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INCINERATION: A COMPREHENSIVE REVIEW

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ABSTRACT

Energy crisis and land filling due to municipal solid waste materials are two predominant problems in the industrialized world. Incineration is a common solution to these problems. Incineration is the thermal treatment of solid waste materials, which converts the waste into ash, flue gases and heat by the combustion of organic substances contained in it. Incineration is the established waste-to-energy technology and is the most common remedy to land filling problems in European countries like Germany, Netherlands and France. This paper is a comprehensive review on incineration, describing the state-of-the-art of the technology. The working and environmental impacts of an incineration plants are thoroughly discussed. Also, the sequence of processes involved in the incineration is explained in details. Finally, the merits and demerits of incineration technology over other waste-to-energy technologies, such as gasification, pyrolysis and anaerobic digestion, are briefly discussed.

Keywords: Waste-to-energy, incineration, landfilling, waste treatment

INTRODUCTION

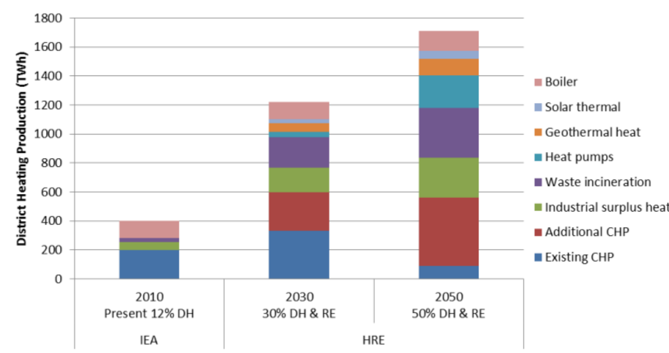

Fig. 1 Waste incineration in district heating (DH) production for the EU27 energy system in 2010, 2030, and 2050, if DH and CHP were expanded to 30% in 2030 and 50% in 2050 [2].

Incineration is the controlled combustion of waste for a defined time at specific temperatures and turbulence. Incinerators have a long history and they date back to 1877, when the first incinerator, designed by Alfred Fryer and engineered by Manlove, Alliott, and Fryer of Nottingham, came into operation for the Manchester Corporation's waste street depot [1]. In incineration, the organic matter in the waste is combusted and the residue along with the inorganic constituents is obtained as ash. Incineration is an attractive option in the energy deficient modern world due to its polygeneration capability. Waste incineration is used in conjunction with combined heat and power plants and district heating applications in many countries.

Municipal solid waste (MSW) incinerators supply partially renewable energy, which is based on biomass that can be used to lessen the load on coal, gas and oil powered plants. This in turn, helps to reduce greenhouse gas emissions. Every ton of MSW incinerated prevents one ton of CO_2 equivalents from reaching the atmosphere [3].Energy produced can serve multiple purposes including electricity generation, district heating [4, 5] and supply of steam for industries. For treatment of medical waste, incineration is found to be the best method in use, as it destroys pathogens and other contagious elements effectively at high incineration temperatures. Incineration also provides an easy way of heavy metal separation in waste as heavy metals can be easily separated by the proper treatment of the incinerator ash whereas mechanical separation is very energy and labor intensive. MSW incineration reduces the need of landfills and increases the life of existing landfills. Even though incineration causes the emission of dioxins, furans and CO_2 in small amounts, it avoids the production of methane gas from waste. This paper is an attempt to review the waste incineration technology with relevance to its fundamental features and processes. The working and characteristics of various incineration technologies along with their merits and demerits are discussed. The incineration emissions, treatment and handling of incineration products and the laws and policies regarding these are conversed. Comparison with other waste to energy (WTE) technologies like pyrolysis, gasification, and anaerobic/aerobic digestion are discussed. Also, the recent developments and future scope are briefly discussed.

