COMMISSION OF THE EUROPEAN COMMUNITIES
DG XII – RESEARCH, SCIENCE, EDUCATION

RAW MATERIALS

RESEARCH AND DEVELOPMENT

STUDIES ON SECONDARY RAW MATERIALS

V. THERMAL PROCESSES FOR WASTE DISPOSAL

September 1979

COMMISSION OF THE EUROPEAN COMMUNITIES
(Directorate General XII - Research, Science, Education)

ASSESSMENT OF CURRENT TECHNOLOGY OF THERMAL PROCESSES FOR WASTE DISPOSAL, WITH PARTICULAR EMPHASIS ON RESOURCE RECOVERY

= Report by A. Buekens and J. Schoeters and [illegible] J.N. Gony and P. Renoux =

Report by

A. Buekens et al and J. Schoeters

= Raw Materials Research and Development: Studies on Secondary Raw Materials, Vol. V =

VRIJE UNIVERSITEIT BRUSSEL
Department of Chemical Engineering
and Industrial Chemistry
Pleinlaan 2
1050-Brussels
(Belgium)

November 1977

XII/696/79

LEGAL NOTICE

PREFACE

This volume is part of a series of assessment studies on Secondary Raw Materials that have been prepared under the sponsorship of the "Commission of the European Communities" (Directorate-General for Research, Science and Education).

The decision to carry out such studies, as well as other work to be published under the general heading "Raw Materials Research and Development", results from current concern about prospects of supplying the European Community with raw materials in sufficient quantities and at acceptable costs in the mid- to long-term. An essential part in defining the purpose and scope of the work was played by a Sub-Committee of CREST (1), established to investigate on-going activities in the member states, both in the areas of primary and secondary raw materials, in order to determine what R & D actions, if any, should be undertaken by the Community to alleviate its supply problems.

The volume comprises 2 reports, prepared under contracts with the European Economic Community and both issued under the title:

"Assessment of current technology of thermal processes for waste disposal, with particular emphasis on resource recovery" :

1. Report from the VRIJE UNIVERSITEIT BRUSSEL, (Contract no. 282-76-9 ECI B)

2. Report from the BUREAU DE RECHERCHES GEOLOGIQUES ET MINIERES, Orléans (Contract no. 283-76-9 ECI F)

---

(1) Set up by the resolution of the Council of Ministers of the European Communities of 14 January 1974, the Scientific and Technical Research Committee (CREST) is responsible for assisting the Community Institutions in the field of scientific research and technological development.

INTRODUCTION

This report gives a survey of our activities in the study for the European Economic Community "Assessment of Current Technology of Thermal Processes for Waste Disposal, with Particular Emphasis on Resource Recovery".

This study is centered on technical, economic, commercial, institutional, energetic and raw materials aspects of the thermal processing of wastes. Conventional methods, i.e. incineration, are only treated briefly, and attention is mainly paid to the newer methods of thermal treatment, such as gasification, pyrolysis and production of Refuse-Derived-Fuel.

In the course of this study extensive data were collected on current initiatives in thermal waste disposal. It was found, however, that part of the published data were inaccurate. For this reason 2 circular tours were made in the U.S.A., and the most relevant institutions, process developers and plants were visited.
Another study tour was made in Japan, during which many Waste Disposal Authorities ans Waste Recycling Demonstration Plants were visited.

A final report has been subdivided into 4 parts, dealing with (I) Incineration, (II) Pyrolysis and Gasification (III) Refuse Derived Fuel and (IV) General Conclusions. On special request of the competent E.E.C.- Authorities, practical conclusions and recommendations for futher research within E.E.C. were prepared at an early stage and presented in the interim report. In this final report we can confirm almost all of our previous conclusions and recommendations with even more confidence, since our study tour in Japan yielded a wealth of most interesting, supplemental information.

We are greatly indebted to the General Direction of Research, Science and Education for directing and supporting this work and to the many people in Government,Institutions,Research Laboratories and Waste Disposal plants for their help in collecting,evaluating and screening data.In particular we thank R.TIZE,W.DALMIJN,F.COLON and B.KREITER,who joined us in some of our study-tours.

A.BUEKENS and J.SCHOETERS.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

PART I. - DIRECT INCINERATION

PART I. - DIRECT INCINERATION

I. INTRODUCTION

Direct incineration of refuse originated in England during the 19th century. The advent of mechanical grates and modern boilers made direct incineration an established and relatively reliable technique of waste disposal.

In W. Europe heat recovery has been a general practice in large incinerators. The recovery of heat forms a suitable method of cooling the flue gases before dust collection, and somewhat reduces disposal costs, provided a suitable utilization of heat can be found (Table 1)

	Plant Capacity (ton/h)			
	1-3	3-10	10-30	larger than 30
no heat recovery	1	3	-	-
steam is used for :				
-heating and industrial purposes	1	4	5	2
-power generation	-	2	1	9
-both	-	-	4	7
recovery of ferrous metal from ash	-	-	4	9
utilization of ash	-	1	3	12

Table 1. Recovery of heat and slag (1) (W. Germany)
(number of plants)

In the U.S.A. heat recovery was rather exceptional, although a few early plants were provided with waste heat boilers. In 1965 three relatively recent plants used a refractory walled-furnace with a waste heat boiler : Merrick, N.Y.(1952), Miami, Flo.(1956) and Chicago S.W., Ill.(1962). Since 1965, 8 new

Table 2a. : Resource recovery characteristics of North American Incinerator plant (2)

Plant	Design Capacity t/day (tons/day)	Steam per Boiler Unit			Steam		Shredding Prior to Burning	Materials Separation	Year of Initial Startup
		Flow kg/h x 1000	Pressure kPa	Temp. °C	Generated per day * kg x 1000	Use of Steam			
U.S.A.									
Chicago(Southwest)	1089	9	1724	191	411	S+IP	No	Yes[b]	1962
Merrick	544	27	1551	196	2216	IP	No	No	1952
Miami (20th St.)	816	7	1620	343	340	S+IP	No	No	1956
Braintree	218	13	1551	208	305	S	No	No	1970
Chicago(Northwest)	1451	50	1896	212	3307	IP	Yes[d]	Yes[e]	1970
Harrisburg	653	42	1724	236	1007	IP	Yes[f]	Yes[f]	1972
Nashville	653	61	2758	316	1089	S+IP	No	No	1974
Norfolk	327	27	1896	211	435	S+IP	Yes[f]	Yes[d]	1967
Oceanside	680	50	3103	238	762	D+IP	No	No	1965
Portsmouth	136	13	1206	191	NIP	S+IP	No	No	1976
Saugus	1089	84	4757	468	NIP	S	Yes[f]	Yes[f]	1975
Canada									
Hamilton	544	48	1724	204	2286	IP	Yes	Yes[l]	1972
Montreal	1089	45	1724	288	2721	IP+MC	Yes[m]	Yes[g]	1971
Quebec	907	37	4482	327	1089	S	Yes[m]	No	1974

S Sold or under contract to be sold
D For deselinization of water.
IP For in-plant equipment.
MC For heating municipal complex and snow-melting.
NIP Not in production from solid waste as of July 31,1975.
EB To modify, utilize existing boilers.

a. Steam neither utilized nor condensed is wasted.
b. By screens and mechanical belts after burning.
c. Winter usage, much lower in summer.
d. Shredding of bulky items only with magnetic separation prior to burning.
e. By rotary screen after burning.
f. Shredding of bulky items only prior to burning
g. By magnetic separation after burning.
h. Air classification only prior to burning.

i. For one unit, differs for other boilers.
j. Air classification,magnetic-separation prior to burning.
k. Magnetic separation before and after burning.
l. Magnetic separation before burning, bulky items removed.
m. Shearing of bulky items only.

Table 2b. : Energy recovery at Tokyo and suburban incinerators

Plant Location	Capacity (Refuse tons/day)	Generator Capacity (KW)	Electricity Supply (KW)	Hot Water Supply to	Completion Date
(Tokyo)					
Setagaya	900	2,500	In-plant Power	Nursing Home	March 1969
Shakujii	600	1,500	"	-	March 1969
Chitoso	600	1,700	"	Civic Center	January 1971
Ohi	1,200	2,500	"	Youth Center	September 1973
Tamagawa	600	2,500	"	Swimming Pool (Civic Center)	October 1973
Koutou	1,800	3,000	"	Nursing Home	February 1974
Itabashi	1,200	3,200	"	Ward's Public Facility	June 1974
Katsushika	1,200	12,000	5,000(Planned)	nd	March 1977
Adachi	1,000	nd	In-plant Power	nd	March 1977
(Kawasaki)					
Rinkou	600	1,300	"	-	April 1971
Tachibana	600	2,000	"	Nursing Home	December 1974
(Yokohama)					
Kounan	900	3,000	"	Nursing Home	March 1974
Minami-Totsuka	1,500	4,500	"	Swimming Pool	March 1976
(Chiba)					
Shinkou	450	1,200	"	nd	March 1974
(Reference)					
Nishiyodo,Osaka	400	5,400	In-plant Power 700 Contract Sale 2,500	-	June 1965

nd : not determined

water-walled furnaces started operation in the U.S.A. and 3 more in Canada.(2)

II. PROCESS DESCRIPTION

A. CONVENTIONAL INCINERATION

Incineration of solid wastes on mechanical grates is a generally known and accepted practice. Therefore we will only refer to some relevant books and papers.(3)

B. RAW REFUSE AS SUPPLEMENTAL FUEL (figures 1 - 2)

Refuse can be fired as a supplemental fuel in a conventional power plant. The operation of the plant is little affected by the quality and supply rate of refuse, since the part of refuse in heat generation rarely exceeds 20 %.

Several arrangements are possible, depending on wether :

1. refuse and fuel are fired separately (Munich North Block I, Stuttgart) or in a single combustion chamber (Munich North Block II);
2. the economizer, evaporator, superheater, and flue gas cleaning are common to both plants, or partially separated.

The precise arrangements has a bearing on the corrosion and fouling of the boiler tubes, and hence on plant availability. Moreover, the thermal efficiency of a conventional utility boiler is about 85 %. When refuse is fired, together with oil or coal, the efficiency is lowered to about 70 %, due to a higher air factor and fouling rate.

In Munich North Block I plant refuse is burned on a Martin grate in a first combustion chamber. Pulverised coal is fired in a second chamber, separated from the first by a common tube wall. The flue gases from refuse combustion in a first flue are cooled to 800°C and, together, with the flue gases of the

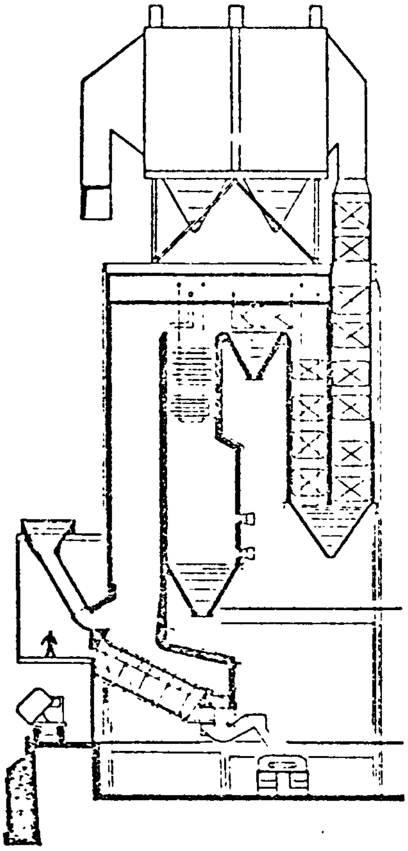


Fig. 1a : Munich North I

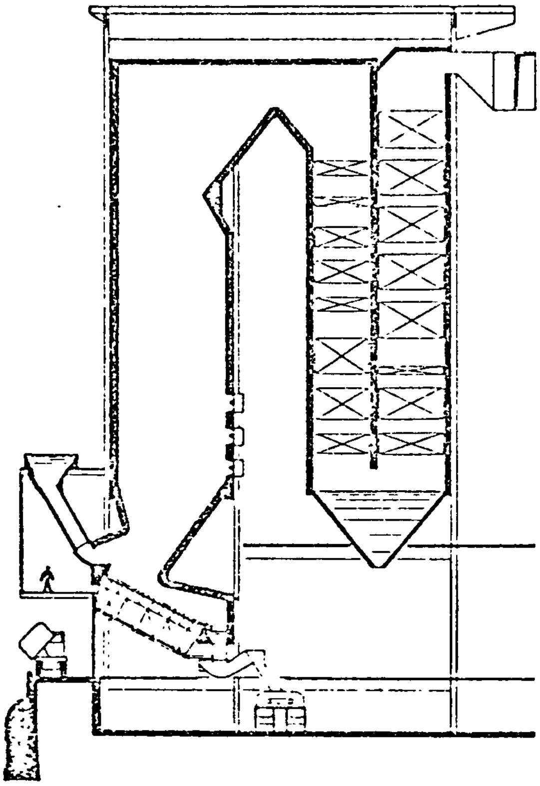


Fig. 1b : Munich North II

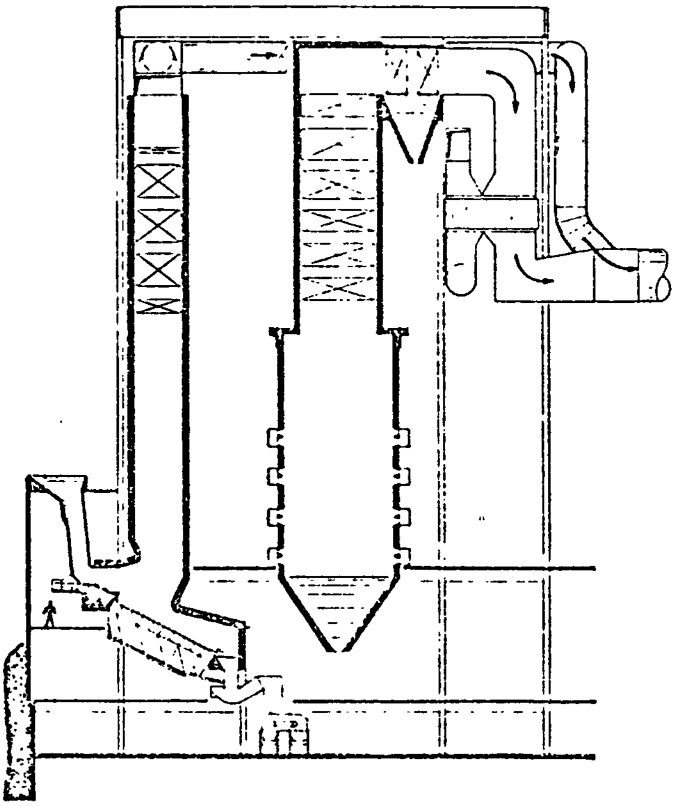


Fig. 1c : Munich South

coal-fired chamber flow through the second and third flue, which contain the superheater and the economizer. The plant can be operated in 3 modes :(figure 1a)

1. in normal operation, with 40 % of the heat load supplied by refuse, and 60 % by pulverised coal;
2. power generation with pulverised coal only;
3. boiler operation at lowered temperature and pressure with only refuse as a fuel. Power is no longer generated. Incinerator heat is used for district heating, excess steam being condensed.

A similar lay-out is used at Stuttgart, the incinerator furnace being separated by a common tube wall from an oil-fired furnace. The plant contains two units, one using a Martin and one a Dusseldorf grate. Depending on the calorific value of refuse (800-2,200 kcal/kg) between 15 and 40 % of the steam output is generated by refuse firing. Normally the oil-fired chamber supplies 75 % of the heat output, but it is capable to supply full plant load without refuse firing.(fig. 2)

The flue gases from refuse firing are cooled to 750°C in a first flue, and flow through the remaining 1 1/2 flue after combination with the other flue gases.

In the Munich North Block II plant pulverised coal at 3 levels is injected through 3 rows of 4 frontal vortex burners, and burned above the refuse grate in a common combustion chamber. The furnace can be operated in 3 modes as in the Block I plant. The thermal efficiency of the plant is somewhat higher because of the improved firing configuration and the lower heat input (20 %, against 40 %) supplied by refuse.(figure 1b)

In Munich South a 124 MW-power plant uses a refuse incinerator as a feedwater preheater, which can be by-passed completely. The availability of the incinerator thus has no influence of that of the power plant. The recovery of heat takes place in low temperature, less corrosive conditions.(figure 1c)

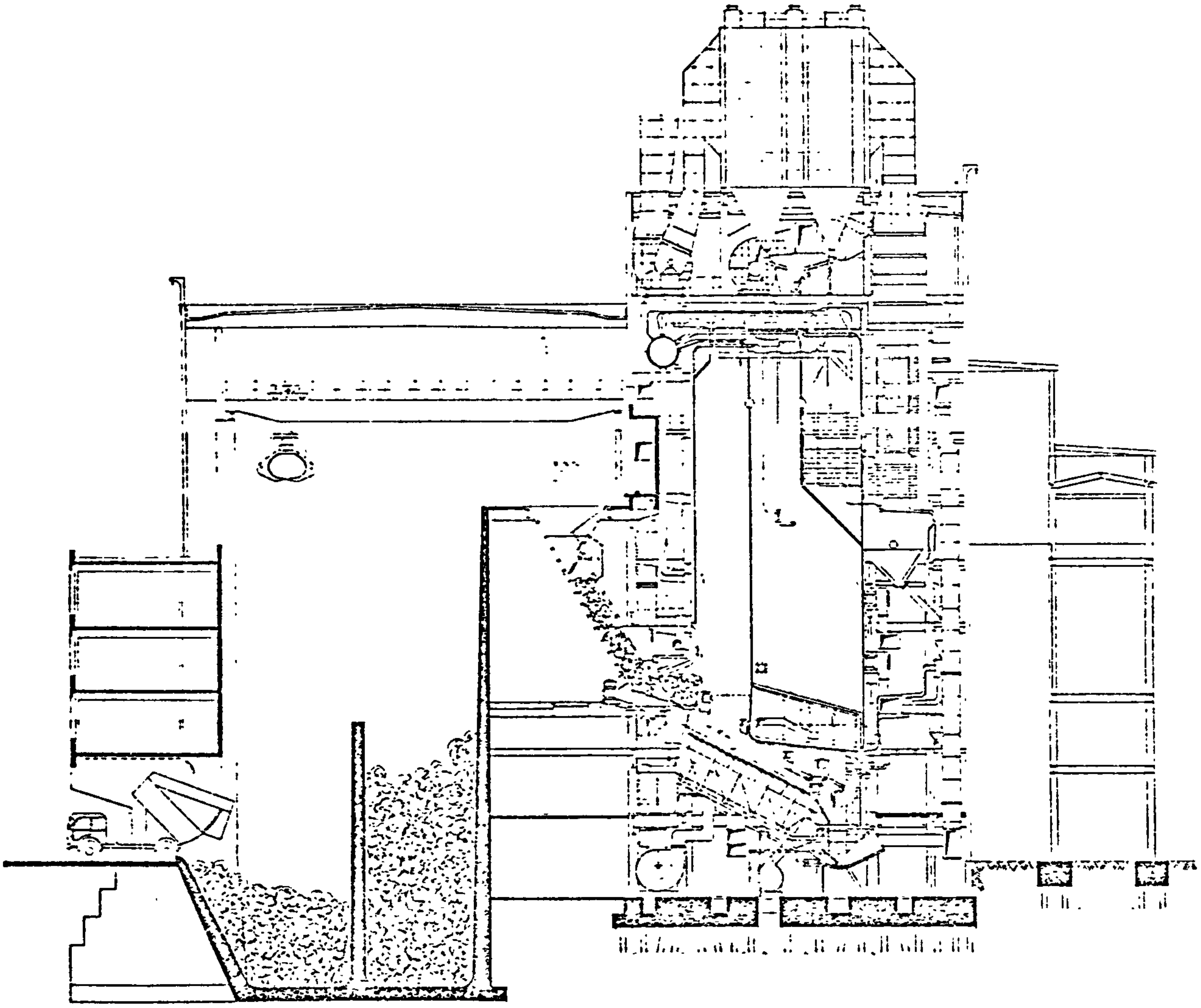


Fig. 2 : Stuttgart.

Fuel	Calorific value kcal/kg	Boiler efficiency %
Natural gas	7,650	86
Town gas	3,600	85
Fuel-Oil (light)	10,000	80-84
Fuel-Oil (Heavy)	9,800	80-82
Coal	6,900-7,700	78-82
Brown-coal	1,600-2,000	76-80
Refuse	1,500-2,500	65-75

Table 2. Boiler efficiency using various fuels (1)

Table 3 gives some data on a number of German power plants, using refuse as a supplemental fuel.

At Essen-Karnap a pulverised coal-fired plant, equipped with a Benson boiler, was provided with travelling grates, for refuse firing. Also at Niederrhein an existing plant was later tranformed, to accomodate refuse firing. This solution requires a lower investment than the erection of a new plant.

Plant	Refuse Firing Capacity(tons/h)	Steam raising Capacity(tons/h)	Operating Conditions	Conventional Fuel
Munich North Block I(1964)	2 x 25	41 (from refuse)	{ 185 bar 540°C	pulverised coal
Stuttgart(1965)	2 x 20	125 (15-40 %from refuse)	{ 70 bar 525°C	oil
Munich North Block II(1966)	1 x 40	81 (from refuse)	{ 185 bar 540°C	pulverised coal
Munich South Block IV-V(1971/69)	2 x 40	81 (from refuse)	{ 185 bar 540°C	natural gas
Essen-Karnap	5 x 20	5 x 130 (total)	{ 100 bar 510°C	pulverised coal
Niederrhein	3 x 22	3 x 50 (total)	{ 84 bar 525°C	-

Tabel 3. Technical data on supplemental fuel plants in W. Germany.

III. ENERGY RECOVERY

A. AVAILABILITY OF INCINERATOR HEAT

The primary purpose of a municipal incinerator is refuse disposal. Storage of refuse is possible only for 2-3 days, inasmuch as adequate pit volume is available. Basically, the refuse is incinerated at a constant rate, near design capacity, the purpose of the storage pit being to bridge the gaps between collection cycle and stoking rate.

In these conditions the heat output of the incinerator is almost uncontrollable, since it is determined by the immediate properties of the refuse fired, In conventional boiler plants the heat output can be regulated by varying the firing rate. Moreover, the inventory of fuel allows for 1-3 months of operation, in case of coal or fuel-oil firing.

The availability of a single incinerator furnace with heat recovery can be estimated at 75/85 %. When a plant is composed of several furnaces, the probability of having at least part of the plant available is higher, but so are the investment and maintenance costs.

Since incinerator availability cannot be guaranteed, full standby capacity under the form of a conventional fuel-fired unit has to be provided. Moreover, cooling capacity should be available to dissipate all heat generated, since incineration is continued also at times when heat demand is non-existent. This inflates investment cost and often results in an inefficient use of incinerator heat.

Integration of the incinerator into a power plant, a large district heating or water desalination system, or another large heat sink, allows the inevitable variations and fluctuations in incinerator heat output to go by unnoticed. The incinerator is used to deliver part of the base-load, the rest of the demand being delivered by a conventional unit with a suitable turn-down ratio.

B. UTILIZATION OF INCINERATOR HEAT

Incinerator heat can be used directly, i.e. under the form of hot flue gases, or indirectly, i.e. under the form of hot water, steam or electric power.

The direct use of hot flue gases as a drying medium is restricted to the drying of wastewater sludge and of wet refuse, because of their dust loading. A rotary kiln, a multiple hearth furnace, a fluidised bed, and a ball mill drier have been used as contacting equipment. Odour problems are avoided by keeping the temperature of the flue gases above 700°C, or by recirculating them into the furnace.

Hot water is generated in small cooling circuits, e.g. in a water jacket surrounding the load shaft or the slag gasifier. The hot water can be used for heating or sanitary purposes.

Steam is produced in a water-wall or a waste-heat boiler. The former is fully integrated with the combustion chamber, the latter is not. The operating pressure is mainly determined by the application of the generated steam. In large plants, with power generation, high pressures (30-120 bars) are required to obtain a reasonable efficiency of the thermodynamic cycle. Generally a pressure of 30-45 bar is selected, the higher pressures requiring excessive superheater temperatures, which are conducive to high temperature corrosion.

A minor amount of steam is required for in-plant use, e.g. for operating the soot blowers, the deaerator, (possibly) turbine-driven fans, compressors, pumps or hammermills, and for plant heating. The remaining steam is available for other uses, such as district heating and cooling, water desalination, indirect sludge drying, or power generation.

1. Possible Steam Cycles

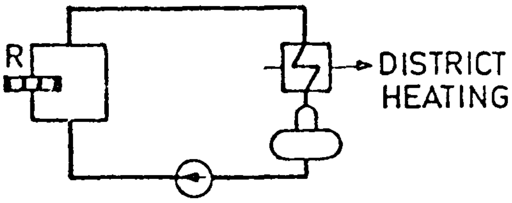
The possible steam cycles are represented schematically in figure 3. In a number of plants all generated steam is condensed. This situation has arisen in a number of plants, where no buyer of steam was found. This arrangement cannot be recommended, since plant investment and operating cost is higher than with spray cooling, and plant availability is lower.

In figure A part of the steam is used for district heating, or other heating purposes (hospitals, swimming pools, slaughter-houses), excess steam being condensed. Heating requirements are high and variable during wintertime, and low during summertime. Standby heating capacity is normally required. Incinerator heat is efficiently used when it only amounts to a fraction of the peak load. In that case, the incinerator over a large part of the year provides the base load, whereas a fossil fuel-fired standby-furnace assists during periods of peak load, and completely covers demand during periods of incinerator shutdown. When the incinerator alone is capable of generating peak load, large amount of heat have to be dissipated during all but the coldest months.

In figure B the steam is expanded in a back-pressure turbine, generating power. The low to medium pressure steam is condensed in a tubular heat exchanger, and serves to heat pressurized water for district heating. Combined power generation/ district heating forms a more flexible arrangement than sole district heating, but shows higher investment costs.

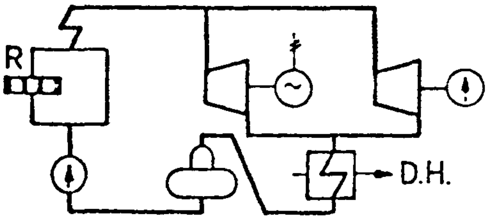
In figure C the steam is completely expanded in a condensation turbine, so that a maximum of power is generated. The generated power has a rather high cost, the production of 5-25 MW requiring almost the same personnel as a 200-1.000 MW-unit. The refuse fired power-plant is of the baseload-type, since the output cannot be varied to meet the demand. The generated power amply covers in-plant needs, so that power can

Type A:
Refuse-fired central heating station



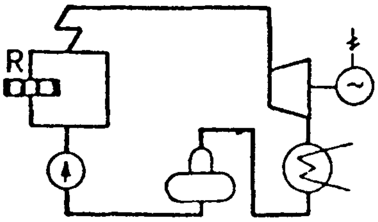
Steam or hot water is produced in a medium-pressure boiler and fed to the long-distance heating network either directly or via a heat exchanger. Such plants generally supply the base load of a network and operate in parallel with fossil-fuel fired plants.

Type B:
Refuse-fired heating station with in-plant power generation



Design similar to A, but the steam is fed in a first stage to backpressure turbines for in-plant power generation, or to several backpressure turbines driving fans and pumps. L.P. steam then conveys its heat to the district heating system.

Type C:
Refuse-fired power station with condensing turbines



Here, the high-pressure steam is fed to condensing turbines with high efficiency for electricity generation.

FIG. 3 : Possible Steam Cycles (6)

be exported to adjacent plants (wastewater treatment,...), resulting in considerable savings. When delivered to the public grid, however, power is normally sold at a low price, which is uniquely based on the resulting fuel savings in conventional power plants. At night power demand is low, and in some contracts the delivery of power to the grid at that moment incurred a penalty rather than yielding a bonus. Since the energy crisis, however, heat or power generation has become more rewarding.

A municipal incinerator can be operated as an independent power plant, or it can be integrated within a larger power generating complex. The latter possibility gives a marked cost advantage, since the feedwater treatment and the turboelectric part in the incinerator plant can be omitted. The boiler feedwater is supplied by the conventional power plant, and steam is returned. Unfortunately, the incinerator boiler often must raise steam at an elevated temperature and pressure, matching these of the main power plant. This has led to severe corrosion problems, especially in the superheater.

2. District Heating and Cooling

The heat demand in district heating systems is closely related to the ambient temperature. During the night and on weekends heat demand is lower. During the morning, when building temperatures are raised, demand is higher.

In Toronto (Canada) the lowest load, in summertime, amounts to 6 % of the winter peak, the mean load factor being 30-40 %. A refuse incinerator, supplying 10 % of the maximum load, can export 92 % of all heat produced, only 8 % requiring dissipation. The remaining heat would be supplied by a conventional fuel-fired furnace.(4)

In Ottawa (Canada) district cooling is supplied to government buildings, using a chilled water distribution system, with turbine driven chillers. The lowest steam demand amounts here to 50 % of peak load, to be compared with 6 % in Toronto.(4)

The incinerator thus can provide a much higher proportion of the steam load, without recurring to heat dissipation.

At Toronto the owning and operating costs of the proposed incinerator is $ 15.8 ton of refuse (1975). Taking into account the sales of heat, this cost decreases to only $ 4.6/ton.(4)

C. HEAT ACCUMULATORS (5)

The marketing of steam is hindered by the limited availability of incinerator plant, and by the difficulty of matching heat supply to demand. Typical steam charts of incinerator boilers show considerable short term and long term fluctuations. A coincidence of a low steam generation rate and a high demand, or vice versa, is highly undesirable, and requires a high turndown capability of the standby boilers, which supply the balance between steam demand and incinerator boiler output. Provisions for an integrated or a separate boiler are necessary anyway, to ensure the continuity of steam generation in case of a boiler breakdown, or a refuse collection strike.

A more consistent output of the incinerator boiler can be obtained either by supplementary firing of oil or gas, or by balancing the output with an accumulator. Compensation by an accumulator forms a means of saving fuel consumption, and may assume two forms:

1. a feedwater accumulator, consisting of a constant pressure, constant volume, variable temperature displacement type of accumulator, which stores steam under the form of deaerated feedwater during periods of high steam output, and diminishes deaeration steam requirements during low generation periods.
   The accumulator is effective mainly where the feedwater temperature and make-up rate are high;
2. a Ruths-type, variable pressure steam accumulator can be used, when steam is sold at reduced pressure;

3. a hot water storage system can be used, in case of a district heating application.

IV. ENVIRONMENTAL ASPECTS OF INCINERATION

A. SURVEY

Refuse and other objectionable wastes can be incinerated to a low-volume, sterilized residue. The operation of well-designed, modern plants has generally been considered to be environmentally acceptable. Yet, it has to be recognized that incineration forms a real or potential source of air, water and soil pollution.

Flue gases are loaden with dust and obnoxious gases. The dust problem has been solved by the use of highly efficient electrostatic precipitators. Recently, concern has been expressed regarding the emission of minute heavy metal particles, the removal of which is more difficult. The emission of obnoxious gases at present can only be controlled by the use of high-efficiency wet scrubbers,which give rise to visible steam plumes.

Much research is currently devoted to dry removal methods, but as yet no effective, proven method is available.

The spreading of odours has rarely raised objections, but a few preventive measures are required.

The wastewaters from an incinerator plant are charged with suspended solids with soluble salts, and with organic material. Wastewater treatment generally consists of settling and neutralisation.

Recently, preventive measures have been taken to avoid groundwater pollution by materials leached from incinerator ash.

Obviously, the soil pollution potential of bottom ash is much lower than that of raw refuse, especially when the ash was formed at high temperature. Tipping of fly-ash raises more problems, fly-ash being finely dispersed and acidic.
Sintering of the fly-ash can alleviate this problem.

B. CAUSES OF AIR POLLUTION

The incineration of wastes forms but a minor source of air pollution, when compared to traffic, conventional furnaces, or industrial processes (table 4). Air pollution by incinerators mainly depends on the chemical composition of the fuel, the kind of furnace, and its operating conditions. Several mechanisms are to be considered in an assessment of air pollution :

1. the mechanical entrainment of ash, dust charred paper, etc.
2. the occurence of incomplete combustion, with emission of carbon monoxide, thermally decomposed and incompletely oxidized organic compounds, and finely dispersed tar and soot particles.
3. the formation of obnoxious gases, from the sulphur, chlorine, fluor and nitrogen compounds, which are present in fuel or wastes.
4. the formation of nitrogen oxide at flame temperature, by combination of nitrogen and oxygen of air.
5. the evaporation of metals and salts in the flame.

	Transportation	Conventional furnaces	Industrial Processes	Miscellaneous	Refuse Incineration	TOTAL
Million Ton/year						
CO	71,2	1,9	7,8	8,6	4,5	94,0
SO_2 + SO_3	0,4	22,1	7,2	0,6	0,1	30,4
NO + NO_2	8,0	6,7	0,2	1,4	0,7	17
Hydrocarbons	13,8	0,7	3,5	6,5	1,4	25,9
Fly-dust	1,2	6,0	5,9	7,2	1,2	21,5
Total	94,6	37,4	24,6	24,3	7,9	188,8
Weight percentage						
CO	75,8	2,0	8,3	9,1	4,8	100
SO_2 + SO_3	1,3	72,7	23,7	2,0	0,3	100
NO + NO_2	47,1	39,4	1,2	8,2	4,1	100
Hydrocarbons	53,3	2,7	13,5	25,1	5,4	100
Fly-dust	5,6	27,9	27,4	33,5	5,6	100
Total	50,1	19,8	13,0	12,9	4,2	100

Table 4. Main sources of air pollution, U.S.A., 1966.

Incinerator emissions

Incinerator emissions depend on the kind and composition of the treated wastes, the type and operating conditions of the furnace, and the nature and efficiency of the gas cleaning plant. Emission levels can be expressed in several ways :

1. as the quantity of pollutant per unit volume of flue gas (mg/m3), at 0°C and 1.013 bar. The flue gas is considered either in the dry or in the wet state.
2. as the quantity of pollutant per ton refuse incinerated (kg/ton);
3. as the quantity of pollutant per unit time (kg/h).

The quantity and composition of flue gases is directly related to the air factor k used for combustion, and to the cooling method. For this reason, the quantity of pollutant per m3 flue gas is often recalculated to a standard air factor, or to a standard volume % of CO_2 in the flue gas.

A typical composition of raw flue gases is given by :

H_2O	10 - 18	vol %
CO_2	6 - 12	"
O_2	7 - 14	"
CO	< 0.1	"
dust	2 - 15	g/m3
Cl^-	400 - 2.000	mg/m3 (as HCl)
F^-	0.5 - 2	" (as HF)
$SO_2 + SO_3$	400 - 1.000	" (mainly SO_2)
$NO + NO_2$	100 - 400	" (largely as NO)

Table 5. Typical composition of raw flue gases(wet basis,s.t.p.)

This composition should be compared to current emission norms, to determine the requirements for gas cleaning equipment. The "Technische Anleitung zur Reinhaltung der Luft" (W. Germany), prescribes the following norms (at 11 vol. % O_2) : dust < 100 mg/m3, Cl^- < 100 mg/m3, F^- < 5 mg/m3, CO < 1 g/m3.

It follows that a removal efficiency of 99-99,5 % is required for dust, and a 95 % efficiency for HCl - removal. The former condition can be met with an electrostatic precipitator, the latter with a high-efficiency wet scrubber.

The hindrance caused by the emission of pollutants can be evaluated better by determining immision levels. Unfortunately, immission is highly dependent on atmospheric stability, speed and direction of the wind, etc.

Immission levels can be expressed as :

1. a mass concentration, i.e. in mg pollutants/m3
2. a volumetric concentration, i.e. in cm3/m3 (for gaseous pollutants only)
3. a particle concentration, i.e. in 1/cm3 (for dust particles only)
4. a rate of particle deposition, i.e. in g/m2, day (for dust particles)

dust deposition	0.35 g/m2,day	0.65 g/m2,day
(< 10µ) dust concentration	0.10 mg/m3	0.20 mg/m3
total dust concentration	0.20 mg/m3	0.40 mg/m3
HCl	0.10 mg/m3	0.20 mg/m3
H F	0.002mg/m3	0.004mg/m3
CO	10.0 mg/m3	30.0 mg/m3
SO_2	0.14 mg/m3	0.40 mg/m3
NO	0.20 mg/m3	0,60 mg/m3
NO_2	0.10 mg/m3	0.30 mg/m3

Table 6. Immission levels according to T.A.-Luft

Dust Collection

Principles

Dust particles can be collected by mechanical separators, fabric and granular filters, electrostatic precipatators and wet scrubbers. The action of mechanical separators is based on gravity, inertia or centrifugal force. Coarse particles (above 50 micron) can be removed by settling, when a sufficient residence time is provided, or by inertia, when the direction of the gas flows is abruptly changed. Cyclone separators are based on centrifugal force, and are highly efficient on particles with a diameter above 20 microns. Below this particle diameter the collection efficiency decreases rapidly. Cyclone separators have often been used in smaller plants or where air pollution codes are lenient. Current codes on dust emission can no longer be met with cyclone separators alone.

Fabric filters can operate at high efficiency, even in the submicron range. They have little been used in refuse incineration, because of their high investment and operating cost, and of their limited lifetime at high temperature. Granular filters, on the contrary, can be used even without flue gas cooling.

The use of a moving bed granular filter has been set forward in the CPU-400 project.

Fluidised bed filters are also temperature resistant, but show only a moderate efficiency and a very high pressure drop.

Electrostatic precipitators are extensively used in incinerator plants, because they offer a high collection efficiency at a moderate operating cost. Initial investment and plant volume are high.

Wet scrubbers in W.Europe have not been used very extensively in refuse incineration, mainly because of their high operating cost and of the formation of a visible steam plume. Wet scrubbers probably will be used increasingly, because they also allow HCl-emission codes to be met, in contradistinction to the other dust separators.

C. WASTEWATERS FROM INCINERATORS

Incinerators effluents vary considerably between the respective sources of wastewater and between different plants. Total consumption, with 0.5-8 m3 water/ton of refuse incinerated, is also highly variable.

When the flue gases are quenched by injection of cooling water, the water (2-3 m3/ton of refuse) completely evaporates, so that no wastewaters arise. The cooling water used in water jackets surrounding the loading shaft, burnout gasifier, and combustion grate, is only thermally polluted, and can be rejected after cooling.

In most incinerators, the bottom-ash is cooled and slaked by a water bath, which forms a hydraulic closure. When this water seal is open, the allowable temperature is limited to 60°C or less. Depending on the quantity and temperature of the ash 3.5 to 6m3 of cooling water is required per ton of refuse. When the water seal is completely closed, ash is cooled mainly by evaporation of water, and requires only 0.2 to 0.4m3 of cooling water per ton of refuse. The evaporated water generally rises into the combustion chamber.

The quench water leaches salts and unburnt organic material from the residue. It contains particles in suspension, and reacts basic. When fly-ash is collected in a wet scrubber, the resulting slurry has an acidic reaction, by absorption of acid gases, such as HCl, SO_2, SO_3, CO_2 and NO_x. Moreover, the collected particles contain adsorbed acid gases. Scrubbing liquor can be recirculated after settling. It is highly corrosive and may cause obstructions and erosion. The required amount of scrubbing water varies between 0.5 and 50 m3/ton of refuse, but is largely constituted by recirculated water.

The incineration of 1 ton of refuse generates about 5.000m3 (s.t.p.) of flue gases, having a typical HCl-concentration of 1 g/m3, which corresponds to a total amount of 5 kg HCl. When this quantity is absorbed to a 5 % solution, it represents a volume of 0.1 m3 of liquor. Conversely a 1 % solution gives rise to 0.5 m3 of liquor. Neutralization with lime requires a supplementary 0.1 m3, for preparation of the lime slurry. Moreover about 0.5 m3 of water is evaporated when cooling the flue gases from 300 to 75°C.

The purification of the boiler feedwater also gives rise to wastewaters, e.g. spent brine, lime sludge, mud, etc., depending on the origin of the feedwater and the kind of treatment required.

The composition of incinerator wastewaters has been repeatedly studied.(7,8-11) Water originating in wet scrubbers or fly-ash spray chambers is generally acidic, whereas quench water from bottom-ash is basic (typically pH = 9.0-11.5), and contains mainly Ca^{++}, Na^{+}, K^{+}, some Al^{3+} and Mg^{++}, and traces Zn^{++} as cations. The main anions are Cl^{-}, SO_4^{2-}, NO_3^{-}. More refined analytical techniques also show the presence of the more common heavy metal ions (Pb, Zn, Hg, Cd,...) in scrubber liquors.

D. LAND POLLUTION

Incinerator ash

Incinerator ash can be subdivided into bottom-ash, fly-ash and fly-dust.

The relative amounts of the different types of ash varies with furnace type and operation method, and with ash content and composition. When coal is burned on a travelling grate about 80 % of the ash ends up as bottom ash, and has a carbon content of 15-50 %. The fly-ash has a carbon content of 30 %. When pulverised coal is fired in suspension in a dry-bottom furnace, fly-ash represents 80 % of total ash. The carbon-in-ash amounts to 2-8 % in front-wall fired boilers, and to 0.5-3 % in tangentially fired (vortex) boilers.

In grate incinerators the bottom represents the bulk(75-90 %) of total ash. The combustible content in new plants amounts to 2-6 %, which compares favourably to older data (5-12 %) and to the combustion of coal on a travelling grate. Unburnt material arises when combustibles are shielded from the fire by ash, or cascade down the grate, and also when an insufficient residence time is provided. The putrescible content is quite low, e.g. 0.01-0.5 wt. % of ash, but the chemical method of analysis has been criticized.

Bottom ash is composed of mineral oxides mainly, such as SiO_2, CaO, Al_2O_3. Its heavy metal content (Pb, Sn, Zn, Cu,...) is generally lower than 1.5 %, but highly variable. Its density amounts to 1.2-2 tons/m3. Depending on the ash handling and draining method used, the moisture content varies in the range of 15 to 20 %.

Many acids and anhydrides being volatile (SO_2, SO_3, HCl, CO_2,...) bottom ash reacts basic, and contains but minor amounts of sulphur (0.1-0.6 %), chlorine (0-0.3 %) and fluor (0.02-0.15 %).

Slagging incineration yields a highly insoluble, high density, glassy material, with a very low combustible content.

Grate siftings generally represent 1-2 % of refuse weight, depending on the grate system used, the degree of wear of the grate bars, and the amount of finely divided material in refuse. The Flynn-Emrich grate features a sieving action of the grate, which inflates the amount of siftings. The burn out of the siftings was found to be quite satisfactory. Grate siftings often have a high density (2-3 tons/m3), because of the presence of large amounts of melting metals.

	Fly-ash(x)			Bottom-ash		
	Min.	Max.	Mean	Min.	Max.	Mean
Combustibles	5.7	10.1	7.2	9	6.6	3.2
S	5.7	10.1	7.2	0.1	0.6	0.2
Cl^-	0.8	2.1	1.3	0	0.3	0.1 (xx)
F^-	0.1	0.39	0,18	0.04	0.13	0.06
SiO_2	28.5	44.6	34.5	52.3	67.4	60.5
Fe_2O_3	6.6	11.6	9.4	4.0	17.6	8.1
Al_2O_3	18.1	27.2	21.4	3.5	14.2	7.1
CaO	10.1	13.5	12.3	8.5	11.3	9.9
MgO	3.3	4.9	3.9	1.2	2.1	1.6
Pb	0.3	1.5	0.7	0.1	0.8	0.2
Mn	0.1	0.15	0.12	0.01	0.1	0.05
Zn	0.2	3.4	1.5	0.07	1.02	0.32
Sn	0.17	0.27	0.27	0.5		0.5
Cu	0.07	0.09	0.08			
Cd	0.01	0.03	0.01			
Cr	0.03	0.09	0.05			

Table 7. Composition of fly-ash and bottom-ash
Hamburg and Bremen, 1973

(x) collected in an electrostatic precipatator
(xx) based on wet ash, with an average of 17.5 % Water content.

Leachate tests have been conducted on incinerator residue, in order to evaluate the risk for groundwater contamination.(7) The total amount of leachate, when treating bottom-ash with deionized water, saturated with CO_2, is very small. Up to 12.3 %, however, can be extracted from fly-ash. Chemical analysis shows Na^+, K^+, Ca^{++}, SO_4^{--}, Cl^- and OH^- to be the main components of the solubilised material, with 60-80 % consisting of NaCl or KCl. Lead, zinc, cadmium and nickel are present only in extremely small amounts, whereas chromium and mercury could not be detected. Fly -ash from the incineration of residuals of a composting plant, however, contained 0.3 % Zn and 0.08 % Cd.

Groundwater and wastewater contamination can be avoided by :

1. treating the bottom-ash and fly-ash separately
2. dry collection of fly-ash, i.e. with multicyclones or an E.S.-precipitator
3. sintering or melting the fly-ash with additives, to reduce its solubility.

Slag deposits form but a minor amount of total ash. Their constitution and reactivity was discussed previously.

Fly-ash typically represents 15-20 % of total ash, i.e. 25-75 kg/ton of refuse, or 5-15 g/m3 (s.t.p.). The combustible content is inflated by the presence of charred paper, and varies between 6 and 15 %. The concentration of sulphur (5.7-10.1 %), chlorine (0.8-2.1 %) and fluor (0.1-0.4 %), and that of heavy metals is markedly higher than in bottom-ash.

Fly-ash is a light, free-flowing powder, with a bulk density of 400-1.000 kg/m3. It solidifies in contact with moisture, which has often led to problems during storage and transportation.

V. EVALUATION

1. Conventional Refuse Incineration

Present Status

Conventional incineration is one of the most widespread methods of refuse disposal, especially in densely populated regions.

Capacity ranges from 50 to 2.500 tpd.

Refuse incineration has been practised for over a hundred years. The present types of municipal incinerators, using mechanical grates, have been used for more than forty years and have attained a high level of technical perfection.

Technical Aspects

Complexity.

Normally the refuse is incinerated without pretreatment. Bulky wastes are shredded by hammermills or cut by hydraulically operated shears.

The flue gases are treated

- using cyclones only, in very small plants (a few tons/h)
- using electrostatic precipitators in the majority of W.European plants.
- using high efficiency scrubbers in the newest plants, in order to meet HCl-emission standards.

Waste water arise in minor quantities only, and is often discharged without further treatment. Scrubber wastewaters should be neutralized with lime or caustic soda; heavy metal oxides should be precipitated, prior to discharge.

The combustion residue is sterilized and can be tipped without risk of putrefaction. Measures to prevent groundwater pollution by leaching are mandatory.

2. Plant reliability

Plant availability generally ranges between 75 and 90 %. Downtime can be caused by :

- failure of mechanical feeding or ash extraction equipment
- failure of boilure tubes, due to corrosion
- excessive fouling of heat transfer surfaces.

Equipment redundance normally consists of dividing total capacity over 2 to 5 units, operated in parallel.

Principal repair and maintenance areas are :

- crane and grapple
- grate bars (replacement after a few years)
- boiler tubes
- refractory lining, especially in cooling tower and in contact areas with sliding refuse.

Possible incidents

Explosion of gas bottles, ammunition, generally causes only minor damage.

Thermal efficiency 55-70 %

The efficiency is mainly limited by :

- the relatively large air factor
- the unfavourably conditions for heat recovery

Environmental Aspects

Dust emission is no longer a problem.

Minute particles of heavy metals are not arrested by the electrostatic precipitators.

Emission of HCl exceeds present emission standards. In W. Germany new units are being equipped with wet scrubbers. This complicates wastewater treatment and increases construction and operating cost.

Capital Cost : high

Operating Cost :	personnel	variable
	power consumption	40 kWh/ton
	utilities : water	0.5 m3/ton
	steam	little.

Possibilities for Resource Recovery

Recovery of heat, under the form of steam, thermal oil, hot air, or hot flue gas.

Recovery of scrap ferrous metal and possibly non ferrous metals and graded clinker from the combustion residue.

VI. CONCLUSIONS

Refuse incineration is a well established, fairly reliable disposal technique. It allows a large volume reduction to be achieved in a short time (about 1h. residence time on the grate) and leaves a sterilized residue. Moreover, heat can be recovered with a fair efficiency (55-70 %) and ferrous metal can be recovered from the solid residue.

On the other hand, several disadvantages have to be recognized :

- incinerators are expensive to own and operate
- air pollution occurs to a certain extent (HCl- and heavy metal emissions). The removal of HCl requires wet scrubbing of the flue gases and inflates operating cost.

GENERAL LITERATURE

1. Proceedings of the National Incinerator Conference, 1964-1966, 1968, 1970, 1972 and 1974.
2. Proceedings of the 1976 National Waste Processing Conference (formerly National Incinerator Conference), Boston, Massachusetts, May, 23-26, 1976.
3. Conversion of Refuse to Energy, Montreux, Switzerland, Nov. 1975.(CRE)

REFERENCES

1. L. BARNISKE and W. SCHENKEL
   Entwicklungsstand der Mullverhrennungsanlagen mit Wärmewertung in der Bundesrepublik Deutschland. CRE, 1975, p.91.
2. R.J. ALVAREZ
   Status paper on conversion of Solid Waste to Energy on the North American Continent, CRE, 1975, p.130.
3. A. BUEKENS
   Vaste Afval, Ontstaan, Verwerking en Beheer.
   Nederlandse Boekhandel, 1975.
4. R.M. BREMMER
   Parameters determining desirability of Refuse fired Steam generators for Central Heating and Cooling in Canada, CRE, 1975, p. 157.
5. G.S. FARKAS
   Requirements and solutions for the conversion of municipal refuse for industrial steam, CRE, 1975, p.464.
6. ANON
   Resource Recovery through Incineration, Josef Martin Feuerungsbau Publication.
7. K. FICHTEL
   Leaching tests of slags and flyashes from municipal waste incinerator-results and recommendations for the operations of incineration plants and the treatment of residues, CRE 1975, p. 366.
8. D.A. WILSON, R.E. BROWN, Proc. National Incinerator Conference 1968, p. 196.
9. R.J. SCHOENBERGER et al., Ibid., p. 204.
10. F.L. CROSS, R.W. ROSS, Proc. Nation. Inc. Conf. 1970, p 69.
11. F.E. MATUSKY, R.K. HAMPTON, Ibid., p. 198.

PART II. - PYROLYSIS AND GASIFICATION

PART II. - PYROLYSIS AND GASIFICATION

I. INTRODUCTION

A. INTRODUCTION

Refuse pyrolysis has only attracted attention during the last decade. The pyrolysis process itself however has been practiced for several centuries e.g. in the conversion of wood into charcoal and various useful chemicals, such as methanol and acetic acid.

The distillation of coal in coking furnaces is a major industrial operation. The production of cokes and steel for the last years as well as the anticipated figures for the coming years are given in fig. 4. (1)

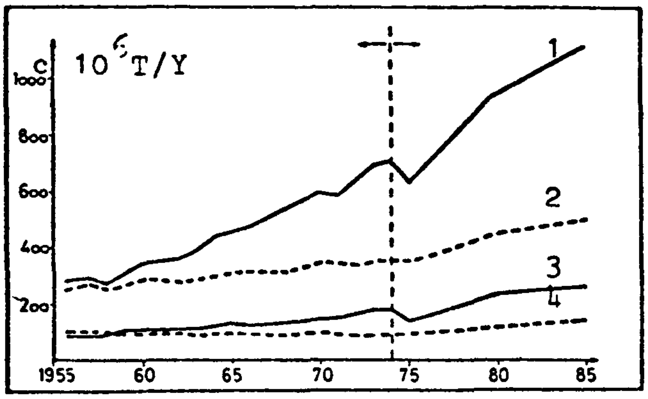


FIG. 4 : World and W. European Cokes and Steel Production.

1. World : Steel
2. World : Cokes
3. W. Europe : Steel
4. W. Europe : Cokes

Besides the main product, cokes tar and gas are also obtained.

The coal gas has a fairly high heating value and is often burned to provide the necessary heat for the coking process.

Coal tar is separated into useful products, such as crude benzene, naphtalene, anthracene and phenantrene oils, pitch, etc., by means of distillation, solvent extraction and other methods (figure 5). (1)

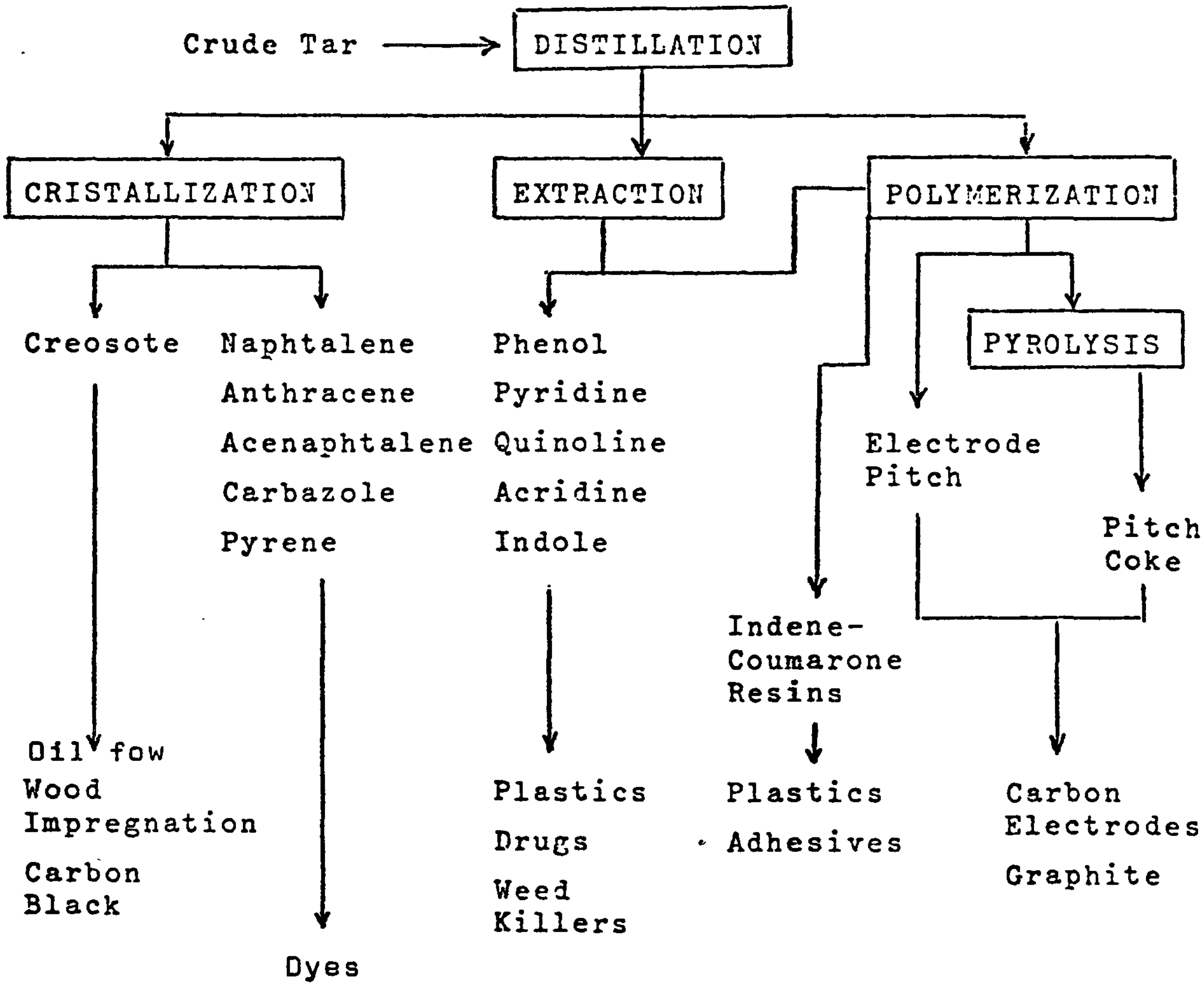


FIG. 5 : Products from Coal Tar

The recent energy crisis renewed the interest in the coal gasification processes that produce a low or medium heating value gas. A large number of coal gasification processes are currently under development. (2)

Some commercially available processes for coal gasification are given in table 8.

Process	Type	Gasification medium
Winkler	fluid bed	Steam, oxygen or air
Koppers Totzek	entrained	Steam + oxygen
Lurgi	moving bed	Steam + oxygen

Table 8. Commercially available coal gasification processes.

B. SURVEY OF MUNICIPAL SOLID WASTE PYROLYSIS AND GASIFICATION PROJECTS

GASIFICATION PROCESSES

NAME	CONSTRUCTOR	LOCATION	CAPACITY	TYPE	REMARKS
Purox	Union Carbide	S. Charleston, W.V.	200 T/D	Shaft furnace	Demonstration Plant. operational.
Andco-Torrax	P. Wurth	Luedelange, Lux.	200 T/D	Shaft furnace	Demonstration Plant in shakedown since 1977.
		Frankfurt, W.Germ.	200 T/D/		Under construction.
	Caliqua	Grasse, France	170 T/D		Project cancelled.
Pyrogas	Motala	Gislaved, Sweden	50 T/D	Shaft furnace	Refuse mixed with coal. Tests in Oaxen have been successfull. The Gislaved demonstration Plant is in shakedown.
Landgard	Monsanto	Baltimore, Ma. USA	900 T/D	Rotary kiln	Numerous difficulties. Monsanto quit project on Feb. 1977. Demonstration Plant under operation at reduced throughput.
Nippon	Nippon Steel	Kitakyushu City	30 T/D	Shaft furnace	Pilot plant to start in 1978.
Hitachi	Hitachi Ltd	?	2,4 T/D	Fluidised bed	Pilot plant (operational)
Mitsui	Mitsui Shipbuilding	Chiba	?	Shaft furnace	Pilot plant (operational)
Battelle NW.	Battelle Pacific Northwest Lab.	Richland, Wash. U.S.A.	5 T/D	Shaft furnace	Research project discontinued.

