Combustion and Energy Recovery

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Technical Terms

Heat Value of Refuse

- British thermal unit (BTU): an amount of energy necessary to heat one pound of water one degree Fahrenheit.
- Kilocalorie: an amount of energy necessary to heat one kilogram of water one degree Celsius.
- Joule
- Kilowatt-hour (kWh)

The amount of energy or heat value in an unknown fuel can be estimated by ultimate analysis, compositional analysis, proximate analysis, and calorimetry.

Table 7-1 Energy Conversions

To convert	to	multiply by
Btu	Calories	252
	Joules	1054
	kWh	2.93×10^{-4}
Calories	Btu	3.97×10^{-3}
	Joules	4.18
	kWh	1.16×10^{-6}
Joules	Btu	9.49×10^{-4}
	Calories	0.239
	kWh	2.78×10^{-7}
Kilowatt-hours	Btu	3413
	Calories	8.62×10^{5}
	Joules	3.6×10^{6}

Ultimate Analysis

Ultimate analysis uses the chemical makeup of the fuel to approximate its heat value.

Example of equation for estimating the heat value of refuse:

$$\text{Btu/lb} = 144\text{C} + 672\text{H} + 6.2\text{O} + 41.4\text{S} - 10.8\text{N}$$

where C, H, O, S, and N are the weight percentages (dry basis) of carbon, hydrogen, oxygen, sulfur, and nitrogen respectively.

Compositional Analysis

Formulas based on compositional analyses are an improvement over formulas based on ultimate analyses.

Using regression analysis and comparing the results to actual measurement of heat value, a compositional model:

$$\text{Btu/lb} = 1238 + 15.6\text{R} + 4.4\text{P} + 2.7\text{G} - 20.7\text{W}$$

where R = plastics, percent by weight on dry basis
P = paper, percent by weight on dry basis
G = food wastes, percent by weight on dry basis
W = water, percent by weight on dry basis

Table 7-3 Typical Heat Values of MSW Components

Component	Heat value, Btu/lb dry weight
Food waste	2000
Paper	7200
Cardboard	7000
Plastics	14,000
Textiles	7500
Rubber	10,000
Leather	7500
Garden trimmings	2800
Wood	8000
Glass	60
Nonferrous metals	300
Ferrous metals	300
Dirt, ashes, other fines	3000

Source: Modified from (7)

Table 7-5 Typical Moisture Contents of MSW

Component	Typical moisture, percent
Food waste	70
Paper	6
Cardboard	5
Plastics	2
Textiles	10
Rubber	2
Leather	10
Garden trimmings	60
Wood	60
Glass	2
Nonferrous metals	2
Ferrous metals	3
Dirt, ashes, other fines	8

Source: Adapted from (9)

Proximate Analysis

In proximate analysis it is assumed that the fuel is composed of two types of materials: volatiles and fixed carbon.

A commonly used proximate analysis equation:

$$\text{Btu/lb} = 8000A + 14{,}500B$$

where A = volatiles, fraction of all dry matter lost at 600°C

B = fixed carbon, fraction of all dry matter lost between 600°C and 950°C

Table 7-6 Typical Proximate Analysis of MSW Components

Component	Moisture	Fraction by weight Volatile	Fixed	Ash
Mixed paper	0.102	0.759	0.084	0.054
Yard waste	0.752	0.186	0.045	0.016
Food waste	0.783	0.170	0.036	0.010
Polyethylene	0.002	0.985	0.001	0.012
Wood	0.200	0.697	0.113	0.008

Source: (10)
(*Note:* If the values in Table 7-6 are to be used in the proximate analysis equation, the fractions have to be recalculated on the basis of *dry matter*.)

Calorimetry

Calorimetry is the referee method of determining heat value of mixed fuels using a bomb calorimeter.

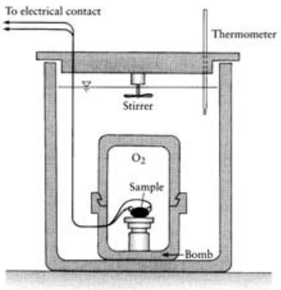


Figure 7-1 Bomb calorimeter used to measure heat value of a fuel.

