

OVERCOMING OBSTACLES TO ENERGY  
RECOVERY FROM INDUSTRIAL WASTES

by

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INTRODUCTION

In man's history, technology has not been the limiting factor in problem solving. It can, therefore, be argued that any existing obstacles to the recovery of energy from industrial waste will yield to the application of technology and engineering; but we must ask ourselves whether we are working on the right leverage in considering energy from industrial waste as having the potential of a major contribution to keeping the cost of energy down and stretching the supplies of fuel.

This presentation intends to demonstrate that the obstacles to energy recovery from industrial waste are a) primarily a problem of economics and b) a problem of engineering economics. Further some specific comments on technological problems involved in the utilization of fluidized bed combustion will be presented as a means of stimulating interest in funding the research which will result in the perfection of the technology.

Before proceeding, a definition of industrial waste is also needed because of the extreme variety of wastes generated in industrial operations. For the purpose of this discussion, industrial waste is intended to comprise essentially only process waste of industries generally in the SIC 28 classification except SIC 281, the industrial inorganic chemicals, and 287, agricultural chemicals.

A) - WASTE AVAILABILITY IN PERSPECTIVE

When reviewing the many studies made on the total quantities of wastes generated, it is at first staggering to see the quantities involved. (Table I) It is quite another matter, however, to consider how much of this waste would actually be available for the generation of energy. It has been calculated that ten percent of our electrical energy requirements could be furnished by the combustion of municipal solid waste. Given the availability of municipal solid waste for combustion this may well be true some day. Projections of total waste generation indicate quantities five times higher than municipal solid waste alone, which given the same availability might provide the opportunity for generating 50 percent of our electrical energy requirements from the burning of waste. This is totally unrealistic and the 1975 MITRE report places estimates on the quantities available for combustion. (Table II) The availability of the waste for burning does not presume its suitability and this we still do not have a measure of the significance of energy from waste in total perspective.

ERDA is being accused of ignoring the energy production potential inherent in waste combustion, [1] but a look at total energy consumption projections indicate the relative minor role which energy from waste could play. If ten percent of our electrical generation could be furnished by energy from waste and if electrical energy generation accounts for 25 percent of total energy consumption, then by 1985 the total energy

from waste will still only account for 2.5 percent of total energy consumed and at the 50 percent level of electrical energy supply could move into the range of the share of natural gas near 12 percent of total energy consumed. ERDA undoubtedly must direct its attention to these possibilities, but the lack of interest at this point in time seems understandable. (Table III)

Virtually no data seems to be available yet, at least to my knowledge, concerning the quantities of chemical processing wastes in accordance with the definition established as a frame of reference for this discussion. EPA is said to be working on this subject, and there is for example the 1976 report on Hazardous Waste Generation, Treatment and Disposal in the Pharmaceutical Industry. [2] Projections as shown in Table II tend to overlap considerably, but a gross estimate could be arrived at by considering the relationship between fossil fuel consumption, hydrocarbons used for chemical manufacturing and assuming an arbitrary average process yield. The assumptions are: Of 75 trillion MJ (71 quadrillion Btu) consumed in 1976, 75 percent are furnished from oil and gas. Total oil and gas consumption are represented to 95 percent by energy use and five percent by organic chemical manufacturing. Five percent of the total quantity of liquid and gaseous fossil fuels consumed at 41,870 KJ/kg (18,000 Btu/lb.) equal a consumption of 73 million metric tons (80 million U.S. tons) per year for chemical manufacturing. At an average 80 percent process yield the waste available for combustion should be in the 14.5 million metric tons (16 million U.S. tons) per year range. Generally these wastes have high heating values and are virtually totally available for combustion since they are generated in concentrated conditions and easily identifiable locations.

We do appear to have a substantial source of energy from waste available and must now address ourselves to the question as to why so little energy is generated from industrial processing waste.

B) - LOGISTICS OF INCINERATION

Brinkerhoff of EPA reported on two studies of incinerators installed. [3] By 1972 well over 100,000 incinerators had been installed, with capacities ranging from 23 to 1,816 kgs/hr (50 to 4,000 lbs/hr) and a total installed capacity of 771,800 kgs/hr (1,700,000 lbs/hr). The estimated annual amount of waste processed is 8.2 million metric tons (9.0 million U.S. tons), and while none of these units have had energy recovery provisions fairly recently, 90 percent of them required afterburners. The net effect of this approach is energy consumption rather than energy recovery.

