

A Comparative Study of European and North American Steam Producing Incinerators

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ABSTRACT

The "Energy Crisis" has focused the attention of American engineers on all possible methods of producing useable energy from domestic refuse. Certain areas of Europe long ago faced similar problems of high fuel prices and environmental restrictions, consequently many steam producing incinerators have been in lengthy service. The authors believe much useful information can be obtained by evaluating the European experience and adapting it to American problems.

EUROPEAN PLANTS

The authors have chosen to confine their discussion to steam producing incinerators, thus no discussion will be made of the many fascinating alternative concepts that have not been in commercial operation.

To better understand the almost universal use of steam producing incinerators for plants handling over 120 tons per day, the following significant factors should be considered:

- 1) Population density — West Germany alone has 62,000,000 people in an area less than the state of Oregon.
- 2) While the fossil fuel prices are constantly changing—in many areas of Europe, fuel costs would be considered exorbitant even under today's American prices.
- 3) In many cities in Europe, central (or district) heating provides a ready demand for the output from steam generating incinerators.

4) Frequently the ownership of the incinerator, the district heating system, hospitals, homes for the aged, and the electrical system will be under the same governmental agency so that the steam producing incinerator becomes an integral part of overall planning.

5) In larger size incineration plants the cost and complication of flue gas cooling and cleaning equipment becomes so great that the plant with heat recovery is less costly.

In comparing European problems, the difference in practices must be examined as well as similarities so that accurate evaluations can be made.

The most significant factor is the dissimilarity of composition of refuse utilized by existing steam generating units, not only in the differences between European and American domestic refuse but there can even be differences between adjacent cities.

In many areas of Europe all of the burnable refuse is consumed in the home for heating. This consists not only of paper products, twigs, branches from trees and shrubs, but all other burnable materials. Frequently, the ash from coal burned by householders or small industries becomes a significant portion of the refuse delivered to a municipal incinerator. However, refuse composition can change quickly if natural gas or light oil becomes available.

In Europe it is invariably found that heat recovery with sale of steam and/or electricity by means of waste incineration is profitable. In some plants it has been possible to lower the disposal costs of refuse by more than 30 percent compared to an incineration without heat recovery.

Table 1. Typical European Steam Producing Incineration Plants

City	Date of Service	Stoker Mfr.	Tons of Refuse Per Day	Steam Per Unit				Dust Separation
				Flow lb/hr x1000	Pres. Psig	Temp. ° F	Use x	
Germany								
Stuttgart	1965	VKW	530	110	1095	975	P	E
Darmstadt	1967	Von Roll	250	55	680	840	DH+P	E
Ludwigshafen	1967	Von Roll	250	50	600	805	DH+P	E
Frankfurt II	1967	Von Roll	400	53	910	930	P	E
Hamburg	1967	Martin	320	60	255	645	PA	—
Hamburg	1972	Martin	650	88	585	770	P	E
Nuremberg	1968	Von Roll	400	81	1195	840	P	E
Sollingen	1969	Von Roll	270	55	680	840	P	E
Leverkusen	1969	Von Roll	270	62	285	580	DH	E
(a) Munich II	1966	Martin	1010	178	2560	995	DH+P	—
(a) Munich III	1969	Martin	1010	178	2560	995	DH+P	—
(a) Munich IV	1971	Martin	1010	178	2560	995	DH+P	—
Dusseldorf	1965	VKW	270	140	1280	930	P	E
Bremen	1969	VKW	330	33	355	420	DH	—
Iserloch	1970	Babcock	210	44	355	480	DH	—
Offenbach	1970	VKW	270	57	355	480	DH	—
Landshut	1971	Von Roll	220	15	285	660	DH	E
Berlin	1967	Duerr	330	49	1240	880	P	—
Berlin	1971	Duerr	420	49	1240	880	P	—
Berlin/GDR	—	VKW	400	77	1380	975	P	—
Switzerland								
Basel	1969	Von Roll	400	88	670	660	DH+P	E + cycl.
Zurich	1969	Von Roll	290	62	525	790	PA	E
Luzern	1970	Von Roll	130	28	570	700	P	E
Hinwil	1970	Martin	130	27	555	750	P	—
Zurich	—	Martin	500	84	570	735	P	—
Netherlands								
Den Haag	1968	Von Roll	400	78	570	800	P	E + cycl.
Amsterdam	1969	Martin	600	95	610	770	P	—
Austria								
Vienna	1971	Martin	400	126	455	SAT	DH+P	E + cycl.
Sweden								
Stockholm	1968	Von Roll	130	(W)	230	250/160	DH	cyclones
Umea	1970	Von Roll	130	(W)	230	355/260	DH	cyclones
Goteborg	1970	Von Roll	400	104	285	420	DH	cyclones
Malmo	1969	Martin	230	1140(w)	130	Hot w.	DH	—

