WASTE INCINERATION TECHNOLOGY

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Summary

This chapter reviews various incinerator furnace types, classified according to their most salient features and usual applications. Mechanical grate incinerators are applied for incinerating household refuse, rotary kilns for industrial waste, and fluidized bed units for sewage sludge.

Incinerator furnaces can be classified according to the types of wastes accepted (gas/liquid vs. solids), the method of exposing burning material to combustion air, improving mixing and increasing turbulence, the use of auxiliary media promoting heat transfer and mixing, and dry or wet methods of ash extraction. In the first, residues are extracted as solids, whereas *wet bottom* or *slagging operation* refers to their tapping as a melt.

1. Selection of Incinerator Furnaces

Incineration is a method of thermally reducing the volume of combustible waste, to cinders, while fly ash is entrained by flue gas.

Since burning in the open (using simple means, e.g. a pit, etc.) is highly polluting, a furnace is needed to achieve adequate control of combustion conditions, draft, and emissions.

The **selection** of a particular type of **incinerator furnace** depends on the types of wastes to be incinerated, on plant capacity, operating schedule, amount, nature and softening point of the ash to be handled, etc. Small incinerators often operate in a one or two shift **schedule**, but continuous operation is always to be preferred, since it enhances useful capacity and reduces

- auxiliary fuel requirements during start-up,
- thermal wear of refractories, and
- plant emissions.

Start-up and shutdown periods are much more polluting and there is strong tendency to allow only pure fuel to be burnt during these periods.

In small or batch-operated plants without heat recovery flue gas is often cooled by injecting cooling water, or by admixing cooling air. These methods typically increase the gas flow at standard temperature and pressure by 30 - 50 percent for water injection in cooling towers and by 300 - 400 percent for admixing air, which quite considerably inflates investment and operating costs of the gas cleaning plant.

In large-scale incinerators **heat recovery** using **waste heat** or **integrated boilers** is considered to be appropriate for cooling the flue gas prior to cleaning, provided that the steam generated can be used for in-plant or other useful purposes, such as power generation, district heating, water desalination, sludge drying, vacuum generation, etc. Still, heat recovery takes place under adverse conditions (fouling and corrosive flue gas), requiring considerable supplemental investment and diminishing plant availability. These disadvantages may be offset by generating revenues, and avoiding the extra cost of requiring much larger gas cleaning plant. Moreover, since it is more sustainable, recovery is often mandatory regardless of economic factors.

Normally medium pressure boilers (1.5-5 MPa) are preferred, avoiding both high-temperature (super-heater surfaces) and dew point corrosion problems. Since fly ash is often tacky above 600° C the contact surfaces are preceded by radiant cooling surfaces and specially designed for

- limiting deposition and adherence of hot, sticky particles,
- convenient cleaning (rapping of panels, soot blowing, shot cleaning of tube banks) and
- easy inspection.

During a furnace standstill it is advisable to keep the boiler tubes hot, by means of imported steam in order to avoid corrosion by hygroscopic acidic deposits, such as chlorides.

The operating temperature of incinerators depends on:

- the calorific value of waste,
- the excess of air applied,
- the cooling of the furnace by an integrated boiler, and
- the initial temperature of air and waste streams.

Some plants operate under **slagging conditions**, at temperatures at which the combustion residue is molten and can be tapped in that state. It is important to ensure a steady slag flow by:

- carefully controlling the composition of the ash at a suitable eutectic composition; iron silicates and glass are examples of compositions with an accessible melting point,
- providing auxiliary burners and, when required,
- fluxes such as fluorspar, to enhance slag fluidity.

Gaseous and liquid waste can be completely combusted using **low excess of air** as far as their composition is sufficiently predictable and constant. In principle, much larger excess is required when firing solid waste, except in incinerator types featuring excellent air/solids contact, e.g. fluidized bed or vortex units. Lower air-flow lengthens residence times in a given volume and reduces entrainment of fly ash with flue gases.

The **volumetric heat release rate** is determined by the quality of the contact with the combustion air and fuel reactivity, which decreases with larger size, higher moisture content and lower energy value. Since combustion intensity is unevenly distributed over the furnace volume, the latter should be defined carefully, when citing values for the heat release rate.