NAME	CONSTRUCTOR	LOCATION	CAPACITY	TYPE	REMARKS
Coors	Adolph Coors	Golden, Co U.S.A.	24 T/D	Fluidised bed	Pilot plant since 1973.
Devco	Devco Management	Queens, N.Y. U.S.A.	7 T/D	Rotary kiln	Sued Monsanto for stealing their proc.
Müva	Johan Sulz Berger	? W. Germany	?	Shaft furnace	Pelletised Refuse.various components have been tested.
Syngas	Battelle Columbus Lab. and Syngas Recycling Co.	? U.S.A.	?	Free fall or moving bed	Gasifier + methanation reactor. Small scale tests on simulated refuse.
Müva	IBO-Planung Köningstein	? W. Germany	?	Shaft furnace	Small Laboratory unit.

PYROLYSIS PROCESSES

NAME	CONSTRUCTION	LOCATION	CAPACITY	TYPE	REMARKS
Garrett	Occidental Petr. Corp.	El Cajon, Cal. U.S.A.	200 T/D	Entrained bed	Demonstration plant (start up in 1977)
Destrugas	Pollution Control	Kalundborg, Denmark	5 T/hr	Shaft furnace	Pilot plant/ Process is being marketed.
Pyrox	Tshikashima Kikai	Miyagi Prefecture	40 T/D	Double fluid bed	Pilot plant operational.
Ebara	Ebara Manuf. Co		5 T/D	Double fluid bed	Pilot plant operational.

NAME	CONSTRUCTOR	LOCATION	CAPACITY	TYPE	REMARKS
Goldshöfe	Fa Kiener	Goldshöfe/Aalen W. Germany	10 T/D	Batch retort	Pilot plant operational
Lantz	Pan American Resources Inc.	Upland, Ca U.S.A.	4 T/D	Rotary Kiln	Pilot plant operational
Agajanian System	Ecology Recycling Unlimited Inc.	Kern County, Ca. U.S.A.	10 T/D	Batch retort	Pilot plant operational
Deco	Enterprise Co	Santa Ana, Ca. U.S.A.	50 T/D	Externally heated serew conveyor	Pilot plant operational
Tasc	Technology Applic. Services Corp.	Japan	16-20 T/D	Plasma convector	Pilot plant operational
Warren Spring	Warren Spring Lab.	Stevenage, England	?	Shaft furnace	Pilot plant operational
US. Bur. of Mines	US. Bureau of Min.			Batch retort	
Techn.Un. Berlin	Technische Univ. Berlin	Berlin, W. Germ.	0.5 T/D	Shaft furnace	Pilot plant operational
Deere	Kelley Co	John Deere Moricon Works	1 T/D	Batch retort	Pyrolysis gases are burned to supply heat for paint drying ovens.
W.VIRGINIA	W. Virginia Univ.	Morgantown, W.VA U.S.A.	1 T/D	Fluid bed	Research project stopped due to lack of funds.
Puretec	Barber-Colman	Irvine, Ca. U.S.A.	1 T/D	Molten lead bath	Project discontinued Aug. 1976.
Sodeteg	Sodeteg Engineering	Grand Queville France	0.5 T/D	Shaft furnace	Project stopped
Kemp	Kemp Reduction	Santa Barbara, Ca U.S.A.	0.5 T/D	Batch retort	Small test unit

II. PROCESS DESCRIPTION

A. DEFINITIONS

1. Pyrolysis or degasification of organic materials is a thermal degradation process conducted without addition of reactive gases (air, steam, hydrogen). Depending on the reaction conditions varying amounts of gaseous and liquid products and carbonaceous residue are produced.

   Municipal refuse has a typical composition $C_6 H_{9.6} O_{3.8} N_{0.1} S_{0.01}$, not unlike that of cellulose $C_6H_{10}O_5$. The pyrolysis of cellulose can be described as follows, as a function of temperature.(3)

Temperature	Chemical process
25-150°C	drying
150-240	loss of chemically bound water
240-400°C	Depolymerization formation of Levoglucosan, Tars, oils CO, CO_2, H_2, CH_4
400-700°C	Dehydrogenation, formation of polycyclic aromatic compounds which or further dehydrogenation yield a carbonaceous residue

2. Gasification of refuse occurs in the same temperature range as pyrolysis. The thermally decomposing material and its carbonaceous residue react with gases, such as air, oxygen, steam, carbon dioxide or hydrogen. The reaction of air, oxygen or hydrogen with the material to be gasified is exothermic and can be used to obtain or to maintain the desired reaction temperature.

The following reactions can occur :

- Gasification with air or oxygen (partial oxydation)

$$C + 1/2\ O_2 \rightarrow CO \qquad \Delta H_r = -29{,}4 \text{ kcal/mole}$$

- Gasification with steam (water-gas reaction)

$$C + H_2O \rightarrow CO + H_2 \qquad \Delta H_r = 28{,}3 \text{ kcal/mole}$$

- Gasification with carbon dioxide (Boudouard reaction)

$$C + CO_2 \rightarrow 2\ CO \qquad \Delta H_r = 38{,}2 \text{ kcal/mole}$$

- Gasification with Hydrogen

$$C + 2H_2 \rightarrow CH_4 \qquad \Delta H_r = -20{,}9 \text{ kcal/mole}$$

The following secondary reactions proceed simultaneously :

- Water-gas shift reaction

$$CO + H_2O \rightarrow H_2 + CO_2 \qquad \Delta H_r = -10{,}1 \text{ kcal/mole}$$

- Methanation

$$CO + 3\ H_2 \rightarrow CH_4 + H_2O \qquad \Delta H_r = -49{,}2 \text{ kcal/mole}$$

B. INFLUENCE OF REACTION PARAMETERS

1. PYROLYSIS PROCESSES

Pyrolysis of refuse generally yields the following products

1. Gas
2. Oil and tar
3. Char

During pyrolysis the moisture content of the refuse is driven off and eventually condenses, forming a water fraction, when the volatile pyrolysis products are cooled below their dewpoint.

The nature and relative quantities of the various products are determined by thermodynamic and by kinetic factors. The most important operational parameters are : feedstock composition, temperature, pressure, residence time of the solid and of the volatile material. The influence of these parameters will now be illustrated by a few examples.

a) Temperature

Hoffmann (4) pyrolysed the combustible fraction of MSW in a batch retort at different reaction temperatures. His results are given in Table 9.

T(°C)	Gases (% w.)	Liquid (% w.)	Char (% w.)
480	12,3	61,1	24,7
650	18,6	59,2	21,8
815	23,7	59,7	17,2
925	24,4	58,7	17,7

Table 9. MSW pyrolysis products as a function of temperature

Some representative results are given in figures :

(6a) pyrolysis of paper in the Warren Spring Laboratories batch reactor (5)

(6b) pyrolysis of dried shredded refuse in the Tsukishima Kikai Co dual fluidized bed reactor (27)

(6c) gasification of dry Shredded refuse in the Hitachi fluidized bed pilot reactor (28)

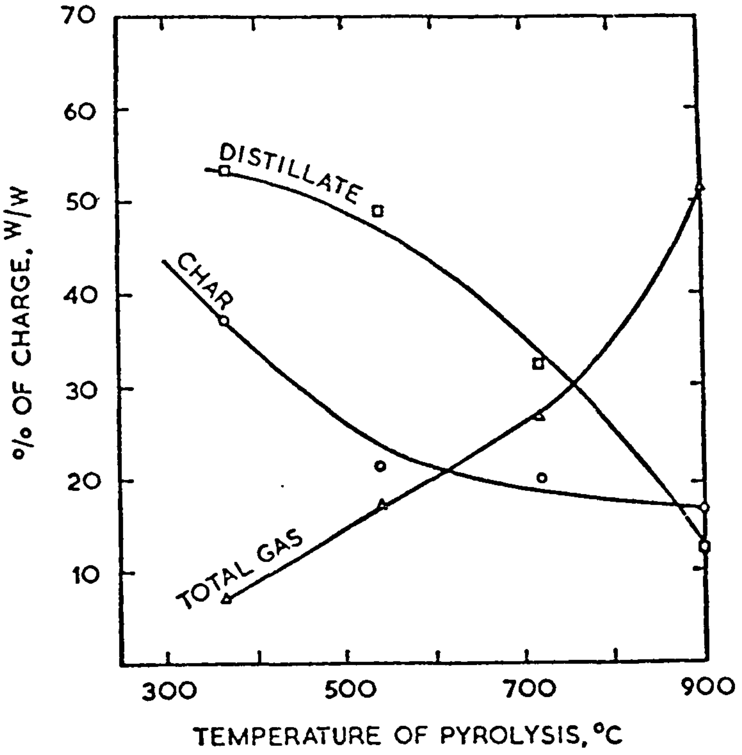


FIG. 6a : PRODUCTS FROM PYROLYSIS OF PAPER BY RAPID HEATING

It can be concluded that high temperatures favour the production of simple gaseous compounds, such as H_2, CO, CO_2, H_2O and CH_4, at the expense of higher hydrocarbons, oil and tar. The carbonaceous residue looses weight by the evolution of volatile material. On the other hand supplementary carbon may be formed in the gas phase, by thermal cracking of oil and tar.

b) Reaction time

A longer residence time favours the occurence of secondary reactions, i.e. the degasification of the charred residue and the further decomposition of volatile products.

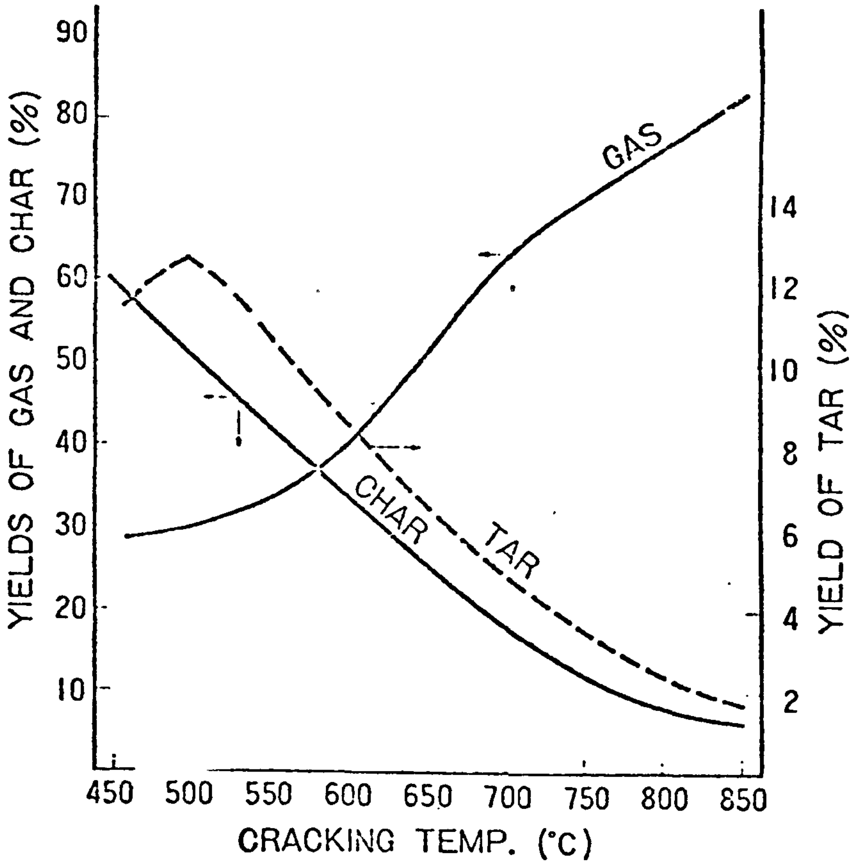


Fig. 6b : Influence of temperature on product distribution. (Tsukishima) (27)

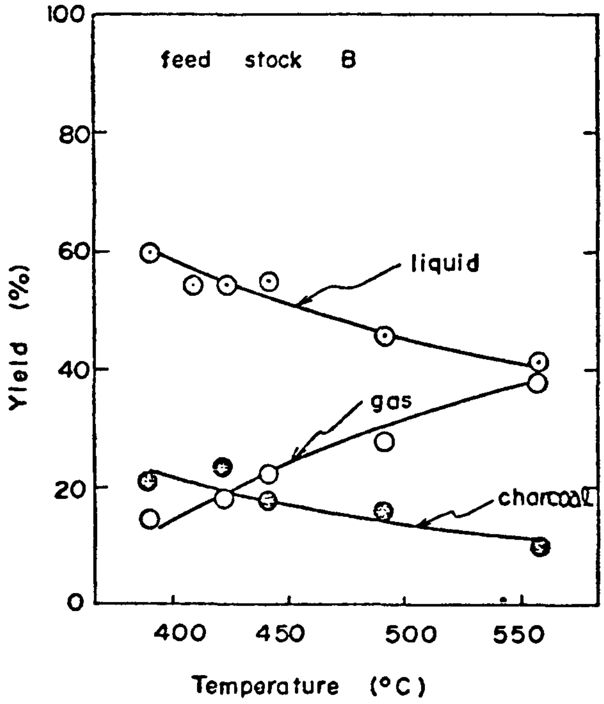


Fig. 6c : Influence of temperature on product distribution. (Hitachi) (28)

The length of the reaction time should be understood in relative, rather than in absolute units. Conversion may be higher after one second at 1000°C than after one hour at 500°C!

A high yield of liquid product is obtained in the Occidental Petroleum flash pyrolysis process, in which a fluff RDF is pyrolysed at 500°C using very short reaction times.

c) Heating rate

Pyrolysis often occurs at non uniform reaction temperatures, which complicates the study of the pyrolysis phenomena. Kaiser and Friedman studied the effect of variable heating rates on the pyrolysis of newsprint: high heating rates were shown to favour a high gas yield, whereas the yields of oil and char decreased (6),(fig. 7).

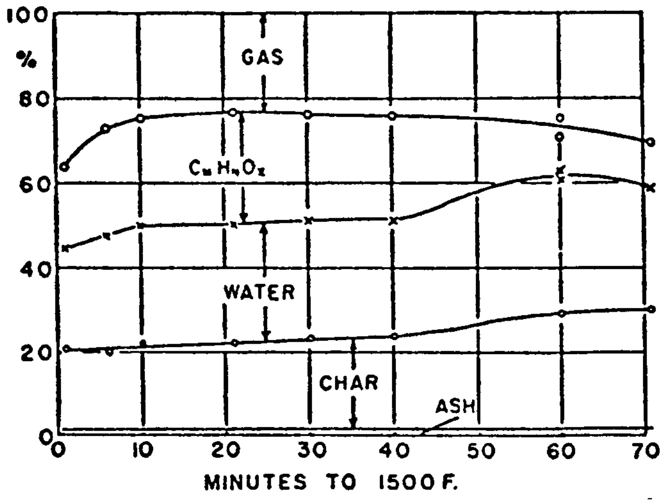


FIG. 7 : Influence of Heating Rate on Pyrolysis Products.

d) Nature of feedstock

Tests made by Kaiser and Friedman (6) with different refuse components gave the results shown in Table 10.

Feedstock	Gas	Tar	Char	Water
Newspaper	25,8	10,2	28,7	33,9
Rubber	17,3	42,5	27,5	3,9
Vegetable feed waste	27,6	20,2	20,2	27,2

Table 10. Pyrolysis products from different wastes

e) Moisture content of the feedstock

The influence of the moisture content of the feedstock on the oil yield is rather dramatic as follows from Hitachi's experiments (figure 8)

Ebara also found that gasification is enhanced by a high moisture content of the feed; the same results are not obtained by addition of a suitable quantity of steam to dry feed materials.

2. GASIFICATION PROCESSES

In most gasification processes the gasifying medium reacts mainly with the charred residue, according to the reactions tabulated under I.2.

Generally the result of a gasification process can be computed from thermodynamic equilibrium data, as a function of temperature, total pressure and partial pressure of the various reactants.

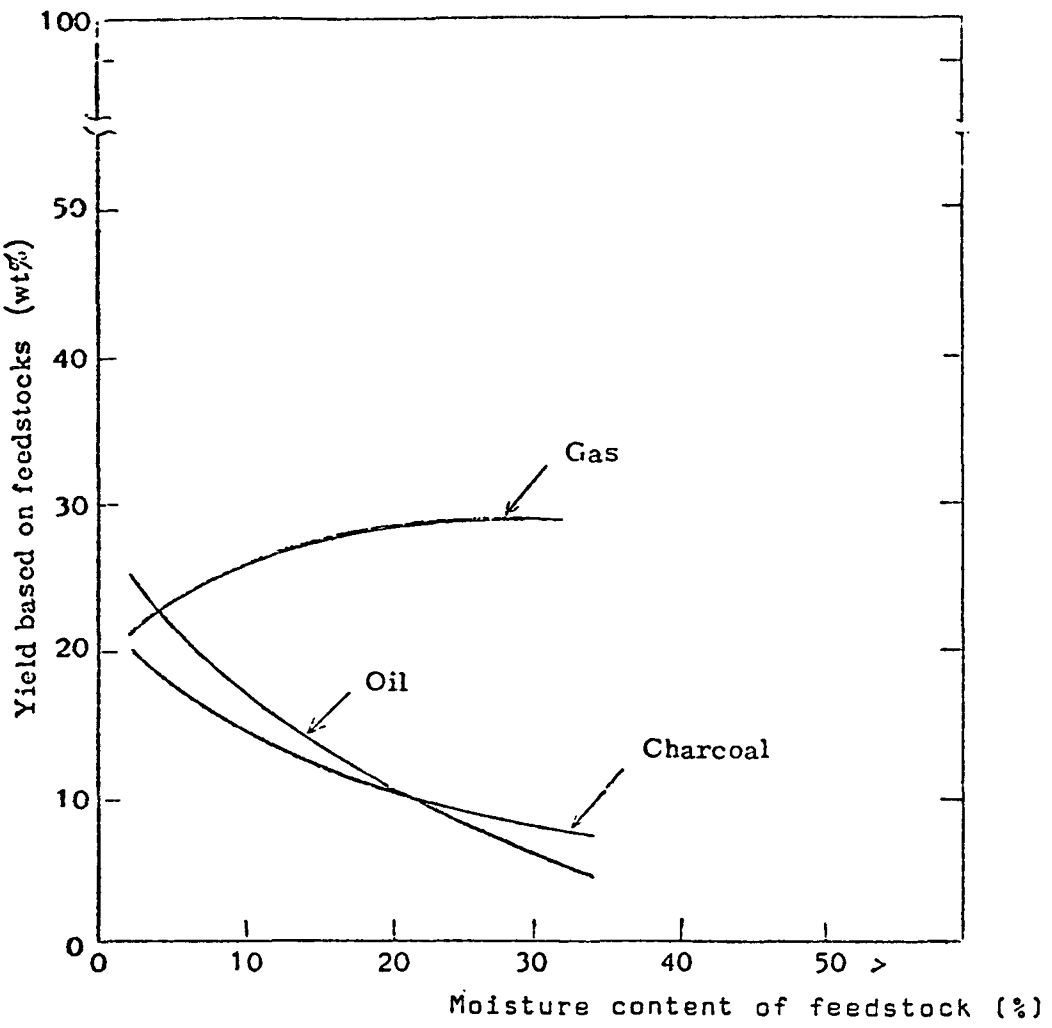


Fig. 8 : Influence of moisture content on product distribution.

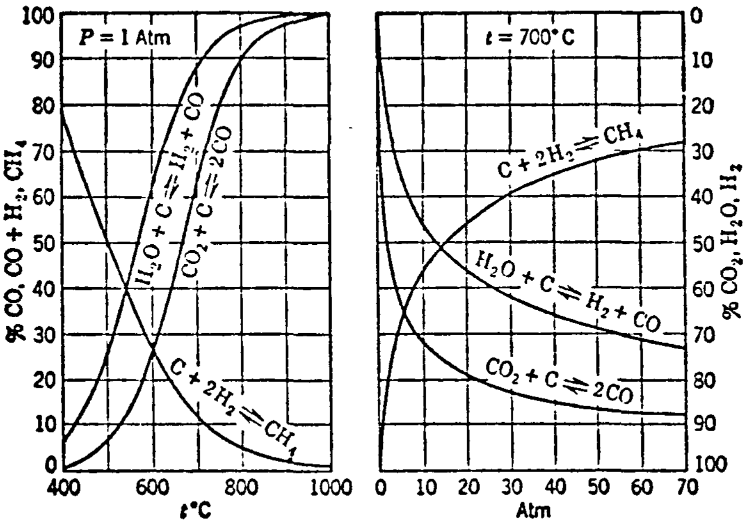
In gasifier practice, the equilibrium approach is generally sufficiently close to warrant this type of approximation.

The following figures present equilibrium data, relevant to gasifier operation. (fig.9)(23)

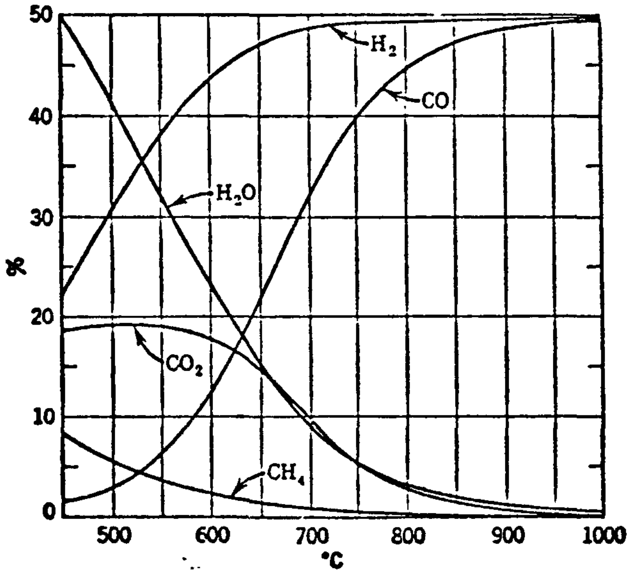
C. REACTOR SYSTEMS

Three basic furnace types are considered here :

1. Vertical shaft furnaces
2. Fluidised bed furnaces
3. Rotary kiln furnaces



Comparison of the three main reactions of gasification.



Water-gas from carbon (wet basis).

FIG. 9 : Equilibrium Data for Gasifiers.

The following types of furnace have not yet been proposed for industrial operation : the multiple hearth furnace, the spouted bed reactor and dilute phase gasification.

1. Vertical shaft furnace

The following processes use a vertical shaft furnace :

a) Destrugas (pyrolysis)
b) Andco-Torrax (gasifier)
c) Nippon Steel (gasifier)
d) Mitsui Engng & Shipbuilding (gasifier)
e) Motala (gasifier)
f) Purox (gasifier)

Different reaction zones can be observed in a vertical shaft gasifier (fig. 10)

Remarks : When ash is extracted as a molten slag, the ash cooling zone is generally replaced by quenching of the slag in a water bath.

In pyrolysis processes the gasification zone is absent.

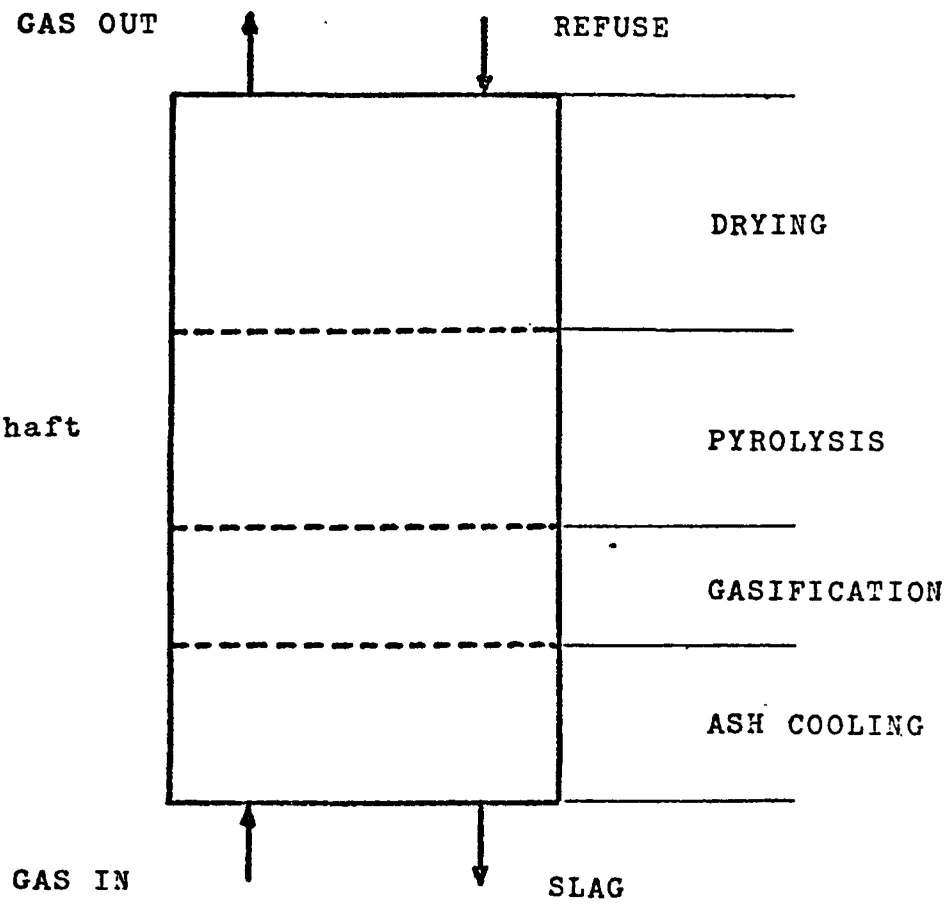


FIG.10 : Vertical shaft Furnace

Process	Gasification medium	Maximal Temperature	Temperat. outlet gas	Remarks
Purox[8]	oxygen	1,600°C	200°C	molten slag
Andco-Torrax	air preheated to 1000°C	1,500°C	450°C	molten slag
Destrugas	none	1,000°C	?	pure, cocurrent pyrolysis
Motala	air + steam	1,500°C	500°C* 100°C*	Refuse + coal
Mitsui	air + steam	1,500°C	?	molten slag

Table 11. Selected vertical shaft processes.

*Gas is taken out at two different locations :

1. gasification products (lower outlet)
2. degasification products and moisture (higher outlet)

Advantages	Disadvantages
Simple construction: almost no moving parts at high temperature. High thermal efficiency when operated in countercurrent.	Low heat transfer rates, especially with externally heated reactors. Bridging and channeling problems. Process Control is difficult.

Table 11 b. Properties of shaft furnaces.

I. Drying : Incoming refuse comes into contact with hot rising gases and loses its physically bound water.

II. Degasification zone: Dried refuse is pyrolysed by hot gases from the gasification zone. Tars and oils are produced in this zone.

III. Gasification zone : preheated and degasified refuse reacts with incoming gases (H_2O, O_2, air) : formation of H_2, CO, CO_2.

IV. Ash cooling zone: Is absent in the Purox and the Andco-Torrax process, in which a molten slag is tapped.

Unclassified refuse has a tendency of bridging and channeling. This results in a non uniform bed and, hence, in a non-uniform flow of gases in the shaft. Dense parts of the refuse bed are impervious to the gas flow and remain wet, cold and unreactive. In gasifiers unconverted oxygen eventually mixes with pyrolysis gases, causing small explosions.

In the Destrugas pyrolysis and the Purox gasification processes this problem is avoided by preliminary shredding. In the Motala process coal is added to increase bed uniformity.

Table 11 gives an over view of some selected vertical shaft processes

2. Fluidized bed reactor

The following processes use a fluidized bed reactor:

a) W. Virginia University (dual bed pyrolysis)
b) Ebara Mfg. Co Ltd (id.)
c) Tsukishima Kikai Co Ltd (id.)
d) Occidental Petroleum (entrained bed pyrolysis)
e) Hitachi Ltd (fluidized bed gasification)

Fluidisation is a process in which a bed of finely divided solid particles is kept in suspension by an upward stream of gas. The fluidised solids behave more or less like a liquid, very good heat transfer rates are obtained due to the rapid movement and the high surface area of the solids available for heat exchange, hence an almost uniform bed temperature is obtained. The bed can be formed either by the pyrolysis residue or by a foreign material (e.g. sand)

The Occidental Petroleum process can be regarded as an extreme form of a fluidised bed, in which the gas flow is so high that solids are conveyed by the gas.

Characteristics of fluidised bed processes are given in table 12.

Process	Fluidising gas	Temperat.	Remarks
W.Virginia	Recycled pyrolysis gas	850°C	Two bed systems.Experiments were discontinued at an early stage
Ebara Mfg Co	Recycled pyrolysis gas	400-700°C	Two bed pyrolysis
Tsukishima Kikai Co Ltd	Steam	700-730°C	Two bed pyrolysis
Occidental Petr.	Recycled pyrolysis gas	500°C	Char particles ± 50 µ
Hitachi Ltd	Air	450-600°C	Partial oxidation

Table 12. Fluidized bed pyrolysis processes.

Advantages	Disadvantages
High rates of heat transfer, hence :-high reaction rates -uniform bed temper. Stable operation is possible, even when sudden changes in refuse composition occur.	Refuse has to be preprocessed (shredding, separation of dense materials,...) High dust load of the gases Loss of fluidisation can occur, due to clinkering of ash and bed material.

Table 12b. Properties of fluidised bed reactors

3. Rotary kiln reactors

Rotary kiln reactors are used in the LANTZ-convertor and in the LANDGARD process.

The operating characteristics of the Landgard system are given in table 13.

Gasifying medium	Temperature	Remarks
air	1100°C	+ flue gases of auxiliary burner

Table 13. LANDGARD process.

Advantages	Disadvantages
Simple Reactor Construction Good mixing of refuse	Preliminary Shredding Required Difficult Handling of Shredded Refuse High wear on refractory Difficult sealing of kiln Difficult control of reaction conditions

Table 13b. Properties of LANDGARD process

III. RECOVERED PRODUCTS

A. GASEOUS PRODUCTS

1. Gasification

The gas produced by gasification of refuse is composed mainly of hydrogen, carbon monoxide, cabon dioxide, methane and higher hydrocarbons. In the case of gasification with air large quantities of nitrogen are also present.

Table 14 gives gas composition reported for a few gasification processes.

Note : All gases are produced from a typical American refuse with a water content of ± 25 % and a gross heating value of 2500 kcal/kg

Most of the gasification processes tend to maximise the gas production. Hence, liquid products, such as oil and tar are recycled into the reactor where they are eventually decomposed. Air is by far the cheapest gasifying medium. A serious disadvantage of gasification with air is the very low heating value of the resulting gases because of dilution with nitrogen. In the Purox system, on the other hand, pure oxygen is used, resulting in the production of a gas with a fairly high heating value. However, the operating costs are higher because of the need for separate oxygen generating plant.

2. Pyrolysis

Pyrolysis gas has a high heating value, as a consequence of the absence of diluting combustion gases and the presence of sizeable amounts of higher hydrocarbons.

Typical analyses of pyrolysis gases are given in Table 15.

Component	Purox(8)	Motala(9)	Andco-Torrax(22)	Landgard(10)	Hitachi(13)	Nippon Steel
H_2(vol %)	26	20	15	7	3	25
CO	40	20	15	7	14	30
CO_2	23	8	14	11	15	24
CH_4	4	2	3	3	2	3
C_nH_m	5	-	2	2	2	1
O_2	-	1	2	2	0.5	-
N_2	1	49	49	69	62	18
Gross heating value kcal/Nm3	3500	1300-1500	1300-1900	1100	1050	1900

Table 14. Composition of gases from gasification processes.

Component	Destrugas(11)	W.Virginia(12)	OXY* (13)	Tsukishima	Ebara
H_2(val.%)	49	44,5	12	23	n.a.
CO	15	24,8	37	34	
CO_2	21	15,8	37	18	
CH_4	11	7	6	13	
C_nH_m	4	8	7	6	
O_2	-	-	-	-	
N_2	-	-	-	-	
Heating value kcal/Nm3	3200 kcal/ Nm3	3600 kcal/ Nm3	3400 kcal/ Nm3	3900 kcal/ Nm3	4500 kcal/Nm3

Table 15. Composition of selected pyrolysis gases.

*The gas is burned inside the plant to provide the heat for the pyrolysis reaction and for the drying of the refuse.

The operating variables have a strong influence on the gas characteristics. The influence of temperature on the amount and heating value of gas, produced from MSW, is illustrated by the results of Hoffmann (4) shown in table 16.

T(°C)	amount of gas m3/kg refuse	heating value kcal/m3	Yield kcal/kg refuse
480	0,118	2700	315
650	0,172	3350	575
815	0,224	3350	685
925	0,21	3100	655

Table 16. Influence of temperature on gas characteristics.

It can be seen that the amount of gas produced increases with temperature. Also its calorific value increases slightly.

High temperatures increase the gas yield. The low temperature decomposition products contain much H_2O, CO_2, CO and H_2. At higher temperatures these primary products are more and more accompanied by hydrocarbon products, having a higher heating value. At still higher temperatures most hydrocarbons are cracked to simpler products, such as H_2, CH_4, C_2H_4, ... and gasified to CO and H_2.

Table 17 shows the effect of the rate of heating on the characteristics of the pyrolysis gas. The table contains data of Kaiser and Friedmann (6) and Burton and Bailie (12).

Rate of heating (min. to 925°C)	Amount of gas m3/kg	Heating value kcal/m3	Yield kcal/kg (refuse)
60^{x}	0,22	3250	720
30^{x}	0,21	3150	665
10^{x}	0,21	3150	665
1^{x}	0,34	3300	1000
± 0,017^{xx}	1,13	3540	4000

Table 17. Effect of heating rate on gas characteristics.

^{x}Newpaper, 925 °C

^{xx}Sawdust, 815 °C fluidised bed.

We can see clearly that higher heating rates increase the amount as well as the energy content of the pyrolysis gas. The high gas yields obtained in a fluidised bed are also obvious.

3. Use of the product gases

a) Fuel gas

The gas has a gross heating value of 1.000 to 4.000 kcal/m3 (s.t.p.)

The properties of some selected fuel gases are given in table 18.

Class	Gas	Gross heating value kcal/m3 (s.t.p.)
High calorific value	methane	9000
	natural gas	8000-9500
Intermediate	hydrogen	3050
	coke oven gas	5000
	water gas	2500
low	producer gas	1000

Table 18. Heating value of some fuel gases.

The low heating value of the pyrolysis gas makes it unsuitable for transportation over long distances. It can be used locally either to raise steam in a specially built boiler at the refuse disposal plant (Andco-Torrax, Landgard) or as a supplemental fuel in a nearby power plant.

The fuel characteristics of a lean pyrolysis gas can be compared to those of a blast furnace gas. Since the rate of gas generation and the fuel properties are varying continuously, the gas can better be used as a supplemental fuel at a large plant existing locally.

b) Synthesis gas

Synthesis gas is a mixture of H_2, CO, CO_2, or N_2 of suitable composition.

The composition required for various syntheses is given in table 19.

Product	H_2	CO	CO_2	N_2
Ammonia	75	-	-	25
Methanol	66,7	33,3	-	-
Oxo-alcohols	50	50	-	-
Fischer-Tropsch	66,7	33,3	-	-

Table 19. Composition of syntesis gas for various synthesis processes.

The synthesis reactions are :

1. Ammonia $3H_2 + N_2 \rightarrow 2NH_3$
2. Methanol $CO + 2H_2 \rightarrow CH_3OH$
3. Oxo-alcohols $C_nH_{2n} + CO + H_2 \rightarrow C_nH_{2n+1}CHO$
4. Fischer-Tropsch (manufacturing of higher hydrocarbons) $n(CO + 2H_2) \rightarrow (CH_2)_n + nH_2O$

These reactions require adequate catalysts which can be poisoned by compounds of sulphur, arsenic, etc.

The use of a pyrolysis gas in a chemical plant can be contemplated, after cleaning, CO-shift conversion, CO_2absorption in suitable media, or methanation.

Union Carbide has proposed its process as a first step in a methanol or ammonia synthesis. Obviously, the process control would be difficult if MSW were the only available feedstock. Moreover, a normally sized plant would require the delivery of refuse of a very large community. Anyway, it seems improbable that this issue will soon be tried in practice.

c) Substitute Natural Gas

By methanation of pyrolysis gas a heating value comparable to natural gas (± 9000 kcal/Nm3) can be obtained.

B- OIL AND TAR

1. Gasification

In gasification processes minor quantities of oils and tar are generated during the thermal decomposition of the incoming refuse. The amount and final destination of these oils is given in table 20.

Process	Amount/ ton refuse	Use
Purox	30 kg	Recycled to furnace.
Motala	40 kg	Burned in a boiler. Fuel value = 8000 kcal/kg.
Landgard	unknown	Direct combustion of pyrolysis gas.
Andco-Torrax	unknown	Direct combustion of pyrolysis gas.
Hitachi	100 to 200 kg	Dependent on moisture content.

Table 20. Oils from gasification processes.

From this table it follows that the Hitachi process features exceptionally high oil yields. These can be explained by a combination of low operating temperatures and low residence times of the products formed; both factors minimize secondary cracking of the oil formed. Moreover, the Hitachi process operates on selected, dry refuse, which also minimizes gas formation (figure

In the Hitachi plant 2 different types of oil are condensed from the product stream; their properties are given in table 21.

	Plastics Oil	Cellulosic Oil
H.H.V. (kcal/kg)	8600	4130
C/H weight ratio	6.2	6.1
Combustible Content (wt %)	97.5	98.8
Viscosity (cpoise)	20(55°C)	22(60°C)

Table 21. Analysis of Hitachi Oils (29)

No data have been published at the moment on the possible recovery or use of these oils.

2. Pyrolysis

The oil and tar forms a highly complicated mixture. Whereas coal tar is primarily a mixture of polycyclic hydrocarbons, the tar from refuse pyrolysis is aliphatic and has a high oxygen content.

Characteristics of the oil obtained by the Occidental Research Flash pyrolysis systems (T = 450 - 560°C; reaction time ± 1 sec) are given in table 22 for different feedstocks (13,20).

The influence of the moisture content on the specific gravity is given in fig.11(20)

The oil has a rather high viscosity. The influence of the temperature and the water content on the viscosity is given in fig.12. (20)

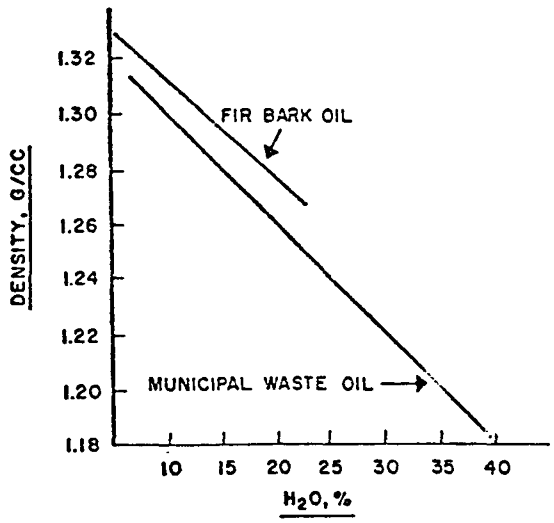


FIG. 11 :. Fluid density vs. moisture (27 °C, 80 °F)

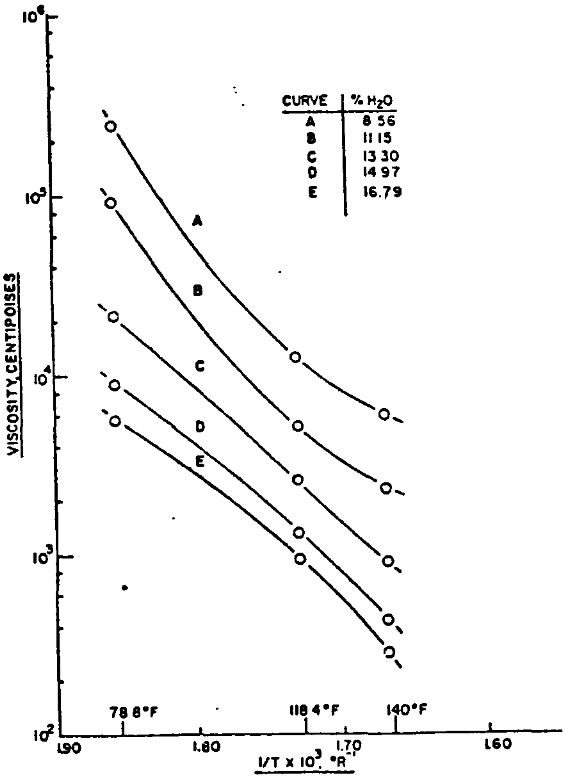


FIG.12 :Effect of temperature and moisture content on viscosity of MSW pyrolytic oil—run 61-73, drum 473

Oil	Animal waste	Rice Hulls	Fir Bark	Grass Straw	Municipal Solid waste
C	64.8	62.4	60.5	58.6	57.0
H	6.9	5.8	6.0	5.6	7.7
N	7.0	1.4	0.5	1.3	1.1
S	0.2	0.1	0.1	0.1	0.2
O	19.8	29.4	30.7	33.9	33.6
Cl	0.2	0.3	0.2	0.1	0.2
Ash	1.1	0.6	2.1	0.5	0.2
kcal/kg	6500	5700	5650	5200	5800
Oil Yield %	20.0	44.2	28.7	35.7	40.0
Water Yield %	10.1	11.2	15.2	19.9	10.0

Table 22. Characteristics of OXY oil.

The Tsukishima Kikai fluidized bed process also yields high temperature (700°C) tar. Distinction can be made between tar condensing above 90-95°C from the product gas and tar condensing below this temperature. The latter is fluid at ambient temperature, the former is not. The analysis of both tar fractions is given in table 23.

	Condensing above 90°C.	Condensing below 90°C
Carbon	71.1 %	76.5
Hydrogen	2.8	2.6
Nitrogen	3.7	3.1
Sulfur	0.5	0.2
Chlorine	0.2	0.2
Oxygen and ash	21.8	16.3

Table 23. Analysis of Tsukishima oils (30)

At 700°C about 5% of the refuse is converted into oil (figure 6b, p. 36). The oil condensing below 90°C has a high aromatic content.

The composition of a high temperature pyrolysis oil (750°C) reported by Sanner et al. (14) shows a high aromatic content (see table 24). These aromatics are produced by secondary condensation reactions of reactive primary products.

Compound	Vol %
Benzene	78,5
Toluene	14,1
Ethylbenzene	0,3
Xylene	0,8

Table 24. Composition of high temperature pyrolysis oil.

In the Destrugas process, the formation of tar is largely prevented by cocurrent operation. The pyrolysis gases are led through the hottest part of the reactor (1000°C) where the larger hydrocarbons are thermally decomposed.

3. Use of the pyrolytic oil

Few data on the application of the oil are available. The Occidental Petroleum flash pyrolysis oil has the following characteristics.

1. The oil has a relatively low heating value (7500 kcal/l.), due to its high oxygen content.
2. Due to its high viscosity, it requires heating before it can be pumped.
3. The use of corrosion resistant materials is necessary.
4. The oil is not miscible to conventional n°6 fuel oil over longrn periods of time.

Laboratory tests have shown that it can be burned succesfully (pure or mixed with n°6) in a utility boiler with a specially designed handling and atomization system. However additional test seem necessary before final conclusions can be drawn.

From our discussions with tar processing companies, it follows that additional markets seem to exist in the field of traditional tar products.

C. SOLID PRODUCTS

1. Gasification

In traditional gasifiers the required heat is supplied by combustion of the charred residue. The resulting gases dry; preheat and thermally decompose the char, whereas the remaining ash is largely free of carbon.

The available data on a number of gasification residues are given in table 25. Obviously, these data are not directly comparable, since they are obtained using refuse fractions with a different composition.

Process	Yield kg/ton refuse	% C	Heating value kcal/kg	Volume ℓ/kg char
Andco-Torrax	170	-	-	0,35
Purox (8)	170	-	-	?
Motala (9)	200	-	-	0,67
Landgard(10)1*	70	50	3900	2,0
2*	170	2	-	0,41

Table 25. Ash from gasification processes.

*The Landgard process produces a residue with an appreciable amount of carbon. This residue is subdivided into a carbon-rich and a glassy fraction by sink/float separation.

The Purox and Andco-Torrax processes are high temperature processes (1500-1600°C) and produce a molten slag. This yield a low volume, inert, glassy material.

2. Pyrolysis

The pyrolysis of refuse yields a residue with an appreciable carbon content, mainly fixed carbon and organics. At higher temperatures the volatile organics are progressively driven off, gradually lowering the char yield.

The results of Hoffmann(4), shown in table 26 and those of Tsukishima Kikai (30) in table 27, illustrate this phenomenon.

Temp. °C	Volatile matter %	Fixed carbon %	Ash %	Heating value kcal/kg
480	21,8	70,5	7,7	6700
650	15,1	70,7	14,3	6750
815	8,1	79,1	12,8	6350
925	8,3	77,2	14,5	6270

Table 26. Influence of temperature on char characteristics.

	450° C	650° C	850° C
Carbon (% weight)	77.2	79.2	85.7
Hydrogen	7	7.5	4.2
Nitrogen	2.8	3.2	3.7
Sulphur	1.1	1.6	1.3
Chlorine	1.1	1.3	0.9
Oxygen	10.9	7.3	4.1

Table 27. Analysis of Tsukishima char (30)

Data on three types of pyrolysis char are given in table 28.

Process	Yield kg/ton refuse	% C	Heat.val. kcal/kg	Volume ℓ/kg
Destrugas(11)	280	?	1600	2,2
Oxy (15)	55*	50 %	4500	?
Tsukishima	180	80 %	?	?

Table 28. Char from pyrolysis processes.

*Part of the char is burned to provide heat for the pyrolysis reaction.

3. Use of the solid residue

a) Substitute for commercial activated carbon

Before the char can be used as an adsorbent it has to be activated with steam or carbon dioxide, to increase its specific surface.

Tests have shown that the resulting adsorption characteristics are far below those of the usual activated carbon (16). This can be attributed to the high ash contents of the pyrolysis char, and probably to the less desirable structure of the charred material.

Because of the additional treatment required (activation) and the inferior properties of the char, the marketing of the solid residue as an adsorbent seems rather low.

b) Use as a fuel

The high ash content, associated with a low calorific value make it a rather marginal alternative for the commercial fosil fuels.Moreover the char concentrates the ash and the heavy metals contained in refuse.

c) Construction material

The granulated slag from the high temperature processes can be used as a substitute for sand or gravel in road construction.

Conclusion.

At present, the solid residue from refuse pyrolysis does not seem to be a recoverable product. It has to be regarded as a waste stream and in most of the cases it will have to be landfilled.

A possible exception is the material produced by high temperature processes (Purox, Andco-Torrax) which can be used as a filler for construction purposes.

IV. ENVIRONMENTAL ASPECTS

1. AIR POLLUTION

The selection and design of a gas treatment plant are based upon :

1- the volumetric flow of gas to be treated

2- the actual composition of the gas

3- the emission standards to be respected

Any pyrolysis or gasification process finally produces flue gases, since the product gases are normally used as a fuel. Some processes directly burn the evolving pyrolysis or gasification gases, whereas others first purify them, generally by means of a wet scrubber.

- Processes in which the gases are directly burned (ANDCO-TORRAX, LANDGARD) generate flue gases that are essentially free from organic contaminants (provided the after combustion chamber is properly designed).
  The main advantage when compared to conventional incineration is the use of a much smaller excess of combustion air, so that the volume of flue gases to be cleaned is reduced.

- Processes in which the produced gas is cooled and cleaned generate a condensate and/or scrubber effluent, which is highly polluted and contains toxic components, such as cyanides, hydrogen sulphide and ammonia (e.g. PUROX, DESTRUGAS, OXY,...).
  In these processes the quality of the product gas is improved as the cost of a severe wastewater problem.

Possible air pollutants are - particulates

- HCL, HF, H_2S, NH_3, HCN

Some pyrolysis and gasification processes feature low gas velocities (e.g. Purox, Destrugas). The entrainment of particulates in these processes is low.

Fluidised bed processes, on the other hand, require elaborate dust arresting equipment.

A major difference with incineration is the presence of a reducing atmosphere in all or part of the furnace. This may cause various problems:

1) the formation of toxic gases, such as CO, NH_3, H_2S, HCN,..., which form a hazard in case of incident.
2) the formation of explosive mixtures with air, e.g.in the event of mechanical damage (rupture of a vessel or of transfer lines) or of an outward or inward leak.
3) the formation of hard tar which condenses in colder parts of the reactor and eventually forms obstructions.

At this moment no operating data are available regarding gaseous emissions from pyrolysis plants. Hence it is not possible at the moment to draw definite conclusions on this point.

An analysis of the pollutants in the Destrugas pyrolysis gas and in the gases after combustion is given in table 29.

Component	Pyrolysis gas	After combustion
HCl	105 mg/Nm^3	0.007 vol. %
HF	0.7mg/Nm^3	0.00014 vol. %
SO_x	231 mg/Nm^3	0.012 vol. %
H_2S	400 ppm	
NH_3	6125 ppm	
HCN	195 ppm	
CO		705 ppm
NO_x		0.006 vol %

Table 29. Pollutants in Destrugas process.

Similar data are given for the Tsukishima pyrolysis process in Table 30, and in Table 31 for the Hitachi gasification process.

Component	Pyrolysis gases	Regenerator gases
NH_3	0.67 vol.%	
H_2S	0.57	
HCl	0.40	
HCN	0.07	
SO_x		118 ppm
NO_x		53 ppm

Table 30. Polluting and hazardous components in the gases of the Tsukishima fluidized bed pyrolysis process. (27)

Component	In the reactor	After cleaning (scrubber)
HCl	40 ppm	0 ppm
Cl_2	18 ppm	0
NH_3	17 ppm	0
NO_x	trace	0
HCN	12 ppm	3
SO_2	270 ppm	2
H_2S	200 ppm	0

Table 31. Polluting and hazardous compounds in Hitachi off gases.(29)

2. WATER POLLUTION

The main sources of waste water in pyrolysis or gasification systems are :

1- Scrubber effluent including condensation water

2- Quench tank effluent

The moisture content of refuse generally amounts to 250-400 kg/ton of raw refuse. In some processes this water is contained in the flue gases, formed by direct combustion of the pyrolysis/gasification products. In other processes this water is condensed, together with volatile organic compounds, oils and tar, and soluble gases and liquids.

Moreover, the scrubber effluent contains any particulates, gases and vapours, which may be washed from the product gas. The quench tank effluent may leach soluble material from the carbonized residue. Conversely, the carbonized residue may adsorb impurities from the waste water and contribute to their purification.

Component	Concentration
pH	8,2
BOD_5	12,700 mg/ℓ
COD	21,300 mg/ℓ
phenols	840 mg/ℓ
cyanides	25 mg/ℓ
NH_3	2250 mg/ℓ
Chloride	1100 mg/ℓ
Sulfates	1780 mg/ℓ
Sulfide	42 mg/ℓ

Table 32. Characteristics of Destrugas waste water.

The water has a very high COD content (some 50.000 mg/ℓ) and contains various organic compounds such as alcohols, ketones, aldehydes and organic acids as well as phenols.(Table 27)

The high BOD and COD-values, as well as the presence of toxic phenols and heavy metals, prohibit a direct biological treatment.

Union Carbide has already stated that a Purox plant will also incorporate a small Unox plant. The cost of such a plant should be considered when evaluating the economics of each process.

3. LAND POLLUTION

Solid waste disposal processes are often characterised by the degree of volume reduction achieved. The best results seem to be obtained by processes using slagging conditions, e.g. Andco-Torrax, Purox, FLK, etc. The remaining volume only amounts to 3-5 % of the original volume of the refuse. Next comes conventional incineration, where the final volume of the residue is about 7-10 % of the original one. Gasification processes probably yield similar results. In pyrolysis processes, however, the incombustible residue is diluted by charred material, which inflates the volume of this residue.

If the charred material can be largely segregated in recoverable metals, ash and char, this situation may be an asset. If, however, the residue is to be tipped, it is a significant drawback of the pyrolysis process.

The quality and properties of the charred residue depend on the reaction conditions. High temperatures and long residence times increase the amount of degasification that takes place; the resulting char is reduced in volume and contains more ash.

Especially in the case that the charred residue is contacted with wastewater, the re-use potential of this residue is low, by contamination with soluble organic and inorganic materials.

Hashegawa et al. (ref.27) studied the distribution of heavy metals over the different fractions obtained in the Tsikashiwa Kikai dual fluidized bed process. Their results are shown in fig (13). It follows that most of the heavy metals are concentrated in the solids (cyclone ash, coarse residue, sand). An exception is mercury that largely is found in the tar.

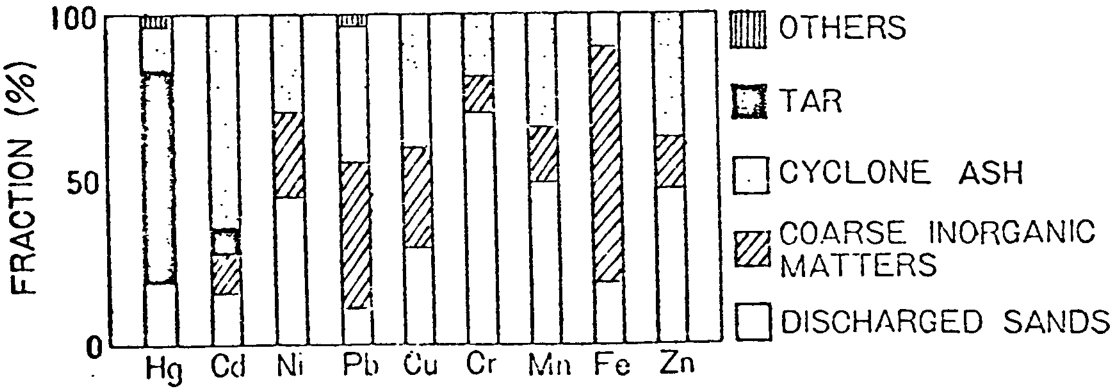


Figure 13 Heavy metals from the municipal solid waste, distributed in the products. Pilot plant.

A similar analysis for the Hitachi process (ref.29) leads to the same conclusions :

	Zn (ppm)	Cd (ppm)	Cr (ppm)	Pb (ppm)
Raw Refuse	32.81	8.33	31.25	37.50
Fluidised sand	8.04	1.08	6.66	10.00
Charcoal	93.75	32.50	125.00	312.50
Product oil	8.64	7.80	5.00	14.50
Dust	312.50	99.37	187.5	450.00

Table 33 . Distribution of heavy metals from Hitachi process

CONCLUSIONS

It has been claimed that gasification and pyrolysis processes have substantial environmental advantages over conventional incineration. At present, there is little evidence to substantiate this claim, and indeed it seems that some of the new processes involve undesirable environmental problems.

Among the advantages claimed one may cite :

- the very low volume of residue in slagging processes Andco-Torrax, Purox, FLK)
- the much lower volume of flue gas to be treated.

Among the apparent disadvantages one may cite :

- the wastewater resulting from the cleaning of the product gas
- the large volume of residue in pyrolysis processes.

Table 34 compares the environmental impact of different pyrolysis processes with conventional incineration.

	Air	Water	Soil
ANDCO-TORRAX	+	0	++
PUROX	++	--	++
LANDGARD (x)	0	0	0
MOTALA	+	0	0
DESTRUGAS	++	--	-
W.VIRGINIA	0	-	?
OXY	+	0	0

Table 34. Evaluation of pyrolysis processes.

(x) The Baltimore Landgard plant is believed to be a poor example of the real possibilities of this system. In Baltimore air pollution abatement plant is definitely inadequate.

V. EVALUATION OF SELECTED PROJECTS

EVALUATION OF SELECTED PYROLYSIS AND GASIFICATION PROJECTS

In this chapter a number of pyrolysis and gasification processes are described and critically evaluated. Unfortunately essential data is lacking in several important areas : generally it is impossible, for example, to relate quantities and compositions of products to actual refuse compositions. It follows that data from different sources are not comparable and that no mass and energy balance can be derived with some confidence.

A most interesting attempt to evaluate different projects was proposed by Thomé-Kozmiensky (24, 25). The shortcomings of indeed any scoring system, on the other hand, were discussed by Rasch (26), who points at the lack of data necessary for the precise evaluation of several processes. The result of such comparison is also quite dependent on the importance one ascribes to items like environmentals, technical or economical aspects.

THERMAL EFFICIENCY OF SELECTED PROCESSES

The thermal efficiency of a process can be defined as :

$$\frac{\text{energy output of the process} - \text{energy consumed in the process}}{\text{energy content of incoming refuse}}$$

It is impossible to assign fixed values to this efficiency, because of the following difficulties :

- the thermal efficiency is highly dependent on the nature of refuse. Dry paper has a much higher energy content than wet garbage and will show a superior thermal efficiency in any process. In less efficient processes garbage may well have a negative thermal efficiency.
- the efficiency again depends on local plant configuration and conditions. In a pyrolysis process, for example, it makes a lot of difference whether the char is used as a fuel

or not. In the latter case it has to be disposed of in a sanitary landfill, which consumes energy !

- the power consumption for the recovery of ferrous metal, glass, etc., from a dense fraction, should not be considered in computing the efficiency of a thermal conversion process.

Thermal efficiencies, when cited in literature, can be defined in many different ways, depending on the degree of conversion to energy considered. The process of converting refuse to energy can be subdivided in a number of steps, each having its own energetic efficiency :

A. PROCESSING : Refuse is shredded, dried and/or separated. Losses in efficiency account for the combustibles lost with the dense fraction, the power consumption for shredding and the fuel consumption for drying.

B. PYROLYSIS : Losses include the sensible heat of the reaction products, the heat losses of the reactor and the power consumption in the purification of the pyrolysis products.

C. STEAM GENERATION : Losses include the sensible heat of the flue gases leaving the boiler plant and of the residue leaving the furnace, the heat of combustion of the combustibles in the residue and the heat losses of the furnace. The thermal efficiency of the boiler is a function mainly of the type of fuel (table 2). Refuse and RDF require a much larger excess of air than the firing of pyrolysis oil or gas, so that the stack losses are much higher. Moreover, boiler fouling with a subsequent gradual loss in efficiency is avoided when firing gas or oil.

