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WASTE FUEL UTILIZATION IN EXISTING BOILERS ON U. S. NAVAL BASES--ETC(U)
JAN 80 H I HOLLANDER, J E BRODERICK N00123-78-C-0868
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The 1976 Resource Conservation and Recovery Act encourages the recovery of material and energy from waste to the maximim extent practicable at federal facilities while complying with state and local requirements. The Navy's solid waste research project is designed to identify and develop cost effective alternatives for meeting RCRA requirements. Additionally to

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reduce Navy dependence on dwindling supplies of natural gas and fuel oil, the Navy has issued guidelines concerning the construction of intermediate and larger boiler plants requiring the capability to burn solid forms of fuel including waste derived fuels as well as coal.

This report provides perspective on the ramifications of firing solid forms of waste derived fuel, separately or in combination with conventional fossil fuels for existing or new installations. The report is divided into two parts, the first part presents a general discussion of typical characteristics of proposed waste fuels and the potential of utilizing these fuels in existing Navy boilers. The second part is a case study addressing a typical installation and assesses the changes, capital costs and potential problem areas that may be encountered in accommodating waste fuel firing.

Based on a site inspection at a 3 boiler Navy plant a conceptual retrofit layout was prepared of a practical system to cofire a waste fuel with the existing fossil fuel. The boiler plant selected routinely fired natural gas and fuel oil. The waste fuel selected was a solid form of shredded waste (nominally 2-in. particle size with most glass, metals and other inerts removed). The cast study revealed that if the wastes were suitably prepared approximately 60 TPD could routinely be consumed with 120 TPD total system capability based on the waste fuel providing 20% of the BTU input requirements during full load operation.

Base loading two retrofitted boilers at their design capacity and accommodating all steam load swings with the conventional fuel fired third boiler, could displace more than 200 barrels of oil per day. At 35 cents per gallon, the annual savings in 1978 fuel costs would amount to over $1,000,000. Not only is there a potential fuel cost avoidance of more than $1,000,000 but there should also be some disposal cost avoidance, although counterbalanced at least in part by the costs for producing RDF. With the significant volume reduction of wastes to be landfilled, the effective life of the land area for this purpose will be materially increased.

SUMMARY

Assignment Perspective

In recognition of the emerging realities regarding the availability and cost of the conventional clean fossil fuels, natural gas and distillate oils, the Department of Defense directed all military branches to develop alternative fuel use capability.

In July, 1976, the Navy issued a guideline entitled ENERGY SOURCE SELECTION AND CRITERIA FOR SHORE FACILITIES, which provided specific direction and procedures. A very brief abstract reveals:

- No facilities 5 million BTUH and greater shall burn natural gas.
- Until such time when solid fuel technology permits relatively efficient, environmentally acceptable and economical burning of solid fuels in boilers below 50 million BTUH fuel, oil will continue to be the primary fuel source.
- In the range 20 to 50 million BTUH, all facilities are to be capable of utilizing all grades of fuel oil, including No. 6 (residual).
- All new facilities 50 million BTU/hr and larger shall be capable of convertion to coal and/or Refuse Derived Fuel (RDF).
- All new generating plants 100 million BTUH and greater shall be designed and constructed to burn coal and/or RDF.
- The use of incinerators with waste heat boilers is to be considered for any new heat generating requirement. Refuse Derived Fuel (RDF) will be considered for all solid-fuel burning facilities. Although RDF may not be used initially, consideration in design shall be given to future use of a coal-RDF combination fuel.
- In the design of all steam generating facilities capable of initial or future solid fuel firing, provisions shall be made to permanently reserve sufficient land area for solid fuel receipt, handling and storage to permit the entire plant to burn solid fuel only.

In this context the Gilbert assignment is intended to provide perspective on the ramifications of solid fuel firing, specifically the various forms of RDF, separately or in combination with conventional fossil fuels, for existing or new installations.

This report focuses on the physical modifications and additions with their associated costs for adapting existing steam generating facilities to utilize the prepared waste fuels. The report is divided into two parts. The first part, Section 2.0, Waste Fuel Utilization, presents a general discussion o the typical characteristics of prepared waste fuels and the potential of utilizing these fuels in existing U.S. Naval Base boilers. This section includes discussions on:

- The character and form of the various types of RDF which might become available to Navy Boiler Plants.
- The various types of solid fuel firing systems which might be applied to typical Naval Base Boiler Plants.
- The principal ramifications in utilizing RDF in one or more of its forms in relation to the typical solid fuel firing systems.
- The typical firing equipment applications to various types of boilers which may be encountered.

The second part of the report, Section 3.0, Case Study, addresses a typical Navy installation and assesses the changes, capital costs, and potential problem areas that may be encountered in accommodating waste fuel firing.

Based on a site inspection at a Naval boiler plant facility designated as typical of a class, a conceptual retrofit layout was prepared of a practical system to co-fire RDF in one or more forms with the fossil fuels currently utilized. The conceptual design is described and the associated application ramifications, environmental concerns, energy conservation implications and cost/benefit analysis are presented.

Findings and Conclusions

The general findings and conclusions drawn from this assessment of RDF characteristics and utilization potential in Navy Base boilers include:

- Since there has been only very limited production of liquid and gaseous RDF forms ... bench scale to pilot operation ... and no on-going operating supply ... most data and information can only be projections with questionable reproducibility and credibility. There are no "reported" commercial size operating facilities currently utilizing or even test burning liquid or gaseous fuels derived from general industrial plant wastes or residential wastes.

- From the meager data which are available it appears that a liquid fuel approaching the quality of Bunker C residual, could be accommodated with only minor modifications to existing heavy oil burner systems. Except for the possible need for soot blowers and/or provisions for water washing, no boiler modifications are anticipated. However, the burner piping train, transport piping, heating, filtering, blending, pumping and storage systems would require special design, with operation closely monitored.

- Gaseous RDF, having at least 300 BTU/SCF and suitably cleaned and dried, could be accommodated in most existing furnace systems with only minor modifications to the burner and its piping train. The RDF gas producer (probably oxygen-blown) would have to be located in close proximity to the fuel using appliance. Lower BTU gas would require extensive modifications to the burner and piping systems, and probably would also impose a significant derating of the boiler system. Introducing hot raw pyrolysis gases directly into a boiler furnace is possible, but of limited attraction for Navy Base facilities.

- There are a number of forms in which a solid RDF can be made available to Navy Base Boiler plants. The RDF quality to be specified, and therefore the degree of refinement required involves a cost/benefit trade-off. This is a facility-specific and site-specific determination.

- The Case Study revealed that a non-complex adaptation could provide practical co-firing of solid RDF with conventional fossil fuels. If suitably prepared solid RDF is made, or were available, approximately 60 tons per day could routinely be consumed with 120 TPD total system capability. This is based on providing RDF for 20% of the BTU input requirements during full load operation.

- o Base loading the two retrofitted boilers at their design capacity and accommodating all steam load swings with the conventional fuel fired third boiler, could displace more than 200 barrels of oil per day. At 35 cents per gallon, the annual savings in 1978 fuel costs would amount to over $1,000,000. Not only is there a potential fuel cost avoidance of more than $1,000,000 but there should also be some disposal cost avoidance, although counter-balanced at least in part by the costs for producing RDF. With the significant volume reduction of wastes to be landfilled, the effective life of the land area for this purpose will be materially increased.

The circumstances encountered in the Case Study can only be representative of a "class" of Navy Base facilities. Similar studies should be conducted for other classes of installations to provide the Navy with a broader basis for determining their waste utilization potential and the corresponding capital requirements to accommodate waste fuel firing.

The Navy should initiate a program for developing a special purpose, modest size steam generating unit configured specifically to accommodate Navy refuse in the as-discarded form. This type of unit would have broad application singly or in multiples at many Navy Base facilities. Some of the principal design and operating objectives which might be incorporated are:

- Capacity range: 25,000 - 30,000 pounds steam per hour
- No superheat
- Optmized energy recovery
- Require (at most) coarse size reduction of solid wastes
- Accommodate waste oils and spent solvents as fuels
- Full generating capacity with heavy fuel oils
- Water cooled furnace/minimum refractories
- Shop - assembled components

- Require only minimal monitoring by operating personnel
- Dry type air pollution control equipment
- Non-complex, robust equipment systems to provide high availability

All new land based Navy boiler installations over 90,000 pounds steam per hour should be designed for multifuel firing, i.e. liquid, gaseous, and solid fossil fuels, as well as cellulosic wastes and RDF. These systems should be designed so that they can be operated at an energy level permitting cogeneration of electric power.

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SECTION 1.0
INTRODUCTION

At the behest of NAVFAC, Gilbert Associates, Inc. was requested by SRI International to assist them in evaluating the potential for utilizing waste - derived fuels in existing U.S. Navy steam generating installations. The Navy, along with other government and private organizations is trying to reduce its dependence on scarce fossil fuels, especially natural gas and distillate oils, and convert to coal and refuse derived fuels (RDF) wherever feasible.

The overall subject of waste fuels utilization covers the broad areas of:

- identification of raw waste quantity and composition,
- waste collection and handling,
- waste preparation for boiler and heater firing,
- modifications to existing fuel using plants,
- cost estimates to utilize the prepared material,
- the environmental implications of burning these waste - derived fuels which involve Federal, State and local regulations.

This report focuses on the physical modifications and costs associated with adapting existing steam generating facilities to utilize the prepared waste fuels. The report is divided into two parts. The first part, Section 2.0, Waste Fuel Utilization, presents a general discussion of the typical characteristics of prepared waste fuels and the potential of utilizing these fuels in existing U.S. Naval Base boilers.

The second part of the report, Section 3.0, Case Study, addresses a typical Navy installation and assesses the changes, capital costs, and potential problem areas that will be encountered to accommodate waste fuel firing.

The general description of waste fuels and their effect when co-fired in a boiler is not intended to be a complete analysis of waste fuel utilization. Rather, it is included to provide an opportunity to comment, in general, on those aspects considered significant from the viewpoint of the designer and boiler operator, as well as to provide the background perspective for the selections made in the Case Study.

The Case Study is a conceptual design study of a retrofit solid waste utilization system. An estimate is made of the quantity of prepared solid waste that can be readily fired in existing boilers without derating or major boiler changes. A schematic flow diagram and site sketches were prepared to assist in identifying the types of waste receiving and handling equipment required. The boiler modifications are shown superimposed on drawings of the existing boiler units. The capital cost estimate included is based on the boiler modifications and necessary equipment additions. Finally, an assessment of the operational changes and possible problem areas is provided to complete the description of the conceptual design study.

SECTION 2.0
WASTE FUEL UTILIZATION

The characteristics of solid, liquid, and gaseous fuels derived from typical industrial and municipal wastes is delineated. However, the sources of the wastes and methods of collection, separation, and preparation are considered too site specific to permit useful discussion. Each of the discussed fuels from prepared wastes is considered to be suitable for direct firing in Navy boilers. The waste fuel characteristics reviewed are those deemed significant to the end user wherein they affect the cost, utilization complexity, or space requirements of an existing plant to handle and acceptably fire the wastes beneficated as a fuel. The waste fuel characterizations are also compared to the corresponding contentional fossil fuels; for example, pyrolysis liquid fuel is compared to typical No. 6 fuel oil.

A description of the modifications required for conventional boilers to utilize the waste - derived fuels characterized and the implications on plant operation are also included in this section. The types of boilers discussed are considered typical of those which may be installed at Navy bases, in the range of 25,000 to 200,000 pounds steam per hour. Boiler types reviewed are those originally designed for stoker or pulverized coal firing as well as oil and gas fired units of both the shop - assembled and field-erected types.

2.1 PERSPECTIVE - The Character of Waste as Fuel

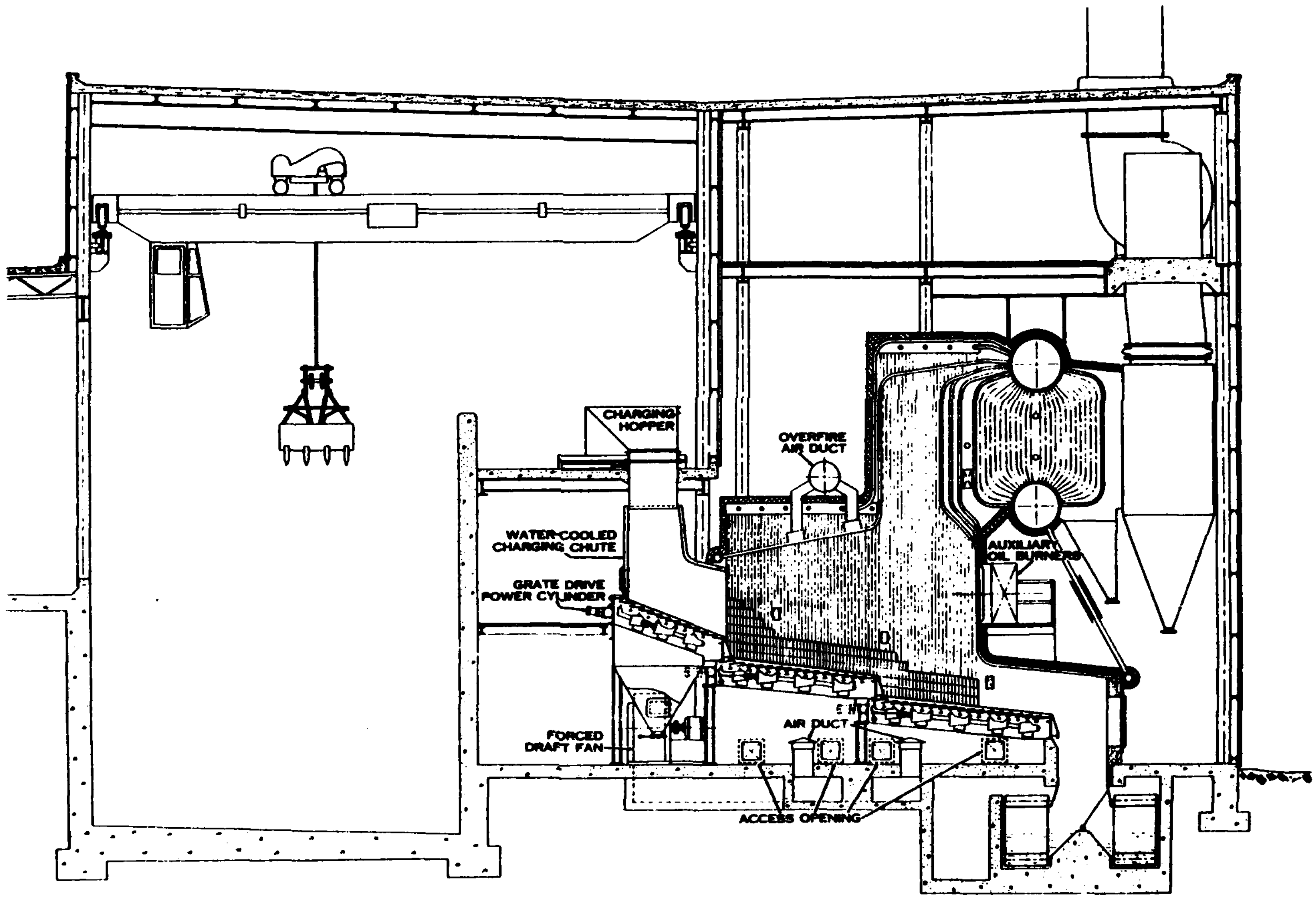
Accompanying the developing industrial revolution was the surge in generation of production and consumer wastes. Not only were greater quantities being generated but also they were of comparatively higher calorific value than those previously produced for decades by the passing agrarian/craft society. In addition, the concentration of population close to the growing industrial centers prompted the construction of incinerators for controlled thermal reduction of the mounting burden of refuse.

The first incinerator designed specifically for this use was placed in operation in England more than 100 years ago. By 1914, there were about 200 incinerator plants in operation in England. Of these, more than 60 were arranged to generate steam for electric power production.

The first incinerator facility of significant size in the United States was constructed before the turn of the century by the U.S. Army on Governor's Island in New York harbor. This facility was not reported to have heat recovery capability.

Since then, particularly since World War II, there have been many "steam raising" incinerator plants installed in Europe and Japan, as well as a significant number of major facilities in the Western hemisphere. About 12 years ago, the U.S. Navy BuDocks established a precedent in the U.S. with a modest size, twin furnace installation having complete waterwalls for base trash and refuse at Norfolk, Virginia. A schematic of this mass burning waterwall incinerator is shown in Figure 1. The steam produced entered the base main distribution loop served by the central fossil fuel fired boiler plant. Another Navy facility of this type, but smaller in capacity, has been installed recently at Portsmouth.

These facilities were designed to thermally process wastes as-discarded or as-received with virtually no beneficiation. However, efforts were made to avoid charging into the system wastes which were oversized, bulky, demolition, obviously noncombustible, or deleterious to the equipment or operation.



FOSTER WHEELER BOILERS
U.S. NAVAL STATION SALVAGE FUEL BOILER PLANT,
NORFOLK, VIRGINIA

FIGURE 1

MASS BURNING WATERWALL INCINERATOR

Today, there are a number of waste firing steam plants operating in the United States. Three basic designs are being used: mass burning in a thick bed on a moving grate, semisuspension firing with burnout on a grate, and supplementary full - suspension firing in existing boilers.

Another method of using the energy content of municipal and industrial solid waste is to prepare new fuels through conversion of the rather large number of high molecular weight species in the waste to a relatively few low molecular weight compounds. The conversion of waste to liquid or gaseous fuels by heat alone (i.e. without oxidation) is called pyrolysis.

The new compounds require energy for their formation so that the total products will possess a heating value less than that of the starting waste materials. The conversion efficiency for gas and liquid fuels derived from waste ranges from 40 to 60 percent as opposed to 60 to 80 percent for solid RDF fuels. The loss of energy may be tolerable because of the following: (1) The physical or chemical form of the new species is convenient; (2) the reduced volume of total gases as compared to that formed in a typical incineration process results in lower capital investment and operational costs for air pollution control.

Advantages of pyrolysis include: production of a clean fuel, recovery of char which can be converted into activated carbon or synthesis gas, lower cost for air pollution control because the volumes of gas requiring cleaning are smaller than those produced by incineration, and production of a residue that is environmentally more acceptable than the raw waste or the ash from an incinerator.

The few pyrolysis plants that have been built have cost more than projected. Operation of these plants has been brief, and under start-up or experimental conditions, so firm operating and maintenance costs are not available. Thus, true plant costs are still unknown. The projected markets for recovered material are not characterized well due to their fragmentation and volatility, so recovered materials credits are uncertain. In summary, plant economics cannot now be accurately quantified.

Over 50 pyrolysis processes have been proposed, and over 35 are claimed to be suitable for processing municipal solid wastes. However, few have progressed beyond the laboratory bench or pilot plant scale. At present, there are no commercial pyrolysis plants operating in the United States.

The four pyrolysis processes which had made the most progress towards commercialization are Flash Pyrolysis for liquids, Landgard and Andco-Torrax for low Btu gas, and Purox for medium Btu gas. The 200 tons per day Flash Pyrolysis demonstration plant and the 1000 tons per day Landgard demonstration plant have run into technical problems and are shut down. The Purox system has been demonstrated at a 200 tons per day demonstration plant. A commercial unit has not yet been built or operated. Andco-Torrax has several 200 tons per day plants operating in Europe; in the United States, only a pilot plant has operated but it has recently been dismantled.

2.1.1 Solid RDF Characteristics*

Even a cursory investigation of the constituent make-up and the basic thermochemical analysis of municipal solid waste reveals significant fuel resource potential and some material resource values. Typical as-discarded, mixed municipal refuse composition is shown in Table 1 with projected composition through 1990. Although this provides

*Source material Reference 1-5.

TABLE 1
MUNICIPAL WASTE COMPOSITION*

	TYPICAL NORTHEAST USA	PROJECTED COMPOSITION			
	1968	1975	1980	1990	TREND
FOOD WASTES	21.1	17.9	16.2	14.0	↙
PAPER PRODUCTS (NEWSPAPER ± 12%)	38.2	40.8	41.5	45.0	↗
YARD WASTES	14.1	13.2	12.9	12.2	↙
METALS	8 7	9.0	9.4	9.0	↗
GLASS	8.8	9.9	10.3	9.5	↗
WOOD	2.7	2.2	2.0	1.6	↙
TEXTILES	2.0	2.1	2.1	2.5	↗
LEATHER, RUBBER	1.5	1.5	1.5	1.5	
PLASTICS	1.1	1.9	2.8	3.5	↗
MISCELLANEOUS	1.8	1.5	1.4	1.2	↙
MOISTURE	25.9	23.4	22.1	20.5	↙
TOTAL ASH	21.8	22.9	23.5	22.4	↙
HHV-BTU/POUND	4,582	4,719	4,811	5,040	↗

*Percent as Discarded

Source: DHEW-NAPCA Contract CPA 22-69-23

PROJECTION FOR BENEFICIATED RDF

MOISTURE	15.9	13.4	12.1	10.5
ASH (LESS METALS, GLASS)	5.5	5.3	5.2	5.2
HHV-BTU POUND	6,760	7,000	7,100	7,250

average values, the constituent make-up can vary widely from season to season and even day to day. However, if the waste is processed to remove much of the metals and ceramics (glass) resulting in a reduction in moisture, the variability of the remaining organic fraction would be moderated and its potential value as a fuel significantly enhanced.

Industrial solid waste consists of production wastes, shipping, packaging, and crating wastes; dunnage; office and cafeteria wastes. Although having similar constituent proportions and characteristics across a spectrum of industries, waste may vary from industry to industry and from plant to plant in the same company.

Table 2 shows the character of general industrial plant wastes. It does not reflect process or production wastes.

The possible variability of the fuel value parameter is of particular interest as is the sulfur content of the discrete fuel constituents. Some of these values are displayed in Table 3.

Apparently, even for discrete constituents, there is sufficient variation to reveal a significant range in calorific value. Obviously, there will also be significant variation in moisture content, ash content, and entrained noncombustibles in a mix of waste materials or a derived fuel fraction.

This is not startling, since variations in conventional industrial fossil fuel quality are commonplace:

- o in coals from a particular seam or even a particular mine.
- o in heavy (residual) fuel oils and, to a lesser extent, in the distillates

TABLE 2
GENERAL INDUSTRIAL PLANT WASTE

	COMPOSITION	PROXIMATE ANALYSIS, PERCENT					
	WEIGHT PERCENT	MOISTURE	VOLATILE MATTER	SULFUR	INERTS	BTU/LB DRY BASIS	ASH FUSION TEMP. °F
CORRUGATED BOARD AND MISC. PAPER	52	8	75	0.2	5.0	7,600	2,230
HARDWOOD (CRATES, PALLETS, ETC.)	28	12	67	0.1	3.0	8,300	2,700
TEXTILES	5	10	80	0.2	3.0	8,000	2,180
PLASTICS (FILM AND RIGID)	4	1	95	0.1	1.5	14,600	–
METALS	3	2	–	0.1	95.0	120	–
MISCELLANEOUS RUBBER	2	2	83	2.0	15.0	11,300	2,240
FOOD WASTES	1	50	20	0.5	5.0	8,400	2,140
SWEEPINGS	5	25	54	0.2	20.0	6,000	2,200
COMPOSITE WEIGHTED ANALYSIS		10	70	0.2	8.0	7,800	

CALORIFIC VALUE (HHV) ADJUSTED TO REFLECT COMPOSITE (10%) MOISTURE = 7,100 BTU/LB

NOTES:

THE GLASS CONSTITUENT IN GENERAL PLANT WASTE IS EXPECTED TO BE LESS THAN 1%.

TABLE 3
SULFUR AND CALORIFIC VALUE OF CONSTITUENTS IN SOLID WASTES

	SULFUR WT.%	BTU/LB DRY BASIS
PAPER PRODUCTS	0.12	7,000-8,000
WOOD	0.11	8,000-9,000
TEXTILES	0.2	7,000-9,000
PLASTICS	1.07-0.55	11,000-18,000
LEATHER/RUBBER	0.40-1.30	10,000-16,000
METAL	0.01	740
GLASS	0	65
FOOD WASTES	0.25	8,000-9,000
YARD WASTES	0.35	8,500-7,500

Although an ultimate analysis does provide the basic information for stoichiometric determinations, the proximate analysis, particularly the volatile matter, provides an indication of combustion performance in the furnace. Table 4 provides representative analyses for a broad range of waste materials that have been utilized as salvage fuels separately or in combination with conventional fuels.

For a relative comparison of these values with a spectrum of U.S. coals, refer to Table 5. Of particular significance is the variance in volatile matter.

The fuels salvaged from wastes usually have significantly higher volatile matter than that of coal, regardless of type.

The empirical volatile matter (VM) determination is intended to reveal the gaseous character of the fuel and, therefore, serve as an indication of its reactivity in a furnace. The traditional procedure is to determine the weight loss of a carefully prepared (air - dried) 1-gram sample which has been subjected to 950°C for seven minutes in a muffle furnace. This procedure, developed and adopted internationally at the turn of the century, and the accumulated library of data on specific coals, have been basic references in equating fuel/furnace performance. However, in recent efforts to utilize lower sulfur content low - rank coals, furnace combustion characteristics (the reactivity of fuel) required more graphic definition with correlations to those higher - rank coals which had been extensively used in the past. The type of graphic data being accumulated is illustrated in Figure 2.

Although similar data are not yet available for waste fuels, the characteristics of subbituminous and lignite would approach what might be anticipated. The surge of gas released even with only modest temperature exposure displays phenomena which have been experienced

TABLE 4
PROXIMATE ANALYSIS OF WASTE FUELS

	M	VM	FC	A	S	BTU/LB (DRY)
PEANUT HUSKS	5.5	68.4	24.9	1.2	0.1	8,467
RICE HULLS	6.2	64.3	13.2	22.5	0.1	6,260
FURFURAL RESIDUE	(55)	70.8	23.2	6.0	0.4	8,600
COFFEE	(70)	80.2	19.4	0.4	0.2	11,420
WOOD - PINE BARK	(50)	73	24.2	2.8	0.1	9,030
GREEN FIR	45	45	9	0.7	0.06	4,910
SEASONED	24	65.5	9.5	1.0	0.08	6,300
KILN DRIED	8	79.2	11.5	1.3	1.0	7,630
CORRUGATED BOARD	8	75	13	5	0.2	7,600
TIRES (GRANULATED)						
TREAD RUBBER	0.9	66.5	29.2	3.4	1.04	16,287
COMPOSITE FIBRE	2.8	80.0	15.3	1.9	1.04	11,846

TABLE 5
PROXIMATE ANALYSIS OF U.S. COALS

	M	VM	FC	A	S	BTU/LB (DRY)
ANTHRACITE	2.5	6.2	79.4	11.9	0.6	12,925
BITUMINOUS - W. VA.	1.0	18.6	77.3	5.1	0.7	14,715
- PENNA.	1.5	23.4	64.9	10.2	2.2	13,800
- PENNA.	1.5	30.7	56.6	11.2	1.8	13,325
- KY.	2.5	36.7	57.5	3.3	0.7	14,480
- OHIO	3.6	40.0	47.3	9.1	4.0	12,850
- ILLINOIS	12.2	38.8	40.0	9.0	3.2	11,340
LIGNITE - N.D.	37.0	26.6	32.2	4.2	0.4	7,255

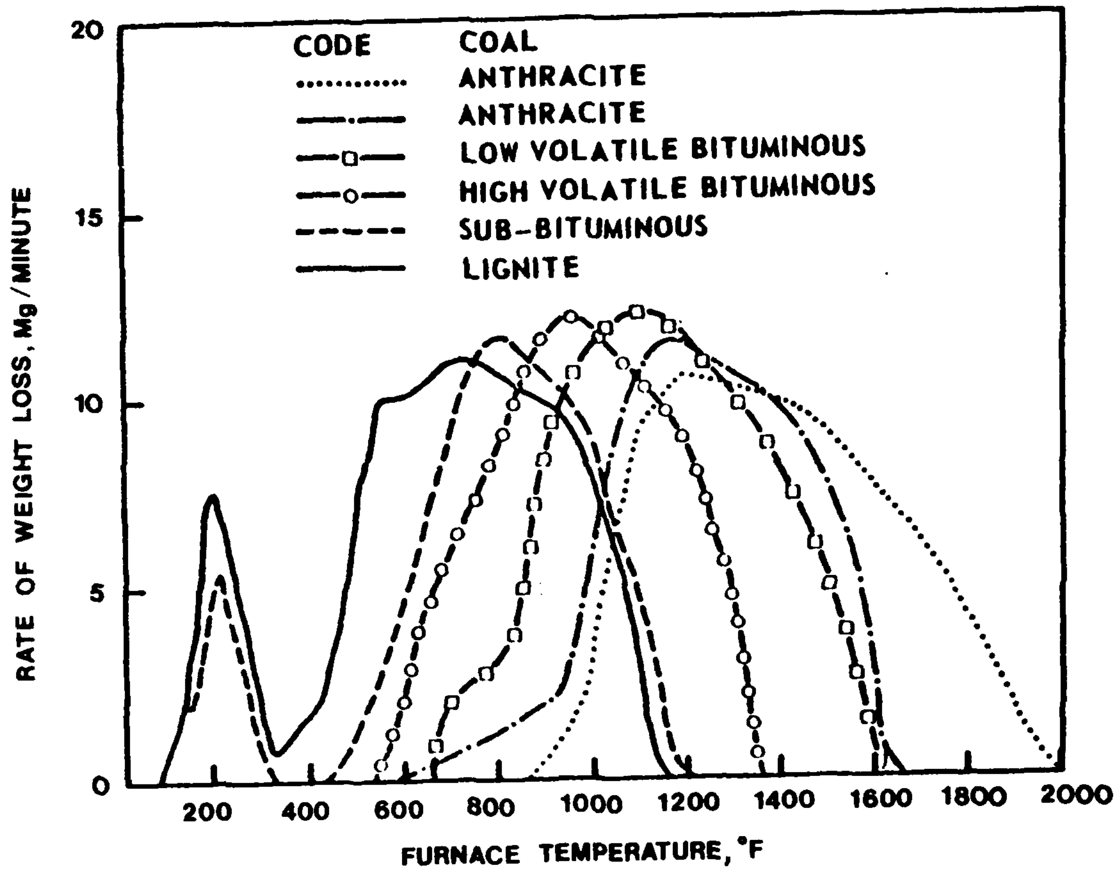


FIGURE 2
COAL-BURNING PROFILES

with some of the more highly reactive dry waste fuels. This would indicate that very rapid ignition and combustion would take place, resulting in long flame contours which require long flame travel in a vertical furnace configuration and ample retention time. To avoid hydrocarbon stratification, provisions must be made for high turbulence, so that the furnace environment can approach that of a "perfectly stirred reactor."

These profiles indicate the rate of volatile energy release (potential reaction intensity) and, in addition, the conventional volatile matter value in the fuel for comparison with the traditional procedures, accumulated data, and performance history.

However, this is only indicative of what may occur in a furnace, since, for reproducibility, the analytical procedure must be under closely controlled conditions in a fuels laboratory using only a "representative" dry 1-gram sample, powdered to pass a No. 60 sieve (openings 250 μm or 0.0098 in.). Therefore, the analysis information would only be a guide and should be correlated with actual field burning trials and trained observation to establish projectable relationships.

Furnace configurations designed for low volatile, slow reacting fuels may not readily accommodate significant quantities of the "gassy", highly reactive nature of salvage fuels, with their long flame characteristics. Yet, in the right fuel mix proportions, they may expedite the combustion of the slower reacting coals without detrimental furnace effect.

Refuse derived fuels (RDF) burned alone or in combination with fossil fuels are best suited for open furnaces with long flame travel. Refractory surfaces for reradiation are not usually required to stimulate the combustion reaction. However, the reactivity of many fuels can be inhibited by moisture, size consist or form, ash content, and entrained inerts.

2.1.1.1 Fouling, Slagging and Clinkering - Fouling, slagging, or clinkering potential of the ash is an area of concern to the user. Since the constituent mix of solid waste varies, an examination of some characteristics of the discrete constituents can be informative. Review of Table 6 provides ash fusion temperature (AFT) values of the combustible residues and the noncombustible constituents commonly found in solid wastes. With the exception of the glass fraction, the remaining components have ash fusion values within the range commonly encountered with most coals. The refined fuels derived from refuse would have much of the ceramics and metals removed.