Dead zones consume sizeable fractions of furnace volume, reducing real residence times and combustion efficiency. The **residence time** of gaseous and liquid wastes in an incinerator amounts to only few seconds. The residence time required for complete combustion of solids is generally about half an hour, except for high intensity-incinerators, firing a Refuse-Derived Fuel obtained by combining shredding, sieving, air classification, and magnetic separation.

Some plants for bulky loads were operated on a full-day burning, nighttime cooling cycle. For fuel-economy and environmental reasons such practices are no longer recommended.

Designing simple incinerators is much simpler today than it was in the 1960s or 1970s, when only an empirical approach was feasible. Computer Fluid Dynamics (CFD) easily derives the flow and mixing characteristics, the rates of heat generation and the temperature and flow fields. Moreover, the trajectories of particles of various sizes can be predicted stochastically.

The operating limits of furnaces may be dictated by various considerations, e.g.:

- Heat balances, and the related high and low operating temperature limits,
- Excessive, adequate, or insufficient thermal load,
- Flame and combustion stability,
- Adequate coverage of a mechanical grates, and
- Provision of sufficient combustion air.

Furnace types can be classified, according to:

- the methods used for contacting wastes with combustion air (e.g. in co-current, counter-current, or cross-current flow; measures for mechanical and pneumatic agitation…),
- the degree of filling the incinerator with solid material,
- dry ash or slagging conditions (wet-bottom furnaces).

2. Gaseous and Liquid Wastes

2.1. Stationary Furnaces

Stationary furnaces (see *Thermal and Catalytic Combustion*) consist of a horizontal or vertical, box-type or cylindrical, refractory-lined combustion chamber, fitted with burners. The main purposes of the resulting enclosure are to:

- limit the cooling of the flame and combustion chamber
- organize the flows of incoming air and outgoing flue gas, without undesirable dead corners, entries of false (uncontrolled) air, or diffuse spreading of fumes.

Avoiding smoke requires operating at slightly sub-atmospheric pressure, since refractory furnace walls are always leaky. For this reason furnaces formed from welded membrane steel or boiler tube panels are very popular.

The selection of waste burners, their position, flame orifice, air supplies, mixing and thermal buoyancy characteristics are prime factors determining performance. The mixing characteristics of the furnace are improved by suitable injection of secondary air enhancing back mixing of flue gas and (in early units) providing periodic changes in the direction of flue gas flow.

Where required, a separate post combustion chamber is used, with its temperature controlled by an auxiliary burner. Heat release rates are high when burning high calorific gases or atomized liquids; they are much lower when burning sludge or wastewater.

The stationary furnace is used for burning gaseous and liquid waste flows, including off-gases, solvents, oils, wastewater, pumpable sludge and meltable and paste-like waste streams. Plastics proper are difficult to fire, for liquid burners will spin threads of molten plastics. Special burners fire several streams simultaneously, e.g. auxiliary fuel, waste oil, wastewater, and pumpable sludge.

Alternatively, various wastes may be injected either into a stable flame or tangentially to it. Wastewater may be largely evaporated in a forced circulation evaporator and then radially blown into the flame of an oil burner.

The main technical limitation is the lack of provisions for eliminating ash or other residues. Ideally, the ash is fine and high melting and blown out of the furnace, then separated by the Air Pollution Control units.

2.2. Submerged Combustion

In Submerged Combustion the flue gases are quenched instantaneously upon leaving the furnace, to stop further reaction (e.g. the oxidation of HCl to chlorine or dioxins formation), or when acid, brine or other solutions must be concentrated by directly contacting hot flue gases and the liquor to be treated.

Heat and mass transfer between flue gas and liquid quench are very fast: the flue gas is almost completely saturated with water vapor and leaves substantially at the temperature of the bath.