We see a similar picture developing in the organic chemical processing industry. In the pharmaceutical industry for example the relatively small quantity of 200,500 metric tons (221,000 U.S. tons) per year of waste is generated in over 700 locations. This simply inhibits any reasonable prospect of efficient energy recovery from waste combustion. Or consider

the potential economics of the following wastes: a) an average of 182 kgs/hr (400 lbs/hr) of a mixture of  $\text{Na}_2\text{CO}_3$ , NaOH, organic carbon and silicate catalyst; b) 2,270 kgs/hr (5,000 lbs/hr) of tar, cooling tower blowdown and liquid containing two percent organic material; c) 23 metric tons (25 U.S. tons) per day of viscous unpumpable water and carbon slurry; d) a few thousand pounds per hour of silicon waste; e) several hundred pounds of fire retardant waste containing organic complexes.

In a 1970 market study the American Gas Association [4] predicted a total installed incinerator capacity of 37 million metric tons (41 million U.S. tons) per year for 1975. This represents less than half of what should now represent industrial waste and it can only be hoped that in building capacity for the disposal of these additional quantities of wastes the proliferation of small units can be avoided.

In favor of proliferation, of course, speaks the great chemical diversity of the wastes. This diversity has the greatest impact on the design of the gas cleaning systems and the by-product potential. By-products which can be obtained from the combustion of industrial wastes are sulfuric acid, hydrochloric acid, sodium sulfate, sodium carbonate with the most significant potential as well as others. This places chemical waste incineration into the same predicament as flue gas desulfurization with respect to solving the by-product marketing problems.

For example, when chlorinated hydrocarbons are being burned at sea at a cost of \$55 per ton, [5] where the greatest cost is probably that of the fuel consumed while energy recovery is not practiced, the opportunity to manufacture by-product hydrochloric acid is foregone.

The dilemma of the logistics of organic waste combustion can be solved by establishing regional industrial waste combustion plants. This proposal is not new, but success has been very limited so far. The main reason in our opinion is the fact that the designs proceed in the direction of burning all types of waste together in one and the same unit. We have proposed for many years that the successful design will provide for three separate incinerators in a regional plant. One unit will operate on wastes free of high ash content, as well as, sulfur and halogen content. Another unit could operate on chlorinated wastes to provide for HCl recovery, while the third one will process wastes containing ash with low eutectic points. All units could be fitted with waste heat boilers for energy recovery.

#### C) - ECONOMICS OF ENERGY RECOVERY

Waste combustion started out more as a nuisance and as a means of disposing of an otherwise not disposable residue or by-product. A notable exception might be the generation of steam associated with chemical recovery in pulp mills, but the development from the first units using a direct contact evaporator to the modern highly efficient recovery boiler took the better part of half a century. Fluidized bed

waste combustion systems are seeing a similar development. The original units only used heat by way of direct contact evaporation. Subsequent units utilized fire tube boilers, which generally have performed adequately, but are limited in their pressure capabilities and require fairly substantial attention to avoid problems of plugging with fly ash or other flue gas dust. Today, water tube waste heat boilers are being used with pressures up to 800 to 900 psig and eventually probably higher. Given today's fuel costs the addition of a waste heat boiler to a waste combustion process will usually have a pay-out between three to six months depending upon the size of the unit. Fuel cost is, therefore, one of the major reasons why energy recovery from industrial waste combustion should be practiced. (Table IV)

There are two other factors which affect the economics of energy recovery. One relates to emission control, the other one to the overall heat balance of a combustion system and its effect upon the environment through non-utilized heat released from the system. (Fig. I, II, III) An emission control system designed to operate on hot flue gas is inherently more expensive and progressively less acceptable than one designed to operate on cool flue gas. The savings accrued may be used to pay in part for the cost of the heat recovery equipment itself. It seems all too obvious that any heat recovered internally in a system, either by way of steam generation, direct contact evaporation, air preheat by means of a heat exchanger or a combustion of such units will result in a lesser discharge of heat to the environment. As we are becoming concerned about thermal pollution we will need to practice internal heat recovery.

