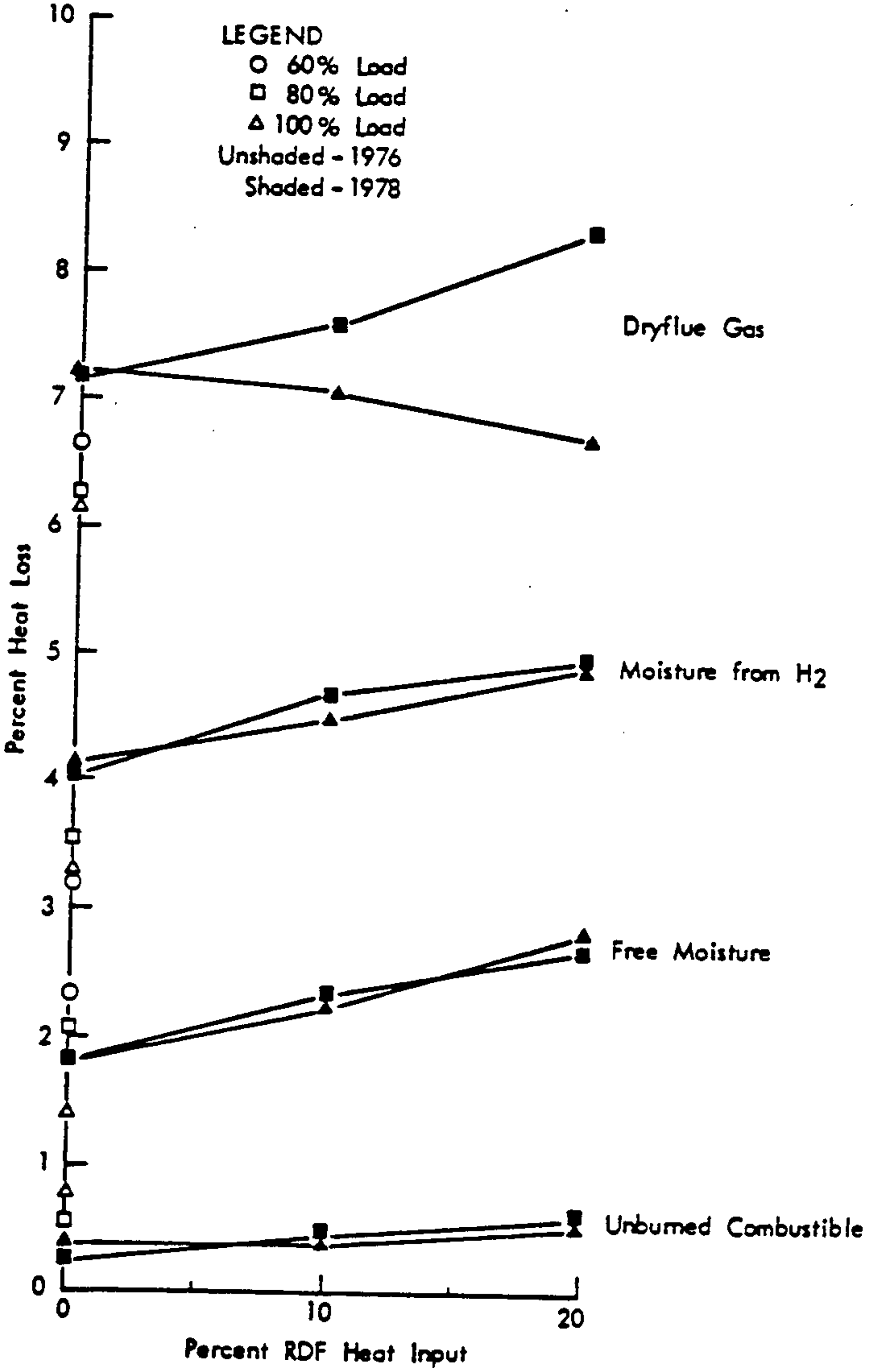
The last area where efficiency losses can occur is in combustible losses in the fly ash and bottom ash. Experience has shown that the percentage of combustibles in the ash can be maintained at about the same level with coal/ RDSF mixtures as with coal only. However, the total amount of ash almost always goes up when coal/RDSF mixtures are burned. This tends to increase the loss of unburned material in the fly ash by a small amount.

It is commonly believed that a greater amount of excess air is required to burn a coal/RDSF mixture. The most recent demonstrations show that this is not the case. With proper location of the RDSF nozzles and with a dump grate installed in the boiler, combustion of coal/RDSF mixture can be completed with 20 percent excess air, which is the normal design excess air for a pulverized coal boiler. Therefore, efficiency losses due to increased excess air are avoidable.

Figure 2.2-1 is an example from the Ames project of the increases in each component of efficiency loss as the percentage of RDSF increases. The drop in dry flue gas loss for the 100 percent load case is a result of a drop in excess air. This drop in excess air occurred because the tendency toward increased flue gas flow when RDSF was introduced could not be handled by the induced draft fan. As a result forced draft air could not be increased to maintain the excess level. By totaling the efficiency losses for the 80 percent load case (See Table 2.2-2) it is evident that total efficiency loss is about 3 percent greater for 20 percent RDSF/80 percent coal versus 100 percent coal.

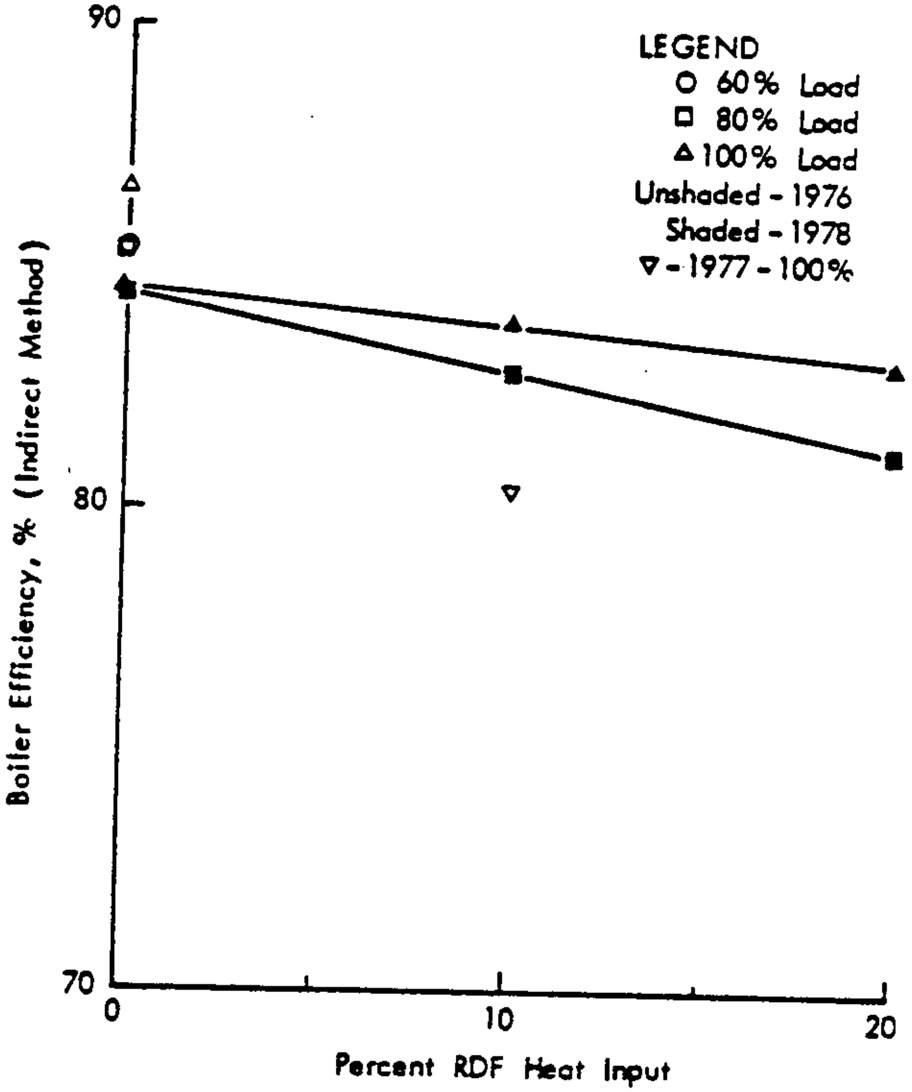
Table 2.2-2 Efficiency Losses Due to RDSF Co-Firing (Ref. 1)

Efficiency Loss Component	100% Coal	20% RDSF/100% Coal	Increase
Dry Flue Gas	7.2	8.3	1.1
Moisture from Combustion of H_2	4.0	4.9	0.9
Free Moisture from Fuel	1.8	2.6	0.8
Unburned Combustibles in Ash	0.3	0.6	0.3
Total Efficiency Loss	13.3%	16.4%	3.1%



BOILER EFFICIENCY LOSSES VS. PERCENT RDSF INPUT (REF. 1)

FIGURE 2.2-1



NET BOILER EFFICIENCY VS. PERCENT RDSF INPUT (REF. 1)

FIGURE 2.2-2

Thus, overall boiler thermal efficiency may be expected to be about 3 percent less when RDSF is co-fired at 20 percent of the total heat input. This drop in efficiency is apparent in Figure 2.2-2 which depicts boiler efficiency as a function of percent RDSF heat input for the Ames project. Again, the fact that the efficiency is better at 100 percent load is because excess air actually decreased as RDSF was increased due to lack of induced draft fan capacity.

2.3 Boiler Operations and Auxiliary Equipment

2.3.1 Bottom Ash System

One of the components of boiler auxiliary equipment that is likely to be affected by co-firing RDSF is the bottom ash handling system. If the performance coal is fired in the boiler at 100 percent load, approximately 24 tph of bottom and fly ash will be generated. However, when a 20 percent RDSF/80 percent coal mixture is fired at 100 percent of design boiler load and the RDSF approaches the "worst case" composition, approximately 39 tph of bottom ash and fly ash will be formed. Thus, there may be as much as a 63 percent increase in total ash.

Moreover, there is a tendency when co-firing RDSF for a greater percentage of the total ash to be converted to bottom ash. For instance, during coal firing at Ames, the bottom ash was typically about 10 percent of the total ash. However, when 20 percent RDSF/80 percent coal was burned, the bottom ash increased to 38 percent of the total ash. The actual quantity of bottom ash increased about six times with 20 percent RDSF/80 percent coal vs. 100 percent coal at 100 percent of boiler design load. This effect is borne out by tests at another demonstration plant, which showed no significant increases in dust loading to the precipitator with a 20 percent RDSF mixture even though the coal averaged about 7 percent ash and the RDSF averaged 22 percent ash. (Ref. 2). This means that most of the additional ash input from the RDSF was actually converted to bottom ash. The net result as far as the bottom ash system is concerned is that bottom ash may have to be pulled out of the hopper as much as 3 to 4 times more frequently than normal. This, in turn, may increase maintenance costs and hasten wear out of this equipment.

2.3.2 Wall Slagging

There has been a definite tendency toward increased slagging when RDSF has been co-fired with coal in older (i.e. pre-1970), higher heat release boilers which have been retrofitted with RDSF co-firing capability. This is normally attributed to the glass in the RDSF. Careful processing can substantially reduce the amount of glass in the RDSF. However, 1 to 2 percent glass can still be expected. A major component of glass is sand (SiO_2). Tests run at Ames comparing the composition of coal ash and

RDSF ash indicates that SiO_2 in the coal ash averages 36.43 percent and in the RDSF ash it averages 51.95 percent. On the other hand Fe_2O_3 averages 22.83 percent in the coal ash and 5.13 percent in the RDSF ash.

These trends are evident in Table 2.3.2-1 which is an analysis of the bottom ash and fly ash for 100 percent coal and for 20 percent RDSF/80 percent coal. Note that by far the biggest changes in ash composition occur in the bottom ash as opposed to the fly ash, and the components most affected by the RDSF are SiO_2 (increases), Fe_2O_3 (decreases), and MgO (decreases). Also note that SO_3 decreases substantially when RDSF is burned. Possible explanations for this will be covered under the discussion on AQCS performance.

Other possible contributors to the formation of slag are metal salts that are formed from metals introduced with the RDSF. Analyses of MSW indicate that it contains significantly higher amounts of metals such as sodium, lead, and zinc than coal. These metals form chloride and sulfate salts, which tend to be stable compounds, that will either melt at furnace temperatures or form very fine particulate matter. The effects of salts will be discussed further in the section of this report covering corrosion and the section on SO_2 control.

With such a dramatic change in composition, the bottom ash is almost certain to have vastly different properties when RDSF is fired. Table 2.3.2-2 is a comparision of ash fusion temperatures for coal and RDSF. Note that the ash fusion temperatures for RDSF are generally 200 + degrees lower than for coal in an oxidizing atmosphere. The lower ash fusion temperatures can contribute to softer, more molten material on the furnace walls. Slagging has generally been observed in the upper part of co-fired furnaces particularly in the area just above the upper burner level. In several cases soot blowers were not effective in shedding the slag. The only means to shed the slag was to rapidly drop load and use thermal shock to free the slag from the walls.