x) = Power production
P = District heating

PA = Plant auxiliaries
E = Electrostatic precipitator
s = Oil fired separately
W = Hot water

Table 1. Typical European Steam Producing Incineration Plants (Cont'd)

City	Date of Service	Stoker Mfgr.	Tons of Refuse Per Day	Steam Per Unit				Dust Separation
				Flow lb/hr x1000	Pres. Psig	Temp. °F	Use x	
<i>France</i>								
Rennes	1968	Martin	130	35	385	440	DH	—
Paris	1969	Martin	130	295	1280	675	P	—
Strasbourg	—	Von Roll	390	72	780	860	DH+P	E
Metz	1970	Martin	160	40	215	635	P	—
<i>England</i>								
Edmonton	1971	VKW	370	89	625	850	P	—
Coventry	1972	Martin	320	70	250	405	P	—
Nottingham	1972	Martin	310	53	385	700	P	—
<i>Soviet Union</i>								
Moscow	1970	Martin	220	32	200	380	DH	—
<i>Italy</i>								
Genova	1971	Von Roll	220	42	455	705	P	E
Milano	1971	Volund	270	50	455	825	DH	—
<i>Finland</i>								
Helsinki	1969	Von Roll	90	35	220	660	DH+P	—
Lahti	1969	Lokomo	130	26	570	840	DH	—
<i>Norway</i>								
Oslo	1966	Esslingen	170	44	355	500	P	—

x)

P = Power production
DH = District heating

E = Electrostatic precipitator

OPERATING EXPERIENCE

Experience shows that the availability of a refuse incineration plant is considerably lower than that of a fossil fuel fired plant.

Plant equipment that is especially vulnerable to breakdowns are the hot surfaces of the steam boiler where corrosion, erosion and different types of fouling occurs. In addition, the moving parts of the grates are damaged frequently as well as nonwater-cooled refractory. The handling of the refuse and fires sometimes cause short shutdowns as well as the boiler plugging caused by ash carryover. The reason for the operative disturbances, of course, vary from plant to plant. The frequency of disturbances is great when the plant is new. A greater portion of the disturbances can be eliminated by only shutting the fuel feed for a short period of time. In many plants the boiler unit has to be completely shut down more than 10 times per year.

The total availability of a refuse incineration boiler after a few years of operation varies between 65 percent and 85 percent.

In order to improve the overall plant availability, multiple boiler units are used with additional boilers for spare capacity. In examining the availability figures it must be borne in mind that not only heat and electricity production is involved but that waste disposal is paramount. And because of this, it is advantageous to equip the plant with a 2-day refuse storage capacity.

As a producer of heat, the refuse incineration boiler has such a low availability factor that it obviously affects the profitability of the heat recovery. Any attempts to improve the availability immediately show up in increasing operating costs or greater capital investment costs.

In Western Europe the heat from incineration with a capacity exceeding 120 tons per day has almost, without exception, been used for district heating and electricity

production. (Hot water producing boilers are considered as an acceptable alternate.)

In West Germany, heat from above 100 tons per day plants is commonly sold to the district heating networks. Above 300 tons-per-day plants commonly produce electricity or transport high pressure steam to another power plant.