We are essentially moving in the direction of higher and higher capital outlays for the same process, where the improvements in efficiency will probably just about keep pace with increased fuel costs.

#### D) - TECHNICAL PROBLEMS

Fluidized bed combustion systems have their own peculiarities, the most significant of which shall be discussed. However, fluidized bed combustion systems do not have two most commonly occurring problem areas in combustion plants, namely corrosion and refractory failures. The most fruitful technical subjects of the chemistry of corrosion of boiler tubes and furnaces parts, as well as, the very complex chemistry of reactions with refractory may be ignored.

##### 1. Combustion Efficiency

The typical fluidized bed combustion system is highly efficient for the simple reason that it is a refractory lined combustion chamber from which no heat is being taken away during the combustion process. This has great advantages in dealing with waste containing great quantities of water, but at the same time becomes a liability in overall thermal efficiency. If a suitable dewatering process is available it is much more efficient to operate at higher temperature and increase the energy

generating capability of the system. A clear example of this may be seen in Table III where the pay-out period of two systems, virtually identical in size, is changed by a factor of two as a result of almost doubled steam generation from the same total energy input. Bruestle [6] presented a chart indicating the permissible water content of waste fuels for proper combustion in furnaces which should be contrasted with Fig. IV showing the permissible water content for fluidized bed combustion systems.

Inherent in the fluidized bed combustion process is the opportunity to preselect the combustion temperature, for example to accommodate problems with a low eutectic ash condition or to minimize the formation of nitric oxides. This allows a designer great flexibility in preselecting the optimum relationships between heat input, fuel condition, combustion temperature, based upon either heat removal from the fluidized bed directly or cooling the combustion system with water or excess air.

## 2. Emissions

It is by now well documented that fluidized bed combustion systems can meet the most stringent particulate emission regulations in effect today. This despite the fact that for a long time particulate collection was thought to be a more difficult or demanding job in a fluidized bed combustion process because normally all ash is carried out as fly ash. Unless a fluidized bed combustion system involves an agglomerating process the fluidized bed reactor does not produce any bottom ash. In comparison to boilers fluidized bed combustion systems produce very little fine particle emissions. [7] It has been suggested that polycyclic organic matter is associated to a large extent with fine particle emissions. [8] It will be important to develop further insight as to which degree this is true and whether fluidized bed combustion reduces or avoids problems with POM emissions as a result of the diminished degree of fine particulate formation.

The ability of fluidized bed combustion systems to control SO<sub>2</sub> emissions by reactions with alkaline materials during the combustion process, as well as, the very minimal formation of nitric oxides have been adequately discussed and documented and further discussion here is not warranted. McGill and Smith discussed the "Fluidized Bed Disposal of Secondary Sludge in Organic Salts" [9] and documented how an air pollution free fluidized bed combustion process can be operated at very low combustion temperatures in order to accommodate a problem with a low eutectic melting point of the ash produced from the combustion of highly salt bearing sludge. There are instances, however, where the eutectic point of an ash is very low. Combustion carried out at a correspondingly low temperature generates substantial quantities of carbon monoxide and hydrocarbons. For small units an easy solution to this problem may be the installation of an afterburner, but the operating costs as well as the capital cost of such a solution are not very attractive for larger systems. The addition of certain alumina and silica compounds to the fluidized bed may result in the reaction of these compounds with the eutectic ash and raise the fusion temperature of the mixture. It has not yet been demonstrated whether such an approach is

economically viable, but a more attractive solution may be the use of carbon monoxide burning catalyst in the fluidized bed combustion process. To the best of our knowledge no research or development work has been done yet with such catalysts, which apparently are also very new to the refining industry at this point. An economically viable solution to the problem of dealing with eutectic ash problems could be of great benefit to many sludge disposal situations.