Table 2.3.2-2 Ash Fusion Temperatures for JEA Performance Coal and RDSF (RDSF Data From Ref. 1)

Reducing Atmosphere	Coal	RDSF
Initial Deformation	1950	2100
Softening	2050	2130
Hemispherical	2050	2150
Fluid	2150	2190
Oxidizing Atmosphere		
Initial Deformation	2300	2120
Softening	2400	2150
Hemispherical	2400	2190
Fluid	2500	2220

All temperatures in °F.

TABLE 2.3.2-1
TYPICAL COMPOSITIONS OF BOTTOM ASH AND FLY ASH (REF. 1)

	Bottom Ash			Fly Ash		
	100 % Coal	20% RDSF 80% Coal	Difference	100% Coal	20% RDSF 80% Coal	Difference
SO_3	15%	1.3	-14.5	3.23	2.43	-0.8
Al_2O_3	6.46	10.9	+4.44	17.0	19.3	+2.3
SiO_2	13.8	55.3	+41.5	41.5	44.1	+2.6
TiO_2	.08	1.06	+ .98	1.24	1.32	+ .08
K_2O	.41	.82	+ .41	1.63	1.65	+ .02
CaO	19.2	11.03	- 8.17	6.99	6.65	-0.34
Fe_2O_3	28.2	11.27	-16.93	24.8	19.5	-5.3
Na_2O_3	1.01	4.46	+ 3.45	1.56	1.67	-0.11
MgO	13.6	2.26	-11.34	0.80	1.10	+ .30
P_2O_5	.34	.52	+ .18	0.73	0.88	+ .15

This problem must be discussed with the boiler manufacturers and an appropriate mitigating measure developed. A possible fix would be the incorporation of additional soot blowers or water lances in the areas of the boiler where this may be a problem. If temperature cycling is found to be the only practical means of shedding slag, then backup power costs during deslagging could be substantial. However, in the opinion of at least one boiler manufacturer, the limitations placed on heat release in modern, coal fired boilers should miminize, if not entirely eliminate, the slagging problem if the boiler is designed with RDSF co-firing in mind. (Ref. 11).

As discussed in Section III.1.2, above, the best way to mitigate the ash problem is to control the ash in the RDSF by proper design and operation of the processing plant, enforced by a sampling program, and by rejection of unsatisfactory RDSF.

2.3.3 Fan Power Requirements

As mentioned in the discussion on boiler efficiency, there is a definite increase in the volume flow of flue gases when RDSF is co-fired with coal. Calculations show that the actual volumetric flow rate of flue gas will increase approximately 5.7 percent when 20 percent RDSF/80 percent coal is fired versus 100 percent coal at the same boiler load. This increase in volume flow rate with its corresponding increase in velocity will result in approximately an 11.7 percent increase in flue gas pressure drop. Moreover, there will be about a 4.9 percent increase in flue gas mass flow. Since induced draft fan horsepower is proportional to mass flow rate and system pressure drop, the total induced draft fan power requirements will increase roughly 17.2 percent. This could lead to as much as a 2280 hp increase in induced draft fan power requirements per boiler.

The increase in induced draft fan horsepower will also be accompanied by an increase in forced draft fan power requirements. Forced draft fan air flow will be increased by about 5.4 percent and total forced draft fan horsepower will be increased by about 17.1 percent for a 20 percent RDSF/80 percent coal mixture versus 100 percent coal. This will raise forced draft fan power requirements by about 370 hp per boiler at design load.

Even though the amount of oxygen is higher in the refuse then in the coal, which tends to reduce combustion air requirements, the total mass flow of fuel (coal and RDSF combined) increases substantially (about 34 percent). The net result is an increase in the forced draft air requirements.

Therefore, between both the induced draft and forced draft fans there is a net increase of 2650 horsepower per boiler when RDSF is fired at 20 percent of the heat input at full boiler load. With regard to induced draft fan capacity, the fan will be sized for 117 percent of boiler design flue gas flow (on coal) and 137 percent of system design flue gas pressure drop . Thus, the capacity of the fan should be adequate for any foreseeable combination of RDSF/coal co-firing.

2.3.4 Superheat Temperature

Experience has shown that there is a tendency for the steam superheat temperature to increase when RDSF is co-fired. This is believed to be a result of the lower radiant characteristics of an RDSF flame versus a coal flame. The reduction in heat transfer by radiation causes the flue gases to be hotter as they approach the upper part of the furnace and the superheater tubes. This is the same effect that has been known for sometime for gas and wood as compared to oil and coal as the trends in Figure 2.3.4-1 indicate. The net result is that tempering water flow may have to be increased between primary and secondary superheater banks to prevent overheating of the secondary superheater tubes. The same effect is likely to be observed on reheater tubes.

2.4 Air And Water Quality Control Systems

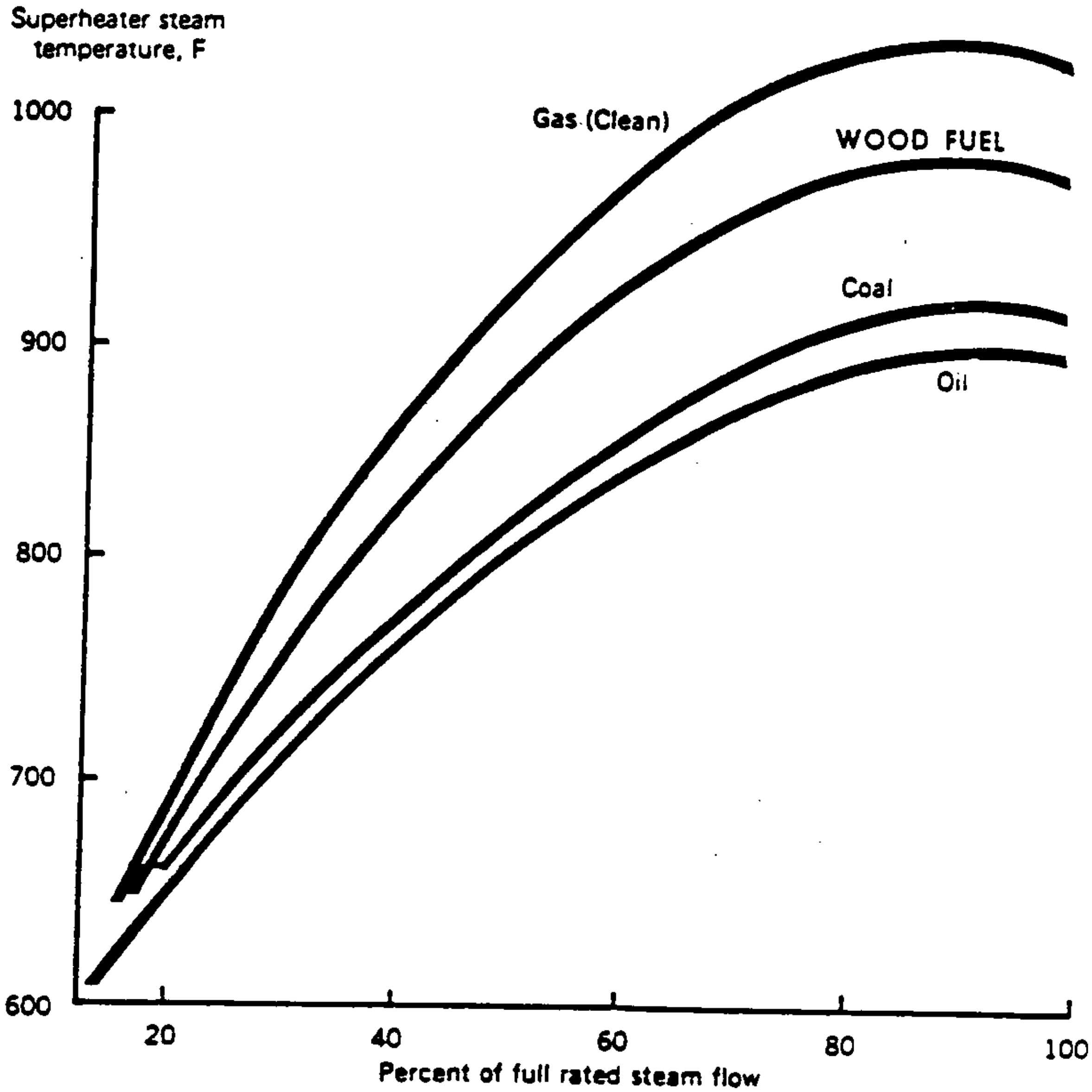
2.4.1 Air Quality Control System

2.4.1.1 Particulate Control

There is substantial evidence that precipitator efficiency is impaired when RDSF is co-fired with coal. Tests conducted at the Ames facility during 1978, show approximately a 1-2 percent drop in precipitator efficiency as the RDSF is increased to 20 percent of the total heat input (See Figure 2.4.1.1-1). Similar results were obtained at another demonstration plant at St. Louis (Ref. 2).

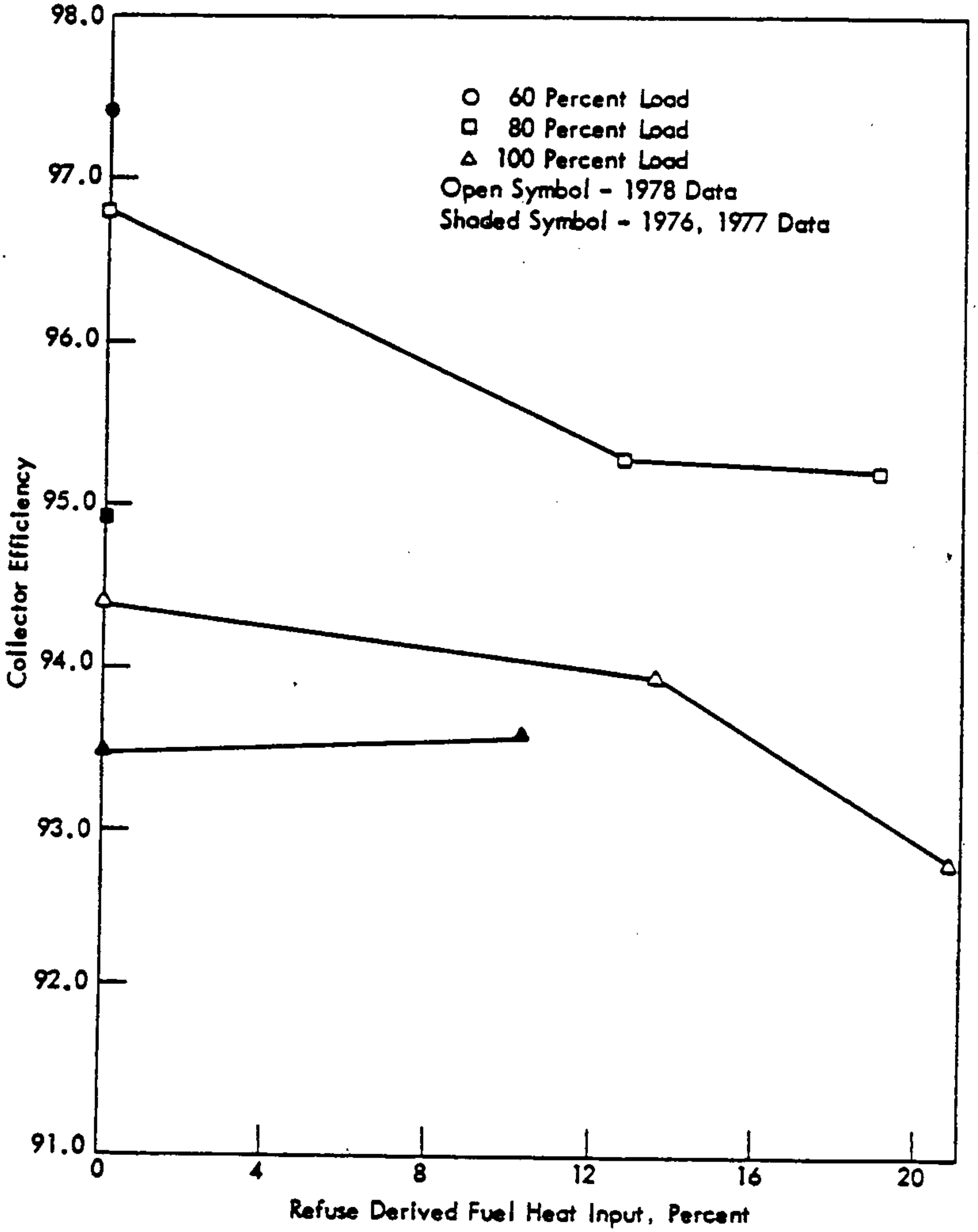
There are basically three reasons why the efficiency of the precipitator decreases. First, the flue gas flowrate increases with RDSF, which in turn increases the velocities in the precipitator. Residence time in the precipitator is critical to collection of the fly ash. Secondly, the resistivity of the fly ash increases when RDSF is introduced. This increase in resistivity is shown dramatically in Figure 2.4.1.1-2, which shows an increase from about 3×10^{11} ohm-cm at 100 percent load and 100 percent coal to about 5.5×10^{11} ohm-cm at 100 percent load and 20 percent RDSF. Finally, there is greater difficulty in collecting the carbon particles from the combustion of paper, cloth, etc.