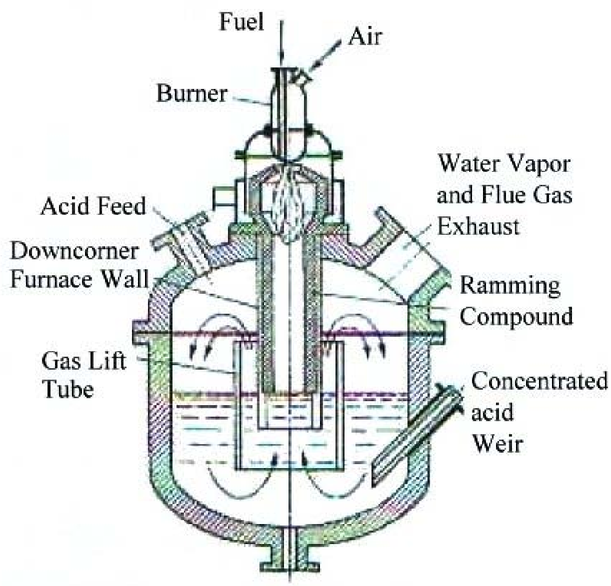

Figure 1: Submerged Combustor

The plant consists of an elongated, slender, vertical furnace, as a downcomer tube plunging into a bath maintained in a wider container. A concentric tube frequently surrounds the downcomer, the formed annular space acting as an airlift and promoting internal mixing of the quenching bath.

Submerged combustors are used for:

- Quenching and cleaning the flue gas;
- Concentrating wastewaters or corrosive acids;
- Recovering a solution of inorganic salts, when firing aqueous solutions of organic salts;
- Recovering dilute hydrochloric acid when firing chlorinated wastes.

Submerged combustors may have a vertical, refractory lined steel shell equipped at the top with a down-firing auxiliary burner. Liquid waste is atomized and injected into the flame, so that they are rapidly dried, thermally decomposed and completely combusted. The inorganic compounds are converted to molten salt particles and flow into the quench vessel, to be recovered as a salt solution or slurry. Another design features a fractionating column on top of the water vessel. Wastewater, contaminated with volatile hydrocarbons is fed on top of the column and the hydrocarbons are stripped off in contact with a rising mixture of flue gas and water vapor. After condensation of the vapors the condensed heavier hydrocarbons are recycled to the quench vessel. The non-condensable are combusted.

3. Solid Wastes

3.1. Classification

Distinction is made between small, dedicated plants for firing local trash, packaging, or pathological waste, with a capacity of few to about two hundred kg h^{-1}, huge Municipal Solid Waste (MSW) incinerators, totaling a capacity of 50 000 to 500 000 tons $year^{-1}$ distributed over several lines, and dedicated rotary kiln or fluidized bed units for specific industrial waste, of intermediate capacity (5 000 to 50 000 tons $year^{-1}$).

A second distinction is made between firing on a floor, a fixed or a mechanical grate, offering a residence time varying from most of a day to ½ hour, and energetic firing arrangements only operating on either coarsely shredded or finely divided waste.

3.2. Logistics and Storage

Small local units were formerly installed in apartment buildings, combining a chute-fed, chimney-combined furnace. These have essentially disappeared, obliterated by current codes on emissions. In isolated U.S. homes and farms trash is still processed by barrel burning, a most polluting business.

Refuse is brought by collection vehicles, barges, rail, or containers, and discharged into a deep, waterproofed concrete bunker of ample volume (Europe and Japan) or stored on a dump floor (USA) and moved by tractors to steel slat elevators. The storage serves for bridging the gaps between supply and incineration. Moreover, mixing wastes of different origins in the bunker, e.g. garden districts, apartments, or commercial, helps in providing a homogenized furnace feed.

Waste is mixed, stacked, and fed into the furnace hoppers by means of traveling cranes, with a voluminous grapple for handling waste. After descending in the load shaft the feed is metered and fed to the furnace and onto the grate using positive-displacement table or ram feeders with adjustable stroke length and frequency.

3.3. Operating Principles

Solid waste is sometimes fed batch-wise, but generally periodically and on the basis of positive mechanical action, exerted using a programmable and controllable (timing and stroke length) hydraulic drive. Periodic loading relies on dust-free systems (a two-slide lock, table or ram feeder). Regular feeding of relatively small amounts is best. Continuous feeding is only possible with a sized material, e.g., shredded fluff or wood shavings. These can be fed by an underfeed screw conveyor, a spreader stoker, a belt/chute system, or a pneumatic conveyer. Many types of waste have awkward handling characteristics, showing no definite angle of repose, being abrasive (glass, sand), yet sticky, tending towards bridging over chutes, clogging passages, and solidifying upon storage.

Solids are burned on the furnace floor or on a grate. Large capacity incinerators, using mechanical grates, are discussed below. Originally, grates were developed for firing lump coal and they exert various duties, namely:

- Supporting, moving, agitating and poking the burning solids;
- Distributing primary air that travels through the burning layer and activates the fire while cooling the grate.