### 3. Material Handling

Material handling systems associated with fluidized bed combustion systems have undergone considerable evolution in the last few years. Fluidized bed combustion systems conventionally had been thought of as forced draft systems. This meant that material which could not be pumped or conveyed pneumatically had to be injected into the reactor through mechanical sealing devices such as lock hoppers or rotary valve feeders. The largest material being handled presently is wood yard waste in a pulp mill in Canada, Figure V, where logs as long as four feet with diameters up to six inches are being handled without size reduction. The physical size of combustible material does not need to be limited at all from the criteria of the fluidized bed operation, but it is subject to limitations in the material handling equipment itself. About three years ago, a fluidized bed combustion system was started up which employs a balanced draft principle. Similar to boilers the system includes an induced draft fan as well as a forced draft fan. This installation has proven itself well and several projects are now under way employing the balanced draft principle. The limitations now exist within the non-combustible material particle size. Further modifications of the fluidized bed reactor design are required in order to permit oversize non-combustible material to be fed into the bed without remaining there.

Several approaches to solving this problem are conceivable and some are being worked on. For the time being, oversize non-combustible material must be removed from the feed stream in order to avoid any undue problems with bed behavior and ash handling. As far as feeding oversize material is concerned the balanced draft system provides a very convenient solution by arranging blower capacities in such a fashion as to create a slight negative pressure in the reactor freeboard. The waste can then be dumped into the reactor through a feed chute opening of sufficient size to prevent jamming of oversize material.

### E) - RESEARCH OPPORTUNITIES

In reviewing the comments made previously, it appears that several research opportunities have been identified in the field of economics, engineering economics and technology, and to that should be added an item not yet mentioned, namely the investigation of additional wastes heretofore untried as fuels. Fly ash from hog fuel boilers, containing 10 to 25 percent unburned carbon, fly ash from oil fired utilities, coal washings and spent activated carbon too contaminated for regeneration all are potential fluidized bed fuels.

In the field of economics, greater attempts should be made at defining and identifying sources of industrial waste suitable for energy recovery. Possibly the experience gained in operating waste exchanges may be used to combine wastes for mutual benefits in incineration or in making regional incinerators economically viable. Similar or identical wastes from various sources could be combined in order to make by-product recovery economically viable. As suggested in the editorial of the May 1976 issue of Environmental Science and Technology, subsidies may have to be established in order to support markets for waste combustion by-products. Logistics do not favor the burning of agricultural residues at all, but possibly portable fuel converters could generate a residue derived fuel which can be transported economically. The proliferation of small incineration units is not in favor of efficient energy recovery from waste and should be discouraged.

In the field of engineering economics, combustion efficiencies can be raised by improved dewatering or concentrating technology, which will avoid the consumption of fossil fuels for use as auxiliary fuel. Fluidized bed combustors with the ability to remove heat from the reactor directly will be required in order to avoid high combustion temperatures, which may again result in the same type of corrosion and erosion problems being experienced in high temperature combustion systems now.

In the technical area a deeper body of knowledge concerning waste combustion emissions needs to be developed. Questions relating to ash particle size formation, polycyclic organic matter emissions and the mechanism of carbon monoxide combustion in fluidized beds need to be explored. Use of afterburners must be discouraged, except where they are a direct means of recovering heat from waste gases. Salty sludges still represent a significant disposal problem and economically viable methods for increasing the fluxing temperature of ash could become very valuable. Untold opportunities exist in adding small fluidized bed combustors to existing natural gas or oil fired boilers in order to direct the hot flue gas through the boiler to replace expensive or unavailable fossil fuel. This approach may well avoid the necessity to de-rate natural gas or oil fired boilers, which results from attempting to fire coal in a unit designed for oil or natural gas firing.

#### SUMMARY

On a very broad basis it appears that great quantities of waste are available for energy generation. The obstacles to the utilization of these wastes are not necessarily technical in nature but more often problems of economics or engineering economics or combinations thereof. Potential opportunities for fruitful research activities have been suggested and if one or another of these are pursued and successful the purpose of this presentation will have been served.