The trend towards more electricity production has during the past years raised boiler pressures and steam temperature in European refuse incineration plants. Pressures are now commonly 1000 to 1500 psig and temperatures 750 to 925°F. The highest pressures and temperatures are those of the Munich plant where refuse and fossil fuels are burned in combination. Here 2600 psig and 850°F reheat has been used.

REFUSE RECEPTION AND PRELIMINARY HANDLING

The varying composition and collection methods is a problem at many European refuse incineration plants. Ordinary household refuse only represents a part of the total. The rest can be called special refuse. The following examples of special refuse may be mentioned: large size objects from households (e.g. furniture, appliances, etc.) ash, shop refuse (boxes, cartons, etc.), construction waste, auto tires and waste oil. Pure industrial refuse is not accepted in most plants. Special refuse is sorted from the household refuse already at the collection stage. Some communities collect large size refuse separately once a week, which then is treated differently from other refuse.

A prerequisite for good technical and economic operation is a sensible construction. Hence, a condition for economic heat recovery is that the burning equipment and the boiler be matched to form a well-functioning unit, where the requirements of each component have been considered as far as possible.

The fouling problems that are present at the melting point of ash, 1800 to 2000°F, result in the requirement of the construction of a water cooled furnace in the immediate neighborhood of the combustion zone, where the gases cool to a temperature below that of the ash adhesion temperature. Simultaneously a long enough residence time at above a temperature 1500°F is required for eliminating the odors.

The arrangement of convective surfaces must be such that they do not collect ash. Severe erosion must also be taken into account. Hot superheaters are usually arranged as platens, spaced 1-2 feet apart. Bare tubes are often preferred in preheaters. The air heater is often left out and an economizer bank is used. Some manufactures use only vertical tubes and arrange the heat exchange surfaces as downward passes only. This is to avoid pluggage. In addition,

efficient soot blowers must be installed. Water spraying has been used to clean membrane-waterwalls during operation.

It is advantageous to have a vertical flow in the furnace. When at the same time a large enough area-volume ratio is the objective, the furnace, especially in larger boilers, turns out to be high and the cross sectional area becomes small. In working out the grate design this limits the width. This has to be compensated by utilizing the available height. The location of the grate in relation to the cooled furnace is important. With refuse having a very low heating value, the radiation from the fuel bed surface to the cold furnace walls must be minimized. It is common practice to cover all furnace wall tubes with refractory for a distance of 15-20 feet above the grate, using studded tubes covered by silicon carbide plastic refractories.

Refuse collection is usually divided into three areas: community collection, special refuse collection firms, and the portion brought by the private individuals. The share of the private individuals is in some areas surprisingly high. The refuse brought by private individuals is often treated as special refuse, since it has proven necessary at least to check what people bring to the plant.

The special refuse must be sorted into combustible refuse and refuse to be destroyed by other means. What is burnt is dependent on the capabilities of the plant. The combustible portion usually goes first to the crusher. Usually the crusher capacity is less than the incineration capacity. The crushed refuse, which usually has a high heating value, is then evenly mixed with all the other waste. Blending of the refuse to an even mixture has turned out to be very important for a successful operation. Thus, in some plants the crane operator uses 75 percent of his time to mix the refuse.

Burning of refuse oil is not possible at all plants. Refuse oil is usually fired in special burners mixed with fuel oil.

EQUIPMENT SELECTION

The efficiency of a waste incineration boiler is low. The high moisture content and ash content cause the greatest losses. In Europe a 65 percent boiler efficiency may be expected (calculated on the lower heating value).

With heat recovery this naturally affects the construction of the burning equipment since the equipment required for the combustion and the heat recovery have to be compatible. Especially the boiler, which must be constructed for lower grade fuel with higher ash content which is very expensive, thus attempts are made to optimize boiler construction. In some cases the results have not been up to expectations. It must be remembered that an efficient and hygienic disposal of the refuse is the

prime purpose, heat recovery being only second in importance.