Indications are that the increased resistivity may be a greater problem than the increase in flue gas velocities. As resistivity increases there is a greater tendency for the precipitator to spark. In fact, sparking rates at the St. Louis facility actually increased by a factor as high as 20 when RDSF was introduced. Since a high sparking rate can damage the precipitator by burning out wires, the rectifier control sets are designed to reduce the power input to the fields as the sparking rate increases. At St. Louis power levels were reduced from 4-18 percent when RDSF was fired. Naturally, as input power is reduced, collection efficiency decreases.



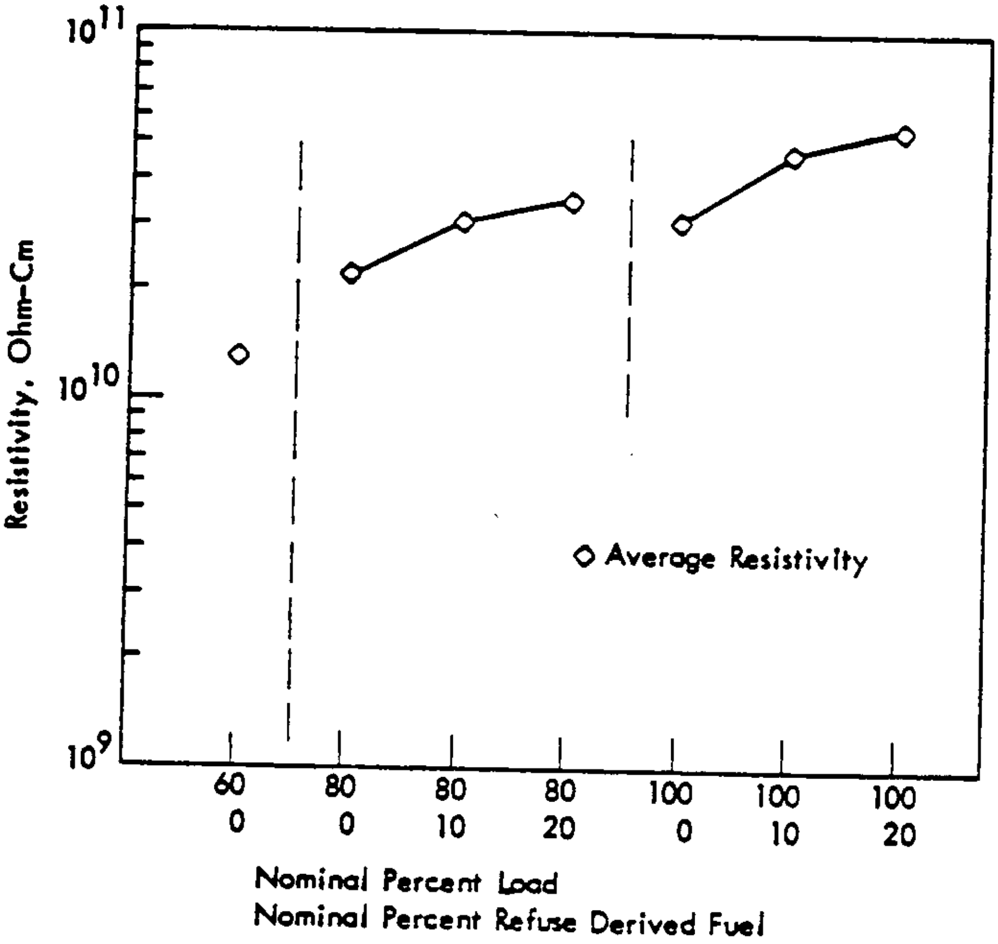
EFFECT OF FUEL ON UNCONTROLLED SUPERHEATER STEAM TEMPERATURE

FIGURE 2.3.4-1



PRECIPITATOR EFFICIENCY VS. PERCENT RDSF INPUT (REF. 1)

FIGURE 2.4.1.1-1



FLY ASH RESISTIVITY VS. PERCENT RDSF INPUT (REF. 1)

FIGURE 2.4.1.1-2

The resistivity of the ash increases when RDSF is introduced probably as a result of the lower sulfur content of the RDSF (compared to coal), which in turn reduces the sulfur content of the flue gas. Tests at Ames showed that the SO_2 and SO_3 in the flue gas is cut almost in half when RDSF approaches 20 percent of the heat input (See discussion on SO_2 emissions in Section 2.4.1.3).

Contrary to expectations, tests showed that there was no significant increase in inlet dust loading to the precipitator when RDSF is fired (this result was with the RDSF nozzles located above or between the coal nozzles). This is consistent with the finding that the additional ash input into the boiler as RDSF is increased tends to increase the bottom ash rather than the fly ash.

In addition to the decrease in precipitator efficiency at Ames when RDSF was fired, it was noted that the particulate matter often contained pieces of a black sooty substance believed to be unburned carbon, which could not be collected by the precipitator. Complaints were even received from persons living near the plant. As a result, the decision was made to relocate the RDSF nozzles to a position below the coal nozzles. This apparently improved the soot problem, actually lowered the inlet dust loading to the precipitator, and reduced the total particulate emissions. However, the precipitator efficiency still went down when RDSF was fired because of the other effects described above.

At JEA, the EPA mandated particulate emission limit is 0.03 $lbm/10^6 Btu$, which in turn requires a precipitator collection efficiency of 99.78 percent. It is uncertain whether this emission limit can be met if RDSF is burned at up to 20 percent of the total heat input, unless the precipitators are substantially increased in size. The precipitators for the Ames and St. Louis projects were designed for 98 percent and 97.5 percent respectively, which, in precipitator design terms, is an order of magnitude less critical than the present JEA design.

It is known that co-firing of refuse tends to result in an increase in carbon material (primarily soot) being discharged from the boiler (see discussion above). This material accepts an electric charge easily, but it also gives up its charge very easily with the result that re-entrainment into the gas stream can readily occur.

To allow for this contingency a precipitator designed for refuse co-firing should be sized along the lines of a precipitator designed for residual oil service. Soot deposits are a characteristic of even the best residual oil flames. This in turn means that gas velocities should approach 3.0 feet per second instead of the 4.5 feet per second normally used in coal service.

If the present precipitator design is retained and a 33 percent decrease in flue gas flow is required to reduce flow velocity from 4.5 fps to 3.0 fps, the boiler load must be reduced at least 33 percent. This in turn would bring the boiler load below the 70 percent load threshold that the boiler manufacturer's recommend for firing RDSF. At that operating point, no RDSF could be fired because the boiler control logic would prevent it. Thus, there is a possibility that if no modification is made to the precipitator, it will not be possible to fire RDSF and meet the allowable particulate emission limit.

A more acceptable alternative is to size the precipitator very conservatively in order to remain within the 0.03 $lbm/10^6 Btu$ limit. The width of the precipitator will have to increase by about 33 percent to reduce the gas velocity the required amount. The increase in width will be accompanied by a reduction in length, while the total plate area will be increased by about 10 percent. This in turn results in approximately a 10 percent increase in cost for both precipitators.

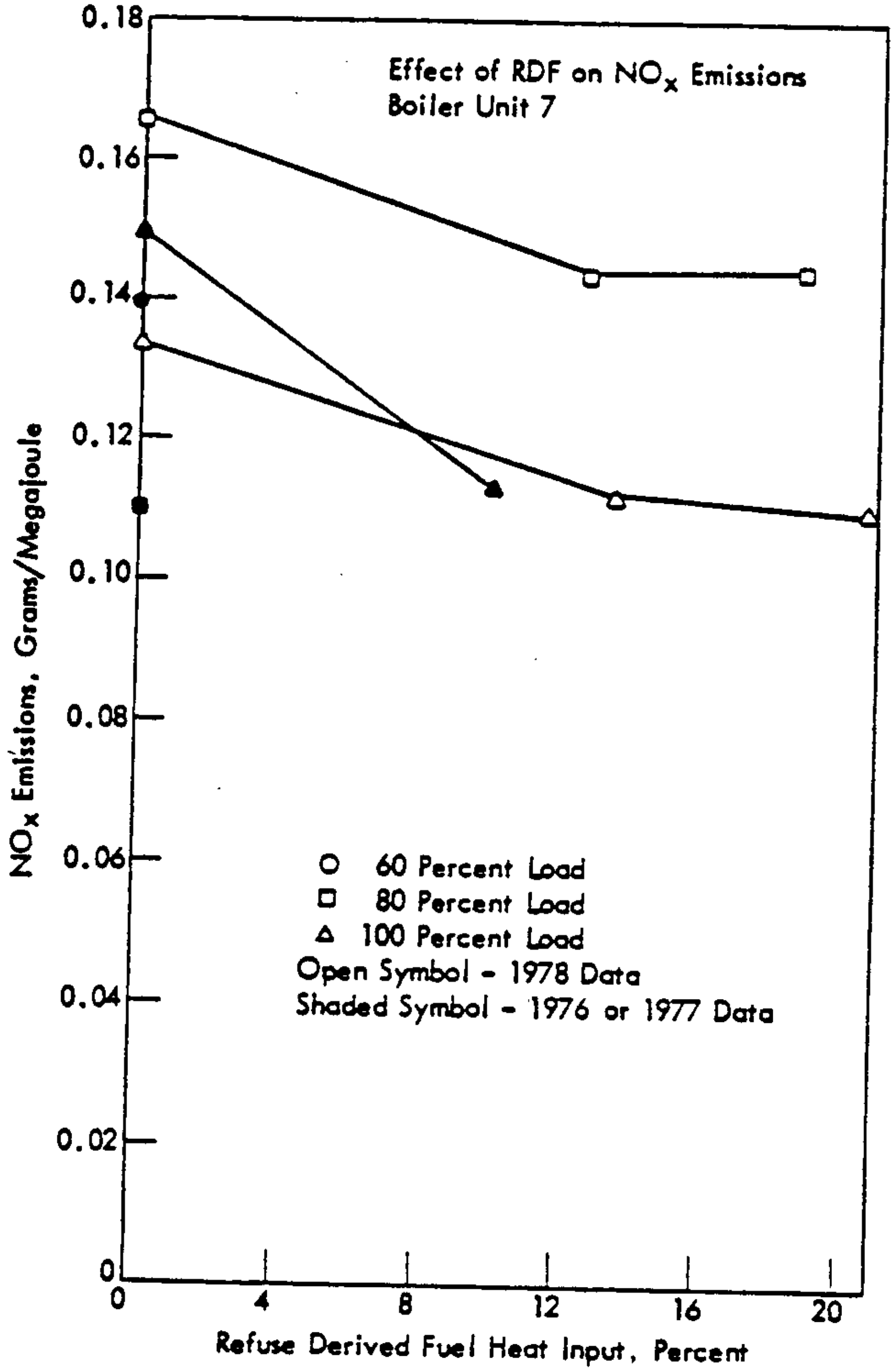
In spite of an increase in precipitator size, it may still be difficult if not impossible to obtain guarantees on the precipitators involving significant monetary penalties for non-performance. The absence of experience with co-firing RDSF in modern boilers fitted with high (99.8 percent) precipitators and the uncertain properties of the ash formed from co-firing with coal make it difficult to predict precipitator performance. The same statement applies although not as rigidly, to guarantees of NO_x by the boiler supplier and guarantees of SO_2 by the scrubber vendor. This is, of course, subject to confirmation during the actual AQCS procurement cycle.

2.4.1.2 NO_x Control

The control of NO_x is not a problem when RDSF is co-fired as illustrated in Figure 2.4.1.2-1. There are two possible reasons for this finding. First, RDSF tends to be lower in fuel-bound nitrogen than coal. Fuel bound nitrogen has been found to be a major contributor to the formation of NO_x. Secondly, the slower combustion characteristics and higher moisture content of RDSF tend to keep flame temperatures slightly lower than with a pure coal flame. A high flame temperature, which contributes to the dissociation of the N_2 and O_2 molecules, have been linked to NO_x formation. In general, NO_x emissions appear to decrease by 10 to 20 percent when RDSF is co-fired at 20 percent of the total heat input.