## REFERENCES

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TABLE I

# U.S. WASTE QUANTITIES DISCARDED

(MILLIONS OF COMBUSTIBLE DRY TONS) \*

Source	Quantity
● <b>Urban</b>	
Household and municipal	84.2
Sewage solids	6.9
Commercial	31.0
Manufacturing plant wastes	11.8
Demolition	3.8
● <b>Manufacturing and Processing</b>	
Wood related wastes	25.7
Textile and fabric wastes	0.3
Non-fabric synthetics	0.4
Food processing solids	0.8
Miscellaneous	0.1
● <b>Agricultural</b>	
Animal wastes	206.7
Crop wastes	170.0
Forest and logging residues	25.9
<b>TOTAL</b>	<b>567.6</b>

\*Conversion factor: (U.S. ton) = 0.907 (metric ton)

Source: *International Research and Technology Corp. 1976*

TABLE II

U.S. WASTE QUANTITIES 1971 (tons X 10<sup>6</sup>)\*\*

	Generated	Available For Energy Recovery
MSW	125	93
Sewage Sludge	12	1.5
Manure	200	26
Crop Waste	390	23
Forestry	55	5
Industrial	44	5.2
(Pharmaceutical)	.22	?
*(Organic)	16	16

\*Authors Estimate

Source: *Mitre Corporation, 1975*

\*\*Conversion factor: (U.S. ton) = 0.907 (metric ton)

TABLE III

# ANNUAL U.S. ENERGY CONSUMPTION (BTU X 10<sup>15</sup>) \*\*

BY CONTRIBUTION

	1976	1985	2000
Consumption _____	71	104	164
Coal % _____	19	21	17
Petroleum % _____	47	44	31
Natural Gas % _____	28	19	12
Oil Shale % _____	0	1	6
Hydro & Geothermal % _____	4.3	4	6
Nuclear % _____	1.7	11	28
*Waste _____	?	2.5	12.5

\*Authors Estimate

Source: Kent Frizfel, Undersecretary of U.S. Dept. of Interior, 1976

\*\*Conversion factor: BTU = 1.055 (KJ)

TABLE IV

# ECONOMICS OF ENERGY RECOVERY IN 1976

(SMALL VS. LARGE INSTALLATIONS)

	A	B	C
Installed Cost of Facility \$	250,000	2,400,000	2,700,000
Steam Quantity Generated Lbs/Hr <sup>‡</sup>	7,500	36,000	60,000
Unit Cost for Steam Generator \$/1000 Lbs/Hr.*	33.35	66.35	45
Payout Time for Steam Generator (Straight Line Depreciation) Months	5.5	3	2.2
Payout Time for Total System Years	2	4.3	2.8

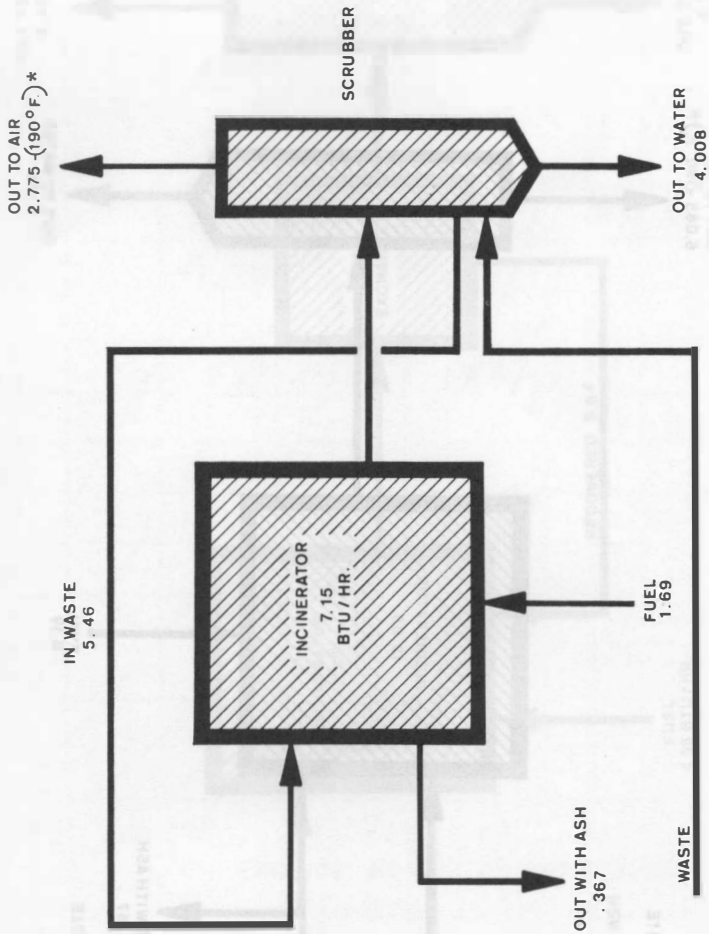
\*Conversion factors: (1b/hr) = 454 (kg/hr)  
 (\$/1000 lbs/hr) = 2.20 (\$/1000 kg/hr)