In Europe thick fuel bed burning is universally practiced — 3 feet or more at the front of the stoker. The stoker hopper is fed by a traveling crane with a grapple or clam shell bucket. During the last 10 years, a few manufacturers have developed grate designs that have managed to obtain a strong foothold in the European market. They are all based on a moving grate, but the movement varies in type. It is the general opinion that satisfactory complete incineration is only obtainable with a moving grate, since a regular movement of the fuel bed is not possible on a stationary grate due to the varying size of waste pieces and varying density of the refuse.

The forward acting stoker is a sloping grate, where every second grate bar row is moving. The moving row pushes the fuel forward, stirring the grate cover. The grate may be divided into 3 sections in between which is a step to improve the mixing. In the air section the grate is divided into several zones. A high air resistance grate must be used in order to prevent crater formation.

The reverse acting grate functions the same as the forward acting stoker except that the fuel is lifted up by pushing towards the back. This promotes ignition from underneath. This grate design is common in larger plants.

The roller grate consists of consecutively placed cylinders with air openings that turn slowly, moving the fuel forward. This grate is also sloping. The lower end of the grate chamber is generally built as a long vault in order to ensure complete burn-out.

Auxiliary oil or gas is burned in the main furnace when needed. Less than 5 percent combustibles in the ash is achieved despite the fact that the ash content of the refuse can reach over 50 percent. The slag is normally dropped into a quenching bath, from which it is transported by means of conveyors, allowing large objects to pass through. Fly ash from hoppers is sometimes mixed with the slag, but usually handled together with the precipitator dust.

When the ash is loaded on transporting vehicles water is added to prevent it from becoming air-borne during transport.

CORROSION

In an incinerator the same kinds of corrosion can appear as in any boiler. This means that high temperature corrosion with vanadium involved, as well as low temperature corrosion with sulfur involved, occurs in incinerators when conditions make them possible.

In addition, corrosions occur which are unusual in normal boilers. It has also been proven that some fuel

components act as a catalyst to increase the reaction rate of the corrosion processes.

According to recent research results by VGB ("Association of Large Utilities", West Germany), corrosion caused by chlorine compounds is very typical in incinerators. In fact, it is claimed that no other corrosion processes have any importance compared to those when only high temperature zones are considered.

The main source of chlorine is PVC, which can have a chlorine content of 56 percent. The amount of PVC in the refuse is increasing continuously. During combustion hydrochloric acid, HCl , is formed. This condenses on the relatively cool furnace or primary superheater tubes. The two most important corrosion mechanisms are considered to be:

a) when air deficiency occurs locally the hydrochloric acid reacts with the tube material or its protection oxide layer, forming FeCl_2 , which is evaporated and carried away. When excess air is available this reaction does not take place or is very slow. Thus, this type of corrosion can be avoided by using enough excess air properly distributed.

b) Where metallic steel is exposed to combustion gases, FeCl_2 is formed besides a protective oxide layer. As the oxide layer increases in thickness and strength, the formation of FeCl_2 becomes slower. This type of corrosion takes place in new boilers or at locations when heavy erosion wears the protective layer away or where soot blowing is too heavy. Possibly the reaction is the same as in a) when it is considered that the formation of oxide consumes the oxygen, thus causing an oxygen deficiency.

Avoiding places of local oxygen deficiency is a difficult task. The usual method is to use a high overall air-fuel ratio, 50-100 percent, over the stoichiometric. Because of the long grate construction in most incinerators, the composition of the combustion gases varies very much from one place to another along the fuel bed. An efficient mixing of the combustion gases is, therefore, a method to avoid local oxygen shortness. The mixing can be made by means of high velocity secondary air jets. Where local corrosion nevertheless occurs, it is often most practical to protect the metal surfaces with thin layers of refractory supported by studs on the tube walls.