D. POWER GENERATION : Power is produced in a turbo-generator. The conversion efficiency mainly depends on the quality of the steam (i.e. pressure and superheat temperature) and on the construction of the turbo-generator.

Table 35, adapted from (21), gives the thermal efficiency at different locations along the conversion path of refuse to energy.

	Efficiency of conversion to combustible	Efficiency of convers. to steam	Efficiency of conversion to electricity
Refuse incineration+	100 %	60 %	21 %
Refuse Derived Fuel**			
(St Louis)	83 %	54 %	23 %
Pyrolysis**			
(OXY)	41 %	32 %	14 %
Gasification+			
(Landgard)	69 %	44 %	15 %
Gasification**			
(Purox)	66 %	52 %	22 %

Table 35 Efficiencies for selected refuse to energy processes

+ Steam conditions 470°C; 650 psi (9750 Btu/kWh)
** " " 540°C;1800 psi (8000 " ")

Depending on the desired end-product, a different efficiency will be found for different processes. The over-all conversion to power (last column) is most representative for the energetic scoring of a given process. So we see that the Landgard process gives a high initial efficiency (69 %) compared to other thermal conversion processes. Because of the low quality of the produced gas, however , susequent steps (steam and electricity generation) are less efficient and result in a low overall conversion.

Similarly, it will be easier to raise high quality steam with Occidental Petroleum pyrolysis oil or Purox gas than with Landgard lean gas or raw refuse. (RDF is in a somewhat privileged position, being fired with a larger quantity of conventional fuel).

It should also be recalled that some figures were obtained from proprietary pilot plant data, which have not yet been confirmed by long term operation !

A. THE DESTRUGAS SYSTEM (17)

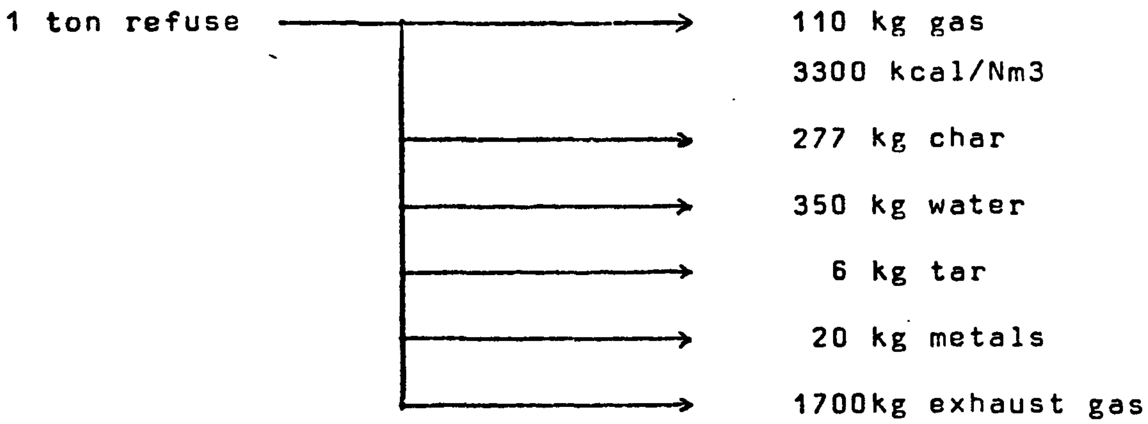
1. Description of the process

Refuse is shredded and stored after magnetic separation of ferrous metal. Eventually it is fed into the pyrolysis reactor.

The pyrolysis reactor is a vertical chamber with a width of 0,3m, a height of 7m and a length of 3m. Refuse descends by gravity. Between two shafts a combustion chamber is provided where part of the produced pyrolysis gas will be burned to provide the required reaction heat.The highest temperature attained is 900-1000°C. Ash is withdrawn at the bottom by means of a rotating valve. The pyrolysis gas is removed slightly above the valve. It is cleaned from particulates and tar by a Venturi scrubber, cooled, washed and stored.

Water from the cooler and scrubber flows into a decanter where solids are separated. The water is cooled and flows to a water treatment plant.

Products from the Destrugas process



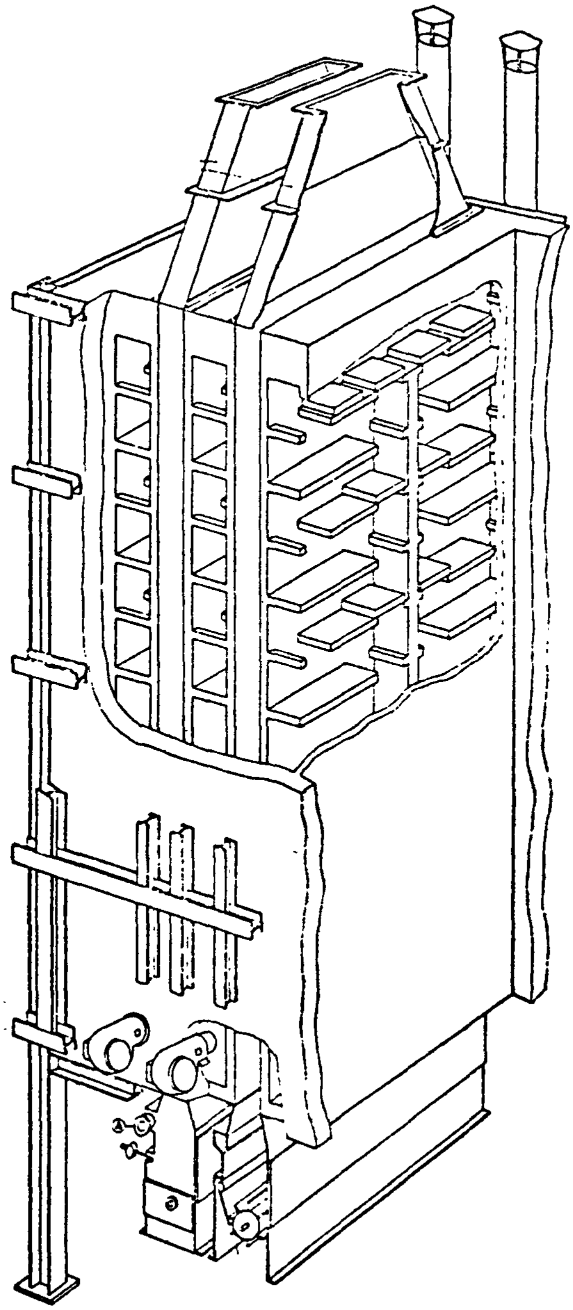


FIG. 14 : DESTRUGAS Reactor.

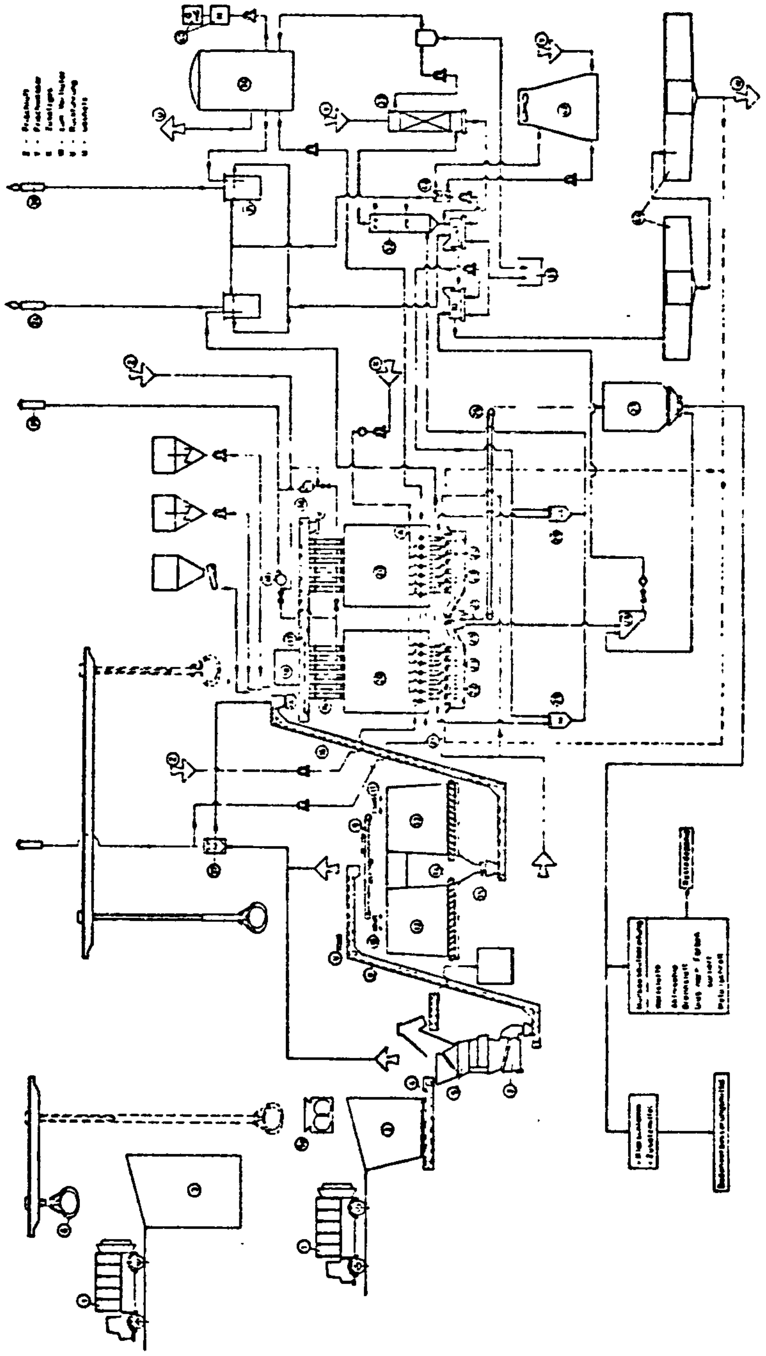


FIG. 15 : DESTRUGAS Process.

2. Evaluation

Presents Status : - Pilot plant in Kalundborg (Denmark) operated at an intermittent basis since 1970. (5 t.p.d.)

Technical Aspects

complexity : pretreatment : shredding (10 cm) and separation of ferrous metal

aftertreatment gas: cooler, scrubber, cooler washing tower

oil: recirculated to reactor

residue: quenching

reliability: availability: possible flow problems in shaft.

redundance : plants will consist of 30 t.p.d. units composed of 5 t.p.d. modules

wear :-shredder
-conveyors
-cracking of furnace walls
-rotary valve for ash withdrawal

possible incidents :

- explosions in shredder
- gas escaping through refuse plug
- damage to furnace walls
- plugging of refuse in shaft

degree of automation : little possibilities for control available

Thermal efficiency: 30 % (refuse comp. : 28% H_2O ; 1750 kcal/kg)
22 % (refuse comp. : 35% H_2O ; 1740 kcal/kg)

Environmental aspects

Air Before purification : particulates :

HCl	105 mg/Nm3
SO_x	230 mg/Nm3
HF	0,7 mg/Nm3

Power requirements not included.

	Burned gases:	particulates:	106 mg/Nm3
		HCl	0,007 vol %(7%CO_2)
		SO_x	0,012 " " "
		HF	0,00014" " "
		CO	705 ppm (7%CO_2)
Water	Scrubber effluent:	COD	2000 mg/ℓ
		pH	8,2
		Phenols	840 mg/ℓ
		Cyanides	25 mg/ℓ
		NH_3	2250 mg/ℓ

300-500 ℓ/ton refuse
Quench water

Soil Char has the same characteristics as incinerator ash
± 300 kg/ton refuse

Noise unknown

Capital costs : unknown

Operating costs:unknown

Recovered products :

1. gas : 110 kg/ton (refuse : 28% H_2O ; 1750 kcal/kg)
   3300 kcal/kg
   to 200 kg/ton (refuse : 35% H_2O ; 1740 kcal/kg)
   3800 kcal/kg
2. char : ± 300 kg/ton ± 1500 kcal/kg
3. metals

3. Conclusions

No full size unit has been built.

The process produces a gas with relatively high heating value.

Several parts (ash removal system, walls) are mechanically vulnerable. It takes a long time for start-up and shut-down (3 weeks) and offers little flexibility. The pyrolysis process is difficult to control and a highly polluted wastewater is produced.

B. THE WEST-VIRGINIA SYSTEM (12)

1. Description of the process

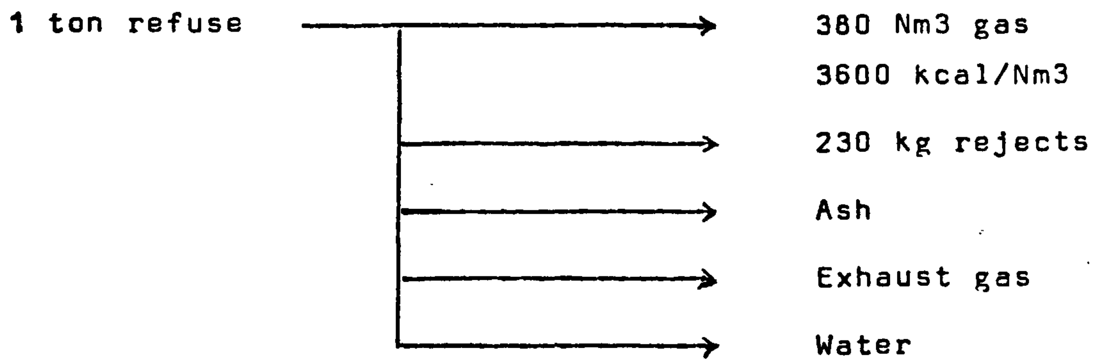
Shredded refuse (3 cm) is fed to an air classifier.

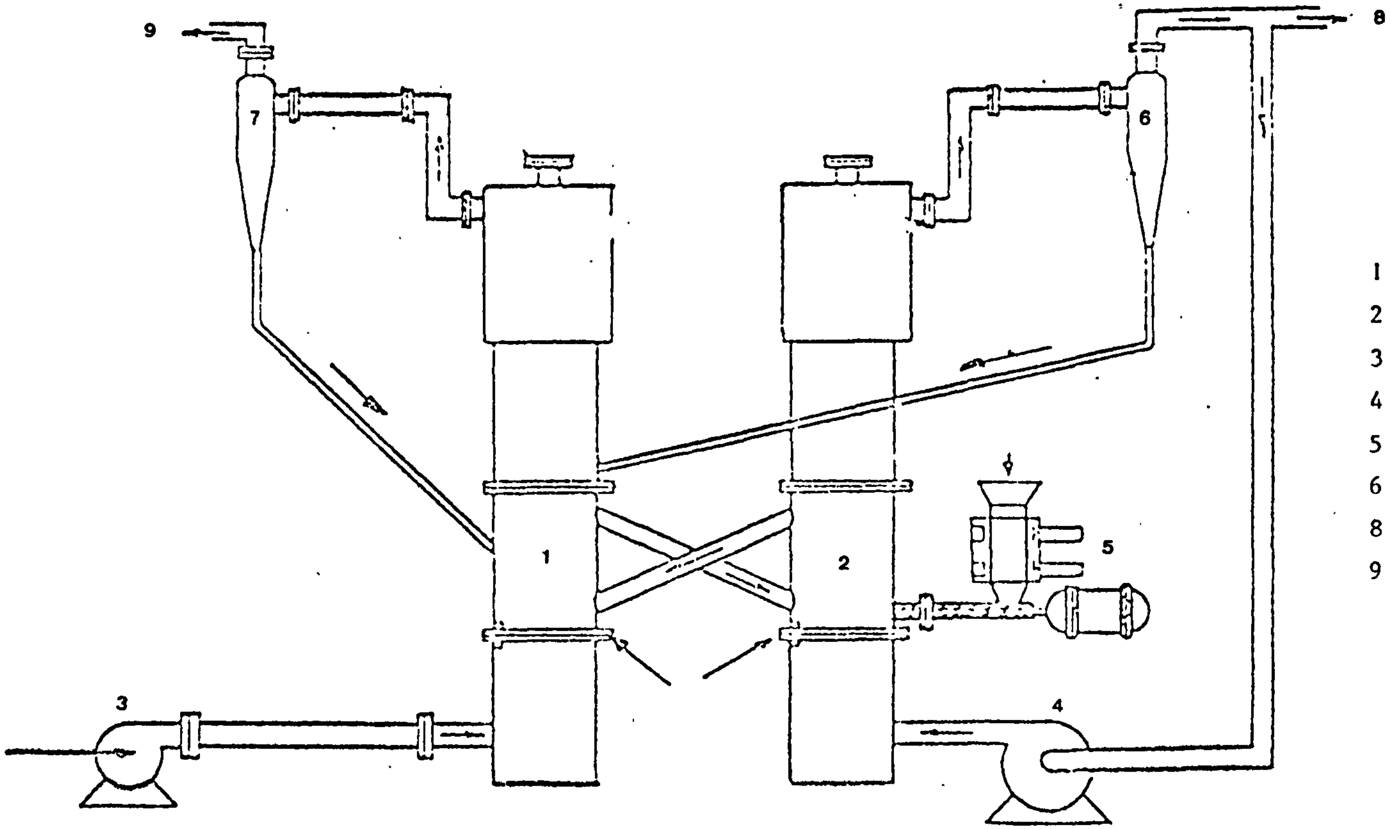
The organic fraction is dried in a rotating drum and fed to a fluid bed pyrolysis reactor.

The bed is made of silica sand and is fluidised by recycled process gas. The pyrolysis temperature is 800-900°C. Gas is cleaned from particles in a two-stage cyclone group. Part of the gas is recycled and used for fluidisation. The other part is cooled and cleaned in an adsorption tower.

The heat for the pyrolysis reaction is obtained by burning part of the char in a second fluidised bed, fluidised with air, circulating hot char to the pyrolysis reactor.

Products from the W. Virginia process





1. Fluidized bed combustor.
2. Fluidized bed pyrolyser.
3. Air blower.
4. Recycle gas blower.
5. Refuse feeder.
6,7. Cyclone.
8. Pyrolysis gas.
9. Combustion gas.

FIG. 16 : WEST VIRGINIA Process.

2. Evaluation

Presents status : - Research project stopped due to lack of funds
- 1 t.p.d. plant operated at University of West-Virginia.

Technical Aspects

complexity : pretreatment : Extensive : shredding to 3 cm; air classification,drying, preheating air.
aftertreatment cyclone cooler
solids : separation of char and sand

reliability: availability : No data available
The process is relatively complicated.
redundance : Unknown
wear :-shredders
-feeding system
possible_incidents :
- explosions in shredder
- toxicity of gases
- explosions due to gas leaks
- defluidisation due to clinkering of sand with ash

degree_of_automation : unknown

Thermal efficiency : unknown

Environmental aspects

Air High dust load expected.

Water The pyrolysis condensate will probably contain organic contaminants.

Soil Char will probably be quite inert.

Noise Unknown

Capital costs : Unknown

Operating costs : unknown

Materials recovered :

1. Pyrolysis gas : 380 Nm3/ton refuse
3600 kcal/Nm3

3. Conclusions

No practical recommandations can be given regarding this system, since it never worked on a large scale.

C. THE DUAL FLUIDIZED BED PYROLYSIS SYSTEM

1. Description of the process

The dual fluidized bed pyrolysis system consists of a pyrolysis and a regeneration reactor, as in Fluid Catalytic Cracking Systems.Shredded refuse after removal of ferrous metal is converted into gas, tar and char in the pyrolysis bed. Char and char-coated bed material are continuously removed from the pyrolysis bed and conveyed to the generator bed, in which the carbonaceous material is burned. The sand is heated by combustion and eventually recirculated to the pyrolysis bed, where it supplies the required heat of reaction.

The Dual Bed System, developed by Ebara Mfg Co, is represented in figure 16 . The material of the regenerator bed is fluidized by combustion air and flows over by gravity into the pyrolysis bed. The material of the pyrolysis bed is fluidized by recirculated pyrolysis gas; floating charred material flows over by gravity into a small storage vessel from which it is elevated to the regenerator bed by means of an air lift.

In the Dual Bed "PYROX" System of Tsukishima Kikai Co Ltd. coke particles are circulated between 2 slender fluidized beds, connected to each other by two down comer transfer lines (figure 17) . The system is a further development of the Kunii-Kunugi

1. Pyrolysis reactor
2. Incinerator
3. Connecting pipe
4. Connecting pipe
5. Feeder
6. Pretreating plant
7. Cyclone
8. Heat exchanger
9. Cooler
10. Blower
11. Blower
12. Scrubber
13. Flare stack
14. Cyclone
15. Heat exchanger
16. Cooler
17. Blower
18. Scrubber
19. Blower
20. Conveyor
21. Bunker

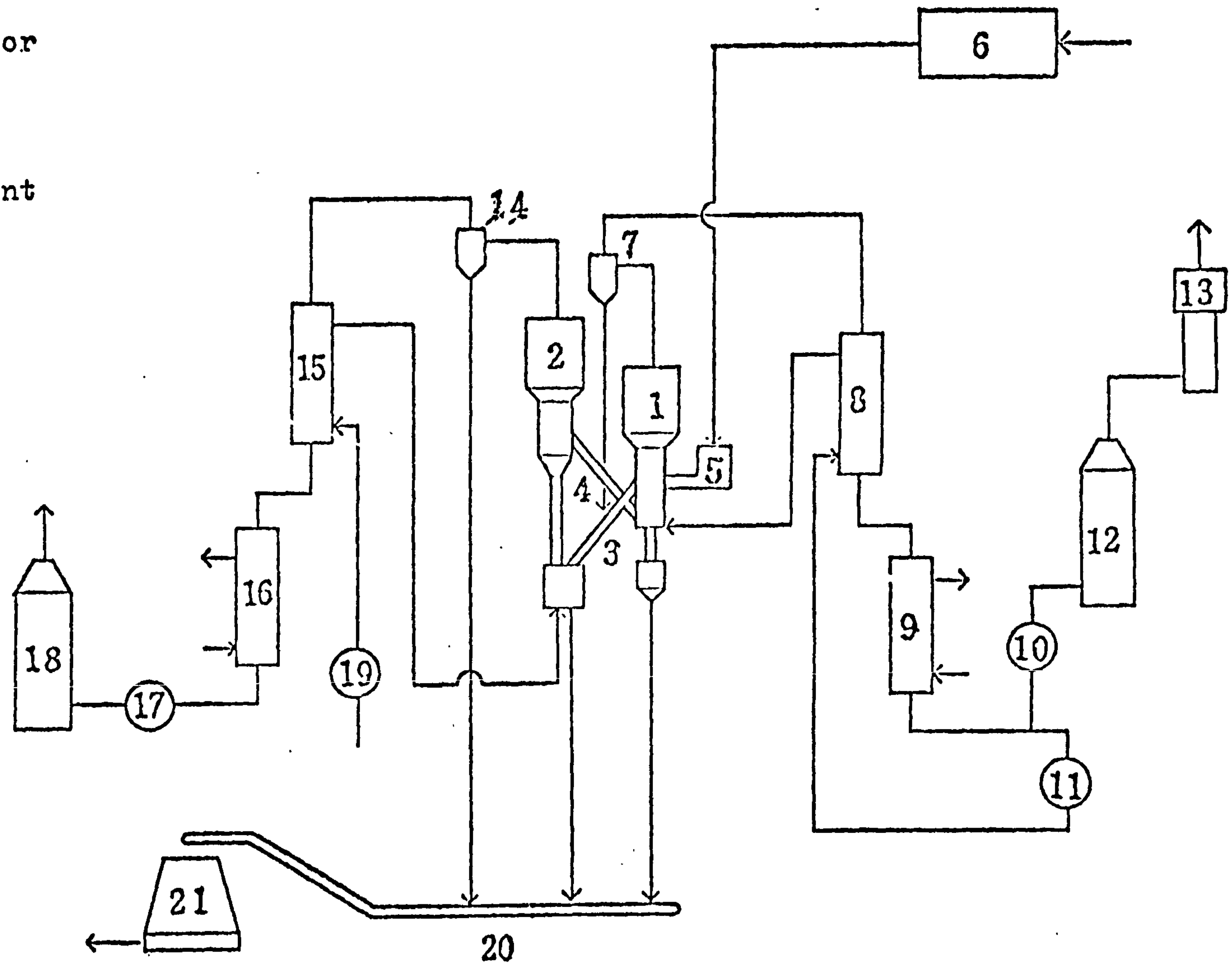


Fig.17 Flow diagram of two-bed pilot plant

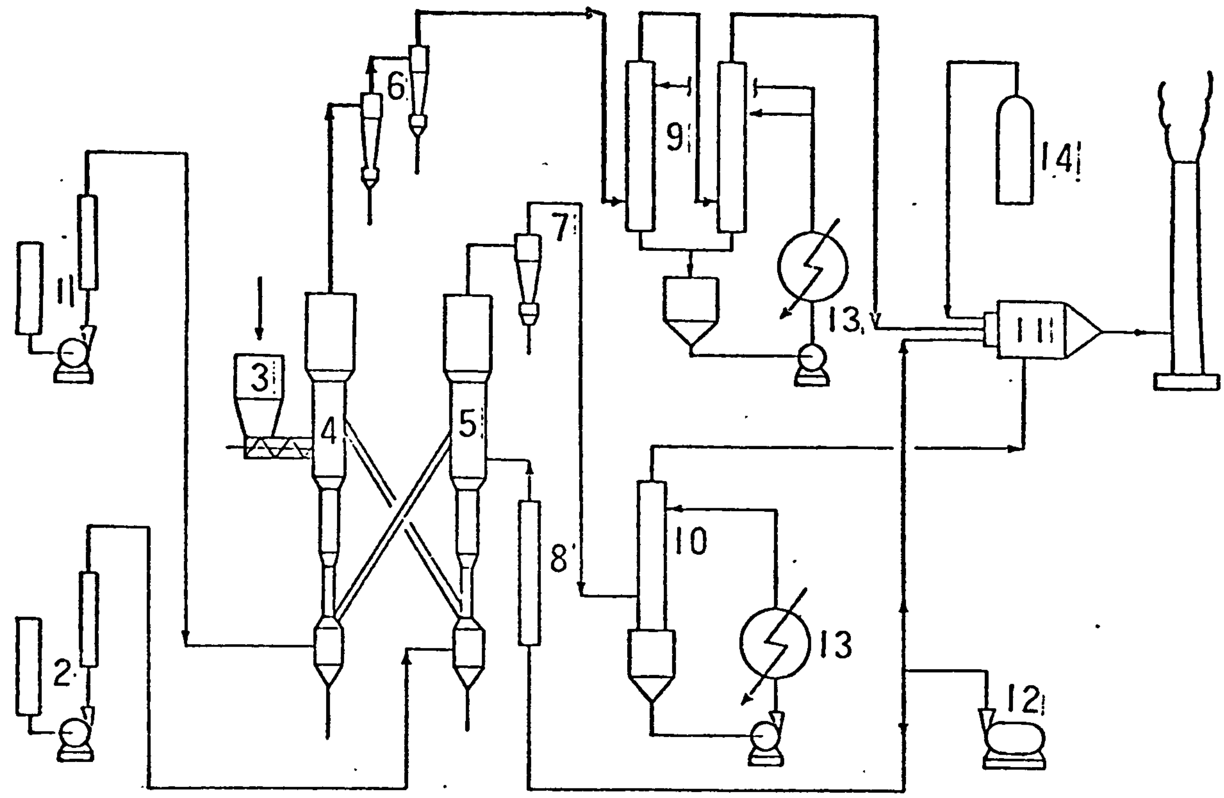
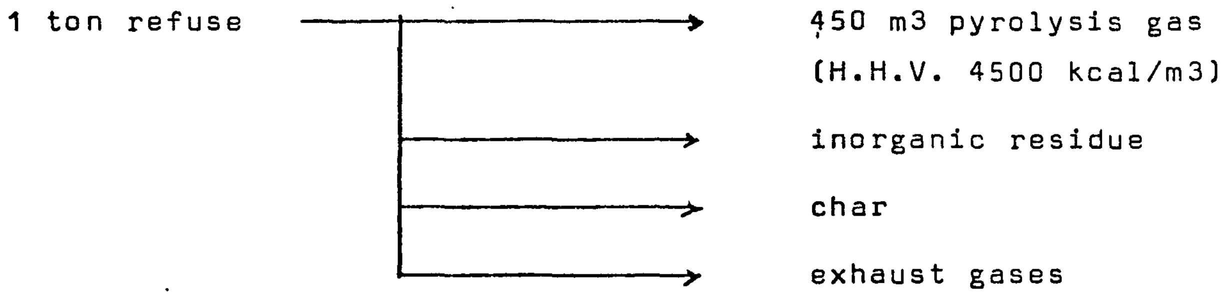


Fig. 18 : TSUKISHIMA KIKAI Proces

1,2. Evaporator.
3. Feed hopper.
4. Cracking Reactor.
5. Regenerator.
6,7. Cyclone Collectors.
8. Air Heater.
9,10. Scrubbers.
11. Afterburner.
12. Air Compressor.
13. Cooler.
14. LPG.

system of heavy oil cracking.

Products from the Dual Bed processes



2.a Evaluation (Ebara Mfg Co)

Ebara tested small size hot models and on cold models studied the influence of the various geometric factors and operating variables, e.q. the position and inclination of downcomer pipes, the sand volume in each bed, the pressure differential between the beds, the gas velocities, the freeboard pressures, and the type of air lift used. Several designs of mechanisms for refuse feeding and for solid residue elimination were extensively tested. The extent of gas leakage from one bed to another was measured, and found to be negligible (0.5 - 1%) in a broad range of bed material sizes (0.2-0.7mm).

After extensive preliminary work a hot 5t/day pilot plant was constructed. Since 1975, it operated intermittently under control of only 1 operator : the temperature and level of each bed, the rates of fluidizing gas, and the pressure in freeboard, connecting pipes and gas ducts were measured continuously and controlled automatically.

Technical aspects

complexity : pretreatment : is required (shredding)
aftertreatment: dust collection, cooling, purification of pyrolysis gas and flue gas.

reliability: availability : no data available
redundance : none

wear : shredders, possibly feeding mechanisms.

possible incidents :-agglomeration of sand particles and loss of fluidization can occur using feed materials having low melting ash components.

degree of automation:high.

Thermal efficiency : unknown

Environmental aspects: the precise composition of the pyrolysis gas has been measured, but the data have not been published and are strictly confidential.

Capital costs : unknown

Operating costs : unknown

Recovered products : 450 m3 fuel gas/ton of refuse

2.b Evaluation (Tsukishima Kikai Co Ltd)

Experiments were performed on a single laboratory scale reactor, a small dual bed pilot plant and a large dual bed demonstration plant. The circulation of sand was studied on a large cold model (45 cm I.D., 60 cm I.D. regenerator, height 10.5m). A demonstration plant (reactor diameter 2m), with a capacity of 1.65 t/h refuse or of 1t/h organic sludge (moisture content 75-83 % water) was operated continuously for 1200 h., with an operating time of 4000 h. in total.

Technical aspects : as under 2a

3. Conclusions

The dual fluidized bed pyrolysis system is conceptually an attractive method of converting municipal refuse into a rich gas. Sufficient experience has been gained with this system to justify a further evaluation at pilot scale.

D. THE OCCIDENTAL PETROLEUM SYSTEM (13,15)

1. Description of the process

a) Feed preparation

Refuse is shredded to approximately 7,5 cm. Ferrous metals are removed by magnetic separation and inorganic material is separated in a zig-zag air classifier. The inorganic fraction is sieved in a rotating screen into fine, medium and oversize fractions. The latter is recycled to the shredder.

The fines contain most of the glass and go to the glass recovery system where a 99 % pure glass fraction is produced by froth flotation.

The medium-sized fraction goes to the aluminium recovery unit where aluminium cans are separated by two linear induction motors in series. The rest of the material is shredded to minus 0,5" and returned to the zig-zag classifier.

The organic fraction from the air classifier is dried in a rotating drum. More inorganic material is separated by a vibrating screen. The organic fraction is then passed through a secondary shredder where it is transformed into

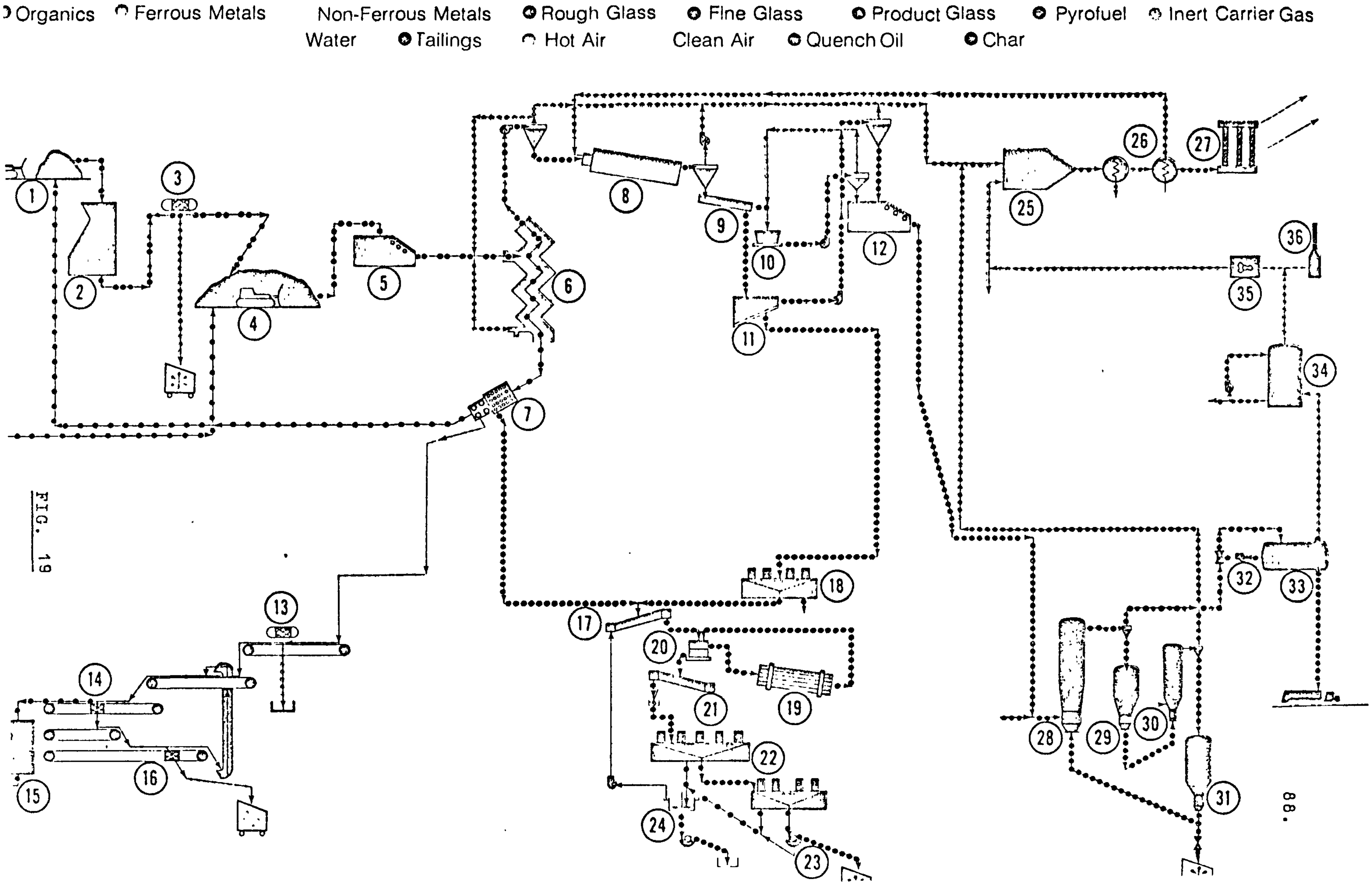

Organics
Ferrous Metals
Non-Ferrous Metals
Rough Glass
Fine Glass
Product Glass
Pyrofuel
Inert Carrier Gas
Water
Tailings
Hot Air
Clean Air
Quench Oil
Char
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36

FIG. 19

a very fine material of approximately 24 mesh size. This material is stored in a storage bin.

b) Pyrolysis section

The organic material is mixed with hot recycle char and is entrained by recycled process gas. The pyrolysis proceeds at a temperature of 500°C. Char is separated by a three stage cyclone group and part of the char is burned to provide heat for the pyrolysis reaction. The rest of the char is quenched with diesel oil. The condensate goes into a decanter where the pyrolysis oil is separated from the quenching fluid.

The gases are cleaned in a scrubber and burned to provide heat for preheating combustion air and for the drying of the refuse. The exhaust gas is cleaned by bag filters.

Products of the Oxy process

1 ton refuse	→	256 kg oil (14%H_2O) 5800 kcal/kg
	→	70 kg ferrous
	→	5 kg glass
	→	6 kg aluminium
	→	55 kg char
	→	19 kg water
	→	440 kg exhaust gas
	→	rejects

2. Evaluation

Present Status : - Demonstration unit(under construction) at El Cajon, San Diego Country. 180t.p.d. Pyrolysis system to start up in summer 77.

- Pilot plant has operated intermittently in La Verne, since March 1971 (4t.p.d.)
- No further installations are planned as Oxy wants to successfully operate the El Cajon plant before further marketing.

Technical aspects

complexity: pretreatment : very extensive : shredding, magnetic separation, air classification, screening, drying, screening, secondary shredding. Final product has a size of minus 14 mesh.

aftertreatment oil : quenching, decantation

gas : cyclone, scrubber, afterburner, heat exchanger, bag filter.

residue : quenching, landfill.

reliability : availability : No data available. However the process is very complicated and difficulties can be expected (2 shredders)

redundance: The actual unit consists of a single train with only the secondary shredding system dedoubled.

wear : High wear is expected in the primary, especially in the secondary shredder and in a number of transfer lines.

possible incidents:
- explosions in shredders
- explosions in pyrolysis system, e.g. after rupture of piping
- toxicity of pyrolysis gases (CO).

degree of automation: No operational data available

Thermal efficiency : 32 % (refuse : 25 % H_2O ; 2500 kcal/kg)

Environmental aspects

Air No operational data available

The pyrolysis gas will be treated in a packed bed scrubber for HCl removal. The combusted gas should contain less than 3 grains/SCF before passing in the atmosphere. The combustion of the oil has been tested. The SO_x-emissions are directly proportional to the sulphur content in the fuel. Sulphur: blended with n°6 (S = 0,4 %): 120-150 ppm
100 % pyrolitic oil : 290 ppm
NOX: blended n°6 : 420 ppm

Water
1. Flotation water : in municipal sewer
2. Condensation water from pyrolysis: high COD content. Water produced by El Cajon plant is the equivalent of waste production of 200 people (according Oxy). No data on possible treatment or costs are available.
3. Scrubber water: no data available. Will have a low pH(HCl) and high COD content. At present this water will be stored in a concrete storage bassin.

Soil
1. Sludge from the froth flotation (90 kg/ton refuse)
2. The residue of the pyrolysis should be completely sterile and could be sent to landfill (60 kg/ton refuse).

Noise
Presently modifications are being made to bring down the noise level in a few areas.

Capital costs : 5 million $ for engineering
9 million $ for construction
(the ground was given by the City of El Cajon for 1$/year)

Operating costs :

personnel : 31 persons for a plant of 180 t.p.d. This should be the same for a 1.000 t.p.d. plant.
costs : ± 1 million $/year

power_consumption : - 135 kWh/sh.ton
- 5 lb n°2/sh.ton
} data from pilot plant

Additional :- wastewater treatment
- disposal of sludge and char

Utilities : N_2 (blanketing, pneumatics)
water (flotation, scrubber)

Materials recovered :

1. Pyrolysis oil : 256 kg/ton refuse (14% H_2O)(Refuse 2500 kcal/kg); \$ 7,5/barrel
   5800 kcal/kg
2. Ferrous metal : 95 % of ferrous in waste
   95 % pure
   price : \$ 35/sh.ton
3. Glass : 70-80 % of glass in refuse
   mixed color 99 % pure
   \$ 20/sh.ton
4. Aluminium : 92-93 % pure
   \$ 300/sh.ton

3. Conclusions

Operating experience with the El Cajon plant is awaited before final conclusions can be drawn. The process is highly complicated (especially the preparation of the refuse) and should only be economical for large units.

The pyrolysis process starts with a favorable product compared to raw refuse and yields an oil that is storeable.

The process also produces ferrous, aluminium and glass.

Combustion tests of the oil on a large scale seem necessary.

E. THE LANDGARD SYSTEM (10)

1. Description of the process

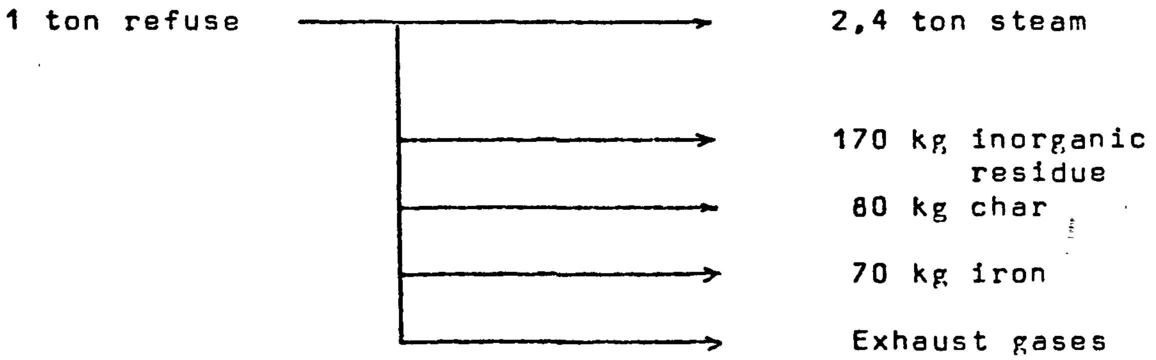
Refuse is shredded to a size of 10 cm by one of two parallel shredders. The shredded refuse goes into a Atlas storage bin from which it is fed to a rotary kiln reactor.

Air is fed countercurrently to the refuse. The heat for the pyrolysis process is obtained by oxidation of part of the refuse and by burning a certain amount of fuel oil at the discharge end of the kiln. The residue is quenched in water; after removal of magnetic metal it is separated in a floating carbonaceous and a sinking inorganic fraction.

The gases are burned and used to raise steam.

Before the exhaust gases are vented, they are washed in a scrubber and passed through a mist eliminator.

Products from the Landgard process



2. Evaluation

Present status : - 30t.p.d. pilot unit operated in St Louis from early 1970 to late 1971, when it was dismantled.
- A 30t.p.d. unit operated satisfactorilly at Kawasaki Heavy Industries, Kobe, Japan for a period of 6 months starting in April 1974.

PROCESS FLOW DIAGRAM

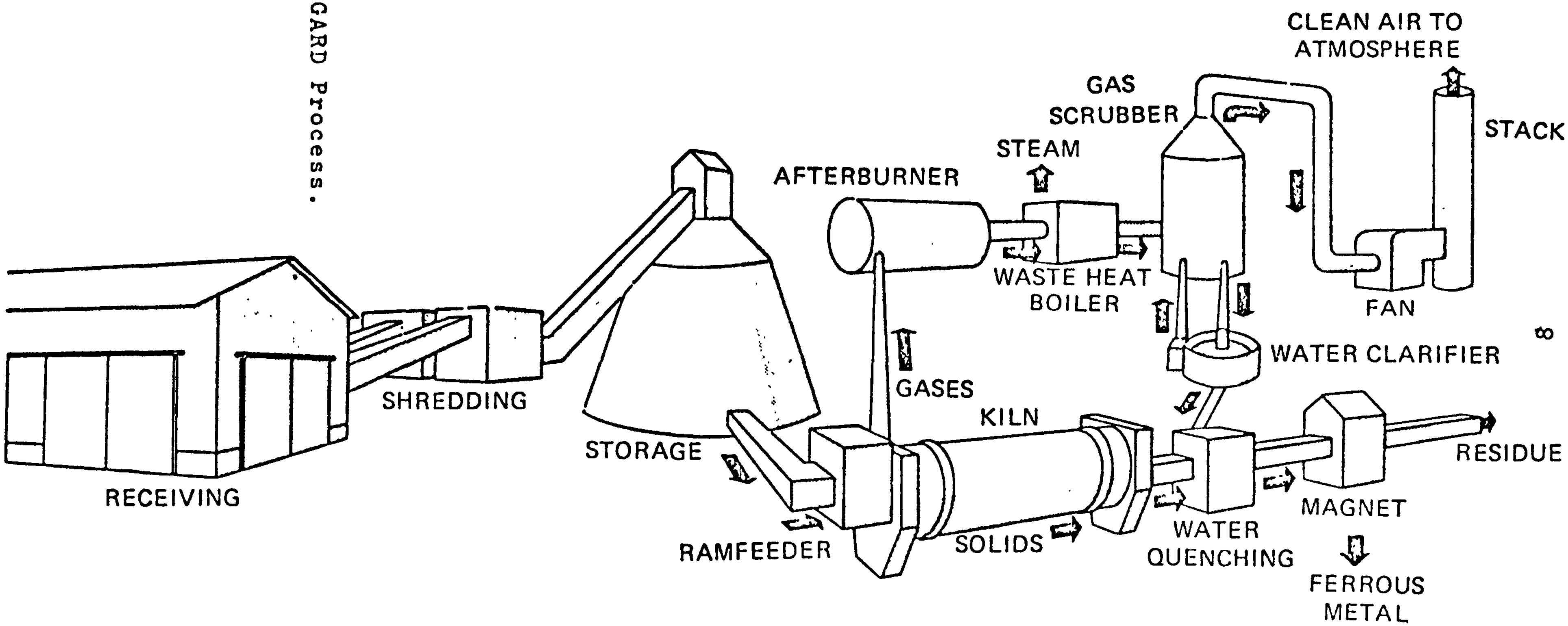


FIG. 20 : LANDGARD Process.

- A commercial 900 t.p.d. plant built by Monsanto Envirochem Div. at Baltimore (Maryland) is presently operated by the city of Baltimore at half capacity. The unit probably has to be revamped totally or will be converted to a conventional incinerator.

Technical Aspects

complexity : pretreatment : Shredding to 10 cm

aftertreatment gas:(Baltimore plant)combustion, heat exchanger, scrubber, mist eliminator. (Kawasahi plant)spray cooling, purification in venturi scrubbers and demister

residue: quenching, dewatering magnetic separation, sink/float separation.
Ignition loss (Kawasaki): 3-12 wt.%
Putrescible matter : 0.1 - 0.3 wt.%

reliability: availability : In late 1976, the unit for some time worked continuously at reduced troughput. Frequent mechanical failures made operation very difficult.

redundance : 2 parallel shredders, rest of the plant is single train, which explains the low availability

wear : -shredders
-Ram feeding system (wrongly designed)
-Refractory lining (material has already been replaced several times)
-discharge system of Atlas bunker
-duct refractoring lining
-conveyors

possible incidents :
- explosions in shredders (already occured)
- explosion in kiln (already occured)
- bridging in Atlas bunker
- toxicity of pyrolysis gases

degree of automation : At present inexistant due to uncontrolable pyrolysis reaction and difficulties with refuse handling -

Thermal efficiency : 74 % (pilot plant figures)
(refuse 21% H_2O ; 2500 kcal/kg)

Environmental aspects

Air	The unit is violating federal standards, due to the poor design of scrubbing and mist eliminating equipment.
Water	scrubber water is highly loaded with solids and has a very low pH-value Quench water
Soil	unknown
Noise	No problems

Capital costs : $ 20.000.000
exact figures of additional money spent by Monsanto are not known

Operating costs :

personnel : unknown
power consumption : 100 kWh/ton (pilot plant figures)
8 gal n° 2/ton (" " ")
Utilities : water (quenching, scrubbing)

Recovered products : (pilot plant data)

1. Steam : 2,4 ton/ton refuse 100-260psi 415°C
refuse : 2500 kcal/kg
2. Ferrous: ± 90 % of input
3. Char : 80 kg/ton
3900 kcal/kg

3. Conclusions

Several parts of the plant (feeding system, kiln refractory, scrubber, steam plume surpressor...) have been wrongly designed. As a result, the plant has not worked properly during the two years during which it has been tested.

On Feb. 15, 1977, Monsanto decided to discontinue work on the Baltimore plant. The city of Baltimore is currently operating the plant at reduced throughput (500 t.p.d.). The future of the system is highly uncertain.

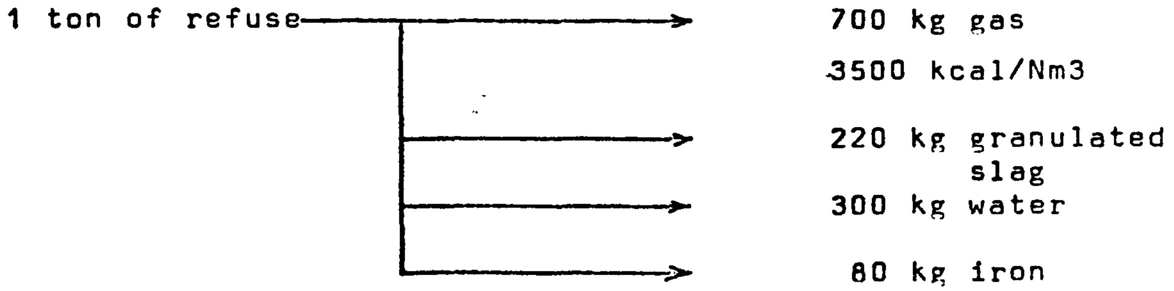
F. THE PUROX SYSTEM (8)

1. Description of the process

Refuse is coarsely shredded before charging it in the vertical shaft reactor. Pure oxygen is blown in at the bottom of the reactor. At the high temperature of the hearth the slag is melted and eventually granulated in a quenching tank.

The pyrolysis gases leave the shaft reactor at about 200°C. They are washed in a scrubber. Dust and oil are separated in an electrostatic precipitator (E.P.) and the water vapour is condensed by cooling. The effluent from the scrubber, E.P., and cooler is treated in an oil separator; the recovered oil is recycled into the reactor.

Products from the Purox process



2. Evaluation

Present status : - Pilot plant in Tarrytown N.Y. was operating in the early seventies. The capacity was 5 t.p.d. It was dimantled

- Demonstration unit in S. Charleston (W.Va.) in intermittent operation since April 1974. Capacity 180t.p.d.
  Presently shut down for modification(combined MSW + sludge processing).

200 T/D PROTOTYPE PLANT
SHREDDED REFUSE
PROCESS DESIGN

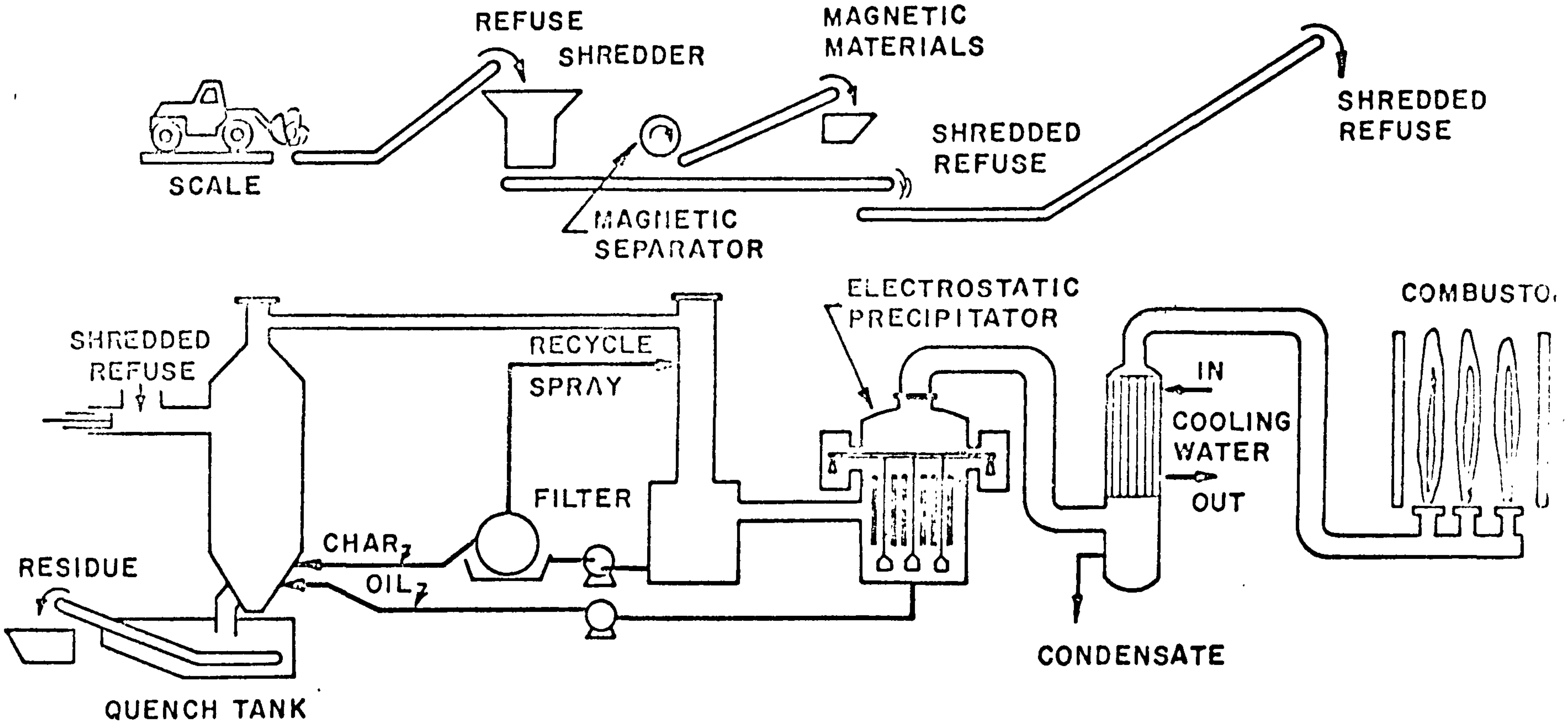


FIG. 21 : PUROX Process.

- Several proposals have been made. Negotiations with Seattle and Westchester seem to be unsuccessful.

Technical aspects

complexity : pretreatment : Coarse shredding (15 cm) and separation of magnetic metal.

aftertreatment gas : scrubber, E.P., Water condensor
residue : quenched and landfilled
water : purification (Unox system)

reliability: availability : The plant has successfully passed an uninterupted run for 90 days at a throughput of 70 t.p.d. The designed 180 t.p.d. was achieved for 3 days only.

redundance : Commercial plants would consist of modular 370 t.p.d. units with separate pretreatment and partially combined gas purification.

wear : -shredders
-ram feeders (?)
-conveyors

possible incidents
- explosion in shredders
- explosion in shaft
- toxicity of pyrolysis gases
- bridging and channeling in reactor.

degree of automation : no data available

Thermal efficiency : 55 % (refuse : 25% H_2O ; 2600 kcal/kg)

Environmental aspects

Air In the product gas after scrubber and E.P.
fly-ash : 10 ppm
sulphur : 15 ppm *
HCl : not measured
NO_x : <1 ppm
HF : not measured
organics: 150 ppm

Water Scrubber and condensation water : 300 l/ton refuse
BOD : 50.000 mg/l.
organic compounds, cyanides, NH_3

Soil The slag should be completely sterile because of high temperature in furnace and can be landfilled. The space required for landfilling is extremely low due to high volume reduction (<3% of incoming refuse)

Noise unknown

Capital costs : $ 13.000.000 (estimated research expenditures)

Operating costs :

personnel : unknown
power consumption : 200 kWh/ sh.ton
(includes oxygen plant, shredder, gas compressor, ram injectors, E.P., buildings and auxiliaries, others. not included ; Unox plant)
utilities : unknown

Recovered products

1. gas	620 Nm3/ton 3500 kcal/Nm3	(refuse 2600 kcal/kg)
2. ferrous metals	30 % of input	
3. slag	220 kg/ton refuse	

3. Conclusions

The South Charleston unit has been sucessfully operated at reduced throughput tests over several weeks.The gasificatio system seems to be working quite well. A gas with a high heating value that burns clearly and an inert slag with very low volume are produced.

The use of pure oxygen and the wastewater plant needed to treat the highly polluted effluent make the process costly.

G. THE ANDCO-TORRAX SYSTEM (18)

1. Description of the process

Unshredded refuse is fed into the top of the vertical shaft reactor. Air preheated to 1.000°C in a cowper is fed into the hearth of the reactor. The high temperature (1500°C) causes the slag to melt. The molten slag flows through a slag tap and is quenched in a water tank.

Pyrolysis gases are withdrawn in a "lantern", situated near the top of the reactor and are directly burned in a cyclonic combustion chamber. Melted particles are separated by cyclonic action and are collected in a quenching tank.

Part of the hot combustion gases is used to heat one of cowpers, which is later used to preheat the incomming air.

The larger part of the gases is used to raise steam in a waste heat boiler. The gas is then cleaned in an E.P. The steam is used for power generation.

Products from the Andco-Torrax process

1 ton refuse → 300 kWh power
→ 170 kg slag
→ exhaust gas

2. Evaluation

Present status :
- A 68 t.p.d. unit located in Orchard Park, N.Y. was operated from the second quarter of 1971 to December 1974.
- A 200 t.p.d. plant is currently undergoing shakedown tests. Construction was completed during 1976.