Base: Steam Cost: \$2.00/1000 Lbs.

Operating Time: 8000 Hrs/Yr.

# INCINERATOR HEAT BALANCE

NOTE: HEAT RECOVERY WITH DIRECT CONTACT EVAPORATOR.

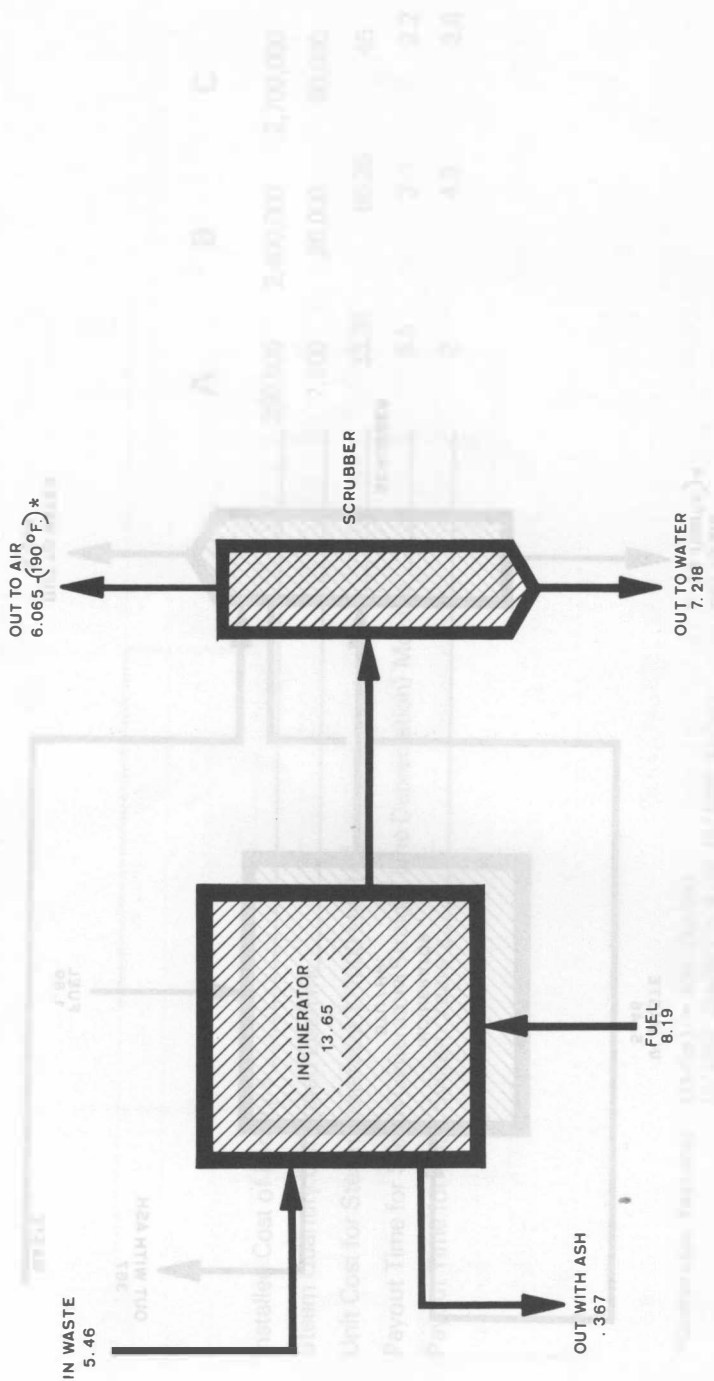


\*Conversion factors: (Btu/hr) = 1.055 (kJ/hr)  
 (°K) = 5/9(°F - 32) + 273.15

Figure I