INCINERATION

Processes and Steps

The main processes for the incineration of MSW are the waste reception, handling, combustion and after-treatment. The steps in these processes are listed and briefly explained below:

- Reception of waste
- Separation and storage of the collected waste and raw materials
- If necessary, then the pretreatment of waste
- Loading of waste into the furnace
- Thermal treatment techniques
- Energy recovery and conversion
- After-treatment stage, flue-gas cleaning techniques
- Management of flue-gas cleaning residue
- Flue gas discharge
- Control and monitoring of emissions
- Control and treatment of waste water (e.g. from site drainage, flue-gas treatment, storage)
- Management and treatment of fly ash/bottom ash

The pretreatment of waste may/may not be applied depending on whether the incinerator is aimed at the combustion of raw residual waste (RRW) or refuse derived fuel (RDF). RRW refers to the residual waste after recycling, reusing and composting. RDF is the form of the waste after it has been energy enriched. This is achieved by the removal of moisture and other incombustible materials like metals, glass, inert materials and so on. Also, volume reducing operations like pelletizing, densification, compacting etc. may be done. The typical energy content in the raw residual waste is 8-11 MJ/kg whereas that for the RDF is 12-17 MJ/kg [6]. The waste collected may be separated into MSW, bio-medical waste and hazardous industrial waste. This separation has to be done as each of the waste needs to be treated in a specific manner so as to properly decimate their harmful contents.

Each separated group of wastes is then fed into the incinerator through the charging door and is combusted completely in a series of steps. The combustion temperature, time and conditions vary with the type of waste incinerated. The energy from combustion is by extracted a suitable heat exchanger. Other products obtained are incinerator bottom ash, fly ash and flue gases. The after-treatment refers to the treatment of the flue gases before releasing them into the atmosphere. Primary concerns in the emissions are about the particulates, dioxins and furans. The particulate emissions are dealt by electrostatic precipitators, scrubbers and bag house filters. Dioxins and furans are treated by selective catalytic reduction.

TYPES OF WASTES AND THEIR TREATMENT

Municipal Solid Waste

It is the waste generated by commercial and residential establishments, which include items of daily use, such as product packaging, food scraps, home appliances, etc. Combustibility of municipal solid waste (MSW) can be assessed using the percentage of ash, moisture and combustible content; Tanners diagram (Fig.2) incorporates these three parameters in a single platform.

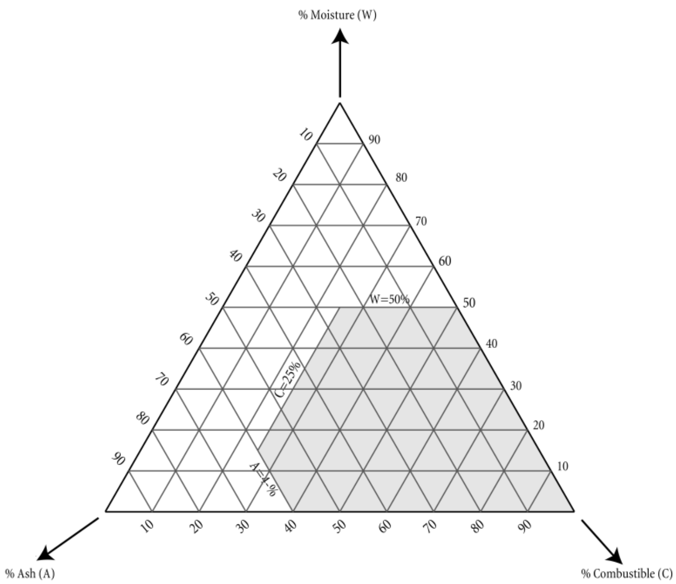

Fig. 2 Tanners diagram [7] of MSWincineration, the World Bank, Washington, D.C.

In order to effectively recover energy from MSW, the incombustible materials need to be separated. For this purpose, several types of separators are used. Magnets and eddy current motors sort out the ferrous metals. Static and moving vibrators are employed to separate the non-ferrous metals. Glass is separated by trommels and other separators [8]. The removal of metals and glass from the waste increases the calorific value and decreases the quantity of recoverable metals from the slag/ash. Gravity separation and hand picking are generally used to sort out paper, card and plastic. This will decrease the calorific value but it also reduces the chlorine loads to be handled as poly vinyl chloride (PVC) is common in plastic waste. Food and garden wastes increase the moisture content and decrease the calorific value of the waste. They can be separated by composting the waste and then separating the biogas evolved by air classification or near infraredspectroscopy (NIS). Bulky wastes are reduced in volume by crocodile shears, shredders, rotor shears and mills. This reduction in volume is needed to size the waste to be easily handled by the feeding equipment and also to homogenize the waste. A bunker enabled with fire protection equipment is used to store the waste blend.