These analyses were made in an oxidizing atmosphere. Based on the experience with coal ash, somewhat lower values in a reducing atmosphere could be anticipated. These data also do not reveal possible synergism and shifting of eutectic when the components are in various combinations. However, referring to the relative percentages of each constituent in the fuel (Table 2) aids in placing possible concerns in more meaningful perspective. The synergism involved in ash fusion temperature can also become a factor when utilizing this salvage fuel as a supplement to coal or oil. Of course, the real significance of this synergism on furnace performance is a function of: type of firing (mass, semisuspension, full - suspension), firing equipment, character of fossil fuel being burned, ratio of fossil fuel to salvage fuel to be utilized, relative fuel size consist, extent of waterwall coverage, heat release, furnace liberation, flame travel, furnace exit temperature, excess air, and furnace turbulence.

TABLE 6
ASH FUSION TEMPERATURES

"Laboratory" Determination of ASTM Fusion
Temperature of Residue Constituents
and Melting Points of Pure Metals

	INITIAL DEFORMATION °F	SOFTENING °F	FLUID °F
CLEAR GLASS	1480	1680	1840
BROWN GLASS	1620	1740	2080
GREEN GLASS	1640	1800	2080
ASH FROM:			
GARBAGE	2020	2140	2200
CARDBOARD, CORRUGATED	2060	2160	2240
MISC. PAPER	2160	2300	2480
GRASS AND DIRT	2080	2240	2320
TEXTILES	2040	2180	2240
HEAVY PLASTICS, LEATHER, RUBBER	2100	2220	2300
BONES AND SHELLS	2800	2800	2800

	MELTING POINTS °F
IRON	2795
IRON OXIDE (Fe_2O_3)	2849
ALUMINUM	1200
ALUMINUM OXIDE (Al_2O_3)	3713
LEAD	622
TIN	449
ZINC	769
LIME (CaO)	4676
SILICON OXIDE (SiO_2)	2930

SOURCE: ASME NATIONAL INCINERATOR CONFERENCE, 1968 PROCEEDINGS, PAGE 140.

THESE TEMPERATURES WERE DETERMINED WITH THE LABORATORY FURNACE HAVING AN OXIDIZING ATMOSPHERE. THE TEMPERATURES COULD BE SOMEWHAT LOWER IN AN OXYGEN DEFICIENT (REDUCING) ATMOSPHERE.

2.1.1.2 Fuel Sizing - The performance of any fuel burning system is enhanced if the fuels can be processed to make their physical and thermochemical properties reliably predictable.

Most wastes resulting from industrial production are of relatively uniform size and of reasonably predictable nature. However, general plant wastes and some production wastes require controlled size reduction to make them suitable as a fuel and facilitate handling, storage, and retrieval.

Entrained moisture is the most significant element influencing combustion and energy recovery efficiency. However, there are practical and economic limits in attaining moisture reduction. Many cellulosic base materials can be consumed as a fuel with moisture levels as high as 50 percent without requiring support fuel.

Many industries who have previously only looked upon the use of their wastes for fuel as an expedient disposal method have recently come to regard their wastes as a reliable (and valuable) local energy resource - even as a by-product of production.

Municipal solid wastes are a source of "processed" fuel (refuse derived fuel), but their varying heterogenetic characteristics necessitate greater refinement than most industrial wastes. One or more stages of size reduction may be necessary with suitable classification/separation processes. This effort tends to provide physical and chemical homogeneity, dispersal, and reduction in moisture, and facilitates effective removal of extraneous noncombustibles, including metals and ceramics, which may have potential "material" resource value. The "realizable" energy value of these wastes does not appear to be materially affected by the benefication to produce a fuel.

Solid Refuse derived fuels (RDF) for use directly in furnaces of existing boiler installations could be available in the following general forms:

- o sized to pass coarse screening 25 cm (10") square openings
- o sized to pass screening with 10 cm (4") square openings
- o sized to pass screening with 2.5 cm (1") square openings
- o powdered to pass screening with 60 mesh opening

The screen sizes shown are only representative. The intermediate and smaller size screen "refined" products can be formed into lump fuels:

- o Cubettes - about the size of ice cubes - 1-1/2" x 1-1/2" x 2"
- o Pellets - cylindrical, approximately - 3/8" dia. x 1" long
- o Slugs - cylindrical, approximately - 1" dia. x 3" long

RDF refined into a powder could be formed into "briquettes" approximately 1-1/2" square. These cellulosic "lump" fuel forms are of higher bulk density, are not spongy, can be handled more nearly like a granular material, and embody reasonable structural integrity.

Each form of RDF will have, within relatively narrow limits, a characteristic bulk density necessitating careful attention to the handling, storage, retrieval, feeding, and burning requirements for practical application.

All these fuels must be weather protected to retain their physical structure and maximize utilization of their energy value.

As with coal preparation, the degree of refinement of salvage fuels should be limited to only that required for practical, economic utilization in each fuel using system.

Realizing the need for establishing firm guidelines for identifying the nature, character and quality of the different forms of material and energy resources extracted from the waste stream, a committee on resource recovery (E-38) was formed under ASTM auspicious. A discussion regarding this ASTM activity to formulate standards and guidelines can be found in Reference 3.

The ASTM E-38 Resource Recovery Committee has tentatively formulated the following guidelines for the different forms of RDF which may become economically available:

RDF-1 - Wastes used as a fuel in its as-discarded form.

RDF-2 - As-discarded wastes processed to coarse particle size with or without ferrous metal separation.

RDF-3 - Combustible waste fraction processed to particle sizes 95 percent passing 2-inch square screening.

RDF-4 - Combustible waste fraction processed into powder form 95 percent combustible passing 10-mesh screening.

RDF-5 - Combustible waste fraction densified (compressed) into the form of pellets, slugs, cubettes or briquettes.

RDF-6 - Combustible waste fraction processed into liquid fuel.

RDF-7 - Combustible waste fraction processed into gaseous fuel.

2.1.1.3 Conversion Potential and Relative Value - The potential steam generation which may be possible from solid waste or refuse derived fuels of various degrees of refinement is illustrated in Figure 3. A probable combustion efficiency was selected for each plot to correspond with the projected degree of fuel refinement and the associated weight of the refined fuel fraction (RFF) produced.

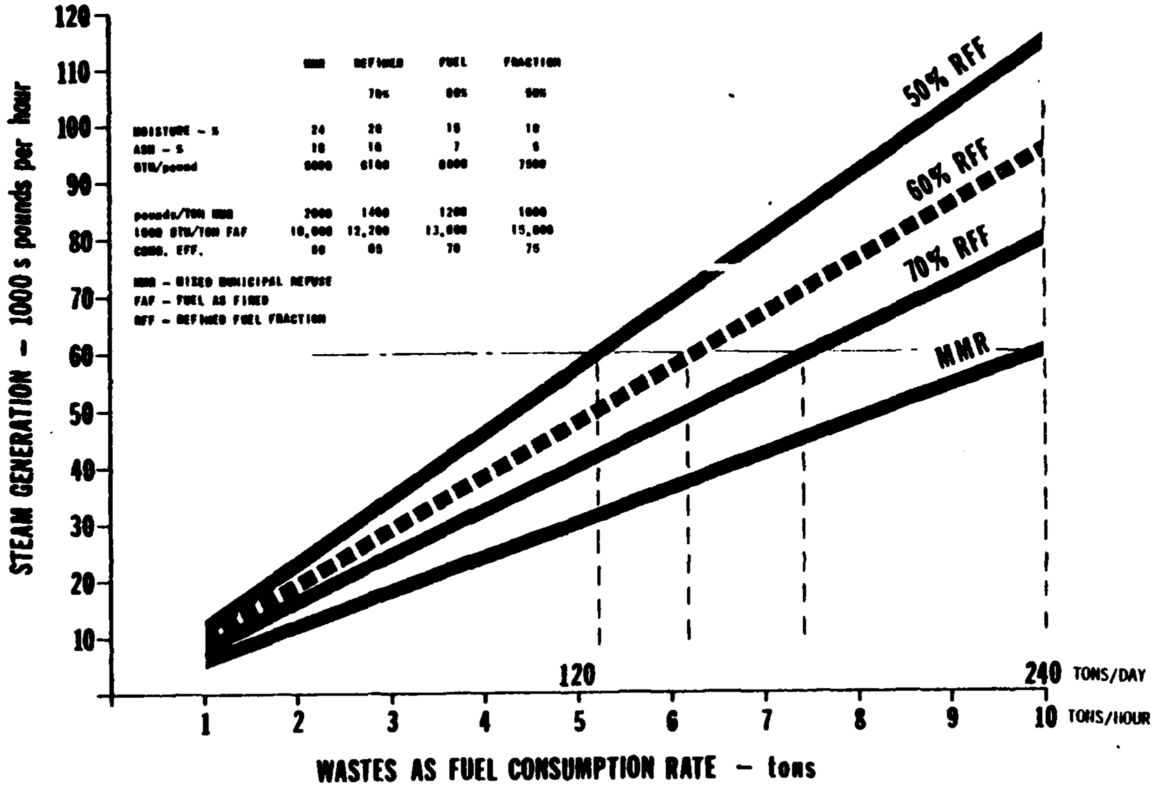


FIGURE 3

POTENTIAL STEAM GENERATION WITH WASTES AS FUEL

The plot in Figure 3 not only indicates the probable steam production which may be expected, but also reveals that approximately the same quantity of steam would be produced from the feedstock in spite of combustible material losses encountered during refinement. Although there would be lesser quantities of derived fuel with increasing degrees of refinement, the RFF increases in quality and, therefore, will be consumed more efficiently. Therefore, the net energy available as steam, would be approximately the same with any of these fuels. The fuel user should find that with more highly refined RDF, the material handling, storage, retrieval, feeding and burning equipment will need to cope with lesser quantities of fuel, as well as resulting ash for handling and disposal. However, additional energy and equipment will have been required for the fuel refinement process.

The plots of relative values of these salvage fuels to conventional fuels as shown in Figure 4 try to account for the "relative fuel utilization efficiency," so that the values displayed would be on an equivalent net-Btu basis. In arriving at the values shown for salvage fuels, other operating costs and capital costs for accommodation were not included, since such costs are considered to be specific to each particular plant and local circumstance.

These plots do reveal some of the fossil fuel displacement potentialities and economic parameters and should assist in determining whether further investigation is warranted.

2.1.2 Liquid RDF Characteristics

There are a number of pyrolysis processes that are being developed to produce liquid fuels from solid wastes and residues. Five of the process developers identified by SRI International in a recent study[6] are listed in Table 7, along with rough estimates of liquid fuel production. Table 8 shows liquid RDF composition data from selected processes and feedstocks.

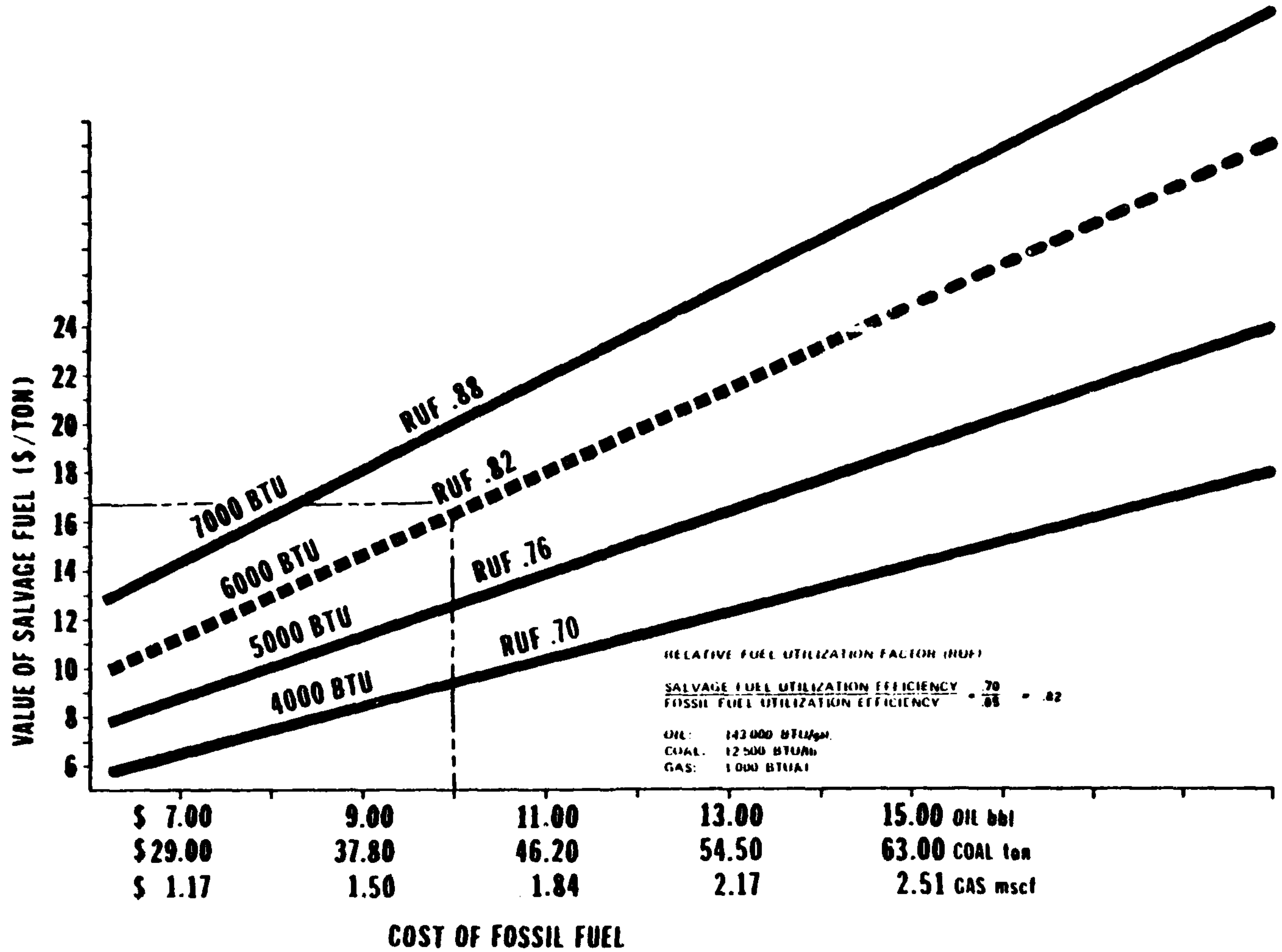


FIGURE 4
RELATIVE VALUE OF SALVAGE FUEL

TABLE 7

TYPICAL LIQUID RDF PRODUCED FROM SELECTED PROCESSES AND FEEDSTOCKS

PROCESS DEVELOPER	REACTOR HEAT TRANSFER TECHNIQUE	FEEDSTOCKS	ESTIMATED LIQUID* FUEL PRODUCTION	DATA SOURCE
ENTERPRISE CO. (SANTA ANA, CA) DECO ENERGY CO. (IRVINE, CA)	INDIRECT	REFUSE	1.25 BBL/TON REFUSE ~ 1.9 BBL/TON DRY ORG.FEED	(7)
		TIRES	3.5-4.0 BBL/TON OF TIRES	(8)
OCCIDENTAL PETROLEUM (LA VERNE, CA)	INDIRECT	REFUSE	1.1 BBL/TON REFUSE ~ 1.7 BBL/TON DRY ORG.FEED	(9)
		FAR**	1.5-2+ BBL/TON DRY ORG.FEED	(10)
TECH-AIR CORP. (ATLANTA, GA)	DIRECT	REFUSE & SCRAP TIRES	< 1.0 BBL/TON DRY ORG.FEED	(11)
		FAR**	1.1-1.6 BBL/TON DRY ORG.FEED	(12)
THERMEX INC. (HAYWARD, CA)	INDIRECT	SCRAP TIRES	2.7 BBL/TON OF TIRES	(13)
TOSCO CORP. (LOS ANGELES, CA)	INDIRECT	SCRAP TIRES	3-4 BBL/TON OF TIRES	(14)

*DATA FROM REFERENCES ON OIL PRODUCTION WAS USED TO ROUGHLY ESTIMATE PRODUCTION PER UNIT MASS OF FEED. NOT ALL ESTIMATES ARE ON COMMON BASIS BECAUSE OF DIFFERENT WATER CONTENTS IN THE LIQUID FUEL.

**FOREST AND AGRICULTURAL RESIDUES.

TABLE 8
LIQUID RDF COMPOSITIONS FROM SELECTED PROCESSES AND FEEDSTOCKS
(WEIGHT %)

COMPONENT	TYPICAL* NO. 6 FUEL OIL	ENTERPRISE PRODUCT (7) FROM REFUSE	OCCIDENTAL PETROLEUM PRODUCTS (8)			TECH-AIR PRODUCTS (11)		TOSCO PRODUCT (13) FROM SCRAP TIRES
			FROM REFUSE	FROM RICE HULLS	FROM FIR BARK	FROM PINE BARK	FROM REFUSE	
CARBON	86.4	85.3	57.0	62.4	60.5	66.8	–	87.1
HYDROGEN	12.9	11.2	7.7	5.8	6.0	6.4	–	9.7
OXYGEN	–	2.2	33.6	29.4	30.7	25.9	–	1.0
NITROGEN	–	0.2	1.1	1.4	0.5	0.2	–	0.6
SULFUR	1.2	0.2	0.2	0.1	0.1	–	–	1.0
CHLORINE	–	0.3	0.2	0.3	0.2	–	–	–
ASH	–	0.02	0.2	0.6	2.1	–	–	–
BTU/LB**	~18,000	17,300	10,500	10,400	10,300	~9,000	10,400	~18,000

*P.F. SCHMIDT, FUEL OIL MANUAL, INDUSTRIAL PRESS INC. (1969).

**IN NUMEROUS CASES HEATING VALUES ARE REPORTED FOR A MIXTURE OF PYROLYTIC OIL AND WATER (5-20 WT.%)/

Data given below are from the Occidental Research Corporation (ORC) Flash Pyrolysis Process. The sample oil was obtained from ORC's 4 ton-per-day pilot plant. The properties of the refuse derived liquid fuel described by Occidental should be representative of what would be expected from any refuse derived liquid fuel.

As with petroleum itself, the oil produced in the ORC process is a complex mixture of molecular weights and structural configurations. While its chemistry has not been investigated in any great detail, sufficient characterization has been made to establish the probable value of the liquid as a utility fuel. Key properties of the product are shown in Table 9, along with those of No. 6 fuel oil for comparison.

Important differences between the two oils include:

- Elemental Analysis - The high oxygen content of the pyrolytic oil, a result of the largely cellulosic composition of the original waste, results in a decreased HHV compared to normal hydrocarbon fuels, and causes marked solubility (60 percent) capability of the oil. Water is retained to decrease viscosity. The oxygen content, in addition to the chloride level, results in some acidity of the product; storage should present no particularly difficult problem, and details of materials to be used will be established during the El Cajon demonstration plant study. An additional characteristic that, thus far, is attributed to the high oxygen content is that extended high temperature storage causes a further increase in viscosity. The oil should be maintained below 160°F until just before atomization. The low sulfur content is a property of the pyrolytic oil that makes it an attractive RDF. The low ash content, being markedly less than solid forms of RDF, is another important feature of the liquid fuel.

- Specific Gravity - The pyrolytic oil has an unusually high density, 34 percent higher than that of the usual fuel oil. The ORC product has a higher energy content per volume than any other refuse derived fuel, a factor that will reduce its transportation costs compared with other RDFs.

- Heating Value - While even on a volumentric basis the HHV of the pyrolytic oil is 23 percent less than that of fuel oil, it is higher than an average coal, and, if used in conjunction with a

TABLE 9
COMPARISON OF NO. 6 FUEL OIL AND OCCIDENTAL'S PYROLYTIC OIL

COMPOSITION, WT.%	NO. 6 OIL	PYROLYTIC OIL
C	87.5	57.0
H	10.5	7.7
S	0.7-3.5	0.2
Cl	–	0.3
ASH	0.5	0.5
N		1.1
O	2.0	33.2
SPECIFIC GRAVITY	0.98	1.30
HEATING VALUE		
BTU/LB	18,200	10,600
BTU/GAL.	148,800	114,900
POUR POINT, °F	65-85	90*
FLASH POINT, °F	150	133*
VISCOSITY, SSU AT 190°F	340	1,150*
PUMPING TEMPERATURE, °F	115	160*
ATOMIZATION TEMPERATURE, °F	220	240*

*PYROLYTIC OIL CONTAINING 14% WATER, AS MARKETED.

liquid fossil fuel, a substantial portion of the total heat input to the furnace can be supplied by it without any major modifications to the system or its steam generating characteristics.

- Flow Properties - The presence of 14 percent water alters flow properties of the pyrolytic oil sufficiently to permit it to be handled with conventional equipment, although the Occidental product remains more viscous than No. 6 oil. The effect of temperature is greater for the synthetic oil, however, such that the atomization temperatures are only 20°F apart.

  The combustion properties of oil produced in the pilot plant were briefly examined in research burners by Combustion Engineering, Inc. Blends of pyrolytic oil of 25 and 50 percent by volume with No. 6 oil derived from Alaskan crude were used. Such blends eventually separate because of the solubility characteristics of the oxygenated oil, but are stable for several hours. Ignition stability proved to be equal to the fossil oil alone, and combustion was successful with properly designed fuel handling equipment. At air levels over two percent excess oxygen, there were negligible quantities of unburned carbon in the stack emissions.

- Ash Content - The ash content is of particular importance to the end user, since it affects the combustion operation. In contrast to solid refuse derived fuels, which can have ash contents of 10 percent or more, synthetic liquid fuels can be produced with less than one percent ash and can, therefore, be burned in power stations without ash handling capability. A comparison of the chemical compositions of a typical solid waste fuel and pyrolytic oil is given in Table 10. An ash analysis of the oil shown in Table 10 is given in Table 11. Sodium and potassium are usually high, followed by iron and aluminum; the zinc value is abnormal. Up to 50 percent of the final ash recovered is water soluble.

2.1.3 Gaseous RDF Characteristics

The three largest scale processes constructed to produce gas from wastes are summarized in Table 12. The three processes that produce a fuel gas are not true pyrolysis processes but rather are partial or starved - air combustion processes. Thus, they all operate in the directly heated mode and use countercurrent flow, which is not optimum for gas production.

TABLE 10
COMPARISON OF TYPICAL REFUSE DERIVED FUEL
AND PYROLYTIC OIL (10)

COMPONENT	RDF WT.%	PYROLYTIC OIL, WT.%
CARBON	30.9	56.8
HYDROGEN	4.8	7.6
SULFUR	0.43	0.2
NITROGEN	0.42	1.1
CHLORINE	0.24	0.02
MOISTURE	23.0	6.4
ASH	17.4	0.32
OXYGEN	22.8	27.6

TABLE 11
ASH ANALYSIS OF PYROLYTIC OIL FROM MUNICIPAL SOLID WASTE (10)

ELEMENT*	WT. % OF OIL	WT. % OF ASH
ASH	0.32	–
Zn	0.086	26.9
Cu	0.004	1.3
Al	0.005	1.6
SiO_2	0.006	1.9
Mg	0.004	1.3
Fe	0.010	3.1
Ca	0.010	3.1
Na	0.065	20.3
K	0.034	10.6
V	0.001	0.3
Ti	0.001	0.3
TOTALS	0.226	70.7

*METALS CALCULATED AS OXIDES ACCOUNT FOR OVER 90% OF TOTAL ASH.

TABLE 12
PYROLYSIS FUEL GAS PROCESSES

LOCATION	BALTIMORE COUNTY, MD	SOUTH CHARLESTON, WV	ERIE COUNTY, NY
PROCESS	MONSANTO LANDGARD	UNION CARBIDE PUROX	ANDCO TORRAX
CAPACITY T/D	1,000	200	75
TEMPERATURE °F	1,200 TO [illegible],800	3,000	3,000
EFFICIENCY (%)	-GAS NET 66 -STEAM 43	-GAS NET 62	-GAS NET 45 -STEAM 36
PREPROCESSING	-SHREDDING	-SHREDDING -MAGNETIC	-NONE
POST-PROCESSING	-MAGNETIC -FLOTATION	-NONE	-NONE
MATERIALS RECOVERED	-IRON -GLASSY AGGREGATE	-IRON -GRANULAR RESIDUE	-NONE
TECHNICAL PROBLEMS	-LOW THROUGHPUT -REFRACTORY DAMAGE -SLAGGING -PARTICULATE EMISSIONS	-REQUIRES OXYGEN PLANT (0.2 TON/TON INPUT)	-NEEDS SUPPLEMENTARY OIL FUEL -PARTICULATE EMISSIONS
COMMENT	-OPERATIONAL ONLY AT PARTIAL CAPACITY	-SPORADICALLY OPERATED FOR TEST PURPOSES	-NON-OPERATIONAL

The nitrogen-free syngas produced in the Purox process is a medium - Btu gas which is interchangeable with natural gas for combustion purposes. The two other gas-producing, partial oxidation, pyrolysis systems that have reached demonstration or semicommercial status using municipal solid waste feedstock (Andco-Torrax and Landgard, which are air blown) produced a low - Btu gas (approximately 120-140 Btu/scf). Other concepts have been tested in small or bench scale units to produce gases, but none appear technically or economically feasible at present.

The composition of the Purox fuel reported by Union Carbide is shown in Table 13. The fuel is principally carbon monoxide and hydrogen, with a small quantity of methane. The heating value of this fuel is approximately 300 Btu/scf.

The municipal solid waste - derived gases discussed here are very similar to gases derived from coal gasification processes as far as their use in utility boilers is concerned. The Union Carbide Purox gas has the same heating value as medium - Btu gas derived from coal.

Since these gases contain no ash, they would comply with the particulate emission standards now in effect. There are no emission standards for SO_2 in the burning of these low or medium heat content fuel gases. Although no NO_x data are available, EPA NO_x limits will probably not be exceeded when burning these fuels[14].

2.2 BOILER RETROFIT CONSIDERATIONS

Although drawing upon the operational experience of hundreds of waste fuel fired boiler installations can be valuable, most of these were initially designed specifically for the waste fuels they are firing. As yet, there are few RDF fired installations which have logged extensive hours in commercial operation. There are also very few existing installations which were adapted to utilize RDF. Those that

TABLE 13
PYROLYSIS FUEL GAS ANALYSIS

COMPONENT	MOL. %	WT. %
CO	44.2	58.9
H_2	31.0	2.9
CO_2	13.2	27.6
CH_4	3.8	2.9
C_2H_4	.9	1.4
N_2	.9	1.2
H_2O	6.0	5.1
TOTAL	100.0	100.0

HHV (BTU/SCF) 290

have been or are being currently adapted will be utilizing finely shredded, classified RDF. However, some tailoring of RDF can be provided to suit the particular type of boiler plant installation under consideration.

Although actual adaptations or new additions to a boiler plant facility will not take place until there are realistic projections of when RDF will become generally available, a commitment to burning RDF may be the essential element for undertaking a suitable waste-to-fuel processing facility.

A "cooperative relationship" with mutual understanding is essential between the fuel user and the fuel producer, if a jointly beneficial arrangement is to be developed and maintained. The fuel production facility must reasonably satisfy the basic fuel quality and quantity requirements of the fuel user who, in turn, must accommodate reasonable variability in the fuel product received.

Some considerations which should be addressed regarding existing boiler installations and the most suitable types of RDF will be described. A boiler system designed for bituminous coal, lignite, and wood - waste firing can most readily accommodate refuse derived fuels. However, there are industrial boiler - furnace systems designed for fuel oil firing which are successfully burning suitably prepared solid waste fuels which are free of inerts and low in moisture.

2.2.1 Stoker Fired Boilers

The first applications of mechanical stokers for burning solid fuels was in the early 1800s. These embryonic installations developed the fundamental principals for most modern stoker designs.

Currently available stoker systems (designed principally for coal firing) have the following operating objectives:

- o to continuously (or intermittently) feed fuel uniformly onto a grate surface within a furnace arranged to provide and main ignition.
- o to proportion the required undergrate combustion air flow to suit the respective stages of energy release in progress on or within the grate system.
- o to clean the fuel bed by removing the ash residue from the active furnace zones.

The basic types of stoker design can be designated as:

- o mass burning
  - fuel overfeed grate
  - fuel underfeed grate
- o thin burning (semisuspension)
  - fuel spreader

Mass burning stoker systems generally burn coals in a "deep" fuel bed (4" to 20" thick). The "green" coal is usually located below the burning coke with ash accumulating on the surface of the bed as it is moved by the stoker mechanism to the ash discharge point. The mass or depth of the fuel bed is a function of several factors, principally: fuel size consist, coking and caking characteristics, ash fusion temperature and moisture content. Segregation of coal sizes is the bane of all stoker systems, particularly the mass burning types. One of the principle attractions of "mass burning" stoker systems is their characteristic low particulate entrainment in the rising furnace gases. Another attraction is their capability to operate through a very wide load range with sustained controlled combustion. However, the mass of fuel in the furnace limits their capability to accommodate rapid, wide swings in steam demand.

The traveling (chain) grate, gate-fed, mass burning stoker types, schematically illustrated in Figure 5, have coal deposited from the stoker coal hopper onto the traveling grate which is slowly moving rearward into the furnace chamber. The depth of the fuel bed (4" to 12") is established by the operator positioning a refractory lined guillotine gate extending across the full width of the unit. Combustion rate is accommodated by grate speed and air flow through a series of air plenum chambers (air zones) located between the grate strands and spanning the width of the furnace.

This type of coal firing, affording continuous ash discharge at the rear of the furnace, has been available for boilers as small as 25,000 pounds of steam per hour and up to 200,000 pounds of steam per hour, for burning virtually the entire spectrum of coals and their tailings, i.e., anthracite to lignite.

The multiple retort underfeed stoker type, schematically illustrated in Figure 6, is made up of a series of adjacent, longitudinal, rearward sloping, U-shaped troughs, interconnected at the top sides by multiple semicircular tuyere plates. These tuyeres introduce the combustion air into the mass of pyrolyzing fuel being forced into, upward, and toward the rear of the furnace. Green coal is deposited from the stoker hoppers into the stoker ram case of each retort. The feed ram and auxilliary retort coal distributor - rams (on push rods) force the coal into the retort and upward through the distillation, pyrolysis, and coke burning zones. The fuel bed thickness (12" to 20") is controlled by the configuration and longitudinal positions of the auxiliary rams within the retorts and the setting of their stroke length. Once established for the nature of the particular fuel being consumed, they rarely require significant adjustment. Combustion rate is controlled by the speed and stroke of the large feed ram beneath

FIGURE 5

MASS BURNING OVERFEED (TRAVELING GRATE) STOKER

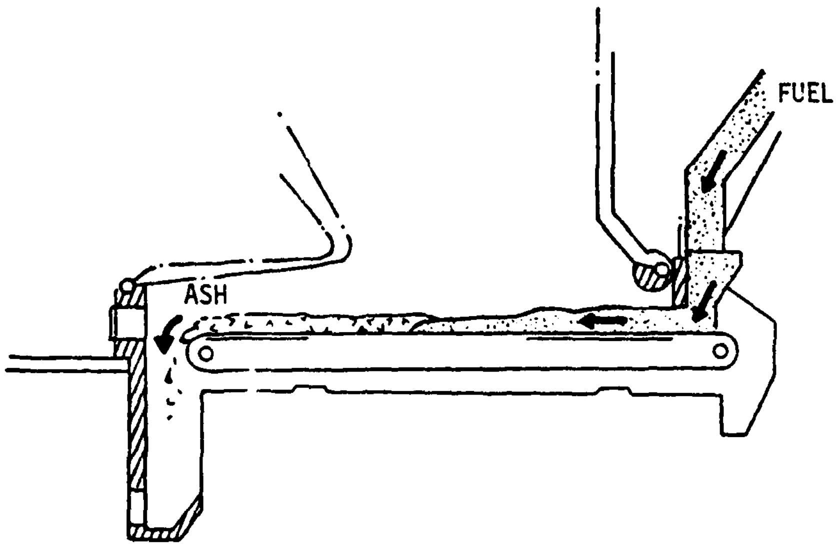
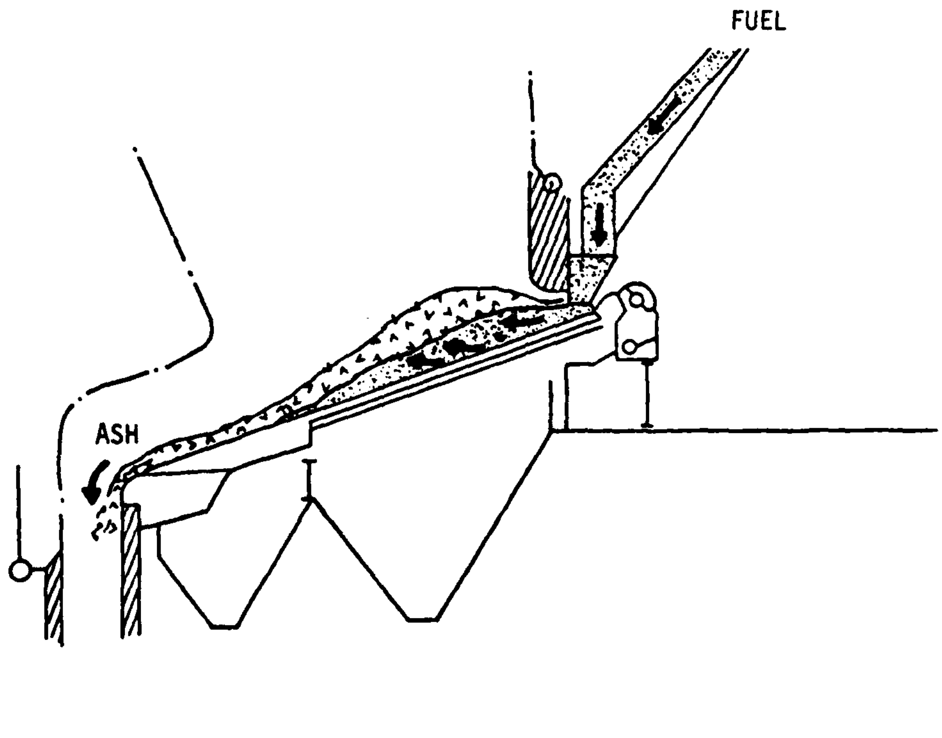


FIGURE 6

MASS BURNING MULTIPLE RETORT UNDERFEED STOKER



each stoker coal hopper and the combustion air flow from the undergrate air plenum chambers.