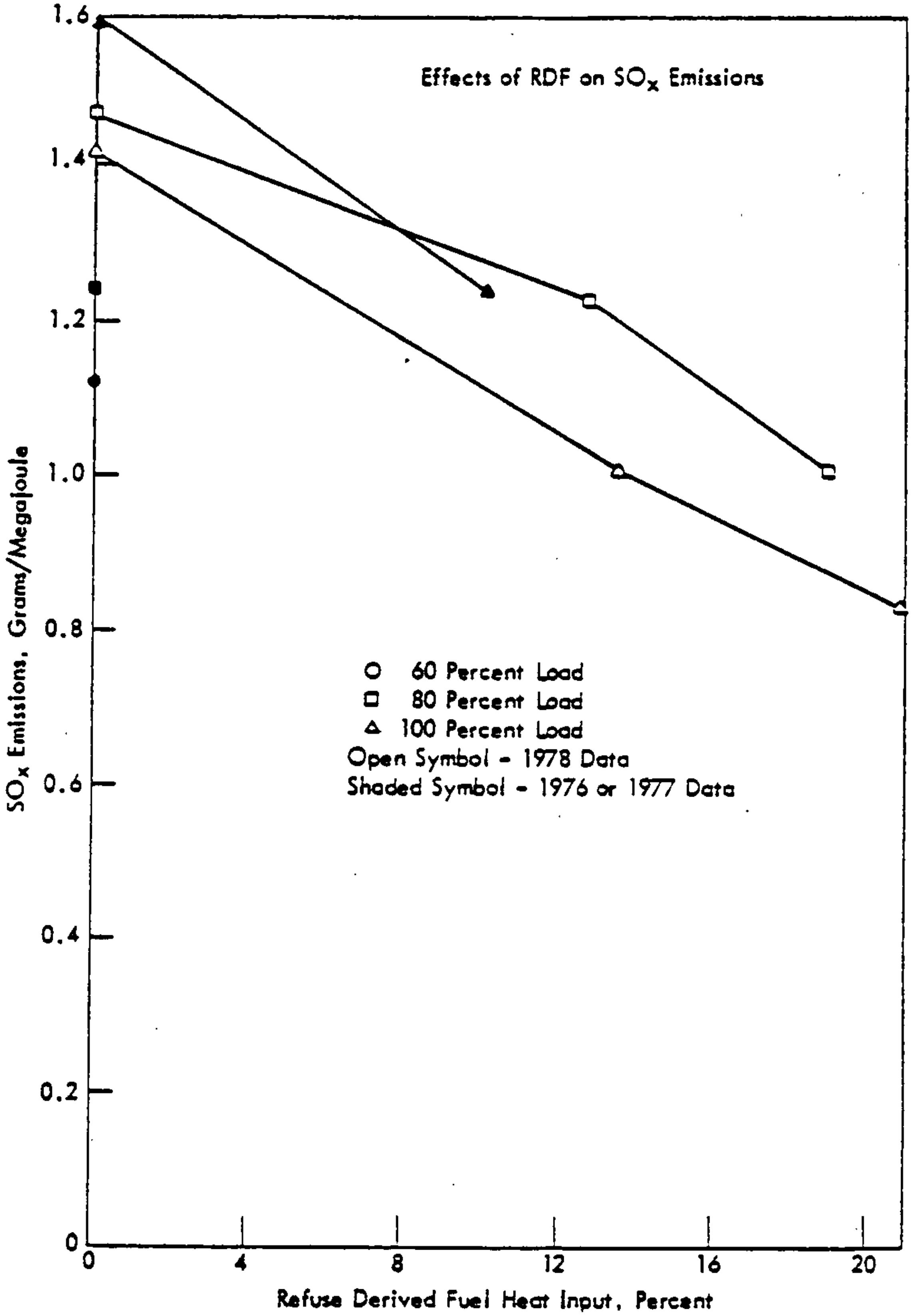
2.4.1.3 SO_2 Control

It has been widely verified that RDSF contains substantially less sulfur than even most low sulfur coals. The sulfur content of RDSF is typically 0.1 to 0.4 percent, while the sulfur content of coal may run from 0.5 to as high as 6 to 7 percent. The result in virtually all cases, when RDSF is co-fired with coal, is a substantial reduction in the emissions of SO_2 and SO_3. A good example of this effect from the Ames system is shown in Figure 2.4.1.3-1. SO_2 and SO_3 emissions were reduced by almost 42 percent as RDSF was increased to 20 percent of the heat input.



NO_x EMISSIONS VS. PERCENT RDSF INPUT (REF.1)

FIGURE 2.4.1.2-1



SO_x EMISSIONS VS. PERCENT RDSF INPUT (REF. 1)

FIGURE 2.4.1.3-1

Often the reduction in SO_2 emissions is more than can be explained by the dilution effect mentioned above. Intensive research into the corrosion mechanisms of MSW, when fired alone or when converted to RDSF and co-fired with coal, has led to the hypothesis that the following type of reaction may be taking place.

$$\text{Metal Chloride} + SO_2 + O_2 + H_2O \longrightarrow \text{Metal Sulfate} + HCl$$

The significant reduction in SO_2 emissions is good evidence of this reaction. As noted in the section on boiler slagging, it is known that RDSF contributes significant quantities of metals, which tend to form chlorides and sulfates. Further evidence for this reaction is the the increasing tendency for chlorine in the RDSF/coal fuel mixture to be converted to HCl as the amount of sulfur in the coal increases (this effect will be discussed further in the section on chloride emissions).

HCl is an extremely soluble gas and it will be absorbed readily in the SO_2 scrubber. However, the increase in chlorine concentration in the scrubber liquor will tend to tie up the calcium as $CaCl_2$ and reduce the free calcium ions available for the reactions leading to the formation of $CaSO_4$. Thus, limestone or lime reagent addition may have to be increased slightly to accommodate the increased chlorine in the scrubber liquor.

Unfortunately, since all of the RDSF demonstration plants operated to date have been modifications of existing units, none have been equipped with SO_2 scrubbers, so there is no actual experience of the effect of RDSF on scrubber performance. How much the reduction in SO_2 may be when firing RDSF depends a great deal on the sulfur content of the coal selected and on the sulfur and trace metals content of the RDSF.

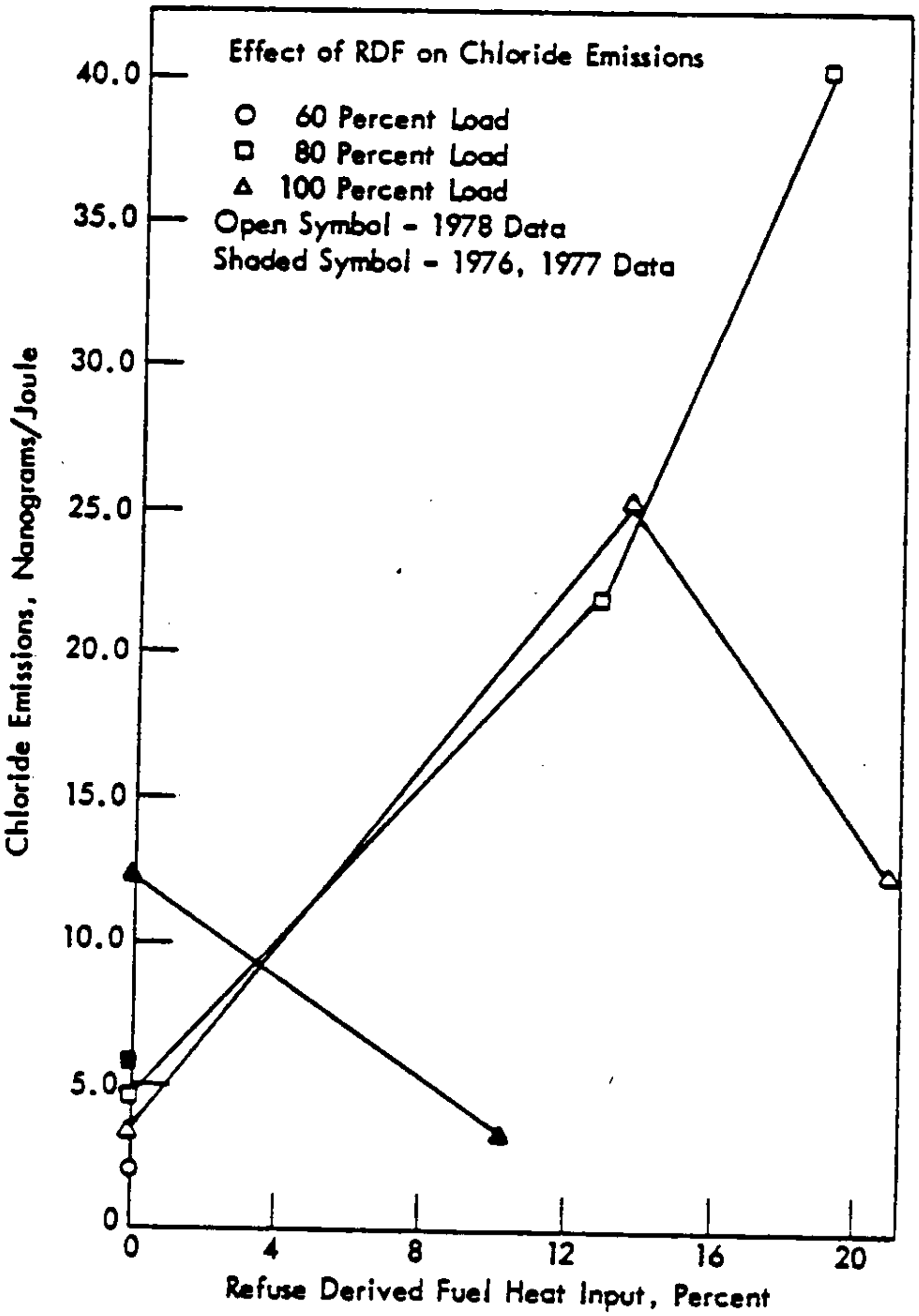
2.4.1.4 Chloride Emissions

Chloride emissions tend to increase noticeably when RDSF is co-fired with coal. The reasons for this seem to be twofold. First, RDSF has a higher chloride content than coal. This is believed to be due to the presence of chlorinated plastics (e.g. polyvinylchlorides) in RDSF. Secondly, the reaction discussed previously for conversion of metal chlorides to metal sulfates tends to favor the formation of HCl which is carried out with the flue gas.

In the tests at Ames, chlorine concentrations in the flue gas increased 2 to 8 times when RDSF was co-fired at up to 20 percent of the heat input as shown in Figure 2.4.1.4-1. In the present system, however, chlorides will probably be trapped in the SO_2 scrubber and should not present an air quality problem.

2.4.1.5 Trace Element Emissions

Table 2.4.1.5-1 is a comparison of the composition of several trace elements in the coal and RDSF at Ames. Only those elements where there is a substantial difference in concentration are shown. Note the tremendous increases in lead, zinc, and copper. Zinc is believed to enter



CHLORIDES EMISSIONS VS. PERCENT RDSF INPUT (REF. 1)

FIGURE 2.4.1.4-1

the RDSF through the filler material in paper. Lead and Copper are probably from inks used in newsprint and colored pictures. The lead, zinc, and copper also were found to increase in the bottom ash when RDSF was fired. Only zinc and lead increased in the fly ash.

Table 2.4.1.5-1 Concentrations of Trace Elements in Coal and RDSF (Ref. 1)

Element	Coal	RDSF
Zinc	66	763
Lead	36	613
Copper	15	572
Manganese	76	194
Gallium	2.5	16
Vanadium	83	154
Chromium	19	34

Concentrations in ppm.

Table 2.4.1.5-2 shows the concentrations of various trace elements in the flue gases at Ames. The scrubber should tend to trap these trace elements and significantly reduce their concentrations in the flue gases at JEA.

Table 2.4.1.5-2 Trace Elements in Flue Gases (Ref. 1)

Element	Flue Gas Concentration (Pg/J)
Cobalt	234
Arsenic	385
Zinc	70.6
Copper	25.6
Manganese	9.5

All others below detection limits.

Pg/J - picograms/joule

NOTE: Trace Elements Sampled While Firing 20 Percent RDSF

Increased emissions of lead, zinc, beryllium, chromium, copper, fluorine, mercury-vapor, mercury-solid, gallium, potassium, and titanium when co-firing RDSF were reported in a survey of emissions tests at several facilities (Ref. 12). Of this list only beryllium and mercury have been addressed in the standards prepared to date by EPA under NESHAPS (National Emission Standards for Hazardous Air Pollutants). These limits are not applicable to a coal-fired power plant or refuse co-fired power plant.

2.4.2 Water Quality

2.4.2.1 Bottom Ash Sluice Water

Since the bottom ash may be in contact with water if a wet system is employed, concentrations of contaminants in the sluice water may be important. Early experience at St. Louis before implementation of the air classifier in the processing plant showed that bottom ash water did not meet state limits for biological oxygen demand (BOD), dissolved oxygen, and suspended solids (Ref. 5). However, that boiler was not equipped with a dump grate. There were no indications of sluice water contamination at Ames, which did employ a dump grate.