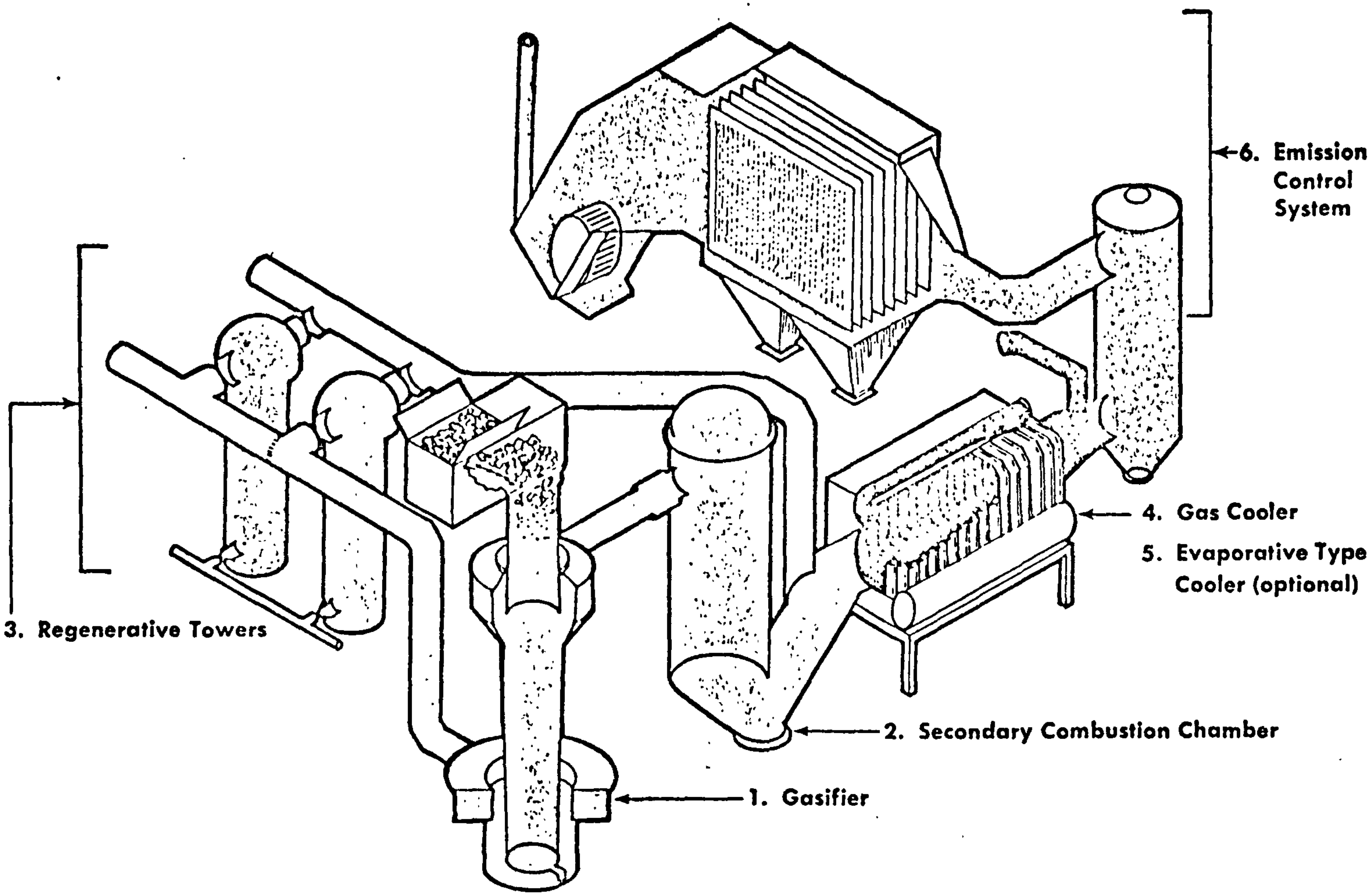


FIG. 22 : ANDCO-TORRAX Process.

- A 170 t.p.d. unit is under construction in Grasse, France.[+]
- A 200 t.p.d. unit is under construction in Frankfurt, W. Germany.

Technical Aspects

complexity : pretreatment : bulky waste is coarsely shredded. Air is preheated in cowpers.

aftertreatment: combustion with solids separation, cooling, E.P.

reliability: availability : No conclusive results are available. The danger of channeling is important in large units, especially. According to some it will be impossible to operate continuously at design capacity.

redundance : No redundance

wear : The refractories can be damaged by the molten slag tap (repair of slag top is planned 2 times a year)

- Ram feeders

possible incidents :

- explosion in shaft
- toxicity of pyrolysis gases
- solidification of slag
- channeling and bridging in shaft

degree of automation : Automation is difficult and the reaction is difficult to control.

Thermal efficiency : 83 % (refuse : 24% H_2O ; 2500 kcal/kg)

Environmental aspects

Air 5500 Nm3/ton refuse

Before purification : particulates : 3,5-5,1 g/Nm3
HCl : 4,1 kg/t
HF 0,24kg/t
SO_2 3,6 kg/t
CO 0-0,6 val. %

Water Little pollution is to be expected from the quench water

[+] Project cancelled.

Soil In principle the volume reduction is extremely high (95-97 %), and the residue is completely sterile.

Despite of the attractive aspect of the residue, unmelted small material can be found in the residue.

Noise The unit will be completely enclosed and no noise hindrance is expected.

Capital costs : unknown

Operating costs

personnel : unknown

power requirements : 70 kWh/ton

Fuel depends upon heating value of refuse.

utilities : water

Recovered products

1. Power : 300 kWh/ton refuse (Net.)
refuse : 2.000 kcal/kg

3. Conclusions

Operating experience with the Lusdelange, Frankfurt and Grasse plants is awaited before definite conclusions can be drawn. The use of unshredded refuse makes channelling in the shaft a major problem.

The process is relatively simple because it uses unshredded refuse. It produces an inert slag with a very low volume. Wastewater should not be a problem.

H. THE NIPPON STEEL SYSTEM

1. Description of the process (figure 23)

Untreated Refuse is charged into a shaft furnace by means of a pit and crane system. It enters the gasifier through a lock formed by two slide valves and on its way down is consecutively dried, heated, pyrolyzed and charred, in countercurrent heat exchange with rising gases. In the hearth of the furnace, the charred residue is burned by a hot blast (450°C), generated in a separate furnace. The remaining material is melted and separates into a layer of slag and one of metal. Slag and metal are tapped every 2 or 3 hours.

The gases are cooled while passing through the charge. They are cleaned in a dry dust collector and in a venturi scrubber. The cleaned gas is partially consumed in the hot blast furnace, the larger part being available for export.

Furnace conditions are monitored by measuring the pressure drop over the shaft and by periodic analysis of the gas, slag and metal. The charging cycle is initiated when the charge descends below a certain level. Operating conditions can be adjusted by the use of auxiliary fuel and by the addition of oxygen to the blast or of flux to the charge.

Products from the Nippon Steel process

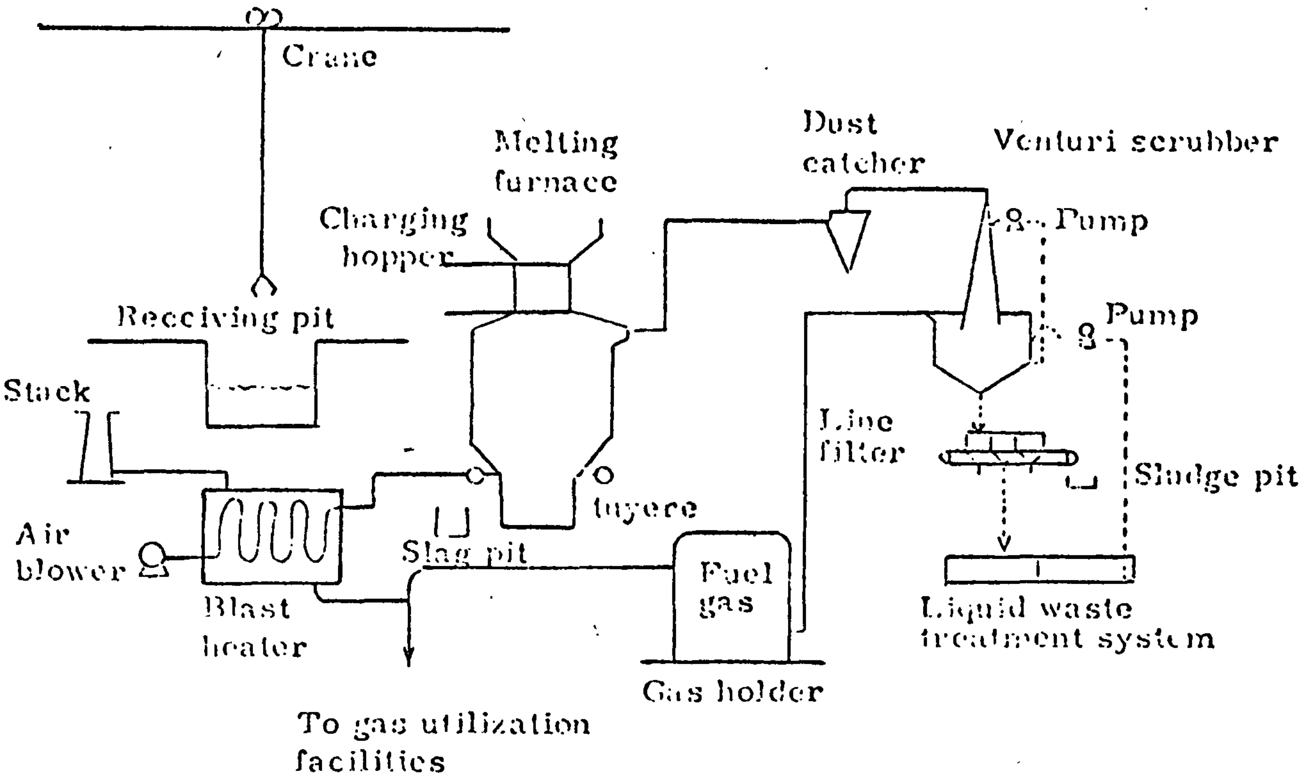
1 ton refuse

450-550 m3(s.t.p.)of gas (2000 kcal/m3)

20-30 kg iron (impure)

n kg inorganic residue

Fig. 23 Waste Melting System



2. Evaluation

Present status : - The process operated successfully at small scale (30 t/day) and will be implemented at an almost identical scale (40 t/day) on one of the "dream islands" of Tokyo Bay, for the disposal of a selectively collected mixture of "unfits for incineration", i.e. plastics, rubber, glass and metal.

Technical aspects

complexity : pretreatment : none required
aftertreatment: dry and wet dust collection
reliability: no data available
other factors: probably comparable to the Andco-Torrax process.

3. Conclusions

As in other shaft furnace processes successful operation was possible in small scale plant. No experience is available at industrial scale (150-1000 ton/day).

I. THE MOTALA SYSTEM (19)

1. Description of the process

Refuse is stored in a storage bunker with a specially designed discharge mechanism at the bottom. Refuse and coal are separately metered to the gasifier reactor. The coal ensures a more homogeneous bed composition and a more uniform movement of the charge in the reactor.

The reactor is a vertical shaft gasifier with at the bottom a conical mechanical grate which discharges the ash.

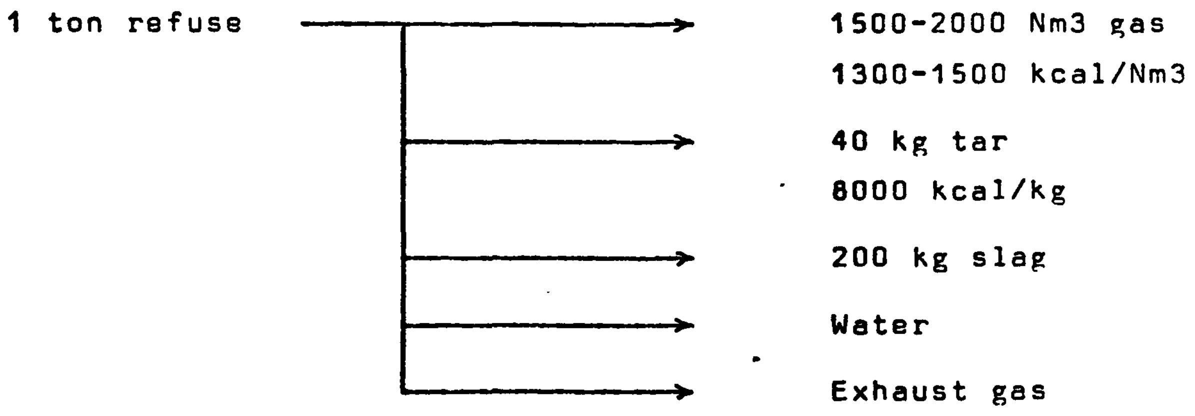
A mixture of air and steam is introduced through the grate.

Gasification products are withdrawn at the top of the gasification zone. The gas is lean and can directly be used after dust removal, since it is free from oil and tar.

Drying and degasification products are withdrawn at the top of the reactor. They contain an appreciable amount of water vapour and of heavy liquids. It is cooled and cleaned in an E.P. Both gas streams are mixed after purification.

The wastewater , formed by condensation of the water vapour or by separation in an E.P., is treated in an oil separated, heated in specially designed evaporator bundles, and used as a gasifying medium.

Products from the MOTALA process



2. Evaluation

Present status : - Demonstration plant in Oaxen, Sweden.
Operating from 1972 to 1974.

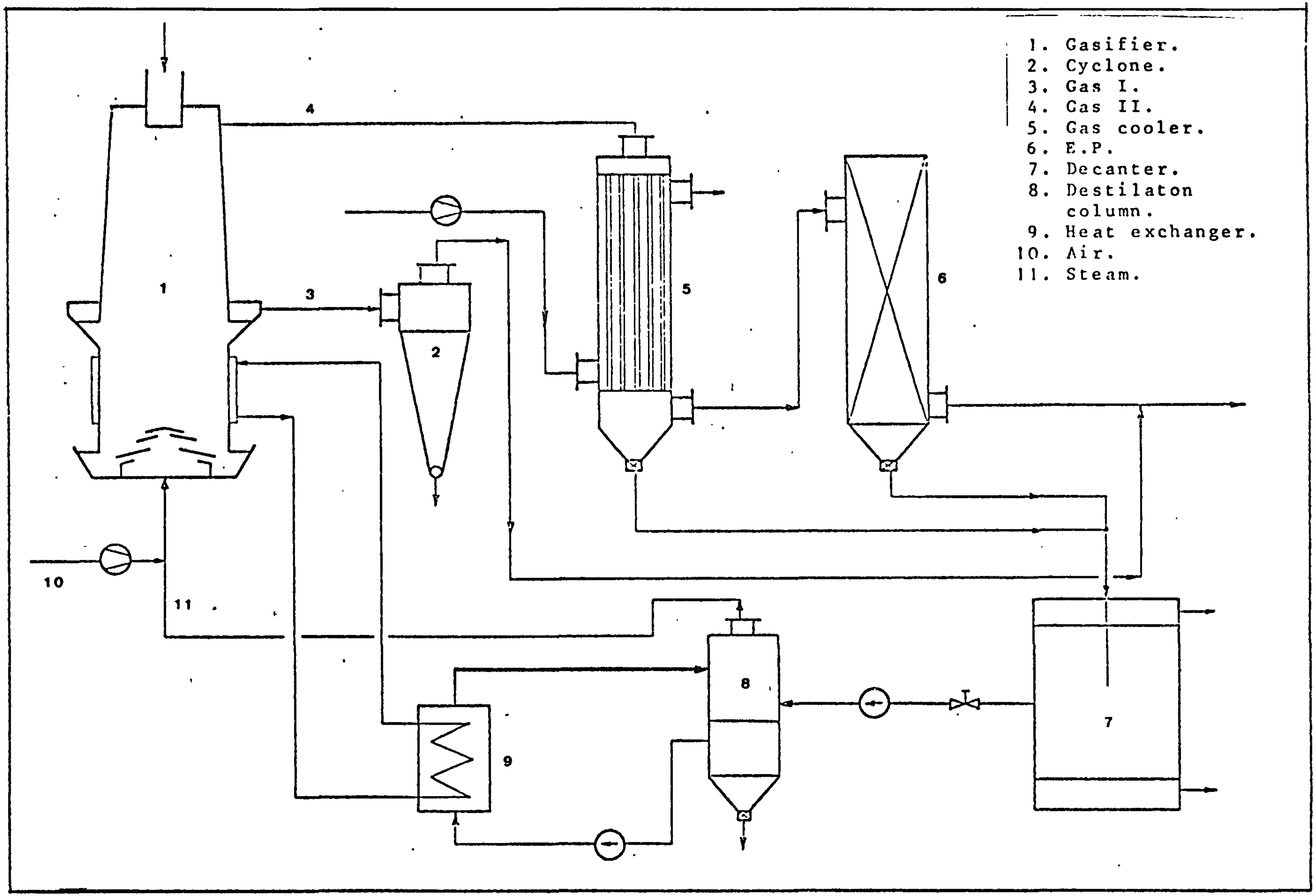


FIG. 24 : MOTALA Process.

- Demonstration plant in Gislaved, Sweden. Operating at 50 t.p.d. refuse + t.p.d. coal.

Technical aspects

complexity : pretreatment : coarse shredding in refuse bunker. Preheating of steam.

aftertreatment gas : 1.* cyclone

2.* cooler (condensation of tar and oil)

E.P.

char: quenching

reliability: availability : channeling problem is lessened by the use of coal.

redundance : plants will be composed of 100 t.p.d.,units with separated subsystems

wear :
-bunker discharge mechanism
-conveyors
-feeding system
-ash withdrawal system

possible incidents :
- explosions in shaft
- toxicity of gases
- channeling and bridging in shaft

degree of automation : The gasification rate is determined by the air flow to the grate

Thermal efficiency : ± 90 % (refuse : 25% H_2O ; 2500 kcal/kg) (power and auxiliary fuel are not accounted for)

Environmental aspects

Air	No data available. Tests are currently being made.
Water	According to Motala no waste water is produced (the condensate is recycled as a gasifying medium)
Soil	The residue can be landfilled without danger
Noise	Unknown

---

* Gas is withdrawn at two different places.

Capital costs : unknown

Operating costs : unknown

Recovered products

1. Gas : 1500-2000 Nm3/ton refuse (refuse 25% H_2O;
   1300-1500 kcal/Nm3 2500 kcal/kg)
2. Oil : 40 kg/ton refuse
   8000 kcal/kg

3. Conclusions

The first complete unit is being tested at Gislaved.

The results of these test should demonstrate the feasibility of the process.

Specially designed refuse bunker, feeding system and ash removal grate are claimed to have resolved the refuse handling problem.

The use of coal seems to reduce the channeling problem.

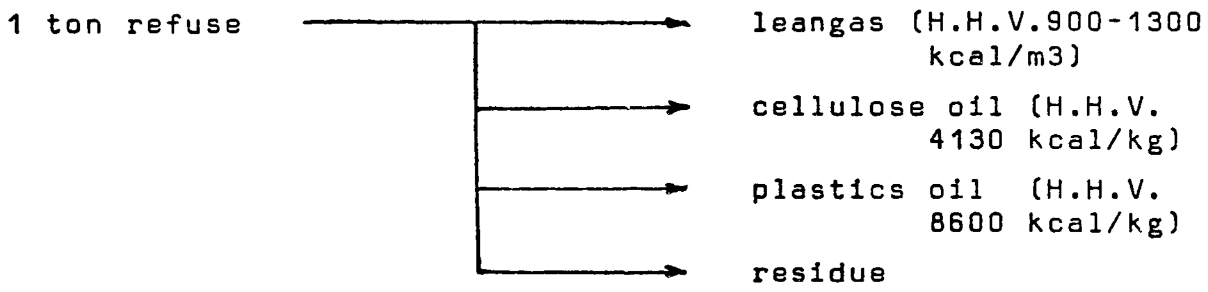
J. THE HITACHI GASIFICATION SYSTEM

1. Description of the process

The feed is shredded to a maximum particle size of 3-5 cm and stored in a hopper. The feeding system consists of a drag conveyor, a rotary lock, a chute and weighing and screw conveyors, delivering the material into a fluidized bed. Charred material floats on top of the bed and is discharged by means of an overflow. Incombustible residue settles into the conical bottom of the distributor and is discharged through a pipe at the center of the distributor. The residue is screened and the fine fraction, i.e. the sand, is recycled to the reactor.

The volatile gasification product is cleaned in 2 cyclone separators and in a 2 step venture scrubber, in which a "plastics oil" is condensed. A scrubbing tower completes the condensation, yielding 2 phases, a "cellulose" oil and wastewater, separated by settling.

Products from the Hitachi process



2. Evaluation

The system has been developed with financial support of MITI for use in an integrated resource recovery system. The experiments were performed on bench scale (16 cm I.D., 5-20kg/h) and on pilot scale (50 cm I.D., 100-150 kg/h). The plant can be operated in a wide range of temperatures (400-700°C) and of superficial velocities (2-14 times the terminal velocity of the

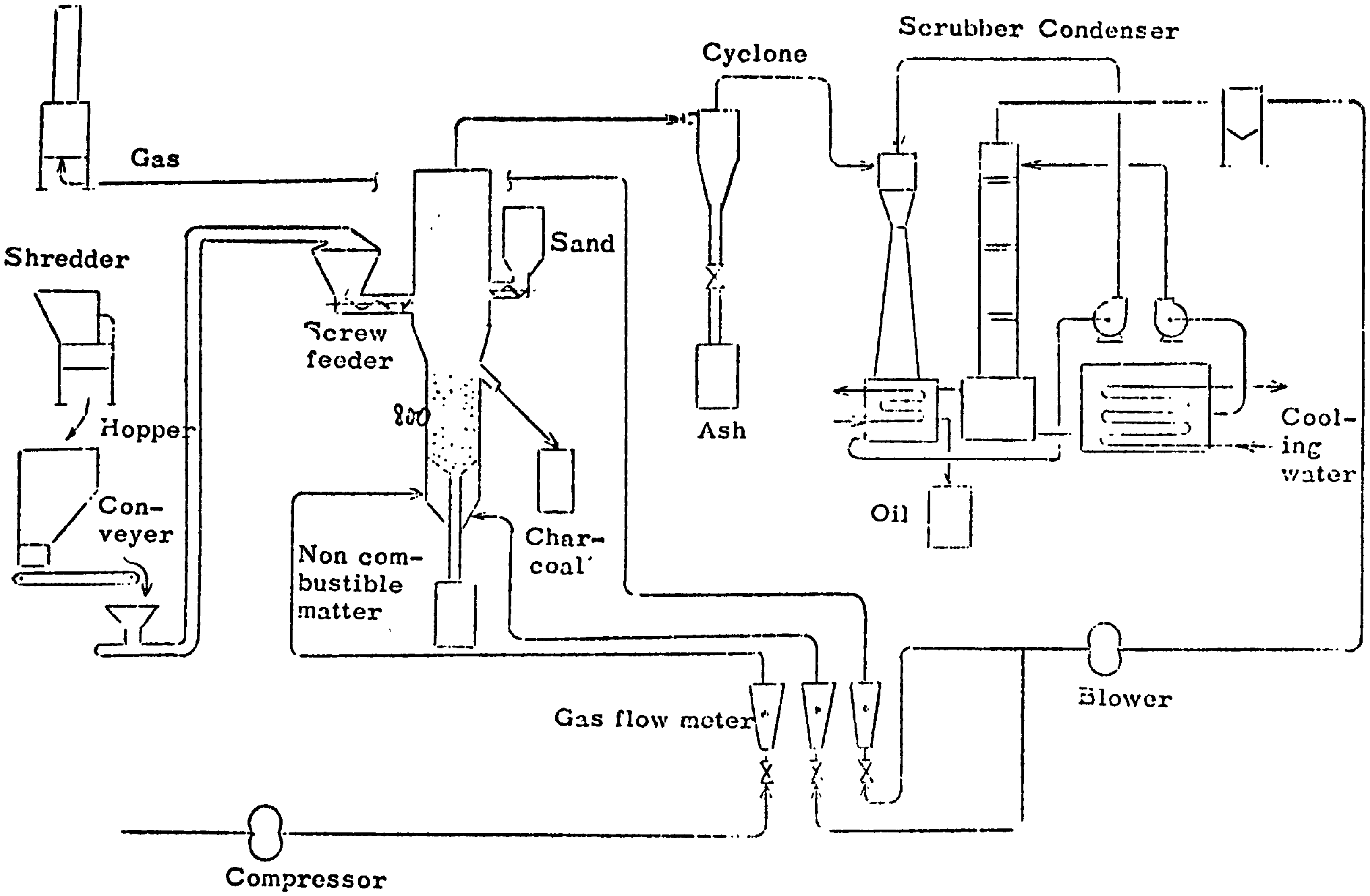


Fig. 25 Schematic flowsheet of the pilot plant

fluidized particles). Stable operating conditions can be maintained by adjusting the feed rates of refuse and air (13).

The plant has been operated with synthetic mixtures of dry refuse. Completion of a Tokyo demonstration plant is foreseen for 1979.

Technical aspects

complexity : pretreatment : shredding to 3-5 cm
possibly drying, to increase the yield of pyrolysis oil.
aftertreatment : gas : dust collection, 2 step condensation, separation of an oil/water mixture
residue : screening, possibly sintering or resource recovery.

reliability: availability : no data available
redundance : none
wear : - shredders
possible incidents : -shredder explosion
- leaking out of toxic gases
- the deposition of tar in the gas cleaning plant
- incomplete separation of dust prior to the oil condensation steps
- difficult separation of cellulose oil from wastewater
- difficulties with the discharge system of incombustibles from the fluidized bed.

degree of automation: a high degree of automation is possible.

Thermal efficiency : no data available

environmentals aspects :
air : no major problems are anticipated
water : scrubber water
residue : unknown

noise : shredder and compressor are sources of noise

capital cost : unknown

operation cost:unknown

recovered products : lean gas, 2 types of oil.

3. Conclusions

The process is promising in several respects : high rates of heat transfer, limited pretreatment of refuse (shredding), storable main product (oil). The merits of the process, however, can only be evaluated from commercial size plant operation.

VI. SUMMARY

	Advantages	Disadvantages
Landgard (x)	Relatively simple plant. Rotary kiln gives a fairly uniform movement to the shredded refuse.	High shredder wear. High wear of the refractory lining of the furnace. Gasification is difficult to control.
(x) It is difficult to judge the Landgard process by the Baltimore plant, since a large part of the equipment at Baltimore is inadequate. Operation has been possible only for limited periods.		
Andco-Torrax	Simple process. Residue has a very low volume. Accepts waste oil, rubber, plastics, sludge,...	Process has not yet operated succesfully at commercial scale. Channeling reduces capacity and causes shaft explosions. Shredding may alleviate this problem. Difficult process control.
Purox	Product gas has a high heating value. Low volume of gas to be purified. Residue has a very low volume. Accepts waste oil, rubber, plastics, sludge, etc..	Shredder wear. Large volume, polluted wastewater. Low energetic efficiency (high temperature slagging operation, use of oxygen) Plant is no longer simple (shredder, oxygen plant, wastewater treatment plant).

	Advantages	Disadvantages
Motala	Relatively simple process. Features specially designed mechanical discharge grates, feeders and locks. No wastewater produced, inspite of gas purification. Accepts rubber and plastics waste.	Shredding will be necessary where no coal is available. Undesirable components (Cl^-, F^-) may be concentrated in the process by recirculating the wastewaters.Motala claims that a solution has been found to this problem.
Destrugas	Product gas has a high heating value. Oil, rubber and plastics can be added to the charge.	Plant is relatively complex, yet has a small capacity. Long start-up and shut-down periods (3 weeks each). Process is not flexible and not controllable-turndown ratio is low -temperature control of the charge is impossible. Obstruction in the coking chamber is possible. Highly polluted wastewaters. High wear on shredders and on refractory walls.

	Advantages	Disadvantages
Occidental Petroleum	Product oil is a storable product. Extensive possibilities for resource recovery (ferrous metal, aluminium, glass).	Highly complicated process. Economical only for large capacities. Skilled personnel required. High wear on shredders and probably in pyrolysis reactor. Oil product has only a limited market; special firing facilities required because of viscosity and corrosivity.
W. Virginia	High gas yield, high heating value. Good control of the pyrolysis conditions. Feed may consist of liquid e.g. sludge, waste oil and even gaseous wastestreams.	Refuse pretreatment required : - size reduction - removal of inert material Loss of fluidisation may occur, due to low melting material.

REFERENCES

1. G. COLLIN
   Technische und Wirtschaftliche Aspekte der Steinkohlen-Teerchemie, Erdöl und Kohle, 29 (4), April 1976.
2. M.R. LINDEN et.al.
   Production of high-BTU gas from coal, Annual Review of Energy, 1, 1976.
3. B. PHILLIPP et.al.
   Zum einfluss einiger chemischer faktoren auf den thermischen Abbau der Cellulose, Cell. Chem. Technol, 6 (4), 1972.
4. D.A. HOFFMAN
   Batch Retort Pyrolysis of Solid Municipal Wastes, Environmental Science and Technology, 2 (11), Nov. 1968.
5. E. DOUGLAS et.al.
   The Pyrolysis of Waste and Product Assessment, Paper to Symposium on Treatment and Recycling of Solid Wastes, Manchester 1974 Institute of Solid Waste Management.
6. E.R. KAISER et.al.
   The pyrolysis of Refuse Components, Combustion, May 1968.
7. W. PETERS & H.D. SCHILLING
   Die Vergasung von Kohle-Grundlagen und Anwendungen, Chemie in unserer Zeit, 10 (1) 1976.
8. T.F. FISHER et.al.
   The Purox System, Paper presented at the 7th Biennial National Waste Processing Conference and Exhibit, May 23-26, 1976, Boston, Massachusetts.
9. ANON.
   MOTALA PYROGAS : brochure
10. ANON.
    Baltimore Demonstration Gas Pyrolysis, EPA publication 530/SW-75 c.i.,1974.
11. ANON.
    Bericht über die Untersuchungen an der Pyrolyseanlage der Firma Pollution Control Ltd. in Kalundborg/ Dänmark, Umweltbundesamt 1976.

12. R.S. BURTON & R. BAILIE
    Fluid Bed Pyrolysis of Solid Waste Materials, Combustion
    February 1974.
13. S. RYSMAN
    The GARRETT pyrolysis process, paper presented at 1 st.
    Symposium on Materials and Energy from Refuse, Antwerp,
    21,-22 October 1976.
14. SANNER et.al.
    Conversion of Municipal and Industrial Refuse into Useful
    Material by Pyrolysis.
    U.S. Bureau of Mines, Rep. of Inv. 7428, Aug. 1970.
15. S.J. LEVY
    San Diego County Demonstrates Pyrolysis of Solid Waste,
    EPA Publication SW - 80 d.2, 1975.
16. P.H. BRUNNER
    Beitrag zur Pyrolysis von Cellulose Für die Herstellung von
    Aktivkohlen aus Cellulosehaltigen Abfallstoffen,
    Eichgenossischen Technischen Hochschule Zürich 1976.
17. K.H. RYMSA
    "DESTRUGAS"-Verfahren, Paper presented at the Symposium
    Neue Technologien zur Abfallbeseitigung, Techn. Univ. Berlin,
    1977.
18. E. LEGILLE & C. MELAN
    The ANDCO-TORRAX Process, a slagging Pyrolysis
    Solid Waste Conversion System, Paper presented at the 1st.
    Symposium on Materials and Energy from Refuse.
19. K.J. THOME-KOZMIENSKY
    Technisch Wirtschaftliche studie zum PYROGAS-Verfahren
    Unpublished Manuscript, Techn. Univ. Berlin, Sept. 1976.
20. K. POBER & H. BAUER
    From Garbage-Oil, Chemical Technology, 7, March 1977.
21. R.S. MECKLINGER
    The relative value of energy derived from municipal refuse, 1976
    Natl. Waste Processing Conference.
22. F.J. PAGE
    Torrax - A system for recovery of energy from solid waste,
    1976 Natl. Waste processing Conference.

23. W. GUMZ
Vergasung fester Brenstoffe : Stoffbilanz und Gleichgewicht
Springer Verlag Berlin 1952.

24. K.J. THOME KOZMIENSKY
Vergleichende Betrachtung von Pyrolyseprozessen
CRE, 1975, p. 320

25. K.J. THOME KOZMIENSKY
Systemanalytischer Ansatz zum Vergleich von Abfallbeseitigungens, Verfahren.
Neue Technologien zur Abfallbeseitigung, Vertieflehrgang am der Technischen Universität Berlin, 1977, p.250.

26. R. RASCH
Ansätze zum Vergleich und zur Bewertung von Abfallbehandlung Verfahren.
G-I-T. Fachzeitschrift für das Laboratorium, 1977, p.951.

27. M. HASHEGAWA et al.
Research and Development of circulation systems between fluidized beds for application of gas-solid reactions.
Pachec 1977.

28. M. HIRATO et al.
Fluidized bed pyrolysis and oil recovery process of municipal solid wastes.
CRE, p. 349.

29. K. SHIMADA
Hitachi Fluidized bed pyrolysis system
Hitachi Research Laboratory

30. M. HIRAOKA & M. KAWAMORA
Pyrolysis of Solid Waste
3d Japan-US Conference on Solid Waste management, May 1976, Tokyo, Japan.

31. K. ITO et al.
Two-bed pyrolysis system. Resource Recovery from Municipal Solid Waste.
Ebora Mfg. Co.

PART III. - REFUSE DERIVED FUEL

PART III. - REFUSE DERIVED FUEL

I. INTRODUCTION

A. INTRODUCTION AND DEFINITIONS

Refuse derived fuel can be defined as refuse, the fuel qualities of which have been improved by homogenising its composition and particle size and by reducing its moisture and ash content.

It was certainly contemplated in the past to sift away the coal ash, or to pulverise refuse before incineration. But these pretreatments never gained acceptance, because they increased plant complexity, investment and operating cost. Moreover, the siftings are not sterilized and require separate disposal, whereas the combustion of pulverised refuse on a grate requires more overpressure, the bed of pulverised refuse being denser.

Meanwhile, the incentives for upgrading refuse to a fuel with more acceptable qualities, became more important :

1. present fuel prices are about 5 times higher than in 1970
2. the calorific value of refuse not seldom attains 1.800-2.000 kcal/kg, and even more in the U.S.A., to be compared with only 1.000-1.500 kcal/kg about 15 years ago.

Pulverised refuse is more homogeneous than raw refuse, and can be fired in suspension. In Hamilton (Ontario) it is pneumatically injected above a travelling grate and largely combusted before landing on the grate, where burnout is completed. The same operating principle has been applied by IMI.

Pulverised refuse presents a steep angle of repose, bridges easily and may even solidify under its own weight, when stacked. Handling difficulties frequently arise, even when it is stored in livebottom hoppers. Pulverised refuse also contains much inert material, which puts a heavy burden on the ash removal system. Part of this inert material can be removed by air classification.

Air classified, pulverised refuse can be transformed into a fluffy material by screening, followed by secondary shredding. Fluff RDF still has undesirable bridging and flow properties.

Further milling and drying of fluff RDF yields a free flowing powder RDF, which can be handled more easily and stored indefinitely. Explosion proof electrical equipment is required, since the powder presents an explosion hazard when mixed with air.

Coarse, fluff or powder RDF can be densified by means of pelletizers or screw auger extruders.

Powdered RDF requires a binder, Densified RDF can also be obtained by pulping the raw refuse, followed by mechanical purification of the pulp, and by mechanical and thermal dewatering. Moist RDF can be fired in furnaces, developed for the combustion of bark.

Densified RDF has the same composition as the parent material, but burns slower. It can be handled and blended together with coal. It has a hard surface, but breaks up with severe handling.(1)

The most economical way of using RDF is to fire it in existing boilers, either by suspension or by stoker firing. Adequate ash handling capacity should be available. Dust and fluff RDF can be fired through slightly modified circular register burners, around a conventional fuel torch. RDF can also be slurried with heavy fuel-oil.(1)

The substitution level of RDF for coal seems to be limited to 20 %, since the required volume for suspension firing is different. 100 % substitution, on the other hand, seems feasible in lignite or brown coal furnaces. Until now, no serious corrosion problems have occured with RDF-firing.

B. SURVEY OF MAJOR PROJECTS

LOCATION	DEVELOPER	CAPACITY	RECOVERED PRODUCTS	REMARKS
Akron, Ohio	Glaus, Pyle, Schomer, Burns and Dehaven	1000 T/D	RDF, Ferrous, provisions for future non ferrous	Under design
Ames,	Henningson, Durham and Richardson.	200 T/D	RDF, ferrous metals aluminium, baled paper	Operational
Baltimore County, Maryland	Teledyne National	600-1200T/D	RDF, ferrous, non ferrous, glass	Operational since early 1977. Shredder explosion caused severe damage soon after startup
Bridgeport, Conneticut	Combustion equipment Ass. and Oxy	1800 T/D	ECO-FUEL II, glass, ferrous, non ferrous aluminium.	Joint venture Oxy-CEA. Capital costs $ 53.000.000 Construction to be complete in March 1978.
Brockton, Massachusets	Combustion equipment Associates	900 T/D	ECO-FUEL II	Pilot plant in shake-down since late 1976.
Chicago, Illinois	Ralph M. Parsons Co Consoer, Townsend and Associates	1000 T/D	RDF, ferrous, dense fraction to be landfilled	In shakedown since several months. Production will start Aug. 1977.
Dade County, Florida	Black-Clawson	3000 T/D	RDF, ferrous metal, glas, aluminium	Plant under construction $83.000.000 capital cost

LOCATION	DEVELOPER	CAPACITY	RECOVERED PRODUCTS	REMARKS
Franklin,OHIO	Black-Clawson	150 T/D	RDF,colour sorted glass,ferrous,aluminium.	Continuous operational since June 1971 (50 t.p.d.)
Hempstead, New York	Black-Clawson	2000 T/D	id.	Under construction. Capital costs $ 73.000.000
State of Delaware	?	500 T/D MSW 230 T/D sewage	RDF,ferrous,nonferrous,glass,agricultural/horticulral products	?
Lane County, Oregon	Allis Chalmers	500 T/D	RDF,ferrous metals	Under construction
Milwaukee, Wisconsin	Americology	1000 T/D	RDF,ferrous metals	Undergoing start-up. Capital cost $ 18.000.000. Fuel sold for $ .80/10^6 BTU
Monroe County, New York	Raytheon Service	2000 T/D	RDF,ferrous metals non ferrous metals mixed glass	Under construction
St Louis, Missouri	Union Electric Co	325 T/D	RDF,ferrous metal	Demonstration plant. 50.000 tons processed since 1972.
		6000 T/D	RDF,ferrous,aluminium, tin.	$ 80.000.000 project termin. by Union Electric Co on Feb. 10, 1977.

LOCATION	DEVELOPER	CAPACITY	RECOVERED PRODUCTS	REMARKS
Stevenage, England.	Warren Spring Labs.	50 T/D	RDF, Ferrous metals, Paper.	Pilot plant.
Aachen, W. Germany.	T.H. Aachen	24 T/D	RDF, Ferrous metals, Non-Ferrous metals, Glass, Paper.	Pilot plant.
Haarlem, Netherlands.	TNO	360 T/D	Paper, Ferrous metals Plastics.	Construction finished (1976).
Birmingham England	Imperial Metal Industries Ltd.	180 T/D	RDF, Ferrous metals	Operational since February 1976

II. PROCESS DESCRIPTION

In this part we will describe the different types of RDF produced by a typical process.

1. Coarse RDF (St Louis supplemental full project)
2. Wet pulped RDF (Black Clawson)
3. Fluff RDF (Occidental Research process)
4. Powdered RDF(Eco Fuel II)
5. Briquettes

A. COARSE RDF (St LOUIS SUPPLEMENTAL FUEL PROJECT)(2)

The City of St Louis and the Union Electric Cy demonstrated under an E.P.A. grant the feasibility of using shredded refuse as supplemental fuel in a pulverised coal-fired power plant. In the period from April 1972 to June 1975 almost 60.000 tons or refuse were processed yielding 77 % of pulverised refuse and 5.3 % of ferrous metal, the balance being landfilled.

Calorific value	2.875 kcal/kg	
Bulk density	0,095 g/cm3	
Size distribution (%)	less than 6,3 cm	97,5
	" " 3,8 cm	94,0
	" " 1,9 cm	73,5
	" " 0,95cm	49,0
Composition (wt %)		
Paper	58.9	
Plastic	5.4	
Wood	2.6	
Organics	2.9	
Glass	1.6	
Magnetic metal	0.2	
Other metal	0.6	
Miscellaneous	26.2	
Moisture content	23.1	
Ash content	20.9	
Volatile matter	29.8	
Fixed carbon	10.6	
Total carbon	27.7	
Hydrogen	4.5	
Oxygen	6.8	
Sulphur	0.17	
Nitrogen	0.57	

Table 36. Properties of refuse derived fuel (St.Louis)

The City of St Louis operates a conventional pulverising plant, with shredding to a nominal size of 7,6 cm. The pulverised refuse is separated by air classification into a light combustible fraction, and into a heavy fraction. The light material is then transported to the Union Electric Meramec power plant by trailers. A hydraulic ram built in the truck(A) unloads the refuse into a receiving bin (B). A twin-screw traversing auger located at the bottom of the bin, feeds the pulverised refuse into pneumatic system (D) leading to a 250 m3 surge bin (E). A chain-bucket system sweeps around the pile of refuse and feeds it into a drag conveyor (G). Finally it drops into one of four pneumatic feeding lines (H), which convey the material into a firing nozzle, located in a corner of the power plant boiler (I).(fig.26,27).

Each corner normally contains two gas and four pulverised coal nozzles. In each corner one gas nozzle was replaced by a refuse burner, without affecting furnace operation or flexibility. The boiler load is regulated by the rate of coal firing. The flue gases are cleaned by an electrostatic precipitator(J). The bottom ash is sluiced off into a settling pond.

In comparaison to water walled incinerators, a higher thermal efficiency can be obtained, since the utility units operate at an air excess of only 20-30 %(3). General performance has been satisfactory, but a number of problems have been encountered :

1. jamming of the feeder system by large pieces of metal, wood, etc. The problem was eliminated by the introduction of a preliminary air classification step
2. rapid hammer wear, with reconditioning required after treating 600 tons
3. rapid wear of the pneumatic ducts, especially at the elbows. At most pipe bends replaceable wear plates have been installed, for quick replacement, ceramic materials as well as tungsten carbide are being evaluated as alternative materials.

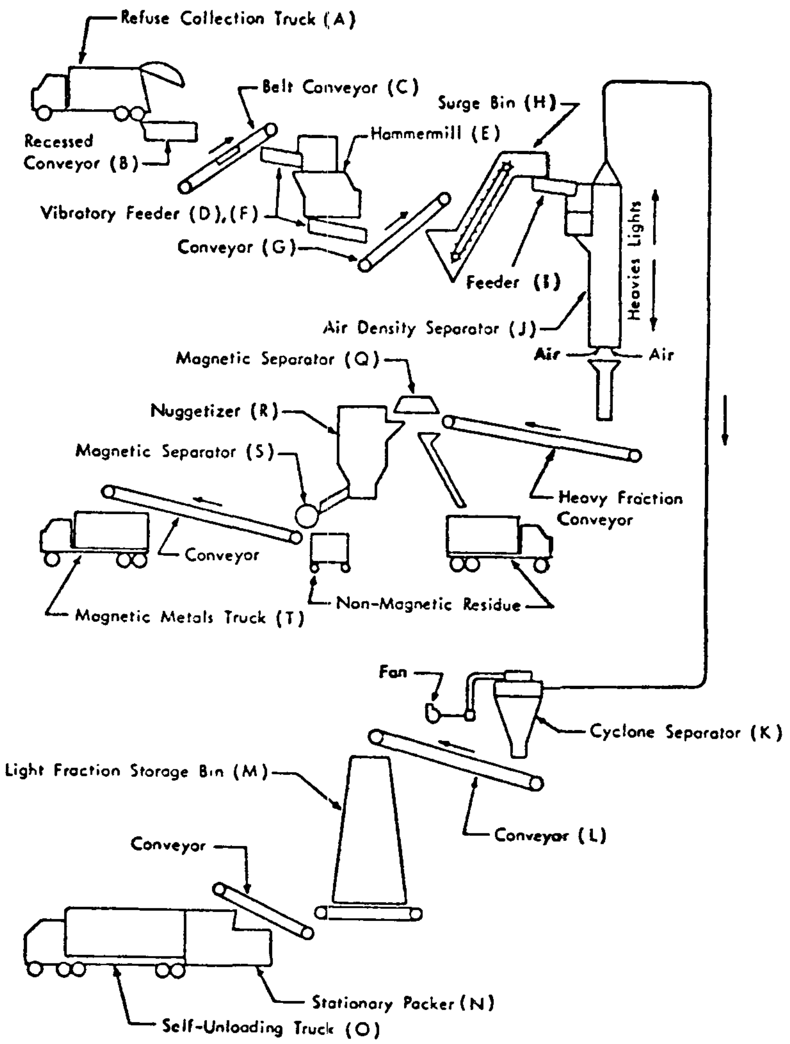


FIG. 26.: Processing Plant Flow Diagram

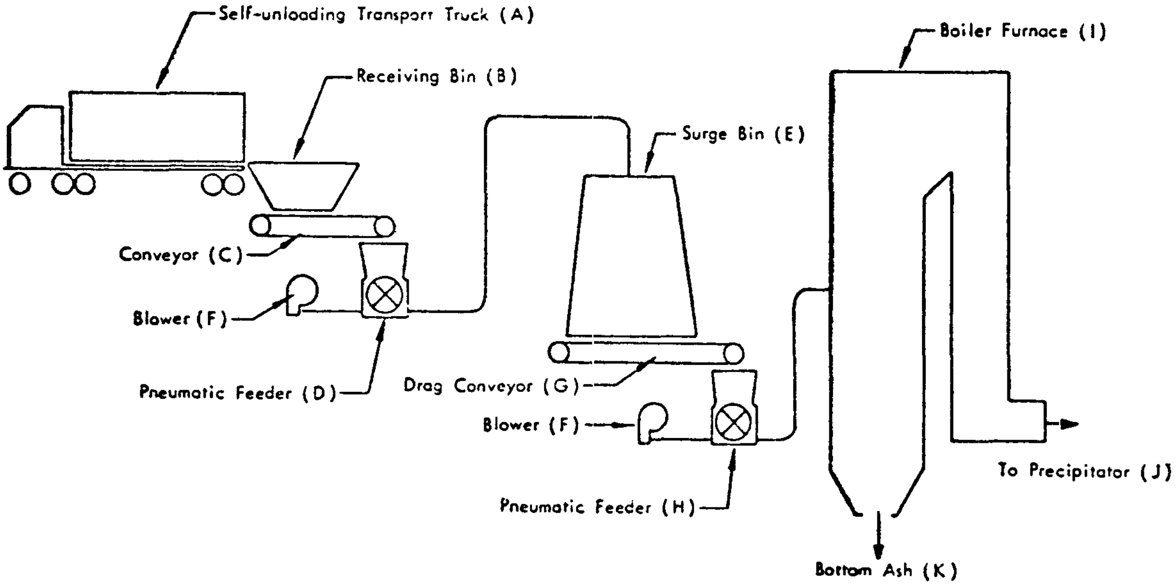


FIG. 27.: Power Plant Flow Diagram

No adverse effects were detected on boiler performance and no unusual signs of slagging, ash deposits or corrosion were found.

The Midwest Research Institute has evaluated the energy conversion and pollutant emission at both the refuse processing and the power plant. A significant particulate emission (9-31 kg/h) was found at the air classification unit, which operates without dust control equipment. High sound levels were found at several locations.

The firing of pulverised refuse did not significantly affect SO_2, NO_x or CO-emissions, and only a minor increase of Cl^- emission was detected. The collection efficiency of the electrostatic precipitator somewhat decreased, the amount of boiler residue augmented by a factor 4-5, and the water pollution level increased for a number of pollutants.[4]

Operating costs for refuse pre-processing over the operating period July 1972-November 1974 averaged $ 5,94/ton of raw refuse, the most important cost factor being direct labour cost. Operating expenses at the power plant amounted to $ 8,52/ton, of which $ 3,83/ton were required by maintenance labour alone. Fixed plant investment, at $ 2,9 million, is not very representative because the required facilities where constructed at an existing plant.

In the above figures no credit was givem for fuel value of refuse and for the scrap recovered. The high cost of the project is ascribed to the experimental nature of this first demonstration plant.(5)

A subsidiary of the Union Electric Cy im the St Louis region planned to build, own and operate a 6.000 toms/day Solid Waste Utilization System (S.W.U.S.), Revenue was to be generated by trash hauler dumping fees and sale of recovered metals and pulverised refuse. The latter would be fired at the 1.400 MW.

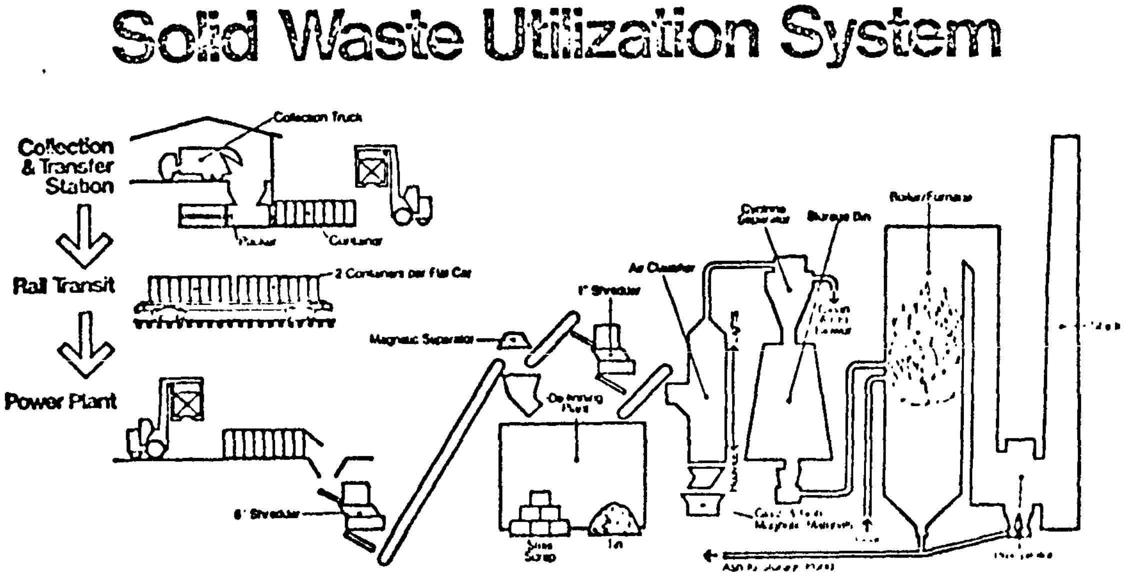


FIG. 28.: Flow Sheet for 6000 T/D Plant.

Labadie plant, and at the 900 MW Meramec plant. The consumption of these plants at present is 900 and 400 tons coal per hour. (fig.19)

The refuse would be hauled by rail to the power plants. Five truck-to-rail transfer stations would be built, where the refuse would be compressed into 75 m3 containers. Two containers, with a payload of 32-36 tons each would be loaded on a flat railroad car.

Processing would involve primary shredding to 15 cm, separation of magnetic metal and of glass, secondary shredding to 2-2,5 cm, and finally, air classification.(6)

The project has now been abandoned, because of financing problems and because of the difficulty of getting the required building and operating licences for all the transfer stations involved.

A number of American communities also committed themselves to a policy of refuse combustion as a supplemental fuel in existing power plants. These projects are at a variable state of completion.(9)

The City of Ames (Iowa) is operating since 1975 a municipally owned supplementary fuel system, with a design capacity of 200 tons/day. The refuse is processed by primary shredding, magnetic separation, secondary shredding, and air classification. The dense fraction is further treated on a trommel screen, to eliminate glass and dirt, and by eddy-current separators, to recover non magnetic metals. Anticipated total cost for refuse disposal is between 0 and 6 $/ton of refuse. In practice cost amounts to 10 $/ton of refuse.

B. WET PULPED R.D.F. (7)

In the Black-Clawson process raw refuse is discharged into a wet pulper, i.e. tub filled with water with a high speed

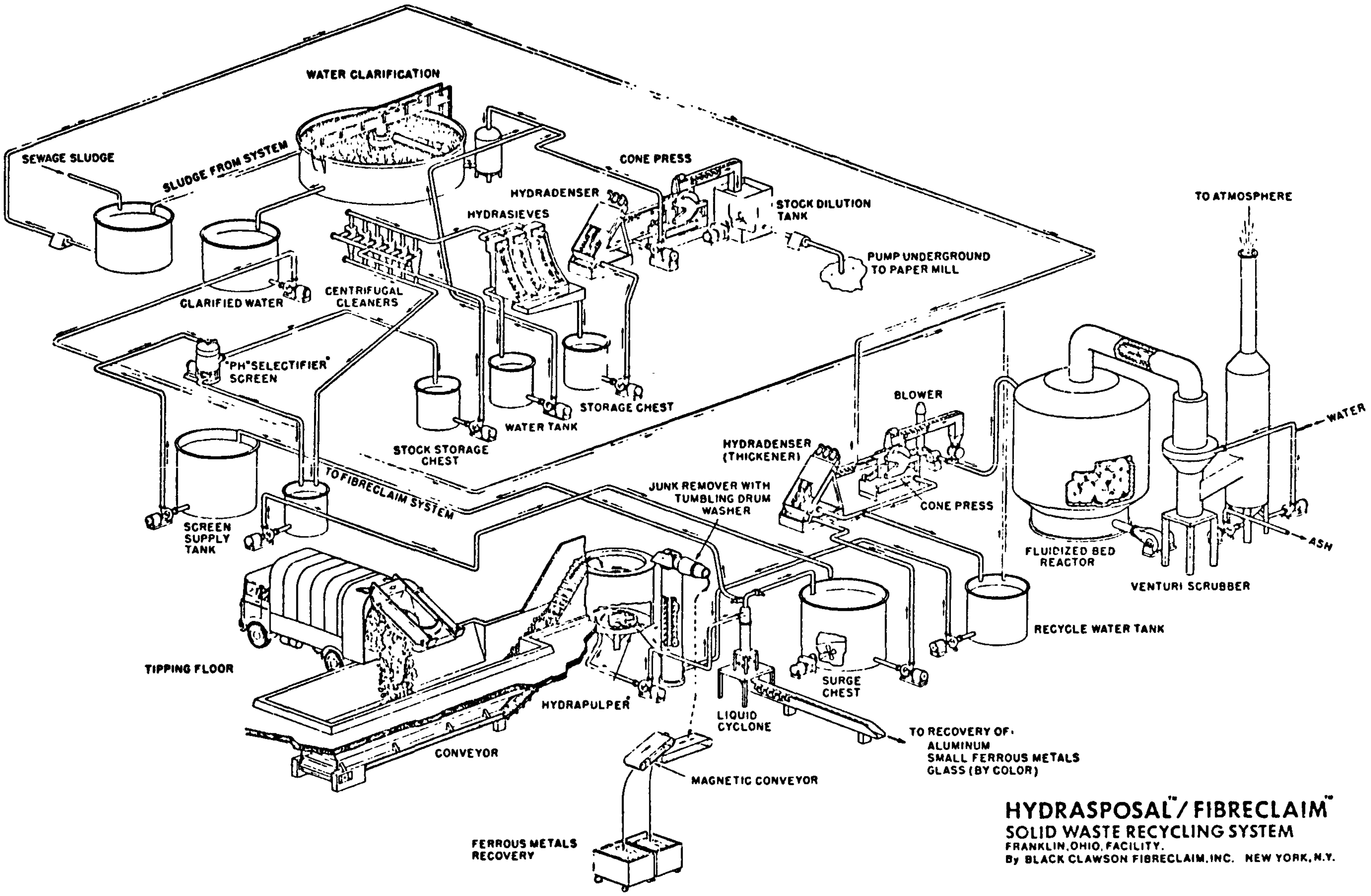
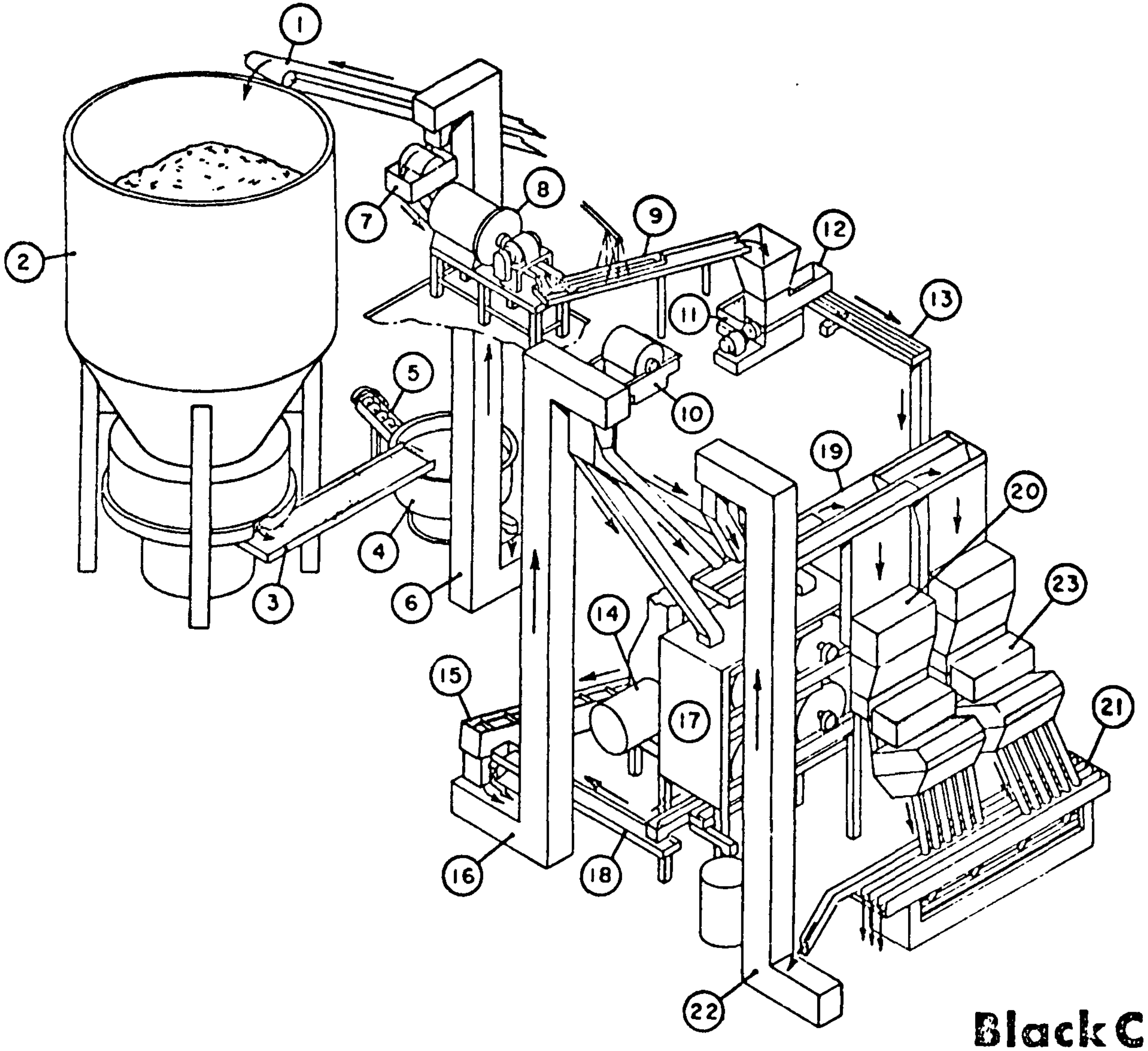


FIG. 29. : BLACK-CLAWSON Process.