In these units, volumetric heat release rates are relatively low, especially when firing moist and dense solid waste. Primary air is introduced through slots between the grate bars, or through holes in the combustion floor.

Pollution codes require furnaces to be preheated by auxiliary burners prior to the feeding of waste. Small incinerators with irregular, batch loading normally require careful post combustion to avoid intolerable levels of PICs.

The solid residue is removed daily and manually in small units, or when the ash content of waste is very low. Larger quantities are removed from an ash pit by periodic movement of a cooled scraper or by pneumatic, hydraulic, screw or drag conveyors, serving hoppers.

The formation of large cinders may jeopardize the operation of such systems. Hence, the amount, thermal consistency and sintering tendency of ash must be carefully considered: low temperature units supply a fine and friable ash, but rising temperatures cause it to sinter, first forming loosely coherent cinders, evolving later to strong and large slag agglomerates.

There is a range in between dry and wet-bottom furnaces, in which smooth slag extraction is virtually impossible, due to its unpredictable thermal behavior. A water bath closes the incinerator at the residue discharge end, quenching the residues.

Some incinerators are provided with supplemental burners for firing waste gases or liquids (e.g. oily waste). These streams are fired either above the burning solids, or in a separate post combustion chamber.

Solid waste incinerators range, depending on their capacity, from small back door or flue-fed apartment incinerators (obsolete by the start of the 1970s, following the introduction of air pollution codes) to gigantic municipal waste incinerators, generally generating power and procuring district heating. Many enterprises used stationary small to medium-sized incinerators for disposal of packaging and garbage. Special units have been developed for the disposal of tires, plastics and other production wastes.

The historical Polyma furnace is a well-known example of such a stationary incinerator. It consists of a horizontal combustion chamber, followed by a post-combustion chamber, a gas cooler and some air pollution control equipment.

Solid waste, such as tires, can be fed by a rake-shaped, internally cooled feeder mechanism. When combustion is completed the feeder revolves over half a turn and becomes a scraper-ash-extractor. Multi-fuel burners burn liquid and finely divided solids in support; sludge can be sprayed into the furnace by nozzles.

BASF pioneered the development of industrial waste incinerators at Ludwigshafen. Originally, it used a vertical stationary furnace for incinerating wastes, contained in bags or barrels. The latter was introduced into a lock, then holed to allow draining the contents and, when necessary, heated. Rotary kilns later replaced this type of furnace.

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Biographical Sketch

Alfons Buekens was born in Aalst, Belgium; he obtained his M.Sc. (1964) and his Ph.D (1967) at Ghent University (RUG) and received the K.V.I.V.-Award (1965), the Robert De Keyser Award (Belgian Shell Co., 1968), the Körber Foundation Award (1988) and the Coca Cola Foundation Award (1989). Dr. Buekens was full professor at the Vrije Universiteit Brussel (VUB), since 2002 emeritus. He lectured in Ankara, Cochabamba, Delft, Essen, Sofia, Surabaya, and was in 2002 and 2003 Invited Professor at the Tohoku University of Sendai.

Since 1976 he acted as an Environmental Consultant for the European Union, for UNIDO and WHO and as an Advisor to Forschungszentrum Karlsruhe, T.N.O. and VITO. For 25 years, he advised the major industrial Belgian Bank and conducted more than 600 audits of enterprise.

Main activities are in thermal and catalytic processes, waste management, and flue gas cleaning, with emphasis on heavy metals, dioxins, and other semi-volatiles. He coordinated diverse national and international research projects (Acronyms Cycleplast, Upcycle, and Minidip). Dr. Buekens is author of one book, edited several books and a Technical Encyclopedia and authored more than 90 scientific publications in refereed journals and more than 150 presentations at international congresses. He is a member of Editorial Boards for different journals and book series.

He played a role in the foundation of the Flemish Waste Management Authority O.V.A.M., of a hazardous waste enterprise INDAVER, and the Environmental Protection Agency B.I.M./I.B.G.E. He was principal ministerial advisor in Brussels for matters regarding Environment, Housing, and Classified Enterprise (1989). Since 1970 he has been a Member of the Board of the Belgian Consumer Association and of Conseur, grouping more than a million members in Belgium, Italy, Portugal, and Spain.

He is licensed expert for conducting Environmental Impact Assessments (Air, Water, Soil) and Safety Studies regarding large accidents (Seveso Directive).