Hazardous Waste

Hazardous waste consists of various industrial wastes, effluents, commercial byproducts and discarded commercial products which pose substantial threat to the public health and environment. For example; heavy metals, arsenic, mercury, radioactive materials and so on. Incinerator plants that handle hazardous waste can be classified in to merchant plants and dedicated plants. Merchant plants are generally owned by private companies, municipalities or corporations and they compete in the global market. Dedicated plants are owned by only private companies, mainly to treat their own waste. Merchant plants are flexible whereas dedicated plants are made to treat specific type of hazardous waste. The reception of hazardous waste is made after receiving information about the origin of the waste, toxic materials contained, combustion parameters, moisture, calorific value, safety, environmental concerns and legally binding policies regarding the waste [9]. In order to avoid undesirable reactions, the transportation of the waste should be done with specified packaging requirements. The solid hazardous waste is fed by cranes and feed hoppers and is stored in bunkers whereas hazardous waste in the form of liquid or sludge is stored mainly in tank farms with an inert gas atmosphere. Liquid and sludge waste is handled through pumps and pipelines. Storage in drums is also preferred. Toxic, odorous, corrosive and reactive liquids are stored in their transportation containers only and are fed into the incinerator through direct injection devices. Due to the homogeneity of the hazardous wastes, the necessity of separation required is less.

Industrial and Sewage Sludge

It is the output from waste water treatment plants in domestic and industrial sectors. It may contain heavy metals, saline water, spent waste solvents and chemicals due to sludge treatment [10]. Pretreatment of the sewage sludge is done through screening, stabilization, conditioning, mechanical dewatering and thermal dewatering methods. Mechanical dewatering through chamber filter passes, centrifuges, decanters and belt filter passes etc., can produce dry solids percentages in the range of 10-45% [9]. Conditioning is done to remove the inorganic flocking substances such as lime, coal, aluminum salts and iron salts. Still the water content in the sludge is high therefore thermal dewatering or drying is made to make the sludge fit for incineration. Sludge digestion can also be done as a part of treatment process. Large reduction in sludge volume, destruction of toxic substances, increase in calorific value and odor minimized operation makes incineration the most preferred technique for sludge disposal.

Clinical Waste

The clinical (medical) waste can be grouped into hazardous waste, which contains infectious chemical, toxic or pharmaceutical waste, anatomical and pathological waste, sharps, radioactive waste and other waste such as glass, paper, packaging material etc. About 75-90% of the every day's clinical waste is non-hazardous [11]. Plastics constitute about 14% of the clinical waste and in thata good amount is contributed by PVC [12]. Clinical waste has to be stored in an environment of temperature not more than 10°C when required to be stored for more than 48 hours. Manual handling should be minimized for medical waste and all handling and storage platforms must be impermeable and sealed from drainage. Pre-treatment of the clinical waste may include shredding, steam and boiling water sterilization. Mechanical compaction of clinical waste has to be done with care so as to not release fluids containing pathogens.

Incineration is an attractive option for biomedical waste due to high temperatures, which destroys infectious compounds and thereby reduction in volume of the waste by 90%. A study by Blenkharn[13] has proposed a metric, the sterility assurance levels to ensure proper treatment of clinical waste in incinerators.

INCINERATOR UNIT

An incinerator of practical use consists of a waste handling system (shredders, mills, shears), waste feeding system (conveyor belts, feeders and hoppers), combustion chambers, flue gas cleaning system (scrubbers, electrostatic precipitators), draught inducing equipment and a chimney. The typical setup of an incineration unit (semi-pyrolitic) is shown in Fig. (3).