The capacity range for the application of rear-ash-discharge multiple retort underfeed stokers has been from 30,000 pounds of steam per hour to 200,000 pounds of steam per hour. However, the spectrum of suitable fuels is limited to Eastern bituminous coals which are noncaking, have 20-40 percent volatile matter, six to eight percent ash, +2,400^{o}F AFT, less than 20 percent Fe_2O_3 in the ash, and uniform grading in fuel size consist of 2" x 0" with not more than 25 percent less than 1/4".

Cofiring of RDF with coal in mass burning, lump-coal fired furnaces would be accomplished best by feeding a mix of formed RDF with most bituminous coals. The densified RDF would have to be formed into pellets, slugs, cubettes, or briquettes which can maintain reasonable structural integrity during the mechanical handling and furnace feeding regimes to be encountered. Introducing RDF in any form on top of the actively burning coal mass would initially tend to blanket the fire, impede flow of the pyrolysis gases, promote stratification of the hydrocarbons, stimulate development of hot spots, depress the ash fusion temperature, and, consequently, induce caking and clinkering.

The gate-fed travelling (chain) grate stokers or the multiple retort underfeed stoker systems should be capable of accommodating RDF as a significant percentage of their fuel requirements. However, the actual ratio of RDF to coal blend depends on many factors such as coal characteristics, steam load, available grate area, stoker feeding capacity, lower furnace configuration, extent of furnace cooling, flame travel, and practical provisions for blending, handling, storage, and retrieval facilities.

Thin burning (semisuspension) spreader firing systems schematically illustrated in Figure 7 are those which feed and distribute smaller size consist fuels uniformly across the width and length of the furnace, onto a grate surface, on top of the ash bed of the fuel already consumed. The bed on the grate is usually maintained quite thin (2" to 6"), but adequate to provide insulation from flame radiation and avoid impeding undergrate combustion air flow.

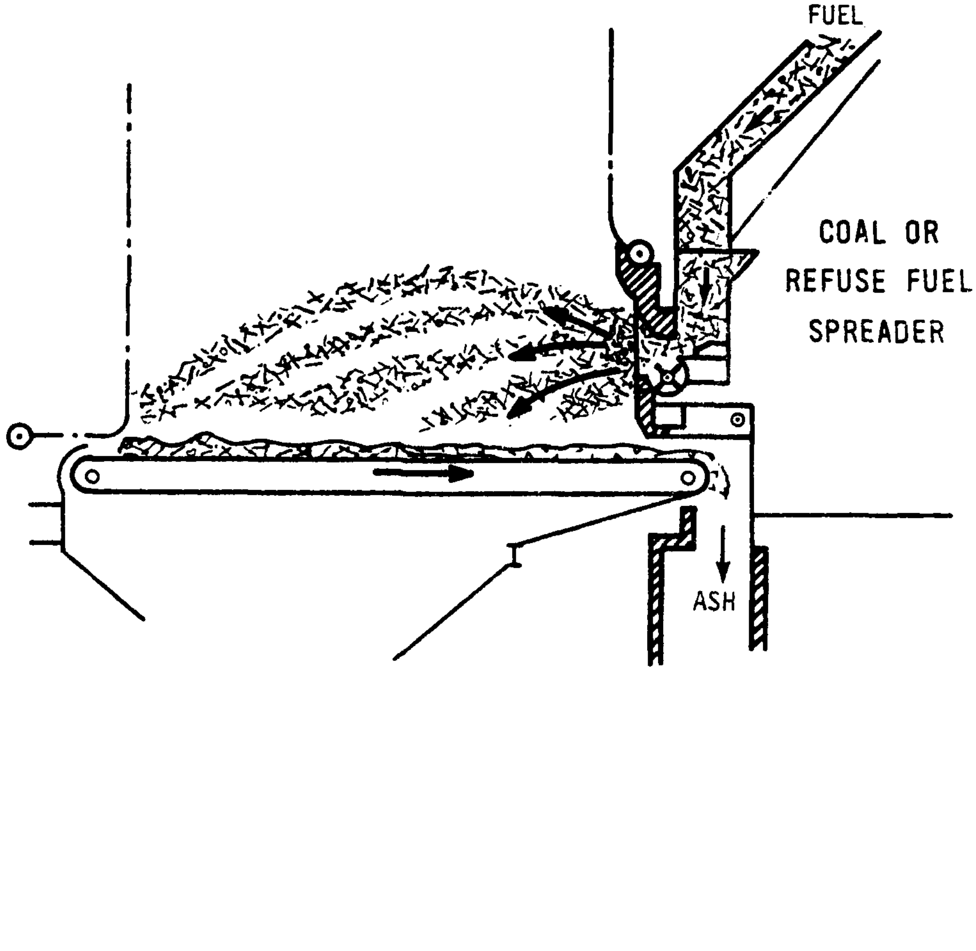
The combustion air cools the grate and the accumulated ash bed as it passes through to the burning coke particles which were not consumed during their travel trajectory from the stoker feeder-spreaders down to the grate surface. The undergrate air flow provides combustion air for the thin coal layer on the bed as well as for the coals in semisuspension. Therefore, low bed temperatures can be maintained permitting the utilization of the lower ash fusion temperature coals. This feature permits the utilization of a broad range of medium - and high - volatile coals. Low volatile coals such as anthracite are not applicable. Highly reactive cellulosic fuels (with as much as 50 percent moisture) can be readily accommodated when suitably sized for the handling and feeding equipment components.

Since so little fuel is in the furnace at any one time, spreader stoker operation can be very responsive to load swings approaching that possible with powdered, liquid, or gaseous fuel. However, the capability for wide load range operation is limited. When operating below one-third design capacity, the furnace and bed conditions tend to be unstable, evidenced by lazy, smokey gases rising from the bed and by objectional stack opacity.

The rapid - response, semisuspension burning feature has associated with it significant particulate entrainment in the combustion gases. This is accentuated at the higher grate heat release rates and when the fuels have a high percentage of fines.

FIGURE 7

THIN BURNING (SEMISUSPENSION) SPREADER STOKER

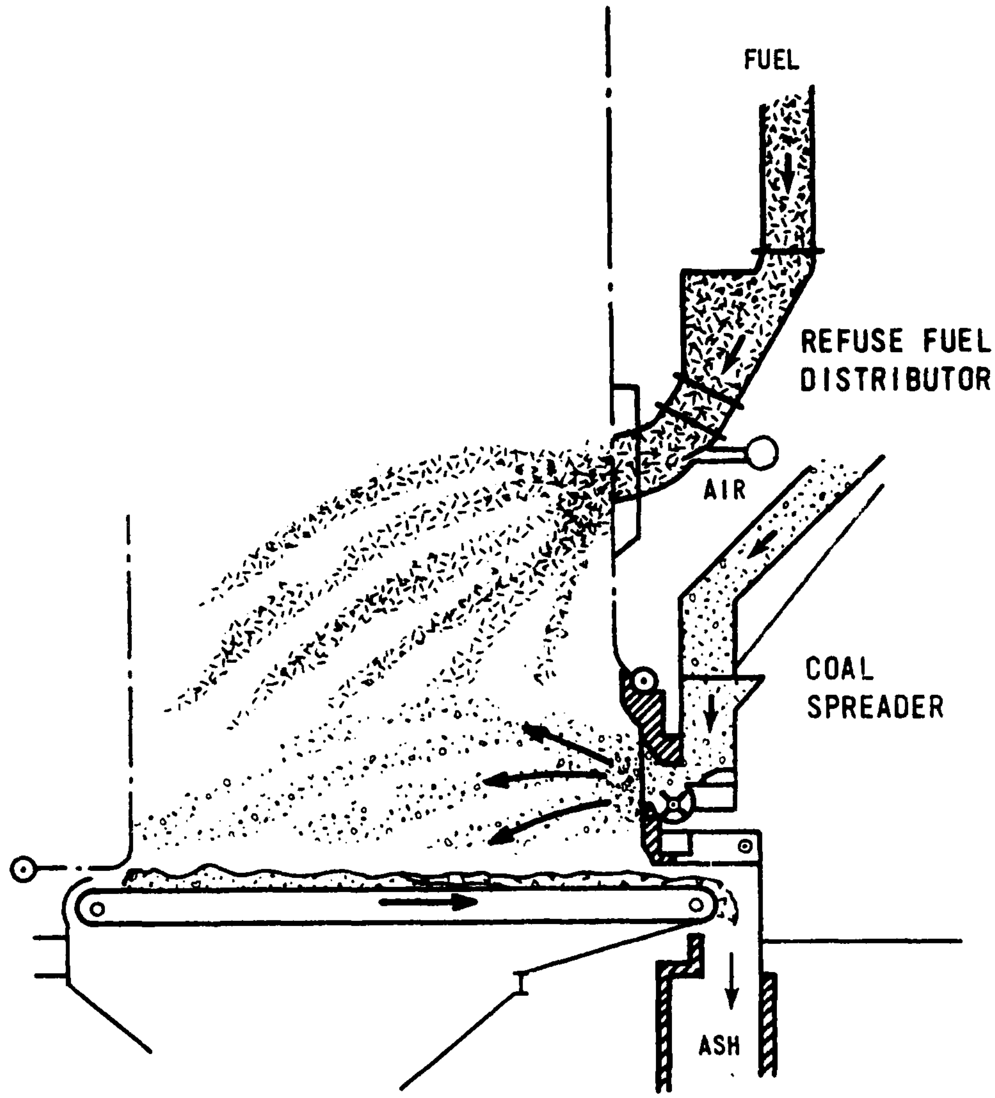


The larger installations can accommodate a coal size consist of 1-1/2" x 0" with the smaller, shorter furnace installations requiring 3/4" x 0". To minimize entrainment and fly-carbon loss, the fines should be limited to no more than 15 percent less than 1/4" at the point of coal shipment. This allows for some coal size degradation in transit, handling, and rehandling at the user plant. The degree of degradation in fuel size is also a function of the friability character of the coal as well as inherent and entrained moisture. Uniform proportions of the natural fracture sizing of the coal is desireable, but concentrations of narrow bands in sizing can be troublesome, and, therefore, every effort is made to avoid coal size segregation.

Spreader firing refuse fuels separately or in combination with fossil fuels has been commonplace in industry. There are several installations currently firing RDF as a principal fuel, and two new plants are currently under construction. The existing operating plant is also equipped to burn oil or gas as supplementary fuels. The plants under construction will be equipped to burn coal as well. This concept is illustrated schematically in Figure 8. The refuse fuel distributors can be located alternately in the rear furnace wall or arranged in each furnace side wall; location and number of fuel distributors is determined to provide feeding capacity and uniform spread onto the grate.

Refuse fuel size consist must readily flow through the equipment into the furnace and approach uniform distribution within the furnace both laterally and longitudinally. The coarser material will land on the bed where combustion will be completed. For most installations, refuse fuels sized to pass 4" square screening can be accommodated. Removal of the fines, usually laden with inerts, would be desireable for the reasons previously cited. Densified RDF, in the form of pellets, would be especially tractable and could probably be blended with coal and fed into the furnace with the conventional mechanical

FIGURE 8
THIN BURNING (SEMISUSPENSION) SPREADER STOKER
WITH REFUSE COFIRING



feeder distributors used for coal. However, since these mechanical feeders are volumetric mechanisms, the ratio of densified RDF-to-coal in the fuel blend may limit fuel feeding capacity in relation to steam demand.

The granular like densified-RDF pellets could be fired separately from the coal by the mechanical distributor assemblies if the spreader feed hoppers were segmented laterally with a division plate. These approaches introduce the fuel as close to the grate as practical and, thereby, provide maximum flame travel for gas and particulate burnout.

Spreader stoker systems are available for a wide range of boiler types and capacities, such as at Great Lakes Naval Training Station and Little Creek Amphibious Base. Systems have been supplied for generating as little as 10,000 pounds of steam per hour utilizing stationary or intermittent dumping grates. Large systems have been applied for power cogeneration facilities greater than 400,000 pounds of steam per hour utilizing twin sets of traveling grates.

Illustrations of various stoker configurations and industrial boiler applications are given in Exhibit A. Detailed descriptions of stoker mechanisms, operation, fuel selection, and burning characteristics are described in the literature. This report covers only the waste fuel firing aspects relating to each stoker type and its application.

Control of stack emission should first be exercised at the source. If particulate entrainment is minimized at the source, the burden on the air pollution control device and appurtenances, gas enclosures, and heat transfer surfaces, are reduced. Therefore, an ideal system would afford complete combustion of the fuel and avoid entrainment of solids in the rising gas stream, having all of the residue discharged at the bottom of the furnace. Although all present stoker firing systems have substantially less particulate than do full - suspension firing systems (e.g. pulverized coal), the "ideal circumstance" of no entrainment can only be approached.

The uniformity of fuel quality and fuel size consist, the method by which the fuel is introduced, the ability to control uniformity of fuel and combustion air distribution in the furnace, the fuel bed depth on the grate, the fuel burning rate (grate heat release rate), volumetric furnace energy release rate, furnace gas velocity, furnace turbulence, and excess air required to assure complete combustion all have a bearing on the quantity and nature of the particles entrained in the rising gases.

2.2.1.1 Stoker Application Overview

Although a refined refuse derived fuel may be available in densified form, when compared to coal, it is still significantly lower in calorific value and specific density. Therefore, three to four times the volume of even densified - RDF may have to be fired to produce the energy equivalent of coal. The principle considerations, which should be addressed for utilization in existing or new installations, are:

- adequacy of grate area for the volume of the fuel which can be handled and still provide good burnout.
- adequacy of the fuel feed mechanisms which are usually volumetric, not gravimetric.
- adequacy of fuel handling, storage and retrieval systems.
- provisions required for consistent homogeneous blending of the fuels

Relative fuel quantity determinations become more apparent when comparisons are made on the basis of "equivalent" million Btu. This analysis should also factor in the anticipated "relative fuel utilization efficiency". A major influence will probably be the difference in total moisture in the fuels to be fired.

Although probable ratios of salvage fuel to fossil fuel may be projected by reviewing the various factors and constraints, the practical operating ratio will finally be determined by actual burning trials, the usual procedure used in the final analysis in determining the suitability and performance of a new coal supply. Nevertheless, analyses and projections are necessary so that system requirements for fuel handling and controls can be anticipated and provided.

2.2.2 Full - Suspension Fired Boilers

A firing system where solid fuels are fired, in a manner similar to that for gas and oil, without a fuel supporting - burning surface (grate or hearth) is referred to as full - suspension firing. This concept became available with the development of coal pulverizers capable of consistently producing coal powdered to a fineness to pass 50 mesh screening with at least 65 percent passing a 200-mesh (0.0029") screen.

By resorting to pulverized coal firing, it became possible to design and construct steam generators far larger in capacity than previously practical with grate-fired systems. Pulverized coal (PC) fired systems could operate with much lower excess air, higher combustion air temperatures, and significantly less carbon loss in the residues. Therefore, these systems were 3 to 6 percent more efficient than other methods of coal firing.

With suitably designed furnace-boiler systems, pulverized firing can accommodate the widest variance in coal quality, and is insensitive to the delivered coal size consist.

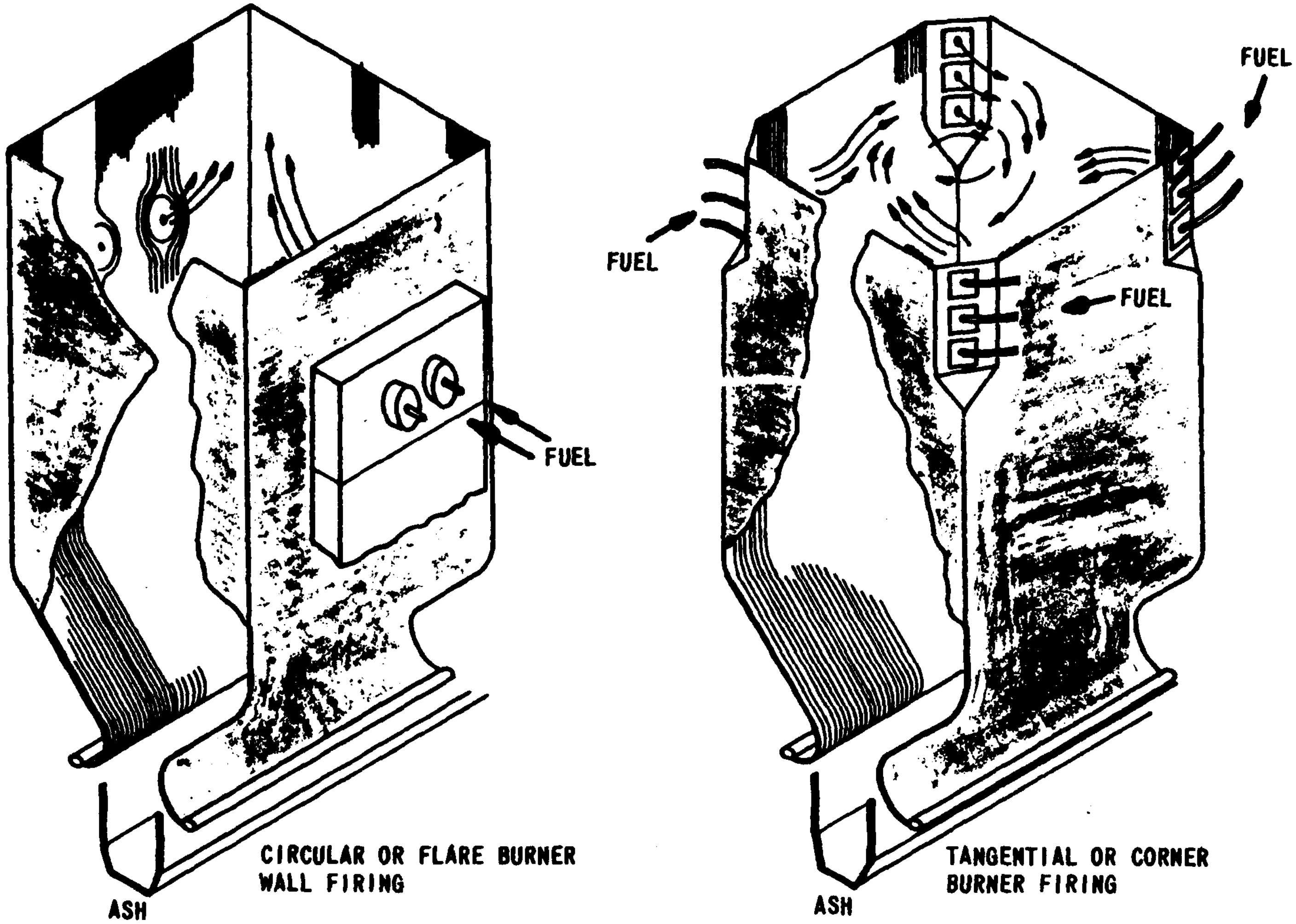
Run-of-mine coal can be accommodated, since most PC fired plants are equipped with a crusher to control the top size entering the coal handling-storage system from which the metering feeder to the pulverizer is supplied. Combustion air drawn from the air heater to the pulverizer dries the coal, expedites grinding, and is exhausted as primary air entrained with powdered coal to the burners on the furnace. A schematic of a full suspension firing boiler is shown in Figure 9.

PC firing, lacking the energy reservoir and heat release inertia available with grate fired systems, is sensitive to flame stability especially at partial load firing rates and wide load swings. Since the fuel is in powdered form, most of the ash is entrained and carried with the combustion gases through the system. Approximately 15 percent of the ash is deposited in the furnace. The actual quantity is a function of the agglomerating potential of the fine particles and the slag accumulations which are periodically shed from the furnace walls into the furnace ash hopper.

With the increased sensitivity to particulate stack emissions, the application of electrostatic precipitators (ESP) is required. The current regulatory trends will soon require precipitators or bag houses on most semisuspension (spreader) coal fired systems. This will narrow the previous competitive cost advantage of stoker fired systems in capacities of 100,000 to 300,000 pounds of steam per hour.

One general classification of pulverized coal firing is by type and arrangement of burners. Circular (flare) burners fire horizontally through the furnace walls (or in opposing walls). Tangential or corner fired burners can be applied in essentially square furnace cross sections. All other burner types and configurations are variations of these two.

Burner selection and application are influenced by many considerations including:



CIRCULAR OR FLARE BURNER WALL FIRING

TANGENTIAL OR CORNER BURNER FIRING

FIGURE 9
FULL SUSPENSION FIRING

- o Thermochemical character of the fuels and associated ash
- o Rate of fuel consumption
- o Fineness of pulverization
- o Steam load characteristics
  - base load versus swinging load
  - peaking and duration
  - extent of low load operation
- o Size, shape and volume of the furnace
- o Heat liberation rate
- o Flame travel
- o Furnace wall construction
- o Provisions for other forms of fuel and their character i.e. - gas, distillate/residual fuel oils, spent lubricants, liquid hydrocarbons and solvents, and lean or spent process gases, etc.

Multifuel burner configurations are generally available to fire conventional fossil fuels separately or in combination. Illustrations showing the multifuel burner configuration and typical full - suspension firing installations are presented in Exhibit B.

Special burner systems, (similarly configured) are available to accommodate finely sized cellulosic fuels such as wood flour, sander dust, fine sawdust and shavings. Direct cofiring of fine-sized solid waste fuels has been confined to those which are very low in free moisture and ash.

All of the reported installations burning shredded RDF in full suspension have been corner fired installations. There are two boiler units equipped with special horizontal cylindrical vortex burner systems which have been burning powdered RDF sporadically. Many test burns may have been conducted but will not be reported or publicized until the systems are in routine operation.

There have been several extensive test programs undertaken wherein pelletized RDF was fed in combination with coal into a pulverizer and subsequently consumed. However, because of a lack of supply and other commercial considerations, there is no on-going program underway as yet.

Before the "low cost oil era" of 1950-1970, there were many modest size PC fired installations, as small as 30,000 pounds of steam per hour. Typical industrial class PC fired boiler installations are illustrated in Exhibit F. Full - suspension firing boilers can be designed for gas, distillate, or residual oils, flash-dried waste water treatment sludge, shredded/classified plant waste, liquid hydrocarbon wastes, and pulverized coal, as illustrated in Exhibit B-7. The bottom of the furnace is equipped with power-dumping grates to permit burning to completion of any coarse combustibles not consumed in the upper furnace. The ash residues from the furnace, air heater hoppers, and precipitator hoppers are vacuum conveyed to an ash silo for off-site disposal. An electrostatic precipitator will insure conformance with environmental regulations.

2.2.3 Oil Fired Boilers

Combustion tests on boiler type burners were conducted on the pyrolytic oil (Pyroil) by Combustion Engineering[15] and KVB Equipment Corporation[16]. These tests used oil produced in Occidental's 4 ton per day pilot plant and may not be representative of a large scale commercial unit. The 200 ton per day demonstration plant at El Cajon, CA has run into difficulties and has not been able to furnish oil for large scale combustion tests[17].

The Combustion Engineering (C-E) burning test program consisted of two phases: Phase I involved bench-scale analyses of Pyroil to establish handling properties and burning characteristics as determined by conventional ASTM measurements. Phase II involved pilot-scale (~ 10 gal/hr) burning tests in a C-E test furnace. The burning tests permitted a qualitative evaluation of handling properties and combustion characteristics under actual working conditions. Conclusions from the Combustion Engineering test were:

- Pilot-scale laboratory tests indicated that Pyroil or blends of Pyroil with No. 6 fuel oil can be successfully burned in a utility boiler with a properly designed fuels handling and atomization system.
- More stringent requirements are necessary to obviate plugging when handling Pyroil or blends of Pyroil with No. 6 fuel oil compared with a No. 6 fuel oil only, because of:
  - Pyroil's higher initial viscosity.
  - Pyroil's propensity for undergoing changes which adversely affect viscosity given sufficient time and temperature.
- Pyroil was found to be compatible with three No. 6 oils representing two geographic sources. However, it is not necessarily compatible with all No. 6 fuel oils. Since no criteria exist for determining the compatibility of various No. 6 fuel oils with Pyroil, it is imperative that this compatibility be determined for each No. 6 oil in question.
- Ignition stability of properly atomized Pyroil or blends of Pyroil with No. 6 fuel oil was equal to that obtained on No. 6 fuel oil alone.
- The complete fuels handling system must be purged with No. 6 fuel oil immediately before shutdown when burning Pyroil or blends of Pyroil with No. 6 fuel oil to avoid plugging of lines and/or spray tips.
- Stack emissions indicated negligible amounts of unburned carbon when burning Pyroil or blends of Pyroil and No. 6 oil at excess oxygen levels over two percent.

- Sulfur dioxide in the flue gas (corrected to three percent excess oxygen) when burning 100 percent Pyroil was in the 250-300 ppm range, close to that expected for a 0.3 percent sulfur fuel.

- Nitrogen oxide in the flue gas (corrected to three percent excess oxygen) when burning 100 percent Pyroil was on the order of 400 ppm, somewhat less than the calculated value for a 1.3 percent nitrogen fuel, assuming no thermal NO_x.

- The test program was not set up to evaluate any corrosion potential associated with the handling and burning of Pyroil.

The Combustion Engineering tests were carried out using a pyrolytic oil derived from municipal refuse. The more recent tests by KVB were made on pyrolytic oil derived from Douglas fir bark and rice hulls. The conclusions of the KVB tests were:

- The pyrolytic oils gave stable, smoke-free combustion over a wide range of firing conditions. These pilot-scale tests indicate that pyrolytic oil can be burned in a large boiler with a properly designed fuel handling system, if the time which the fuel spends at elevated temperature is minimized.

- The pyrolytic oils appeared to be compatible with three residual oils representing different geographical sources. However, the residual oils did not completely purge the fuel system of pyrolytic oils.

- The most likely initial problems encountered by pyrolytic oil users would be in quality control, storage, pumping, and atomizer blockage. Users should run thorough pumping and atomizing tests before attempting to fire the oils. Fuel specifications should restrict suspended solids, gum formation, heating value changes, viscosity changes, and other variations which are possible in any fuel oil or which may, in some cases, be peculiar to pyrolytic oils.

- When firing barkoil, the Federal NO_x limitations on new units can be met with very little margin by using staged combustion.

- The pyrolytic oils tested had such a low sulfur content that no problems due to sulfur oxide corrosion or sulfur oxide emissions are anticipated from this oil.

- o Stack gas cleanup would be required to meet EPA particulate regulations on the oils tested. However, the particulates emissions could possibly be reduced by improved filtration of the fuels in the production process.

The successful combustion of pyrolytic oil blended with No. 6 fuel oil was unexpected, since the two are immiscible. The blend is a dispersion. Firing such a blend in a utility boiler has two important advantages. Blends have a greatly diminished corrosive effect beyond any dilution factor on mild steel compared to pyrolytic oil alone, and pyrolytic oil can serve to "blend down" the otherwise unacceptable sulfur content of No. 6 oil.

2.2.4 Gas Fired Boilers

Studies on converting existing boilers and newly designed units to burn medium-Btu gas[18,19] tend to confirm that there is relatively minor impact to existing boiler designs and performance. However, for low-Btu gas, the increased fuel volume results in an increased flue gas quantity which becomes excessive for fuel gas below 250 - 300 Btu/scf.

Although the air-to-fuel ratio is much less for refuse gas than for natural gas, the much greater fuel volume results in an increase in the amount of flue gas. This problem is accentuated by the expected requirement of high excess air when burning low-Btu gas in a package boiler designed for natural gas firing. The boiler would have to be derated when retrofit with a refuse gas having a heating value much less than 300 Btu/scf. In addition, several changes would occur in the heat transfer pattern within the boiler. The significantly higher mass flow would result in a higher superheat temperature, even with the same furnace exit temperature. The lower flame temperature of refuse gas compared to natural gas would decrease radiant heat transfer in the front of the boiler. However, this will be offset by the greater flame luminosity resulting from the sum total of higher CO_2 and H_2O content of the flue gas, plus the presence of trace amounts of higher hydrocarbons. The higher dry gas heat loss of the refuse gas will be more than compensated for by the much lower latent heat loss as a result of less water in the flue gas.

In addition to the combustion aspects of retrofitting an existing boiler to fire refuse derived gas, the following items must be considered:

- o Fuel gas piping (ducts) and valves significantly increase in size as the calorific value of the fuel decreases.
- o Burners may have to be enlarged or replaced, or additional burners added. This may not always be possible or practical.
- o It may be desireable, or even necessary, to operate with balanced draft using an induced draft fan rather than a forced draft fan and a pressurized furnace. Since the refuse gas contains a large quantity of carbon monoxide, it is toxic. Prudent design may require suction operation of the boiler system.
- o System modifications and/or additions will probably be required to the ignition, flame safeguard, and combustion control.

Other conclusions regarding low- and medium-Btu gas utilization in existing units include[5]:

- o Units designed for coal firing can accommodate a fuel gas with a lower heating value than can units designed for natural gas firing.
- o Some coal fired units may be suitable for a fuel gas having a heating value as low as 130 Btu/scf, although, there would be less difficulty if the fuel gas had a heating value of at least 200 Btu/scf.
- o Natural-gas fired units can burn a fuel gas of 300 Btu/scf or higher with only minor changes to the units.

- It may be very expensive and perhaps impracticable to alter existing natural-gas fired units to handle a fuel gas with heating values much below 300 Btu/scf.

- Unit efficiency will decrease slightly because of increasing heat loss to the stack when fuel gas is burned with a heating value much less than 300 Btu/scf.

SECTION 3.0
CASE STUDY

The overall objective of the Case Study was to evaluate the feasibility and potential problems associated with converting a "typical" Navy facility to utilize waste fuels.

The typical facility was based on an operating Navy installation, although the evaluation was not strictly site-specific. While there is no such thing as a typical facility, an evaluation of the problems and complexities involved in converting an operating boiler plant should give greater insight into the difficulties that will be encountered in adapting Navy installations to waste fuel firing.

The waste fuels considered include representative solid, liquid, and gaseous fuels derived from typical municipal and Navy waste.

- Solid RDF Case - The evaluation of the solid RDF case consists of a conceptual design study which identifies the major conversion parameters needed to determine a first-cut conversion cost estimate.

The major conversion parameters referred to include the following:

- Characterization of the solid RDF feed.
- Determination of relative steam capacity to be generated from waste.
- Selection of waste handling, storage, and feed system.
- Determination of waste fuel firing system and furnace ash removal system.
- Selection of fly ash particulate removal system.