Targets of Waste Management

- **Waste that could not be avoided has to be utilized as far as possible**
- **The amount of harmful substances in the waste has to be kept as small as possible**
- **Assure a sustainable treatment and disposal of waste that could not be utilized**

Overall, assure safe disposal and that problems are not shifted to following generations

No longer possible to deposit untreated waste!

TA-Siedlungsabfall, 1993 in Germany

Targets of Incineration including their positive effects

Reduction by volume	⇨ **Save of landfill space**
Inertisation of hazardous waste residues **Destruction or concentration of contaminants**	⇨ **Minimizing / controlling emissions**
Recovery of waste energy	⇨ **Conserve energy resources**
Transforming residues into usable secondary products	⇨ **Conserve raw-materials and resources**

Concept of Combustion

The energy from the sun is stored, using the process of photosynthesis, in organic molecules, and this energy is released as the the organic materials decompose.

The photosynthesis process:

$$CO_2 + \text{sunlight} + \text{nutrients} + H_2O \rightarrow (HC)_x + O_2$$

where the $(HC)_x$ represents an infinite variety of hydrocarbons.

The degradation of the high-energy organics:

$$(HC)_x + O_2 \rightarrow CO_2 + H_2O + \text{heat energy}$$

Combustion of the organic fraction of refuse is simply a very rapid decomposition process.

Combustion Hardware Used for MSW

- Incinerators: refuse is burned without recovering energy and flue gas cleaning (see Fig. 1,2)

- Waste-to-energy combustor with flue gas cleaning:

  -modern combustors combine solid waste combustion with energy recovery (see Fig. 3,4, most refuse combustors operate in the range of 980 to 1090ºC).

  - the combustor with a modification of the combustion chamber (rotary kiln, see Fig. 5,6) and a modificcation of a furnace wall (water wall, Fig. 7).

- Modular starved air combustor (Fig. 8).

- Pyrolysis (gasification): it is destructive distillation, or combustion in the absence of oxygen (Fig. 9).

$$C_6H_{10}O_5 + \text{heat energy} \rightarrow CH_4 + H_2 + CO_2 + C_2H_2 + C + H_2O$$

First incineration plant on the European Continent

due to cholera epidemic

Figure 1. Incineration Plant Bullerdeich (1896 - 1924)

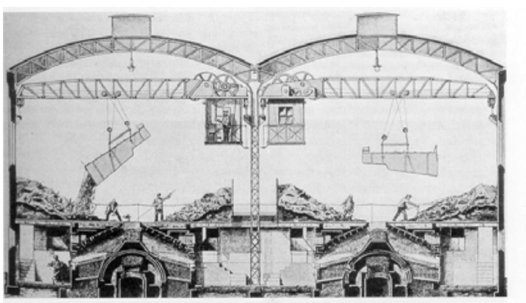


Figure 2. Cross-section of Bullerdeich Furnaces

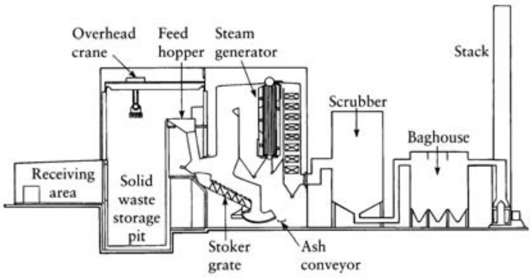


Figure 3. A typical municipal solid waste combustor

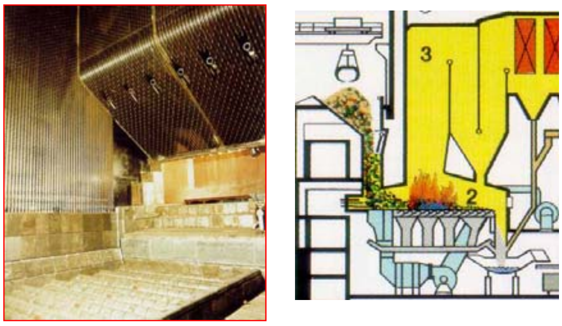


Figure 4. Grate Firing System for MSW Incineration

1. Solid waste
2. Barrels
3. Front wall with burner an injection for fuids and pasty substances
4. Rotary kiln
5. VORTEX-Afterburner with injection
6. Slag removal
7. Secondary air