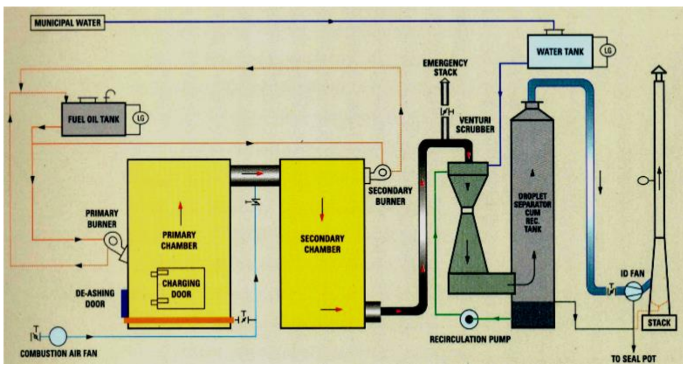

Fig. 3 Incinerator (semi-pyrolitic) setup [14].

The waste, after pretreatment by the waste handling system, is the energy enriched and homogenized form. This is fed into the charging door of the incinerator by means of a feeder system. The charging door opens to the incinerator furnace or the primary combustion chamber in which the primary combustion of the waste takes place. This is lined with refractory and insulating bricks. Inside the primary furnace, a suitable fuel supply is provided, which improves the combustion of waste. Combustion is generally initiated by electrical sparking. The waste is fed into the incinerator only after the desired temperature is reached inside the primary combustion chamber. The temperature inside the primary combustion chamber is around 850°C. Combustion occurs inside the primary chamber, with less air. Therefore, the ash settles at the bottom of the primary combustion chamber and can be taken out through the de-ashing door. An induced draught fan is provided at the end of the whole system so as to provide the driving force for the flow of flue gases through the system.

The gases evolved in the primary chamber flows to the secondary combustion chamber due to the induced draught. The negative draught created also ensures the operator safety at the charging door by preventing the flue gases from leaking through it. In the secondary combustion chamber, temperatures vary around 1050°C. The flue gases coming from the primary combustion chamber burn in the presence of excess air to produce CO_2 and H_2 as the main products. Adequate residence time needs to be provided to accomplish this. About 80% of the total energy available in the waste can be recovered through the use of a boiler. Steam is produced at the boilers using this heat and is used for power generation. Waste incineration plants can also serve as CHP's (Combined Heat and Power plants) and therefore can be polygeneration systems. The flue gases are then cooled for after-treatment by mixing some ambient air through an emergency stack. Flue gas cleaning is generally done through two stages. In the first stage, the acid producing chemical compounds are removed by wet scrubbers and droplet separators. Generally, a venture scrubbing device and a centrifugal droplet separator are used for this purpose. In the second stage, the fly ash, which is the cause of particulates in the flue gases, is treated by electrostatic precipitators, scrubbers or baghouse filters. Selective catalytic reduction may be performed to reduce NO_x emissions. In order to ensure that the emissions produced are below the permitted levels, a flue gas monitoring system is also employed. Ash handling mechanisms treat and remove the bottom ash.

TYPES OF INCINERATORS

Starved Air Incinerators

These are also known as controlled air incinerators or semi-pyrolitic incinerators. In this type of incinerators, the waste is loaded directly into a primary combustion chamber. No grates or other waste handling equipment is present and the waste is combusted directly on the combustion chamber floor, which is made-up of refractory bricks and/or vitrified tiles. Auxiliary burners are located inside the primary combustion chamber, which are either fuelled by oil or natural gas. They are used only at the starting since the primary combustion chamber acquires enough temperature once it is in continuous use. The auxiliary burners heat the waste and pyrolysis of the waste happens. This occurs in a temperature range of 700-800°C. The temperature of the primary combustion chamber is maintained by a suitable cooling system, usually water based. The pyrolysis at low air-fuel ratios causes the volatilization of the waste. The gases evolved mainly contain partially and unburned hydrocarbons and CO. They move at very low velocities into a secondary combustion chamber in which excess air is supplied. Here, combustion temperatures vary from 1000°C to 1200 °C and complete combustion takes place. A study by Jangsawang et *al.,* [15] reported that the monitoring of CO emission can be used to determine the optimum temperature settings for efficient operation. Another study has shown that a slight increase in the secondary air supply will decrease the CO emissions in incineration of wastes with high combustible content [16].

Excess Air Incinerators

They are compact cubes with many internal chambers and baffles. Excess air incinerators are generally modular units designed to treat waste from small facilities. The waste is generally combusted completely in two or more chambers in the presence of excess air. Generally, excess air incinerators are used to incinerate biomedical waste and clinical waste with air percentage varying from 100% to 300% [17].