A preliminary equipment selection was made to establish a basis for estimating equipment and installation costs. Potential problem areas, uncertainties, and risks associated with this conversion are described.

- o Liquid and Gaseous RDF Cases - The evaluation of the liquid and gaseous RDF cases will be limited to a qualitative discussion of converting this typical installation to utilize these respective waste fuels. This discussion will cover the various aspects involved in selecting a representative waste fuel specification, the extent to which this waste fuel can be utilized, and the potential problems expected.

3.1 CONVERSION TO SOLID RDF

The Naval installation selected as typical for the conceptual waste fuel conversion study has three major boilers in its central steam generating facility. Two identical boilers were installed in the 1950s and have a steam production capacity of 125,000 pounds per hour. These boilers are designed to operate on natural gas, distillate oil or residual oil. A third boiler was installed in 1970 and is rated at 200,000 pounds of steam per hour. This boiler also fires natural gas, distillate oil or residual oil.

All three boilers operate at 610 psig with superheat to provide steam for turbine generators. The turbine extraction steam is used for heating, absorption air conditioning, and process. The two duplicate boilers were designed with generous tube spacings and are suitable for firing significant quantities of solid RDF with their normal fossil fuels.

The design basis for the conceptual study is:

- o Both duplicate boilers will be converted to utilize solid RDF.
- o The solid RDF will be fed to the boilers from a single receiving station.
- o The characterization and quantity of solid RDF fired is selected to avoid derating the boiler output. The boilers will operate at current conditions (610 psig, 650°F) when firing RDF.
- o The particulate removal system is to permit operation in conformance with environmental regulations.
- o The boiler retrofit design will assume that both boilers will fire heavy fuel oil as their primary fuel. The heavy fuel oil will have the following characteristics:
  - Higher heating value = 18,300 Btu/lb.
  - Ash content = 0.2 Wt. %
  - Sulfur content = 0.7 Wt. %
- o The lowest cost equipment alternative will be selected consistent with providing reliable and efficient plant operation.
- o Prepared solid RDF will be delivered to the boiler plant site by means of enclosed horizontal self-unloading trucks.

Solid RDF prepared from a combination of general industrial plant waste and municipal refuse with the following characteristics will be delivered to the boiler plant receiving station.

- o Higher heating value = 6,800 Btu/lb.
- o Bulk density (to boiler) = 5 pcf (approximately)
- o Moisture content = 12 Wt. %

- o Ash content = 10 Wt. %
- o VM content = 65 Wt. %
- o FC content = 13 Wt. %
- o Sulfur content = 0.2 Wt. %
- o Ash softening temp. = 2,100°F (reducing atmos.)

The "as received" solid RDF should be relatively free of metals and glass and should be of a uniform (95% passing 2 inch screen) size consist. The waste should not contain any detectable putrescible materials.

A shredded form of solid RDF was chosen for the Case Study over an extended or briquetted form because the shredded material is easier and less expensive to prepare and is more readily available. However, an extruded or briquetted RDF will in general be easier to handle and store and will be less expensive to retrofit to a furnace system designed to the fire stoker coal.

Determination of Solid RDF Firing Capacity - The two boilers being considered for modification to accommodate supplemental solid RDF firing were originally designed conservatively with respect to recent practice for natural gas and distillate oil firing. The generous furnace volume and draft system should easily accommodate up to 20 percent prepared solid RDF firing in combination with heavy fuel oil, with no loss in steam output capability and a projected boiler efficiency of 82 percent. The increase in combustion gas moisture content and particulate loadings when firing solid waste fuels may require some adjustment in superheat control procedures. This will be discussed in more detail in Section 3.1.4.

The original steam generator system design also provided the space and additional fan capacity for the future installation of a mechanical dust collector. Conceivably, future coal firing was a consideration. The particulate loadings that will be experienced when firing the solid RDF will require the installation of a collector to satisfy environmental regulations. This will be covered in detail in Section 3.1.2.

3.1.1 System Description

The solid RDF utilization system selected is shown schematically in Drawing C-040-005. The prepared solid waste fuel will be delivered by truck and dropped into a live-bottom receiving bin. A pneumatic feed system will convey this material to two 10-ton metering surge bins. The RDF will feed by gravity into each boiler at a relatively constant rate of 4,870 pounds per hour. The primary boiler fuel is residual fuel oil. At the full load condition of 125,000 pounds of steam per hour per boiler, the residual fuel oil feed rate is 7,280 pounds per hour per boiler.

The RDF firing will produce approximately 340 pounds per hour of bottom ash which will be collected in the ash hoppers located under the dumping grate. Fly ash will be collected at three locations. The first collection location is in the boiler bank hopper; the fly ash collected here is rich in carbon and will be reinjected into the furnace. The remaining fly ash will be collected in the air heater hopper and the air pollution control device hoppers. The estimated quantity of fly ash collected at these locations is 145 pounds per hour per boiler; this material will be disposed of with the bottom ash.

Drawing C-040-001 shows the site plan for this facility. The RDF storage bins will be located above the existing two boilers. The RDF receiving/feeding station will be installed to the west (left) of the existing fuel oil storage tanks. A pneumatic piping system will feed the solid RDF as received to the two storage bins. The prepared RDF will be brought in by truck using existing roads. A new road and unloading ramp will be constructed to lead the trucks to the receiving station.

3.1.1.1 Solid RDF Handling System - Drawing D-040-002 shows a side elevation of the conceptual arrangement. The solid RDF is self-unloaded from the truck at the far right into an enclosed receiving station. Horizontal self-unloading trucks are to be utilized to limit receiving building height (1). (Numbers in parenthesis refer to numbers on figures.) Tipping dump trucks require considerable roof clearance when unloading and this unnecessarily increases the cost of the enclosure.

The prepared waste material is discharged into the live-bottom bin (2). This receiving bin is a steel rectangular structure specifically designed to hold and discharge nongranular, poor flowing materials. The RDF is removed from the bottom of the bin with twin, counterrotating unloading augers (3) which are track mounted to traverse the entire length of the bin. This system insures that material will be withdrawn from the entire bottom cross section of the bin. Consequently, the entire bin is active; there are no areas of dead storage.

The RDF discharged from the receiving bin is deposited onto a belt conveyor (4) and then into a rotary sealing valve (5). The rotary seal valve transfers the RDF into the pneumatic system with a minimum loss of conveying air pressure.

A positive displacement transport air blower (6) provides air at approximately three psi to the pneumatic feeder (5). The aspirator entrains the RDF into the air stream within the piping system (8). A six inch diameter piping system conveys the material to the surge storage bins (10). The RDF stream can be directed to either of the storage bins by means of a remote controlled diverter gate (9). This is shown in the conceptual arrangement plan view Drawing D-040-003. The pneumatic conveying system will use long sweep rectangular shaped elbows at all turning sections. All conveying piping elbows are arranged with removable wear plates that can be readily replaced. These wear plates can be fabricated of specially hardened steel to maximize wear life. Access doors are provided to allow for routine inspection of the wear plates.

The solid RDF storage system consists of two special metering surge bins. Each bin has a 4 00 cubic foot effective storage capacity (10 tons RDF) which represents about four hours supply of fuel feed at full design capacity. One bin will be located above each boiler. The RDF will be blown directly into the bin. The conveying duct will enter the bin near the top and the conveying air will be vented from the bin roof through two continuous filter units provided with automatic reverse jet compressed air cleaning.

The live-center bins will contain multiple vertical screws along the bin center and a pair of horizontal augers at the discharge. The augers deliver RDF at a controlled rate to the feed chute at each side of the furnace. Both the horizontal and vertical screws are driven by an electric motor from the base of the unit.

The lower section of the surge bin is tapered at the bottom. The fibrous RDF will tend to compact there. However, the vertical screws counteract this compacting and loosen the RDF above the horizontal augers permitting ready withdrawal from the bin. The vertical screws also permit single point bin loading with the screws tending to distribute the incoming material uniformly throughout the bin. The horizontal bin unloading augers (11) are arranged to simultaneously discharge RDF in opposite directions, i.e., toward each furnace sidewall depositing into gravity supply chutes (12) to the furnace pneumatic fuel distributors located beneath the present furnace side waterwall headers. The bin unloading augers are equipped with variable speed drives. However, once the optimum feed rate and air-to-fuel ratio are established, they will be held constant with variations in fossil fuel to satisfy steam demand. This is accomplished automatically with the fossil fuel burners.

3.1.1.2 Boiler Retrofit Description - The twin boilers that provide the basis for this RDF retrofit study are illustrated in Figure 10. These two field-erected units are each capable of producing 125,000 pounds of steam per hour when firing natural gas, distillate oil or residual oil. The design steam operating conditions are 610 psig and 650°F which provides approximately 160°F of superheat. These boilers were originally installed in the early 1950s. Each unit is a complete system equipped with an economizer, tubular air heater, induced draft fan and exhaust stack.

These boilers are generously designed for gas and oil firing by present day standards. The furnace volume and boiler tube spacing should readily accommodate the greater combustion gas volume associated with solid RDF firing of up to 20 percent of the total Btu input.

The boilers are presently provided with soot blowers in the superheater, boiler bank and air heater sections, and there are also provisions for installation of additional blowers if and when required. Allowance was made in the original design and erection for the addition of a high efficiency mechanical dust collector. This "typical" Navy installation is located in the southern part of the United States, and the boiler plant is a semi-outdoor installation with only the firing

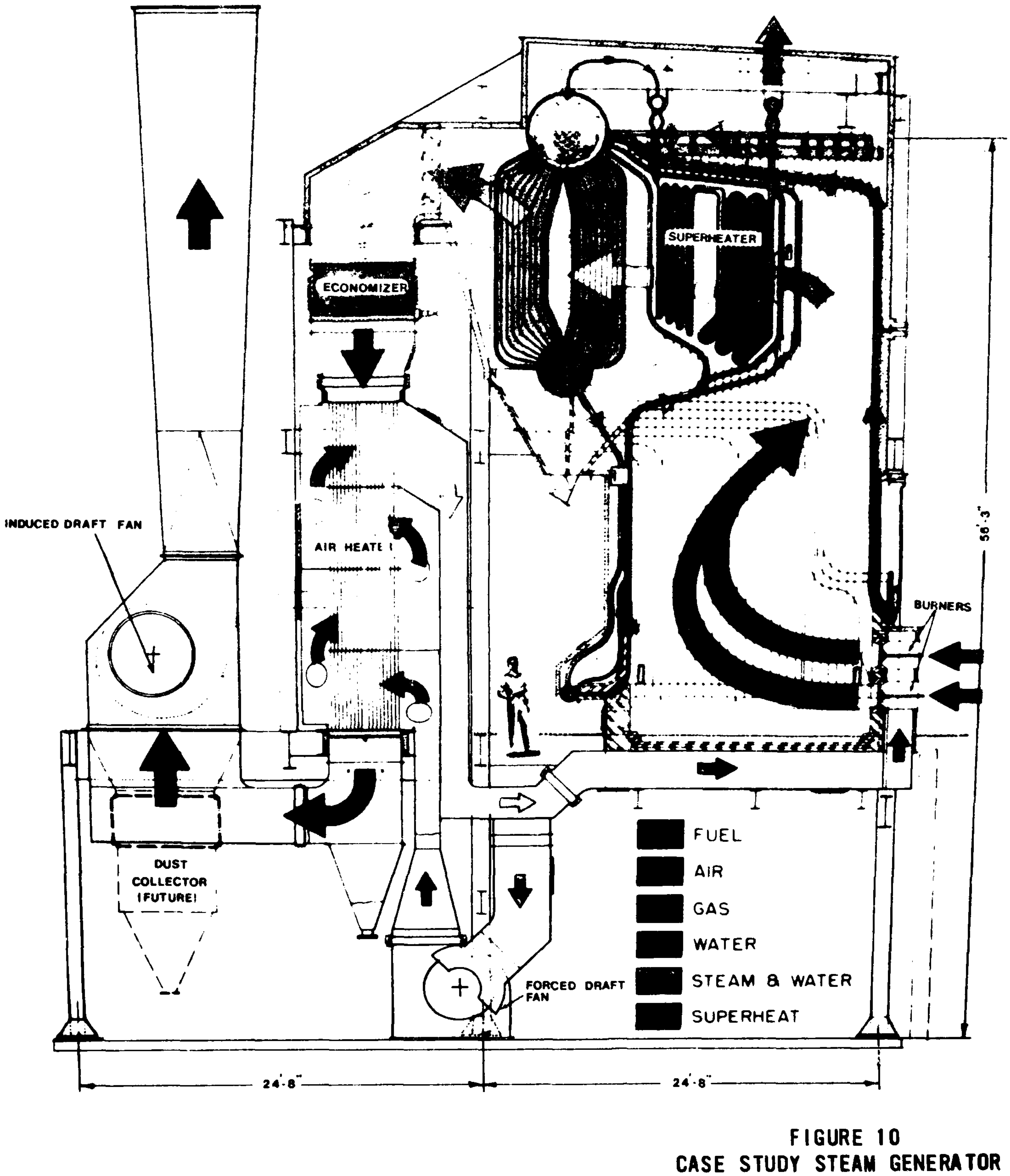


FIGURE 10
CASE STUDY STEAM GENERATOR
EXISTING ARRANGEMENT
125,000 POUNDS STEAM PER HOUR
610 PSIG, 650°F TT

aisle enclosed. The absence of a complete enclosure simplifies the installation of the RDF surge bins above the boilers and the RDF feed chutes to the furnace.

Drawing C-040-004 illustrates the proposed adaptations superimposed on the original side elevation of the steam generating unit. The items shown in heavy outline represent either new equipment additions or items requiring major modifications. No changes are anticipated to the boiler pressure parts. The modifications and additions to the system are divided into the RDF feed system, the combustion system and the ash removal system.

- RDF Feed System - As mentioned previously, the RDF will be gravity fed from the controlled discharge surge bin (A) located above each boiler. The feed chutes (B) on each side of the boiler, will direct the RDF to the pneumatic distributors (C). These air swept pneumatic distributors require a rectangular opening in each lower refractory furnace side wall of approximately one foot by two feet. The RDF fuel is dispersed and blown into the furnace chamber onto the grate by high pressure air from air blower (K). This air blower also supplies the overfire turbulence jets and fly-carbon reinjection jets (E).

  A motorized rotating damper located in the air inlet to the RDF distributor continuously varies air pressure and quantity to create a pulsating flow of solid RDF which provides an even distribution of fuel across the furnace.

- Waste Combustion System - The RDF is fed into the furnace at a constant feed rate. Irregularities in the heating value of the RDF and changes in steam demand are accommodated by varying the oil fuel flow. No changes appear necessary in the oil firing automatic combustion control system.

  The RDF feeders will be located below the oil firing burner level. Therefore, the RDF combustion gases must pass through the oil flame prior to entering the water-cooled furnace.

  The solid RDF will enter the boiler furnace in a thin, widely dispersed stream. Some of this material will burn in suspension, and the coarser slower burning fractions will be consumed on the grate.

Overfire air jets using high pressure air will be provided in the furnace wall below the RDF distributor spouts to enhance the suspension burning of the solid waste fuel. This same high pressure air blower will provide air for reinjecting the high carbon fly ash collected in the boiler bank soot hoppers (F). This material will be reinjected into the furnace close to the grate surface.

A power operated dumping grate (D) in three longitudinal sections is used to burn the solid waste fuel that is not consumed in suspension. This coarser RDF material should form a fairly uniform layer on the grate and with the accumulating ash shield it from the radiant flame above. The undergrate air (H) supplied through the forced draft fan system provides the primary air for fuel combustion.

Although this primary air is at 350°F as it is introduced into the undergrate plenum, it does cool the grate elements and accumulating ash bed as it passes through to the combustion zone above.

- Ash Removal System - The grate is divided into three longitudinal sections. The purpo e of the separate sections is to minimize disturbance of the f rnace environment during the ash dumping periods. The boiler operator will periodically observe the ash accumulating on the grates using the observation (fire) door installed in the front of the furnace. When the depth of ash exceeds a given level, the operator will dump each grate section in sequence. This consists of closing off the undergrate air supply (H) to the section being cleaned. The dumping mechanism is activated and the ash discharged by gravity into the bottom ash hopper (G). The grate is then returned to its normal position, and the air supply is reestablished. The other grate sections are cleaned in sequence in the same manner.

  Approximately five to ten minutes may be required for the entire grate cleaning operation. Depending on the quantity and nature of the RDF ash, grate cleaning may be required once or twice each shift. In view of the quantity of RDF to be fired and the small quantity of associated residue, the power-dumping grate system for intermittant cleaning into a large undergrate ash hopper below was considered entirely adequate. The same rationale applied to the selection of dumpster containers in lieu of vacuum pneumatic handling system and residue storage silo.

  At regular intervals, the ashes in the bottom ash hoppers (G) are deposited in the dumpster containers (M). A power operated ash gate (L) seals the hopper during normal operation.

3.1.1.3 Particulate Removal System - The steam generating plant considered in this Case Study presently burns natural gas or fuel oil. No particulate removal equipment is currently required to meet emission standards with these fuels.

The solid RDF feedstock selected for this Case Study contains 10 percent ash. Thirty percent of this ash will be entrained in the combustion gas. The remaining ash will accumulate on the grate and be dumped into the bottom ash hopper for disposal. The entrained fly ash from RDF and fuel oil firing will exceed stack emission criteria, thus requiring the installation of a particulate removal device.

Firing 20 percent solid RDF will increase the particulate loadings at full load to nearly ten times greater than with gas/oil firing alone. The combination of fly ash from RDF and fuel oil could result in a particulate level in the flue gas of almost 1.0 pound per million Btu of fuel input. Since the Case Study boiler capacities are below the Federal EPA Btu input limits (250 million Btu per hour), the state regulations will apply. The most stringent state codes identified for boilers of this capacity require a maximum particulate emission level of less than 0.15 pounds per million Btu per hour input. To meet this level, a particulate collector efficiency of at least 85 percent is required.

The original design provided for the possible future installation of a mechanical dust collector. There are available mechanical collectors suitable for this retrofit application which claim to have efficiencies greater than 93 percent. These mechanical particulate collectors are 6 inch diameter multitube cyclone units in a common housing requiring a pressure loss of three inches of water. This additional suction can be accomodated by the present induced draft fan.

Operation of this device at half load will drop the dust removal efficiency to approximately 89 percent which will still meet the most demanding environmental regulations. In addition, at partial loads the gas velocity and therefore particulate entrainment is lower and consequently the dust loading to the air pollution control device will be lower.

3.1.1.4 Draft System Modifications - Burning solid RDF requires more excess air than firing natural gas or fuel oil. The relatively small amount of RDF consumed compared to fuel oil, however, does not increase the air requirements significantly. The present forced and induced draft fans should be adequate.

A small quantity of additional air required will be made up by the new high pressure overfire air blower. This blower is required to provide high pressure air (20 to 25 inches of water) for the fly-carbon reinjection nozzles, grate overfire turbulence jets, and air for the distribution of solid RDF across the furnace.

The air duct supply system (beneath the existing furnace floor - Figure 10) to the front wall burners would be modified similar to that shown on Drawing C-040-004. This would permit separate air supply to each grate section at the upper rear of each plenum - ash hopper. A new air supply duct will be required (located along side of the ash hopper) to the burner plenum.

3.1.1.5 Operating Concept - The two identical boilers will be modified to fire prepared solid RDF with fuel oil. The maximum RDF firing rate is approximately one-fifth of the heat input at their rated steam capacity of 125,000 pounds per hour. This corresponds to an RDF firing rate of slightly less than 5,000 pounds per hour per boiler. The RDF will be fed at a constant rate with fluctuations in steam load being made up by automatically varying the fuel oil firing rate. When no RDF is available, the entire steam load will be carried by firing 100 percent fuel oil or natural gas. When this situation is anticipated for short periods of time, the ash layer on the grate will be allowed to build up to insulate the grate from the radiant flame. For long periods of time a 6 inch layer of crushed fire brick should be spread on the grate.

The two combination fuel-fired steam generators will have a potential solid RDF firing capability of almost 120 tons per day. The maximum assumed steam load turn-down is 50 percent for a single boiler while maintaining stable controlled combustion. Therefore, the total system turndown ratio is 4 to 1.

The RDF will be delivered by horizontal self-unloading trailer type trucks. A full truck load is approximately 20 tons. A consumption rate of 120 tons of RDF per day is equivalent to six deliveries per day or one trailer truckload every four hours. The primary RDF storage is provided in the two 10-ton surge bins.

The positive pressure pneumatic bin feed system is sized to handle 40 tons per hour, and, therefore, approximately one half-hour will be required to transfer the unloaded RDF material into the surge storage bin above each boiler. The truck can be unloaded in about 20 minutes, since the receiving bin has 6 tons of storage capacity. The surge bins are provided with level indicators which will enable the operator to control fill rate and storage level. During unloading the operator will alternately fill each surge bin by actuating a remote controlled diverter valve to control into which bin the material is to be fed.

The RDF material will be fed from the surge bins at a constant rate to the furnace supply chutes located at each side of the boiler setting. The RDF furnace distributors are arranged in a staggered mode so that the fuel trajectories will not interfere with each other and affect uniformity of fuel distribution across the grate.

Control of the ash level on the dump grate will be performed by the operator. He will observe the ash level and periodically actuate the dumping grates. The bottom ash from beneath the stoker grates will be discharged periodically (once or twice per shift) into dumpster containers for off-site disposal. The fly ash from the air heater hoppers and dust collector hoppers will discharge through monitored rotary sealing valves into dumpster containers for off-site disposal.

3.1.2 Environmental Considerations

3.1.2.1 Air Pollution - The boiler size under consideration is less than the 250 million Btu per hour input (actual 160 million Btu per hour) which would require compliance with Federal New Source Performance Standards. Therefore, individual state and local regulations would apply.

- Particulates:- For the case study unit, the combustion of supplementary RDF will probably increase the particulate loading and will necessitate enlarging or replacing the existing control device. If a new control device is required, a conventional high efficiency multi-cyclone collector should be sufficient to meet the regulations.

  The particulate emission limit for new facilities larger than 250 million Btu/hr input is 0.10 pounds/million Btu. Most states have emission criteria less stringent than this for existing units of lessor capacity and base their regulations on the aggregate heat content of all fuels burned. For the Case Study (160 million Btu/hr input), the particulate emission criteria of the states surveyed fell within the range of 0.15 to 0.60 pounds/million Btu.

  The expected loading for the Case Study is 0.98 pounds per million Btu (with 20 percent RDF) and an 85 percent efficient collector will bring it within the most stringent state regulation (0.15 pounds per million Btu).

  For facilities with lower heat input, the standards are not as demanding. For 50 percent load or 80 million Btu per hour input, the several states investigated have standards ranging from about 0.15 to 0.60 pounds per million Btu, with most above the 0.20 pounds per million Btu level. Generally, the lower the Btu per hour input, the higher the allowable pounds per million Btu of particulates emissions. Using 80 million Btu per hour input and RDF as 40 percent of that total (32 million Btu), the expected emission loading would be about 1.875 pounds per million Btu. An efficiency of about 92 percent would be required to meet the most stringent standard of 0.15 pounds per million Btu, and a efficiency of about 85 percent to meet the standards as adopted by most states for this size facility (above 0.25 pounds per million Btu). In a location with less stringent standards for existing plants of this size, an efficiency of less than 85 percent would be adequate.

The collector considered for the Case Study is a multicyclone having 6 inch diameter tubes and a pressure drop of 3 inches of water. The mechanical collector has an efficiency of 93 to 94 percent at design capacity. Therefore, some performance reserve is available to cope with upset conditions such as higher ash bearing oil or RDF.

Since standards and methods for determining required particulate emission levels vary from state to state, a high efficiency particulate removal device (scrubber, baghouse, ESP) may be required in some states resulting in an increased investment cost over that cited in the Case Study.

- Sulfur Dioxide - The fuel combination of RDF and oil in a boiler will not increase the sulfur dioxide emission to the atmosphere. With a combination of 80 percent fuel oil and 20 percent RDF, there would be no change in the sulfur emissions. Oil with a sulfur content of less than 0.8 percent would be within the state as well as Federal standards. The standards for SO_2 for existing plants less than 250 million Btu per hour ranged from 0.85 to 6.0 pounds per million Btu per hour input.

- Opacity - The opacity regulations are receiving greater emphasis and enforcement activity as a result of the 1977 amendments to the Clean Air Act. Opacity problems are caused by an increased particulate loading reducing light transmittance. The opacity requirements are 20 percent for a six minute period and up to 40 percent for a two minute period. The increased particulate loading as a result of the possibly higher ash content of the waste fuel may increase the opacity rating, but the mechanical collector and adherence to proper operating conditions will be adequate to remain within allowable limits.

3.1.2.2 Water Pollution and Solid Waste - The utilization of RDF in the boiler will add significantly to the amount of ash (as much as 340 pounds per hour) for disposal. The increased volume in itself should be no more than a bulk handling problem and can be successfully disposed of in a landfill.

3.1.2.3 Impact From Increased Particulate Loading - Should particulate levels exceed assumed concentrations and the air pollution control equipment not achieve the efficiency level necessary to meet the standards, then a collector with higher efficiency, either a filter collector or an electrostatic precipitator (ESP), will be required. However, the reserve margin in the collector considered should perform adequately with a particulate concentration approximately 20 percent higher than anticipated

If the particle size distribution were smaller than assumed, the efficiency of the control equipment would also be lowered. This would necessitate a collector with higher efficiency, again either a filter collector or electrostatic precipitator.

3.1.3 Capital Cost Estimate

The estimated capital cost to adapt the two boilers to burn 20 percent prepared solid waste fuel (RDF) is $1,736,000. The cost breakdown is given in Table 14. The direct capital cost total includes the installed cost of the receiving station, pneumatic RDF transport system, waste storage and feed bins, modifications to the boilers, and ash removal and dust collection equipment. The total project capital cost includes the above installed costs plus the costs for design engineering, start-up, construction management, and 20 percent contingency.

TABLE 14
CONCEPTUAL CAPITAL COST ESTIMATE
AUGUST 1978 COSTS

DESCRIPTION	
CIVIL/STRUCTURAL	$ 174,000
UNLOADING EQUIPMENT	93,000
PNEUMATIC CONVEYOR SYSTEM	417,000
BOILER MODIFICATIONS	258,000
DUST COLLECTORS	84,000
INSTRUMENTATION	20,000
ELECTRICAL	70,000
TOTAL DIRECT COST	$1,116,000
FIELD INDIRECT	143,0000
TOTAL CONSTRUCTION	$1,259.000
ENGINEERING	188,000
SUBTOTAL	$1,447,000
CONTINGENCY	289,000
TOTAL PROJECT CAPITAL COST	$1,736,000

TABLE 15
BASIS FOR CAPITAL COST ESTIMATE

- VENDOR BUDGETARY QUOTATIONS WERE OBTAINED FOR MAJOR EQUIPMENT ITEMS SUCH AS:
  - UNLOADING EQUIPMENT
  - PNEUMATIC CONVEYOR SYSTEM
  - GRATE AND HIGH PRESSURE OVER-FIRE AIR SYSTEM
  - DUST COLLECTORS
- OTHER MATERIAL AND EQUIPMENT PRICE ESTIMATES BASED ON GILBERT ASSOCIATES "IN-HOUSE" DATA.
- LABOR COSTS DEVELOPED USING AVERAGE RATE FOR U.S. AND INCLUDE BASE RATE PLUS FRINGE BENEFITS, PAYROLL TAXES AND INSURANCE.
- SPACE AVAILABLE, NO LAND PURCHASE.
- NO TRANSPORTATION COSTS INCLUDED
- AUGUST 1978 COSTS, NO ESCALATION INCLUDED.
- NO ALLOWANCE FOR FUNDS USED DURING CONSTRUCTION.
- SPARE PARTS NOT INCLUDED.
- FIELD INDIRECT COSTS INCLUDE:
  - TEMPORARY CONSTRUCTION FACILITIES
  - FIELD NON-MANUAL SUPERVISION
  - HOME OFFICE SUPPORT
  - FIELD OFFICE OVERHEAD
  - SMALL TOOLS & EXPENDABLE SUPPLIES
  - CONSTRUCTION EQUIPMENT
  - CONTRACTORS OVERHEAD AND PROFIT

The basis for the cost estimate is listed in Table 15. The purpose of the capital cost analysis is to try to establish a relationship between the retrofit funding requirements and the quantity of waste material consumed and the quantity of "scarce" fossil fuels saved. The estimate is based on an inspection of the representative installation and engineering sketches. Only those drawings deemed necessary to ensure the practicality of the concept and provide information essential for cost estimating were prepared. However, this estimate should establish a basic data point for evaluating the magnitude of funding requirements for retrofitting similar steam generating facilities to firing prepared solid waste as a supplementary fuel.

The direct capital costs presented in Table 14 are broken down into the major equipment areas. The civil/structural category consists of the building housing, RDF receiving bin, and associated site work, which includes the ramp for truck delivery. The unloading equipment encompasses the receiving bin, traversing unloader, mechanical conveyor, and supporting steel. The pneumatic conveyor system is made up of the rotary sealing valve, transport air blower, pneumatic feeder, pneumatic conveyor lines, diverter gate, surge bins, air filters, and supporting steel. Using mechanical conveyors in place of the pneumatic system would increase the total cost of this category slightly, from $417,000 to $428,000.

The cost of the steam generator modifications is $258,000. The items included in this category include the removal of the bottom sections and some supporting steel of both boilers, installation of dumping grates, feed chutes, fly-carbon reinjection systems, high pressure air systems, undergrate air plenums and ash hoppers, refractories, insulation, casings and ductwork, and new supporting steel.

The installation of dust collectors on both boilers will cost $84,000. This includes the dust collectors, ducting modifications, supporting steel, fly ash rotary valves and operators, and insulation and lagging. In addition to the above, $20,000 was allowed for new instrumentation and $70,000 for electrical work.

3.1.4 Potential Problem Areas

Waste-to-energy facilities in Europe and North America have operated successfully for a number of years. With proper design and operation, problems can be kept to a minimum. However, several areas will require additional attention to maintain a high boiler availability.

The control of boiler slagging, fouling and metal wastage are the most sensitive potential problem areas. Metal wastage in waste-to-energy boiler plants can arise from molten chlorides on tube surfaces and the reaction of chlorides in the dust deposits. Care in operation is the primary control in minimizing metal wastage. Many plants have found that too vigorous use of soot blowers can expose fresh metal surfaces to attack. As in all boiler units metal wastage is accelerated due to poor heat transfer resulting from internal scaling in the boiler tubes caused by poor control of boiler water quality. Adequate shredding of the raw waste, accompanied by metals and glass separation, will improve combustion and furnace control and reduce fire-gas side deposition. Control of boiler tube deposits and metal wastage when firing wastes fuels, although more difficult than with most conventional fossil fuel firing, has been demonstrated, and can be accomplished with proper design and operation.

A particulate control device will be required when burning solid wastes to meet environmental emission regulations. Firing with oil and 20 percent refuse derived fuel will require a high efficiency, mechanical, multiclone collector which should be adequate to meet emission criteria. If proportionately more RDF is used (greater than approximately 40 percent), an electrostatic precipitator or baghouse may have to be employed to control particulate discharge.

Since RDF requires increased excess air and may have different burning characteristics than the fossil fuels for which the system was originally designed, the superheat temperature control may need adjustment. Internal spray cooling is commonly used to control superheat temperature. Additionally, the air preheat temperature must be limited to about 400°F to protect the grate from heat damage. Bypass (tempering) air can be used to maintain an appropriate undergrate air temperature while utilizing full air temperature in the fly-carbon reinjection and overfire air turbulence systems.

The RDF and ash handling systems will add to the complexity of the plant. Proper design, operation, and maintenance will allow trouble-free operation. These systems will require increased operator attention, but it should ordinarily be limited to RDF unloading (approximately one truck every four hours) and ash removal (approximately once a shift).

3.2 IMPLICATIONS OF ACCOMMODATING LIQUID RDF

A major drawback at this time to using liquid RDF is obtaining an adequate supply. There are no commercial pyrolysis plants producing liquids from refuse. Laboratory studies and pilot plants have demonstrated the concept, but operations of these plants have been brief and under start-up or experimental conditions. An EPA-funded 200 ton per day demonstration plant using the Occidental Flash Pyrolytic Process has not been successful and is now shut down. Other developers, such as DECO Energy Co. and Enterprise Co. have produced small amounts of liquids for test purposes. Therefore, both the operation and cost of a liquid RDF production plant are still unknown. To obtain an adequate supply the user would probably have to take the added risk of owning and operating a conversion plant.