Glass and Metal Recovery Plant



1 - Conveyor, from Hydrasposal
2 - Bin
3 - Conveyor
4 - Rotary Screen
5 - Fines Dewaterer
6 - Elevator
7 - Magnet
8 - Heavy Media Separator
9 - Washing Conveyor
10 - Media Recovery
11 - Aluminum Dewatering Screen
12 - Jig
13 - Conveyor
14 - Dryer
15 - Conveyor with Magnetic Pulley
16 - Elevator
17 - High Tension Electrostatic Separator
18 - Conveyor
19 - Conveyor
20 - Transparency Sorter
21 - Conveyor
22 - Elevator
23 - Color Sorter

Black Clawson Fibreclaim, Inc.

cutting rotor at the bottom. Pulpable and friable material is thus converted into a slurry, which is extracted through a perforated plate with 1" slots, situated beneath the rotor.(fig.29)

Non pulpable material is rejected by centrifugal force through a discharge aperture in the side of the tub, and is conveyed by a junker (bucket elevator) to a magnetic separator. Non magnetic material is recycled into the pulper, and leaves eventually, after size reduction, through the perforated plate.

The pulp is grossly purified from inorganic material in a low pressure drop (0,2-0,35 bar) hydrocyclone. Glass, metals, ceramics are eliminated here, and will be separated further in the glass plant.

At this point the slurry can be purified in a Fibreclaim plant, in which long papermaking fibers are separated from contaminants. When no market exists for fibers, the latter becomes part of the fuel fraction.

The organic material is pumped to thickeners and to a Fibercone press. The resulting cake is fluffed and then conveyed pneumatically into a fluidised bed reactor. It can also be transformed into a low ash, high moisture RDF.

C. FLUFF R.D.F. (Occidental Research Process)

See " The Occidental Research Process" in Part II.

D. POWDERED R.D.F. (ECO-FUEL II) (8)

Combustion Equipment Associates, Inc. (New-York) has developed a method of producing a marketable RDF. In a first system refuse is shredded in a flail mill, dried, and air classified. Secondary shredding and further mechanical separation yields "Eco-Fuel^R I". The processing method later was improved, to yield Eco-Fuel^R II, the properties of which are given in table 37.

	Eco-Fuel II	Eco-Fuel I	Shredded Dried	Fuel Undried
Combustible wt %	88,6	78,5	77,0	50-60
Ash wt %	9,4	11,5	13,0	20
Moisture wt %	2,0	10	10,0	20-30
Higher Heating value kcal/kg	4.300	3.800	3.800	2.800
Average Particle Size mm.	0,15	12,5	19	50-75
Bulk Density g/ml	0,48-0,56	0,11-0,16	0,05-0,08	0,06-0,10
Storage life	indefinite	indefinite	indefinite	indefinite

Table 37. Properties of refuse derived fuels (RDF)

The production process consists of (see fig.30)

1. primary size reduction using a dual rotor flail mill. The articulated flail arms pass the hard materials through without damage, thus decreasing power requirements, capital and maintenance cost
2. separation of magnetic materials
3. air classification
4. screening of the light fraction for removal of glass and dirt, using either a vibrating or a trommel screen
5. addition of about 0,5 wt % of an (undisclosed) unorganic material, which embrittles the cellulosic materials
6. mixing of the chemical treated waste with hot steel balls in a ball mill.

At the temperature of the ball mill (100-200°C) moisture evaporates almost immediatly and the embrittling effect of the added chemical is enhanced which further diminishes the power

ECO-FUEL® II Process Flow

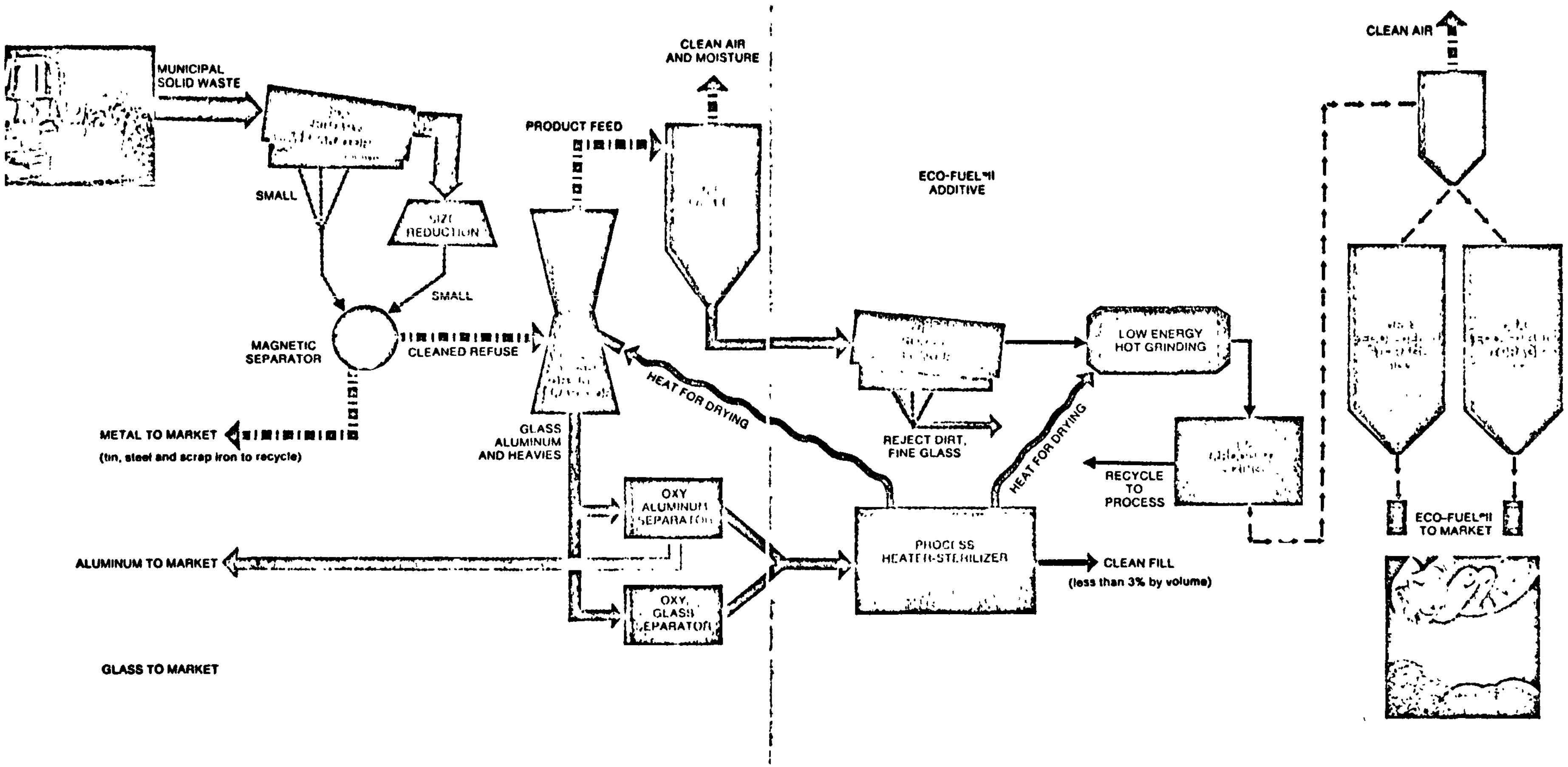


FIG. 30.

requirements of milling. The latter can be adapted, by varying the milling temperature and the amount of added chemical, which also increases the economic flexibility of the process.

The ball mill discharge is screened into three fractions : Eco-Fuel II, unground material, and grinding balls. Combustion of the unground material, together with the fine dirt and glass, removed during the screening step, yields a sterilised material, to be landfilled, and hot flue gases, to reheat the steel balls to the operating temperature. Prior to combustion the non ferrous metals are recovered from the unground material.

The net energetic efficiency of Eco-Fuel production attains surprisingly high values (over 70 %), as a consequence of the low power requirements for milling (table 38).

particle size (mm)	12,7	2,5	0,25	0,15
conventional mill (kWh/ton)	50	70	100	105
Eco-Fuel^R-II	-	-	-	33

Table 38. Pulverisation power requirements.

R = Registered Trade Mark

Eco-Fuel has numerous potential applications. It can be burned in a conventional pulverised coal burner, slurried with residual oil up to 40 wt %, or compacted into briquettes by means of a roll briquetter. It forms a suitable feedstock for pyrolysis, or for conversion into synthesis gas. It can even be transformed into particle board or fireplace logs.

Until recently Eco-Fuel was only produced at pilot scale. Fuel is being made during present testing operations at the

900 t.p.d.-plant at Brockton, Massachusetts. Furthermore, the final contract is signed to construct a 2400 t.p.d. plant at Bridgeport, Connecticut.

The construction of similar plants, one in the Greater Hartford region (G.B.), a second in the Housatonic Valley region is being negotiated.

E. BRIQUETTING OF WASTES

Household and commercial wastes can be transformed into briquettes, which can be used for heating purposes. The briquettes should have a sufficient calorific value, to make their manufacture and transport worthwhile, and to be saleable. During combustion the formation of toxic or corrosive gases should be minimal.

Materials such as straw, paper, wood meal, bark cuttings, packaging materials, plastics, rubber and household refuse were incorporated into briquettes; after pulverising and drying, up to an optimal moisture content of about 10 %. Before pressing, a binder is added, e.g. aminoplasts or polyols, hardened with isocyanates. The addition of binder obviously affects the cost of briquetting.

With the exception of briquettes made from plastics, the calorific value of most types of briquettes is rather low (ca 4.000 kcal/kg) to very low, for instance when using wet bark as raw material. The calorific value is improved by the addition of waste oil.

Briquetting of the light, air classified fraction of pulverised refuse is accomplished fairly easily. The resulting briquettes are formed by extruding the material through a large perforated cylinder, with 1/2" or 1" holes.

The resulting briquettes are storable for a prolonged period, and can be conveyed and stored without handling problems.

F. SOME REMARKS CONNECTED WITH THE DESIGN OF RDF PLANTS

1) As in other refuse treatment plants adequate traffic control should be provided. Entrance, discharge points and exit should be suitably located, to permit easy manoevring of refuse vehicles. Care should be taken that paper is not blown about by prevailing winds and that dust control and site cleaning are possible.

2) Refuse storage bunkers or floors should have adequate storage capacity.

3) Conveyors and storage bunkers form an important part of the plant and should be given more attention during design.

4) Shredder selection is still a very difficult point. The selection of a shredder should depend on the rest of the system; in many systems it is undesirable that glass bottles be completely pulverised and that aluminium cans be crumpled. Remarkably, the primary and secondary shredder are often identical, inspite of the intrinsic difference in their aim and operation.

In the U.S.A. shredding is by brute force mainly. In European sorting systems refuse is firstly screened (Warren Springs) or coarsely and selectively shredded in slowly rotating disc mills (T.H. Aachen).

5) Refuse is vastly different from one location to another. By and large it is impossible to apply data (recovery, product grade, efficiency, wear,....) from one plant to another.

6) Shredder explosion and subsequent fires should be counted with in design.

7) All equipment is subjected to unusually high wear, to a dusty atmosphere and to the occurence of contraries. Hence it should be designed in view of easy maintenance and of frequent and rapid replacement. In the case of non-scheduled shutdown

provisions should exist for emptying each part of the plant.

8) Dedoubling of production lines seems adviseable

9) Equipment for pneumatic conveying should be studied in wiew of high wear

10) Often equipment is selected on a "least cost" basis, by lack of proper design and selection criteria. This situation will cause unnecessary and irremediable operating problems.

11) Intermediate storage of shredded refuse should be avoided as long as no satisfactory equipment is developped.

III. Environmental Aspects of RDF

Distinction should be made between the RDF - preparation and the RDF - firing facilities.

The environmental impact of RDF - preparation was assessed under an E.P.A. contract at St. Louis, Missouri. Results obtained at this plant were probably less favourable than in new, specially conceived plants, because of the prototype nature of the St. Louis operations.

From our own visits to refuse pretreatment plants it follows that

- shredder operation creates dust and noise problems
- air classification and refuse handling increase the dust load in the plant
- the explosion and fire hazards are significant
- shredders and moving equipment present a safety hazard to personnel

The following countermeasures have been observed :

- supply of dust masks and ear plugs
- spraying water into the primary & secondary shredders
- enclosing all conveyors and providing a very large number of large access doors for servicing and troubleshooting
- separating the shredding equipment by firewalls from the refuse storage and conveying area
- providing "bombs" which release inert gases in case of shredder explosion, sweeping the explosion wave into an upward innocuous direction
- providing proper fire fighting equipment
- extraction of air at all dust generating locations and purificatio of the exhaust air in baghouses
- recirculation of process air.

Some plants were plagued by inadequate conveying equipment, forcing manual intervention on refuse. Most plants had an atmosphere loaden with fluffy particles. Esthetic conditions inside RDF - plants were often inadequate.

Yet, it is felt that with good design, equipment selection and maintenance, it is possible to make a RDF - plant operating nicely. In these respect the Chicago plant (in shakedown at present) has left a rather favourable impression.

The environmental aspects of RDF - firing are closely related to the quality and composition of RDF.
Generally , it can be stated that :
1) RDF has a very low sulphur content
2) RDF has a relatively high chlorine and ash content when compared to conventional fuel.

Generally the Amexican air classifiers use only a very crude separation method : the light fraction is aspired from a falling stream of refuse or from a refuse layer situated on a vibrating conveyor. The use of a more efficient air classifier, e.g. of the zig-zag type, could further reduce the ash content of RDF. The sulphur and chlorine content, on the other hand, cannot be lowered.

RDF -firing has the following effects on the environmental effect of utility boilers:
- sulphur emission is somewhat reduced
- HCl and dust emission become much larger
- the quantity of bottom ash is markedly increased.

Moreover, the availability of the boilers and their auxiliary equipment will be reduced by firing RDF as a supplemental fuel. This fact is often ignored at present, but will become apparent when more operating experience becomes available.

IV. Evaluation of selected projects

A. St. Louis, Missouri

1. Process Description

See 2.A.

2. Evaluation

Key Participants : Union Electric Co. and its subsidiary
Union Colliery Co.
Environmental Protection Agency

Status of the Project :

RDF was prepared and fired in an existing pulverized coal boiler for an extensive testing period, starting in spring 1972. EPA granted $ 3.3. million.

Processing capacity : 325 tons/8h shift

Union Colliery Co planned to develop a Solid Waste Utilization System, with a capacity of 6000 tpd. Due to problems with financing and operating licences the present status is uncertain.

Technical Aspects:

Complexity: single stage shredding, air classification, ferrous removal from the dense fraction
Redundance: no redundance in pilot plant
6000 tpd plant would consist of 4 separate trains
Wear : high hammer wear on the 1250 Hp hammermill
Possible Accidents : none reported
Degree of Automation : little

Other particularities: In the plant the magnetic metal fraction was classified in a nuggetiser mill. For the 6000 tpd facility it was planned to sell the ferrous fraction to a secondary metal processor for detinning.

Thermal Efficiency: for conversion to steam:54% (27% H_2O, 2500 kcal/kg)

Environmental Aspects: inconclusive air emission tests have been made

Capital cost : Union Colliery 6,000 tpd scheme : 70,000,000 \$ (1977)

Operating cost : Personnel : \$ 4.9 /ton refuse
Power : \$ 0.21/ton refuse
Parts and supplies : \$ 0.79/ton refuse
(pilot plant data)

Recovered Products : 1. Steam
2. Ferrous Metals
3. Tin

3. Conclusion

The original plant has been dismantled.

The St. Louis project was the first large RDF - project, its results were considered to be encouraging, and many more RDF - projects have been launched.

B. Chicago, Illinois

1. Process Description

Raw refuse is shredded in a 80 ton per hour Williams coarse shredder (4 to 6 " size) and separated into a light and a heavy fraction in a Triple-S air classifier. The heavy material is magnetically separated to remove ferrous components. The light fraction is fed to a Carborundum shredder. The shredded material (1") is pneumatically conveyed over approx. 1000 ft. to a consolidated Edison storage bin.
The shredded waste is burned at Commonwealth Edison Co's coal burning boilers.

2. Evaluation

Key participants : City of Chicago
Ralph M. Parsons Co.
Consoer, Townsend & Associates

Present Status : 1000 tpd plant constructed, in shakedown since several months. Actual production would start by August 1977.

Technological Aspects :

Complexity : coarse shredding, air classifier, magnetic fine shredding of light separation on heavy fraction, fine shredding of light fraction, pneumatic conveying to Consolidated Edison storage bin

Plant Reliability : availability : no data available
redundance : RDF-preparation line is completely dedoubled
wear : no data available
possible incidents : explosion & fire
wear in pneumatic conveying lines
problems in storage bin

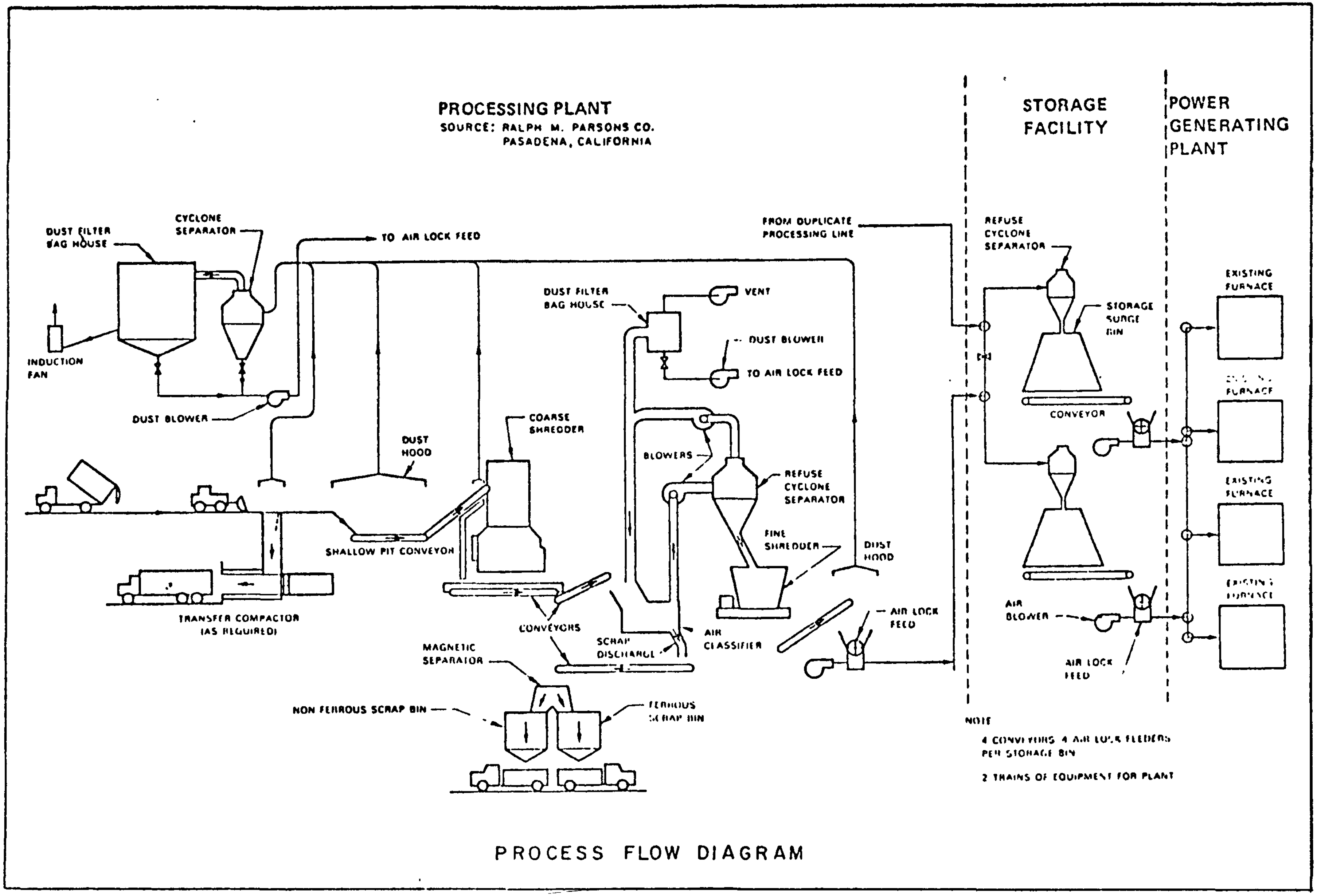


FIG. 31: CHICAGO, ILLINOIS
AUXILIARY FUEL PRODUCTION
CITY OF CHICAGO

incomplete burnout in Consolidated Edison boilers, tipping floor capacity is relatively low

degree of automation : fairly high

Thermal Efficiency : the plant is not yet in operation

Capital Costs : $ 20 500 000 (1977)

Operating Costs : unknown

Recovered Products : fuel sold to Commonwealth Edison for $ $30/10^6$ BTV

3. Conclusion

Well designed plant.

The shredder does not seem to have an explosion relief device. The air classifier has been selected on a lowest cost basis, not on performance criteria.

C. Baltimore County, Maryland

1. Process Description

Refuse is shredded by a Tracor-Marksman 1000 Hp shredder. Ferrous metals are magnetically separated (DINGS). Two stage air classification, aluminum separation and glass recovery.

2. Evaluation

Key Participants : Baltimore County
Maryland Environmental Service
Teledyne National

Present Status : - 600 - 1200 tpd plant operational since early 1977. Soon after start-up severe damage was caused by a shredder explosion and fire.
- 1000 tpd plant under construction. Start-up scheduled for early 1980.

Technological Aspects :

complexity : shredder, magnetic removal of ferrous metal, two stages of air classification. Separation of glass and aluminium from residue

plant reliability : availability

soon after start-up an explosion caused $ 300.000 damage and forced 3 month shutdown of half the plant

redundance

3 primary shredders, 2 three stage magnets

wear

1000 hP reversible hammermill 900 revs/min capacity 75 tons/h requires hard face welding after processing 3500 tons/refuse. Size distribution of the product : 95% below 5", 80% below 3".

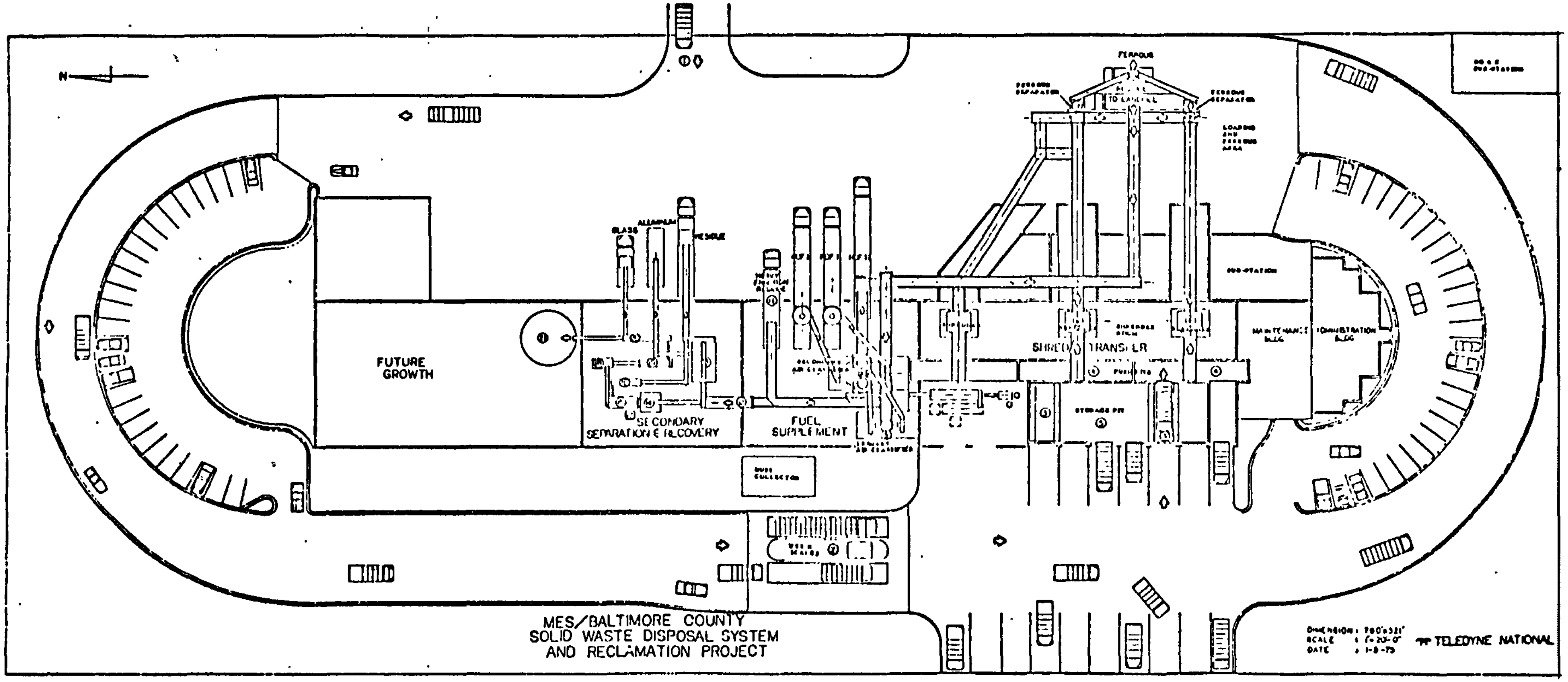


FIG. 32. : BALTIMORE COUNTY RDF Plant.

possible incidents

see under availability

Plant lay-out could be better, especially in the secondary separation & recovery section.

Conveyors are completely enclosed, yet there is a significant dust problem.

degree of automation

T.V. monitoring of pushbin & shredder feed interphone & radio control provided

other particularities

threestage DINGS magnets

primary conveyor fed by crane & grapple, temp. of the bearings is monitored continuously

thermal efficiency

Thermal efficiency : not yet determined

Environmental Aspects : - air : plant air is dusty
- water: none
- soil : quantity of subsisting residue is not known
- noise: acceptable level

Capital Cost : 8.400.000 $

Operating Cost: unknown

Possibilities for Resource Recovery :

RDF I, RDF II, ferrous metal, glass, alum.
(300-400 $ /ton)

3. Conclusion

Teledyne has shown inventivity in searching for new product applications. RDF-firing tests were conducted at a utility (distance 23 miles), having a Research-Cottrell precipitator, and in a cement kiln, using 30-50% RDF (based upon heat content). Pelletizing and compositing tests were also conducted.

Lightweight aggregate was made, using 88% ground glass, foamed with styrene. Concrete blocks and pipe insulation material was also prepared.

D. Black Clawson, Franklin, Ohio

1. Process Description

See 2.B.

The input and output of the Franklin Plant are given in the following table :

Inputs			Outputs
Glass	9.7	4	Color-sorted glass
Ferrous metals	10.1	9.7	Ferrous metals
Nonferrous metals	0.6	0.3	Alumi
Paper	26	13	Paper fiber
Plastics, leather, textiles, wood	6.1	34	Organics (burned)
Food and yard waste	17		
Miscellaneous inorganics	2.5		
Moisture	28	28	Water vapor
		11	Residue to landfill
Total	100	100	

Table 39. Summary of Inputs and Outputs, Franklin Plant (in tons, based on 100 tons of residential solid waste)

2. Evaluation

Present status :

150 tpd plant in continuous operation since June 1971 in Franklin, Ohio (only 50 tpd being processed in shift operation).

2000 tpd plant under construction for the City of Hempstead, New York. Announced cost 73.000.000 $.

Contracts signed for a 3000 tpd plant for Dade County, Florida. Announced cost 82.000.000 $.

150 tpd demonstration unit at Higashi-Kurume City(Tokyo) operating since March 1975.

Technical aspects :

complexity : number of operation involved is relatively large, but equipment used is standard and fairly reliable
plant can be operated by a small number of operators (4 operators + 2 maintenance people at Franklin)

reliability: plant availability is very large at Franklin
no redundance at Franklin
wear is important on the following items:
hammers of rotor to be replaced after 200 h
stators of pulper " " " 600 h
cyclone linings (rubber, polyurethane,...) to be replaced after 200 h for the first,
800-1.000 h for the others.
possible incidents: no fire or explosion danger
no slime formation has occured

thermal efficiency : depends on plant configuration

environmental aspects :

- no substantial air pollution
- wastewater is recirculated to adjacent treatment plant at Franklin. It is claimed that operating with a closed water circuit is possible.
- wastes to be tipped are about 5% by volume of incoming refuse.

capital cost :

	Capacity (tpd)	Capital Cost
Franklin	150	3.200.000 $ (197
Hempstead	2,000	73.000.000 $ announced
Dade County	3,000	82.000.000 $ announced

operating cost :

Personnel of Franklin consists of :

- 1 scale operator
- 1 plant operator
- 2 operators at the glass plant
- 2 maintenance operators

Power consumption : not available

Utilities " : " " "

possibilities for Resource Recovery :

paper fiber, RDF, ferrous metal, aluminium, colour sorted glass

3. Conclusions

The Franklin Plant is a small, partially experimental plant, operating continuously at 1/3 of design capacity (operation in 1 shift, 3-6 h/day, 5 days/week).

The plant seems to perform well, and to be reliable. The "glass plant" leaves room for further improvements.

E. Ames, Iowa

1. Process Description

1. RDF Preparation

Primary shredding

Magnetic separation by overband magnet with 3 magnetic fields, situated over the refuse discharge point.

Secondary shredding by identical shredder

Air classifier

Dense material further treated in trommel screen and aluminium separator.

2. RDF Firing

Atlas storage bin with 4 drag conveyors, each discharging over a fluffing roll and a rota valve. Four pneumatic conveying lines, which allow for the feeding of one suspension fired (or two travelling grate boilers).

2. Evaluation

1. RDF Preparation

Key Participants : City of Ames
Henningson, Durham & Richardson, Inc.

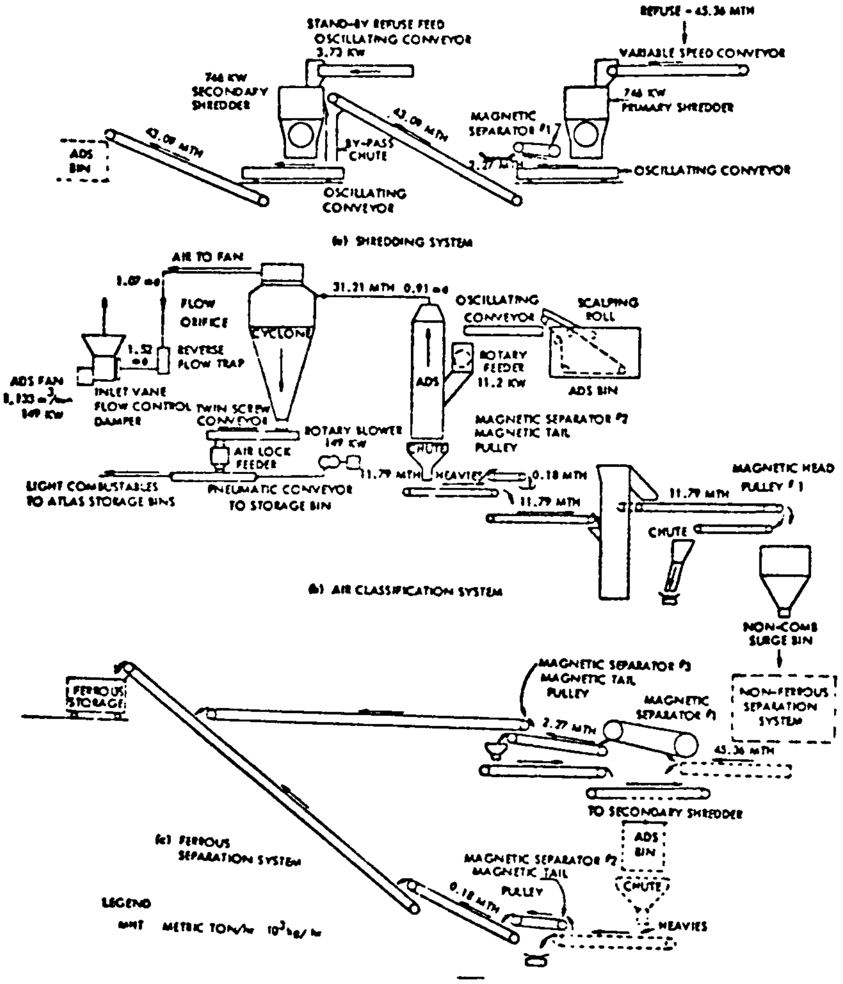


FIG. 33. : PROCESS EQUIPMENT FLOW DIAGRAM.

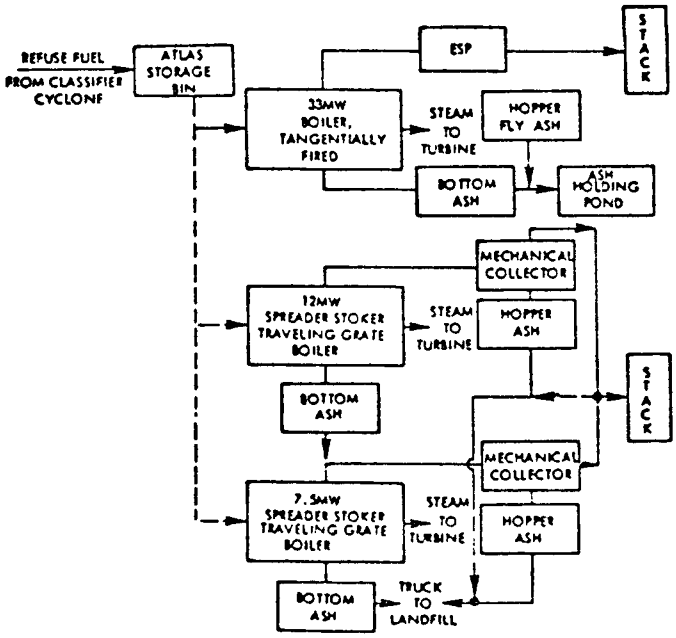


FIG. 34 : MSW FLOW STREAM FROM ATLAS STORAGE BIN THROUGH POWER PLANT.

Present Status : plant is operational
announced capacity : 200 tpd (currently receiving 160 tpd)
in operation since November 1975

Technical Aspects : complexity baling of separately delivered wastepaper
course shredding 6", magnetic separation, fine shredding, (1-1.5") air classification, screening of and aluminium recovery from dense fraction
redundance : none
wear : hammer face turned after 12.000 to
hammers replaced after 24.000 tons
possible incidents : an explosion occured when shredding a propane pressure can. It was followed by an explosion (or fire?) following the product line
telephone wire wrapped around the rotor
alumi separator cooling system froze during wintertime
degree of automation : fair
other particularities :primary and secondary shredder both of the same construction (Americ. Pulverizer, 1000 hP, 48 hammers, 700 revs/min).
0.3 gallon of water is injected through 3 nozzles in each shredder for dust control
conveyors are not enclosed

Thermal efficiency : refuse processing requires 58 kWh/ton
86% is recovered as supplemental fuel, equivalent to 754 kWh/ton

Environmental Aspects: - air : Dust problem is alleviated (reduction of 70%) by water sprays in shredders
- water:none
- soil :no data available
- noise:no data available

Capital Cost : 6.100.000 $

Operationg Cost : detailed data yet to be received

gross operating cost : 20 $ /ton
credit for RDF : 8 $ /ton
other credits : 2 $ /ton (7% F_e, 0.3 Al)
net credits : 10 $ /ton

The credit for RDF is unusually high: RDF is sold at the same price/ Btu as the local Iowa coal.

Possibilities for Resource Recovery : RDF, ferrous, metal, aluminium, baled paper.

2. RDF Firing

Present Status : in operation since 1976.
attained capacity : 35,000 ton of RDF in 1976

Technical aspects: complexity : Atlas storage bin, equiped with 4 drag conveyors, each discharging in a separate pneumatic duct over a rotary valve. Discharge point is equiped with fluffing roll.

plant reliability - availability -

RDF - firing plant was not operating

suspension firing boiler is not used, due to the incomplete burn-out

1 travelling grate was being repaired

1 turbine on the second boiler was being repaired

boiler plant was designed for high ash, high moisture, low Btu Iowa coal. Operating conditions are low: 900 psi pressure, 900°F superheat temp. Fouling occured already in superheater. Manual cleaning required every 2 months instead of every year, using coal only.

additional sootblowers to be installed.

redundance

4 separate pneumatic conveying lines

3 existing boilers

wear

use of 15° segments of abrasion resistant iron in elbows:

Esco Alloy 35 AW, Martensitic white iron with 2.3-2.8%C, 24-28%Cr, 0.4-0.6%V

elbows are replaced by loosening 4 bolts

blades of starvalve are sharpened each week (blades showed 1 cm wear!)

possible incidents

fire in hopper burned all cables. Construction of steam pipe for fire fighting in hopper is contemplated.

degree of automation

operator controls the percentage of fuel value delivered by RDF

other particularities

RDF properties :

caloric value	2600 - 4400 kcal/kg
density	80 - 160 kg/m^3
size	below1 1/2"

Existing Furnaces

kg steam / h	RDF/total % by Btu	Type of Furnace
165.000	20	Suspension firing, no longer used
57,000	50	Travelling grate stokes
43,000	50	Travelling grate stokes

Thermal Efficiency : is lowered by the use of RDF
excess of air increases from 50 to 60%

Environmental Aspects :no data available

Capital cost :no data available

Operating cost :see RDF - preparation plant

Possibilities for Resource Recovery: steam

3. Conclusion

RDF suspension firing leads to incomplete combustion. Travelling grate combustion gives better results. The storage bin seems unsatisfactory and the pneumatic conveying has severe wear problems. Boiler fouling is more important than with coal firing.

F. IMI (Imperial Metal Industries) (10)

In 1972, Imperial Metal Industries decided to investigate the possibilities of firing refuse in one of the five water tube boilers of their Witton Works, Birmingham. They decided to convert a Babcoch & Wilcox CTM water tube boiler with chain grate stoker for firing a mixed feed of refuse and coal (Fig. 35).

At the RDF preparation plant, the incomming refuse is shredded by a 42F Tolemache vertical shaft hammermill to 90% minus 75 mm. Ferrous metals are removed by an in-line overband magnetic separator. The refuse is then stored in a container and transported to the power plant.

Here, the shredded refuse is fed to the furnace by a variable speed conveyor. It is blown in through two burners in the rear wall situated over the coal fire. The refuse is partially burned in suspension, the remainder falling on the grate burns out. The boiler produces 45 tons/h steam at 15,5 bar and 425°C.

The refuse burning part has a capacity of 180 t/day. The thermal output ratio is 50 % refuse/50 % coal.

The unit is operational since April 1976. The conversion of a second boiler os planned for September 1976.

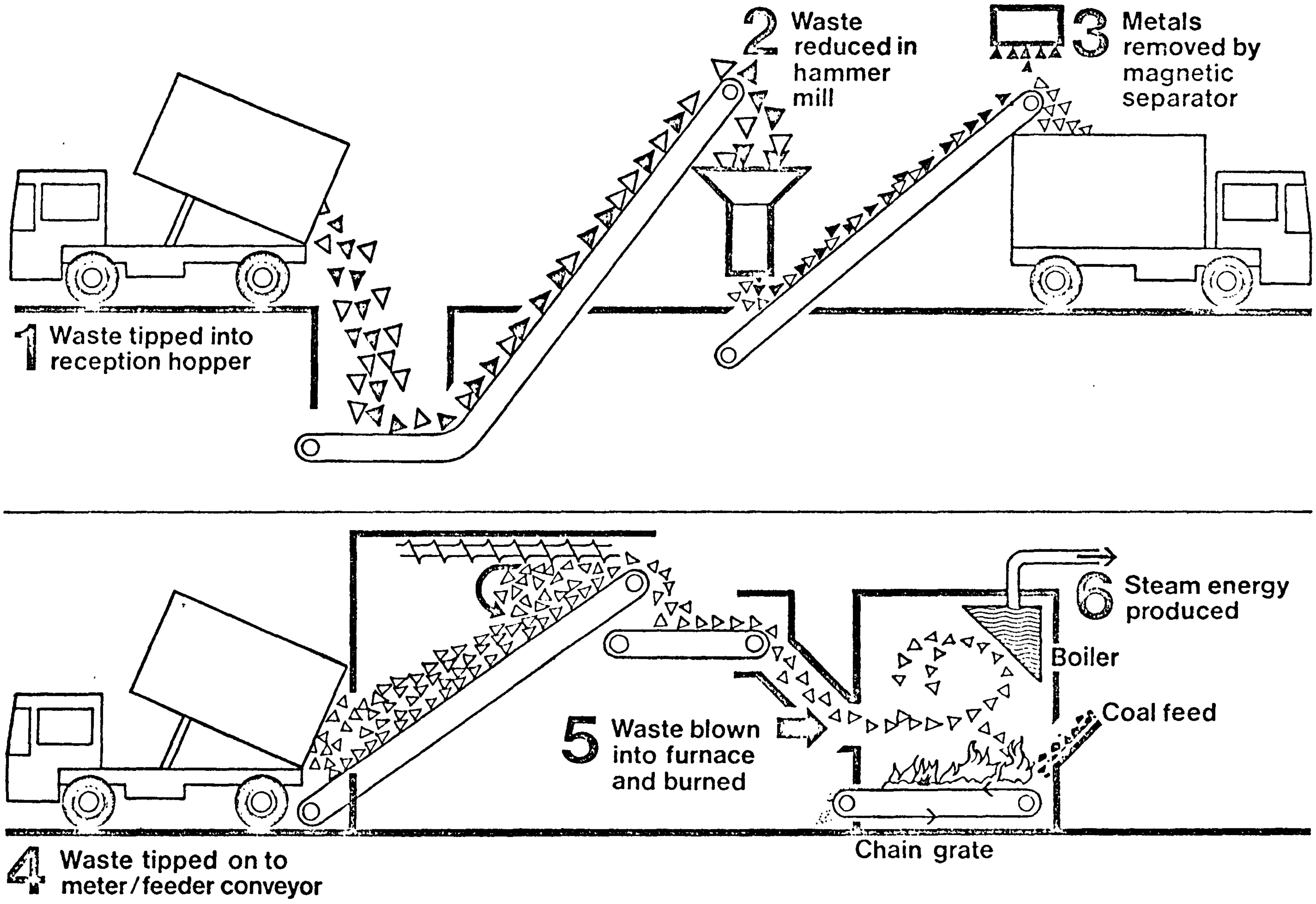


FIG. 35. IMI flow diagram.

V. Fluidizèd bed combustion

Fluidized bed combustion of wastes shows numerous advantages over other combustion systems :

1 The operation is simple and can be fully automated.

2 The volume of flue gas is low, due to the very low excess of air (15-30 %).

3 In situ elimination of pollutants (SO_2, NO_x, HCl,...) is possible by addition of solid additives like limestone or dolomite.

4 The temperature is very stable and unaffected by sudden changes in refuse composition, because of the large heat capacity.

5 NO_x formation is low, because of the low temperature and excess of air.

The fluidized bed has also some disadvantages.

1 The refuse has to be pretreated : shredding and separation of inorganics is usually required to ensure a proper functioning of the combustor.

2 The gases are usually highly laden with dust.

3 Combustion air should be delivered at a much higher over-pressure than in a conventional incinerator.

The combustion of municipal solid waste is currently studied in Japan and in the United States.

Ishikawagima-Harima Heavy Industries have developed a fluidized bed combustor for pulverized municipal refuse.(fig. 36). The distribution for the fluidizing gas is constituted by several rows of perforated tubes. Under the fluidized bed a moving bed is formed by withdrawal of sand at the bottom of the combustor. The sand is recirculated after screening off the cinders.

A first commercial plant with a capacity of 1.5 t/h was built at Matsudo City (Chiba Prefecture). The bed area is 2.5m2. The feed material is pretreated by size reduction and magnetic separation (11).

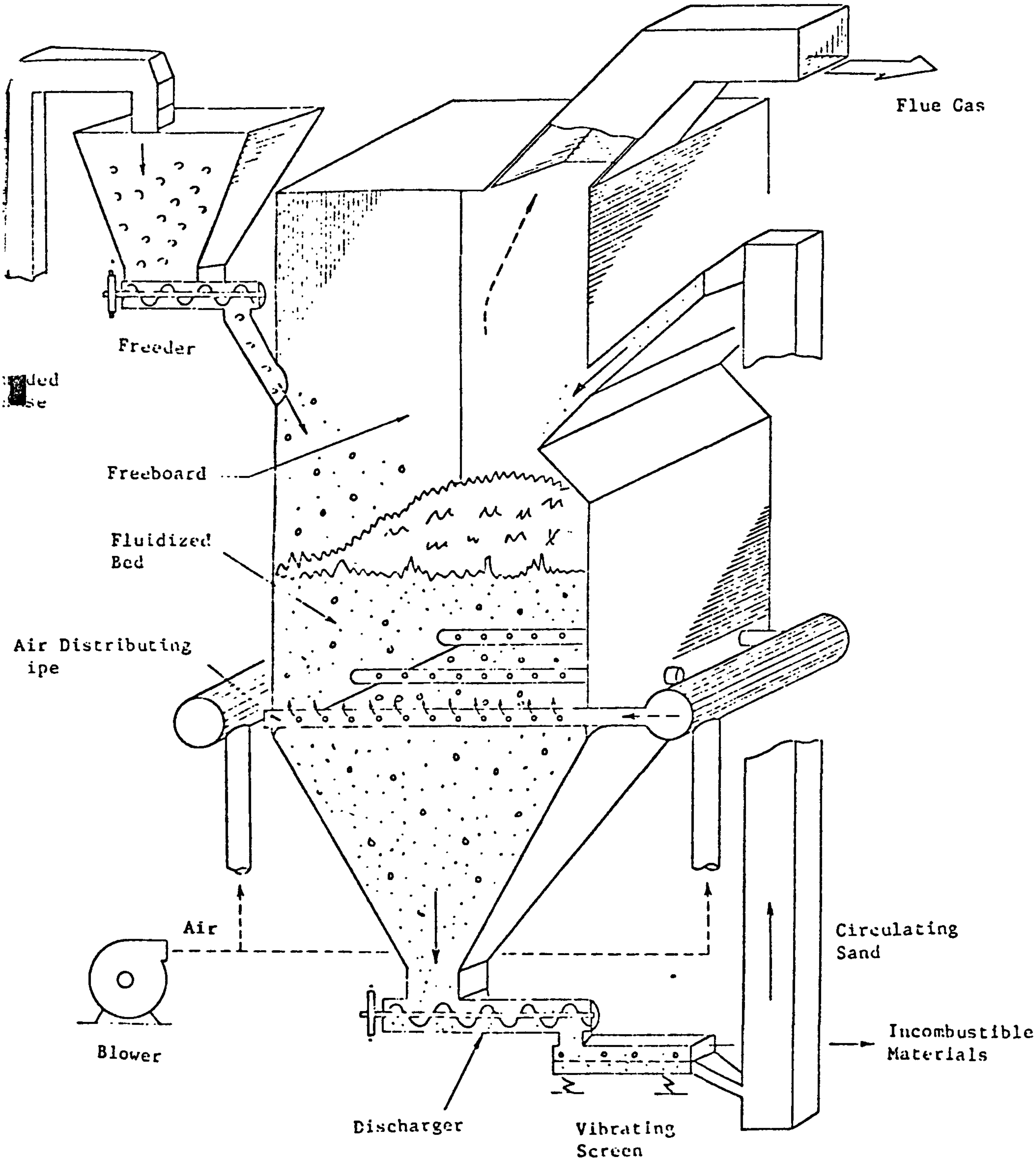


FIG. 36 : IMI Fluidized bed combustion.

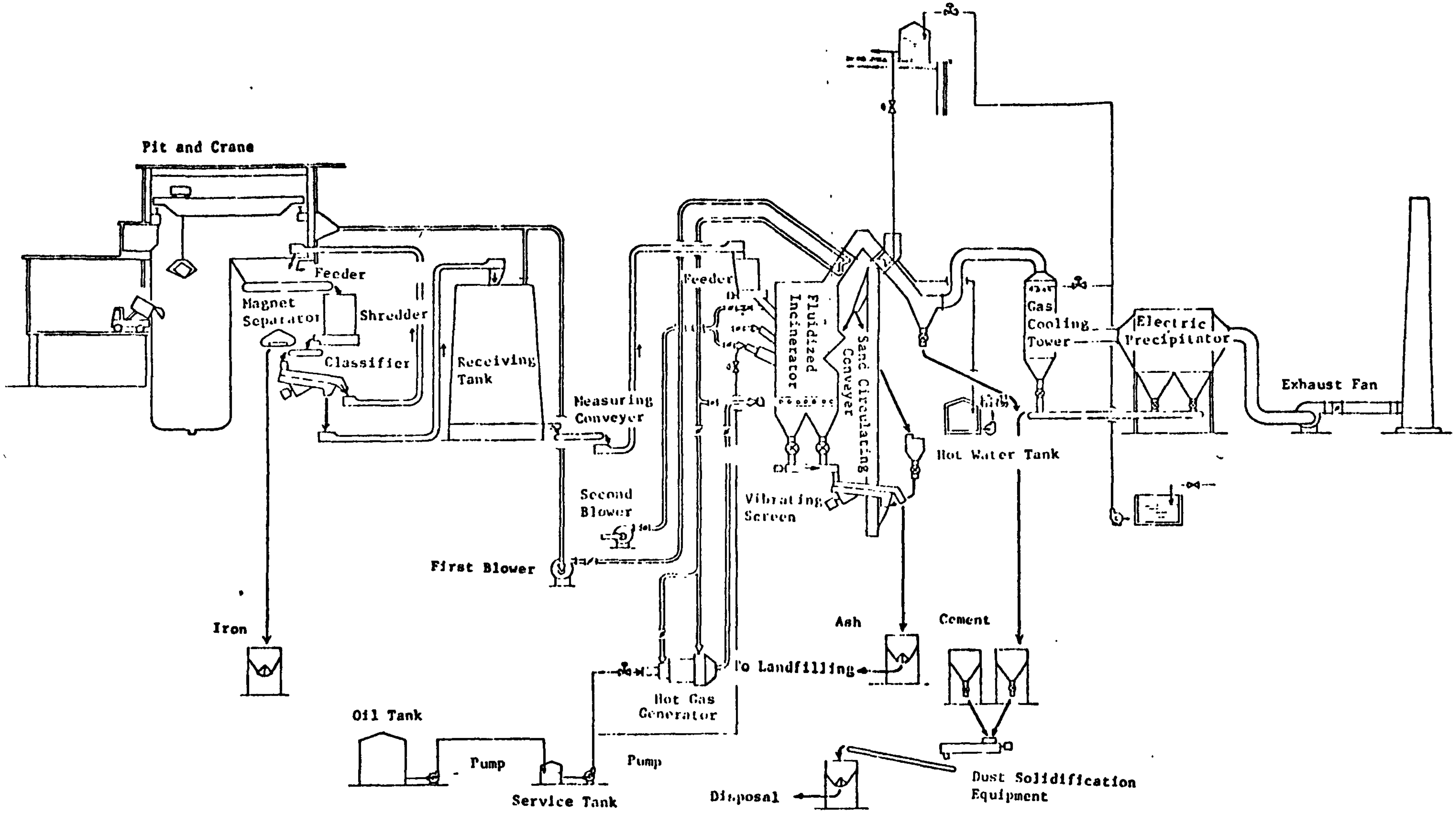


FIG. 37 : IMI Fluidized bed combustion flow diagram.

In the United States, the Combustion Power Company Inc. with funds of the Environmental Protection Agency, studied the combustion of shredded, air classified waste in a pressurized fluidized bed. The hot gases are expanded in a gas turbine coupled to a generator to produce electricity.(12,13).

A 70 t/d pilot plant has been built in Menlo Park, California (fig. 38,39).

The raw refuse is shredded in two shredders to a maximum size of 2" and classified in a zig-zag air classifier. The light fraction (83%) contains mainly paper and wood. The heavy fraction mainly consists of metals, glass and ash. The light fraction is conveyed pneumatically into the reactor via two rotary airlock feeders. These 30" rotors discharge into two 6" feed pipes leading to the fluidized bed. The combustion is a 6,7m high x 2,9m diameter cylindral vessel (fig. 40) operating at 100 psi and 870°C.

The off-gasses are cleaned in three stage cyclone separators and expended in a Ruston Hornsby TA 1500 turbine/generator.

Due to deposits of aluminium oxide on the stator blades, experiments had to be discontinued in 1973. A granular filter was developed to improve the separation of particulates prior to entering the turbine (fig. 41). The difficulties with aluminium deposits also led to the development of an aluminium separation system (AL-MAG).