Modular Incinerators

They are small capacity incinerator units that are designed to process about 300mg of waste per day. Most of the modular incinerators have their working technology similar to controlled air incinerators. Waste is generally loaded into the incinerator by a hydraulic ram. Sometimes, manual loading is also done. Wastes are handled inside the primary combustion chamber using grate technology. Since modular incinerators are generally designed with more emphasis on treating the waste than for energy recovery, they may/may not have heat recovery systems.

Grate Incinerators

Grate incinerators are the most widely used technology in waste incineration. Although mainly used for treating MSW, they are also used in incineration of industrial wastes, non-hazardous wastes, sewage sludge and some clinical wastes. The grate consists of a flexible/non flexible frame made up of metal chains and plates. Sufficient cooling is required to maintain the mechanical strength of the grates. The different types of grate technologies, their characteristics and the waste they are used to handle are shown in Table (1). The functions served by the grate are to transport the materials in the incinerator furnace, to stock the waste, to distribute the primary combustion air to the waste layer, to loosen the waste and to position the incineration zone. A modelling study by Ryu et *al.,*[18] have given insight into the incineration phenomena on grates. A study in this domain by Abhishek Asthana et *al.,*[19] gave a new model named GARBED-ss which in two dimensions was able to describe most of the chemical, thermal and physical phenomena in the combustion of MSW bed on a travelling grate incinerator. Grates are preferred widely due to their reliability, ability to handle wide range of thermal loads and their effectiveness in handling different types of wastes. Also, grates can handle waste easily, irrespective to their dispersion and homogeneity. Some disadvantages of grates are the requirement of monitoring the grate temperature and cooling, the high expense associated and the complexity of the mechanical drives used in it.

Rotary Kiln Incinerators

They are the most widely used technology for the incineration of hazardous wastes. A rotary kiln consists of a horizontal rotating hollow cylinder supported by rollers or drums. The waste is fed through a hopper into the cylindrical vessel; it moves through the vessel by gravity since the vessel is horizontally inclined. Waste is exposed to oxygen and heat as it moves through the vessel. The rotational speed and the horizontal inclination of the cylindrical vessel determines the residence time of waste in the vessel. Rotary kilns are actually primary combustion chambers. The solid residues/ash fallsout of the vessel whereas the flue gases go into the secondary combustion chamber. Here, complete combustion of the flue gases takes place. Rotary kilns provide good residence time and are able to handle wastes containing water content as high as 60% and offer wide range of temperatures. They have on overall thermal efficiency of 80%, which is attractive. Some of the demerits associated with rotary kilns are their limited capacity, high cost and complicated design procedure. Vermeulen et *al.,* [20] compared cement kiln and rotary kilns for the effective combustion of calorific industrial waste and concluded that Rotary kilns are more preferable.

Table 1.Types of grate technologies, characteristics and wastes handled

Name	Characteristics	Wastes handled
Fixed grate	Made up of a metal grate in a furnace with an ash pit at the bottom. Waste is moved by a series of rams.	Raw MSW, pretreated MSW
Moving or travelling grate	Mechanically actuated continuous linkages of chains and plates. Small slots in between the grate elements provide part of the air for combustion	Raw MSW (widely handled), pretreated MSW (widely handled), Clinical waste
Rocking grate	Similar to moving grate but mechanical pivoting is done to give rocking action to agitate the waste. Developed for handling compost and combustion residue.	Raw MSW, pretreated MSW, Clinical waste, Hazardous waste (rarely handled)
Reciprocating grate	Grates are placed across the width of the furnace, but put one above another. Alternate sections move back and forth whereas adjacent grates remain still. Waste is agitated, mixed and moved in a sequential manner.	Raw MSW, pretreated MSW, Clinical waste, Hazardous waste (rarely handled)
Roller grate	Metals cylinders and rollers arranged in a stepped fashion; the rollers roll in the direction of waste movement. Waste is stirred due to the tumbling effect created by this.	Raw MSW, pretreated MSW (widely handled), Clinical waste, Hazardous waste (rarely handled)