The two main advantages of liquid RDF (its use in existing equipment with only minor modifications and its ability to be readily shippable and storable) must be balanced against the cost and operability of the conversion plant itself (which is ill-defined at this time) and the efficiency penalty which is inherent in any refuse conversion process. Useful energy in the liquid RDF product has been estimated at 35-40 percent of the original energy content of the refuse as compared to 60-80 percent for processed solid RDF. For the same thermal input, approximately twice as much refuse must be processed for liquid RDF as opposed to solid RDF.

Boiler modifications to use liquid RDF should be minor. While only limited characterization of liquid RDF has been accomplished, pilot scale laboratory tests indicated that this fuel, and blends of it with No. 6 oil, can be successfully fired with properly designed fuels handling and atomization systems. More stringent handling requirements are necessary because of the aggressive nature of the liquid RDF, and to prevent plugging because of the high viscosity of the liquid RDF.

The most likely problems to be encountered by liquid RDF users include storage, pumping, and atomizer blockage. While the HHV of the liquid RDF is less than that of fuel oil, it is higher than an average coal. If used in conjunction with a liquid fossil fuel, a substantial portion of the heat input to the boiler can be supplied by liquid RDF without any major modifications. Blends of up to 50 percent by volume with three different No. 6 oils have been fired successfully. Such blends eventually separate, but are stable for several hours. Compatibility would have to be determined for each fuel oil in question.

Liquid RDF is low in ash and can be burned in boilers without ash handling capability. At excess air levels over two percent, there were negligible quantities of unburned carbon in the stack emissions. Nitrogen oxides and sulfur dioxides were also low and well within EPA limits. Corrosion problems associated with handling and burning liquid RDF has already been encountered, is of concern but with only limited supply available has not been evaluated but are considered areas of concern.

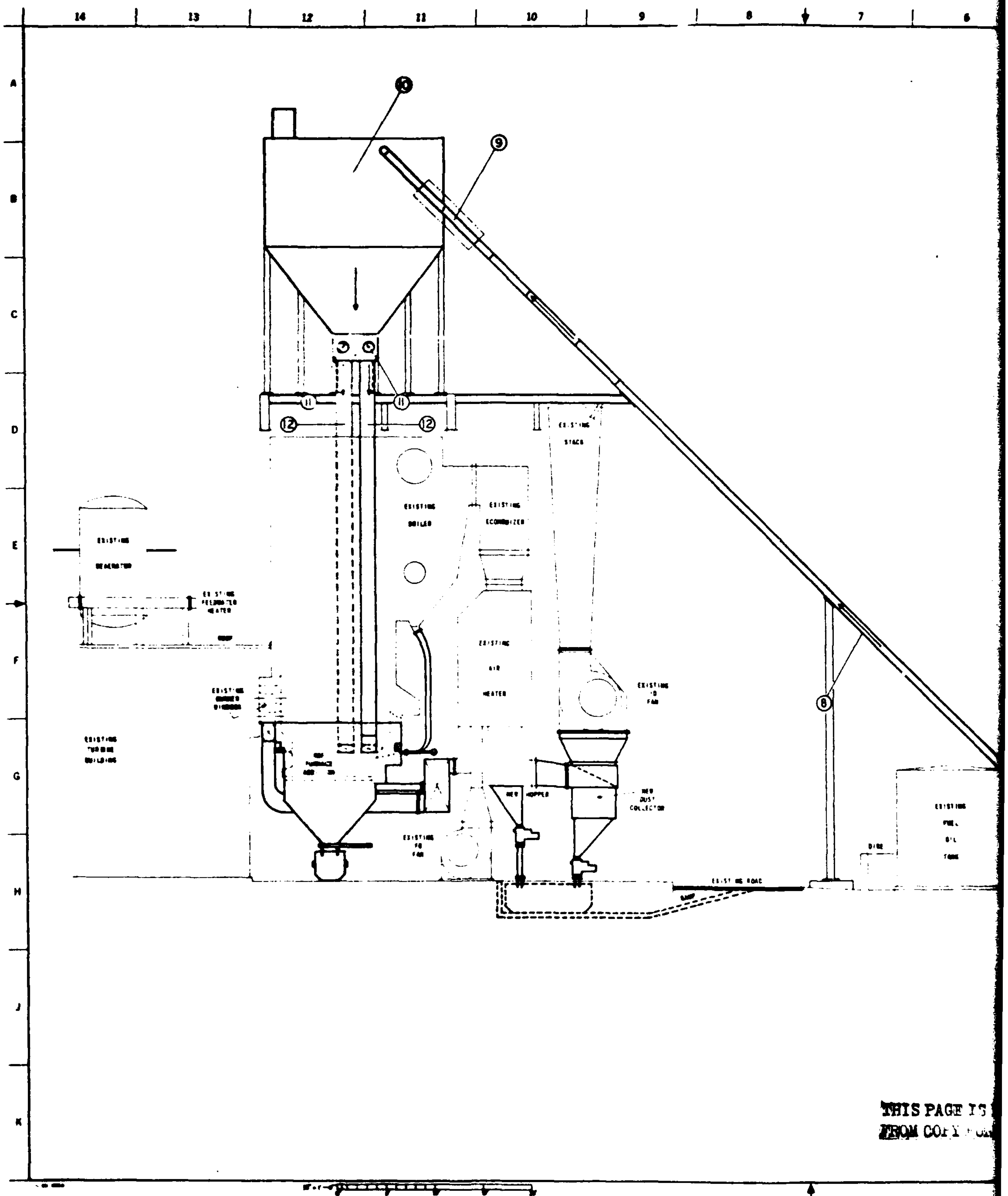
3.3 IMPLICATIONS OF ACCOMMODATING GASEOUS RDF

Boiler modifications to use gaseous RDF should be minor for a gas above approximately 300 Btu/scf. However, as the fuel heating value falls much below 250-300 Btu/scf, the boiler would have to be derated, and major modifications to the fuel gas piping and burners would be required. Of the three primary processes being developed to gasify refuse, only Union Carbide's Purox oxygen blown process produces a fuel gas heating value above 300 Btu/scf. This process has been demonstrated in a 5 ton per day pilot plant and a 200-ton per day demonstration facility. Commercial plants have not yet been built.

In contrast to liquid or solid RDF, the gaseous RDF producer must be in close proximity to the fuel using system. As with liquid RDF, the advantage of gaseous RDF (i.e. its use in existing equipment with only minor modifications) must be balanced against the cost and operability of the gas production facility itself and the efficiency penalty which is inherent in any refuse-to-fuel conversion process. Net energy produced in the Purox process has been estimated at 65-70 percent of the original content of the refuse.

The most important aspect of firing low-Btu gas compared to conventional fossil fuels is the large increase in fuel weight which must be admitted to the furnace and the resultant increase in total combustion products which will flow over the heat absorbing surfaces. This large change in total combustion gas flow (up to 60 percent, depending on the fuels) will increase gas velocities and shift heat absorption patterns within the components of the steam generating unit. The ability of existing components to operate under these new conditions or under the modifications required is the major evaluation factor.

With a fuel gas above 300 Btu/scf, the rated output of existing steam generating units and components can be achieved with only minor modifications to the windbox and firing system equipment. Major modifications to the existing steam generating unit and auxiliary components are necessary to fire lower Btu fuel gas.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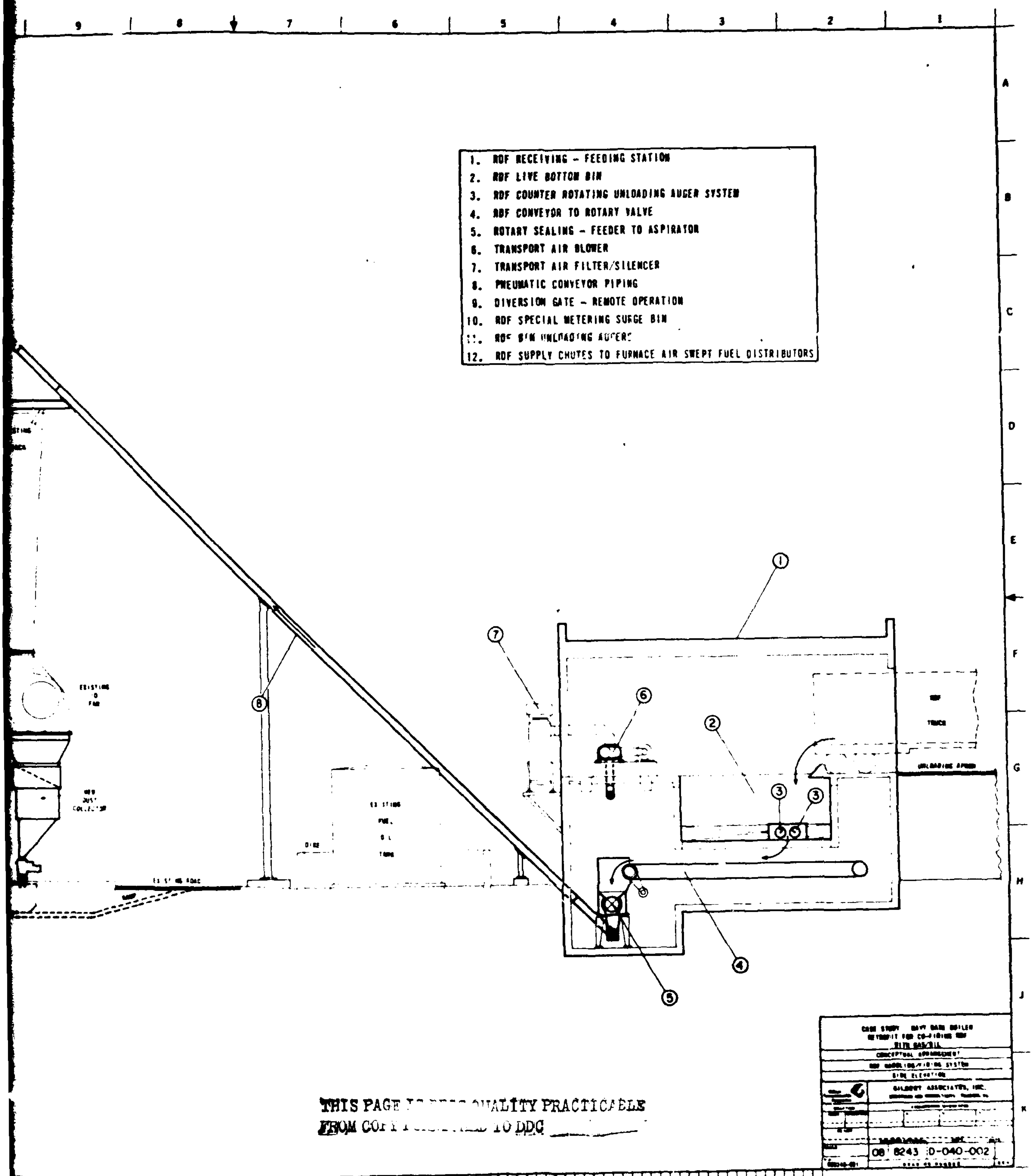
EXISTING FUEL OIL TANK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2. RDF LIVE BOTTOM BIN
3. RDF COUNTER ROTATING UNLOADING AUGER SYSTEM
4. RDF CONVEYOR TO ROTARY VALVE
5. ROTARY SEALING - FEEDER TO ASPIRATOR
6. TRANSPORT AIR BLOWER
7. TRANSPORT AIR FILTER/SILENCER
8. PNEUMATIC CONVEYOR PIPING
9. DIVERSION GATE - REMOTE OPERATION
10. RDF SPECIAL METERING SURGE BIN
11. RDF BIN UNLOADING AUGERS
12. RDF SUPPLY CHUTES TO FURNACE AIR SWEPT FUEL DISTRIBUTORS
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WASTE FUEL UTILIZATION IN EXISTING BOILERS ON U. S. NAVAL BASES--ETC(U)
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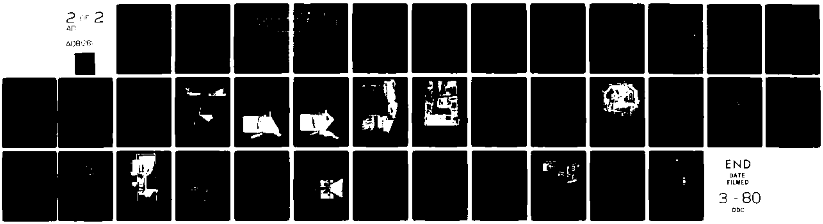

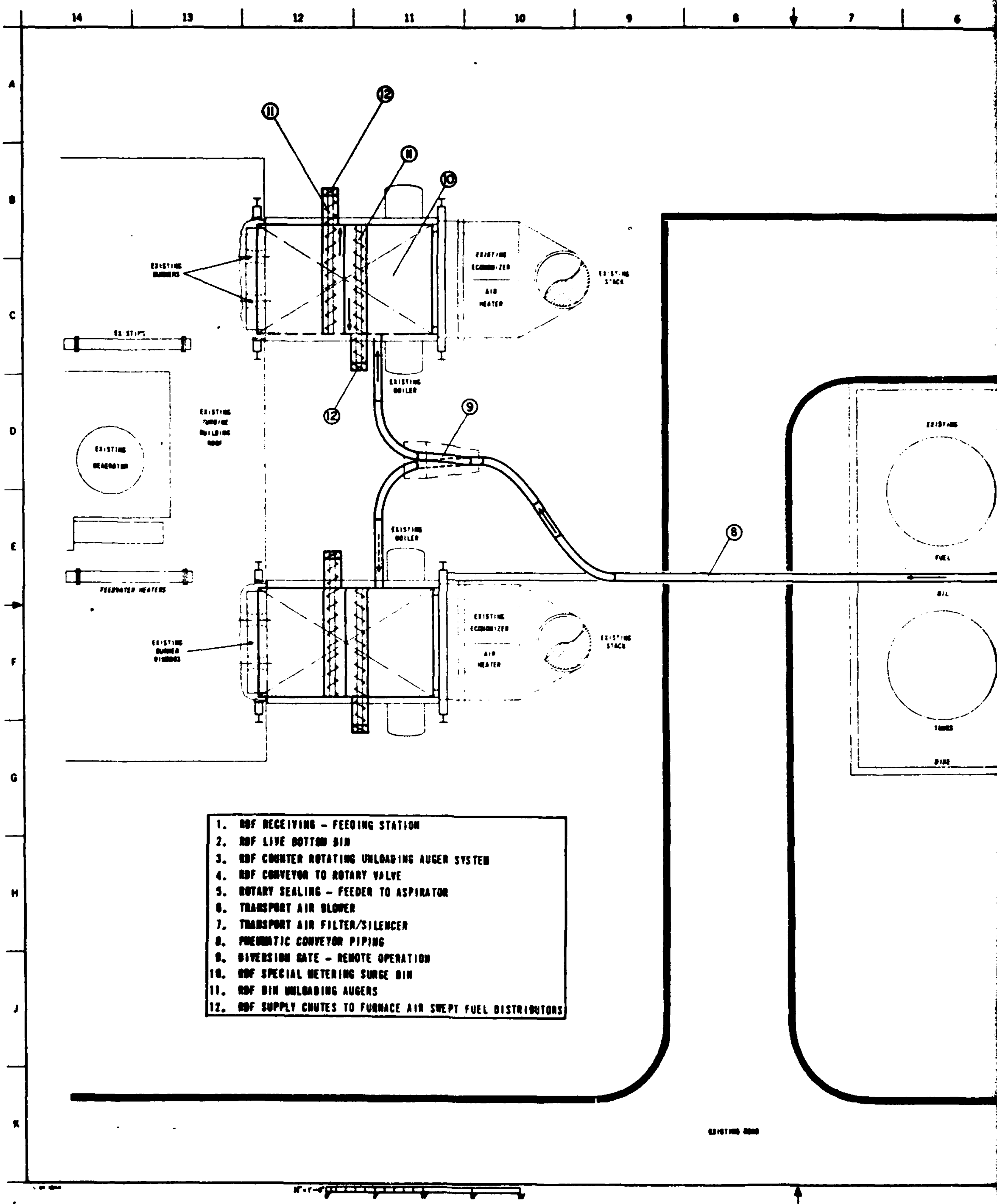

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EXISTING FUEL OIL TANKS
DIKE
EXISTING ROAD
1. RDF RECEIVING - FEEDING STATION
2. RDF LIVE BOTTOM BIN
3. RDF COUNTER ROTATING UNLOADING AUGER SYSTEM
4. RDF CONVEYOR TO ROTARY VALVE
5. ROTARY SEALING - FEEDER TO ASPIRATOR
6. TRANSPORT AIR BLOWER
7. TRANSPORT AIR FILTER/SILENCER
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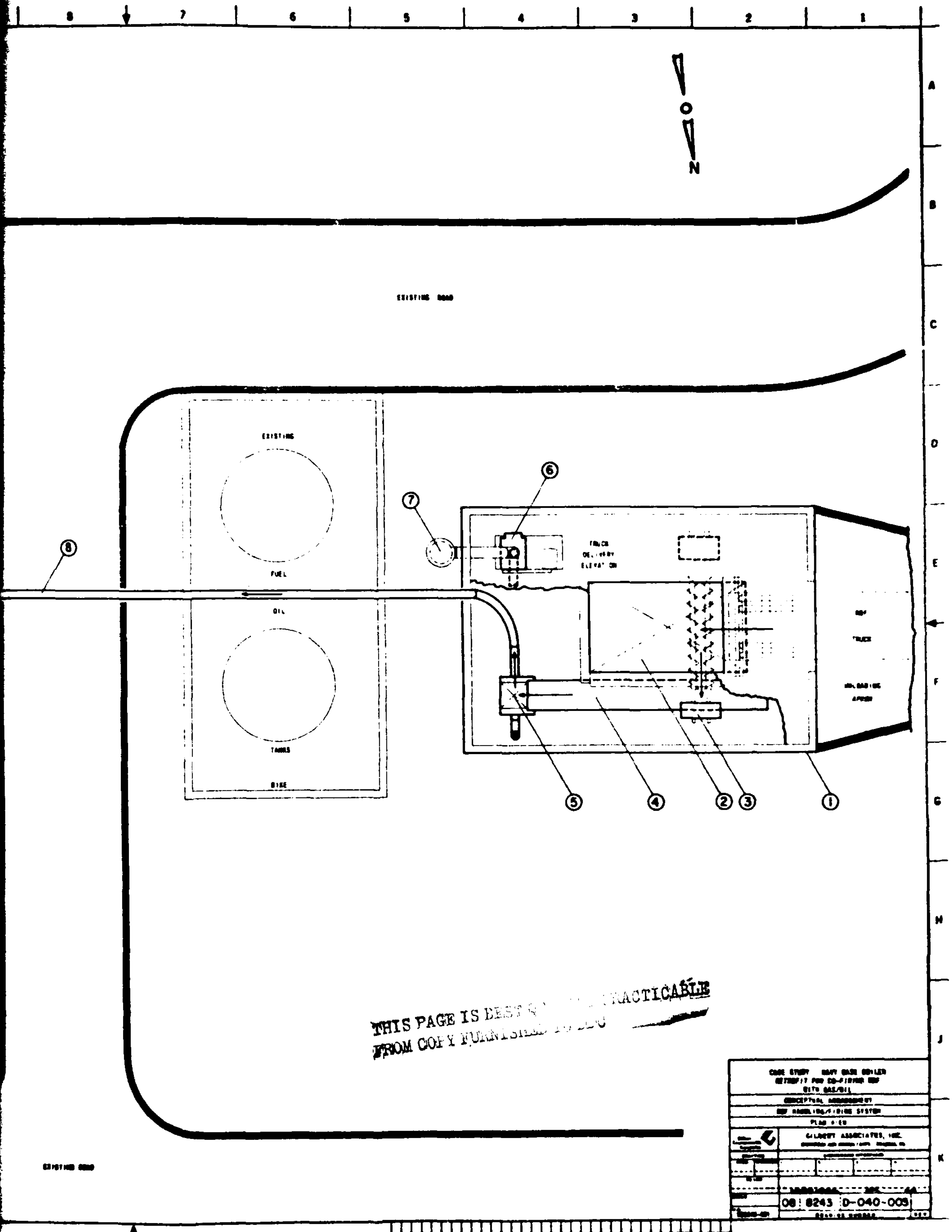
10. RDF SPECIAL METERING SURGE BIN
11. RDF BIN UNLOADING AUGERS
12. RDF SUPPLY CHUTES TO FURNACE AIR SWEPT FUEL DISTRIBUTORS



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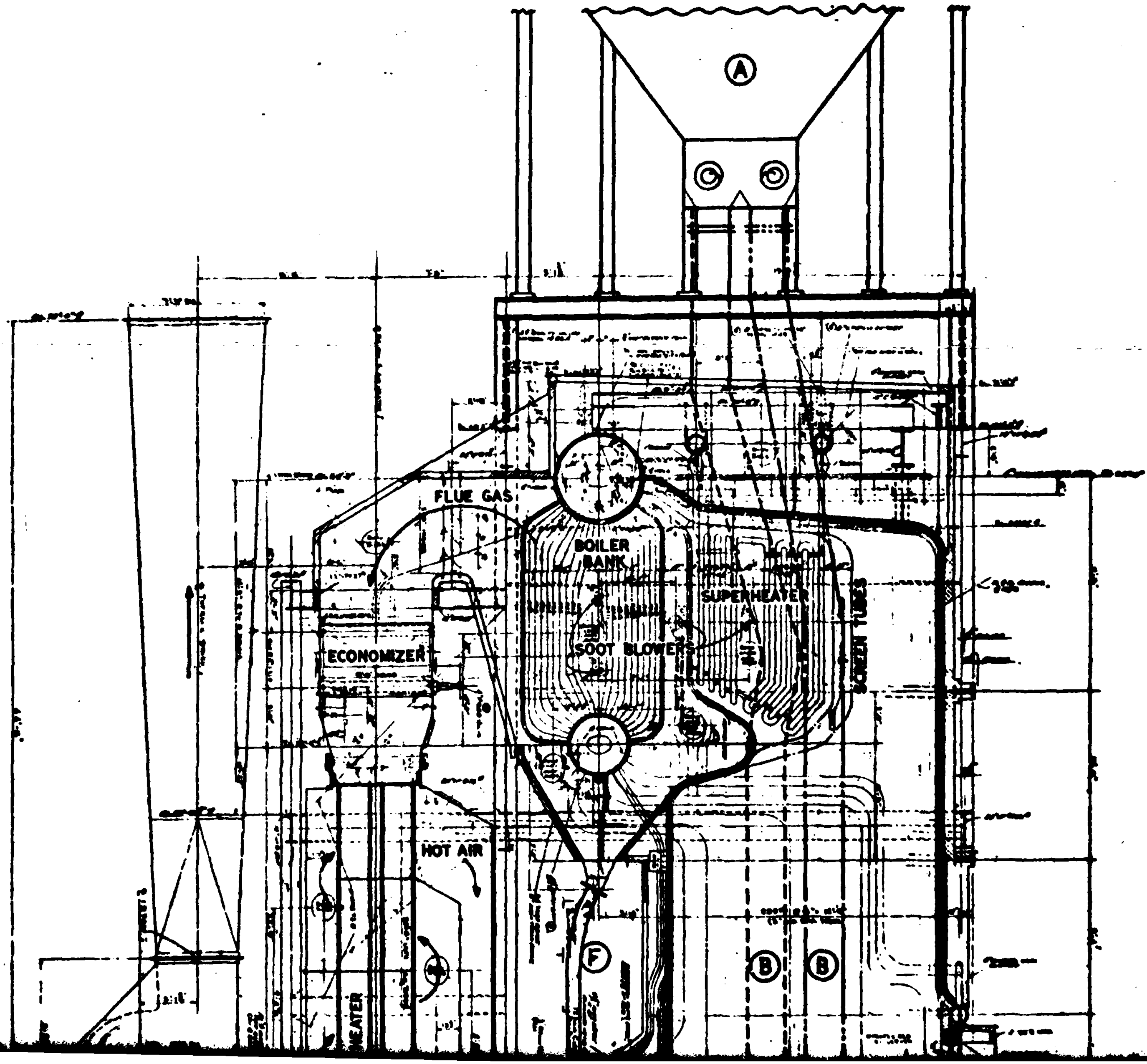
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SECTION 4.0
CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study is to assess the characteristics of prepared fuels from wastes and their potential for utilization in existing Navy Base Boilers and to evaluate the complexities and costs of utilizing prepared waste in a representative Navy installation.

The conclusions drawn from this study are divided into two areas: broad conclusions based on the generic assessment of waste fuels and specific conclusions based on the case study.

4.1 GENERAL CONCLUSIONS FOR UTILIZING WASTE

- There are a number of forms in which a solid RDF can be made available to Navy Base boiler plants. These include coarse and finely shredded, extruded, powdered, and briquetted material.

- The RDF quality to be specified and, therefore, the degree of refinement required is a cost/benefit trade-off. This is a facility-specific and site-specific determination.

- It may not be practical to adapt (retrofit) some of the smaller facilities to utilize some form of RDF. Refined RDF may not be available, or in sufficient quantity to warrant retrofitting.

- There has been only very limited production of liquid and gaseous forms of RDF and no on-going operating supply. Most data and information are projections with questionable reproducibility and credibility. There are no "reported" commercial size operating facilities currently utilizing or even test burning liquid or gaseous fuels derived from general industrial plant wastes or residential wastes. From available data, a liquid fuel approaching the quality of residual could be accommodated with only minor modifications in existing heavy oil burner systems. Except for the possible need for soot blowers and/or provisions for water washing, no modifications to the boiler pressure parts would be anticipated. However, the burner piping train, transport piping, heating, filtering, blending, pumping, and storage systems would require special design and closely monitored operation.

- Gaseous RDF having 250-300 Btu/scf or more, suitably cleaned and dried could be accommodated in most existing furnace systems with only minor modifications to the burner and its piping train. The RDF gas producer (probably oxygen blown) would have to be located within reasonable proximity to the fuel-using appliance. Lower Btu gas would require extensive modifications to the burner and piping systems and may also require a significant derating of the boiler system. Introducing hot raw pyrolysis gases directly into a boiler furnace is possible but of limited attraction for Navy Base facilities.

For facilities requiring more than 100,000 pounds of steam per hour at elevated steam conditions permitting cogeneration, new multifuel fired single pass steam generators should be employed similar to the "model" unit illustrated and described in the Recommendations.

4.2 CONCLUSIONS BASED ON THE CASE STUDY

- The Case Study reveals that a noncomplex adaptation could provide practical cofiring of RDF with conventional fossil fuels.
- If suitably prepared solid RDF is available, approximately 60 tons per day can always be consumed with 120 tons per day total system capability. This is based on providing RDF for 20 percent of the Btu input requirements during full load operation.
- Base loading the two retrofitted boilers at their design RDF capacity and accommodating all steam load swings with conventional fossil fuel could displace 220 barrels of oil per day, which equates to approximately 79,000 barrels of oil per year. At 35 cents per gallon, the annual savings in 1978 fuel costs would amount to $1,160,000.
- Not only is there a potential reduction in fuel costs of over $1,000,000, but some disposal cost savings should be realized (counterbalanced, perhaps, by the cost of producing RDF).
- With the significant volume reduction of wastes to be landfilled the effective life of the landfill area for this purpose will be materially increased.

4.3 RECOMMENDATIONS

- The circumstances encountered in the Case Study can only be representative of a "class" of Navy Base facilities. Similar studies should be conducted for other classes of installations to provide the Navy with a broader basis for determining their waste utilization potential and the corresponding capital requirements to accommodate waste fuel firing. Class categorization might be by:

  -- boiler capacity - pounds steam per hour
  - less than 30,000
  - 30,000 to 90,000
  - greater than 90,000

  -- boiler type and age

  -- type of fuel firing capability

  -- type of steam demand and usage

  -- geographic region

  The delineation of classes and number of case studies required to serve the Navy's needs should be determined as a result of a sufficiently detailed inventory of existing Navy boiler plant facilities.

- The Navy should initiate a program for developing a special purpose, modest size steam generating unit configured specifically to accommodate Navy refuse in the essentially as-discarded form. This type of unit would have broad application as single or multiple units at many Navy Base facilities. Some of the principal design and operating objectives which might be incorporated are:

  - capacity range 25,000-30,000 pounds of steam per hour
  - no superheat
  - optimized energy recovery
  - coarse size reduction of solid wastes
  - waste oils and spent solvents to be accommodated as fuels
  - full generating capacity with heavy fuel oils

- water-cooled furnace, minimum refractories

- shop assembled components

- minimal monitoring required by operating personnel

- dry air pollution control equipment

- noncomplex, robust equipment systems to provide high availability

o All new land-based Navy boiler installations of over 90,000 pounds of steam per hour should be designed for multifuel firing, i.e., liquid, gaseous, and solid fossil fuels, as well as cellulosic wastes and RDF. These systems should be designed so that they can be operated at an energy level permitting cogeneration of electric power.

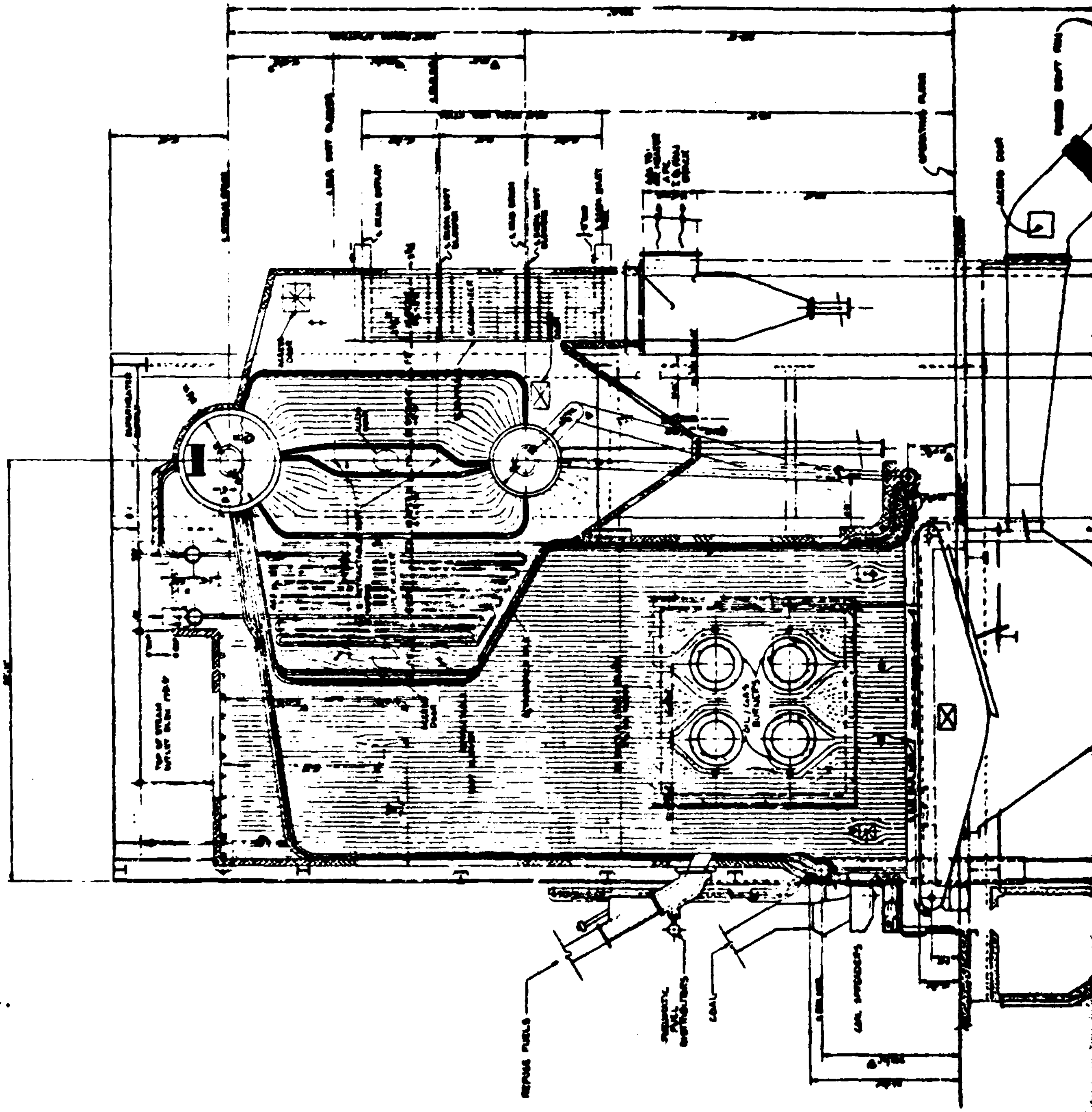
A "model" industrial-class boiler configuration arranged to accommodate multifuels for separate or combined firing is illustrated in Drawing C-041-004.