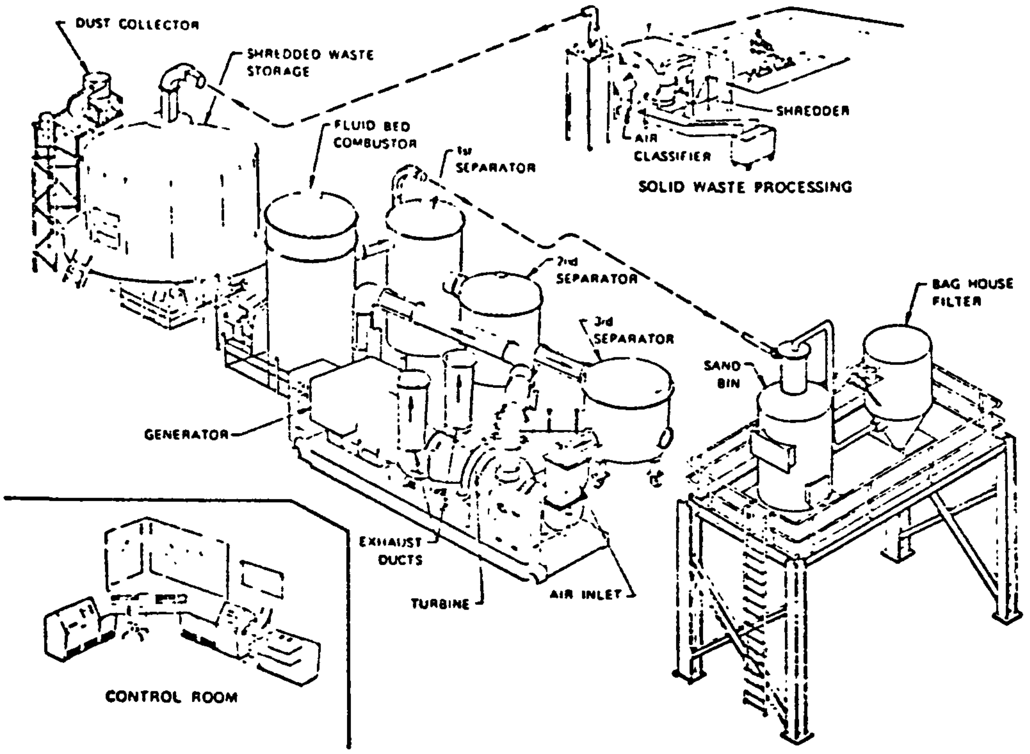


FIG. 38 : CPU-400 PILOT PLANT

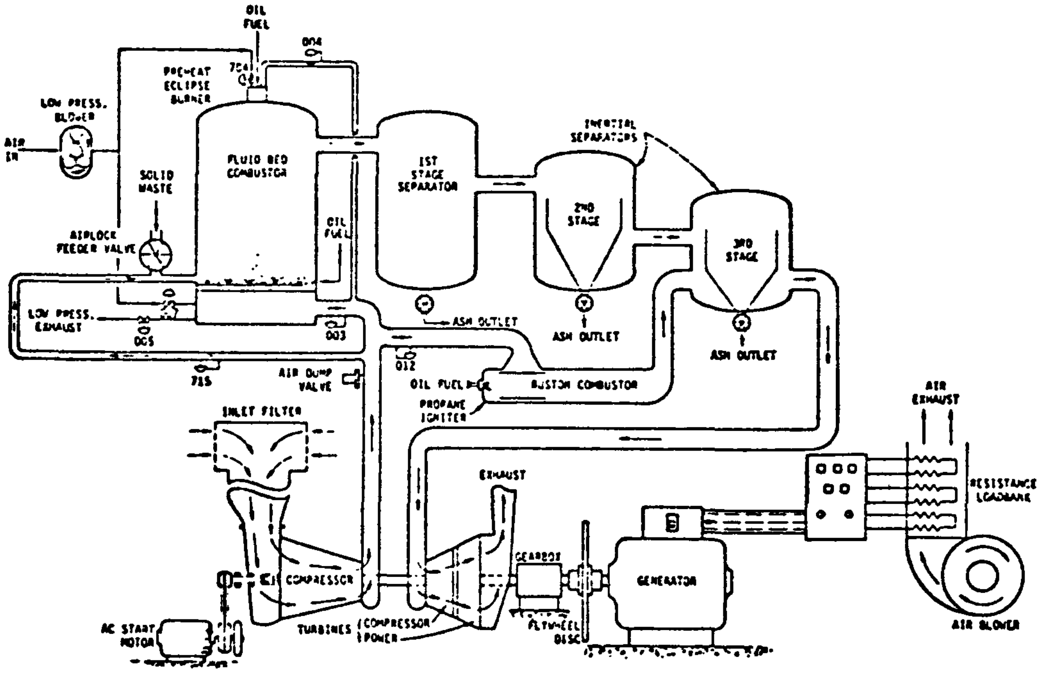


FIG.39. : CPU-400 SYSTEM SCHEMATIC

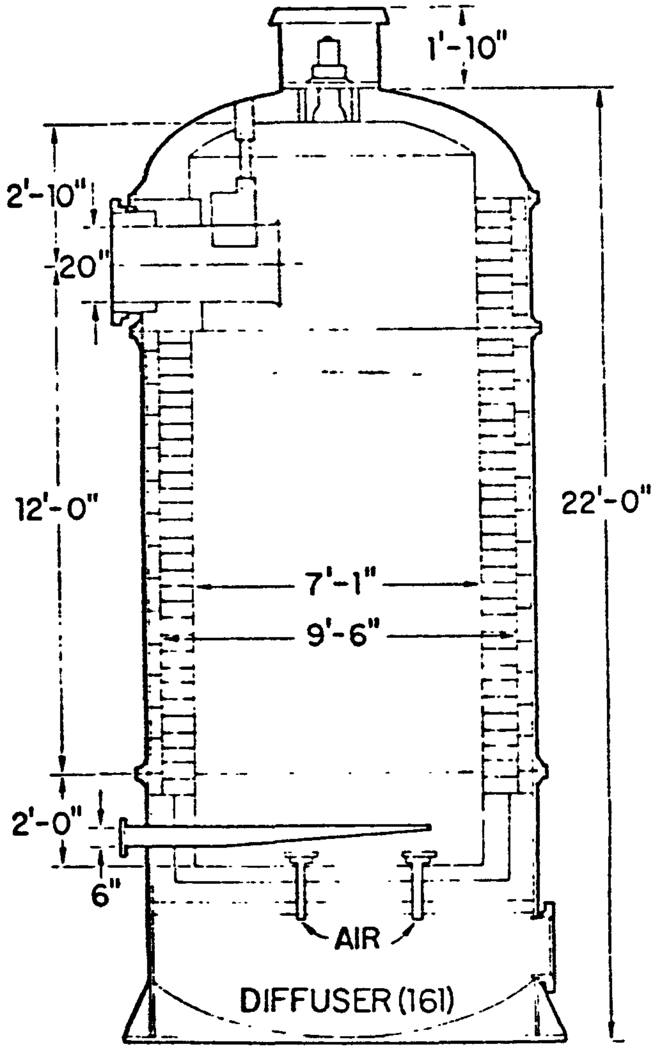


FIG. 40 : FLUIDIZED BED COMBUSTOR

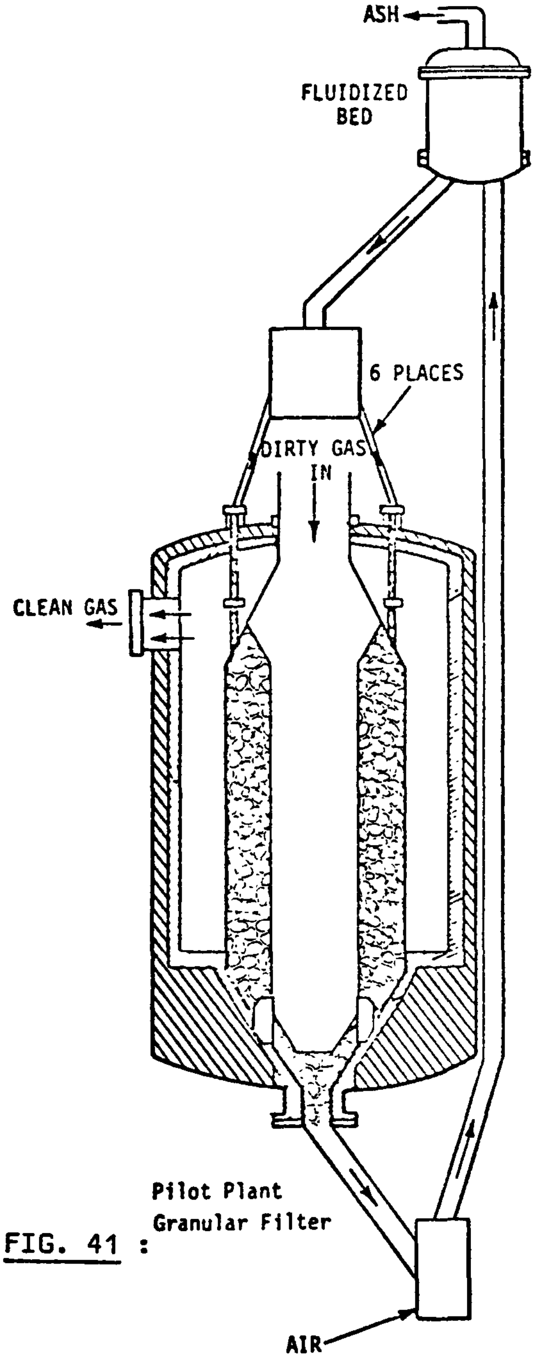


FIG. 41 : Pilot Plant Granular Filter

VI.Conclusions

1. The production of RDF from raw municipal refuse is one of the most promising lines of development in refuse treatment. Among 21 American Resource Recovery Projects, RDF preparation systems number 14, if one includes 2 Eco Fuel and 3 wet pulping ventures! Moreover RDF preparation plants are relatively inexpensive when compared to municipal incinerators.

2. In the U.S.A. the production of RDF generally proceeds by : coarse shredding, magnetic metal removal, fine shredding, air classification. The sequence of these operations can be modified, depending on local situation and on the type of resources recovered.

3. Most operating problems can be overcome by proper plant engineering and equipment specification and selection.
The most relevant operating problems are :

in the RDF preparation plant
- hammer wear in the hammermills
- conveyor maintenance
- dust control
- safety problems, i.e. explosion danger in the hammermill, danger of fire and/or explosion in the processing plant

in the RDF firing unit
- RDF - storage
- wear in the pneumatic conveying system (rotary valves, elbows)
- fouling of boiler tubes
- incomplete burn-out

4. Most hammermills in the U.S.A. operate on a brute force principle. Wear is highly variable from one plant to another, depending on the desired degree of size reduction, pulveriser construction, hammer configuration, metal of construction,etc...

5. Conveyor operation and maintenance normally should not be a problem. Some conveyors have been ill specified and installed. In combination with a dusty atmosphere and dirty working conditions this contributes to wear and destruction.

6. Dust control seems to be a problem almost everywhere. Proper enclosing of moving equipment, aspiring of air at the locations where dust is generated and judicious installation of spray nozzles can alleviate this problem, which is basically one of design.

7. Shredders should be provided with adequate means of directing explosion waves into an innocuous direction. There is a danger of subsequent dust explosions or fire when appropriate measures are not taken.

8. Storage of RDF has an extremely poor record. Solidification and bridging is a problem in almost every plant operating at present.

9. Wear is extremely important in the rotary star valves, feeding the pneumatic conveyor lines. Wear is very important at all elbows. Replaceable elbows are being used, either constructed in special cast iron, or lined internally with fused basalt.

10. Fouling of boiler tubes seems to be more important than expected. At Ames we asked a plant operator whether RDF-firing went all right. His answer was "Firing is all right, but cleaning the boiler isn't."

11. Burn-out often seems to be incomplete in RDF suspension firing. It seems that firing over a mechanical grate has a much better record.

12. In view of the handling difficulties of conventional RDF, it seems worthwhile to develop fuels with more desirable properties, e.g. Eco-Fuel II, briquettes, etc...

13. An assesment of Eco-Fuel II is difficult, since all available information was published by the developer.

GENERAL LITERATURE

1. Final reports on our visits to U.S.A. plants (in preparation)
2. Proceedings of the 1976 National Waste Processing Conference (formerly National Incinerator Conference), Boston, Massachusetts, May 23-26,1976 (NIC)
3. Conversion of Refuse to Energy, Montreux, Switserland, November 1975. (CRE)

REFERENCES

1. H.G. RIGO et.al.
   Preparation and use of refuse derived fuels in industrial scale applications, CRE 1975
2. D. BENDERSKY et.al.
   St. Louis refuse fuel demonstration plant, Technical and enonomic performance, CRE 1975 , p. 190
3. MULLEN
   NIC, 1974, p. 191
4. J.D. KILGROE et.al.
   Emissions and energy conversion from refuse processing and mixed fuel boiler firing, CRE 1975
5. H.D. FUNK & A.D. CHANTLAND
   Solid Waste for Power Generation fuel in a small city, CRE, 1975, p.268.
6. D.L. KLUMB
   Union Electric company's solid waste utilization system, CRE 1975, p.488.
7. D.G. ARELLA
   Recovering Resources from Solid Waste using Wet-Processing EPA Publication SW-47d., 1974
8. R.M. BENINGSON et.al.
   Production of ECO-FUEL II from Municipal Solid Waste, CRE 1975, p.14.
9. J.D. PARKHURST
   Report on Status of Technology in Recovery of Resources from Solid Wastes , County Sanitation Districts of L.A., 1976.

10. J. MARSHALL & K. HARVEY
The use of Refuse as a Supplemental Fuel
Public Works Congress, 1976, p. Y(2)1.

11. M. HIRAOKA
Proc. 3rd Japan-US. Conference on Solid Waste Management, May 1976, Tokyo, Japan.

12. R.A. CHAPMAN et al.
CPU-400 Solid-Waste-Fired Gas Turbine Development.
Proceedings 1974 National Inc. Conf., p. 347.

13. R.A. CHAPMAN
Development of a Solid-Waste-Fired Gas Turbine System
CRE, 1975, p. 343.

PART IV. - GENERAL CONCLUSIONS

I. THERMAL PROCESSING

The thermal processing of municipal refuse can be subdivided in :

- incineration
- gasification
- pyrolysis
- preparation of Refuse-Derived-Fuel

Incineration is the oldest and, at present, the most reliable of these methods. The main disadvantage of conventional refuse incineration is the high investment and operating cost.

Gasification of refuse is a new application of old gasifier technology. When air is used as a gasifying medium a lean gas is produced, which can neither be stored, nor transported over a long distance. Oils and tars are only formed in minor quantities. When the moisture is condensed from the product gases, a highly polluted and difficult to treat wastewater is formed. Slagging operation yields a compact, sterile granulate, which can probably be re-used as a substitute for sand or gravel.

It has been claimed that gasifiers are much simpler in construction than conventional mechanical grate incinerators. Strictly speaking this is true, but until now no gasifier has proven its reliability in continuous, every-day operation. Channeling problems in shaft furnaces and wear problems in rotary kilns are not yet under control.

Gasification with oxygen has the merit of producing a smaller quantity of a gas, with much better properties, either as a fuel or as a chemical raw material. The added complexity and operating cost make such a process difficult to justify except in special cases, e.g. near existing fertilizer, methanol, or methanation plant.

The rate of pyrolysis of refuse is generally controlled by heat transfer. Externally heated pyrolysis reactors have many disadvantages and are not suitable for treating municipal refuse. At most they may prove useful in special cases e.g. when valuable and well defined pyrolysis products can be recovered in high yield. Externally heated pyrolysis chambers with a fixed or a slowly moving bed of refuse have a very low throughput per unit volume. A typical example is the Destrugas reactor. In a particular Warren Springs reactor heat transfer is improved by cross-flow circulation of pyrolysis gas. With regard to the heating of feedstock, however, only the fluidized bed and the entrained bed pyrolysis reactors are really efficient.

Some pyrolysis processes require a very extensive preparation of the feedstock, e.g. the Occidental Petroleum process. Although such processes have some merits in recovering raw materials from refuse it is doubtful that such plants, involving complex pretreatment of refuse as a prerequisite to thermal conversion, are a good solution to the municipal refuse disposal problem.

The preparation of Refuse Derived Fuel is an attractive alternative to the use of raw refuse as a supplemental fuel. The processing cost is obviously much higher, but this is more than compensated in case an existing power plant can replace a municipal incinerator yet to be constructed. In a different approach, when no power plant is available for burning R.D.F., special furnaces can be developed for firing RDF, thus extending the sales potential of RDF beyond the limited number of coal firing utilities. It is a debatable point, however, whether small RDF burning furnaces will be capable of meeting current Air Pollution Standards without recurring to expensive flue gas cleaning plant.

Moreover, the production of RDF still has to deal with a number of design and engineering problems. It is to be feared that many plants perform unsatisfactorily, due to poor plant design and ill specification and selection of shredders, air classifiers and conveyors.

In the long term the firing of RDF will lead to boiler fouling and corrosion. Hopefully, the RDF-firing utilities will make a good use of the practical experience, gained on refuse boilers.

II. PROCESSING OF THE RESIDUE (*)

According to a report, prepared by Mr Gony and Mr Clin (B.R.G.M., Orléans) sufficient quantities of incinerator residue are available at present to warrant an in-depth investigation of the separation of this residue. Relevant quantities of ferrous metal, non ferrous metal and re-usable slag can thus be recovered.

Similarly, separation can be attempted of the residue obtained in gasification or pyrolysis processes. It is believed that separation of pure fractions will be easy in some of these processes; due to the low processing temperatures and to the reducing conditions little oxidation of metal takes place. Moreover, at low temperatures the rate of diffusion of contaminants, e.g. tin in steel, is very low.

High temperature, slagging operation, in the other hand, yields a residue which no longer can be sorted by mechanical or physical methods.

(*) This topic is discussed also in a separate paper prepared by Mr Gony and Mr Clin (B.R.G.M.)

PART V. - RECOMMENDATIONS FOR FURTHER RESEARCH AT E.E.C.-LEVEL

I. INTRODUCTION

Basically, waste disposal is an applied science. Hence resource recovery from refuse is more aided by proper plant design and engineering, by suitable equipment specification and selection, and by promoting an exchange of ideas and practical information than by fundamental research. A first recommendation for action at the E.E.C.-level would be to promote regular contacts between specialists in thermal processing from the various E.E.C.-countries. Although such contacts are already frequent at the national level, international contacts on an E.E.C.-basis have been virtually non-existing. More in particular, much pertinent information never left the territory of one particular language, let it be English, French, German or Italian.

At this moment numerous new technologies are being elaborated and implemented. Inevitably, the initial phases of these projects are accompanied by many design and procurement errors, which should be avoided in later designs. An organized exchange of information would be extremely valuable in this respect.

II. THERMAL TREATMENT TECHNIQUES

Incineration

Incineration is an old and well established technique, which leaves but limited room for further development. Still some areas for further development have been identified :

- firing of pulverised refuse over a mechanical grate (see under RDF)
- combustion of suitable prepared refuse in a fluidized bed furnace or in a cyclonic furnace.
- solving the corrosion problems in wet scrubbers and in subsequent plant (exhaust fan, chimney).

- dry removal of HCl from the flue gases
- collection of minute heavy metal particles using wet scrubbers
- elimination of heavy metals from scrubbers wastewaters.

Gasification

At present, the construction of a large E.E.C. demonstration plant does not seem to be justified. In the near future more operating data will be available from the Paul Wurth-plant near Luxemburg, the Purox plant of Charleston and the Landgard plant in Baltimore.

Future E.E.C.-work should be limited to pilot plant or bench scale research work, since this type of work generates more data at less cost. Moreover, the establishment of E.E.C. smal scale demonstration plants would serve many useful purposes : it could be operated in various modes (incineration, gasification, pyrolysis) and for treating various materials (pulverized refuse, RDF, sludge, composting residual, hospital wastes,...)

Different types of reactor can be studied : the fixed bed or shaft gasifier, the rotary kiln, the fluidized bed and the diluted phase gasifier. In view of the present experience it seems, however, that small scale experiments in fixed bed and rotary kiln gasifiers cannot be extrapolated to large scale operation.

Fluidized bed reactors, on the other hand, may be implemented at small scale, yet, deliver valuable information regarding the products obtainable during large scale operation. Moreover, fluidized bed units are being studied in at least 4 E.E.C.-countries, and can serve as a means of promoting the exchange of technical experience and expertise between E.E.C.-countries.

Pyrolysis

The design and construction of a large scale pyrolysis plant is not justified at present. With regard to the rate determining step, i.e. heat transfer, only 3 types of equipment deserve consideration :

- flash pyrolysis
- fluidised bed pyrolysis
- pyrolysis in a fixed bed, with recirculation of pyrolysis gases through the bed.

These studies can be conducted at bench scale or pilot scale (throughput 1-300 kg/h) and be aimed at the determination of optimum conditions for the production of specific products, e.g. heating oils (low temperature, short residence time), rich gases (high temperature,very short residence time), aromatic products (high temperature, somewhat longer residence time) or specific chemicals.

Later experiments at pilot scale will generate the required quantities of liquid and solid pyrolysis products to allow for their commercial evaluation. Furthermore, a detailed comparison between pilot scale results with the results obtained at bench scale is most useful in view of eventually scaling up the plant to a commercial size.

Pyrolysis oils, obtained from various products and in different operating conditions, will be thoroughly characterized and analysed. They would eventually be supplied to different companies, to assess their marketability in noble applications.

Pyrolysis char can be assessed as an adsorbent, after various activation procedures. Its combustion can be studied in a suitable type of combustor, e.g. a steam raising fluidized bed combustor.

RDF - preparation and firing

It is recommended that a practical extensive research programme be launched in the preparation of a fuel from the organic fraction from refuse. However, the detailed programme of such a research is outside the scope of this study, the problem of refuse sorting being studied by another team.

Moreover, many of the problems associated with RDF-preparation are technological in nature and can better be left to competent equipment manufacturers. This is the case e.g. for shredding, air classifying, magnetic separation and wet pulping equipment, and for storage bins and refuse conveyors.

Likewise, the problems of safety and dust control are engineering problems, to be solved by contractors.

With regard to RDF-firing we consider that 2 types of furnaces deserve further testing:

- suspension firing of pulverised refuse over a travelling grate, as in the I.M.I. system and at East Hamilton, Ontario. The required plant can be installed in an existing travelling grate boiler.
- suspension firing of different waste materials in a cyclonic furnace. Determination of the combustion behaviour, the firing capacity and the degree of bunr-out in a pilot scale combustor (capacity range 100-2.000 kg/h).

II. RESOURCE RECOVERY FROM THE RESIDUE OF THERMAL PROCESSING(x)

From the study conducted by B.R.G.M. it follows that sufficient quantities of incinerator residue are available in most E.E.C. countries to warrant further R & D-work on the recovery of materials from this residue. Previous work by B.R.G.M. (1) showed that incinerator residue can be separated in various recoverable materials.

The most appropriate topics for further study in the field of incinerator residue are identified as follows :

- evaluation of the technical efficiency and economic relevance of the various dry or wet separation methods, in view of both global and individual utilization perspectives.
- further study of the utilization potential of ferrous scrap contamined by tin and copper. This study involves either the development of appropriate refining methods or the search for specific applications of the contamined products.
- further study of the possibilities of using slag and glass in brick manufacturing, concrete formulations and road underlay or ambankment, with actual tests conducted at an industrial level.
- assessment of the beneficial environmental factors associated with the utilization of the incinerator residue and with the recovery of resources from this residue.

It is evident that this study can be extended, to include the residue of new methods of thermal treatment, such as pyrolysis, gasification or RDF-firing in utility boilers should such residues become available in suitable quantities. It is conceivable that the residue of pyrolysis or gasification be in a form, which makes the recovery of resources easier technically and more attractive economically. Indeed a thermal treatment involving low temperatures and starved air will limit or avoid altogether the oxidation of valuable metals and the diffusion of harmful contaminants into these metals.

(x) Based on a Document prepared by Mr Gony and Mr Clin (B.R.G.M., Orléans, France) and on discussions at Orléans on November 17, 1977.

COMMISSION OF THE EUROPEAN COMMUNITIES
(Directorate General XII - Research, Science, Education)

ASSESSMENT OF CURRENT TECHNOLOGY OF THERMAL PROCESSES FOR WASTE DISPOSAL, WITH PARTICULAR EMPHASIS ON RESOURCE RECOVERY

Report by

J.N. Gony and P. Renoux

BUREAU DE RECHERCHES
GEOLOGIQUES ET MINIERES
Service géologique national
Département Minéralurgie
B.P. 60 09
45018-Orléans Cedex
(France)

December 1977

CONTENTS

ABSTRACT

This report describes the work carried out by B.R.G.M., acting as representative of the co-pilot country -France- in the CREST study "Technology of incineration of consumer wastes".

With the agreement of the delegate of the pilot country -Belgium- and the "R & D on consumer waste" party, the two following topics have been investigated :

- estimation of incineration residues availability within the EEC countries,
- beneficiation possibilities of incineration wastes.

Some major results stand out :

- there are :
  - . over 80 incinerators, the unit capacity of which is over 100 000 t/year, with the following estimated quantities of recoverable products : 1 000 000 t of ferrous scraps, 45 000 t of non-ferrous metals, 1 500 000 t of glass, 2 000 000 t of slag ;
  - . about 9 incinerators, the unit capacity of which is over 400 000 t/year, with the following estimated quantities of recoverable products : 200 000 t of ferrous scraps, 12 000 t of non-ferrous metals, 500 000 t of glass, 600 000 t of slag ;

- first industrial projects for incineration wastes beneficiation could concern France, Germany, the Netherlands, United Kingdom, where local higher productions of clinker are available,

- economics of separation processes require a better regulation of the metal market, the development of mineral fraction utilization, and also taking into account of all external factors referring to ressources wastage and environmental pollution.

A list of recommendations relating to general and specific actions to promote within the EEC is joined.

This report was first submitted under the reference number 77 SGN 612 MIN from the B.R.G.M.

PART I

ESTIMATION OF INCINERATION RESIDUES AVAILABILITY WITHIN THE COMMON MARKET COUNTRIES

1. INTRODUCTION

The purpose of this part of the study is to assess the possibilities of supplying secondary materials from incineration refuses within the Common Market ;

- the incinerators selected have an annual input of over 100 000 tonnes ;
- the quantities of materials to be recovered are estimated, either indirectly, from raw urban waste analysis in the various countries, or directly, from incineration residues composition, when available.

However, a survey of incinerators and the average compositions of urban waste obtained from the literature turned out often to be insufficient and out-of-date : a list of questions was therefore sent to the various Common Market countries, to the ministries, to specialized firms and incinerator managers, in order to check up some results.

The following points are therefore presented successively :

- the "incinerators" survey : questionnaire, list of bodies consulted, replies obtained ;
- the summary of the results, with regard to incineration plants in the Common Market, to the composition of the waste materials treated, to the amounts of materials which make up their residues.

2. PRESENTATION OF THE INQUIRY "INCINERATORS"

2.1. INTRODUCTION LETTER AND MAILING LIST.

BRGM

BUREAU DE RECHERCHES GÉOLOGIQUES ET MINIÈRES

ÉTABLISSEMENT PUBLIC A CARACTERE INDUSTRIEL ET COMMERCIAL

Service Géologique National

B.P. 6009 – 45018 Orléans Cédex
Tél.: (38) ~~[illegible]~~ 63.80.01
Télex 780258 BURGEOL

Orléans, le

Dear Sirs,

The French Bureau de Recherches Géologiques et Minières has been commissionned, by the Scientific and Technical Research Commitee from the European Economic Community, to carry out a survey on the utilization of incinerated waste residues.

In order to carry out this assignment, we would appreciate if you could complete the enclosed questionnaire concerning the main achievement of your country in this field, and return it before next June 30th.

Thanking you in advance for your kind help.

Yours sincerely,

Siège : 6-8, rue Chasseloup-Laubat – 75015 Paris – R.C. 582 056 149 B Paris – Tél.: 783.94.00 –
Adresse telég. Burgéolog Paris – Telex 270844 F Burgéol.

ORGANIZATIONS CONTACTED

BELGIUM

- M. Nicolas HILGERS
  Ministère de la Santé Publique
  Cabinet du Ministre
  Centre Administratif de l'Etat
  Esplanade 7 - BRUXELLES

- M. I. VAN VAERENBERGH
  Services de programmation de la politique scientifique
  Rue de la Science, 8
  1040 BRUXELLES

- Usine de Traitement Industriel des résidus urbains de la ville de Bruxelles
  BRUXELLES-SCHAERBECK
  BELGIQUE

- Usine de Traitement Industriel des résidus urbains de la ville de Charleroi
  CHARLEROI
  BELGIQUE

DENMARK

- Dr A.S. WELINDER
  Miljostyrelsen
  KAMPMANNSGADEL
  KOPENHAVEN

IRELAND

- Dr E. MAC MAHON
  Institute for Industrial Research and Standards
  Balhymum Rd
  DUBLIN 9

FEDERAL REPUBLIC OF GERMANY

- Dr WOLBECK
  Bundesministerium des Innern
  D-53 BONN
  RHEINDORFERSTR. 198

- Müllverbrennungs-Anlage Berlin
  BERLIN
  BUNDESREPUBLIK-DEUTSCHLAND

- Verband Kommunaler Städtereinigungsbetriebe
  Umweltbundesamt. Abteilung Abfallwirtschaft
  Bismarkplatz, 1
  1000 - BERLIN 33

- Müllverbrennungs-Anlage Bonn-Bad Godesberg
  BAD GODESBERG
  B.R.D.

- Müllverbrennungs-Anlage Hagen
  HAGEN
  B.R.D.

- Müllverbrennungs Anlage Hamburg II
  HAMBURG-STELLINGER MOOR
  B.R.D.

- Müllverbrennungs Anlage Bremen
  BREMEN
  B.R.D.

- Müllverbrennungs Anlage Düsseldorf
  DUSSELDORF
  B.R.D.

ITALY

- M. Eugenio PANETTA
  Ministerio dell'Interno
  Via Valdagno, 14
  ROMA - ITALIA

- Impianto d'incenerimento dei rifiuti solidi urbani di Milano
  Via Zama
  MILANO - ITALIA

- Impianto d'incenerimento dei rifiuti solidi urbani di Firenze
  FIRENZE - ITALIA

LUXEMBOURG

- Usine de traitement industriel des résidus urbains de la ville de Luxembourg
  GRAND DUCHE DU LUXEMBOURG
  LUXEMBOURG

- M. Paul WEBER
  Ministère de la santé publique et de l'environnement
  Ia, rue A. Lumière
  LUXEMBOURG

THE NETHERLANDS

- M. Hans ERASMUS
  Ministerie van Volksgezondheid en Milieuhygiëne
  Dr Reijersstraat 12
  LEIDSCHENDAM
  NEDERLANDS

- Stichting Verwijdering Afvalstoffen
  Amersfoort
  UTRECHTSEWEG 223
  NEDERLANDS

- Rotterdam refuse incineration plant
  (Afvals verwerking rijmond)
  BOTLEK - ROTTERDAM
  NEDERLANDS

UNITED KINGDOM

- Edmonton refuse incineration plant (G.L.C.)
  EDMONTON
  GREAT BRITAIN

- Coventry refuse incineration plant
  COVENTRY
  GREAT BRITAIN

- Nottingham refuse incineration plant
  NOTTINGHAM
  GREAT BRITAIN

- Birmingham refuse incineration plant
  Birmingham
  GREAT BRITAIN

- Dr R. BERRY
  Director of National Anti-waste Programme
  Department of Industry
  Millbank Tower
  LONDON SW I
  GREAT BRITAIN

2.2. LIST OF QUESTIONS.

1. Information on the various processes used for municipal waste disposal (incineration, composting...) used in your country with their respective total mass imput.

2. Average composition of domestic wastes and seasonal or yearly variations the year.

3. Characteristics of incinerators having an annual capacity of more 100 000 tons.

Town	Started in year	Type and number of furnaces	Nominal capacity (for each furnace) t/h	Annual production					
				Power generation	Steam			Clinker*	Fly ash*
					Product.	t°	Pressure		
If you have no breakdown of incineration characterisation please write the information on a national basis									

4. Average composition of incineration residues (clinkers and fly ash).

5. Statement of recovery.

		Town	Quantity t/y	Sale value /t	Direct recovery cost/t	Amortization cost (t)
Iron scrap recovery						
Other types of utilisation						
Without scrap removal	After crushing and sizing					
	Without crushing and sizing					
With scrap removal	After crushing and sizing					
	Without crushing and sizing					

6. Average cost of transportation and landfilling of the residues.

7. Papers about the same topic you could join to this questionnaire or mention.

8. Eventual remarks.

2.3. GENERAL RESULTS.

2.3.1. Belgium

The results come, either from the Services for Scientific information, or from the Ministry of Public Health.

Details on the various methods of elimination.

The figures available concern the Flemish part of the country (Cf table n°1).

	IN OPERATION		UNDER CONSTRUCTION		THOSE WITH COMPLETED PLANS		TOTAL	
	n°	INHABITANTS CONCERNED	n°	INHABITANTS CONCERNED	n°	INHABITANTS CONCERNED	n°	INHABITANTS CONCERNED
INCINERATING PLANT	8	± 484 000	9	± 984 000	1	± 142 000	18	± 1 610 000 (29,0%)
PULVERIZING PLANT	4	± 672 000	3	± 374 000	1	± 200 000	8	± 1 246 000 (22,4%)
COMPOSTING PLANT	1	± 160 000	1	± 320 000	2	± —	4	± 480 000 (8,7%)
TOTAL	13	± 1 316 000 (23,7%)	13	± 1 678 000 (30,2%)	4	± 342 000 (6,2%)	30	± 3 336 000 (60,1%)

Table 1. : Distribution of the elimination methods used in Flemish Belgium

Average composition of urban waste.

An information file of the Credit Communal de Belgique gives the following composition :

		Average*
paper and cardboard	30 - 40 %	20.9
food waste	12 - 18 %	10.6
ashes, earth, ceramics	20 - 30 %	
glass	4 - 9 %	7.5
plastics	2 - 7 %	4.1
wood, textiles	6 - 10 %	
miscellaneous	3 - 5 %	
metals	4 - 6 %	5.0

---

* Partial results for the Luxembourg province obtained in 1972/1973.

List of incinerating plants (table n°12

Only one incinerator with a capacity of over 100 000 tonnes per annum is given, that of Schaerbeek (Brussels 2), which started operation in May 1957 : fitted with two grate furnaces of 8 tonnes per hour capacity each, it produces 330 to 350 KWh and 2 tonnes of steam/t of input.

Data on the elimination of the incinerator residues.

The residues of scrap iron appears locally at ROULERS (586 tonnes per annum sold at 0.40 F.B. per kg, including transport).

Otherwise, the average cost of transport and dumping of the residues varies from 400 F.B./t to 550 F.B./t, depending on the population density and the size of the area covered by the incineration plant.

2.3.2. Denmark.

No data yet received from the contacted organization.

2.3.3. Federal Republic of Germany.

The most important information was provided by the V.G.B. (Technische Vereinigung der GrosskraftwerkBertreib), the Stagen Municipality, the cleansing Departments of the towns of Berlin and Bremen.

Information on the various methods of handling used.

- Compost production : 16 plants running (simple compost) - 8 of which are connected to incineration plants.
- Shredding : 26 plants working.
- Incineration plants : 39 plants in use, divided up as shown in table 2.

Average composition of household waste collected in main towns.

Cf table n° 3.

Composition of incineration residues.

The incineration residues make up 34 % of the feed and consist of 4 % - scrap iron
3 % - fly ash
27 % - clinkers.

An example of the chemical composition of fly ash is given in table 25.

TOWN	DATE OF FIRST OPERATION	TYPE AND NUMBER OF FURNACES	NOMINAL CAPACITY t/h	ANNUAL TOTAL HANDLED (X 1000 t)	POPULATION SUPPLIED (X 1000)	STEAM		USE OF POWER	IRON-REMOVING	USE MADE OF CLINKERS
						PRESSURE (at)	TEMPERA. °C			
Berlin	1967	Borsig 4 4	12,5 16	400	1 100	73	470	Electric	yes	yes compaction
Bonn	1966	Koppers-Witna 2	10	33,5	80	10	250	Industry	no	ballast
Bremen	1969	Dürr 3	15	180	600	21	215	Heating	yes	yes
Darmstadt	1967/73	Von Roll 2 1	10 12	120	310	40	450	Heating	no	no
Düsseldorf	1965/72	Dürr 4 1	10 12,5	330	834	90-100	500	Electric	yes	yes
Essen Karnap	1960	Babcock, Dürr 5	20	355	1 400	100	500	Heating	yes	no
Frankfurt/main	1966	Von Roll 4	12 and 15	270	960	60	500	Heating	yes, but no in use	sent to foreign firm
Hagen	1967	V.K.W. 3	6	100	335	14	196	Heating of swimming pools	yes	ballast
Hamburg I	1958 1963/67	Von Roll/Martin 2 3 1	6,5 7,3 7,5-12	190 70	500 100	18	340	Electric Heating	yes	yes
Hamburg II	1973	Martin 2	19,5	260	600	4,1	410	Electric	no	yes
Iserlohn	1970 1974	Babcock 2 V.K.W. 1	8 16	104	300	17	250	Heating	yes	no
Kassel	1968/69	Dürr 1 1	10	110	350	42	250	Electric	yes	ballast (partly)
Leverkusen	1969	Von Roll 2	10	106	358	20	305	Electric Heating	no	no
Ludwigshafen	1967	Von Roll 3	10	85	250	42	420	Heating	no	no
Mannheim	1965/73	KSG/ENT 2 1	12 20	150	330	120	500	Heating	no	sent to foreign firm
München Nord	1964/66	Martin 2 1	25 40	230	1 400	205	540	Electric	yes	no
München Sud	1970/71	Martin 1 V.K.W. 1	40 40	220		205	350	For heating + elect.power station	yes	no
Nürnberg	1968	Von Roll 3	15	185	515	80	450	Sent to heating plant	no	no
Oberhausen	1972	V.K.W. 3	22	350	1 000	64	480	Sent to heating plant	previsted	previsted
Offenbach	1970	V.K.W. 3	10	170	500	16	250	Heating	no	no
Solingen	1969	Von Roll 2	10	90	242	42	250	Heating	yes	no
Stuttgart	1965/71	Martin 2	20	250	660	77	525	Electric	yes	sent to foreign firm
Bremerhaven	1977	Von Roll 3	10	150	250	40	400	Heating	no	no
Göppingen	1975	V.K.W. 2	12	120-140	233	39	410	Heating	no	no
Kempten (All)	1975	Von Roll 1	4	50	100	25	225	-	no	no
Kiel Sud	1975	V.K.W. 2	5	80	200	14	197	Heating	no	delivered to firm
Krefeld	1975	V.K.W. 2	12	79	330	19	375	Electric heating	no	delivered to firm
Wuppertal	1976	V.K.W. 4	15	250	550	29	350	Electric	no	delivered to firm

TABLE N° 2

LIST OF INCINERATION PLANTS IN WESTERN GERMANY.

(Müll und Abfall, May 1975)

	BERLIN	HAMBOURG	DÜSSELDORF	AIX LA CH.	AVERAGE
Miscellaneous waste	3,5	3,5	4,0	4,1	7
Fines and ash	15,0	35,0	38,1	22,0	28
Putrescibles	25,0			16,6	15
Textiles	2,0	3,0	3,1	1,6	3
Plastics	5,0	5,5	6,2	4,5	3
Metals	4,5	4,0	4,4	6,9	7
Glass	15,0	17,0	16,4	13,5	9
Paper, cardboard	30,0	32,0	27,8	30,8	28

TABLE N° 3

AVERAGE COMPOSITION OF HOUSEHOLD WASTE PRODUCED IN THE BIG TOWNS OF W. GERMANY

Data on the elimination of the residues.

Iron-removal is not carried out systematically (13 plants out of 39).

The scrap iron is sold at 30 D.M. per tonne.

The clinker is reused as ballast in 16 plants. Without previous iron-removal, clinker is sold at 1,50 D.M. per tonne, with iron-removal, 10 D.M. per tonne (Berlin).

The cost of transport and dumping of incineration residues is about 16 D.M. per tonne.

2.3.4. Ireland.

According to the organization consulted, all the urban waste produced in Ireland is dumped and shows a composition about the same as that found in the United Kingdom.

2.3.5. Italy.

The main results were provided by the A.M.N.U. (Azienda Municipale Nettezza Urbana) of Milan.

Information on the various methods of elimination.

The various methods used for urban waste disposal are : incineration, composting and reutilisation. The respective annual amounts (1973) are the following (Cf table n° 4) :

Incineration	1 730 000 tonnes
Mixed treatment	713 000 tonnes
Composting	33 000 tonnes
Recovery	606 000 tonnes

Average composition of urban waste in the large towns (cf table n° 5)
(Results refer to Milan)

List of incineration plants.

Cf table n° 6.

Composition of incineration slag.

Cf table n° 7.

	NORTHERN ITALY		CENTRAL ITALY		SOUTHERN & INSULAR ITALY	
	QUANTITY t/year	%	QUANTITY t/year	%	QUANTITY t/year	%
Incineration	1 324 000	20,9	335 000	11,4	71 000	1,5
Mixed treatment	184 000	3,2	302 000	9,3	227 000	4,7
Composting	22 000		11 000		—	—
Recovery	—	—	606 000	18,0	—	—
Total treated (a)	1 530 000	24,1	1 304 000	38,7	298 000	6,2
Total landfilled (b)	1 903 000	30,0	228 000	6,8	659 000	13,7
Open dumping (c)	2 917 000	45,9	1 836 000	54,5	3 850 000	80,1
TOTAL a + b + c	6 350 000	100,0	3 368 000	100,0	4 807 000	100,0

TABLE N° 4

GEOGRAPHICAL DISTRIBUTION OF THE METHODS OF ELIMINATION OF URBAN WASTE IN ITALY (1973)

	May July 1971	Sept.Oct. 1972	Nov. 1973	June 1974	Sept.Oct. 1975
Fines 0 - 5 mm %	3,65	3,48	3,83	3,08	3,05
Fines 5 - 20 mm %	6,62	8,19	7,14	6,29	5,39
Putrescibles %	28,50	20,87	25,77	22,00	30,17
Cellulosic materials %	44,45	47,08	39,79	45,27	39,33
Plastics %	5,27	7,00	8,08	9,21	8,86
Combustion waste %	—	—	—	—	—
Uncombustible materials %	11,51	13,38	13,66	14,15	13,20
TOTAL	100,00	100,00	100,00	100,00	100,00
Chemical composition					
Moisture	36,94	35,50	30,86	33,09	34,73
Combustibles	43,24	43,80	47,49	45,14	43,19
Ashes	19,82	20,70	21,55	21,77	22,08
TOTAL	100,00	100,00	100,00	100,00	100,00

TABLE N° 5

COMPOSITION OF MILAN URBAN WASTE

TABLE N° 6

LIST OF MAIN INCINERATORS IN ITALY

SITUATION	DATE OF CONSTRUCTION	CAPACITY t/day	% UTILIZATION	REMARKS
LIGURIA				
Genova	1971	630	90	Prod. of electric power
La Spezia	1973	200	59	Prod. of steam for industrial use
LOMBARDIA				
Gergano	1965	150	68	
Bollate	1972	130	72	
Busto A.	1972	200	95	
Como	1967	100	95	
Mantova	1965	100	40	
Milano 1	1968	400	66	
Milano 2	1973	400	66	
Pavia	1973	130	55	
Rho	1973	100	32	
Sesto San Giovanni	1967	120	95	
VENETO				
Chioggia	1973	120	87	Mixed (compost plant)
Padova (1° formo)	1962	135	40	With production of electric power
Padova (2° formo)	1969	150		
Venezia	1969	200	73	
FRIULI E VENEZIA GIULIA				
Trieste	1972	400	46	
EMILIA ROMAGNA				
Bologna	1973	400	83	
Reggio Emilia	1969	200	77	
TOSCANA				
Firenze	1973	450	73	
Livorno	1973	200	70	
Massa	1972	120	89	
S. Casciano	1966	100	75	
UMBRIA				
Perugia	1972	100	58	

List of main incinerators in Italy (continued)

situation	date of construction	capacity t/day	% utilization	remarks
LAZIO				
Frosinone	1973	120	22	
Roma 1)	1963	700	95	
Roma 2)	1965	550	95	Recuperation of heat for steam production.
Roma 3)	1970	550	95	
Roma 4)	1970	550	95	
ABRUZZI				
Pescara	1969	150	80	
PUGLIE				
Bari	1973 - 1974	250	93	Mixed
Foggia	1973	120	82	Mixed
Lecce	1966	50	95	Mixed
CALABRIA				
Reggio Calabria	1973	150	93	
SICILIA				
Palermo	1964	150	40	
SARDEGNA				
Cagliari	1967	150	49	Mixed

	1970	1970	1971	1971	1971
SiO_2	41,29	54,32	52,43	43,51	66,04
Al_2O_3	23,22	16,15	8,63	22,20	2,25
Fe_2O_3	7,26	6,73	16,24	7,79	4,33
CaO	15,73	10,56	10,04	18,81	9,84
MgO	8,59	6,45	3,12	3,17	2,68
Na_2O	2,50	4,67	8,03	1,88	12,42
K_2O	0,24	0,11	1,29	1,79	1,27

TABLE N° 7

COMPOSITION OF MILAN INCINERATOR SLAG (DRY WEIGHT %)

2.3.6. Luxembourg.

Information on the various methods of elimination.

According to the SIDOR (Intercommunal Association for waste destruction from the communes and cantons of Luxembourg, Esche, Capellen, Lendelange), the methods of elimination are divided up as follows :

- Incineration : 100 000 t/year
- Sanitary landfill : 29 000 t/year.

Average composition of household waste.

No up-to-date statistical data were given.

Incinerating plants.

An incinerator is being prepared for service at Lendelange, equiped with 2 X 8 tonnes per hour MARTIN furnaces, and an 8 tonnes per hour each pyrofusion furnace which will handle 100 000 t/year of waste, and will generate 25 million KWh, 170 000 t of steam (385°C, 35 bars), 40 000 t of clinker each year.

Data on the elimination of incineration residues.

Landfill without scrap iron-removal or crushing is considered to a certain extent ; the average costs of which would reach 52,80 F. Lux./t.

2.3.7. The Netherlands.

The S.V.A. (Stichting Verwigdering Afvalstoffen) answered the questionnaire for the Netherlands.

Information on the various methods of elimination.

The various methods for handling waste used in the Netherlands are incineration, composting, and sanitary landfill. The respective annual amounts (in tonnes) are as follows (1975 value) :

Incineration	1 340 000 tonnes per annum
Compost production	290 000 tonnes per annum
Dumping	2 700 000 tonnes per annum

Average composition of household waste.

The average composition of household waste collected over the last six years is shown on table n° 20.

List of incineration plants.

Cf table n° 7.

Data on the elimination of these residues.

Nearly all the towns recover scrap iron, a total of 40 000 tonnes per annum, sold 30 to 70 florins/t. In Amsterdam, Rotterdam and A.V.K. Botlek, 230 000 tonnes of clinker per annum are crushed, screened and sold at 1,5 to 4 florins per ton.

TOWN	DATE OF FIRST OPERATION	TYPE AND NUMBER OF FURNACES	NOMINAL CAPACITY PER FURNACE t/hour	ANNUAL PRODUCTION					
				ELECTRICITY (KWh)	STEAM (t)			CLINKER (t)	FLY ASH (t)
					PRODUCTION	t°	PRESSURE		
Amsterdam	1968	MARTIN X 4	16	13 X 10^7KWh	–		–	80 000	11 600
Arnhem	1975	DÜRR X 3	12	–	–		–	34 900	*
A.V.R. Botlek	1972	DÜRR X 6	20	4,6 X 10^7	450 t/h		–	89 500	7 500
Dordrecht	1972	MARTIN X 3	7	–	–		–	32 300	2 500
Den Haag	1967/1974	VON ROLL X 4	12,5	5 X 10^7	–		–	83 900	*
Rotterdam	1963	MARTIN X 4	13	6 X 10^7	–		–	48 600	6 000

* Fly ashes are included in the clinker

TABLE N° 7
LIST OF INCINERATION PLANTS IN THE NETHERLANDS

As for the cost of dumping incinerator residues, it lies between 10 and 20 florins/t.

2.3.8. United Kingdom.

The information was given mainly by the Department of the Environment and the District Heating Branch of Nottingham.

Disposal methods :

Two complementary replies were given : the first table (table n° 8) gives the origin and quantity of urban waste handled by the W.D.A.S. (Waste Disposal Assessments), the second is related to the various disposal methods (table 9).

List of incineration plants.

Cf table n° 10.

(Interpretation of the initials of the firms.)

MB	Motherwell Bridge Tacol Ltd
RHF	Redman Heenan Fronde, now HES Heenan Environmental System Ltd
HT	Clarke Chapman - John Thompson Ltd
IC	International Combustion Ltd
HW	Head Wrightson Process Engineering Ltd
SH	Simon Handling Ltd
CJB	Constructors John Brown (Projects) Ltd
B & S	Brunn and Sorrenson A/S
B & W	Babcock and Wilcox Ltd

Composition of incineration residues.

The approximate composition is :

Carbon	10-15 %	
Glass	25-30 %	
Metals	10 %	(iron mostly)
Humidity	25-35 %	
Vegetable matter	< 0,3 %	

Data on incineration residues disposal.

The total quantity of residues disposed for all the incinerators was 184 368 tonnes for the year 1974-1975.

The cost of dumping for the years 1975-1976 is 1,32 per tonne to which a transport cost of £ 2,50 per tonne per 10 miles is added.

The recuperation of iron scraps alone is also carried out, as reported in table 11.

TYPE OF AUTHORITY	WASTE DELIVERED BY COLLECTION AUTHORITIES (INCLUDING CIVIC AMENITY WASTE)	WASTE DELIVERED BY COMMERCE AND INDUSTRY	OTHER WASTES	TOTAL WASTE DISPOSED OF BY WDAs	WASTE SENT TO OTHER WDAs FOR DISPOSAL (INCLUDED IN COLUMN 4)
Great London Council (G.L.C.)	2,742	105	33	2,880	0
(percent)	(95)	(4)	(1)	(100)	(0)
Metropolitan Counties	4,454	1,395	10	5,859	7
(percent)	(76)	(24)	(0,2)	(100)	(0,1)
Non-Metropolitan Counties	9,939	4,004	1,061	15,004	70
(percent)	(66)	(27)	(7)	(100)	(0,5)
TOTAL	17,135	5,504	1,104	23,743	77
(percent)	(72)	(23)	(5)	(100)	(0,3)

TABLE N° 8

WASTE ACCEPTED FOR DISPOSAL BY WDAs IN ENGLAND : 1974-75 (Thousands of tonnes)

Landfill (untreated)	17 412 337 tonnes
Landfill after shredding/pulverizing	696 724 tonnes
Direct incineration	1 939 588 tonnes
Separation and incineration	346 020 tonnes
Contractors and other waste disposal authorities	2 895 217 tonnes[*]
Others	78 957 tonnes[**]
TOTAL	23 368 843 tonnes[***]

[*] Most of this will be disposed by landfilling.

[**] Compost production is included in this total : for West Sussex (8 105), Leicestershire (4 605) and Derbyshire (3 000) = 15 710 tonnes.

[***] This is the total for waste from collection authorities, commerce and industry, and "others".

TABLE N° 9

URBAN WASTE DISPOSAL IN GREAT BRITAIN

TOWN	DATE OF FIRST OPERATION	TYPE AND NUMBER OF FURNACE	NOMINAL CAPACITY PER FURNACE (t/h)	ANNUAL PRODUCTION				
				ELECTRICITY	STEAM			OTHER INFORMATIONS
					PRODUCTION	t°	PRESSURE	
Middleton	1966	MB 1	8					Cleaning of gases by cyclone
Sutton	1966	RHF 1	10					
York	1967	RHF 1	8					
G.L.C. Edmonton	1967	MB 5	14	2 X 2,5 MW 4 X 12,5 MW	5 X 39 000 Kg/d	455	44Kg/cm²	Heat recovery with production of electric energ
Derby	1967	IC 2	7					Cleaning of gases by cyclone
B'ham Perry Bar	1967	HW 2	12					
Glasgow-Dawsholm	1968	MB 2	12					
Bristol	1968	MB 2	15					
Exeter	1968	HW 1	9					
Bolton	1968	RHF 1	16					
Basingstoke	1968	RHF 1	9					
Edinburgh	1969	RHF 2	12					
Tynemouth	1969	RHF 2	10					
Sunderland	1969	IC 2	10					
Gateshead	1969	IC 2	10					
S. Shields	1969	IC 2	10					
Blackburn	1969	RHF 1	11					
Renfrew	1970	MB 2	8					
Coventry	1970	HW 3	12					Heat recovery and resold to Chrysler car firm
Nottingham	1970	HW 2	11	2 X 2,6 MW/H	3 X 20 500 Kg/d	345	25	District heating plant
Wolverhampton	1970	MB 2	10					
Winchester	1971	RHF 1	9					
Blaby	1971	RHF 2	10					
Rhondda	1971	IC 1	9					
Swindon	1971	CJB 1	12					Heat recovery
Havant	1971	JT 1	14					Incineration for waste waters
Rockdale	1972	RHF 1	8					
Dawley	1972	RHF 1	10					
New Forest	1972	RB 1	11					
Teeside	1972	RHF 2	16					Incineration of waste waters
Sheffield	1973	B & W 2	10					District heating plant
Portsmouth	1973	IC 2	10					
Stoke on Trent	1973	RHF 2	10					
B'ham-Tyseley	1974	RHF 2	15					
Birkenhead	1974	RHF 2	14					
Dundee	1975	RHF 2	7					
Leicester	1974	2	10					

TABLE N°10

LIST OF MAIN INCINERATORS IN UNITED KINGDOM

	QUANTITY OF IRON EXTRACTED t/year	SALE PRICE £ PER TONNE	QUANTITY OF SLAG	SALE PRICE £ PER TONNE
TOWN OF NOTTINGHAM	1 405	14	–	–
UNITED KINGDOM TOTAL	70 000	13	70 000	1

TABLE N°11

ESTIMATION OF THE QUANTITIES OF IRON SCRAP RECUPERATED FROM INCINERATOR RESIDUES IN U.K.

3. SUMMING UP OF RESULTS.

3.1. SELECTION OF MAIN INCINERATORS IN THE COMMON MARKET COUNTRIES.

This selection concerns the incinerators handling more than 100 000 tonnes of household waste per year, as following :

Belgium (Cf table n° 12).
Bruxelles - Schaerbeck - Charleroi.

Federal Republic of Germany (Cf table n° 13).
Berlin - Essen (Karnap) - Oberhausen - Düsseldorf - Frankfurt/Main - Hamburg II (Stellingermoor) - Stuttgart - Wuppertal - München nord - Hamburg I (Billbrook) - Würnberg - Bremen - Mannheim - Bremerhaven - Göppingen - Darmstadt - Kassel - Iserlohn - Hagen.

France (Cf table n° 14).
Paris (Ivry) - Paris (Issy) - Paris (St Ouen) - Lille - Strasbourg - Lyon (Gerland) - Nice (Est) - Dijon - Nancy - Rouen - Le Mans - Le Havre - Antibes - Paris (Plaisir) - Caen (Colombelles) - Lens (Noyelles) Toulouse.

Italy (Cf table n° 15).
Genova - Firenze - Milano I - Milano II - Trieste - Bologna.

Luxemburg (Cf table n° 12).
Luxembourg.

The Netherlands (Cf table n° 16).
A.V.R. Botlek - Amsterdam - Rotterdam - Benhrag - Arnhem - Dordrecht.

United Kingdom (Cf table n° 17).
G.L.C. Edmonton - Covenrry - Teeside - Bristol - B'ham (Tyseley) - Birkenhead - Edinburgh - Glasgow (Dawsholm) - B'ham (Perry Bar) - Nottingham - Wolwerhampton - S. Shiclos - Gateshead - Sundreland - Tynemouth - Stoke on trent - Leicester - Portsmouth - Blaby - Sheffield - Renfrew - Bolton - Derby - Havant - Dundez - Salford - Dudley - Swindon - Huddersfield - Blackburn.

3.2. AVERAGE COMPOSITION OF RAW HOUSEHOLD REFUSE PRODUCED IN THE COMMON MARKET COUNTRIES.

TOWN	HEAT RECOVERY	QUANTITY HANDLED (tonnes)	TYPE OF FURNACE	DATE OF FIRST OPERATION
Bruxelles-Schaerbeck	R	400 t/d	VON ROLL	
Charleroi	-	2 X 7,5 t/h		1976
Luxembourg	-	2 X 9 t/h		1976

TABLE N°12
MAIN INCINERATION PLANTS OF BELGIUM AND LUXEMBURG

TOWN	METHOD OF TREATMENT	YEAR OF CONSTRUCTION	NOMINAL CAPACITY (t/h)	TYPE OF FURNACE	DAILY QUANTITY TREATED (t/day)	ANNUAL QUANTITY TREATED (t/y)
Berlin	Incineration and power recovery	1967	4 X 12,5 4 X 16	Borsig Walzenrost	1 096	400 000
Essen-Karnap	Incineration and power recovery	1971	5 X 20	Babcock	973	355 000
Oberhausen	Incineration and power recovery	1960	3 X 22	V.K.W.	959	350 000
Düsseldorf	Incineration and power recovery	1965	4 X 10 1 X 12,5	Dürrwerke V.K.W.	904	330 000
Frankfurt/Main	Incineration and power recovery	1966	4 X 12 - 15	Von Roll	740	270 000
Hamburg II	Incineration and power recovery	1973	2 X 19,5	Martin	712	260 000
Stuttgart	Incineration and power recovery	1965	2 X 20 1 X 20	Martin V.K.W.	685	250 000
Wuppertal	Incineration and power recovery	1976	4 X 15	V.K.W.	685	250 000
München Nord	Incineration and power recovery	1964	2 X 25 1 X 40	Martin	630	230 000
München Süd	Incineration and power recovery	1970	1 X 40 1 X 40	Martin V.K.W.	603	220 000
Hamburg I	Incineration and power recovery	1963	1 X 7,3 1 X 7,5 - 12	Von Roll Martin	521 191	190 000 70 000
Nürnberg	Incineration and steam recovery	1968	3 X 15	Von Roll	507	185 000
Bremen	Incineration and heat recovery	1969	3 X 15	Dürrwerke	493	180 000
Mannheim	Incineration and heat recovery	1965	1 X 20	KSG/EUT	411	150 000
Bremen Haven	Incineration and heat recovery	1977	3 X 10	Von Roll	411	150 000
Göppingen	Incineration and heat recovery	1975	2 X 12	V.K.W.	356	120-140 000
Darmstadt	Incineration and heat recovery	1973	2 X 10 1 X 12	Von Roll	329	120 000
Kassel	Incineration and power recovery	1969	1 X 10 1 X 10	Dürrwerke	301	110 000
Iserlohn	Incineration and heat recovery	1974	2 X 8 1 X 16	Babcock V.K.W.	285	104 000
Hagen	Incineration and heat recovery	1966	3 X 6	V.K.W.	274	100 000
					TOTAL WESTERN GERMANY	4 404 000

TABLE N°13

MAIN INCINERATION PLANTS IN WESTERN GERMANY

TOWN	METHOD OF TREATMENT	YEAR OF CONSTRUCTION	NOMINAL CAPACITY (t/h)	TYPE OF FURNACE	DAILY QUANTITY TREATED (t/day)	ANNUAL QUANTITY TREATED (t/year)
Paris (Ivry)	Incineration and heat recovery	June 69	2 X 50 t/h	Martin	2 400	876 000
Paris (Issy)	Incineration and heat recovery	1965	4 X 17	Martin	1 300 to 1800	547 500
Paris (St Ouen)	Incineration and heat recovery	1964	4 X 6	Volund	1 200	438 000
Lille	Incineration	1974	40	Volund	960	350 400
Strasbourg	Incineration and heat recovery	1974	3 X 11	Von Roll	650	237 250
Lyon (Gerland)	Incineration and heat recovery	1963	4 X 8	Volund	580	211 700
Nice (Est)	Incineration and heat recovery	1977	2 X 12	Martin	576	210 240
Dijon	Incineration	1974	2 X 12	Von Roll	576	210 240
Nancy	Incineration	1936-1974	9 X 1,25 9 X 1,25	Heenan	540	197 100
Rouen	Incineration	1970	2 X 10,2	F.C.E.	490	178 704
Le Mans	Incineration	1974	2 X 10	Von Roll	480	175 200
Le Havre	Incineration	1970	2 X 8,5	V.K.W.	408	148 920
Antibes	Incineration	1970	2 X 9	Martin	432	157 680
Paris (Plaisir)	Incineration and heat recovery	En constr.	2 X 8	Martin	384	140 160
Caen (Colombelles)	Incineration	1972	2 X 7,5	Martin	360	131 400
Lens (Noyelles)	Incineration	1973	2 X 6,7	Martin	340	124 100
Argenteuil	Incineration	1975	2 X 6,5	Von Roll	312	113 880
Toulouse	Incineration and heat recovery	1970	2 X 7	V.K.W.	300	109 500
Grenoble	Incineration and heat recovery	1972	2 X 6,25	V.K.W.	300	109 500
					TOTAL FRANCE	5 017 874

TABLE N°14

MAIN INCINERATION PLANTS IN FRANCE

TOWN	METHOD OF TREATMENT	YEAR OF CONSTRUCTION	CAPACITY (t/d)	% UTILIZED	AMOUNT TREATED (t/y)
Genova	Incineration and power recovery	1971	630	90	206 955
Firenze	Incineration	1973	450	73	119 900
Milano I	Incineration and power recovery	1968	400	66	96 360
Milano II	Incineration and power recovery	1973	400	66	96 360
Trieste	Incineration	1972	400	46	67 160
Bologna	Incineration	1973	400	83	121 180
			TOTAL ITALY		640 755

TABLE N°15

DATA ON INCINERATION PLANTS IN ITALY

TOWN	METHOD OF TREATMENT	DATE OF CONSTRUCTION	NOMINAL CAPACITY (t/h)	TYPE OF FURNACE	DAILY QUANTITY (t/d)	ANNUAL QUANTITY TREATED (t/y)
A.V.R. Bötlek	Incineration and power recovery	1972	6 X 20	DÜRR	2 880	1 051 200
Amsterdam	Incineration and power recovery	1968	4 X 16	Martin	1 536	560 640
Rotterdam	Incineration and power recovery	1963	4 X 13	Martin	1 248	455 520
Den Haag	Incineration and power recovery	1967-1974	4 X 12,5	Von Roll	1 200	438 000
Arnhem	Incineration	1975	3 X 12	DÜRR	864	315 360
Dordrecht	Incineration	1972	3 X 7	DÜRR	504	183 960
				TOTAL NETHERLANDS		3 004 680

TABLE N°16

DATA ON INCINERATION PLANTS IN THE NETHERLANDS

TOWN	METHOD OF TREATMENT	DATE OF FIRST OPERATION	NOMINAL CAPACITY (t/h)	AMOUNT DAILY TREATED	ANNUAL TOTAL TREATED
G.L.C. Edmonton	Incineration and heat recovery	1967	5 X 14,2	1 704	621 960
Coventry	Incineration and heat recovery	1970	3 X 12,2	878	320 616
Teeside	Incineration	1972	2 X 16	768	280 320
Bristol	Incineration	1968	2 X 15,2	730	266 304
B'ham-Tyseley	Incineration	1974	2 X 15	720	262 800
Birkenhead	Incineration	1974	2 X 14	672	245 280
Edinburgh	Incineration	1969	2 X 12,7	610	222 504
Glasgow-Dawsholm	Incineration	1968	2 X 12,2	586	213 744
B'ham-Perry Bar	Incineration	1967	2 X 12,2	586	213 744
Nottingham	Incineration and heat recovery	1970	2 X 11,8	566	206 736
Wolverhampton	Incineration	1970	2 X 10,15	487	177 828
S. Shields	Incineration	1969	2 X 10,15	487	177 828
Gateshead	Incineration	1969	2 X 10,15	487	177 828
Sunderland	Incineration	1969	2 X 10,15	487	177 828
Tynemouth	Incineration	1969	2 X 10,15	487	177 828
Stoke on Trent	Incineration	1973	2 X 10,15	487	177 828
Leicester	Incineration	1974	2 X 10,15	487	177 828
Portsmouth	Incineration	1973	2 X 10,15	487	177 828
Blaby	Incineration	1971	2 X 10,15	487	177 828
Sheffield	Incineration and heat recovery	1973	2 X 10,15	487	177 828
Renfrew	Incineration	1970	2 X 8,1	389	141 912
Bolton	Incineration	1968	1 X 16,25	390	142 350
Derby	Incineration	1967	2 X 7,6	365	133 152
Havant	Incineration	1971	1 X 14,2	341	124 392
Dundee	Incineration	1975	2 X 7	336	122 640
Salford	Incineration	1971	2 X 6,6	317	115 632
Dudley	Incineration	1966	2 X 6,3	302	110 376
Swindon	Incineration and heat recovery	1971	1 X 12,2	293	106 872
Huddersfield	Incineration	1972	2 X 6	288	105 120
Blackburn	Incineration	1969	1 X 11,5	276	100 740
			TOTAL UNITED KINGDOM		5 821 474

TABLE N°17

MAIN INCINERATION PLANTS IN UNITED KINGDOM

3.2.1. Belgium.

In spite of the lack of up-to-date results the average composition can be estimated as follows :

Fines	25 %
Putrescible materials	15 %
Paper	32 %
Plastics	3,5 %
Miscellaneous combustibles	12,5 %
Glass	7 %
Metals	5 %

3.2.2. Federal Republic of Germany.

Annual variations of the composition of waste from the town of Berlin are, for instance, as follows :

	1963	1977
Paper-cardboard	18,5	30,0
Glass	9,8	15,0
Metal	4,9	4,5
Plastics	1,0	5,0
Putrescible materials	21,2	25,0
Fines	1,7	2,0
Others	12,6	3,5

TABLE N°18

Average composition of household waste for the town of Berlin (as %).