Due to the possible increase in bottom ash generation and sluice water flow, the sizing of the ash settling pond will have to be reviewed if it is decided that RDSF will be burned. There is presently only a 20 percent margin in the design capacity of the pond and additional land for a larger pond is not readily available. Alternatives that would have to be considered wold be deepening the pond by raising the berms or provision for a remote landfill site.

2.5 Corrosion

Corrosion in boilers co-firing RDSF has been a concern due to very bad experience in waterwall incinerators firing 100 percent raw garbage, both in Europe and the U.S. in the last two decades (Ref. 6). Material losses of 0.1 to 0.2 mils per hour have been reported for steels in incinerator service burning raw, unprocessed refuse. As more and more data on co-firing becomes available, however, it is rapidly becoming apparent that bulk incineration of pure, raw refuse and co-firing have relatively little in common when it comes to the severity of corrosion.

The best example of this was a series of experiments run in a stoker-fired boiler at the Municipal Electric Plant in Columbus, Ohio (Ref. 7). Table 2.5-1, which is taken from this report, shows corrosion rates of steels and stainless steels for situations where RDSF was co-fired at up to 74 percent by weight versus a case where 100 percent refuse was fired. Corrosion rates for co-firing are substantially lower than for 100 percent refuse, and comparable to those experienced when burning 100 percent coal (0.01 to 0.02 mils per hour).

These results are verified by the initial corrosion tests at Ames, where two stoker-fired units operated for 1000 hours with up to 50 percent by weight RDSF (Ref. 8). Corrosion of waterwall tubes was nonexistent and corrosion of superheater tubes, if any, was less than 0.025 mm. Corrosion data on the pulverized-coal unit at Ames is not available yet.

TABLE 2.5-1
CORROSION RATES FOR VARIOUS ALLOYS AS A FUNCTION OF METAL TEMPERATURE (REF. 7)

(All data in mils/hour)

Alloy	Metal Temp. F	Probe 30 1% Coal	Probe 28 3% S Coal	Probe 34 5% S Coal	Probe 31 3% S Coal 28 Wt % Refuse	Probe 33 5% S Coal 27 Wt % Refuse	Probe 35 3% S Coal 36 Wt % Refuse	Probe 36 3% S Coal 42 Wt % Refuse	Probe 37 3% S Coal 75 Wt % Refuse	100% Refuse
A106	500	0.004	0.005	0.002	0.002	0.002	0.003	0.001	0.006	0.16
	700	0.008	0.007	0.020	0.010	0.021	0.008	0.012	0.013	0.18
	900	0.022	0.027	0.063	0.030	0.068	0.031	0.035	0.020	0.20
T11	500	0.005	0.005	0.002	0.004	0.003	0.002	0.002	-	0.10
	700	0.006	0.007	0.013	0.005	0.018	0.006	0.005	-	0.12
	900	0.013	0.022	0.034	0.022	0.037	0.020	0.020	-	0.18
316	500	0.003	Nil	Nil	Nil	Nil	Nil	Nil	0.004	-
	700	0.005	Nil	0.001	0.001	0.001	Nil	Nil	0.004	0.056
	900	0.006	0.001	0.002	0.001	0.002	0.004	0.002	0.004	0.056
446	500	0.003	Nil	Nil	0.001	0.001	-	-	-	-
	700	0.007	Nil	0.005	0.001	0.001	-	-	-	0.050
	900	0.001	0.001	0.001	0.001	-	-	-	-	0.050
310	500	Nil	Nil	Nil	Nil	Nil	Nil	Nil	0.0005	-
	700	Nil	Nil	Nil	0.0005	0.0005	Nil	Nil	0.0007	0.032
	900	0.0001	0.0005	0.0005	0.0005	0.001	0.0005	0.001	0.001	0.032
JS700	500	Nil	Nil	-	Nil	-	-	-	-	-
	700	Nil	Nil	-	0.0005	-	-	-	-	-
	900	0.0006	Nil	-	0.0005	-	-	-	-	-
405	500	-	-	0.001	-	0.001	Nil	Nil	-	-
	700	-	-	0.003	-	0.009	0.002	0.006	-	-
	900	-	-	0.008	-	0.010	0.010	0.012	-	-
P5	500	-	-	-	-	-	0.003	-	-	-
	700	-	-	-	-	-	0.008	0.012	-	-
	900	-	-	-	-	-	0.020	0.013	-	-
P9	500	-	-	-	-	-	-	-	0.009	-
	700	-	-	-	-	-	-	-	0.010	-
	900	-	-	-	-	-	-	-	0.012	-
347	500	-	-	-	-	-	-	-	0.002	-
	700	-	-	-	-	-	-	-	0.002	-
	900	-	-	-	-	-	-	-	0.002	-

Another series of corrosion tests were run at Milwaukee, Wisconsin, where RDSF has been co-fired since 1977, in two 2400 psi, 1050°F pulverized coal units rated at 310 MW each (Ref. 10). This test program used corrosion probes mounted in several areas of the backend of the boiler from the superheater tubes down to the air heater. A metal temperature range of 220°F to 1210°F was included, and RDSF heat input rates ranged from 10 to 15 percent. Coals ranged from 1.0 to 3.9 percent sulfur (average sulfur content was 2.4 percent). The study concluded that wastage of boiler materials did not appear to be noticeably affected by the co-firing of RDSF.

Why corrosion rates are substantially lower in co-fired boilers as opposed to incinerators is not well understood. Chloride concentrations increase when RDSF is fired and sulfates and chlorides are found in deposits of co-fired units just as they are found on badly-corroded incinerator tubes. It is believed that the reaction

$$\text{Metal Chloride} + SO_2 + O_2 + H_2O \rightarrow \text{Metal Sulfate} + HCl$$

occurs in incinerators and the same reaction appears to exist in co-fired units as described in previous sections of this report.

The major difference between the deposits in co-fired units and incinerators is a reduction of the chloride concentration within the deposit. Moreover, co-firing is usually accompanied by larger increases in HCl emissions than just the increased weight of chlorine input would indicate. This evidence seems to verify that the above reaction is indeed occuring. Due to the larger amounts of sulfur available from the coal in a co-fired unit, the sulfate and HCl formation is favored much more heavily.

The Ames tests verified that significant amounts of sulfates were in the deposits of the stoker boiler waterwalls and superheater tubes, yet corrosion rates were undetectable. Hence, it would appear that the metal chlorides are the major contributors to incinerator corrosion. In co-fired units the chlorides tend to be converted to HCl. HCl vapor is not very corrosive as long as it is not allowed to condense to a liquid. It should be noted, however, that the coal for the Ames tests contained 3.5 to 6.7 percent sulfur which would tend to favor sulfate formation. Also, the Columbus, Ohio tests used coal with 3 to 5 percent sulfur.

In summary, to date there has been no evidence of significant corrosion on any components of a boiler or precipitator in co-firing service as long as the sulfur content of the coal averages 2.5 percent or greater. If the sulfur content of the coal were to drop below 2.5 percent, there may be a greater tendency for chloride corrosion.

With regard to corrosion of the scrubber and its auxiliary equipment, co-firing of RDSF will probably have relatively little additional effect. The scrubber environment is already an extremely corrosive one and material selections based on normal scrubber service should be adequate to handle the additional corrosion potential which would be expected from condensing HCl vapors.

3.0 RDSF HANDLING AND FIRING EQUIPMENT

This section describes all the equipment required to receive, store, and burn the processed RDSF. It is assumed that all processing of the RDSF is done at a separate facility built and operated by the Jacksonville Department of Sanitation.

3.1 Alternatives for RDSF Transport, Storage, and Handling

There are two possible options with regard to the transporting of the RDSF from the processing facility to the power plant. If the processing site is more than a mile away from the power plant site, then RDSF could be loaded into 75 cu. yd. transfer trailers for transport to the power plant. If the processing plant is closer than a mile, it may be possible to use belt conveyors to transfer material to the power plant site. The costs for both options will be presented, since each has some advantages over the other.

Another question that must be considered is the location of storage in the RDSF flow scheme. In order to minimize the unit cost of processing RDSF, the processing plant should always operate close to design rate and should be planned to operate on an 8-hour day initially, if possible, which will permit expansion to two shift operations as the waste stream increases. The present rate of garbage pick-up at Jacksonville is about 1950 tpd. At a 75 percent conversion rate, this will produce approximately 1460 tpd of RDSF. Therefore, the production rate of RDSF will be roughly 1460 tpd per 8 hour day operation or 183 tph. Since the maximum continuous burn rate of the RDSF is 200 tph (100 tph per boiler), there will be many days when it will not be possible for the power plant to burn a whole day's production of RDSF in 8 hours. Hence, there is is a need to provide storage for the RDSF, in addition to that provided in the raw refuse pit going into the processing plant. This additional storage should be provided between the processing plant and the power plant for the reasons discussed below.

If storage were to be provided only in the raw refuse pit before the processing plant, then the processing plant must be designed for 200 tph (two lines at 100 tph each) in order to match the burning capability of the two boilers. The problem with this design approach is that there may be days when only one boiler is burning RDSF at a reduced rate of perhaps only 50 tph. Then the processing plant can only operate at 50 tph or less. The garbage that cannot be processed during the day, which amounts to 1064 tons [(183-50) tph x 8 hours], must be processed the next day or the plant must operate extra shifts (all at one half of design capacity for one line) in order to catch up. If extra shifts are not worked and the garbage is processed the next day, then the raw refuse storage pit may fill before the next day is over, and the excess garbage will have to be landfilled with a resulting loss of revenue as well as an additional landfilling cost. Of course, additional storage can be provided in the raw refuse storage pit, but with this design, the processing plant can only process what the boilers can burn at any given time, and it may be difficult for the processing plant to keep up with raw garbage collection.

On the other hand, if the storage capacity is provided between the processing plant and the boiler, then even if the boilers can only burn 50 tph there will be no need to landfill waste. The processing plant will process 1460 tons each day. If this flow is discharged starting in the morning into a empty plant storage system, it will accumulate at the rate of 133 tph for a total of 1064 tons at the end of an 8 hour day of processing (see calculations below).

Storage System Filling Rate - Burn Rate = Net Rate of Filling

$$\frac{1460 \text{ tpd}}{8 \text{ hrs/day}} - 50 \text{ tph} = 133 \text{ tph}$$

The boiler will burn RDSF continuously at the rate of 50 tph and the storage system will only have remaining 660 tons [1460 tons - (50 tph x the remaining 16 hrs.] by the beginning of the next processing day. At that rate, the same operating mode could be maintained for more than 2 days before running out of storage capacity. During the 2 days, the processing plant can continue to run at full capacity.

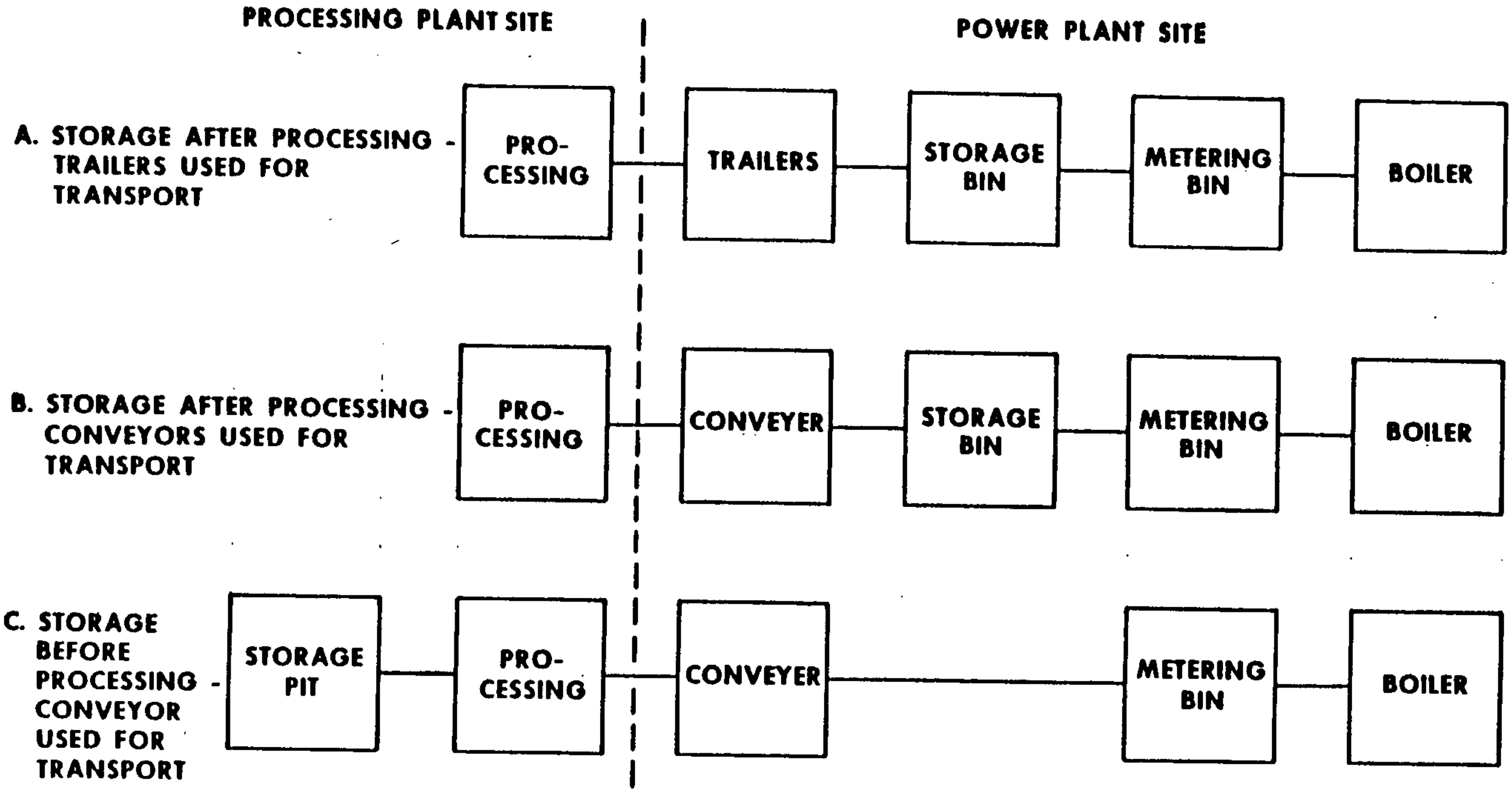
The point of this discussion is the following: To limit storage capacity to the raw refuse pit before the processing plant will result in coupling the processing plant operations very closely to the power plant operations, which is undesirable from a scheduling and cost standpoint. Consequently, it is recommended that RDSF storage capacity be provided between the processing plant and the power plant. The options which have been discussed are diagrammed in Figure 3.1-1. However, as a result of the reasons discussed above, only options A and B appear to be viable alternatives. Consequently, the remaining discussion concentrates on flow schemes A and B.