The sulfur content of the flue gases is usually much lower than in oil or coal-fired boilers. Hence, sulfate corrosion is of minor importance in incinerators. Low temperature corrosion can, however, be severe. This may be due to catalytic oxidation of SO_2 at medium temperatures of 600 to 1700°F. A variety of catalysts can be found, e.g. vanadium, lead, sodium and potassium. Also, other components may influence either the SO_3 -formation or the corrosion rate.

Alkaline sulfates of different kinds play obviously an important role in intermediate temperature corrosion cases. The mechanism of these processes is not known in great detail. Relatively highly corrosive Na- and K-sulfates have been found in many boilers. Their corrosion maximum is in the temperature range of 900 to 1300°F but, as mentioned above, sulfate corrosion is not the major problem in incinerators.

AIR PROTECTION

The flue gases contain solid as well as gaseous pollutants. The concentrations vary very much from one plant to another. The dust content, entering the precipitator calculated to 12 percent CO₂ content of the flue gas, is 1.5...7.5 grains/st.cu.ft. As a mean value 3.5 grains/st.cu.ft. may be used. It must be observed that during sootblowing the concentration can be considerably higher.

The content of sulfur oxides is usually small compared to gases from oil or coal burning. A major part of the sulfur oxides may be from the auxiliary firing. Restrictions to the emission of sulfur dioxide from incineration have not been set by any country in Europe.

Formation of hydrochloric acid can become an environmental problem. With a PVC-content of 2 percent, not unusual today, the flue gases contain about 690 ppm HCl at a 12 percent CO₂ level. No rules exist concerning allowable emission, but existing emission rules or recommendations may locally force to build a high stack because of the HCl-emission. HCl can relatively easily be scrubbed out of the gases because it is very soluble in water. It is, however, not easily separated from water and can thus form a water pollution problem.

Most counties already have limits to the dust emission. The most common limit is 0.106 grains/st.cu.ft. Collection efficiencies of about 97 percent are thus needed in most cases.

Electrostatic precipitators are used in all modern plants. Some years ago there were some difficulties with low resistivity paper flakes passing through the electrostatic precipitators. A number of plants were then equipped with an additional dynamic separator after the electrostatic. This caused an additional pressure drop of approximately 2 in H₂O. Modern electrostatic precipitators have an improved shape of plate electrodes to collect weakly charged particles and additional mechanical separators are usually not required.

NORTH AMERICAN PLANTS

The use of steam producing refuse incinerators in North America is comparatively new. The number of plants and

the total operating experience is far less than that in Europe.

In examining the background, the great economical, political and ecological differences as compared to European conditions, at the time that these plants were conceived and authorized should be borne in mind. Significant factors were:

- 1) Low average population density, with only minor pollution problems in many areas.
- 2) Abundant sanitary land fill areas, where refuse could be used to reclaim unuseable land for residential, industrial or recreational purposes.
- 3) Central or district heating systems uncommon and confined to the central core of larger northern cities.
- 4) High labor and equipment cost.
- 5) Low cost electricity, oil and gas.
- 6) Little if any household coal ash.
- 7) Erratic demand and prices for iron or steel scrap.
- 8) High heating value of domestic waste.

In most cases the principal justification for steam producing incinerators was on the basis of volume reduction of material to be hauled to sanitary landfill. Frequently there was no opportunity for sale of steam, so that steam not used by the plant itself was condensed and the heat dissipated to the atmosphere. Montreal and Norfolk Navy Yard are the only plants that are using steam in district heating systems. Even today attempts to sell steam to private industry has not met with success.

As heating value of refuse has continued to increase, and the water and air pollution requirements became more severe, the use of water cooled furnaces with boilers and air heaters and/or economizers became justified. Since, however, commercial power generation has not been included, only low pressure boilers have been used.