This shows that the metal content remains stable, while glass (9,8 to 15,0) and plastic (1 to 5) show a marked increase. Ash and fines contents, resulting from the use of solid fuels, decrease strongly.

Generally speaking, the composition of household waste divided up as follows :

Fines	20 - 30 %
Putrescible materials	10 - 25 %
Papers	27 - 32 %
Plastics	3 - 6 %
Miscellaneous combustibles	5 - 10 %
Glass	10 - 20 %
Metals	4 - 7 %

3.2.3. France.

The composition of urban waste ranges as it follows :

Fines	10 - 20 %
Putrescible materials	15 - 30 %
Paper	20 - 40 %
Plastics	2 - 6 %
Miscellaneous fuels	6 - 11 %
Glass	2 - 8 %
Metals	2 - 6 %

As an example, the composition of household waste collected in Paris, in 1975 was :

Fine elements :		
0 - 8 mm	8 %	
8 - 19 mm	9,2 %	
Vegetable matter	17,3 %	
Papers	36,6 %	
Metals	3,7 %	(ferrous : 86 % ; non-ferrous : 14 %)
Rags	3 %	
Glass	10 %	
Bones	1,2 %	
Miscellaneous combustibles	3,8 %	
Miscellaneous incombustibles	2,8 %	
Plastics	3,5 %	

3.2.4. Great Britain.

Statistical studies, carried out each year, lead to the following values :

TYPE OF REFUSE	AVERAGE QUANTITY PER DWELLING (Kgs)	%
Minus 2 cm	2,07	17,8
Vegetable and putrescibles	2,38	20,5
Paper	3,44	29,6
Metal	0,94	8,1
Textiles	0,34	2,9
Glass	1,10	9,5
Plastics	0,46	4,0
Unclassified	0,93	8,0
TOTAL	11,63	100,0

TABLE N°19

Average analysis of domestic refuse 1975 in U.K.

As a result, the following variation are obtained :

Fines	17 - 19 %
Vegetable and putrescibles	19 - 21 %
Papers	25 - 30 %
Plastics	4 - 5 %
Miscellaneous combustibles	11 - 14 %
Glass	9 - 10 %
Metals	8 - 9 %

The seasonal variations, for each of these items seem unimportant on a national scale.

3.2.5. Italy.

The results correspond to the average composition of urban waste in Italian towns, according to analysis carried out on household refuse of the town of Milan.

Fines	8 - 15 %
Putrescible materials	20 - 30 %
Papers	39 - 47 %
Plastics	5 - 9 %
Miscellaneous combustibles	9 - 15 %
Glass	8 - 12 %
Metals	3 - 4 %

3.2.6. The Netherlands.

The averages considered during the years 1971 to 1976 are as follows :

Component	1971	1972	1973	1974	1975	1976
Vegetable, fruit garden refuse	49,7 %	45,0 %	45,5 %	48,1 %	48,7 %	48,1 %
Paper	25,5	26,1	25,6	22,6	23,0	22,3
Textiles, rope	1,9	2,3	2,2	1,8	1,7	1,9
Glass	10,0	11,7	11,9	13,0	12,0	12,7
Iron	3,1	3,3	3,2	3,1	3,0	2,6
Bricks, pottery	1,3	2,4	1,8	1,4	1,9	1,6
Polymers	4,7	5,2	5,1	5,3	5,6	5,8
Non-ferrous metals	0	0,2	0,2	0,1	0,3	0,3
Bread	1,9	2,1	2,1	2,3	1,7	1,9
Carpets, mats	0,2	0,3	0,3	0,3	0,2	0,4
Bones, animal refuse	0,3	0,5	0,5	0,8	0,9	0,9
Dead bodies	0,1	0	0,4	0	0	0
Leather, rubber	0,6	0,5	0,7	0,8	0,4	0,7
Wood	0,8	0,7	0,8	0,4	0,6	0,5
Specialities (e.g. batteries)	-	-	-	-	-	0,3

TABLE N°20

AVERAGE COMPOSITIONS OF NETHERLANDS WASTES FROM 1971 TO 1976

The following minima and maxima composition are obtained :

Fines	5 - 10 %
Putrescible materials	45 - 50 %
Papers	22 - 26 %
Plastics	4 - 6 %
Miscellaneous combustibles	6 - 10 %
Glass	10 - 13 %
Metals	3 - 4 %

A careful study was carried out by the S.V.A. on the content variations of miscellaneous constituents in three boroughs : Arnheim, Amsterdam and Overasselt.

It appears, notably :

- that the ferrous metal content is always higher in winter when it can exceed 4 % ;
- that the proportion of non-ferrous metals is also higher in winter and in spring, and depends on the size of the town.

For the same town, the glass contents remain constant throughout the year, but the average value, depending on the size of the agglomeration, varies, for example for Amsterdam new District, from 15 to 20 %, and for Overasselt, from 8 to 12 %.

3.2.7. Recapitulation of the different results on composition.

Table21 groups together all the composition results set out above. Taking into account the moisture of the different components as follows :

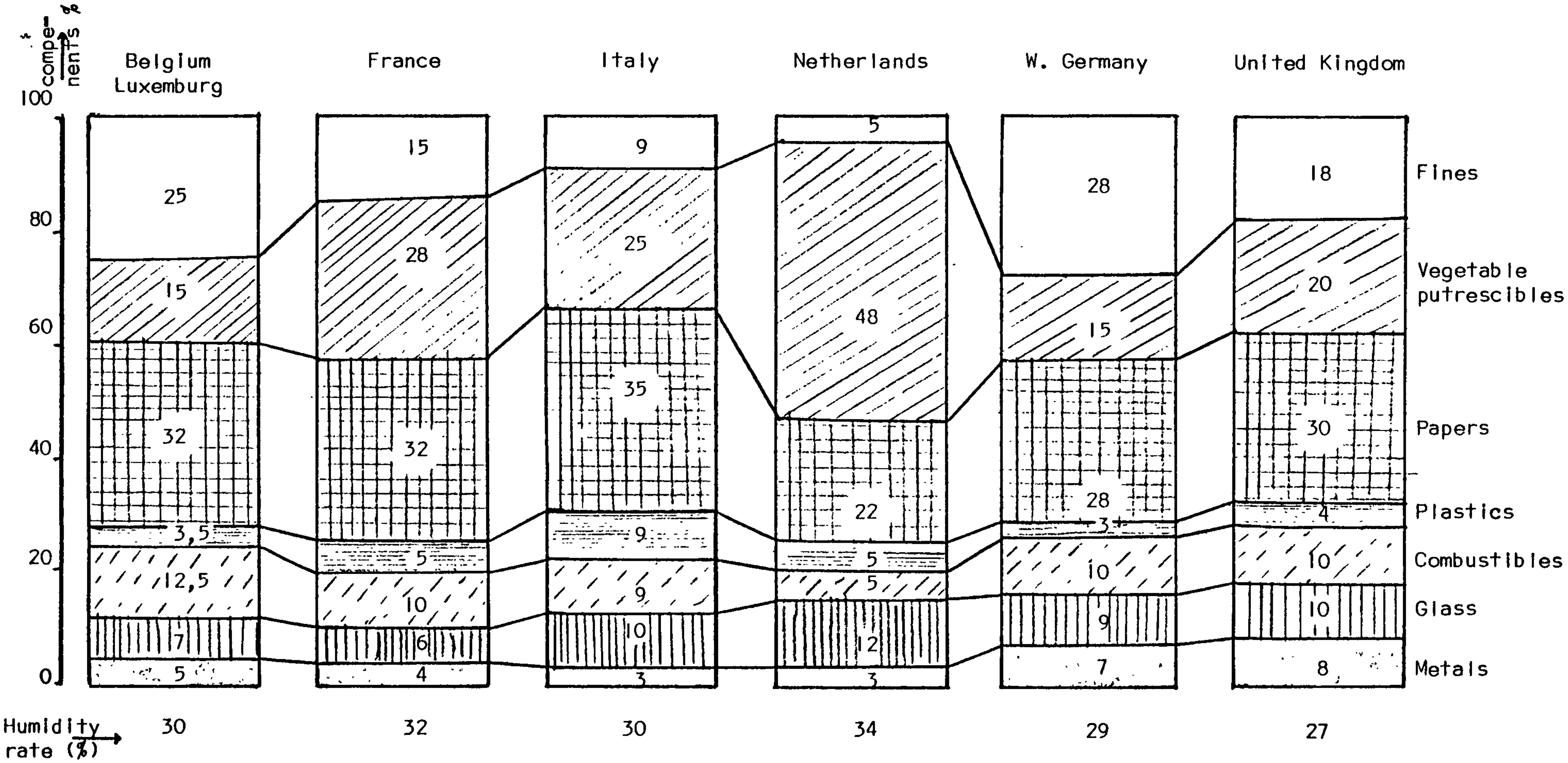
Fines	40 %
Putrescible materials	60 %
Miscellaneous combustibles Papers	10 %
Plastics	1 %
Glass Metals	0,5 %

The average compositions on a dry basis can be calculated. They compare each others as shown in figure 1.

	BELGIUM LUXEMBURG		FRANCE		ITALY		NETHERLANDS		FED. REP. OF GERMANY		UNITED KINGDOM	
	weight wet %	weight dry %	weight wet %	weight dry %	weight wet %	weight dry %	weight wet %	weight dry %	weight wet %	weight dry %	weight wet %	weight dry %
Fines	25	15	10-20	6-12	8-15	5- 9	5-10	3- 6	20-30	12-18	17-19	10-11
Putrescible materials	15	6	15-30	6-12	20-30	8-12	45-50	18-20	10-25	4-10	19-21	8- 9
Papers	32	29	20-40	18-36	39-47	35-42	22-26	20-23	27-32	24-29	25-30	22-27
Plastics	3,5	3,5	2- 6	2- 6	5- 9	5- 9	4- 6	4- 6	3- 6	3- 6	4- 5	4- 5
Miscellaneous comb.	12,5	11,5	6-11	5-10	9-15	8-14	6-10	5- 9	5-10	4- 9	11-14	10-13
Glass	7	7	2- 8	2- 8	8-12	8-12	10-13	10-13	10-20	10-20	9-10	9-10
Metals	5	5	2- 6	2- 6	3- 4	3- 4	3- 4	3- 4	4- 7	4- 7	8- 9	8- 9
TOTAL	100	70	100	68	100	70	100	66	100	71	100	73
Total combustibles				54-64		54-59		49-53		44-57		54-56

TABLE N°21

EEC HOUSEHOLD REFUSE COMPOSITION RANGE



EVOLUTION OF AVERAGE COMPOSITIONS AS DRY PRODUCTS
OF THE URBAN WASTE OF DIEFERENT COMMON MARKET COUNTRIES

Fig. 1

3.3. ESTIMATION OF THE AVERAGE COMPOSITIONS OF INCINERATOR RESIDUES IN THE EEC.

3.3.1. Clinkers.

Method used.

As the composition of clinkers in ferrous and non-ferrous metals, glass and slag is rarely analysed, it was thought necessary to provide a preliminary estimation for each of the member countries.

The method used is based on the dry weight estimation of raw household waste, to avoid moisture differences occuring between the different countries (as for instance in the case of putrescible materials between The Netherlands and W-Germany : -respectively 48 and 15 % of urban waste-).From an average ash rate of combustible materials, the quantity of ash produced per dry tonne incinerated is calculated. Added to the quantities of metals and glass, which have no reduction rate, that gives the total quantity of clinker and then the percentage of its different components.

Estimation of an average ash-rate of combustible materials.

The dry compositions once calculated, the average ash-rate Tc of the combustible fraction is determined as follows : in Paris, the incineration of one ton of raw refuse (dry weight) gives 250 Kgs of clinker (dry weight), divided up into 100 Kgs of glass, 40 Kgs of metals and 110 Kgs of slag, made up by ashes of combustible materials which represent originally 58 % of the total waste ; then, the ash rate of these components is : $Tc = \frac{110}{580} = 0,19$.

Overall composition of clinker.

- Assuming that this rate remains almost the same for all the Common Market countries, the corresponding quantities of ash can be estimated.
- The quantities of ferrous metals and glass are directly obtained from raw refuse contents.
- The quantity (NF) of non-ferrous metals is valued apart from ferrous metals content (Mt), according to the correlation :

$$NF = \frac{Mt \times 0,8}{18}$$

For instance, in the case of U.K. , (Cf table 21), one ton of dry untreated waste contains between 540 to 560 Kgs of combustibles which will produce 100 to 111 Kgs of ash (540 X 0,19 ; 560 X 0,19), between 80 and 90 Kgs of metals and 90 to 100 Kgs of glass. Then, the clinker composition can be estimated as follows :

Metals :	ferrous	29 - 31	Glass	30 - 33
	non-ferrous	1 - 1,5	Slag	34,5 - 40

The complete results for EEC are collected up in table 22.

		REFERENCE PARIS IVRY	BELGIUM LUXEMBURG	FRANCE	ITALY	NETHERLANDS	FED. REP. OF GERMANY	UNITED KINGDOM
quantity per tonne of raw refuse	Metals (Kg)	40	50	20 - 60	30 - 40	30 - 40	40 - 70	80 - 90
	Glass	100	40	20 - 80	80 -120	100 -130	100 -200	90 -100
	Slag	110	110	100 -120	100 -110	100 -110	80 -100	100 -110
composition %	Ferrous metals	25 - 27	13 - 15	13 - 22	13 - 14	12 - 14	17 - 18	29 - 31
	Non-ferrous metals	0,7 - 1,5	1 - 2	0,6 - 1	0,6 - 0,7	0,6 - 0,8	0,8 - 0,9	1 - 1,5
	Glass	40 - 45	30 - 35	14 - 31	38 - 44	43 - 46	45 - 54	30 - 33
	Slag	26 - 28	48 - 66	46 - 71	41 - 48	39 - 43	27 - 36	34 - 40

TABLE N°22

ESTIMATION OF THE AVERAGE COMPOSITIONS OF INCINERATOR CLINKERS PRODUCED IN DIFFERENT COMMON MARKET COUNTRIES

3.3.2. Composition of fly ash.

The composition of fly ash is not systematically analyzed. Gathered results concern : the compositions of Paris-Ivry (Cf table 23), average composition of The Netherlands (Cf table 24) and the composition in West-Germany (Cf table25).

The quantities of fly ash collected annually in a few incinerators of the Common Market are as follows :

Berlin	10 000 tonnes
Bremen	4 000 tonnes
Hagen	5 000 tonnes
Amsterdam	11 600 tonnes
A.V.R. Botlek	7 500 tonnes
Dordrecht	2 500 tonnes
Rotterdam	6 000 tonnes

Fly ashes so represent 2 to 3 % of the input.

But, in the majority of cases, they are frequently included with clinkers.

3.4. ESTIMATION OF THE QUANTITIES OF MATERIALS RECOVERABLE FROM INCINERATION REFUSE.

Such quantities are evaluated from incineration facilities, which exist in the different Common Market countries. The results are shown :
- For incinerators with a capacity of over 100 000 tonnes (Cf table 26)
- For incinerators with a capacity of over 200 000 tonnes (Cf table 27)
- For incinerators with a capacity of over 400 000 tonnes (Cf table 28).

The main conclusions are :
- The country having the most glass and metals in its clinkers is also the biggest producer : this country is the United Kingdom. Following U.K., come Western Germany, France, The Netherlands and Italy, where many incinerators exist, but mostly of small capacity.
- Italy does not come into the list of countries with the greatest capacities for incineration, its biggest being at Genova (206 953 tons). France possesses three big incinerators in Paris (Ivry, Issy, St Ouen) ; The Netherlands possesses A.V.R. Botlek, Amsterdam, Rotterdam, the Hague ; in Western Germany, worth noticing is Berlin's, and in U.K. that of the Great London Council, Edmonton.

ELEMENT	CONTENT %	ELEMENT	CONTENT %
Si	14,1	Be	< 3
Ca	8,5	B	180
K	4,0	V	180
Mg	2,6	Cr	800
Na	3,2	Mn	2 300
Cl	1,0	Co	50
P	5,8	Ni	150
S	3,2	Cu	1 500
Al	7,4	Ga	40
Fe	2,6	Ge	< 6
Pb	1,4	Sr	400
Sn	0,34	Y	60
Ti	0,7	Mo	70
Zn	2,7	Ag	130
Ba	0,3	Cd	240

TABLE N°23

COMPOSITION OF FLY ASH FROM PARIS-IVRY INCINERATOR

COMPONENT	FLY ASH
SiO_2	47,4 %
Al_2O_3	11,7
TiO_2	1,7
Fe_2O_3	2,9
CaO	10,5
MgO	2,0
K_2O	3,2
Na_2O	3,0
P_2O_5	1,0
Combustible	11,0
PbO	1,0
BaO	0,3
MnO	0,3
ZnO	1,3
SnO	0,2
Cl	2,5
Moisture	-

TABLE N°24

AVERAGE COMPOSITION OF
FLY ASH IN THE NETHERLANDS

	Average		Minimum		Maximum	
	Whole sample	Water soluble matter	Whole sample	Water soluble matter	Whole sample	Water soluble matter
SiO_2	19,77 %	0,04 %	2,73 %	0,01 %	39,30 %	0,09 %
TiO_2	0,75 %	< 0,01 %	0,14 %	< 0,01 %	1,26 %	< 0,01 %
Al_2O_3	12,09 %	0,04 %	0,89 %	0,01 %	19,30 %	0,06 %
Fe_2O_3	6,80 %	< 0,01 %	1,47 %	< 0,01 %	12,10 %	< 0,01 %
MgO	1,67 %	0,22 %	0,53 %	0,03 %	3,03 %	0,31 %
CaO	11,07 %	2,11 %	7,00 %	0,85 %	17,14 %	3,29 %
PbO	2,01 %	37 ppm	0,05 %	0,66 ppm	6,67 %	139 ppm
ZnO	6,02 %	3,73 %	0,42 %	0,42 %	16,50 %	14,90 %
Na_2O	4,49 %	2,70 %	0,67 %	0,43 %	10,33 %	7,92 %
K_2O	7,10 %	4,41 %	2,53 %	0,04 %	13,72 %	11,75 %
P_2O_5	1,25 %	< 0,005 %	0,10 %	< 0,005 %	3,05 %	< 0,005 %
SO_3	15,92 %	10,1 %	2,0 %	2,0 %	32,80 %	29,1 %
Cl	4,29 %	2,41 %	0,07 %	0,02 %	8,30 %	7,45 %
Ag	68 ppm	1,5 ppm	9 ppm	0,03 ppm	151 ppm	41 ppm
As	177 ppm	6 ppm	49 ppm	4 ppm	527 ppm	7 ppm
B	258 ppm	53 ppm	90 ppm	25 ppm	450 ppm	95 ppm
Ba	2108 ppm	12 ppm	1000 ppm	6 ppm	3200 ppm	16 ppm
Be	4 ppm	0,2 ppm	1 ppm	0,1 ppm	7 ppm	0,2 ppm
Bi	501 ppm	< 0,2 ppm	68 ppm	< 0,2 ppm	1680 ppm	< 0,2 ppm
Cd	505 ppm	346 ppm	60 ppm	2 ppm	1200 ppm	1060 ppm
Co	38 ppm	1 ppm	20 ppm	0,4 ppm	61 ppm	2,2 ppm
Cr	371 ppm	5 ppm	140 ppm	0,4 ppm	510 ppm	25 ppm
Cu	1450 ppm	72 ppm	140 ppm	6 ppm	3500 ppm	224 ppm
F	1722 ppm	466 ppm	250 ppm	166 ppm	4120 ppm	988 ppm
Hg	133 ppm	0,2 ppm	1 ppm	0,08 ppm	770 ppm	0,5 ppm
Mn	958 ppm	67 ppm	550 ppm	13 ppm	1500 ppm	150 ppm
Mo	80 ppm	< 2 ppm	21 ppm	< 2 ppm	122 ppm	< 2 ppm
Ni	183 ppm	12 ppm	40 ppm	1 ppm	360 ppm	25 ppm
Sb	297 ppm	0,9 ppm	80 ppm	0,5 ppm	663 ppm	1,6 ppm
Sn	2540 ppm	not det.	595 ppm	not det.	4500 ppm	not det.
Sr	287 ppm	85 ppm	125 ppm	13 ppm	460 ppm	219 ppm
Tl	12 ppm	< 2 ppm	6 ppm	< 2 ppm	22 ppm	< 2 ppm
V	157 ppm	8,2 ppm	30 ppm	2 ppm	345 ppm	16 ppm

EXAMPLE OF RESULTS OF CHEMICAL ANALYSIS OF INCINERATOR FLY ASH IN W. GERMANY

TABLE N°25

- As the European centers are now equipped with incinerators, the results collected at the present time should not change much during the next years, except through extension or renovation of the existing plants.

	BELGIUM	FRANCE	ITALY	LUXEMBURG	NETHERLANDS	FED. REP. OF GERMANY	UNITED KINGDOM
Clinker	40	702-1305	135-173	40	691-841	969-1630	1572-1746
Ferrous metals	5-6	126-235	17-23	5-6	90-110	165-277	471-524
Non-ferrous metals	0,4-0,8	6-10	0,8-1	0,4-0,8	4,8-6	8,7- 15	20-23
Glass	12-14	162-300	54-69	12-14	311-379	484-815	503-559
Slag	19-26	421-783	61-78	19-26	276-337	290-521	582-646
Number of incinerators concerned	1	19	6	1	6	20	30

X 10^3 t

TABLE N°26

QUANTITIES OF MATERIALS RECOVERABLE FROM INCINERATOR RESIDUES (FROM COMMON MARKET INCINERATORS WITH AN ANNUAL CAPACITY OF OVER 100 000 TONNES)

	FRANCE	ITALY	NETHERLANDS	FED. REP. OF GERMANY	UNITED KINGDOM
Clinker	431-801	43-56	649-790	591-993	770-856
Ferrous metals	73-136	5-7	84-103	100-169	231-257
Non-ferrous metals	4-8	0,3-0,4	4,5-5,5	5-9	11-13
Glass	108-200	17-22	292-355	295-497	231-257
Slag	259-481	19-25	266-324	189-318	285-317
Number of incinerators concerned	8	1	5	10	10

X 10^3 t

TABLE N°27

QUANTITIES OF MATERIALS RECOVERABLE FROM INCINERATOR RESIDUES (FROM COMMON MARKET INCINERATORS WITH AN ANNUAL CAPACITY OF OVER 200 000 TONNES)

	FRANCE	NETHERLANDS	FED. REP. OF GERMANY	UNITED KINGDOM
Clinker	260-484	576-701	88-148	168-186
Ferrous metals	44-82	75-91	16-26	50-56
Non-ferrous metals	2-5	4-5	0,8-1,3	2,5-2,8
Glass	65-121	259-315	44-74	50-56
Slag	156-290	230-280	28-47	60-67
Number of incinerators concerned	3	4	1	1

X 10^3 t

TABLE N°28

QUANTITIES OF MATERIALS RECOVERABLE FROM INCINERATOR RESIDUES (FROM COMMON MARKET INCINERATORS WITH AN ANNUAL CAPACITY OF OVER 400 000 TONNES)

PART 2

BENEFICIATION POSSIBILITIES OF INCINERATION REFUSE

I. TECHNOLOGY FOR CLINKER BENEFICIATION.

I.I. PROCESSES ALLOWING A PARTIAL BENEFICIATION OF CLINKERS.

(Iron removal, with or without size reduction.)

Iron scrap recovery systems are frequently associated with incinerators by :

- Raw scrap removal,
- Shredding and clean scrap extraction.

I.I.I. Raw scrap removal.

For example, that needs the following operations, as running at Ivry (France) incinerator (Cf figure 2) :

- Evacuation by conveyor belts of the clinker when coming out from the incinerator,
- Primary magnetic separation by magnetic drum,
- Screening of the residues by grizzly : the undersize is stored, the oversize ("metallic monsters") joins the magnetics,
- Concentration of the magnetics by overband.

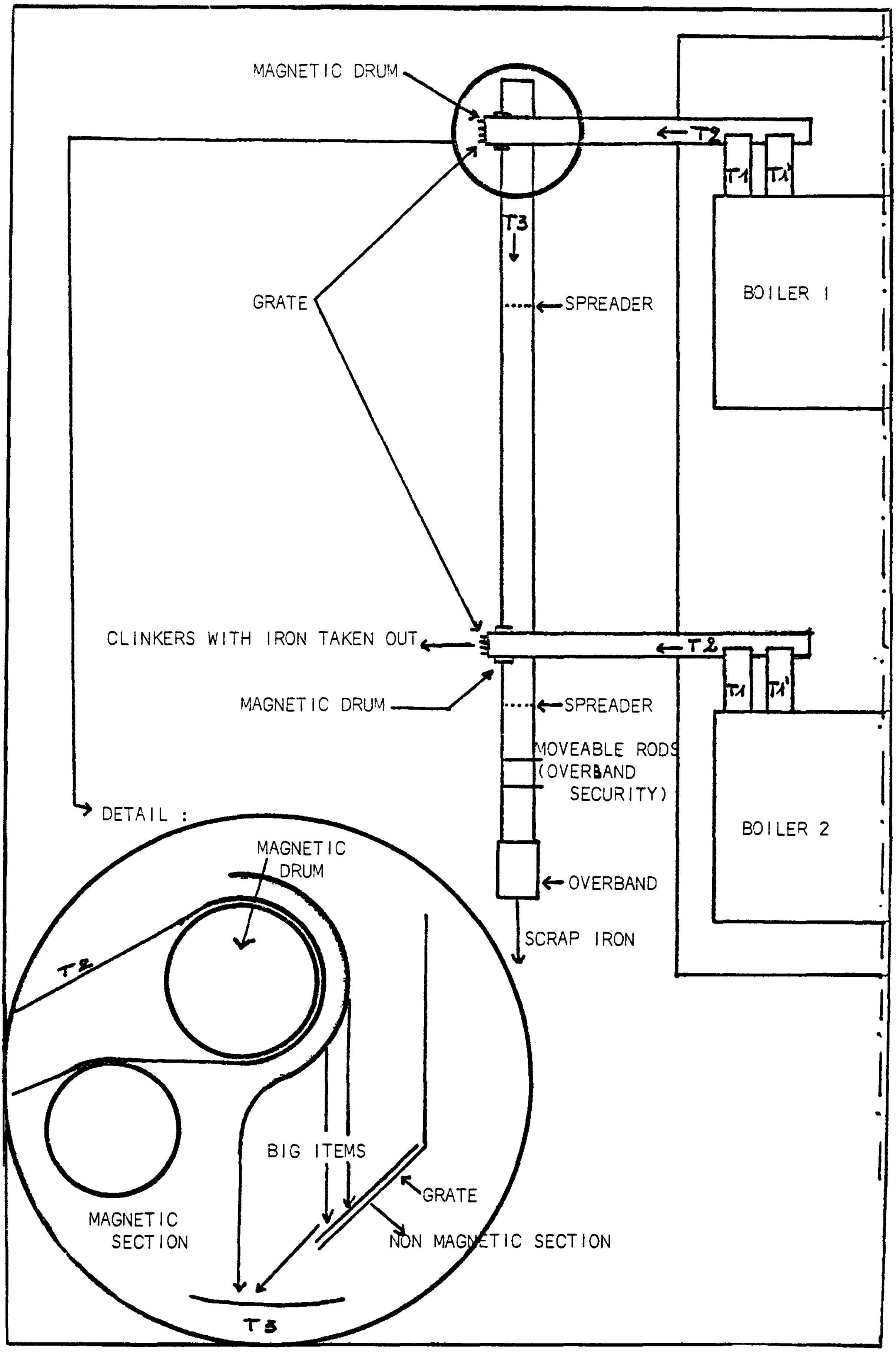
This method of iron removal improves the clinker quality, and makes easier its utilization as filler.

I.I.2. Extraction of scrap iron with size reduction.

Hazemag Process :

Hazemag mechanical constructions have, for instance, designed a process which relies on the use of an impact-shredding : iron scraps are liberated and the slag, finely reduced, can be used after sizing for road embankements or as an additive to concrete (Cf figure 3).

The plants thus equipped in the Common Market countries are as follows :



REMOVING IRON FROM CLINKERS (TIRU Works - Ivry)
Fig. 2

1. Incinerator
2, 3, 6, 10 + 13. Conveyors
4. Crusher HAZEMAG
5. Vibrating extractor

7. Magnetic separator
8 + 9. Hopper and vibrating screen
11 + 12. Hopper and vibrating screen
14. Hopper
15. Outputs hoppers

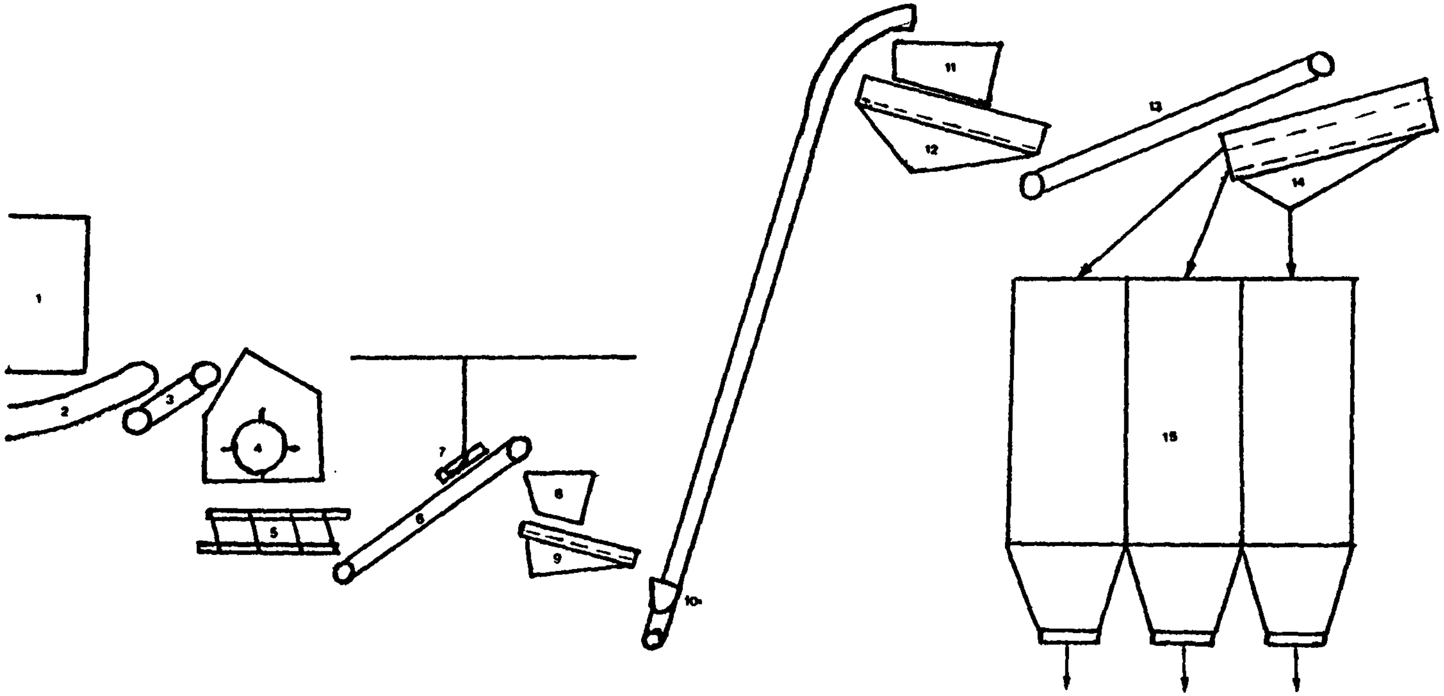


Fig.3
HAZEMAG PROCESS OPERATIONS

		shredder type	input	Starting up year
HAMBURG	Germany	Shredder SAP 4	15 t/h	1963
MUENCHEN	Germany	Shredder AP 4/S	20 t/h	1964
STUTTGART	Germany	Shredder AP 4/S	20 t/h	1965
FRANCFORT	Germany	Shredder AP 4/S	20 t/h	1965
ROTTERDAM	Netherlands	Shredder SAP 4/S	15 t/h	1967
ROTTERDAM	Netherlands	Shredder SAP 4/S	15 t/h	1967
KASSEL	Germany	Shredder SAP 3/S	10 t/h	1968
AMSTERDAM	Netherlands	Shredder AP 4/S	20 t/h	1969
AMSTERDAM	Netherlands	Shredder AP 4/S	20 t/h	1969
ROTTERDAM	Netherlands	Shredder AP 4/Sm	20 t/h	1971
ROTTERDAM	Netherlands	Shredder AP 4/Sm	20 t/h	1971
LENS	France	Shredder AP 4/Sm	20 t/h	1973
HENIN-LIETARD	France	Shredder AP 4/Sm	20 t/h	1974

However, the power required and the too-high operating costs can be an obstacle to the development of such a process (as in the case of the towns of Lens and Henin-Lietard where a direct scrap extraction seems now prefered).

CLESID Process :

CLESID (Creusot-Loire Equipement Sidérurgique) is proposing at the present time, another way to process incinerator residues.

That consists essentially of :

- A specific shredder : it is composed of a blades-equipped rotor, turning in an armour-plated envelope fitted with counter blades which can move aside in the case of clogging or in the presence of too-hard pieces ; an exit grate allows the sizing of the output.
- An ancillary handling and sorting equipment : the shredded products are treated by a magnetic drum which separates iron scraps, while dusts are aspirated and concentrated by an air cyclone.

1.1.3. Another mentionned process.

A process, designed in Italy, is oriented toward iron-scrap separation, at the same time as the slag is washed and screened (Cf figure 4) :

- The small fraction under 2 mm would be used as mineralizer for organic fertilizer,
- The intermediate fraction, between 2 and 20 mm, would be used in

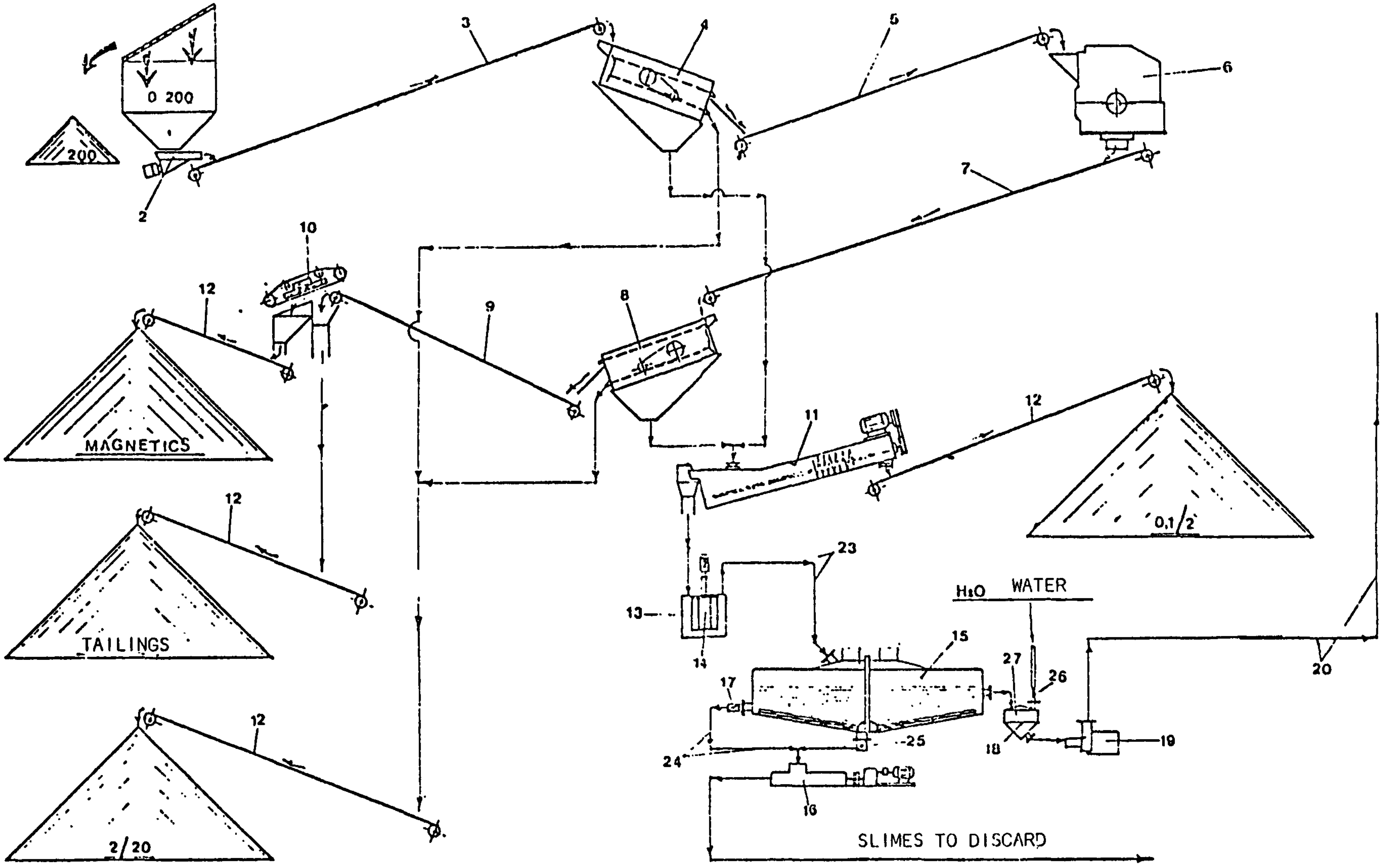


Fig. 4
ITALIAN PROCESS FOR RECUPERATING IRON SCRAPS.
TO RECOVER.

road-making,
- Magnetics are recovered from the coarser fraction.

1.2. PROCESSES FOR TOTAL BENEFICIATION.

For about ten years, several countries have performed research oriented toward the extraction of values from incinerator clinkers. The processes thus developped generally need : simple unit operations only (shredding, milling magnetic separation, flotation ...) and are the following :

- U.S.A. : U.S. Bureau of Mines - Raytheon Process,
- France : B.R.G.M. Process,
- Italy : Instituto Mineraria de Cagliari Process,
- United Kingdom : Warren Spring Laboratory Process.

1.2.1. U.S.B.M.-Raytheon Process.

U.S. Bureau of Mines, now in co-operation with Raytheon Service Company, develops a process, the flowsheet of which has been designed in a 500 Kg/h pilot plant, with the following operations (Cf fig.5).

- Primary screening of the input at 1 1/4" (3,2 cm) in a 3 ft (91 cm) in diameter by 10 ft (305 cm) in length trommel.
- Secondary screening of the undersize fraction at 4 mesh and 20 mesh (0,8 cm).
- Hand picking of the very big iron pieces contained in the oversize fraction which then is shredded with the 4 mesh fraction.
- Screening of the products at 4 mesh and 20 mesh.
- Treatment of all the + 4 mesh fractions :
  - . Magnetic separation by a permanent magnet drum separator,
  - . Secondary shredding of non-magnetics and screening of the products at 4 and 20 mesh.
- Treatment of all the - 4 + 20 mesh fraction :
  - . Magnetic separation by electro-magnetic drum separator,
  - . Dewatering of the non-magnetic particles,
  - . Jigging of the underflow, separated into a light fraction (unburnt material), a heavy fraction (heavy non-ferrous metals) and an intermediate fraction (slag, glass and light non-ferrous metals).
- Treatment of intermediate products :
  - . Roll-milling and size extraction of light metals over 6 mesh (3,3mm),
  - . 16 mesh (1,1 mm) screening and size reduction of the - 6 mesh + 16 mesh fraction, either in a roll mill or a rod mill,
  - . Further extraction of light non-magnetic metals over 14 mesh (1,2 mm) from the milled products.
- 14 mesh fraction beneficiation :
  - . Extraction of the non-magnetic glass powder by high-intensity magnetic wet separator,
  - . Glass recovery by flotation

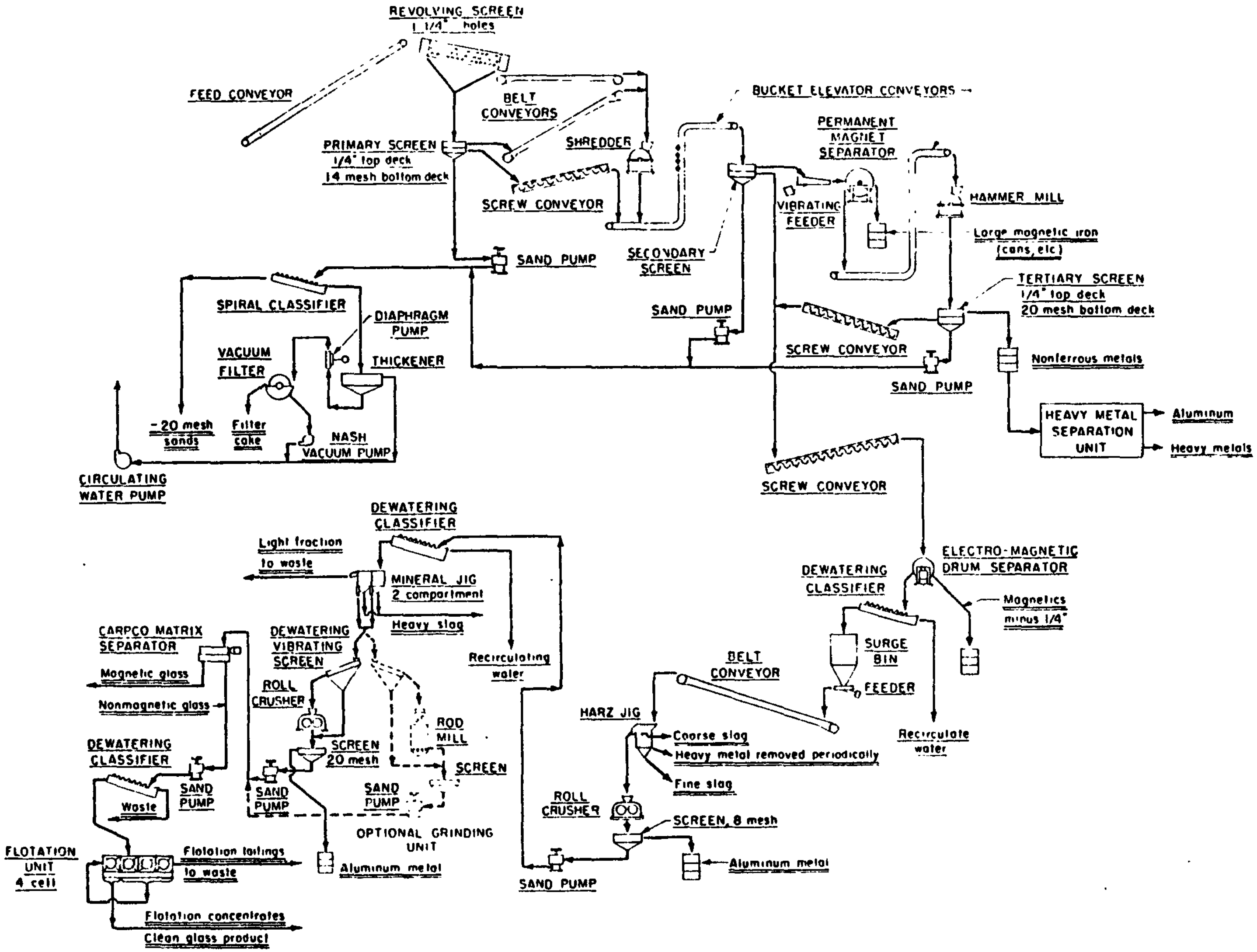


Fig. 5

U.S.B.M. PROCESS FOR MAKING USE OF INCINERATOR RESIDUES :

GENERAL FLOWSHEET

The main outlines of this treatment for a 30 t/h plant projected in LOWELL (Massachusetts) are, as shown in fig. 6 :

- 1'1/4" wet screening by trommel.
- Oversize treatment :
  - . Hand picking of metallic "monsters",
  - . Shredding
  - . Primary scrap extraction by magnetic drum.
- Undersize treatment :
  - . Dewatering,
  - . Fine scrap extraction by electro-magnetic drum.
- Non-ferrous metals extraction in the non-magnetic products :
  - . Jig separation of heavy non-ferrous metals, intermediate fraction and light unburnt elements,
  - . Milling of the intermediates and size extraction of light non-ferrous metals.
- Glass powder concentration from the residual non-metallic fraction :
  - . Elimination of the slag, bricks, tiles and stones by flotation,
  - . Glass concentrate cleaning by high intensity magnetic wet separation.

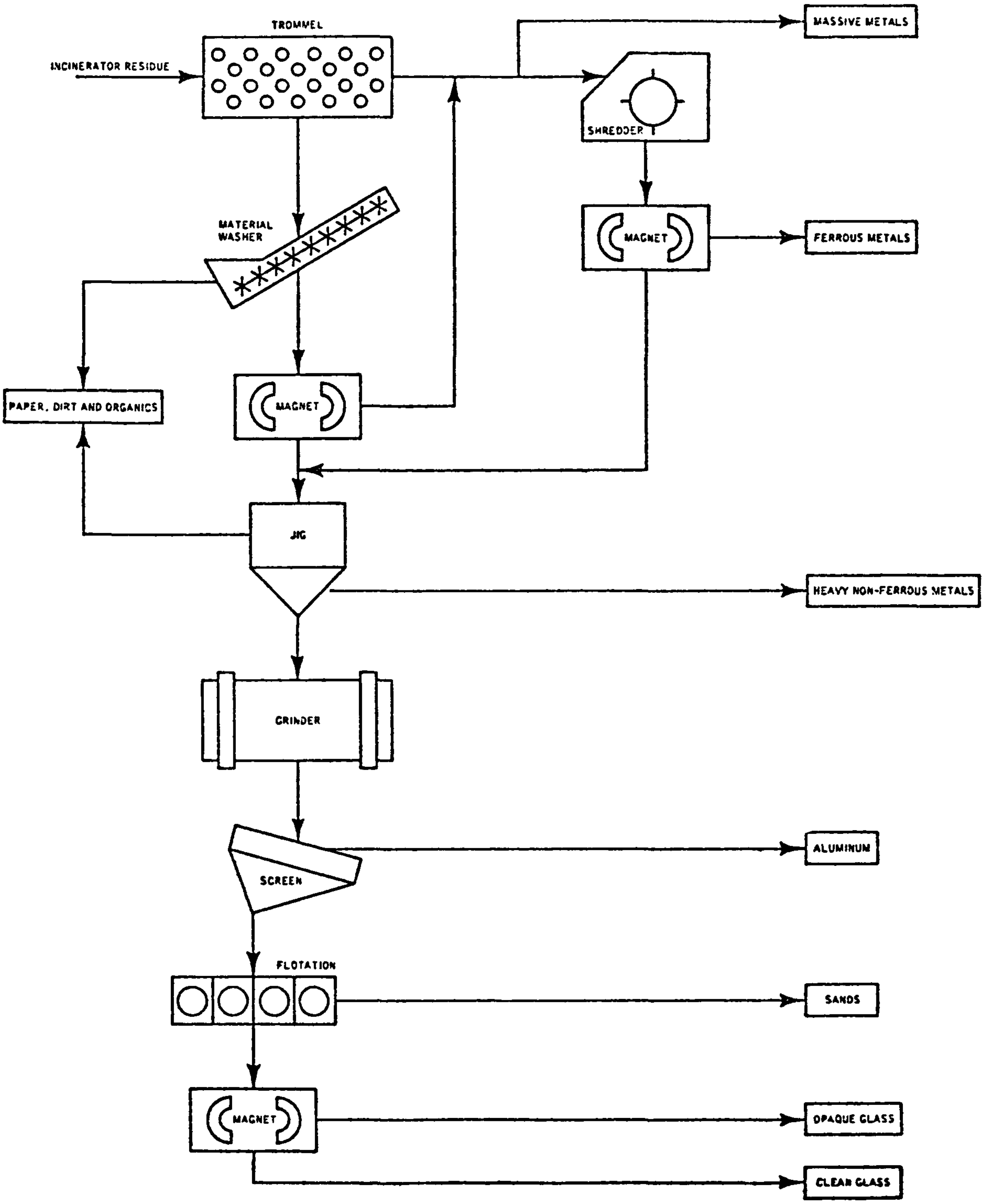
1.2.2. B.R.G.M. Process.

The flowsheet tested at a 1 t/h pilot scale is based on the following operations (Cf figure 7) :

- Separation of elements over 200 mm.
- Screening of the undersize in a trommel punched with 30 mm holes.
- Treatment of the trommel oversize by :
  - . Differential crushing in a hammer -mill which allows the separation of shredded scrap from associated slags,
  - . Magnetic extraction of iron scraps.
- Treatment of the trommel undersize and the non-magnetics by :
  - . Screening at 30 mm to concentrate non-ferrous scrap,
  - . Wet milling of the - 30 mm fraction in a rod mill which flatens the metallic elements and reduces the non-metallic ones.
  - . Extraction of metallic fractions by screening at 2 mm.
- Treatment of the non-metallic pulp :
  - . Wet magnetic separation of iron oxydes and mill-scale,
  - . Recovery of the + 0,1 mm solids by screening,
  - . Thickening of the - 0,1 mm pulp,
  - . Filtering of the underflow, with eventually recycling of all the waters.

As a result of these various operations, the outputs are therefore :

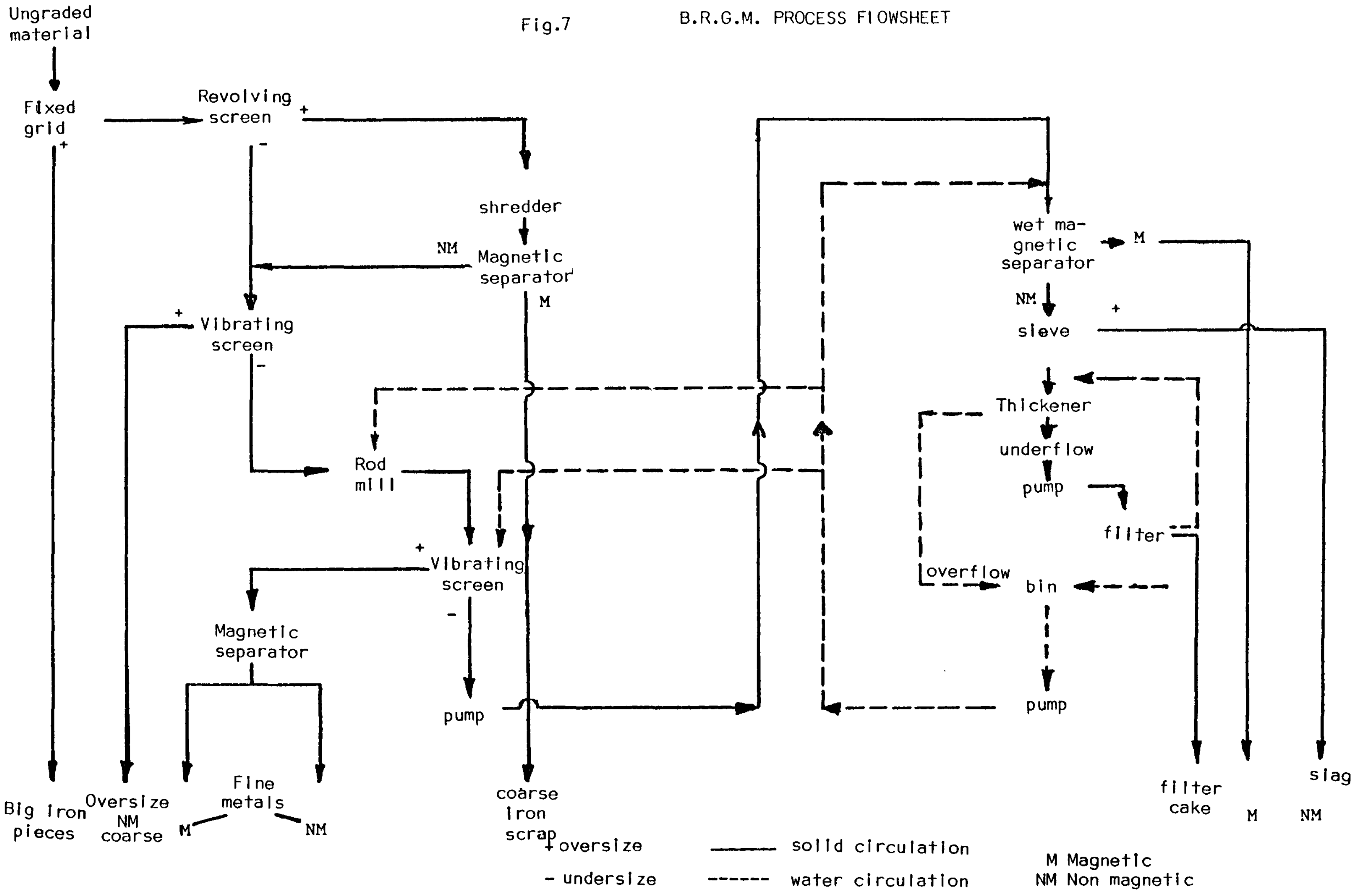
- Magnetic scrap :
  - . Bulky, over 200 mm,
  - . Coarse, between about 30 and 200 mm containing tin-cans mostly,
  - . Fine between about 2 and 30 mm.
- Non-ferrous metals :
  - . Coarse, between about 30 and 200 mm,
  - . Fine, between about 2 and 30 mm.
- Minus 2 mm slags :
  - . Magnetic, enriched in iron containing products,
  - . Non magnetic : glass enriched-fraction over 0,1 mm and filter cake.



FLOWSHEET FOR THE BENEFICIATION OF LOWELL (Mass.) CLINKERS

Fig. 6

Fig.7 B.R.G.M. PROCESS FLOWSHEET



1.2.3. I.M.C. Process.

In this process worked out by Cagliari Mining Institute, the separation of the iron pieces and the non-ferrous metals as well as the extraction of glass, is carried out by dry method (Cf fig. 8); after size separation, ferrous metals are extracted, glass and non-ferrous alloys also.