The unit displayed would be capable of generating 150,000 pounds of steam per hour at 600 psig and 770°F total steam temperature at approximately 86 percent efficiency while burning fossil fuel. The unit is arranged for firing distillate or residual fuel oils, natural gas, and bituminous coal; up to 50 percent Btu input on RDF can be accommodated, displacing a corresponding quantity of fossil fuel. The waste fuel firing (RDF, biomass, waste oils/solvent) would be base loaded with the supplementary fossil fuels responding to variations in steam demand through the automatic combustion control system. Superheat temperature would be controlled by feedwater spray attemperation in the outlet header system.

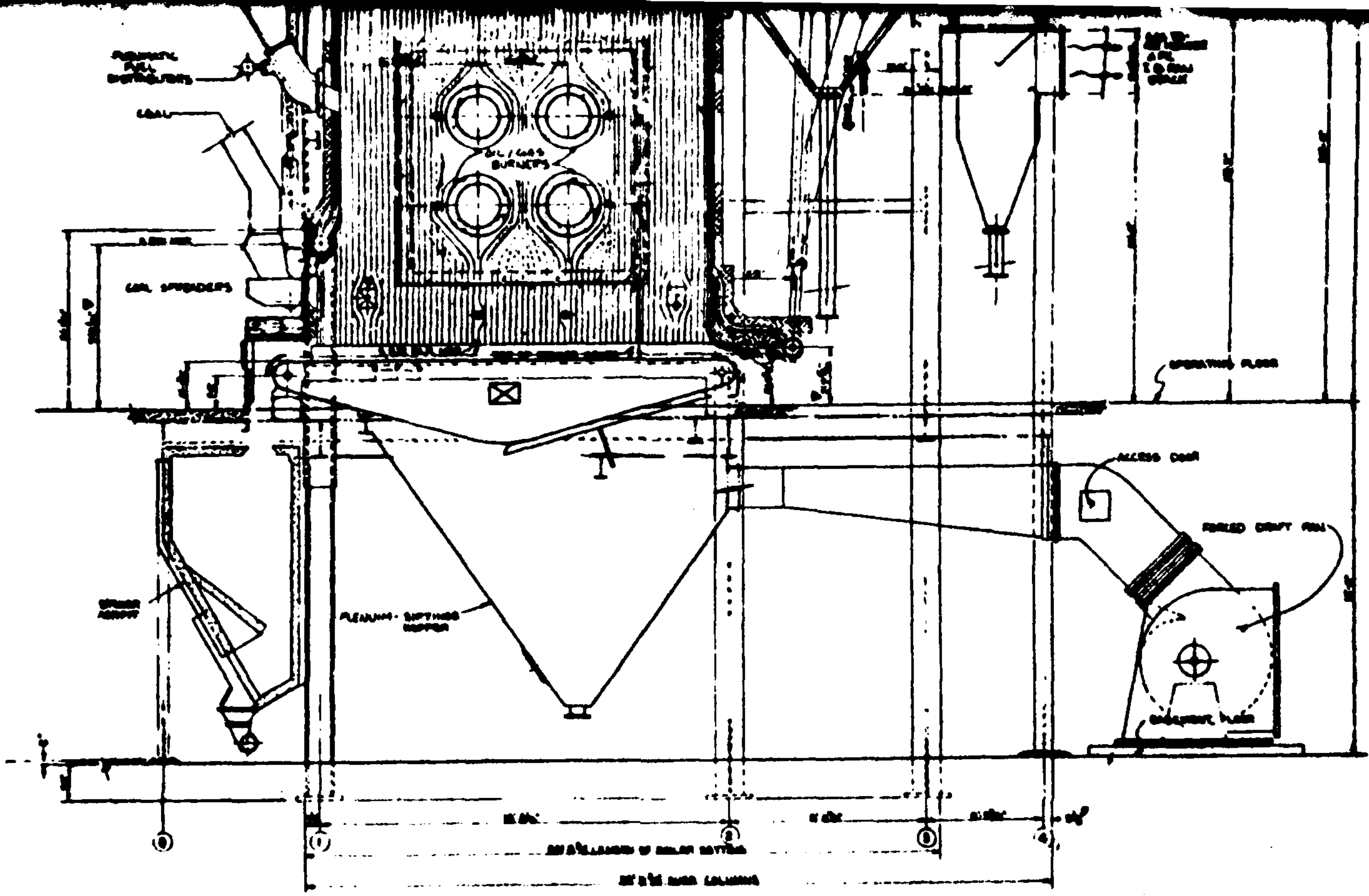
The two drum, single-pass boiler design illustrated is equipped with a totally water-cooled tower furnace arranged with a rear waterwall "nose arch" beneath the slag screened superheater. The configuration of the hoppers beneath the lower drum precludes accumulation of dust deposits on the heat transfer surfaces within the convection banks. Although not illustrated, the economizer heat trap would be followed by a regenerative or tubular air heater and an electrostatic precipitator prior to the induced draft fan and stack.

The furnace is equipped with front continuous ash discharge grates and spreader stoker coal feeders in the lower front wall. The oil/gas burners are located in one sidewall of the furnace, thereby providing uncluttered burner management areas. The cellulosic fuel or RDF is introduced separately into the furnace for semisuspension firing through pneumatic distributor spouts located above each stoker coal feeder. Fly-carbon deposited in the boiler and economizer hoppers would be pneumatically returned to the furnace for energy recovery. The particulate trapped in the electrostatic precipitator, the grate siftings in the undergrate plenum chamber, and the ash discharged by the traveling grates would be pneumatically conveyed to the ash silo.

This design concept would provide Navy Base personnel with an efficient, fuel-versatile, steam generating system that is responsive to wide load swings, has a 3- or 4-to-1 load turndown, is easy to operate and maintain, and has high availability.



REFUSE FUELS
COAL



SECTIONAL SIDE ELEVATION

CAPACITY & DESIGN DATA

1. STEAM CAPACITY - CONTINUOUS [illegible] LB/HR
2. STEAM CAPACITY - [illegible] PEAK [illegible] LB/HR
3. STEAM CONDITIONS - [illegible]

MODEL MULTI-FUEL FIRED STEAM GENERATOR

ARRANGEMENT OF MODEL MULTI-FUEL FIRED STEAM GENERATING SYSTEM
ELEVATION
GILBERT ASSOCIATES, INC.
W.O. 08 8243 C-041-004

2

SECTION 5.0
REFERENCES

1. Hollander - "Processed Refuse - A Salvage Fuel for Existing Boilers" 24th Ontario Industrial Waste Conference.

2. Moore and Ehler, "Western Coals - Laboratory Characterization and Field Evaluations" ASME 73-WA/FU-1.

3. Hollander and Kieffer, "Developing Analytical Procedures For Reproducible Determinations of Thermo-Chemical Characteristics of RDF" - an ASTM Program, 1978 ASME Winter Annual Meeting, December 1978.

4. Mockridge - "Utilization of Package Boilers for the Combustion of Waste Fuels", 1974 American Power Conference.

5. Hollander and Cunningham - "Beneficiated Solid Waste Cubettes as Salvage Fuel for Steam Generation", 1972 ASME National Incinerator Conference.

6. J. L. Jones, et. al., "Pyrolysis, Thermal Gasification, and Liquefaction of Solid Wastes and Residues, Worldwide Status of Processes (as of Fall 1977)", ASME 8th Biennial National Waste Processing Conference, Chicago, Illinois (May 1978).

7. "Enterprise Resource Recovery and Energy Conversion System", undated document obtained from the Enterprise Company, Santa Ana, CA (received September 1977).

8. Personal Communication by SRI International with Mr. Bill Chambers of DECO Energy Company (August 1977).

9. G. T. Preston, "Resource Recovery and Flash Pyrolysis of Municipal Refuse", Clean Fuels from Biomass, Sewage, Urban Refuse and Agricultural Wastes, Institute of Gas Technology, Chicago, IL (January 1976).

10. K. Pober and H. Bauer, "From Garbage--Oil", CHEMTECH, Vol. 7, No. 3 (March 1977).

11. M. D. Bowen, et. a .., "A Vertical Bed Pyrolysis System", Solid Wastes and Residues--Conversion by Advanced Thermal Processes, ACS Symposium Series 76, edited by J. L. Jones, and S. B. Radding, American Chemical Society, Washington, D.C. (March 1978).

12. Personal communication by SRI International with Mr. H. B. Justus of Thermex, Inc., Hayward, CA (August 1977).

13. B. L. Schulman and P. A. White, "Pyrolysis of Scrap Tires Using the Tosco II Process--A Progress Report", Solid Wastes and Residues--Conversion by Advanced Thermal Processes, ACS Symposium Series 76, edited by J. L. Jones and S. B. Radding, American Chemical Society, Washington, D.C. (March 1978).

14. I. W. Henry and H. E. Burbach, "What About Boilers for Low Btu Gas", Electric Light & Power, E/G Edition, May 1974.

15. Borio, R. W., Combustion and Handling Properties of Garrett's Pyrolytic Oil, Final Report, Combustion Division, Combustion Engineering, Inc., Project 900127, December 4, 1972.

16. Sotter, J. G., Knowlton, G. B., Combustion Tests of Pyrolytic Oils Made from Solid Waste Materials, KVB Equipment Corporation, Report No. 5300-148, August 1, 1974.

17. Chatterjee, A. and Garbe, Y. M., "An Overview of San Diego County's Resource Recovery Plant", Paper presented at the ASME 8th Biennial National Waste Processing Conference, Chicago, IL (May 1978).

18. Stewart, J. T., "Low Btu Gas for Industrial Fuel", Presented at the 69th Annual Conference Industrial District Heating Association, Hot Springs, Virginia, June 19-21, 1978.

19. Frendberg, A., Performance Characteristics of Existing Utility Boilers When Fired With Low-Btu Gas, Power Generation Today Conference, Monterey, CA, April 8-10, 1974 EPRI-SR-1.

20. Steam - Its Generation and Use, the Babcock and Wilcox Company, New York.

21. Combustion Engineering, Edited by Otto de Lorenzi, Combustion Engineering Company, Inc., New York.

22. Cataloque Illustrations
    The Babcock & Wilcox Company
    Combustion Engineering Inc.
    Erie City Iron Works - Zurn
    E. Keeler Company
    Riley Stoker Company
    Foster Wheeler Corporation

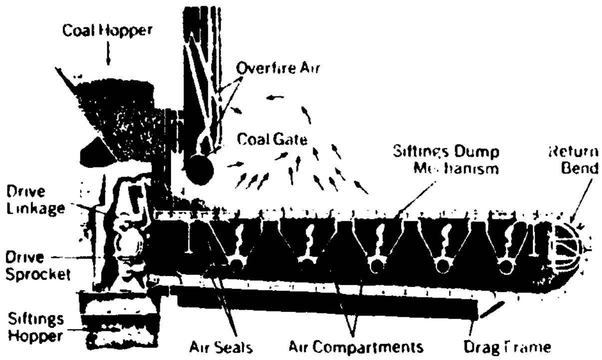
- EXHIBIT A -

STOKER FIRED STEAM GENERATING SYSTEMS

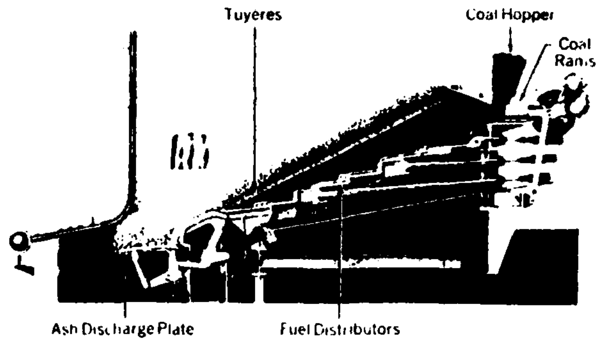
- o Mass Burning Systems
- o Thin Burning (semisuspension) Systems

The exhibits included illustrate the basic elements comprising each type of stoker system, the arrangement of the equipment and their application to typical classes of modest size steam generators. Illustrations are also provided of actual installations at small and large industrial heating plants and those generating electric power.

MASS BURNING STOKER ELEMENTS

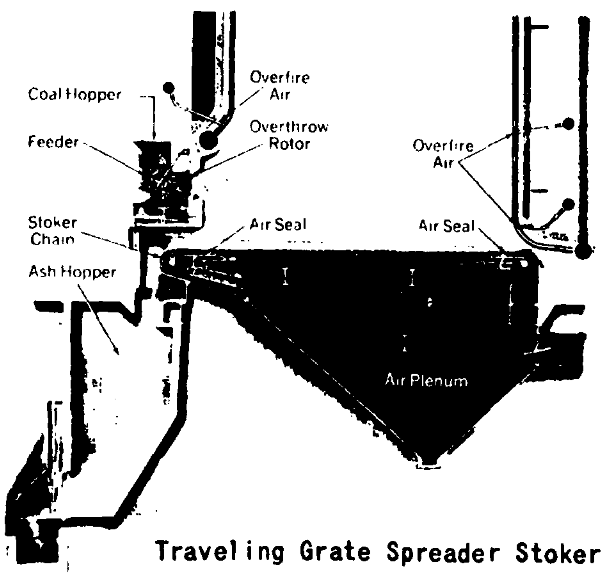


Traveling Grate Gate Fed



Multiple Retort Underfeed

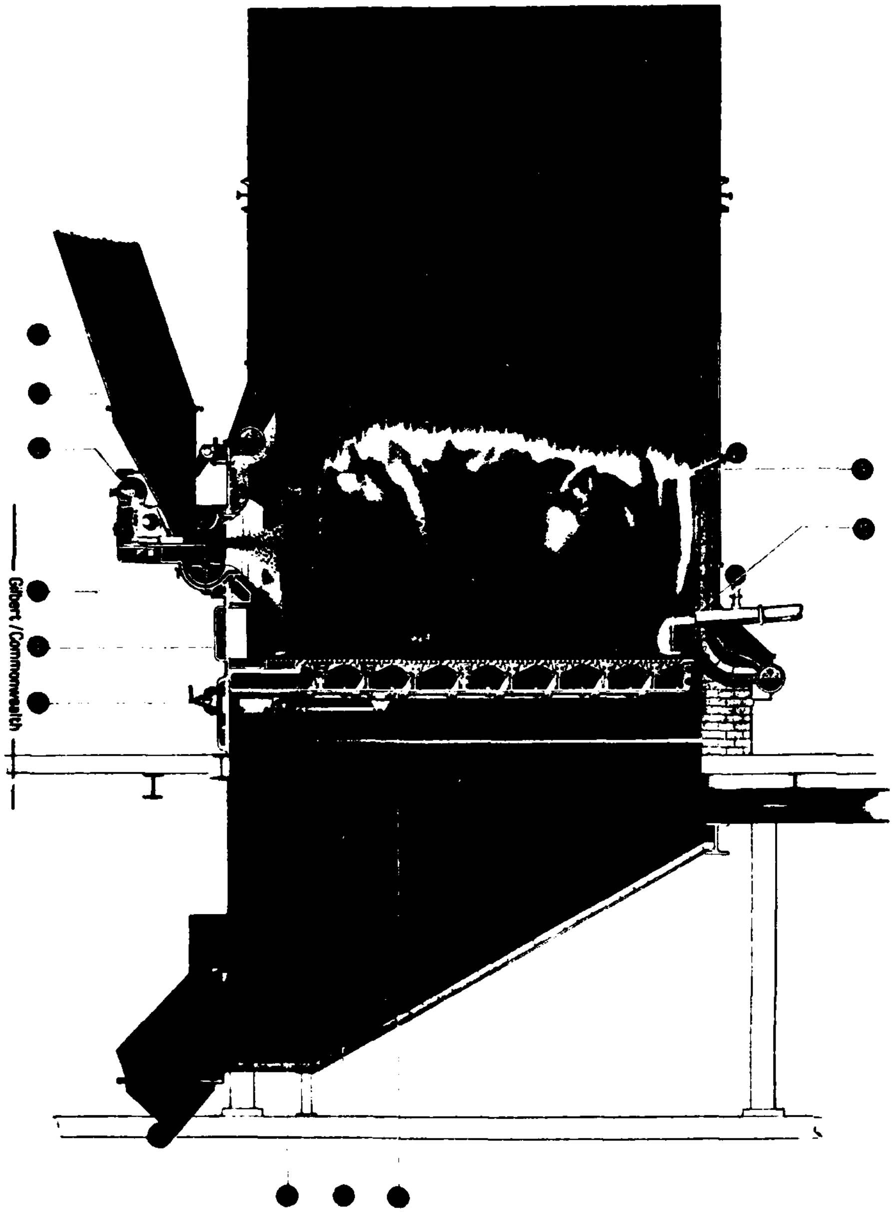
THIN BURNING (SEMI SUSPENSION) SPREADER STOKER ELEMENTS



Traveling Grate Spreader Stoker

EXHIBIT A-1

STOKER ELEMENTS



Elements of a POWER-DUMPING GRATE SPREADER STOKER FOR INTERMITTENT BOTTOM-ASH DISCHARGE

FEATURES

- **Grate surface** is composed of stationary and movable grate sections. Grates are constructed of best quality heavy-duty heat-resisting cast iron alloy with uniformly spaced, tapered, self-cleaning air metering openings to assure even distribution of air through the fuel bed.
- **A four-way control valve** located on the stoker front is used in conjunction with a steam or air-activated power cylinder to provide the dumping mechanism.
- ***The air pressure chamber*** is completely sealed both front and rear to prevent air leakage.
- **Fire and ash door facings** are ground in jigs, assuring close fit and easy interchangeability.
- **Each coal-receiving hopper** is designed to accommodate purchaser's coal handling equipment and provides sufficient coal capacity for its feeder.
- **Reciprocating feeders**, each with three individually controlled pusher blocks, allow fine regulation of the fuel bed and keep the coal moving freely from the hopper. More details on this component are covered on pages 16 and 17.
- **Individual feeder drive** provides for independent control of each feeder and eliminates high maintenance on line shafts, clutches, bearings and universal joints needed for single-drive, multiple-feeder arrangements.
- **The fuel distributor opening** for each feeder is a completely air- and water-cooled casting, constructed of the best quality, heavy-duty, heat-resisting cast iron alloy.
- **An overfire air system** provides turbulence and thorough mixing of the volatile gases, thus assuring complete combustion.
- **A cinder recovery system**, of the straight-through pneumatic type is furnished with all necessary steel pipe, fittings, supports, and heat resistant alloy iron reinjection nozzles.
- **Ash discharge** may be semi-automatic through hopper and optional ash conveyor or manual at operating floor level if sub-floor excavation is not feasible.

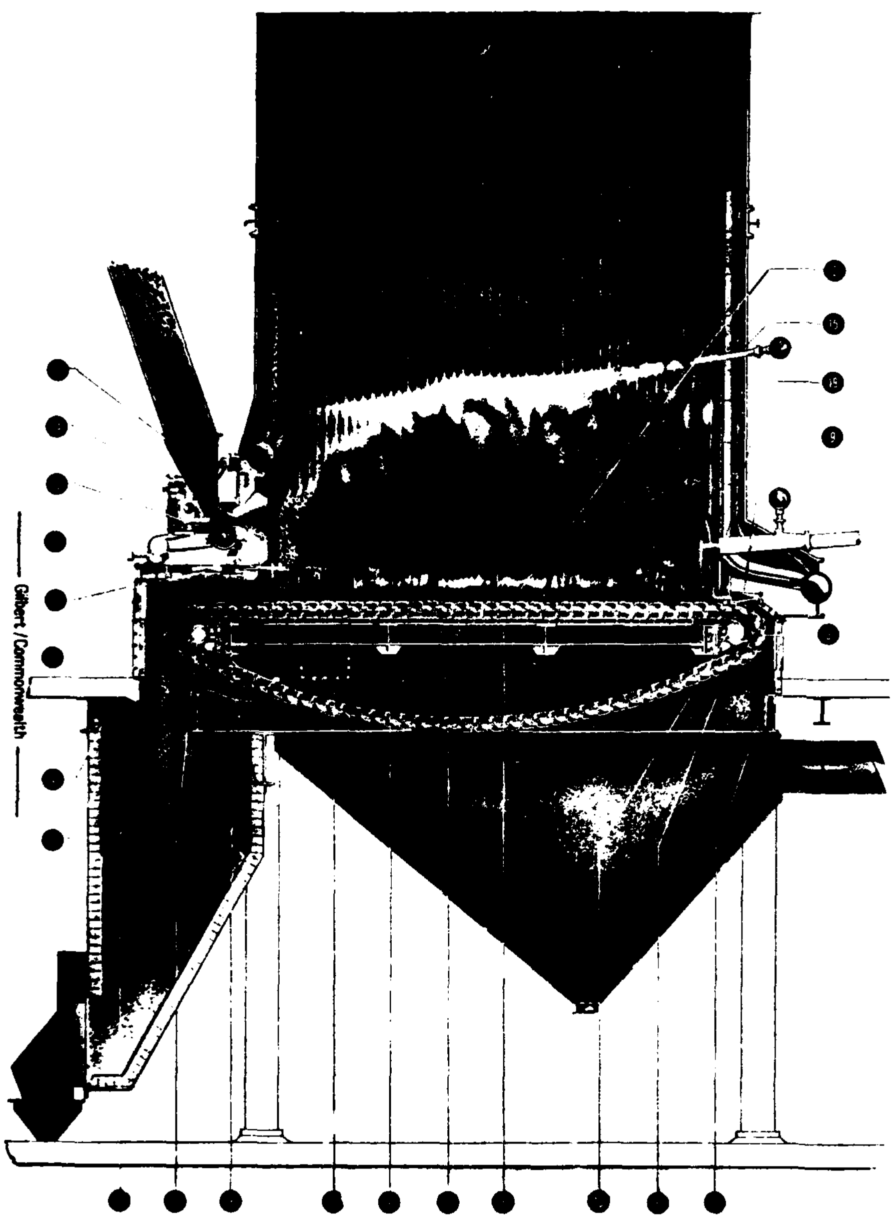
OPERATION

Intermittent power-dumping grate spreader stokers are equipped with the same feeders and thus operate in a similar manner. Fuel is continuously and automatically fed from the fuel receiving hoppers, advanced across the distributor plate by the unique triple pusher block system, picked up by revolving rotor blades and distributed into the furnace. The fuel, mixed with air from strategically-located high pressure over-fire air jets, burns in suspension and on a thin fast-burning fuel bed. Mechanical connections to the combustion control system provide automatic regulation of fuel feeding rate and air supply to conform to variations in load.

The power-dumping grate spreader stoker intermittently discharges ash into the ash pit located directly under the stoker grates. Four-way hand-operated valves, located on the stoker front actuate the steam or pneumatic powered cylinder dumping mechanism.

Gilbert / Commonwealth

Fxhibit A-2



Elements of a SPREADER STOKER FOR CONTINUOUS ASH DISCHARGE

FEATURES

- **Catenary design** provides for automatic take-up or tensioning of grate chains to prevent jamming. Effective catenary is maintained by gravity, thus making external shaft adjustments unnecessary.
- **Grate surface** consists of a series of grates specifically designed for spreader stoker firing. The grates are constructed of best quality heavy-duty heat-resisting cast iron alloy and are made in short sections (12" to 15" long) which can be individually replaced, thus reducing grate maintenance costs.
- **Grate curvature** design keeps the grates closed without the [illegible] auxiliary weights when making the turn around the sprockets.
- **Grate access** is provided by a grate removal door. On removal of one bolt, any grate section can be replaced while the stoker is in operation.
- **Grate support** within the furnace is provided by a series of skids and skid rails, each constructed of chill-hardened cast iron for maximum life.
- **Front and rear grate shafts** carry the grate chains on hardened sprockets. Bearings and sprockets are strategically located along the shafts for *maximum load-bearing efficiency.*
- **The air pressure chamber**, completely sealed both front and rear to prevent air leakage, directs and distributes combustion air through the active grate surface.
- **Three front undergrate air seals** prevent air by-passing to the ash discharge end.
- **The rear coal and air seal** is designed to allow rear water wall expansion while maintaining tightness.
- **The rear retardation seal** proportions air flow through the rear end of the grate to induce coking and ignition of green fuel bed before it reaches the active air admitting area.
- ***Each coal-receiving hopper*** is designed to accommodate purchaser's coal handling equipment and provides sufficient coal capacity for its feeder.
- **Reciprocating feeders**, each with three individually controlled pusher blocks, allow for fine regulation of the fuel bed and keep the coal moving freely from the hopper. More details on this component are covered on pages 16 and 17.
- **Individual feeder drive** provides for independent control of each feeder and eliminates high maintenance on line shafts, clutches, bearings, and universal joints needed for single-drive multiple feeder arrangements.
- **The fuel distributor opening** for each feeder is a completely air- and water-cooled casting, constructed of the best quality, heavy-duty, heat-resisting cast iron alloy.
- **An overfire air system** provides adequate front wall cooling and is strategically located to provide turbulence and thorough mixing of the volatile gases, thus assuring complete combustion.
- **Front and rear access doors**, normally a pair for each feeder, provide for stoker inspection at the ash discharge extension housing (front) *and behind the rear stoker* housing.
- **Undergrate access doors**, located on each side of the stoker housing, provide inspe[illegible] of and access to grate assembly.
- **An ash storage hopper** can be provided for automatic ash discharge and periodic removal by purchaser's ash removal systems.
- **A cinder recovery system** of the straight-through pneumatic type is furnished with all necessary steel pipe, fittings, supports and heat resistant alloy iron reinjection nozzles.

OPERATION

The fuel is continuously and automatically fed from the fuel receiving hoppers, advanced across the distributor plate by the unique triple pusher block system, picked up by revolving rotor blades and distributed into the furnace. The unique triple pusher block system provides steady feeding without furnace "puffs" while the specially-designed rotor blades impart a spraying effect that distributes the fuel uniformly toward the rear of the furnace. Strategically located, high-pressure over-fire air jets provide turbulence and thorough mixing of the fuel and air to assure complete combustion. Fine particles of fuel are rapidly burned in suspension while coarser, heavier particles are spread evenly on the forward moving grates, forming a thin, fast burning fuel bed. The fuel feeding and air supply rates conform to variations in load and are automatically regulated by mechanical connection to the combustion control system. To compensate for variation of the ash content in the fuel, the grate speed can be adjusted from 0 to approximately 30 feet per hour. The ash is continuously discharged over the front end of the grate into an ash pit or horpe

Exhibit A-3

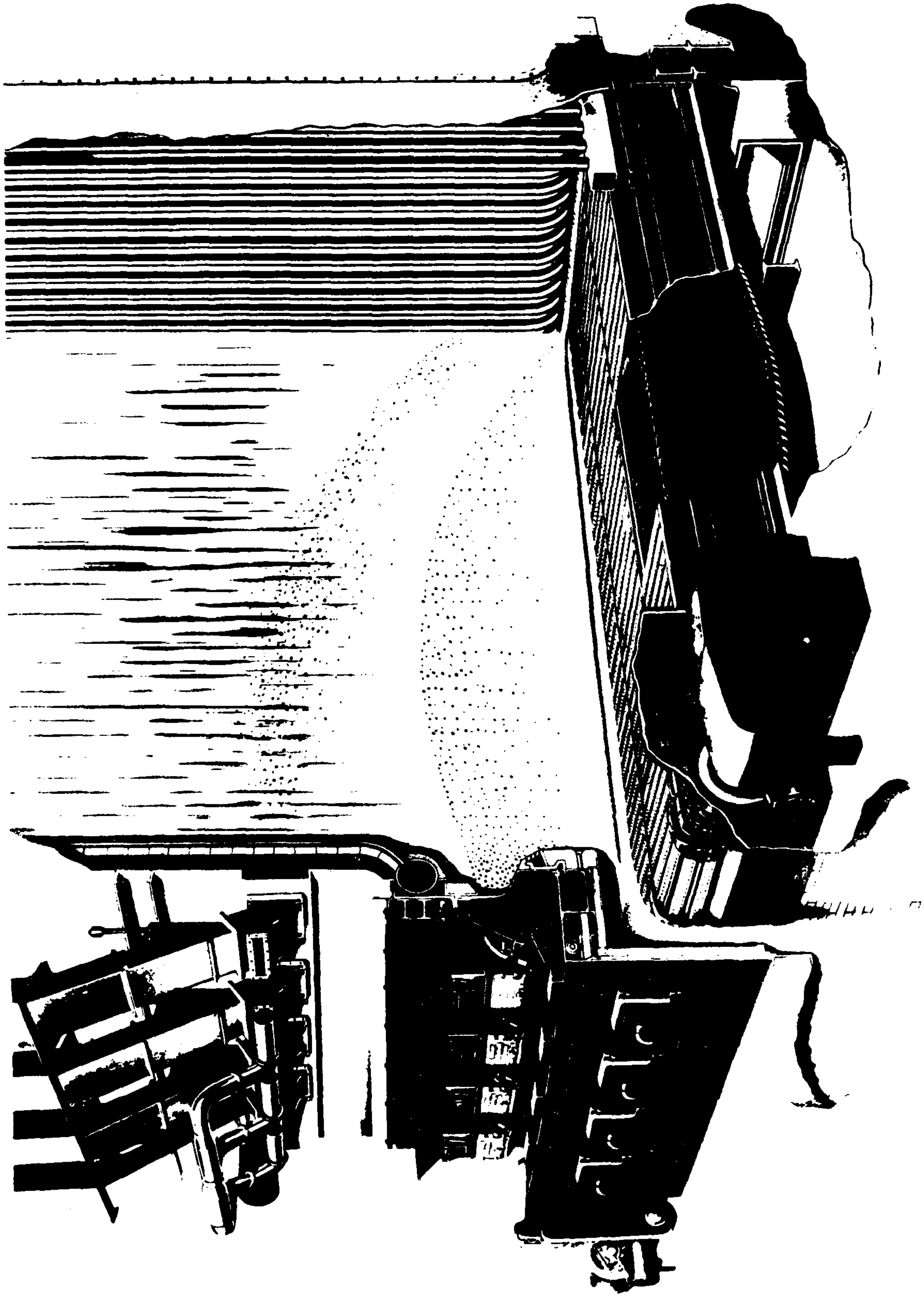
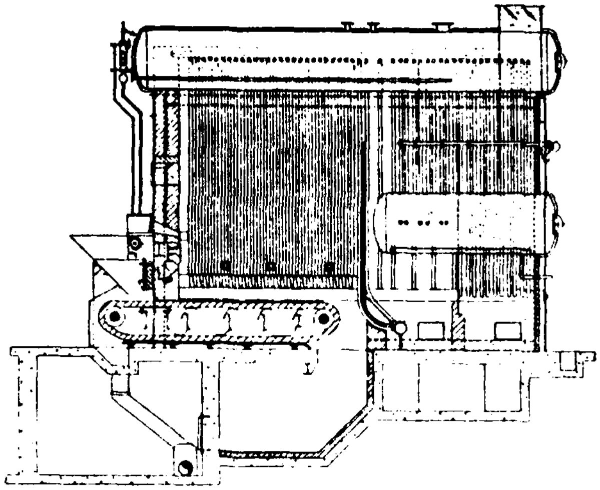