The installations can be segregated into the following categories:

1. Modified European designs, with a thick bed of 3 feet or more, and stokers of the same configuration proven in European operation:
 - (a) with water walls protected by refractory for 15 or 20 feet above the stoker;
Montreal
Chicago Northwest
Harrisburg
Oceanside
 - (b) with refractory protection only at grate line;
Braintree
Norfolk
2. Complete departure from European design, with spreader stokers, thin bed burning on traveling grates and

Table 2. North American Steam Producing Incinerator Plants

City	Date of Service	Stoker Mfg.	Tons of Refuse Per Day	Steam Per Unit				Dust Separation
				Flow lb/hr x1000	Pres. Psig	Temp. °F	Use x)	
Canada								
Montreal	1971	Von Roll	4x300	100	225	500	DH+PA	E
New York								
Oceanside	1965	Flynn & Emrich	2x200	550	325	SAT	PA	E (b)
Virginia								
Norfolk	1967	Detroit	2x180	50	150	SAT	DH+PA	E (b)
Illinois								
Chicago (Northwest)	1972	Martin	4x400	110	250	SAT	PA	E
Pennsylvania								
Harrisburg	1972	Martin	2x360	98	250	SAT	PA	E
Massachusetts								
Braintree	1972	Riley	2x120	36	250	SAT	PA	E
Missouri								
(a) St. Louis (Union Electric)	1972	None	1x200	1250	2400	1000	P	E
Ontario								
Hamilton	1972	Detroit	2x300	106	300	SAT	PA	E

x)

P = Power production
 DH = District heating
 PA = Plant auxiliaries

E = Electrostatic precipitator
 a = 15 percent refuse in pulverized coal fired boiler
 (b) = Being added

refractory protection at grate line, and continuous ash discharge;

East Hamilton

3. Complete departure from European design, with refuse suspension burning as supplemental fuel in a large pulverized coal fired electric utility steam generating plant;

Union Electric

EQUIPMENT SELECTION

Where thick bed burning is practiced, the equipment selection parallels that shown on Fig. 1 for European plants, except that metal baling equipment is eliminated.

The East Hamilton plant is a complete departure from European design in that extensive fuel preparation to shred domestic refuse, remove metal and large non-combustible material before feeding to the stoker is practiced. Then a traveling grate stoker with ash discharge at the front burns the fuel — partly in suspension and the remainder in a thin bed in a water walled boiler that is essentially a duplicate of the many wood refuse burning

units used in the forest products industry in Canada and the U.S. An electrostatic precipitator is used to clean up the gases.

The Union Electric plant shows a complete departure from European practices in that domestic refuse is prepared in East St. Louis through shredding and metal and noncombustible removal before the material is hauled a number of miles to the Union Electric plant. The material is then conveyed pneumatically to existing pulverized coal boilers that are in regular service providing steam for power generation. Refuse fuel at times has provided from 15 percent to 20 percent of the boiler output.

OPERATING EXPERIENCE

The operating experience has varied from plant to plant. In all cases, continuity of services has been provided for by using multiple units.

As some of the plants are going through initial operation, a comparison with the plant shown in Fig. 1 would be meaningless.