Fluidized Bed Incinerators

In this type of incinerators, a strong air flow is used to suspend the sand particles to form a fluidized bed on which the waste is incinerated. It consists of a vertical chamber, in which the fluidized bed material, i.e., sand is located at the lower section. Preheated air is supplied from the bottom at high flow rates to create the fluidized sand bed. The temperature above the bed is higher (around 900°C) than the temperature of the bed (around 650 °C) itself. The waste is usually pretreated to maintain homogeneity and is dropped on the top of this bed. Here, it is dried, combusted and volatilized. Fluidized bed is preferred for the incineration of different types of sludge due to its ability to handle wastes containing water up to 60%, no moving parts, moderate capacity, good residence time and an overall thermal efficiency of 90%. This type of incinerators can handle waste in solid form, liquid form or a mixture of both. Another efficient type of fluidized bed is the circulating fluidized bed. Huang et *al.,* [21] has studied the significance of this technology as an emerging technology in thermal treatment domain. A study by Li et *al.,* [22] have proposed that the integrated drying and incineration of wet sewage sludge with a moisture content of 80% using bubbling and circulating fluidized bed incinerators. Wastage of supply heat to the sand, requirement of automatic control and dust emissions are some of the limitations of fluidized bed incinerators. Circulating fluidized bed and bubbling fluidized bed are two developed varieties of the fluidized bed incinerators.

Onsite Incinerators

Onsite incinerators, also referred as emergency incinerators ,are limited capacity incinerators, which can be transported and then assembled onsite. They are used in case of emergencies like animal epidemic outbreak, bio-hazards, chemical and radioactive accidents, etc. An overview of the onsite incineration technology providing technological descriptions can be seen in the report [23] prepared by EPA (Environmental Protection Agency) for the US Govt., dated March 1998.

EMISSIONS AND THEIR TREATMENT

Particulates

These consist of the fly ash and the heavy metal particulates of Arsenic, Antimony, Cobalt, Copper, Mercury, Cadmium, Chromium, Nickel, Thallium, Manganese and Vanadium. Particulate emissions in the flue gases arise from improper ignition, off-design loading of wastes, excessive draught, increased air velocities and disturbance of fire in between the incineration process [24]. Mechanical separators (cyclones and multi-cyclones), electrostatic precipitators (condensation, wet), wet-scrubbers (ionization, venturi-type) and bag house filters (fabric filters) are the commonly used technology to control particulate emissions.

Acidic Gases

The acidic gases found in the emissions are HF, HCl, NO_x and SO_2. The production of HCl is mainly due to the presence of PVC and sodium chlorides in the waste. Oils, tires and house hold refuse contribute to the formation of SO_2. Polytetrafluoroethelyne (PTFE) is commonly found in general plastics and causes the formation of HFs. NO_x formation comes from many sources including air. For the treatment of all acidic gases except NO_xs in the emissions, mainly treatment with alkaline reagents is done. The treatment methods can be classified into dry, semi-wet and wet processes. In dry process, a dry sorption agent like lime is added. For semi-wet process, a sorption agent in the form of suspension or slurry is added (for example, lime solution) and in wet process, the sorption agent added is aqueous, (for example, hydrogen peroxide solution). The products after sorption obtained for dry, semi-wet and wet process are dry residue, slurry and aqueous, respectively. For the treatment of NO_xs, SNCR (Selective Non Catalytic Reduction) and SCR (Selective Catalytic Reduction) are the main techniques used. SNCR implements the addition of ammonia to reduce NO_xs, whereas SCR mixes the flue gases with ammonia and then passes the mixture over a catalyst (Rhodium, Platinum, Zeolites, etc.) mesh. A study by Harris et *al.,* [25] showed that N_2O emissions were ten times lower with the use of SCR when compared to SNCR. Prevention of excess air in incineration, FGR (Flue Gas Recirculation), Oxygen injection, water injection and natural gas injection are some of the other techniques used for control of NOx emissions. A recent study [26] used a calcium based porous sorbent having high surface area for the simultaneous removal of SO_2 and particulate matter. The ways to avoid the formation of secondary pollutants (acidic oxides, dioxins and heavy metal compounds) are discussed by Li [27].