EXHIBIT A-4

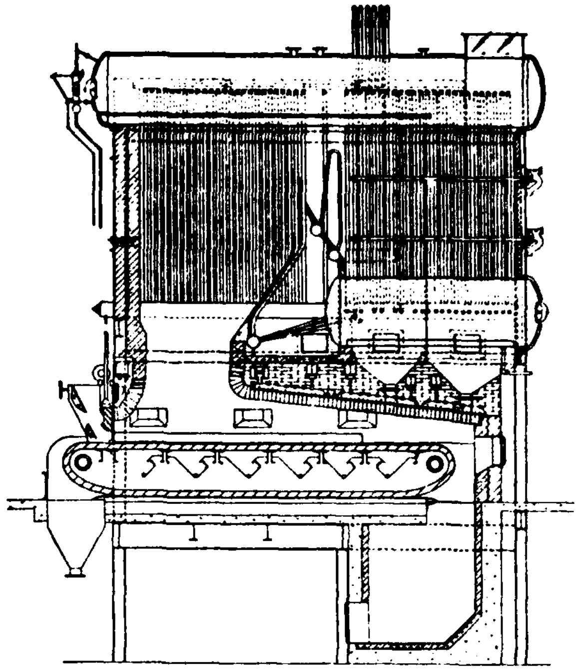
ARRANGEMENT OF TRAVELING GRATE STOKER WITH COAL AND REFUSE SPREADERS

EXHIBIT A-5

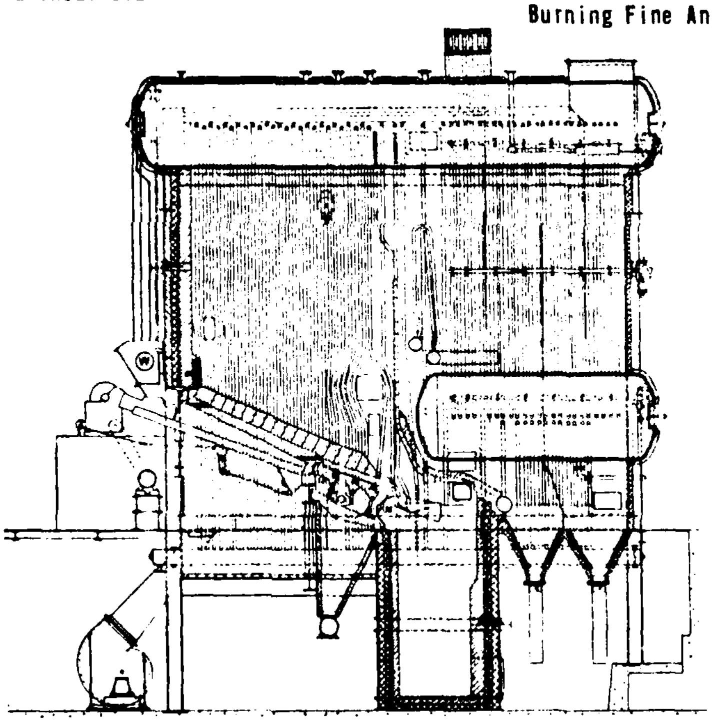
ARRANGEMENT OF COAL AND REFUSE FUEL FEEDER DISTRIBUTOR SYSTEMS



Type CP Boiler and Chain Grate Stoker for Burning Bituminous Coal



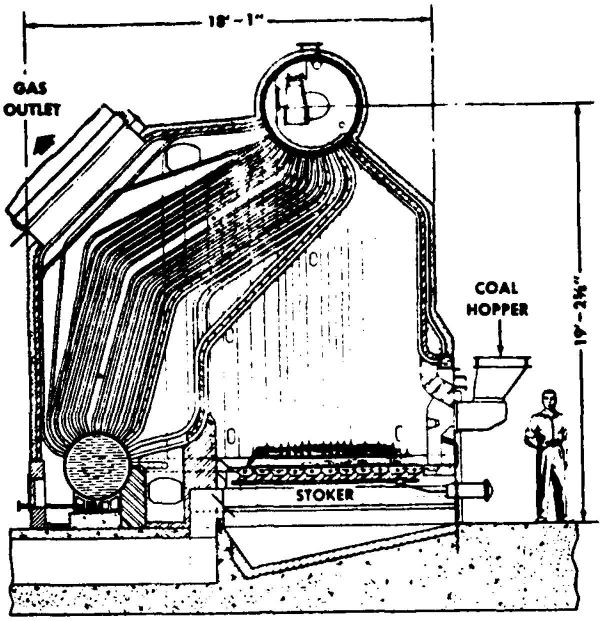
Type CP Boiler and Traveling Grate Stoker for Burning Fine Anthracite Coal



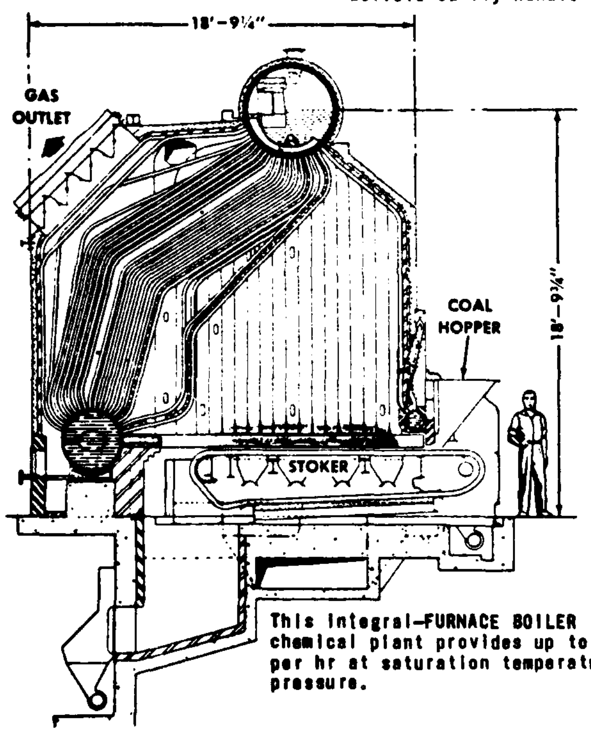
Type CP Boiler, Super Heater and Multiple Retort Stoker

EXHIBIT A-6

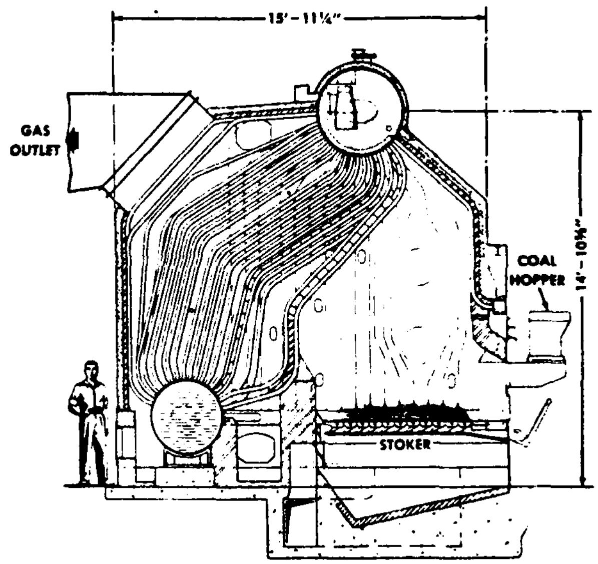
TYPICAL SHOP ASSEMBLED STOKER FIRED BOILER APPLICATIONS



Two Integra -Furnace boilers provide processing steam in a southeastern textile mill. Each unit has a steam capacity o 40,000 lb per hr at 150 lb pressure. The boilers ea ily handle rapidly and widely varying loads.



This Integral-FURNACE BOILER IN A Pittsburgh chemical plant provides up to 30,000 LB steam per hr at saturation temperature and 250 lb pressure.



A southeastern cotton mill obtains up to 17,000 lb steam per hour for processing from this boiler. It initially uses coal fired on a spreader stoker but has a sidewall arranged for future installation of oil and gas burners

EXHIBIT A-7

TYPICAL SMALL INDUSTRIAL STOKER FIRED BOILER APPLICATIONS

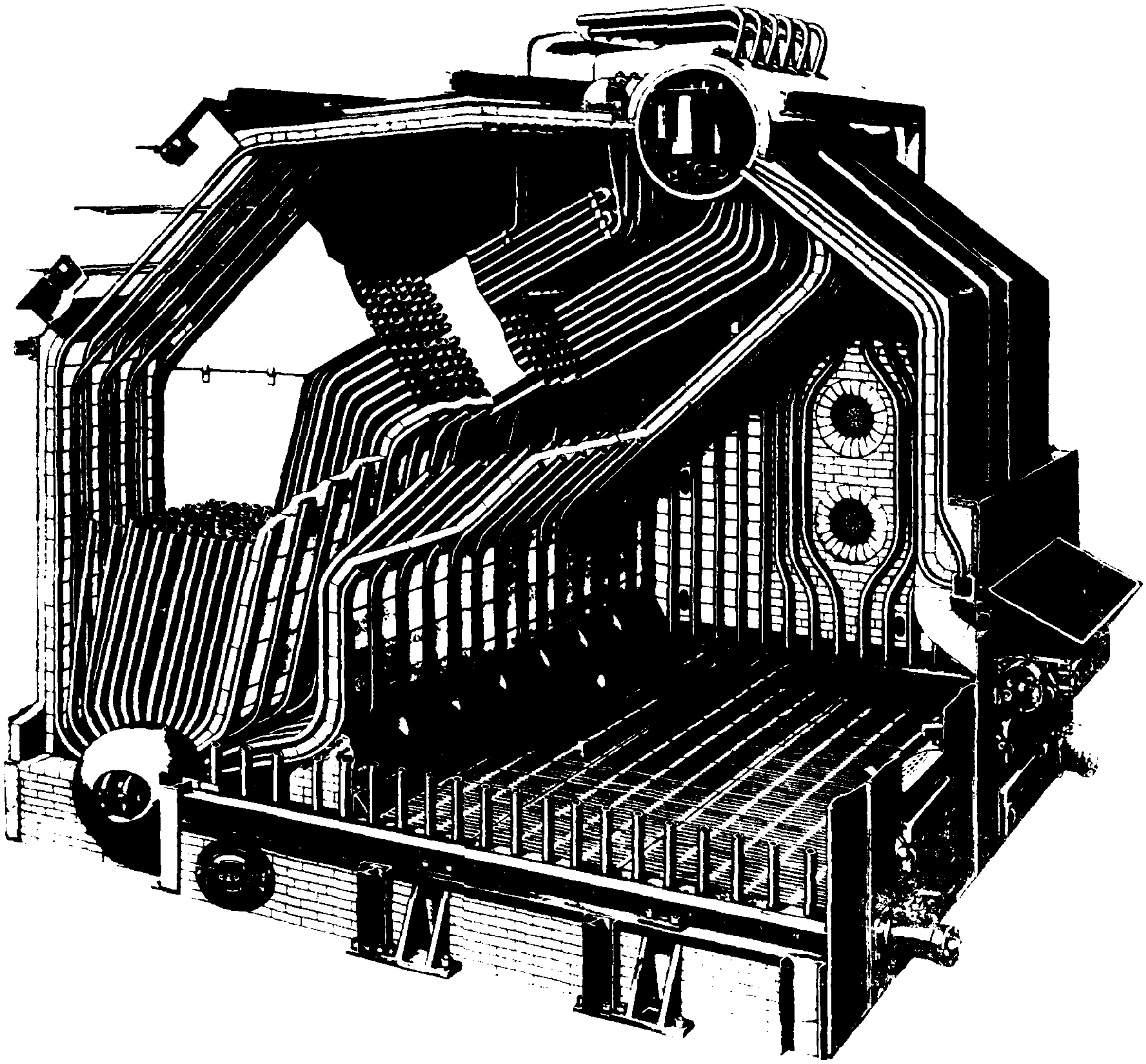


EXHIBIT A-8

TYPICAL SMALL INDUSTRIAL SIZE BOILER ARRANGEMENT
WITH DUMPING GRATE, SPREADER STOKER, AND OIL/GAS BURNERS-
CAPACITY RANGE: 25,000 TO 50,000 LBS STM/HR

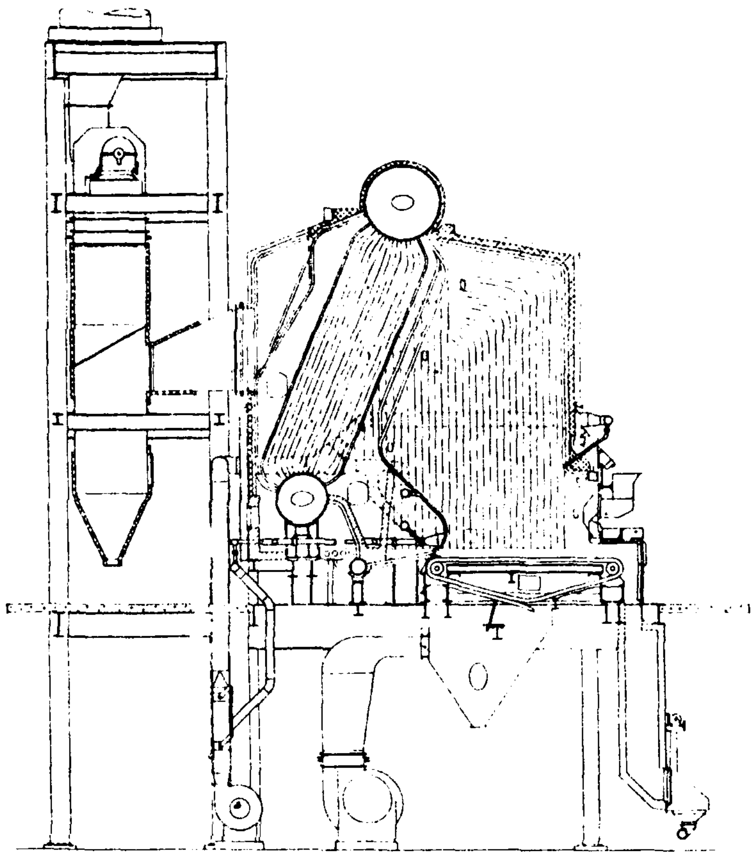


EXHIBIT A-9

TYPICAL SEMISUSPENSION FIRING TRAVELING GRATE SPREADER STOKER INSTALLATION
CAPACITY RANGE: 50,000 TO 90,000 POUNDS OF STEAM PER HOUR

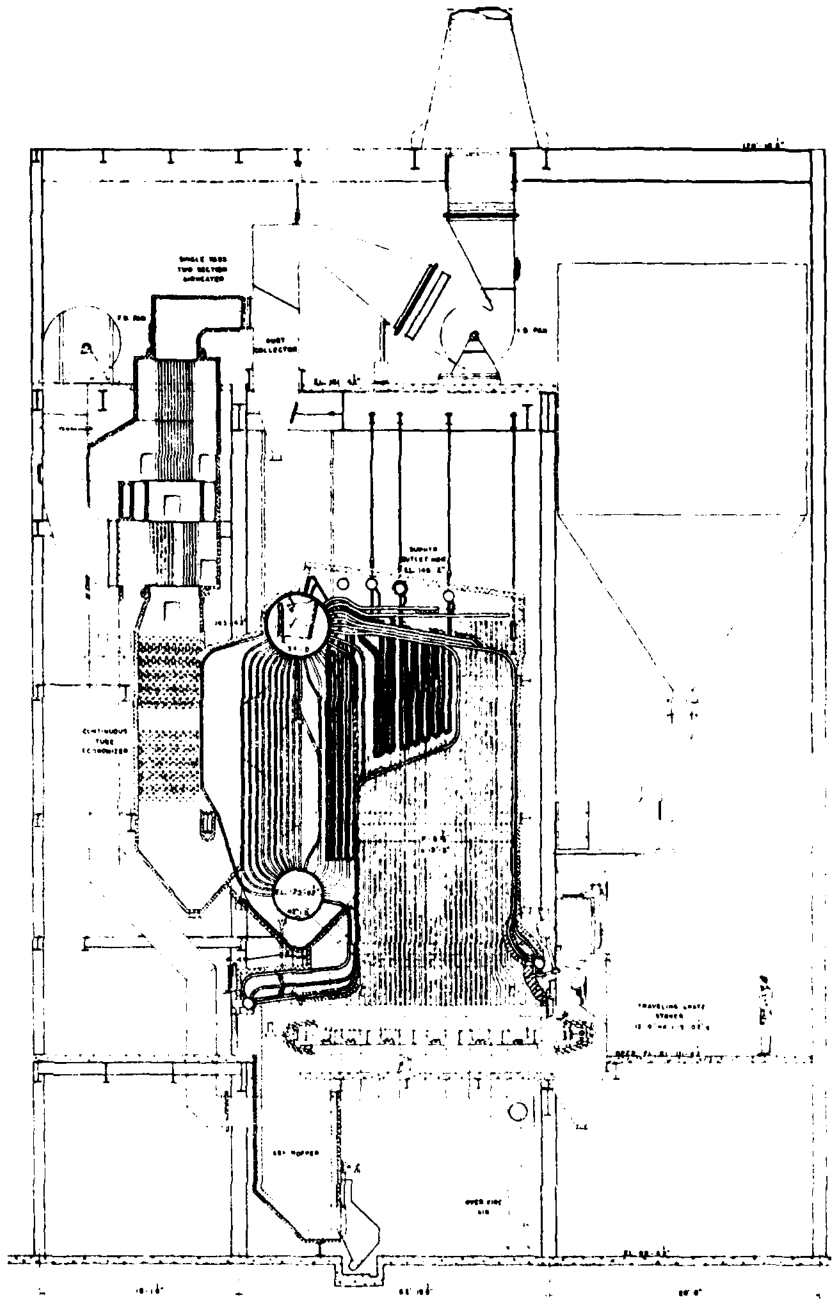


EXHIBIT A-10

TYPICAL MASS BURNING TRAVELING GRATE INSTALLATION
70,000 POUNDS OF STEAM PER HOUR
900 PSIG 900° F TT

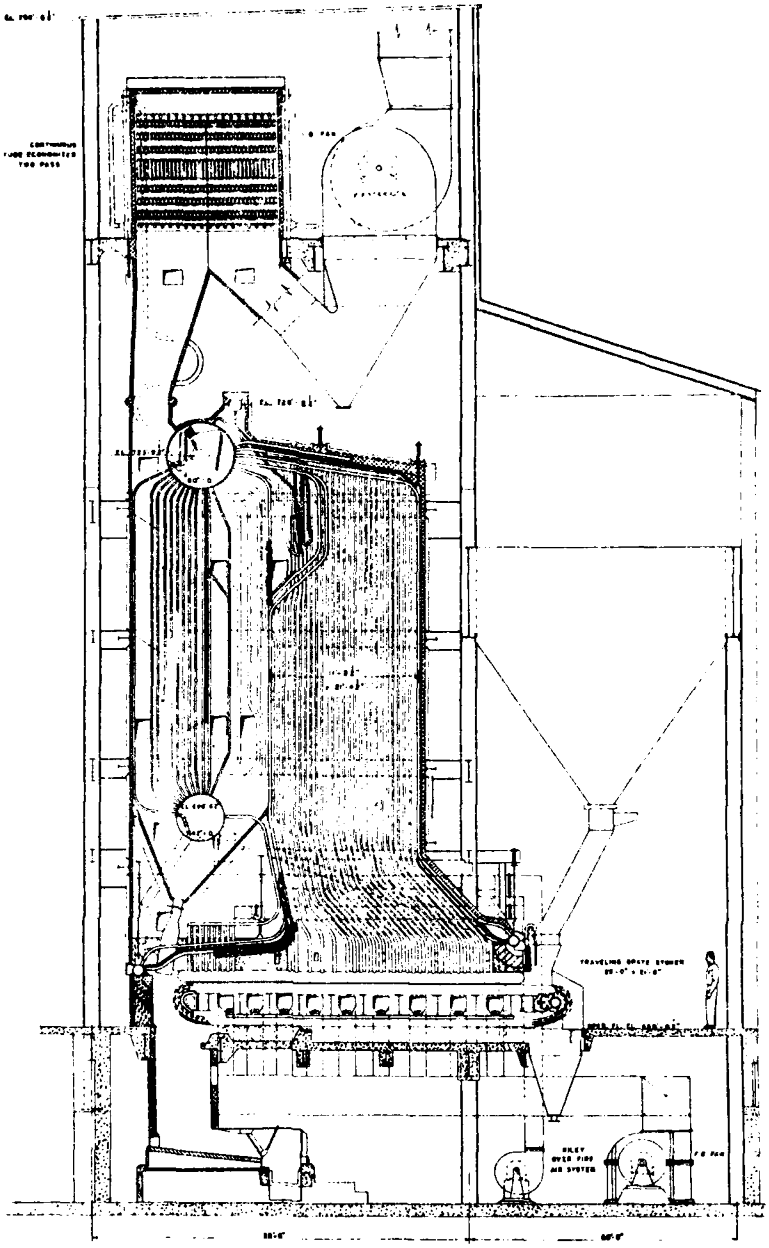


EXHIBIT A-11

TYPICAL MASS BURNING TRAVELING GRATE INSTALLATION
150,000 POUNDS OF STEAM PER HOUR
210 PSIG 442° F TT

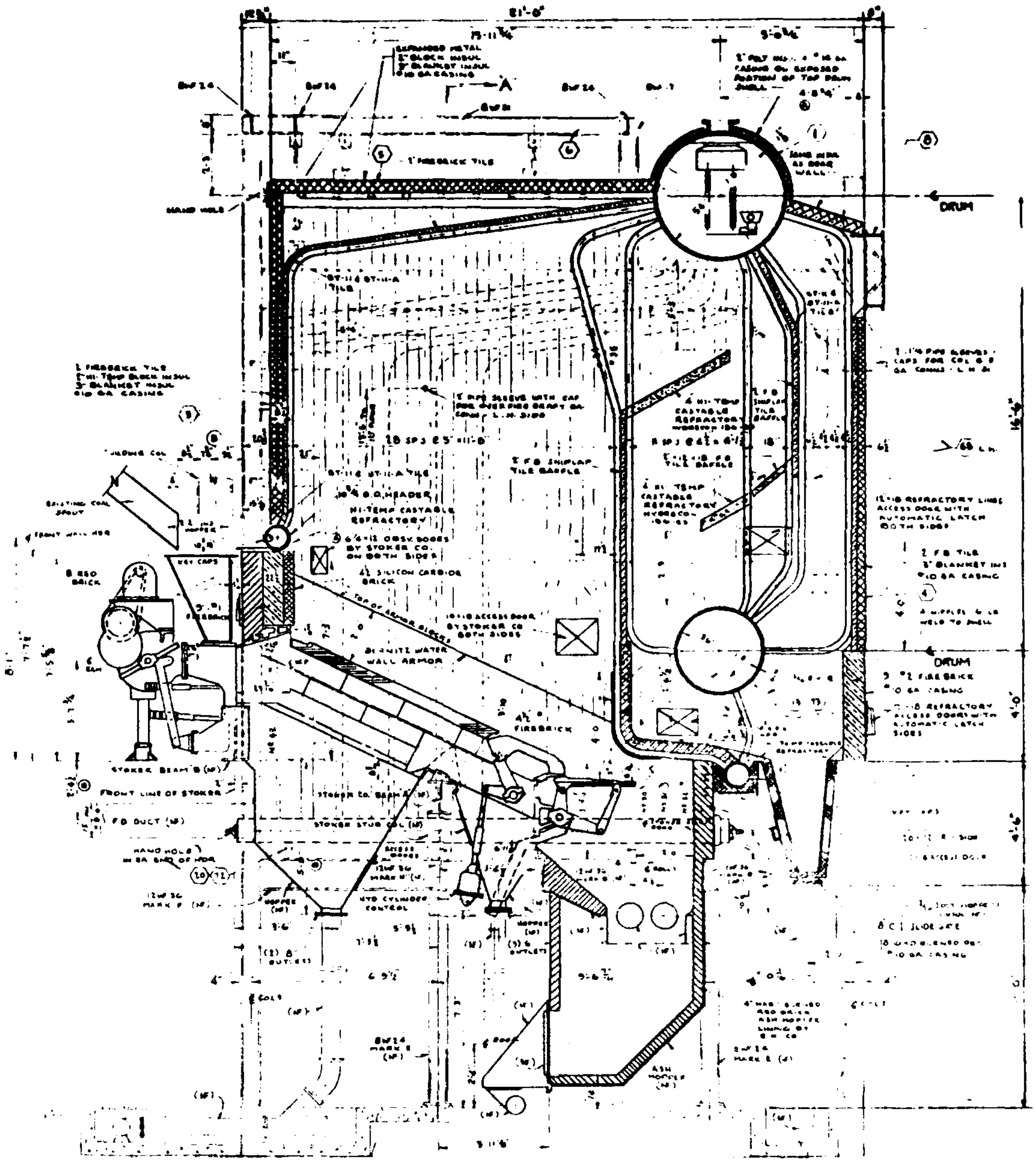


EXHIBIT A-12

TYPICAL MULTIPLE RETORT UNDERFEED STOKER INSTALLATION
50,000 POUNDS OF STEAM PER HOUR
150 PSIG SATURATED

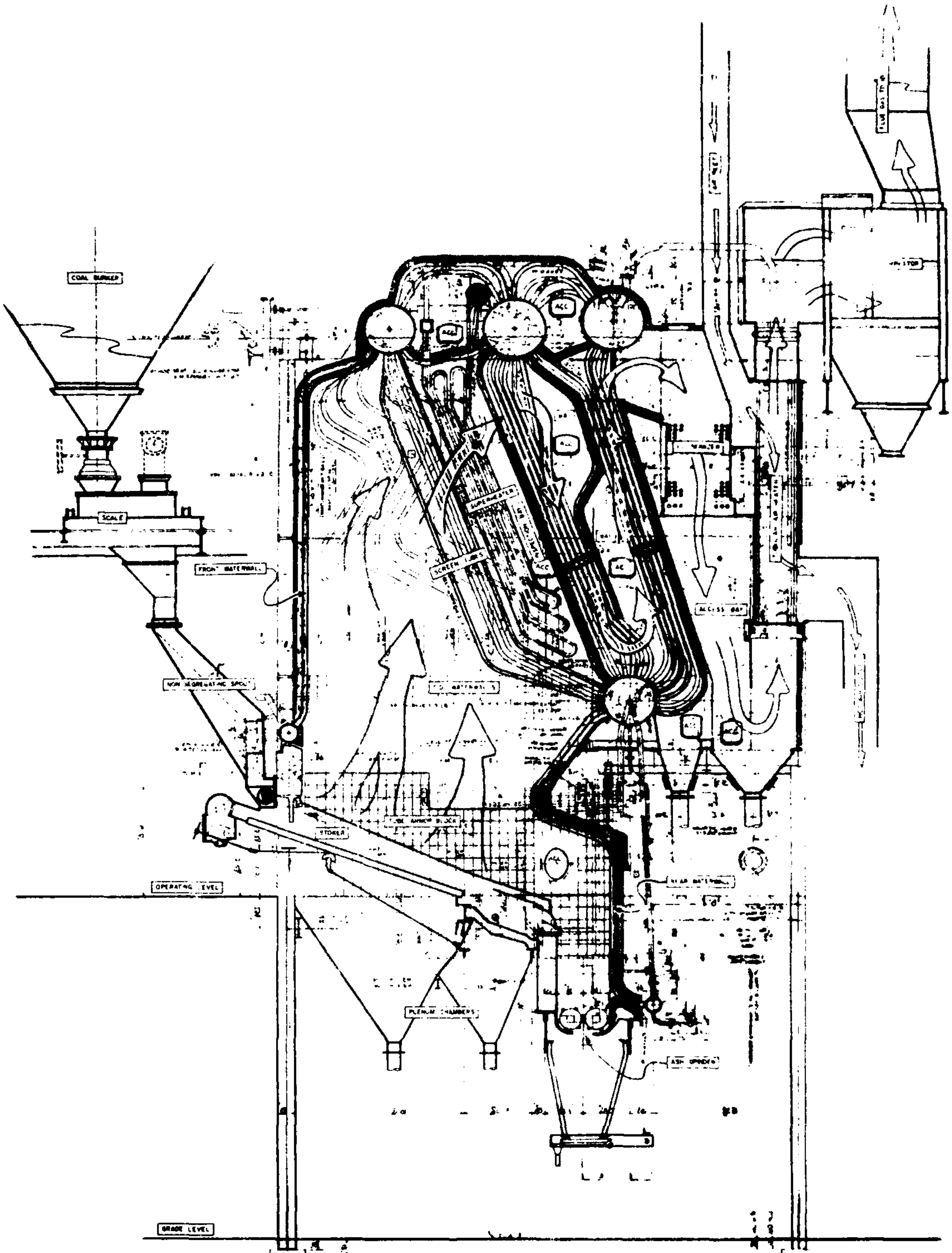


EXHIBIT A-13

TYPICAL MULTIPLE RETORT UNDERFEED STOKER INSTALLATION
125,000 POUNDS OF STEAM PER HOUR
385 PSIG 700° F TT

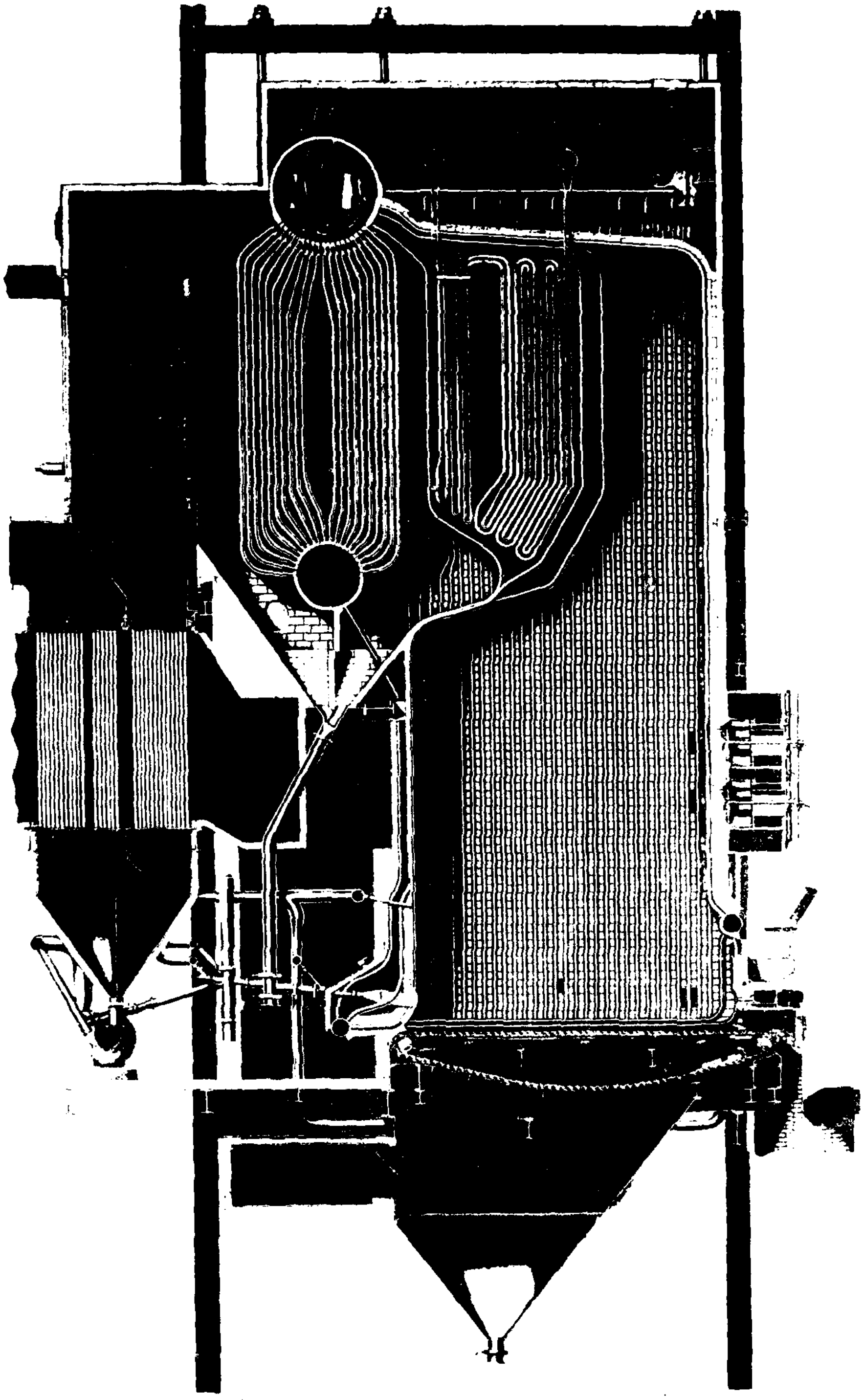


EXHIBIT A-14

TYPICAL SEMISUSPENSION FIRING TRAVELING GRATE SPREADER BOILER
130,000 POUNDS OF STEAM PER HOUR
875 PSIG 910° F TT, 375° FW