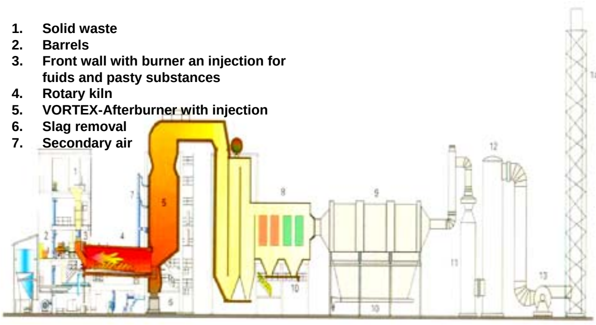
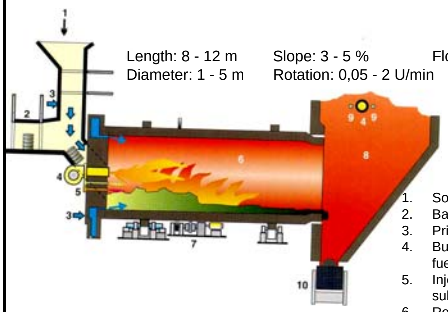


Figure 5. Rotary Kiln Cross Section of a Hazardous Waste Incineration Plant

Length: 8 - 12 m
Diameter: 1 - 5 m

Slope: 3 - 5 %
Rotation: 0,05 - 2 U/min

Flow rate: 0,1 - 20 Mg/h



1. Solid waste
2. Barrels
3. Primary air
4. Burner for fluids / auxiliary fuel
5. Injection for fluids or pasty substances/ auxiliary fuel
6. Rotary kiln
7. Rotary kiln drive
8. Afterburner
9. Injection for wastewaters
10. Slag removal

Figure 6. Rotary Kiln

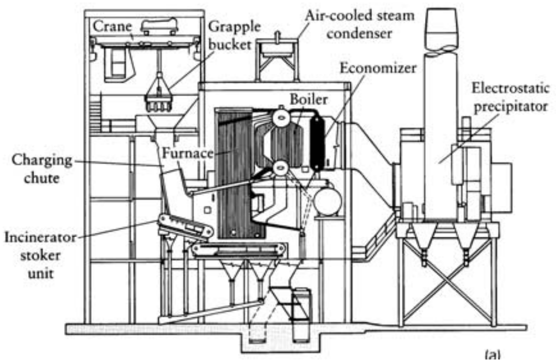


Figure 7. Water-wall tubes lining the furnace of an MSW combustor

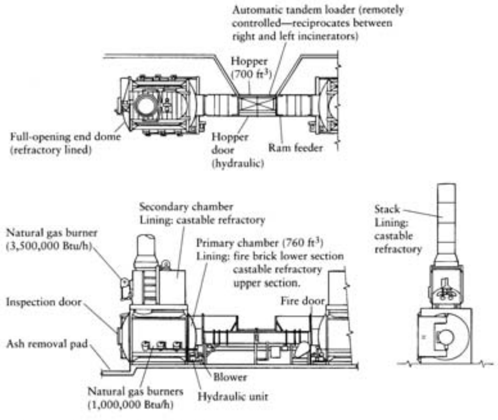
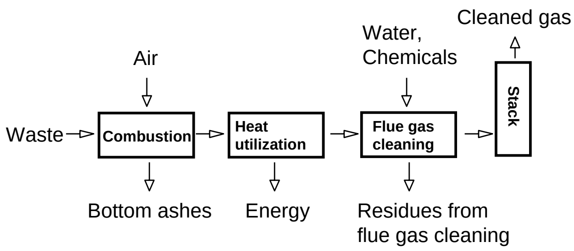


Figure 8. Modular Combustor

Figure 8. Pyrolysis Plant (Plastic waste to Oil)

Principle Scheme of a Waste Incineration Plant



Design of an Incinerator

Influencing factors:

Firing System

- the firing system used
- For the grate
  (min. length 4 m, better >6 m))

Waste

- Waste quantity
- Waste composition and structure
  (Calorific value)

Air

- Amount of combustion air
  (about 4.5 - 5 times the waste flow)
- Temperature of combustion air

Characteristic parameter:
Thermal load of the grate
(1.8 - 2.5 (max 3.0) GJ/m^2h)

Firing Sytems for Incineration

Kind of waste	Firing system
Municipal waste	Grate firing
Hazardous waste	Rotary furnace
Sewage sludge	Fluidized bed

Two criteria that can be easily monitored, ensure complete combustion of the solid waste and recovery:

(1) ash must not exceed a percent combustible level.