3.2 Equipment Requirements for Transporting RDSF in Transfer Trailers.

Each of the major pieces of equipment for receiving RDSF in transfer trailers; unloading, storing, and metering the RDSF to the boilers; and all boiler and AQCS modifications necessary to burn RDSF are described below. A layout of the proposed equipment and equipment schematic are presented in Figures 3.2-1 and 3.2.2 at the end of this section.

3.2 Unloading Bin (Item A, Figure 3.2-2)

The size of the unloading bin is determined by the number of trucks that must be unloaded simultaneously. Assuming a bulk density for the RDSF of 15 lb. per cu. ft., this number is determined as follows:



OPTIONS FOR STORAGE AND TRANSPORT OF RDSF

FIGURE 3.1-1

$$\text{Normally RDSF Transfer Rate} = \frac{1460 \text{ tpd}}{8 \text{ hr/day}} = 183 \text{ tph}$$

$$\text{Converting to cu. yds. per hr.} = \frac{183 \text{ tph} \times 2000 \text{ lb./ton}}{15 \text{ lb./ft}^3 \times 27 \text{ ft}^3/\text{yd}^3} = $$

$$= 904 \text{ yd}^3/\text{hr}$$

$$\text{Number of trucks required per hour} = \frac{904 \text{ yd}^3/\text{hr}}{75 \text{ yd}^3/\text{truck}} = 12 \text{ trucks/hr.}$$

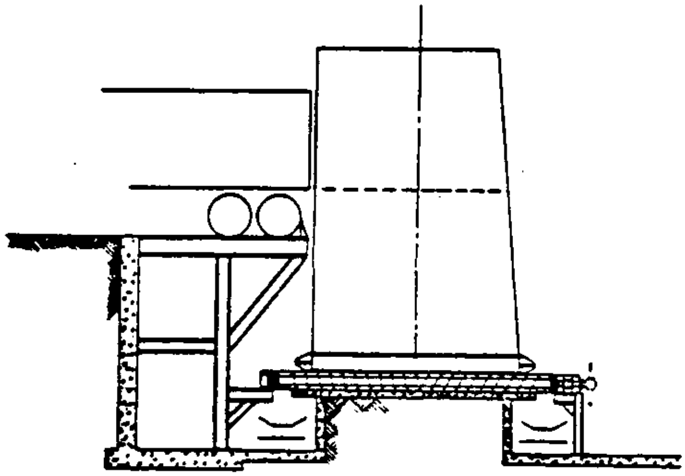
Assuming that it takes 10 minutes to unload one truck, then each truck station can handle 6 trucks per hour. Thus, as a minimum, 2 truck unloading stations must be provided. However, to allow for non-uniform dispatching of trucks and to allow for future expansion of the facility, an unloading station capable of handling 3 trucks simultaneously is necessary. The cost of the trucks are not included in the analysis. A tractor and trailer combination can be expected to cost in the neighborhood of $100,000. The trailers are equipped with a ram device that travels from the front to the back of the trailer in several minutes, pushing the material out the backend into the unloading bin.

A cross sectional view of the unloading bin is shown in Figure 3.2.1-1. The bin is approximately 18 ft. wide at the bottom, 36 ft. high, and about 36 ft. long. The bin is equipped with 27 screw conveyors that cover the bottom of the bin and discharge material to both sides of the bin where it falls on belt conveyors on either side. The screws are capable of emptying the bin at the rate of 300 tph. In order to keep the equipment above ground, an elevated apron with a turnaround must be provided to raise the trailer beds up to the elevation of the unloading bin. The apron just in front of the unloading bin should be covered to prevent rain from entering the bin.

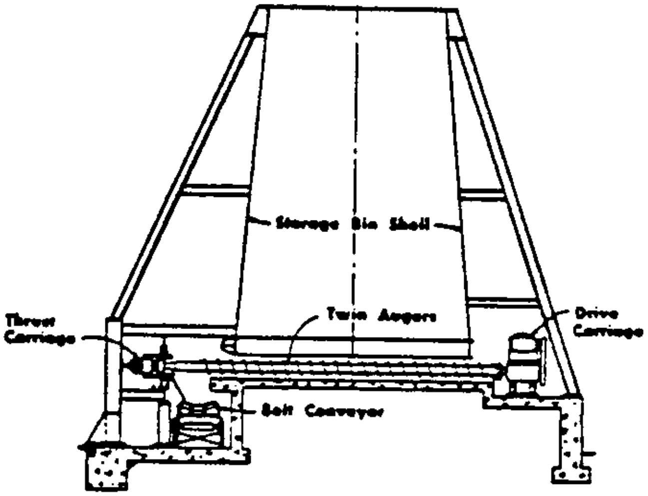
In order to prevent the escape of dust from the unloading bin, a dust control system consisting of a blower and baghouse will be provided. The exhaust system will pull a vacuum on the bin, the baghouse will trap the dust, and a rotary air lock will return the dust to a downstream conveyor.

3.2.2 Conveyors from Unloading Bin to Storage System

Horizontal conveyors receive the RDSF from the unloading bin screw conveyors, run the length of the unloading bin, and deposit the RDSF on elevating belt conveyors that lead up to the storage bin. Each horizontal conveyor has a capacity of 150 tph and is about 40 feet long. All conveyors in the system are designed to run at no more than 200 feet per minute to avoid loss of RDSF due to windage. Bulk density on all conveyors is assumed to be 8 pounds per cu. ft.



UNLOADING BIN



STORAGE BIN

CROSS SECTIONAL VIEW OF UNLOADING BIN AND STORAGE BIN

FIGURE 3.2.1-1

Elevating conveyors carry the RDSF to the top of the storage bins. These conveyors have a 14° incline. Each elevating conveyor has a capacity of 150 tph and is about 140 feet long. All conveyors in the RDSF system have enclosed galleries. Each transfer point is protected from loss of fugitive dust by a dust control system consisting of a blower and baghouse. Dust is collected from the exhaust and returned to the conveyors.

3.3 Equipment Requirements for Transporting RDSF by Conveyor

As mentioned previously, if the processing plant is located within a mile of the power plant, it may be economical to use one long belt conveyor to carry the material to the storage bins. The required conveyor would be 84 inches wide and would be approximately 3600 feet long if the processing plant were located across Island Drive. The installed cost of such a conveyor in 1980 dollars would be approximately $5,500,000.

The conveyor would eliminate the unloading bin and its associated conveyors as well as trailer packers at the processing facility and the transfer trailers themselves. This equipment would be worth approximately $1,800,000. It is estimated that the difference in initial capital cost ($3,700,000) would be offset in approximately 7 years by savings in operating costs of the trucks and in driver salaries.

3.4 Storage Systems (Items B and C on Figure 3.2-2)

The total amount of storage is based on one day's production of RDSF (1460 tons). Two storage systems have been selected with each system having a capacity of 750 tons for a total nominal storage capacity of 1500 tons. The volume of the bin in each system is about 100,000 cu. ft. and the bulk density of the RDSF in storage is about 15 lb. per cu. ft. The storage system bins (See Figure 3.2.1-1 for cross sectional view) are approximately 275 feet long, 40 feet high, and 35 feet wide at the bottom.

Each bin is equipped with a distributing conveyor that runs the length of the bin at the top. As the RDSF moves along this conveyor, a travelling plow moves back and forth along the belt distributing the RDSF evenly into the bin. The top of the bin is enclosed. Two pairs of travelling screw conveyors are used to empty each bin. Each pair of screws has a capacity of 50 tph and travels back and forth covering one-half the bin length. The screw conveyors discharge onto a horizontal belt conveyor that runs the length of the storage bin.

3.5 Conveyors from Storage Bin to Packer Building

Horizontal belt conveyors approximately 275 feet long carry the RDSF at the rate of 100 tph from each storage system to a pair of elevating belt conveyors leading up to the packer building. The pair of elevating conveyors also have a capacity of 100 tph each.

3.6 Packer Building (Items D and E on Figure 3.2-2)

The purpose of the packer building is to provide a means for unloading the storage systems if the boilers are down or if for some reason they cannot burn RDSF. RDSF has a tendency to set up if allowed to sit in storage for more than 2 to 3 days. The packer building houses 2 horizontal belt conveyors, each with a capacity of 100 tph and each equipped with a retractable plow. With the plow in the retracted position the RDSF will pass through the packer building to the boiler. With the plow down, the plow will push the RDSF off the belt into the hopper of a transfer trailer packer. The trailer packers with a capacity of 506 cu. yd. per hour each have a ram device which pushes the material into the trailers and then automatically shuts down when the material is packed with a preset maximum force. Each packer is capable of unloading its corresponding bin in about 16 hours.

3.7 Conveyors from Packer Building to Metering Bin

These conveyors carry the RDSF from the packer building to the metering bin which is located near the firing level of the boilers.

3.8 Fluffing Rolls (Item F on Figure 3.2-2)

The fluffing rolls are mounted at the end of the conveyors that dump into the metering bin. Their purpose is to fluff and aerate the RDSF to facilitate its ready combustion in the boilers.

3.9 Metering Bins and Pneumatic Feeders (Items G, H, I on Figure 3.2-2)

The purpose of the metering bin is to provide some surge capacity and to provide a place to measure the level of RDSF for control of the belt conveyors feeding from the storage bin. If the metering bin level gets too high, then flow from the storage bin is halted. After the level of the metering bin is reduced, then flow is resumed again.

The pneumatic feeders consist of a rotary air lock feeder and pneumatic blower. The speed of the air lock feeder determines the feed rate of RDSF to the boiler. The air lock feature prevents blow back of air into the metering bin. The blower provides the air to convey the RDSF to the boiler. The costs of both the metering bins and pneumatic feeders are included in the cost of the boiler modifications in Table 3.11-1.

3.10 Boiler Modifications (Item J on Figure 3.2-2)

The boiler modifications consist of the RDSF nozzles and the dump grate which were discussed in Section III-2.1 of this report.