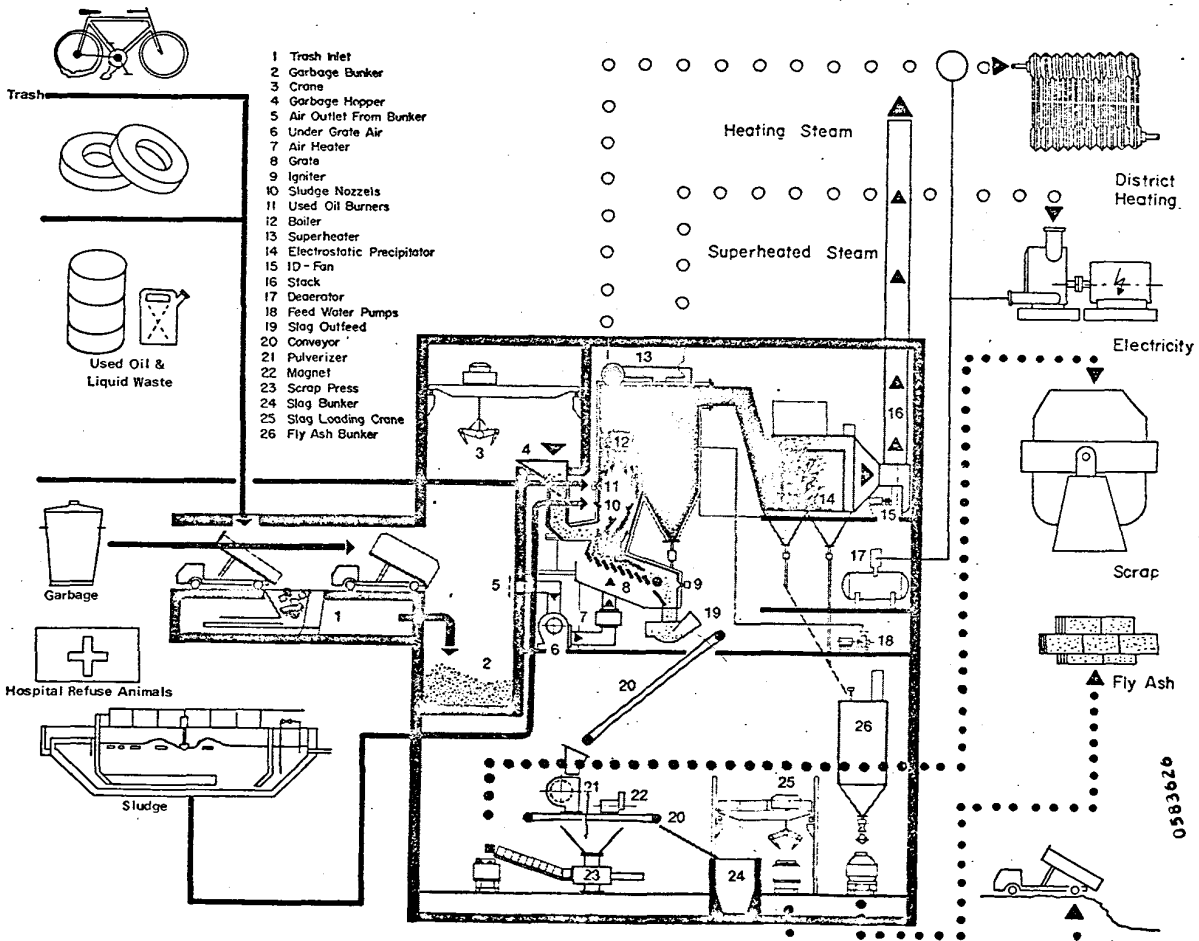


FIG. 1. MODERN EUROPEAN PLANT.

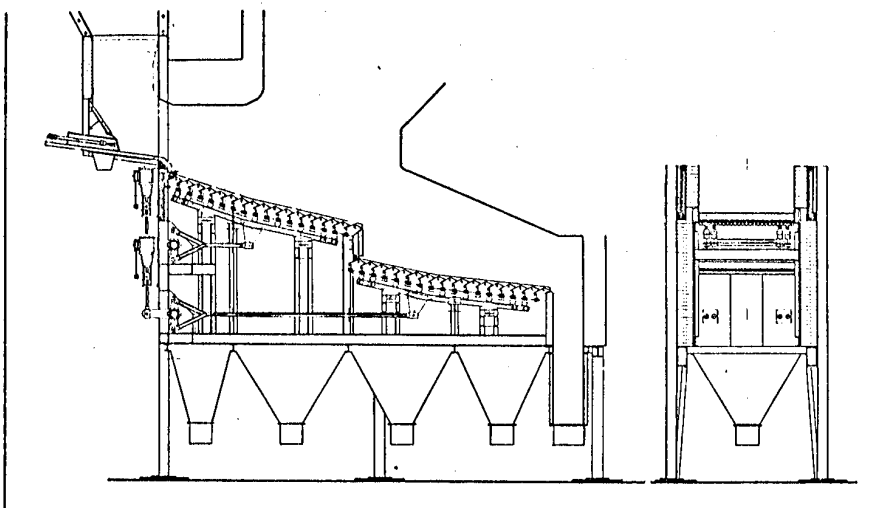


FIG. 2 OPPOSED MOTION REVOLVING GRATE.