# INCINERATOR HEAT BALANCE

NOTE: NO HEAT RECOVERY  
ALL NUMBERS IN  $10^6$  BTU/HR.\*

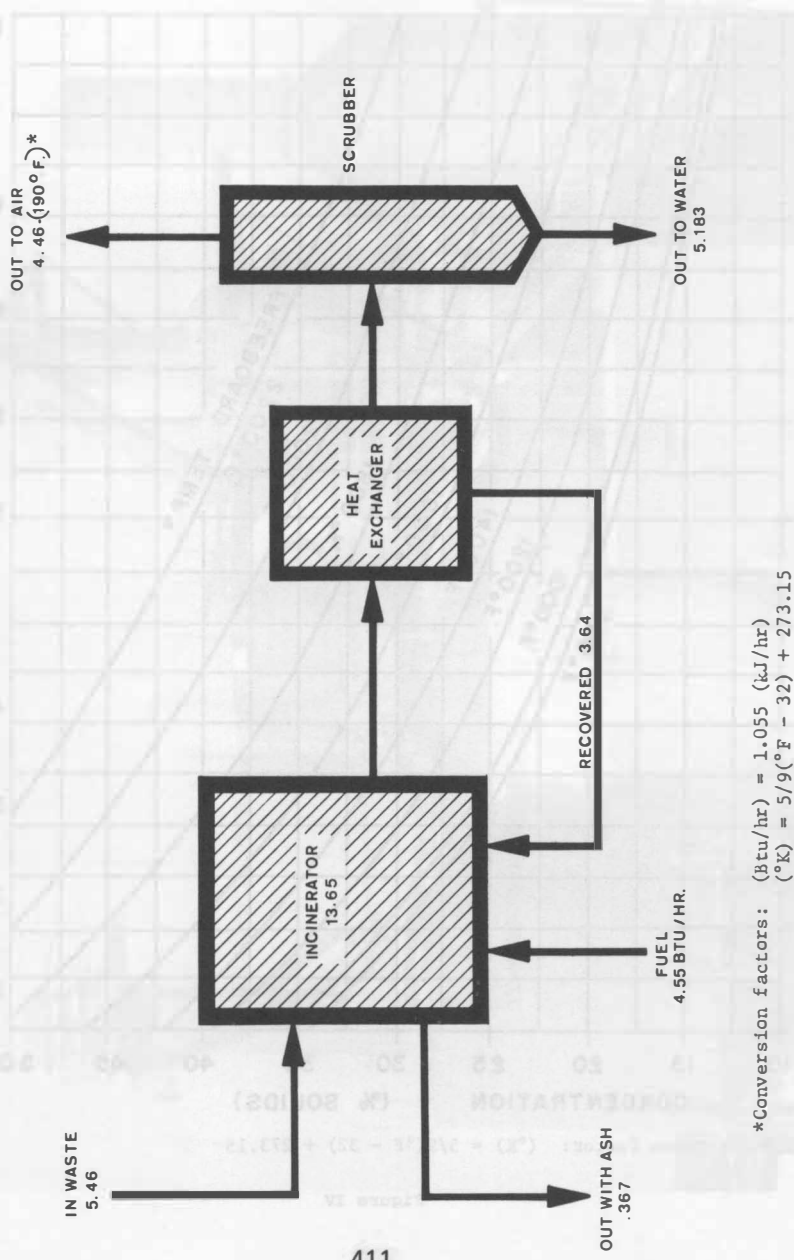


\*Conversion factors: (Btu/hr) = 1.055 (kJ/hr)  
(°K) = 5/9(°F - 32) + 273.15

Figure II

# INCINERATOR HEAT BALANCE

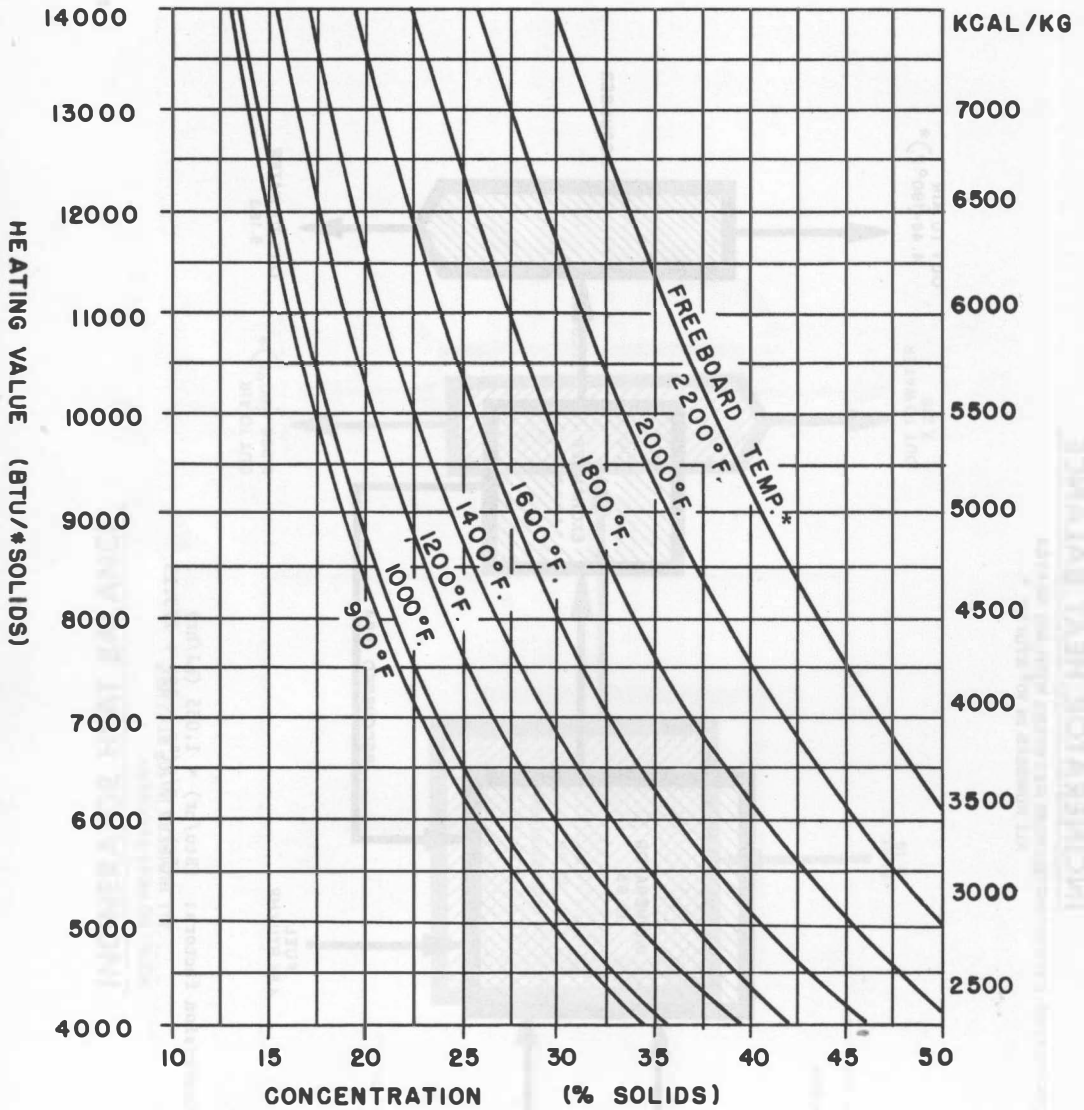
NOTE: HEAT RECOVERY WITH AIR HEATER  
ALL NUMBERS IN 10<sup>6</sup> BTU/HR. \*



\*Conversion factors: (Btu/hr) = 1.055 (kJ/hr)  
(°K) = 5/9(°F - 32) + 273.15

Figure III





\*Conversion factor:  $(^{\circ}\text{K}) = 5/9(^{\circ}\text{F} - 32) + 273.15$

Figure IV