3.11 Precipitator Modifications

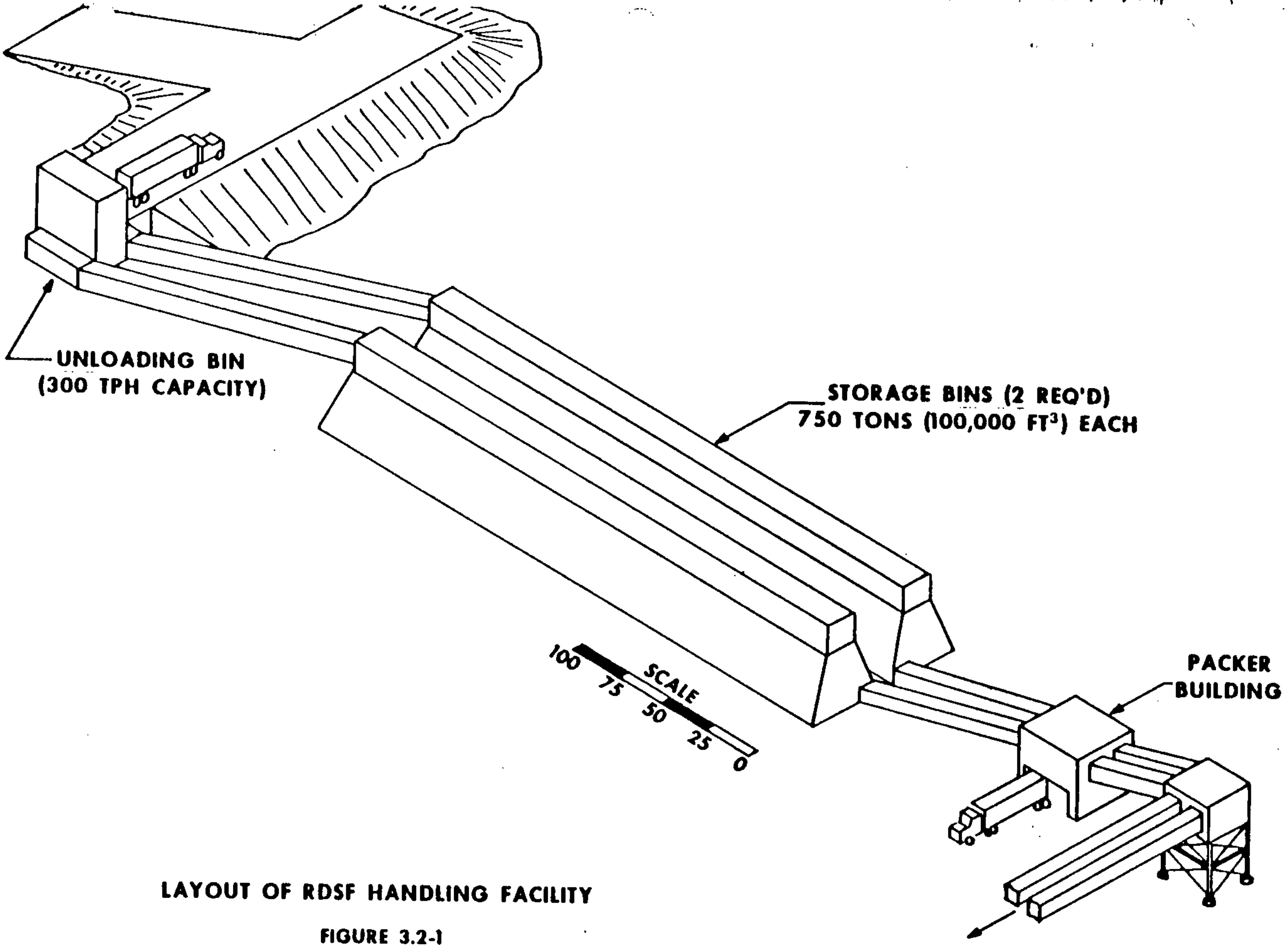
To date, there is no experience with very high (99.8+) efficiency precipitators on boilers co-firing RDSF with coal. It is estimated that in order to insure that particulate emissions are kept below 0.03 lb. per million Btu, it will be necessary to enlarge the precipitators by at least 10 percent. An order-of-magnitude estimate of the costs resulting from this modification and associated changes in the ductwork is included in the cost analysis.

3.12 Capital Cost Analysis

Conceptual estimates of the capital costs for all capital equipment are summarized in Table 3.11-1. The costs for each individual item were based on order-of-magnitude estimates of today's cost, expressed in 1980 dollars. The costs are totaled and then indirect construction costs, cost of services, escalation and a 20 percent contingency are added to give a total cost in 1985 dollars. The following factors were used for escalation (10.5 percent - 1980, 9 percent - 1981, 8 percent - 1982, 8 percent-1983). Interest during construction is based on 3 years at 7.5 percent per year. Finally, the capacity charge based on 1736 Kw (maximum operating electrical load) at $890/Kw is added to give the total initial project cost in 1985 dollars.

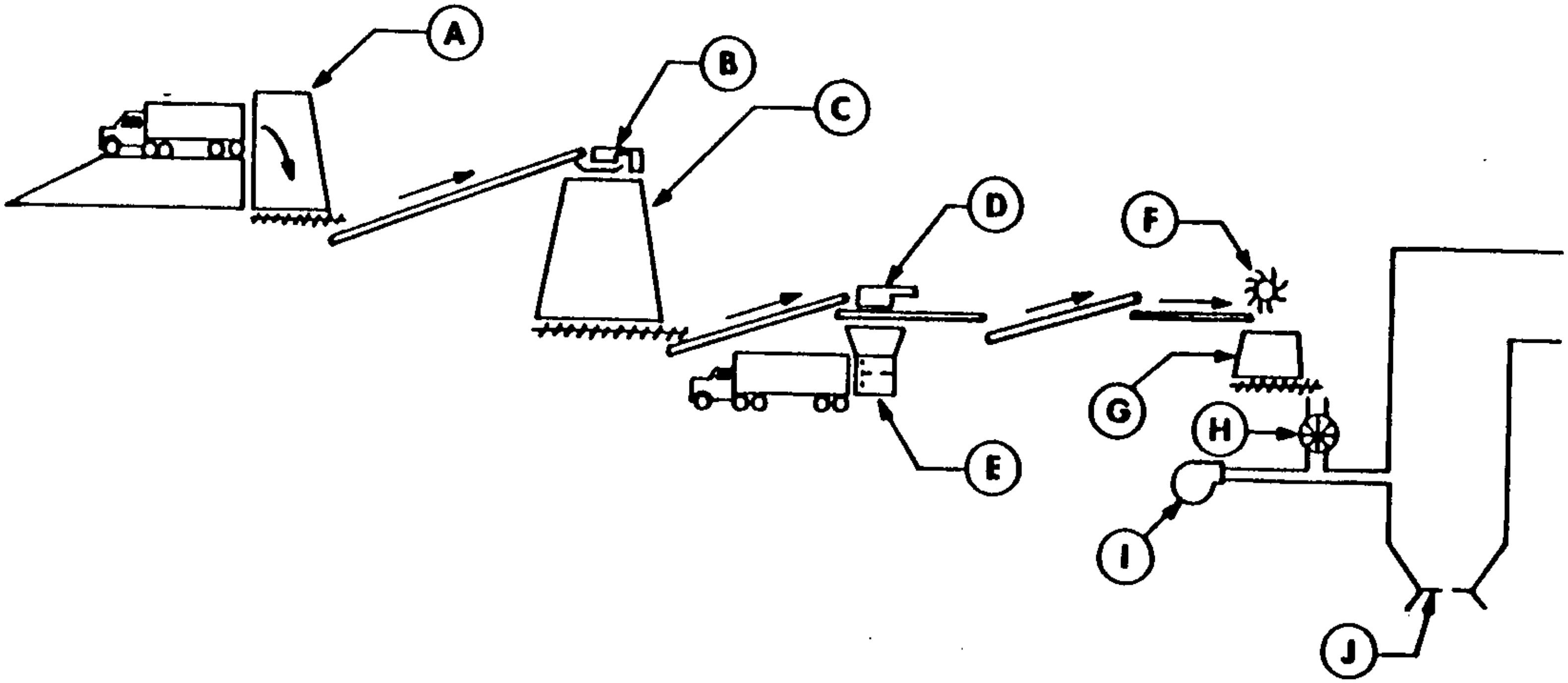
TABLE 3.11-1
ORDER-OF-MAGNITUDE CONCEPTUAL ESTIMATES CAPITAL COSTS OF PLANT MODIFICATIONS FOR CO-FIRING REFUSE DERIVED SOLID FUEL

Item	Description	Costs ($1000)
(1)	RDSF Equipment	7,885
(2)	Boiler Modifications	4,650
(3)	Precipitator Modifications	7,715
(4)	Total Direct Construction Cost (1980)	20,250
(5)	Indirect Costs and Cost of Services	2,430
(6)	Contingency	4,536
(7)	Escalation	11,159
(8)	Interest During Construction	9,210
(9)	Total Project Cost (1985)	47,584
(10)	Maximum Electrical Load	1,736 kW
(11)	Capacity Charge	1,545
(12)	Total Capital Cost (1985)	45,129
(13)	Fixed Charges (11.11%)	5,458



LAYOUT OF RDSF HANDLING FACILITY

FIGURE 3.2-1



A — UNLOADING BIN - 300 TPH CAPACITY - HANDLES UP TO 3 TRAILERS SIMULTANEOUSLY
B — TRAVELLING PLOW - DISTRIBUTES RDSF INTO STORAGE BIN
C — STORAGE BIN - 2 REQUIRED - EACH WITH 750 TON CAPACITY
D — RETRACTABLE PLOW - USED TO DIVERT RDSF INTO PACKERS - 2 REQUIRED
E — TRANSFER TRAILER PACKER - 2 REQUIRED - EACH WITH 506 YD^3/HR CAPACITY
F — FLUFFING ROLL - 2 REQUIRED
G — METERING BIN - 2 REQUIRED
H — ROTARY AIR LOCK FEEDER - 2 REQUIRED
I — PNEUMATIC BLOWER - 2 REQUIRED
J — BOILER DUMP GRATE - 2 REQUIRED

SCHEMATIC OF RDSF HANDLING FACILITY

FIGURE 3.2-2

4.0 ECONOMIC ANALYSIS OF RDSF FACILITY

This section presents an economic analysis of the proposed refuse burning facility. The objective of this section is to present the assumptions and calculations leading to the estimation of a fuel fee, which will be paid by the power plant to the Department of Sanitation. The fuel fee, along with the reduction in landfill costs, provides the cash flows which in turn must offset the capital and operating costs of the processing plant.

4.1 Assumptions of Economic Analysis

For purposes of the economic analysis it is assumed that all direct capital costs and operating costs for the RDSF installation will be accounted for separately from other plant capital and operating costs, wherever practicable. It is assumed that the power plant does not benefit from the burning of the refuse. For the purposes of this study the structuring of the "fuel fee" allows the power plant to "break even". This is based on the principle that the power plant should assume little or no risk in the venture. All electrical equipment directly associated with RDSF handling and burning should be separately metered where possible. Likewise, the operating labor and maintenance on the RDSF equipment should be separately accounted for. This data will be used to perform a periodic review of the fuel fee to insure that a fair price is being paid for the RDSF. In the long run this will insure that the utility and its customers do not subsidize garbage disposal and, likewise, that the sanitation department does not subsidize power generation.

Table 4.1-1 presents the basic assumptions used for the economic analysis.

4.2 Operating Costs

4.2.1 Electric Power

The trailer unloading system and boiler feed system will have maximum power consumptions of 570.7 kW and 330.8 kW respectively. The power consumption per ton of RDSF handled is more useful for calculation of the true operating costs. This number, which is 3.6 kWH per ton of RDSF, is used to develop the following costs for direct electric power.

Total RDSF Burned per year = 1460 tpd x 365 days/yr
= 532,900 tpy

Direct Electric Power Cost = 532,900 tpy x 3.6 kWH/Ton x 0.0204$/kWH x 1.57 (Esc. to 1985)
= $61,444/yr

TABLE 4.1-1
ASSUMPTIONS OF ECONOMIC ANALYSIS

Annual Fixed Charge Rate			11.11 Percent	
Escalation:	Labor:	1980	10.5 Percent	Total 63 Percent to 1985
		1981	9 Percent	
		1982	8 Percent	
		Balance	8 Percent	
	Energy:		9.6 Percent	Total 57 Percent to 1985
Labor Cost (1980 $)			$30,000/yr	
Energy Charge (1980 $)			$ .0204/kW	
Coal Cost - As-Fired (1980 $)			$ 1.98/10^6Btu	
Coal Handling and Pulverizing (1980 $)			$ .034/10^6Btu	
Levelization Factors:	Material		3.9529	
	Labor		3.8948	
	Energy		3.8635	

There are also indirect electric power costs resulting from increased load on the induced draft and forced draft fans. The increased fan power under worst conditions is 2650 hp at 20 percent heat input from RDSF. Since the average RDSF burn rate is 10 percent of two boilers, the average increase in fan power is found as follows.

$$\text{Average Increase in Fan Power} = \frac{10\%}{20\%} \times 2(2650)\text{hp} = 2650 \text{ hp or } 1977 \text{ kW}$$

As discussed in Section 1.1 and Table 1.1-4, RDSF firing would occur, on the average, 5300 hours per year.

The cost of this power on a continuous basis is calculated below:

Indirect Electric Power Cost = 1977 kW x 5300 hr/yr x \$.0204/kWH x 1.57 = \$335,592.