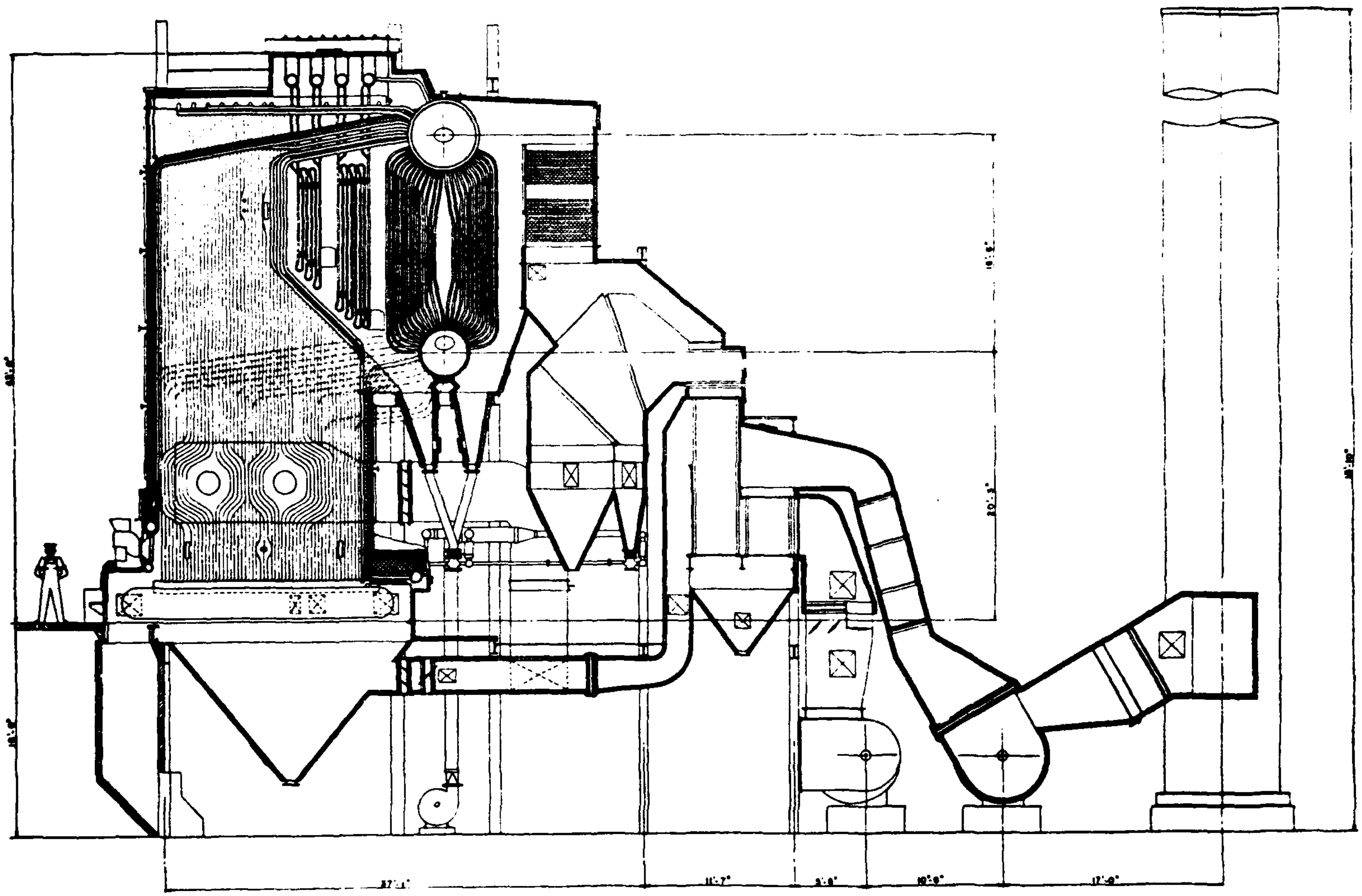


EXHIBIT A-15

TYPICAL SEMISUSPENSION FIRING TRAVELING GRATE SPREADER INSTALLATION
125,000 POUNDS OF STEAM PER HOUR
630 PSIG 830° F TT, 350° F FW

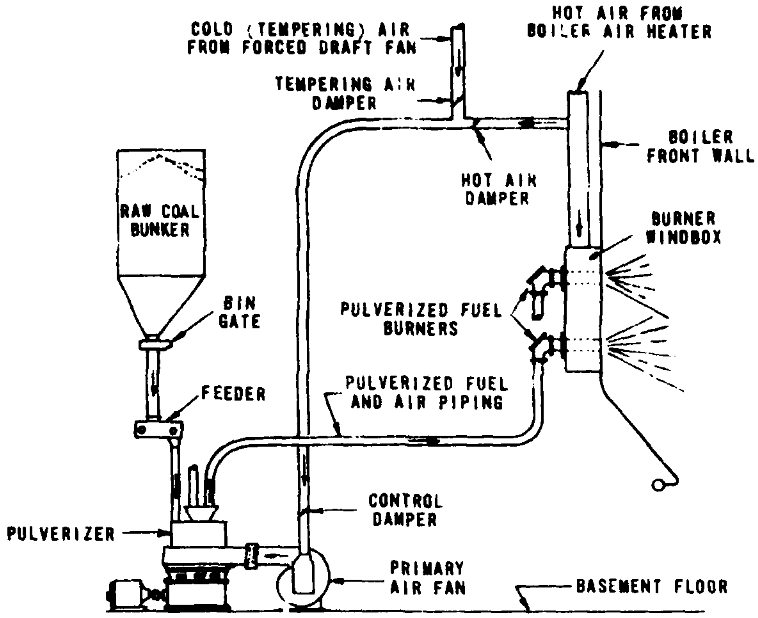
- EXHIBIT B -

FULL SUSPENSION FIRED STEAM GENERATING SYSTEMS

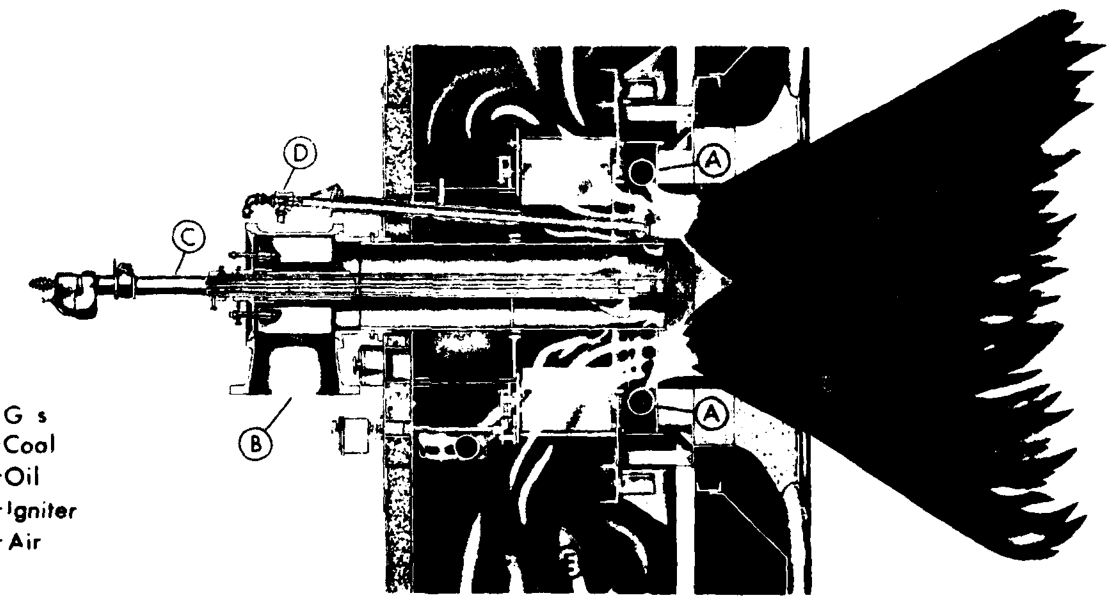
The exhibits included illustrate the basic elements of a typical equipment train for pulverized coal firing, cross section of a circular multifuel burner as well as several applications and typical installations at small and large industrial size heating plants and those generating electric power.

Exhibit B-7 illustrates an intermediate capacity facility designed to consume with tangential burner nozzles, distillate or heavy fuel oil, spent hydrocarbon liquids, dewatered and flash dried industrial wastewater treatment plant sludges, and future pulverized coal.

Exhibit B-6 illustrates a modest size shop-assembled package boiler system designed to burn oil and finely sized, dry hardwood wastes.



DIRECT FIFING SYSTEM FOR PULVERIZED COAL



-G s
B-Coal
C-Oil
D-Igniter
E-Air

EXHIBIT B-I

MULTIFUEL BURNER

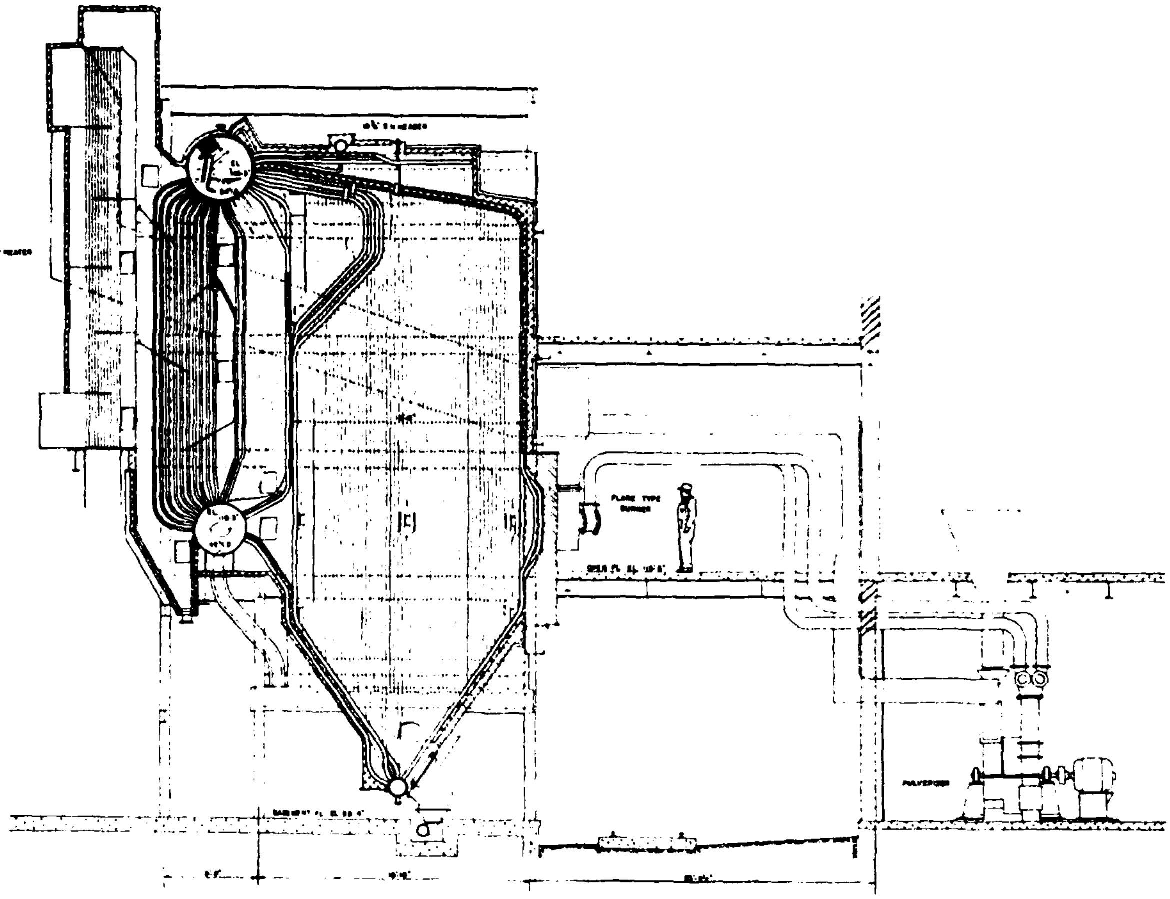


EXHIBIT B-2

TYPICAL FULL SUSPENSION FIRING INSTALLATION
PULVERIZED COAL/OIL/GAS
75,000 POUNDS OF STEAM PER HOUR
450 PSIG SATURATED

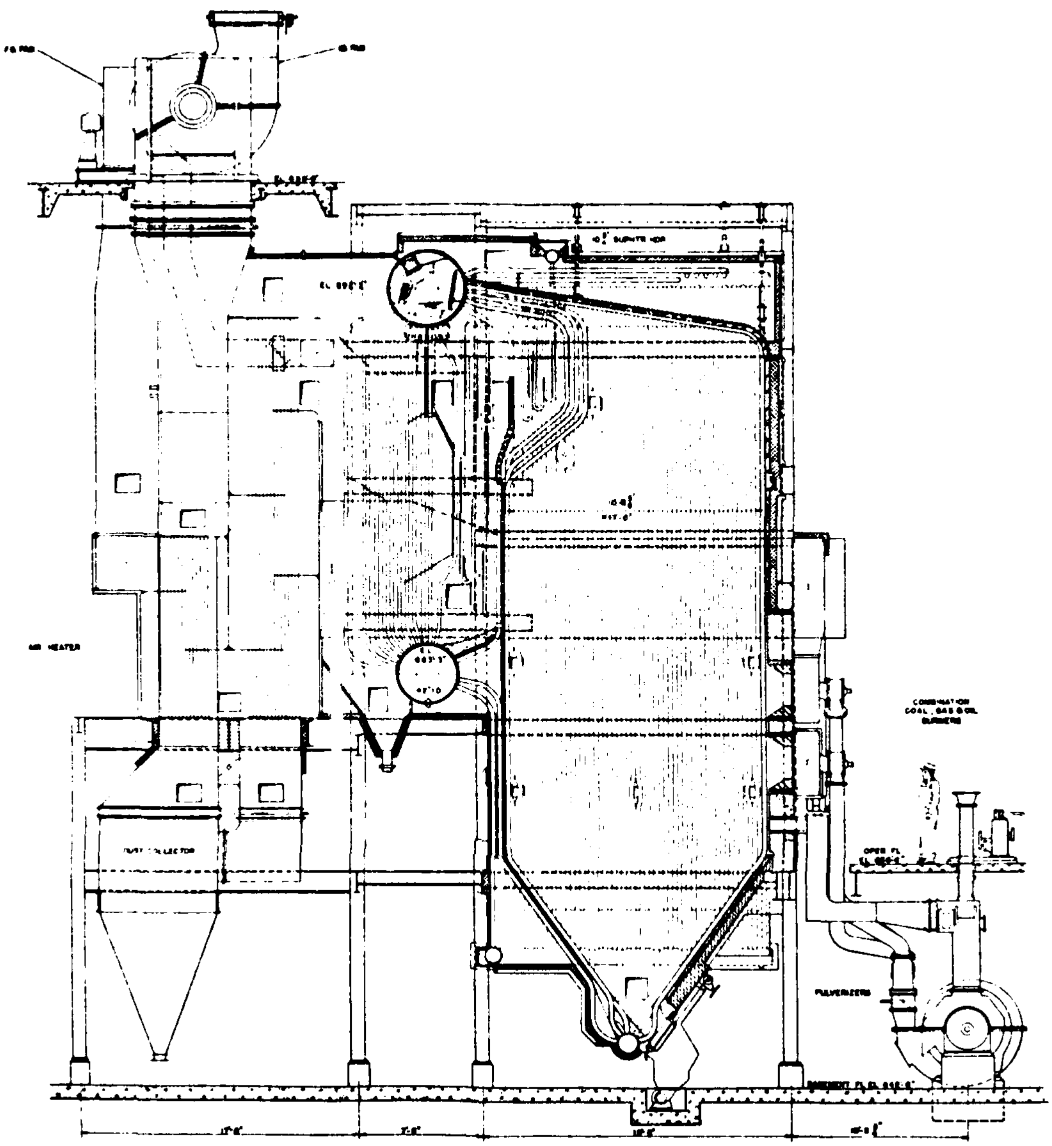


EXHIBIT B-3

TYPICAL FULL SUSPENSION FIRING INSTALLATION
PULVERIZED COAL/OIL/GAS
100,000 POUNDS OF STEAM PER HOUR
725 PSIG 750 F TT

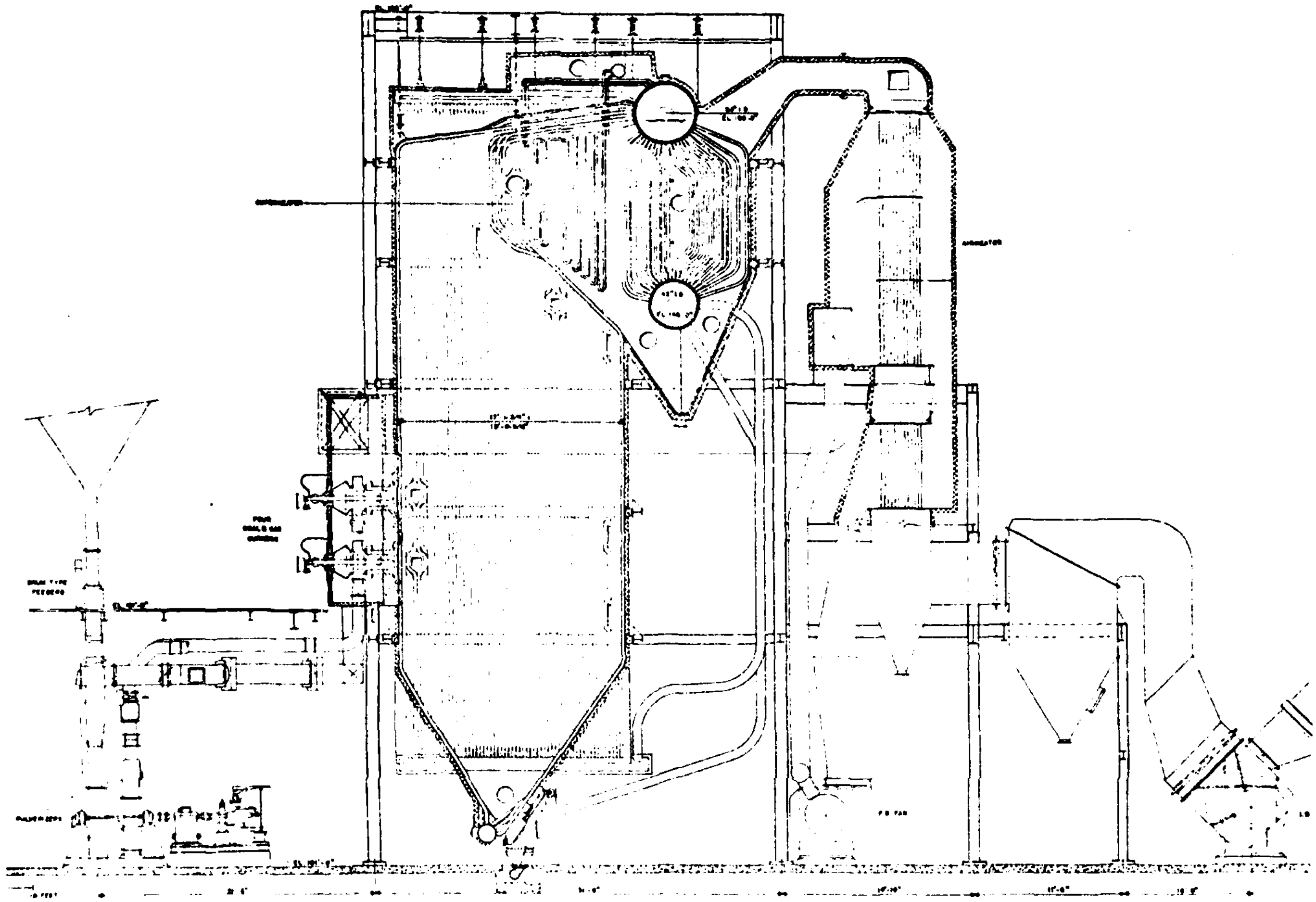


EXHIBIT B-4

MODERN FULL SUSPENSION FIRING INSTALLATION
PULVERIZED COAL/OIL/GAS
165,000 POUNDS OF STEAM PER HOUR
650 PSIG 750 F TT

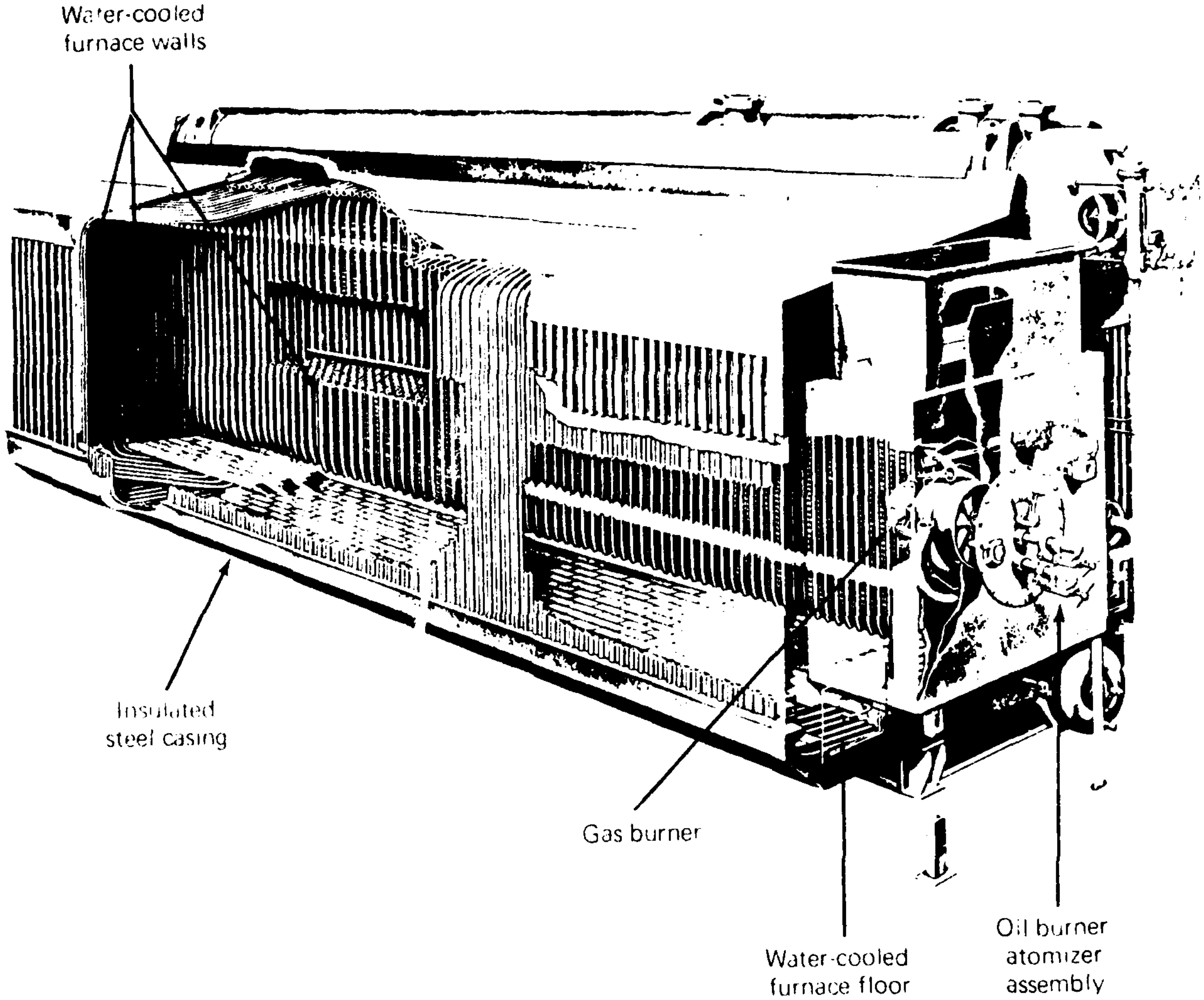


EXHIBIT B-5

TYPICAL SHOP ASSEMBLED PACKAGE D TYPE BOILER ARRANGEMENT
NATURAL GAS AND FUEL OIL FIRING
CAPACITY: 25,000 TO 150,000 POUNDS OF STEAM PER HOUR

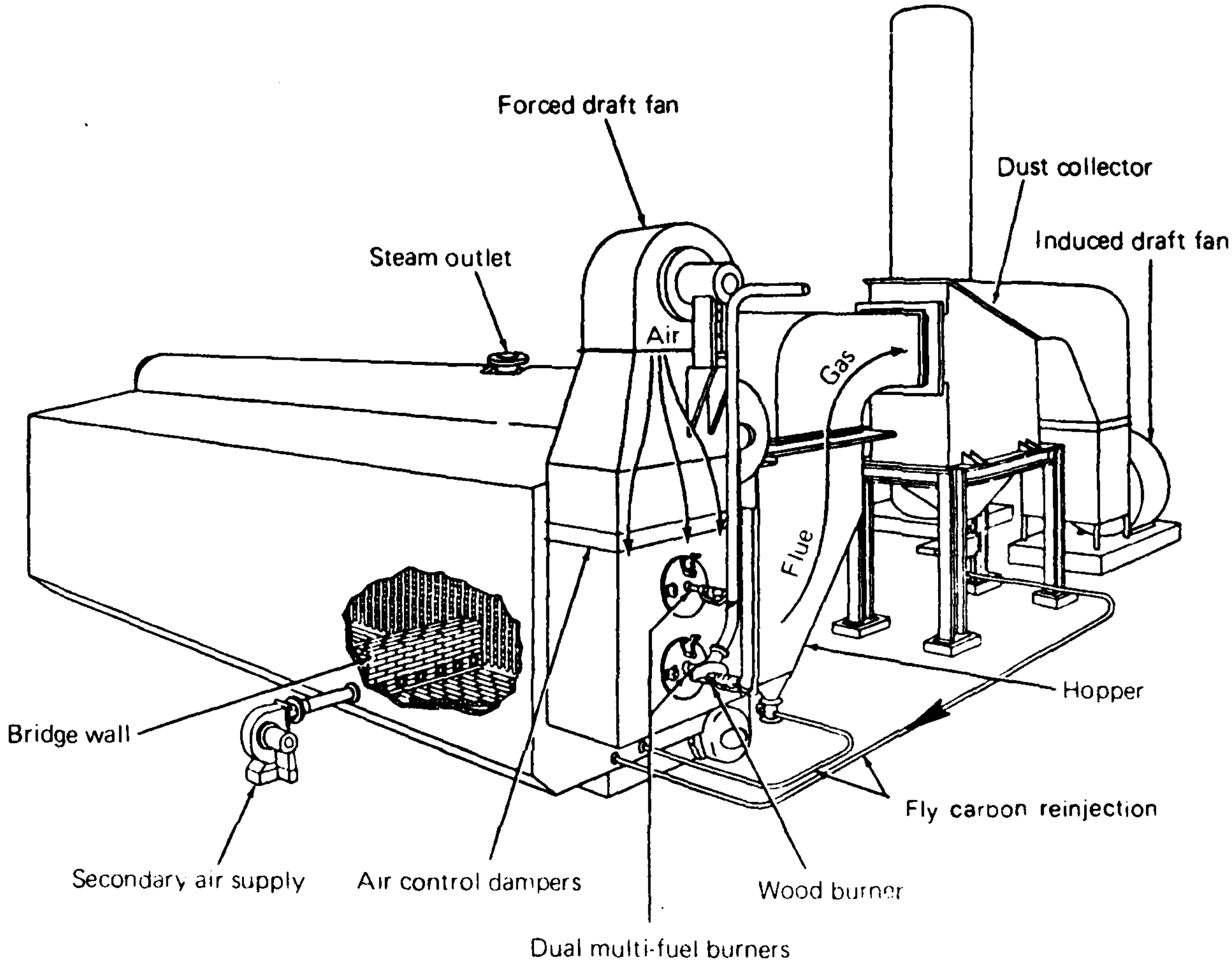
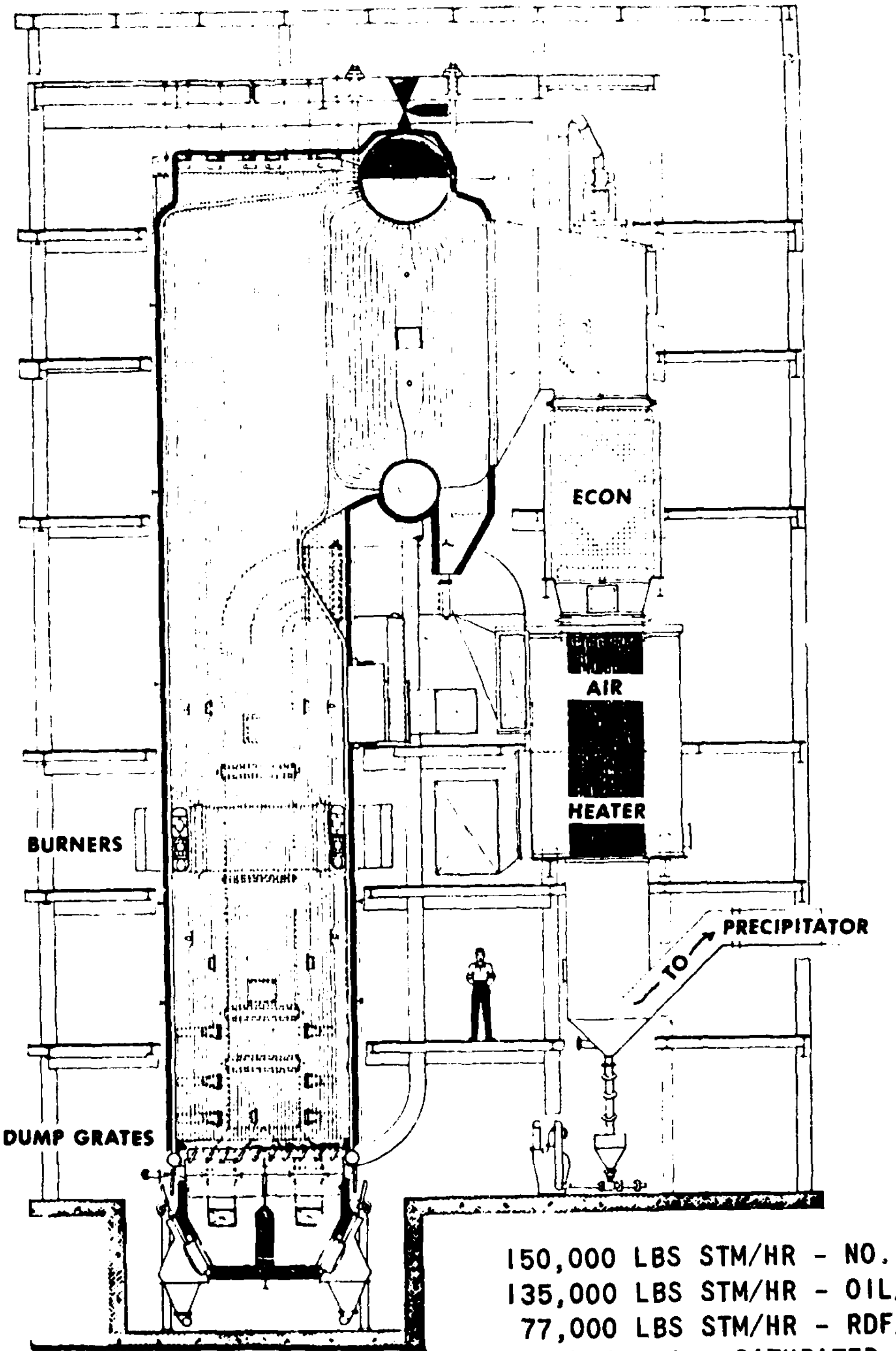


EXHIBIT B-6
SHOP ASSEMBLED PACKAGE D TYPE BOILER INSTALLATION
NATURAL GAS, FUEL OIL AND PREPARED DRY WOOD FIRING
30,000 POUNDS STEAM/HOUR AT 150 PSIG, SATURATED



150,000 LBS STM/HR - NO. 6 OIL/PC
135,000 LBS STM/HR - OIL/RDF/SLUDGE
77,000 LBS STM/HR - RDF/SLUDGE
400 psig, SATURATED

EXHIBIT B-7

FULL SUSPENSION TANGENTIAL FIRING