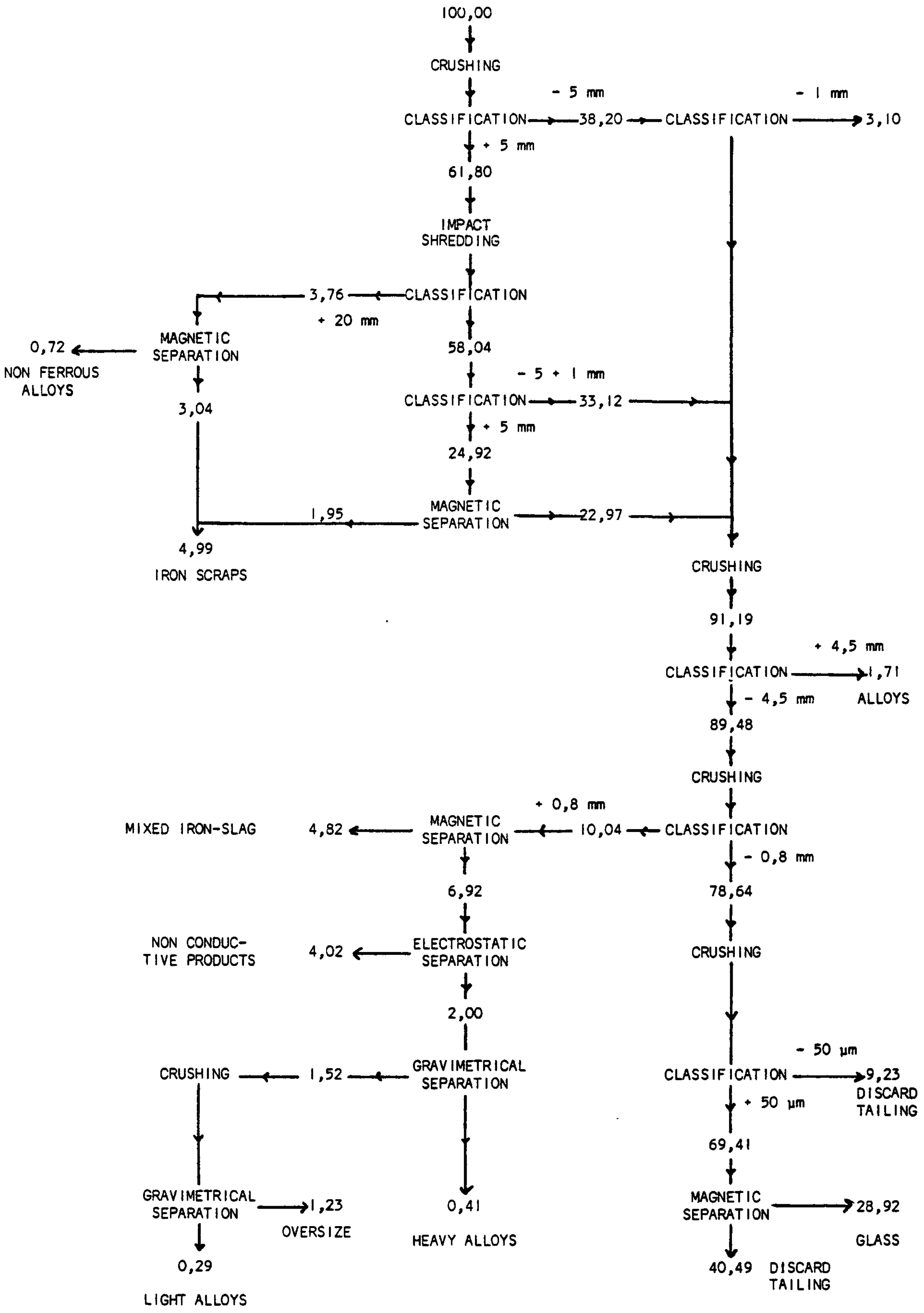
The final outputs are made up with :

- 6,7 Kgs of light non-ferrous metals
- 3,9 Kgs of heavy non-ferrous metals
- 509 Kgs of ferrous metals
- 260 Kgs of glass, per tonne.

1.2.4. W.S.L. Process.

The following operations were tested on a pilot scale on the site of the Sutton incinerator (Cf fig. 9) :

- Screening of the input by a + 6" (15 cm) grizzly and discard of the oversize.
- Drying and shredding of the undersize.
- Screening at 3/4" and 8 mesh (1,9 cm and 2,4 mm) of the products :
  . That 3/4"fraction, after magnetic scrap removal by overband, is processed on a fluid bed separator which separates light and heavy non-ferrous metals,
  . The - 3/4" + 8 mesh fraction, after scrap removal, is reduced in a roll mill and screened at 1/4" (0,6 mm) and 8 mesh (2,4 mm),
  . The + 1/4" join up with the + 3/4" before the overband,
  . The - 1/4" + 8 mesh are crushed in a roll mill and screened at 8 mesh, the oversize joins the + 3/4" fraction also,
  . All the - 8 mesh are conveyed to discard.



I.M.C. FLOWSHEET FOR CLINKERS BENEFICIATION

Fig. 8

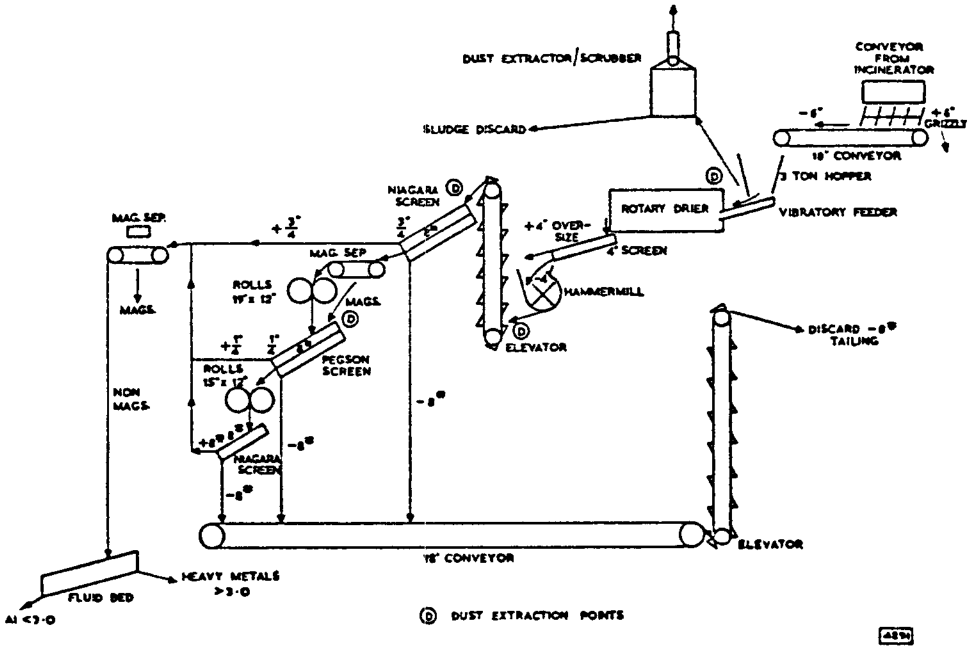


Fig. 9

W.S.L. PILOT PLANT FLOWSHEET

2. RECOVERY OF METALS FROM FLY ASHES.

Fly ashes are disposed either mixed with the clinker, or separately.

In the former case, that represents a small proportion compared to clinker, and would probably bring no important changes in the beneficiation processes above described.

In the latter case, its overall utilization does not yet seem to have been specifically studied, nor developed in particular. The thermic removal of some non-ferrous metals contained in the range of a few thousand p.p.m. (tin, copper) or even higher (lead, zinc) has however been considered by BRGM :

- Under inert atmosphere at temperatures not exceeding 900°C, recovery rates around 90 % are reached for lead, zinc and tin.
- Under ambient atmosphere, the following extraction rates are obtained ;

Element	750°C	950°C
Pb	94	95
Cu	75	98
Zn	28	46

Accordingly, under relatively simple experimental conditions, the extraction of lead, copper, zinc and tin seems possible under temperatures below 900°C, the recuperation rates exceeding 90 % and sometimes reaching 98 %, depending on the treatment atmosphere :

- In inert conditions, the extraction of copper remains moderate.
- In oxyding conditions, practically no tin is extracted and only a little zinc.

3. PRODUCTS UTILIZATION.

3.1. TOTAL CLINKER UTILIZATION IN PUBLIC WORKS AFTER IRON-REMOVAL.

The problems linked up with this field of utilization depend upon scrap iron content, presence of components uncompatible with concrete, and variation in volume as a result of water absorption.

3.1.1. Effect of residual scrap iron.

At the present time, studies are being carried out in the Netherlands for the town of Amsterdam, on the oxydation of the residual scrap iron contained in clinkers. They show that a compaction under a 2 kg/cm^2 pressure avoid water penetration into a road basement made up of clinker mixed with 5 % cement and 7 % asphalt, and stop ferrous metals oxydation (Hielsbergen A., Kellerman G.H., Van de Brink J. - Use of incinerator slag as a road base material).

3.1.2. Changes in volume as a result of water action.

(Study directed by the Staatliches Material Prüfungsamt Nordrheim Westfalen - Dortmund).

Tests were made on the smelling of clinker samples as a function of their moisture content. After forty days, it was seen, for example, that differences in length are as following :

- New clinkers	0,82 mm./m
- Already dumped clinkers	0,53 mm./m

3.1.3. Incompatibility with concrete.

(Study carried out by the S.M.N.W. Dortmund).

The components of clinker which could be incompatible with concrete are in the following proportions (%) :

	New clinker	Already dumped clinker
CaO	7,6	7,3
MgO	1,1	2,7
SO^3	0,4	0,4
Cl^-	0,5	0,3
NH_4^+	traces	traces
S^{2-}	<0,1	<0,01

Thus, they only occur in limited quantities, so the concrete would not be affected by them.

3.2. UTILIZATION OF THE DIFFERENT CONSTITUENTS OF CLINKER.

3.2.1. Magnetic metals.

3.2.1.1. Quality.

Only the products of the B.R.G.M. and U.S.B.M. processes will be described, the similarity between the results allowing generalization.

B.R.G.M. Process.

Studies were based on clinker coming from incinerators of Paris (Ivry), Metz, Lyon and Paris (St Ouen). They allow certain comparisons about the differences of quantity and composition as a result of incinerators capacity and site to be made.

The quantities of scrap iron recovered show seasonal variations :

In Paris, low values in summer and the beginning of the year, high in the middle of autumn.

In Metz, generally smaller amounts with minima at the beginning of autumn and the end of winter.

Analytical results are set out in tables 29 and 30.

The light can scraps stand out by their high content in sulphur, phosphorous, tin and lead, low content in silicium, nickel and copper : scraps coming from Ivry contain more silicium, copper, nickel and cobalt than Metz ones.

The higher content in tin and lead at Metz seems to be explained by the fact that the incineration temperature is lower there.

The elements, which could be noxious to recycling, are, therefore :

- Sulphur in higher content at Ivry than at Metz.
- Copper, as combined in light scraps and associated in heavy ones.
- Tin coming from tin plate coating, which makes up most of the light scrap.

U.S.B.M. Process.

The compositions of ferrous products are set out in the table 31.
They also show high copper and tin contents.

3.2.1.2. Possibilities of utilization.

Recycling problems.

The ultimate copper content of the scrap iron usually ranges from 0,1 to 0,2 %. As the iron scraps recovered from clinkers contain up to 4 % copper, some utilization limits can appear. U.S. Bureau of Mines has thus performed many researches in this field :

ELEMENT	LIGHT SCRAP - 200 + 2mm			HEAVY SCRAP - 200 + 30 mm		
	MINIMUM CONTENT %	AVERAGE CONTENT %	MAXIMUM CONTENT %	MINIMUM CONTENT %	AVERAGE CONTENT %	MAXIMUM CONTENT %
Fe	81,0	85,0	88,2	80	83,9	87,7
Mn	0,27	0,40	0,52	0,28	0,37	0,45
S	0,110	0,150	0,207	0,110	0,113	0,115
P	0,045	0,116	0,251	0,034	0,087	0,140
Si	0,969	1,68	2,81	1,88	1,99	2,09
Ni	0,149	0,150	0,165	0,147	0,166	0,185
Mo	< 0,01	-	0,018	< 0,01	-	0,02
V	< 0,005	-	< 0,01	< 0,005	-	< 0,01
Co	0,012	0,043	0,074	-	0,09	-
Cu	0,92	1,02	1,21	1,05	1,12	1,19
Sn	0,180	0,196	0,210	0,078	0,098	0,117
Pb	0,004	0,028	0,050	0,004	0,005	0,005

TABLE N° 29

CHEMICAL COMPOSITION OF FERROUS METALS RECOVERED FROM CLINKERS BY B.R.G.M. PROCESS

IVRY RESULTS

ELEMENT	LIGHT SCRAP - 200 + 2mm			HEAVY SCRAP - 200 + 30 mm		
	MINIMUM CONTENT %	AVERAGE CONTENT %	MAXIMUM CONTENT %	MINIMUM CONTENT %	AVERAGE CONTENT %	MAXIMUM CONTENT %
Fe	82,0	83,75	87,0	82,5	85,0	87,5
Mn	0,318	0,411	0,534	0,620	0,648	0,672
S	0,073	0,093	0,120	0,063	0,071	0,079
P	0,044	0,057	0,071	< 0,010	0,050	0,094
Si	1,20	1,43	1,73	1,650	1,707	1,764
Ni	0,081	0,098	0,124	0,126	0,135	0,144
Mo	< 0,005	-	0,008	< 0,010	< 0,010	0,010
V	< 0,005	-	< 0,01	< 0,005	< 0,01	< 0,01
Co	< 0,005	< 0,005	< 0,005	-	< 0,005	-
Cu	0,335	0,479	0,550	0,632	0,901	1,170
Sn	0,219	0,241	0,259	0,074	0,089	0,103
Pb	0,013	0,021	0,032	0,003	0,018	0,032

TABLE N° 30

CHEMICAL COMPOSITION OF FERROUS METALS RECOVERED FROM CLINKERS BY B.R.G.M. PROCESS

METZ RESULTS

SAMPLE N°	C	S	Mn	P	Sn	Cu	Cr	Ni	Mo	Pb	Si
1. coarse	1,62 *	0,03	<1,0	<0,02	0,20	0,37	<0,03	<1,0	<0,01	<0,01	0,13
2. coarse **	0,02	0,03	0,01	0,03	0,16	0,44	0,01	0,10	0,02	0,10	-
3. coarse	0,04	0,06	0,02	<0,01	0,24	0,22	-	-	-	-	0,10
4. coarse	0,04	0,04	0,01	<0,01	0,21	0,32	-	-	-	-	0,10
5. fine	0,20	0,12	<0,1	<0,02	0,20	0,38	<0,03	<1,0	<0,01	<0,01	<0,05
6. fine	1,35 *	0,04	0,10	0,06	0,17	0,24	0,05	0,35	<0,01	<0,01	0,11

* Carbon probably picked up from clay-graphite crucible used in smelting.

** Mean of 20 melts independently smelted and analysed by a major steel producer

TABLE N° 31

U.S.B.M. PROCESS

TYPICAL COMPOSITIONS OF FERROUS METAL SMELTED FROM INCINERATOR RESIDUE PRODUCTS, PERCENT

- in the laboratory, a process of elimination by melted salts was tested : this consists in separating the copper as sulfide, after sodium sulphate addition (copper removal from molten ferrous scrap : a pilot study - Bureau of Mines report investigation - 1974 - RI 7914) ;

- copper dissolution in an ammoniacal solution has also been studied according to the following reaction :

$$Cu^{o} + Cu(NH_3)_4^{++} \rightarrow 2Cu(NH_3)_2^{+}$$

$$2Cu(NH_3)_2^{+} + (NH_4)_2CO_3 + 2NH_4OH + 1/2O_2 \rightarrow 2Cu(NH_3)_4 + CO_2 + 3H_2O$$

(Reducing copper or tin impurities in ferrous scrap recovered from incinerated main refuse - Bureau of Mines report of investigation - 1973 - RI 7776 - p.3/4).

Another study was conducted to determine problems associated with the use of ferrous fractions from urban refuse as melting stock for steelmaking and to evaluate the resulting steel products. The study involved 50-pound ingots from laboratory melts and 50-pound ingots from 1 ton electric-arc-furnace melts. The 50 pound ingots from the laboratory melts and the arc-furnace melts were hot rolled to provide materialsfor mechanical and corrosion testing. Results include the following : most steels rolled successfully and exhibited acceptable surface and edge condition. Tensile strengths of the plain carbon steels were not significantly affected by copper up to concentrations of 0,65 % and were not affected by tin content up to 0,16 %. Yield strength increased with increasing copper and tin contents, and impact strength decreased with increasing tin content. Hardness increased slightly with increasing copper content. In general, properties of the steel produced were not measurably affected by charge composition (that is, melting stock), melting practice, or method of scrap preparation.

Industrial utilizations.

Scrap iron extracted from incinerator clinkers is suitable for blast furnaces or steel making furnaces because of its weak density which allows the charges to be ventilated. The supply possibilities to steel industry would however be more important, but need to dilute the impurities in charge of better quality, which is made during high demand periods.

As for special copper steels and castings, their market seems limited.

3.2.2. Non-magnetic metals.

3.2.2.1. Quality.

B.R.G.M. Process.

The results set out in the tables 32 and 33 refer to Ivry and Metz incinerators : it may be noted that at Ivry, compared to Metz, the light products contain more copper, silicium and alloyed iron and less zinc, lead, tin. The heavy products have higher contents of copper, silicium, alloyed iron and nickel and lower contents of zinc and tin. This could result from the more intensive incineration method used at Ivry, which would create thermodynamic conditions more favourable

ELEMENT	LIGHT METALS						HEAVY METALS					
	CONTENTS OF SMELTED PRODUCTS			QUANTITY OF METALLIC ELEMENTS RECOVERABLE BY SMELTING OF 100 KG OF LIGHT CONCENTRATE (KG)			CONTENTS OF SMELTED PRODUCTS			QUANTITY OF METALLIC ELEMENTS RECOVERABLE BY SMELTING OF 100 KG OF HEAVY CONCENTRATE (KG)		
	MINIMUM	AVERAGE	MAXIMUM	MINIMUM	AVERAGE	MAXIMUM	MINIMUM	AVERAGE	MAXIMUM	MINIMUM	AVERAGE	MAXIMUM
Free iron				2,83	5,40	8,60				16,59	37,55	54,4
Stainless steel				-	0,28	0,85				0,38	1,83	3,84
Smelting efficiency before iron removal				69,40	74,85	78,90				40,51	55,66	71,61
Al	92,5	94,19	95,62	64,20	71,63	78,90				0,15	2,06	4,28
Cu	1,07	1,55	2,25	0,84	1,15	1,56	57,80	62,29	70,06	23,41	34,87	47,29
Mg	0,03	0,05	0,10	0,02	0,04	0,08	-	-	-	-	-	-
Si	1,55	2,20	2,60	1,16	1,64	1,81	0,66	1,69	3,00	0,27	1,07	2,15
Alloyed iron	0,72	1,14	1,55	0,54	0,85	1,08	0,12	0,31	0,46	0,09	0,17	0,24
Mn	0,11	0,14	0,18	0,09	0,11	0,14	traces	0,05	0,15	traces	0,02	0,06
Ni	0,03	0,05	0,08	0,02	0,04	0,06	0,39	0,44	0,48	0,16	0,24	0,32
Zn	0,08	0,34	0,49	0,06	0,26	0,37	19,82	22,5	26,40	8,18	12,55	18,91
Pb	0,03	0,14	0,24	0,02	0,11	0,19	4,42	10,20	15,59	2,98	5,20	6,84
Sn	traces	traces	0,02	traces	traces	0,02	0,55	0,70	0,88	0,22	0,39	0,47
Ti	0,02	0,03	0,03	0,02	0,02	0,02	-	-	-	-	-	-

TABLE N° 32
CHEMICAL COMPOSITION OF NON MAGNETIC METALS
RECOVERED FROM CLINKERS BY B.R.G.M. PROCESS

IVRY RESULTS

ELEMENT	LIGHT METALS						HEAVY METALS					
	CONTENTS OF SMELTED PRODUCTS			QUANTITY OF METALLIC ELEMENTS RECOVERABLE BY SMELTING OF 100 KG OF LIGHT CONCENTRATE (KG)			CONTENTS OF SMELTED PRODUCTS			QUANTITY OF METALLIC ELEMENTS RECOVERABLE BY SMELTING OF 100 KG OF HEAVY CONCENTRATE (KG)		
	MINIMUM	AVERAGE	MAXIMUM	MINIMUM	AVERAGE	MAXIMUM	MINIMUM	AVERAGE	MAXIMUM	MINIMUM	AVERAGE	MAXIMUM
Free iron				1,20	2,58	5,47				6,08	8,91	12,20
Stainless steel				traces	0,22	0,70				0,30	1,19	2,50
Smelting efficiency before iron removal				76,52	80,30	81,60				73,20	76,67	82,67
Al	94,76	95,29	96,01	73,47	76,51	78,02	0,70	1,51	2,27	0,48	1,18	1,87
Cu	0,77	1,03	1,30	0,63	0,82	1,06	55,48	59,15	62,70	42,56	46,99	53,22
Mg	0,01	0,05	0,10	0,01	0,05	0,08	-	-	-	-	-	-
Si	1,40	1,74	2,04	1,07	1,40	1,66	0,29	1,11	2,10	0,21	0,87	1,74
Alloyed iron	0,62	0,80	1,01	0,47	0,64	0,82	0,05	0,15	0,22	0,04	0,11	0,15
Mn	0,14	0,18	0,20	0,11	0,14	0,16	traces	0,02	0,04	0,02	0,02	0,03
Ni	0,03	0,06	0,10	0,02	0,05	0,07	0,26	0,38	0,47	0,19	0,29	0,32
Zn	0,34	0,51	0,67	0,28	0,41	0,55	20,76	28,93	34,00	14,20	22,49	28,01
Pb	0,12	0,29	0,46	0,09	0,23	0,37	6,15	10,95	17,74	4,61	6,08	14,62
Sn	traces	0,04	0,12	traces	0,03	0,10	0,43	0,74	1,00	0,31	0,57	0,82
Ti	0,01	0,03	0,04	0,01	0,02	0,02	-	-	-	-	-	-

TABLE N° 33
CHEMICAL COMPOSITION OF NON MAGNETIC METALS
RECOVERED FROM CLINKERS BY B.R.G.M. PROCESS

METZ RESULTS

to the volatilization of metals like lead, copper, zinc and tin. They would also favour the development of aluminothermic reactions.

U.S.B.M. Process.

The composition of aluminous phases is shown in the table 34.

As for the heavy non-ferrous products, after smelting, they give the compositions shown in the table 35.

W.S.L. Process.

The compositions of light and heavy metallic concentrates are set out in the table 36.

3.2.2.2. Possibilities of recycling light non-ferrous fractions.

In France, for instance, these products come under the term "déchets de casserole" ("pan scrap"). They are used, to obtain either aluminum (secondary smelting), or to elaborate special alloys.

3.2.2.3. Possibilities of recycling heavy non-ferrous fractions.

These products can be put into the category "laiton mêlé" ("mixed brass") containing 45 to 80 % of copper, and recycled of as follows :

- smelted in a water-jacket furnace, producing a copper matte, and converted into blister copper containing 98 to 99 % copper which can be refined by electrolysis, removing residual impurities like lead, arsenic, antimony and bismuth ;
- the extraction by hydrochloric leaching has, on the other hand, been studied (The cupric chloride hydrometallurgical process for recovery from scrap - Journal of Metals - July 1976) ;
- treatment by differential sweating is also being performed at the moment.

3.2.3. Associated slags.

3.2.3.1. Quality.

As an illustration, the compositions of the different fractions separated by the B.R.G.M. process are set out in detail for the case of clinkers coming from Ivry and Metz incinerators (Cf table 37 and 38).

3.2.3.2. Possibilities of using non-magnetic phases.

The compositions of non-magnetic products can be compared with those of raw or synthetic materials, which are used by industry :

SAMPLE N°	Al*	Cu	Zn	Fe	Pb	Sn	Mg	Mn	Si
1	97,55	0,16	0,03	1,3	0,12	0,012	0,38	0,30	0,15
2	97,31	0,43	0,24	0,83	0,43	0,03	0,02	0,41	0,30
3 *	96,5	0,5	0,3	0,9	0,1	<0,05	<0,05	0,1	1,5
4 *	97,0	0,2	0,2	0,8	0,2	<0,05	<0,05	0,05	1,0
5	96,5	0,6	0,3	0,8	0,1	<0,05	0,4	0,6	0,7
6 * #	94,1	1,10	0,35	0,95	0,10	-	0,10	0,40	2,80

* Obtained by difference.
** Smelted, sampled, and analyzed by major aluminum producer.
\# Also contains 0,05 percent each Cr, Ni, Ti and Bi.

TABLE N° 34
TYPICAL COMPOSITIONS OF ALUMINUM SMELTED FROM
INCINERATOR RESIDUE PRODUCTS, IN PERCENT
U.S.B.M. PROCESS

Sample N°	Cu*	Zn	Al	Fe	Pb	Sn	Ni
1	54,5	35,7	3,8	1,3	3,3	0,6	0,8
2	59,3	35,8	0,25	0,10	4,3	0,22	-
3	54,65	35,85	2,44	0,30	5,54	1,19	-
4	56,4	33,5	2,78	1,39	2,86	1,4	1,65
5	50,4	38,5	3,52	0,84	4,93	0,30	1,48

U.S.B.M. Process

TYPICAL COMPOSITIONS OF HEAVY-NON FERROUS METALS
SMELTED FROM INCINERATOR RESIDUE PRODUCTS,
IN PERCENT

TABLE N° 35

PRODUCT	Cu	Ni	Pb	Al	Zn	Fe	Sn	Ag	Si
Heavy metal ("Cu")	51,7	0,64	3,4	2,18	40	0,50	0,50	0,15	
Light metal ("Al")	2,6	0,2	0,6	88	4,2	0,7	2		1,1

TABLE N° 36
W.S.L. PROCESS
CHEMICAL ASSAYS (WT. %) OF NON-FERROUS METAL PRODUCTS

	SIEVING OVERSIZE			MAGNETIC SLAG			FILTER CAKE		
	MINIMUM	AVERAGE	MAXIMUM	MINIMUM	AVERAGE	MAXIMUM	MINIMUM	AVERAGE	MAXIMUM
SiO_2 %	50,80	54,02	56,60	23,85	25,27	26,30	42,70	44,45	46,60
Al metal %	0,40	0,48	0,60	0,16	0,19	0,20	0,29	0,35	0,38
Al_2O_3 %	5,65	6,94	7,70	4,15	5,04	5,90	6,90	7,59	8,25
Fe metal %	0,40	0,53	0,74	4,40	5,13	6,10	0,68	0,76	0,80
FeO %	4,35	7,26	9,25	18,45	20,97	26,45	2,95	6,02	7,55
Fe_2O_3 %	-	4,60	8,95	19,65	23,76	31,30	0,90	4,54	8,50
MnO %	0,23	0,24	0,27	0,38	0,47	0,62	0,37	0,41	0,46
MgO %	1,75	2,39	3,10	1,50	2,10	2,95	2,00	3,26	4,65
CaO %	10,80	11,07	11,35	6,75	7,16	7,60	13,75	15,01	16,10
Na_2O %	6,20	6,70	7,80	2,80	2,84	3,00	4,65	4,91	5,50
TiO_2 %	0,46	0,57	0,73	0,47	0,79	1,58	0,57	0,63	0,69
K_2O %	1,00	1,05	1,10	0,45	0,55	0,65	0,80	1,00	1,15
P_2O_5 %	0,82	0,93	1,07	0,70	0,79	0,84	1,08	1,17	1,25
Cl %	0,04	0,05	0,07	0,04	0,05	0,07	0,07	0,13	0,21
S %	0,24	0,27	0,30	0,30	0,37	0,50	0,78	1,17	1,78
H_2O^- %	0,22	0,33	0,60	0,10	0,25	0,60	0,25	0,70	0,90
H_2O^+ %	0,35	0,52	0,65	0,10	0,32	0,55	0,90	1,21	1,80
C Total %	1,80	2,37	2,75	0,17	0,56	1,08	2,10	2,82	3,45
C organic %	0,60	1,33	1,96	-	0,29	0,87	1,28	1,91	2,80
Cu ppm	625	910	1 200	1 850	2 880	4 250	1 200	1 420	1 700
Zn ppm	2 250	2 490	2 900	2 400	3 010	3 400	4 900	6 300	9 300
B ppm	150	210	245	30	90	145	65	170	260
Pb ppm	1 100	1 200	1 440	1 100	1 250	1 380	1 500	2 050	2 700
Sn ppm	160	320	380	390	720	950	215	600	800

TABLE N° 37

CHEMICAL COMPOSITION OF SLAGS RECOVERED FROM CLINKERS BY B.R.G.M. PROCESS

IVRY RESULTS

	SIEVING OVERSIZE			MAGNETIC SLAG			FILTER CAKE		
	MINIMUM	AVERAGE	MAXIMUM	MINIMUM	AVERAGE	MAXIMUM	MINIMUM	AVERAGE	MAXIMUM
SiO_2 %	56,00	56,50	57,50	22,40	24,60	26,00	44,70	46,50	49,20
Al metal %	0,33	0,38	0,40	0,14	0,18	0,22	0,29	0,38	0,42
Al_2O_3 %	5,90	6,50	6,85	4,30	5,47	6,20	6,25	7,19	7,70
Fe metal %	0,18	0,24	0,29	3,40	4,06	4,50	0,68	0,71	0,75
FeO %	3,20	3,43	3,65	23,60	25,70	28,75	3,35	4,17	5,45
Fe_2O_3 %	1,62	2,04	2,35	20,65	23,60	26,20	2,70	3,47	4,20
MnO %	0,21	0,22	0,24	0,44	0,45	0,46	0,38	0,40	0,41
MgO %	1,30	1,96	2,20	2,00	2,60	3,65	2,10	2,80	4,30
CaO %	10,9	11,30	11,75	6,25	6,90	7,70	14,15	14,60	15,00
Na_2O %	7,35	7,95	8,90	2,70	2,86	3,00	5,15	5,97	7,25
TiO_2 %	0,40	0,43	0,48	0,39	0,48	0,73	0,50	0,54	0,61
K_2O %	1,15	1,21	1,25	0,70	0,77	0,85	1,25	1,29	1,35
P_2O_5 %	0,90	0,97	1,05	0,72	0,80	0,94	1,23	1,28	1,37
Cl %	0,07	0,10	0,14	0,04	0,09	0,14	0,11	0,18	0,28
S %	0,17	0,21	0,25	0,20	0,28	0,34	0,05	0,60	0,82
H_2O^- %	0,20	0,29	0,50	0,10	0,29	0,45	0,60	0,83	1,15
H_2O^+ %	0,25	0,75	1,25	0,10	0,33	0,64	0,10	1,25	2,50
C total %	3,45	4,44	5,25	0,03	0,40	0,78	3,35	3,89	4,35
C organic %	0,94	1,88	3,30	-	0,16	0,60	1,76	2,45	3,35
Cu ppm	440	590	1 000	1 050	1 280	1 700	500	650	900
Zn ppm	1 650	1 850	2 250	2 200	2 560	3 400	3 400	3 800	4 750
B ppm	150	220	280	32	90	140	58	150	225
Pb ppm	900	980	1 050	900	940	1 050	1 200	1 600	2 000
Sn ppm	150	190	240	410	670	950	180	350	550

TABLE N° 38

CHEMICAL COMPOSITION OF SLAGS RECOVERED FROM CLINKERS BY B.R.G.M. PROCESS

METZ RESULTS

- their alumina content is distinctly lower than that of common clay, and comes close to that of blast furnace slag or Portland cement ;
- their lime content is half-way between that of pozzolanes and that of the blast furnace slag ;
- their silica content is in the same range as that of the natural pozzolane and silico-aluminous fly-ash.

Fluctuations in the main element contents are relatively limited. Under These conditions, several fields of utilization are possible.

Utilization in the brick industry.

The most interesting products are those which give a minimum heat shrinkage and keep a normal porosity to fired bricks : the fine slag function would, then, be less adapted, and would be used more as a sintering agent.

Incorporation to concrete.

Slags can be used a complementary granulate in concrete making, as indicated by setting, resistance and shrinkage tests.

Utilization as road material.

As long as the content of combustible matter is less than 5 %, the residues, the size of which ranges between 0,1 and 0,2 mm, can be used as basement aggregate.

3.2.3.3. Possibilities of utilization of magnetic slags.

In the steel industry, their low iron content (40 % on an average) gives them a value about the same as refining and reduction costs, so that their beneficiation depends on transport rates. Moreover, their content in lime and non-ferrous elements could need some changes in the running of the blast furnaces and also in steel quality.
Accordingly, they rather form a complementary material in steel-making, their quantity being besides relatively small.

They could be used in cement-making as a flux speeding up clinkerisation in the case of mixtures with an insufficient alumino-ferrous rate.

3.2.3.4. Glass beneficiation.

Apart from its use as cullet (very restricted due to iron contamination), glass extracted from clinkers can be used as glass wool or expanded aggregates.

Expanded glass. B.R.G.M. results.

Compared to natural materials (clay) or to cullet, a mixture made up of 50 % of plain cullet and 50 % of glass extracted from clinker gives the following properties :

AGGREGATE MATERIAL	BULK DENSITY	WATER ABSORPTION CAPACITY
Expanded clay	0,30 to 0,45	5 to 20 %
Expanded clinker glass	0,2	22 %
Expanded cullet	0,13 to 0,20	15 to 20 %

TABLE N° 39 : COMPARISON BETWEEN DIFFERENT EXPANDED PRODUCTS

Glass wool.(U.S.B.M. results)

From a mixture made up of glass extracted from clinkers, dolomite and alumina, two qualities of fiber have been produced, one fine, the other coarse, depending on the original composition of the mixture.

WOOL FIBER	WEIGHT PERCENT			
	RESIDUE GLASS	DOLOMITE	ALUMINA	TOTAL
Fine	46	52	2	100,0
Coarse	78	20	2	100,0

TABLE N° 40 : COMPOSITION OF RESIDUE GLASS
MIXTURES FOR WOOL FIBER MAKING

In each case, the smelted product is blown by an air current and transformed into fibers in a proportion of about 70 %. The glass wool thus obtained can be compared in chemical composition with a commercial sample in the following way :

WOOL FIBER	ANALYSIS PERCENT						
	SiO_2	Al_2O_3	Na_2O	CaO	MgO	Fe_2O_3	K_2O
Fine	42,4	4,4	8,35	28,0	15,0	0,25	0,29
Coarse	60,3	4,2	12,50	14,3	3,9	0,16	0,29
Commercial	41,0	4,5	0,17	35,3	14,1	1,6	0,82

TABLE N° 41
CHEMICAL ANALYSES OF TEST FIBERS
AND A COMMERCIAL GLASS WOOL

4. ECONOMICS OF THE PROCESSES.

4.1. VALUE OF RECOVERED PRODUCTS.

4.1.1. Scrap-iron.

Ferrous scrap can be sold either directly to steel industry or through dealers. Steel industry generally only buys directly, if products have a constant high quality, for example, machining swarfs and setting up scraps. Prices are much higher than dealer's ones (twice as much or more for low quality scrap-iron), but transportation is included. The contracts are, in most cases, monthly.

Scrap dealers can bid for annual contracts, but base them on very strict revisional clauses and prices are generally lower.

As the scrap-iron market is, especially in France, in a particularly depressed state, prices are now not significant enough for a long-range trend which could be estimated within the average following limits ;

	Belgium	France	Italy	Netherlands	West Germany	United Kingdom
Selling price per tonne		60 - 120 F	15000 - 30000 lires	30-70 florins	20-40 D.M.	£6-12

TABLE N° 42 : COMPARISON OF IRON SCRAP PRICES IN THE EEC.

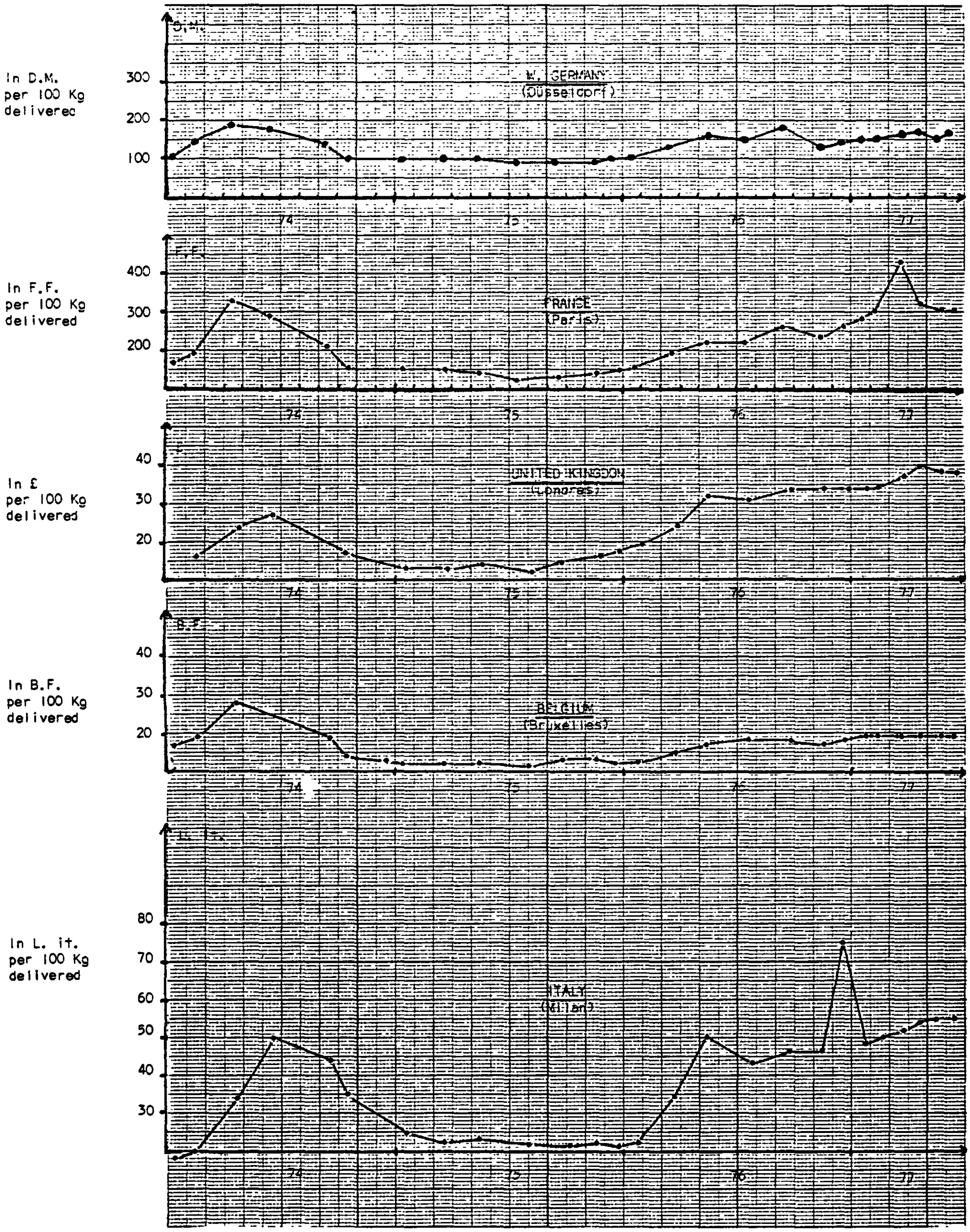
4.1.2. Aluminum.

In the figure 10 are set out market fluctuations during the last three years in the Common Market, ranging between the limits indicated in table 43.

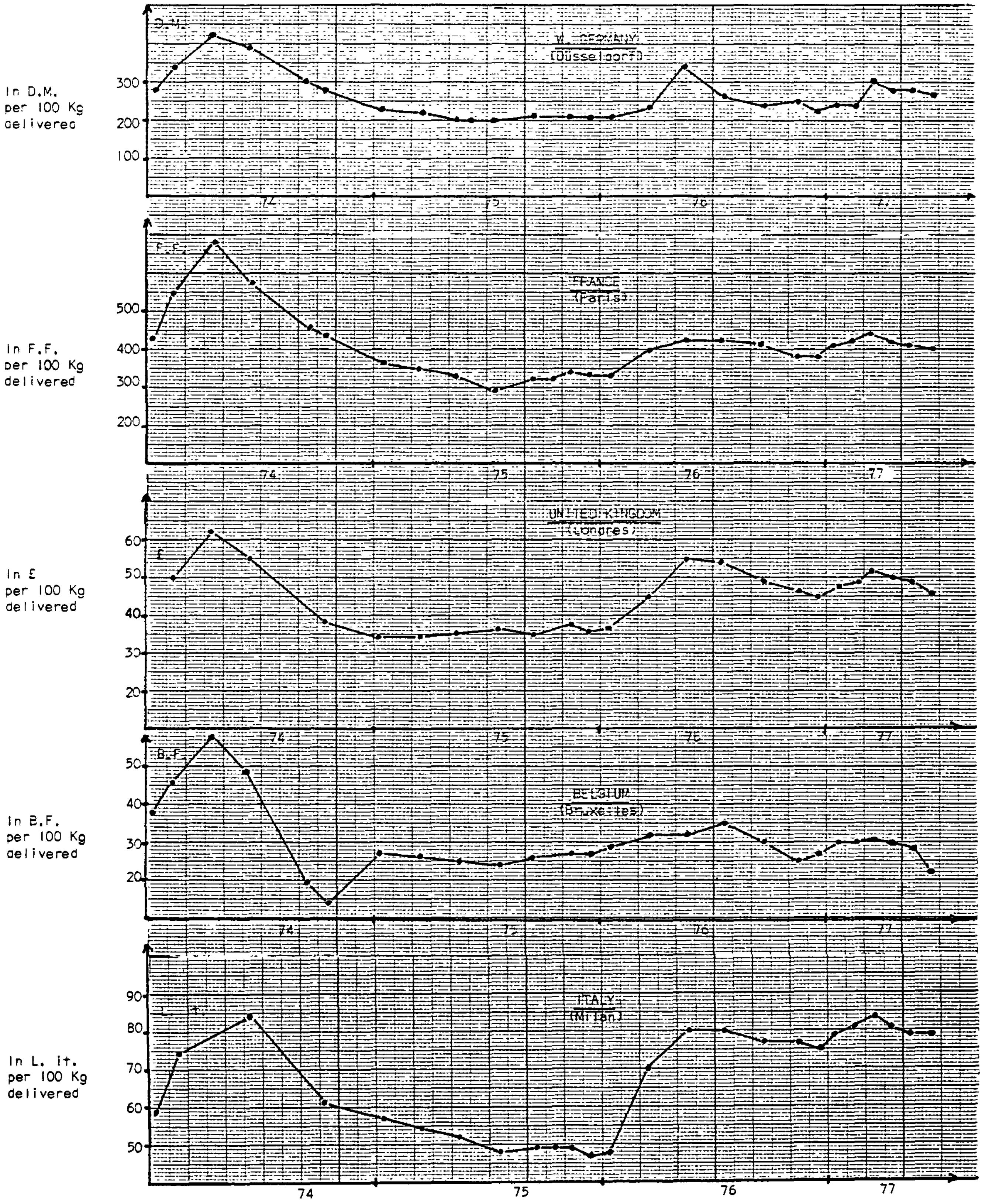
4.1.3. Heavy non-ferrous metals.

These products, refered to as "mixed brass" have market value which have varied during the last three years, as reported in figure 11 and ranged in table 44.

These values must be in fact lowered by 15 to 30 %, due to transformation costs into usefull commercial products, as well as transportation charges to secondary smelters who carry out refining.



VARIATION IN OLD SCRAP ALUMINIUM PRICES (OLD PANS ETC...)
IN FIVE EEC COUNTRIES.
(in current D.M., F.F., £, B.F., L. it.)



VARIATION IN MIXED SCRAP BRASS PRICES
IN FIVE EEC COUNTRIES
(in current D.M., F.F., £, B.F., L.It)

	BELGIUM	FRANCE	ITALY	NETHERLANDS	WEST GERMANY	U.K.
Average rate	18 F.B.	230 F.	40 000 L.	Not available	140 D.M.	£ 28
Maximum rate	28 F.B.	430 F.	75 000 L.	Not available	190 D.M.	£ 41
Minimum rate	12 F.B.	120 F.	22 000 L.	Not available	90 D.M.	£ 14

TABLE N° 43 : COMPARISON OF ALUMINUM SCRAP PRICES IN THE EEC (PER 100 KG)

	BELGIUM	FRANCE	ITALY	NETHERLANDS	WEST GERMANY	U.K.
Average value	28 F.B.	400 F.	70 000 L.	-	250 D.M.	£ 45
Maximum value	58 F.B.	680 F.	84 000 L.	-	420 D.M.	£ 62
Minimum value	14 F.B.	280 F.	47 000 L.	-	200 D.M.	£ 33

TABLE N° 44 : COMPARISON OF HEAVY NON FERROUS SCRAP METALS PRICES IN THE EEC (PER 100 KG)

4.1.4. Slags.

Inside the Common Market countries, there already exists a certain market for iron-free clinkers. Although the amounts so disposed are hard to evaluate, market prices seem, on the whole to lie around the values indicated in table 45.

According to their field of utilization, slags which result from overall treatments could, in the first instance, be commercialized at least on the same basis.

Once their properties confirmed at an industrial basis, they could probably be sold more by reference to raw materials which they could be substituted to.

4.2. ECONOMICS OF TOTAL INCINERATION RESIDUES BENEFICIATION.

4.2.1. U.S.B.M.-Raytheon process.

Economic data related to a demonstration plant, designed to handle 250 tons per 8 hours a day of incinerator residue projected, in Lowell (Massachussetts) are the following.

4.2.1.1. Capital costs [*]

Design, Construction Management, Shakedown	$798 000
Equipment & Construction	$3 321 000
TOTAL	$4 119 000

---

[*] Capital costs are based on 1975 estimates and quotes at Lowell, Massachussetts, and do not include cost for land.

PLACE	SALE PRICE PER TON	COST OF DUMPING
United Kingdom	£ 1	£ 1,32
Amsterdam - Rotterdam	1,5 - 40 Fl.	10 - 20 Fl.
Berlin	10 D.M.	16 D.M.
Lens-Lievin (France)	2 - 5 frs	
Paris	3,5 frs	

TABLE N° 45 : COMPARISON OF CLINKER PRICES AND DISPOSAL COSTS IN THE E.E.C.

4.2.1.2. Estimated revenues *

	Percent Recovery (dry weight basis)	Value $/Ton	Revenue $/Ton Input Residue
Aluminum	1,25	250	3,12
Copper/Zinc	0,63	330	2,08
Ferrous	14,6	32,90	4,80
Clean Glass	30,0	22,50	6,75
Sand	24,17	2,00	0,50
Filter cake	15,6	0	0
Organics	13,75	0	0
	100,00		17,25

4.2.1.3. Projected operating economics.

	1 shift/day (250 tons of residue per 8-hour-day, 260 days-per-year, 65 000 tons processed per year)	
	Cost (Income) per year	Cost (Profit) per ton input
Capital cost**	$424 000	$6,50
Operation and Maintenance***	$734 000	$11,30
TOTAL COST	$1 158 000	$17,80
Revenue	(1 122 000)	(17,25)
Net Cost	$36 000	$0,55

---

*Based on material values quoted by interested secondary materials buyers in March 1975. Aluminum and copper-zinc values are F.O.B. the resource recovery plant. Haul costs for the remaining materials are not included in the above quoted values. However, hauling costs have been included in the operating cost estimates.

**Capital costs are amortized using an economic life span of 15 years and 6 % interest rate.

***Operating and maintenance costs are based on 11 to 12 persons/shift.

4.2.2. B.R.G.M. Process.

Following data concern a plant handling 240 t per 8 hours a day of clinker :

4.2.2.1. Capital costs[*]

Design, construction, Management, shakedown	2,2 X 10^6 F.F.
Equipment and construction	6,8 X 10^6 F.F.
TOTAL	9,0 X 10^6 F.F.

4.2.2.2. Estimated revenues[**]

	Percent Recovery (dry weight basis)	Value F/ton	Revenue F/ton input Residue
Aluminum Copper/Zinc } mixed	0,75	1 350	10,10
Ferrous	14,0	110	15,40
Magnetic slag	7,0	0	0
Non magnetic sand	58,3	5	4,30
Filter cake	20,0	0	0
TOTALS	100,00		29,80

---

[*] Based on 1975 estimates, not including land cost.

[**] Based on material values quoted by interested secondary materials buyers in 1975. Haul costs for the remaining materials are not included in the above quoted values.

4.2.2.3. Projected operating economics.

	1 shift/day (240 tons of residue per 8-hour-day, 250 days-per-year, 60 000 tons processed per year)	
	Cost (Income) per year X 10^6 F	Cost (Profit) per ton input
Capital Cost[x]	1,18	19,60
Operation and Maintenance[xx]	1,17	19,50
TOTAL COST	2,35	39,10
Revenue	(1,79)	(29,80)
Net Cost	0,56	9,30

4.2.3. W.S.L. Process.

For a plant treating 25 t/h, 5 days/week, the following assessment of profitability is estimated.

4.2.3.1. Capital costs[xxx]

Capital equipment, contingencies,	48 840 £
Installation costs	48 840 £
TOTAL	97 680 £

---

[x] Capital costs are amortized using an economic life span of 15 years and a 10 % interest rate.

[xx] Operating and maintenance costs are based on 9 persons/shift.

[xxx] Based on 1972 values, without allowance for land purchase, transport or traction.

4.2.3.2. Estimated revenues

	Percent Recovery (dry weight basis)	Value £/ton	Revenue £/ton input residue
Aluminum	0,60	53[*]	0,32
Copper/Zinc	0,56	171[*]	0,96
Ferrous[**]	2,5	5	0,13
Mineral materials	96,2	0	0
TOTALS	100,00		1,41

4.2.3.3. Projected operating economics.

	1 shift/day (200 tons of residue per 8-hour-day 260 days-per-year, 52 000 tons processed per year)	
	Cost (Income) per year	Cost (Profit) per ton input
Capital cost [***]	£14 600	£0,28
Operation and Maintenance	£63 400	£1,22
TOTAL COST	£78 000	£1,50
Revenue	£(73 300)	£(1,41)
Net cost	£4 700	£0 09

4.2.4. Operating data comparisons.

To comparisons between the above results, a common assessment basis is considered, with the following specifications :

---

[*] Based on material values quoted by L.M.E.

[**] Ferrous metal extraction prior to residue processing.

[***] Capital costs are amortized using an economic life span of 10 years and a 8 % interest rate.

- capital costs : actualized in 1975 (to limit distorsions resulting from market variations and escalation rates) ;
- plant schedule : assumed to be 8 hour-day, 250 days per year, with a 30 t/h capacity (i.e. 60 000 t/year) ;
- depreciation and interest : calculated over 10 years at a rate of interest of 10 % ;
- hauling costs for the discarded materials : not taken into account.

Within these considerations, a first comparison can be made between the various processes, according to the table here after.

	U.S.B.M.Process	B.R.G.M.Process	W.S.L. Process
Capital cost (1)	4,1 X 10^6 \$	9,0 X 10^6 F	156 X 10^3 £
Annual expenses :			
. Capital charges	670 X 10^3 \$	1,46 X 10^6 F	25,4 X 10^3 £
. Operating costs	734 X 10^3 \$	1,17 X 10^6 F	131 X 10^3 £
. Total	1 404 X 10^3 \$	2,63 X 10^6 F	156,4 X 10^3 £
Annual revenues (2)	1 035 X 10^3 \$	1,79 X 10^6 F	127 X 10^3 £
Annual charges (3)	369 X 10^3 \$	0,84 X 10^6 F	25,4 X 10^3 £
Charge per ton input	6,15	14	0,49
Turn over ratio (2)/(1) %	25,2	19,8	81,4
Return on investment (3)/(1) %	- 9,0	- 9,3	- 18,8

TABLE N° 46 : COMPARISON OF PROCESSES ECONOMICS

It appears, each process considered in its national background, that :

- all the profits are very sensitive to ferrous and non-ferrous metals markets ;
- external costs can occurr because of the quantities of slag to dispose, and eventually burden economics if hauling and disposal conditions are hard ;
- if the main part of the slag is marketed, even free net process charges become lower than actual clinker disposal costs ;
- turn over ratios can reach interesting values ;
- returns on investment in these annual capital cost conditions could certainly expected to be substantially better if longer amortization time is allowed.

5. INFLUENCE OF NEW THERMAL CONVERSION PROCESSES ON THE QUALITY OR QUANTITY OF THE RESIDUES

Pyrolysis is chemical decomposition of waste in a high temperature and low oxygen athmosphere. Acting therefore as a destructive distillation, it permits then, the re-utilization of organic waste in the form of oil-like liquids or hydrocarbon gas, which are simpler and more interesting economically. When carried out at high temperatures it can, moreover, be accompanied by the smelting of mineral ashes and even metallic elements, which cuts down considerably the volume of residues to dispose of.

The available data on a number of pyrolysis residues are given in table 47, as reported by the pilot country :

PROCESS	SOLID RESIDUE YIELD KG/TON REFUSE	% C
Andco-Torrax	170 (molten slag)	-
Purox	170 (molten slag)	-
Motala	200	-
Landgard*	70	50
Landgard**	170	2
Destrugas	280	?
Oxy*	55***	50
Oxy**	81	-

* Carbon rich fraction
** Mineral and metallic fraction
*** Part of the char is burned to provide heat for the pyrolysis reaction.

TABLE N° 47 : COMPARISON OF SOLID RESIDUE YIELD BETWEEN DIFFERENT PYROLYSIS PROCESSES.

The claimed uses of such products are the following :

- Carbonaceous materials :
as far as that fraction is available under a particulate state, it presents surface properties after steam or CO_2 activation to improve pore size distribution ; the pilot country so mentions the determination of adsorption isotherms gives results far below those of the usual activated carbon ; it can be attributed to the high ash contents of the pyrolysis char, and probably to the less desirable structure of the charred material. The marketability of such products as activated carbon actually appears rather poor. Their use as solid fuel seems also limited, because of their high ash content associated with a low calorific value ;

- mineral materials :

no result is yet available to demonstrate if the same field of utilization as incineration refuse sands is possible either in the brick industry, or as road basement, or for concrete production. Their content in bituminous components, soluble salts, trace metals seems however be an obstacle, eventually enhanced by water pollution considerations.

PART 3

CONCLUSION

I. MAJOR FACTS.

As a result of the present study, the following points can be set out :

Quantities of materials recoverable from EEC incineration clinkers :

A first estimation indicates that :

- for an annual unit-capacity of over 100 000 tons, there exists more than 80 incinerators where could be separated and recovered annually :
  800 000 to 1 100 000 t of ferrous scrap
  40 000 to 57 000 t of non-ferrous metals
  1 000 000 to 2 000 000 t of glass
  1 600 000 to 2 400 000 t of slag ;
- for an annual unit-capacity of over 200 000 tons, more than 30 incinerators could allow the beneficiation of :
  500 000 to 700 000 t of ferrous scrap
  25 000 to 36 000 t of non-ferrous metals
  900 000 to 1 300 000 t of glass
  1 000 000 to 1 500 000 t of slag ;
- for an annual unit-capacity of over 400 000 tons, 9 incinerators are concerned from which annually it could be reclaimed :
  187 000 to 255 000 t of ferrous scrap
  9 000 to 14 000 t of non-ferrous metals
  410 000 to 560 000 t of glass
  470 000 to 680 000 t of slag.

Available recovery technology :

With regards to an efficient policy of ressources conservation and environment preservation, it seems more rational to develop a technology allowing separation and reclamation of metallic and mineral values as complete as possible. Basically, such processes exist, which have been tested at pilot plant scale, and now need to be demonstrated in full scale plants : first industrial projects could so concern France, Germany, the Netherlands, United Kingdom more particularly, because of local higher productions of clinker.

Materials utilization :

- Despite their content in tin and copper, ferrous scraps seem acceptable by the iron and steel industry, either for common iron products, or for special ones.

- Non-ferrous metals offer better recycling possibilities in the secondary smelting industry.

- Mineral slags show interesting properties for the brick industry, concrete production, road basement which are industrial applications quite recommended for such bulky products.

Processing economics :

All the processes are characterized by major revenues assessed on the sale of metallic scraps minor revenues or no losses from the disposal of mineral fractions : to be less sensitive to market fluctuations and haulage costs, they require :

- a better regulation of the metal market,
- the demonstration of mineral fraction use as substitute for industrial raw materials,
- taking into account of all external factors referring to ressources wastage and environmental pollution the combination of which provides the best incentive to the development of waste separation and recovery.

2. RECOMMENDATIONS FOR INCINERATION RESIDUE SEPARATION AND UTILIZATION IN THE E.E.C.

Areas related to incineration residue separation and utilization where more R and D are required concern both general action and specific intervention.

General action.

It should include the following topics :

- basic data collection on :
  - incinerators having a capacity over 100 000 t/year,
  - composition of raw refuse and incineration residues analyzed on a standard method,
  - production of incineration residues and their disposal conditions.
- Information exchange on incentives to develop recovery of values from mineral and metallic wastes (separation technology, refuse promotion, market regulations, ...).
- Evaluation of differences in national contexts to select specific or comparative actions.

Specific interventions.

The most appropriate items to investigate are the following :

- separation technology : evaluation of the technical efficiency and the economical interest of various dry or wet processes, leading to global or selective utilization perspectives.
- Materials recovery : a special attention must be attached to the utilization of ferrous scrap contaminated by tin and copper which involves either the development of removal methods or the search for specific applications ; the substitution of slag and glass to raw materials commonly used in brick-making, concrete preparation, road underlay or embankment is also to be tested on an industrial level.
- Environmental effects : benefits towards environment protection resulting from the development of incinerated refuses utilization should be carefully estimated to give a complete view of the interest to promote a more rational elimination of such wastes through their recycling.