(2) exhaust gas in the stack must be within a predetermined temperature range.

Mass Burn versus RDF (Refuse Derived Fuel)

- A mass burn unit has no preprocessing of solid waste prior to being fed into the combustion unit.
- In a RDF system the solid waste is processed prior to combustion to remove noncombustible item and to reduce the size of the combustible fraction, thus producing a more uniform fuel at a higher heat value.

Table 7-11 ASTM Refuse-Derived Fuel Designations

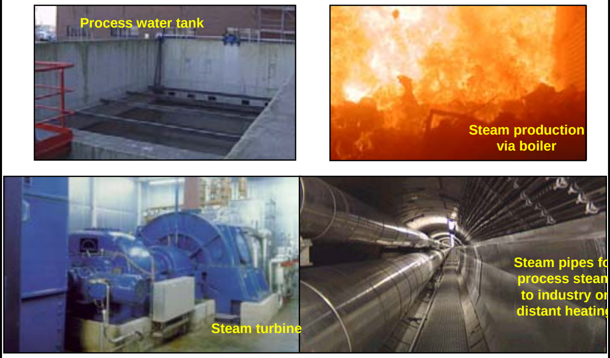
Name	Description
RDF-1	Unprocessed MSW (the mass burn option)
RDF-2	MSW shredded but no separation of materials
RDF-3	Organic fraction of shredded MSW. This is usually produced in a materials recovery facility (MRF) or from source-separated organics such as newsprint.
RDF-4	Organic waste produced by a MRF that has been further shredded into a fine, almost powder, form, sometimes called *fluff*
RDF-5	Organic waste produced by a MRF that has been densified by a pelletizer or a similar device. These pellets can often be fired with coal in existing furnaces.
RDF-6	Organic fraction of the waste that has been further processed into a liquid fuel such as oil
RDF-7	Organic waste processed into a gaseous fuel

Undesirable Effects of Combustion

- Waste Heat
- Ash
- Air Pollutants

Energy Recovery

Waste to Energy Equipment



Ash

Table 7-12 Materials Found in Typical MSW Ash

Material	Percent by weight
Metals	16.1
Combustibles	4.0
Ferrous metal	18.3
Nonferrous metal	2.7
Glass	26.2
Ceramics	8.3
Mineral, ash, other	24.1

Source: (21)

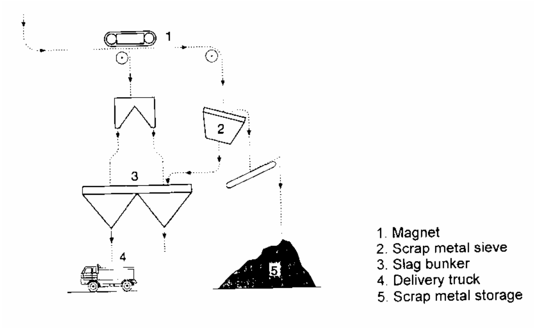
Ash

Table 7-13 Total Metal in Combined Ash

Metal	mg/kg of ash by weight
Aluminum	17,800
Calcium	33,600
Sodium	3,800
Iron	20,400
Lead	3,100
Cadmium	35
Zinc	4,100
Manganese	500
Mercury	less than 3

Source: Modified from (22)

Bottom Ashes Conditioning and Shipment



Emplacement of Stabilised Slag for Road Construction

Air Pollutants

- Particulates
- Gases: CO, SO_2, HC, NO_x, Mercury vapor, Dioxin

Development of Emissions from Waste Incineration in Germany (daily mean values)

	Fly ash [mg/Nm³]	HCl [mg/Nm³]	SO_2 [mg/Nm³]	NO_x [mg/Nm³]	Hg [mg/Nm³]	Cd, Tl [mg/Nm³]	Dioxins, Furanes [ng/Nm³]
1970	100	1000	500	300	0,5	0,2	50
1980	50	100	100	300	0,2	0,1	20
1990	1	5	20	100	0,01	0,005	0,05
2000*	0,4	0,1	2,44	82	0,0005	0,0006	0,0023