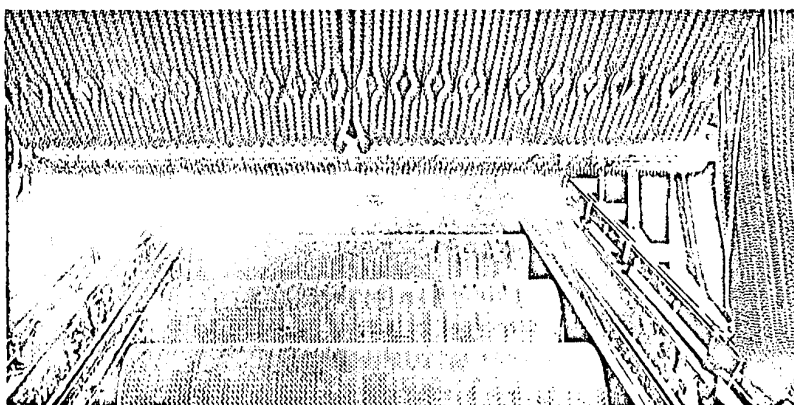


FIG. 3 ROLLER GRATE INSTALLED IN MODERN WATER WALL FURNACE (BEFORE APPLICATION OF REFRACTORY).

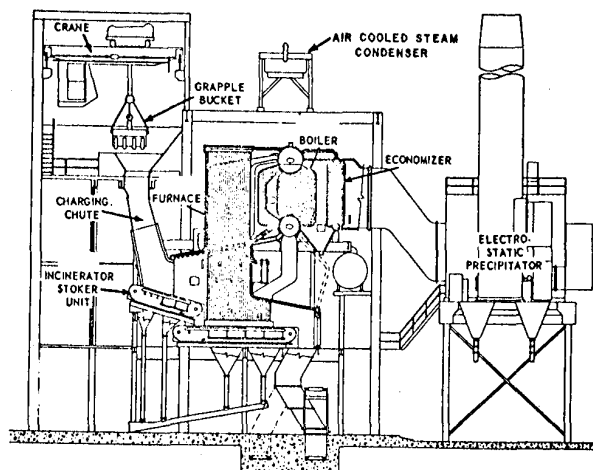


FIG. 4 CHAIN GRATE STOKER.

[illegible]

In general, after the shake-down period, the availability has been as good or better than that of European plants.

CORROSION

In evaluating corrosion all of the operating factors must be considered. Reports vary from little or no water wall or boiler corrosion, to such severe corrosion that one Ocean-side boiler is being completely replaced in less than seven years operation.

When the water walls are refractory protected for 15 or 20 feet, it would be reasonable to expect minimal corrosion at the low operating pressures involved.

Surprisingly enough no corrosion has been observed at East Hamilton, Braintree or Norfolk even though the refractory protection is limited to grate line areas. However, refuse is not always burned 24 hours per day and there are periods when gas or oil is burned without refuse.

No corrosion has been observed in the combination firing of refuse and pulverized coal at Union Electric.

To date the refuse load has been a small fraction of the total fuel burned.

Before definitive conclusions can be made on corrosion problems of the latest installations more operating time at design refuse burning capacity will have to be accumulated.

ASH AND SLAG DISPOSAL

Markets have not been developed for slag and flyash. The scrap metal market has been sporadic — prices as low as \$10.00 per ton have been quoted. Chicago Northwest has been able to develop long term contracts. Some of the other plants dump their metal with the slag. Oceanside

uses part of the scrap metal to construct the berm around their sanitary landfill.

AIR PROTECTION

While some of the earlier plants were installed with low efficiency collection devices, these are now all being replaced with electrostatic precipitators.

All the newer plants have included electrostatic precipitators which have demonstrated that they meet today's stringent air pollution requirements.

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