4.2.2 Labor Costs

Labor costs are based on a requirement for two operators two shifts per day to supervise trucks, to operate the RDSF handling equipment, and to sample the RDSF for determining the Btu and ash content. Additionally, one boiler plant operator will be required one-half time two shifts per day on the boiler to monitor RDSF feed equipment operation and to operate the dump grate on an hourly basis. The labor costs attributable to the RDSF equipment operators are broken out in the calculations, as they may be directly charageable to the Department of Sanitation. The labor charges associated with the Boiler Plant Operator and not broken out, as it would be difficult to separate them from the cost of normal operations.

4.2.3 Maintenance Costs

Based on actual experience, maintenance costs on RDSF equipment run approximately 2.5 percent of the initial capital cost of the equipment itself. In the fuel fee calculations, maintenance is broken into two components - that associated with the RDSF equipment external to the powerhouse and that associated with the RDSF equipment within the powerhouse. The cost of maintenance on the handling and storage equipment is separated because it may be decided to bill these charges directly to the Department of Sanitation. The other maintenance costs, which are attributable to the boiler feed equipment and dump grate are not readily separable. It is assumed that the firing of RDSF will have no impact on the balance of the plant's facilities.

4.3 Coal Savings

The savings of coal is calculated on the basis of the Btu's supplied by the RDSF, adjusted for the fact that boiler efficiency is reduced by as much as 3 percent when 20 percent RDSF is burned. In a manner similar to the fan power calculation, the average efficiency drop when RDSF is burned is calculated as follows:

$$\frac{10\%\ \text{Average Heat Input}\ X\ 3\%}{20\%\ \text{Max Heat Input}} = 1.5\%$$

Assuming that boiler efficiency on coal alone is 89 percent, then efficiency at the average RDSF firing rate is 87.5 percent. Thus, the amount of coal saved is found as follows:

$$532{,}900\ \text{tpy RDSF} \times 2000\ \text{lb/ton} \times 6100\ \text{Btu/lb RDSF}\ X\ \frac{.875}{.89}$$

$$= 6.392\ X\ 10^{12}\ \text{Btu}$$

At the 1985 cost of coal ($3.11/$10^6$ Btu), this is worth $19,879,000 per year. In a similar manner the savings in coal handling and pulverizing costs are worth $319,600 per year in 1985 dollars.

4.4 Assumptions for Fuel Fee Calculation

The fuel fee must be calculated on a year by year basis. This section will present a calculation of the fuel fee for the year 1985 and will give a projection of levelized fuel fees over 40 years to the year 2025.

The fuel fee is estimated in two different ways. The first approach assumes that all direct labor, direct electricity, direct maintenance, and fixed charges on all capital are charged directly to the Department of Sanitation. This results in a higher value for the fuel fee, since the power plant is bearing the least amount of the cost of getting the RDSF to the boiler. This is called the "gross" fuel fee.

The other approach subtracts off the estimated costs of the direct labor, direct electricity, direct maintenance, and fixed charges on capital. This results in a "net" fuel fee. The net fee represents the estimated net revenue received by the Department of Sanitation from the operations at the power plant.

4.5 Fuel Fee Calculations for 1985

Table 4.5-1 shows the calculations for the gross fuel fee. Costs are shown in parentheses to indicate that they are subtracted in the calculation. Table 4.5-2 shows the calculations for the net fuel fee. The gross fuel fee is $36.60 per ton ($3.03/10^6 Btu) and the net fuel fee is $25.51 per ton ($2.07/10^6 Btu). For comparison the cost of coal in 1985 is projected to be approximately $77.72 per ton ($3.11/10^6 Btu).

4.6 Projected Fuel Fee (Levelized)

Tables 4.6-1 and 4.6-2 present levelized estimates of the gross and net fuel fees over the life of the plant through the year 2025. Although the rate of RDSF production is likely to increase by approximately 1.5 percent per year (from 1460 tpd in 1980 to 2648 tpd in the year 2025) in accordance with projected population growth in Duval County (Ref. 9), the levelized figures in Tables 4.6-1 and 4.6-2 conservatively assume no increase in refuse processing or RDSF firing rate. The levelized gross annual fee is $74,114,000 and the annual levelized net fuel fee is $66,890,000.

TABLE 4.5-1
GROSS RDSF FUEL FEE

Item	Description	Amount ($1000)
(1)	Energy Savings (Displaced Coal)	$19,879
(2)	Coal Processing Savings	320
(3)	Electric Power: RDSF Equipment	(0)
	FD and ID fans (Net)	(336)
(4)	Labor Costs (Boiler Operator Only)	(49)
(5)	Maintenance Costs (Boiler Equip. 2.5% of $12,365*)	(309)
(6)	Capital Costs (All Borne by Sanitation Dept.)	(0)
(7)	Gross Annual RDSF Fuel Fee	$19,505
(8)	Annual Tons RDSF	532,900 tons/yr.
(9)	Gross RDSF Fuel Fee Per Ton	$36.60/ton

* $4,650 + $7,715 = $12,365 is the cost of the boiler and precipitator modifications from Table 3.11-1.

TABLE 4.5-2
NET RDSF FUEL FEE

Item	Description	Amount ($1000)
(1)	Gross Annual RDSF Fuel Fee	$19,505
(2)	Labor Cost (Sanitation Dept.)	(196)
(3)	Maintenance Cost (RDSF Equip. 2.5% of $7,885*)	(197)
(4)	Electric Power (RDSF Equip.)	(61)
(5)	Capital Costs (AFCR = 11.11%)	(5,458)
(6)	Net Annual RDSF Fuel Fee	$13,593
(7)	Annual Tons RDSF	532,900 tons/yr.
(8)	Net RDSF Fuel Fee Per Ton	$25.57/ton

* $7,885 is cost of the RDSF equipment from Table 3.11-1.

TABLE 4.6-1

LEVELIZED GROSS RDSF FUEL FEE

Item	Description	Amount ($1000)
(1)	Energy Savings	$76,803
(2)	Electric Power - RDSF Equipment	(0)
(3)	FD and ID Fans (Net)	(1296)
(4)	Labor Costs (Boiler Operator Only)	(190)
(5)	Maintenance Costs (Boiler Equipment)	(1,203)
(6)	Levelized Capital Costs (All Borne by Sanitation Dept.)	(0)
(7)	Levelized Annual RDSF Gross Fuel Fee	$74,114
(8)	Annual Tons RDSF (Assumed Constant)	532,900tons/yr
(9)	Levelized Gross RDSF Fuel Fee Per Ton	$139.08/ton

TABLE 4.6-2
LEVELIZED NET RDSF FUEL FEE

Item	Description	Amount ($1000)
(1)	Levelized Gross RDSF Fuel Fee	$74,114
(2)	Labor Cost (Sanitation Dept.)	(763)
(3)	Maintenance Cost (RDSF Equip.)	(767)
(4)	Electric Power (RDSF Equip.)	(236)
(5)	Levelized Capital Cost (same as annual fixed charges)	($5,458)
(6)	Levelized Annual Net Fuel Fee	$66,890
(7)	Annual Tons RDSF (Assumed Constant)	532,900tons/yr.
(8)	Levelized Net Fuel Fee Per Ton	$125.52/ton

5.0 CONCLUSIONS

The purpose of this study was to assess the technical and environmental feasibility of co-firing RDSF in the new Jacksonville power plant. Based on the experience of others and considering this experience in the light of anticipated conditions at the new power plant, there appear to be no insurmountable barriers to the co-firing of RDSF. However, several of the obstacles can only be overcome at considerable cost, which must, in turn be offset by the anticipated revenues if the proposed project is to be economically viable.

5.1 Effects on Boiler and AQCS Operations

With regard to the effects of co-firing RDSF on boiler and AQCS operations the following conclusions can be stated.

a. The magnitude of the impact on boiler operations resulting from co-firing RDSF will be largely dependent on the quality of the RDSF provided by the processing plant. Hence, there is a need for early and continual involvement of the JEA in the development of RDSF fuel specifications and in the actual design of the processing plant.

b. The nature of the effects of co-firing RDSF can be summarized as follows:

- Substantial increases in bottom ash generation may be anticipated, even with the installation of the dump grate. This can probably be handled by increasing the frequency of pulling bottom ash from the boiler hoppers. Sizing of the ash settling pond will have to be reviewed.

- Increases in flue gas volume, mass, velocity, and pressure drop will be observed, resulting from increased moisture in the flue gas. Induced draft fan power may increase as much as 17 percent at maximum RDSF firing rates.

- A reduction of as much as 3 percent in boiler thermal efficiency at a 20 percent RDSF flow may take place, again due primarily to increased flue gas moisture content.

- An increased potential for furnace wall slagging with a potential for increased costs due to additional soot blowers or other slag control measures is anticipated. Sudden load shedding may sometimes be required to shed slag (if other measures are not 100 percent effective). An increase in superheat temperature may occur requiring a desuperheater control system capable of providing more spray down water.

- A loss of up to 2 percentage points in precipitator efficiency over a 100 percent coal design. Precipitator size must be increased at least 10 percent to regain the required efficiency.

- A probable reduction in SO_2 emissions with the amount of reduction depending on relative sulfur concentration in the coal and the RDSF.

- A reduction in NO_x emissions.

- A potential for increased organics and solids in the ash sluice water.

- A potential for increased corrosion in the boiler, precipitator, and scrubbers due to increased in chlorides in the flue gases.

5.2 Economic Analysis

The initial cost in 1985 dollars of the RDSF facilities is $49,129,000. This figure includes all unloading, storage, and conveying equipment as well as all boiler and precipitator modifications.

Based on the available data and the results of this investigation, the maximum "gross fuel fee" which would be paid by the JEA for the RDSF is estimated to be $36.60 per ton in 1985 dollars. This number assumes that the costs of owning and operating the RDSF facilities at the power plant site are all directly assumed by the City of Jacksonville.

If the costs of owning and operating the RDSF facility at the power plant are assumed by the JEA, an estimated maximum "net fuel fee" of $25.51 per ton results. This number also represents the net revenue available to the Department of Sanitation from operations at the power plant. On an annual basis, an estimated net revenue of about $13,593,000 results in the year 1985. Levelized annual net revenue over the life of the plant is estimated to be $66,890,000/yr.

6.0 RECOMMENDATIONS

6.1 Criteria for a Decision on Refuse Co-firing

A decision to proceed with the RDSF system must include the following essential ingredients:

a. Favorable economics of the total RDSF system including the processing plant. Naturally, a major consideration in the economics is the future availability of landfill sites.

b. A satisfactory agreement between JEA and the Department of Sanitation on the quality of the RDSF and on the method for calculating the fuel fee.

c. A willingness on the part of JEA to accept the risk of potential operating problems associated with co-firing the RDSF.

IV REFERENCES

1. "Evaluation of the Ames Solid Waste Recovery Systems Refuse Processing Plant and Suspension - Fired Steam Generators", Draft Report EPA Grant #R803903-01-0 b, A. W. Joenson, et.al.

2. St. Louis/Union Electric Refuse Firing Demonstration Air Pollution Test Report EPA-650/2-7-073, Aug. 1974.

3. "The Acid Test for Bridgeport", Gregg E. Easterbrook; Waste Age; May, 1978 pp. 46-52.

4. "Evaluation of the Performance of the Disc Screens Installed at the City of Ames, Iowa Resource Recovery Facility", by D.E. Fiscus, et.al.; Paper to be presented at ASME Solid Waste Processing Conference; Wash., D.C.; May 11-14, 1980.

5. "Emissions and Energy Conversion from Refuse Processing and Mixed Fuel Boiler Firing" James D. Kilgore, et.al.; Paper presented at Fifth International Conference on Conversion of Refuse to Energy; Montreux, Switzerland; Nov. 3-5, 1975.

6. "Corrosion Problems in Incinerators" by F. Nowak; Combustion; Nov., 1968; pp. 32-39.

7. "Corrosion and Deposits from Combustion of Solid Waste" by H.H. Krause, et.al.; Journal of Engineering for Power, Vol. 101; Oct., 1979; pp. 592-597.

8. "Evaluation of the Ames Solid Waste Recovery System Part II: Performance of the Stoker Fired Steam Generators." by D. Van Meter; et.al.; EPA Report #EPA-GCC/7-79-229; October, 1979.

9. University of Florida, Bureau of Economic and Business Research.

10. "Co-Firing Coal and Refuse-Derived Fuel in a Utility Steam Generator: Operational Experience and Corrosion Probe Evaluation"; by R.J. Petersdorf, et.al.; Paper presented at American Power Conference; April 21-23, 1980; Chicago, Ill.

11. Telephone Conversation between Jack Laing, District Manager, Babcock and Wilcox Co., Atlanta, GA; May 1, 1980; and A.T. Clary, Ebasco Consulting Engineering.

12. "Air Pollution Emissions and Control Technology for Waste-As-Fuel Processes", by T. W. Devitt, et.al.; PEDCo. Environmental, Inc. EPA Contract No. 68-03-25-9; Oct. 1979.