Dioxins and Furans

Polychlorinated dibenzodioxins (PCDDs), or simply dioxins, are a group of polyhalogenated organic compounds that are formed in almost all waste combustion processes. They are classified as carcinogens or cancer causing agents. Dioxins are produced in incineration mainly through the homogeneous reactions occurring in the temperature range 500°C to 800°C and through the heterogeneous reactions occurring at lower temperatures (200°C to 400°C). Dioxins are also formed in the de novo reactions of the fly ash [28]. It was also reported that the peripheral utilities of a waste incineration plant can also be contributors of dioxins [29]. The way to avoid formation of dioxin is sorting the MSW properly, avoiding composting of organic waste and avoiding incomplete combustion [27]. Furan is an aromatic ring organic compound, which is also a carcinogen. Emission of dioxins and furans is reduced by cracking methods, which uses exposure of the flue gases to high temperatures over an adequate residence time to ensure that the molecular rings of dioxin and furan compounds crack and react to form harmless compounds. This may cause the emission of NO_xs as high temperature causes splitting of N_2 and O_2.

COMBUSTION PRODUCTS AND THEIR HANDLING

Bottom Ash and Boiler Ash

Bottom ash is the residue of waste obtained after the primary combustion. Boiler ash is the ash obtained throughout many operations in a waste incineration plant. They are formed mainly due to the increased carbon content in the waste, presence of inert materials and metals. A study focused on the characteristics of incinerator ash was done by AwassadaPhongphiphat et *al.,*[30]and was reported that the presence of heavy metals in the bottom ash was less due to 1000°C+ combustion temperatures. Studies regarding the safety [31], resource recovery potential [32] and use of incinerator bottom ash [33] suggested that there were no significant risks in the use of incinerator bottom ash for construction purpose, even for residential buildings and that the recovery of ferrous and non-ferrous metals were possible with high efficiencies. Some of the operations performed for treatment of bottom and boiler ash are size reduction, segregation of ferrous and non-ferrous metals, aqueous washing (in order to remove soluble salts) and ageing. If to be landfilled, condensation treatment is also done to reduce the permeability so as to lessen the chance of leaking of hazardous substances [34]. For the using of incinerator ash for construction purposes, treatment with a hydraulic or hydrocarbon binder is done. It is also seen that incinerator bottom ash can be used to replace pulverized fuel ash and clay [35]. Thermal treatment including,vitrification, melting and sintering is done to make and contain inert metals in a glassy matrix. In some cases, the ash after the thermal treatment is compacted into blocks and is used in landfills.

Fly Ash and FGT Residues

Fly ash mainly consists of the particulate matter in the flue gas, such as unburned hydrocarbon compounds, fine combustion residues, etc. It also contains compounds of sodium, calcium and potassium with chlorine and Sulphur. Toxic compounds of heavy metals, likePb, As, Zn, Cu etc., and toxic organic compounds like dioxins. The flue gas treatment (FGT) residues refer to the sludges and solid wastes obtained from the scrubbers, precipitators, etc., used for flue gas treatment. In a study by Ŝyc et *al.,*[36],the fly ash from the incinerator was found to have alkaline nature, whereas the FGT from the electro static precipitators and the catalytic filters were found to have slightly acidic nature. It was inferred that the undesired properties such as solubility, heavy metals and organic contaminants tend to increase with the decrease in the temperature of the point of ash separation. The treatment of fly ash is done through separation and material recovery methods [37], stabilization/solidification methods and thermal treatment methods [34]. It can be seen that properly treated fly ash and FGT residue need not be dumped into landfills but can be used for many productive applications. Fly ash is now being used in construction materials such as for alinite cement [38], sulfoaluminate cement clinkers [39], lightweight aggregates [40], etc., with proper treatment [41]. New applications like the production of calcium phosphate hydrogel with the use of incinerator fly ash (documented in a recent study [42]) shows the importance of upcoming research in this domain.

ENVIRONMENTAL IMPACTS AND GOVERNMENT POLICIES

Although the technological advancements have succeeded in reducing the emissions from incinerators, many studies have been conducted on the assessment of the environmental impacts of incineration technologies. A study by Zhao et *al.,* [43] for the city of Shuozhou reported that the co-incineration of MSW with coal contributed to global warming and eco-toxicity in soil, due to its fossil CO_2 and heavy metal emissions. It was suggested that more attention should be given on emissions of heavy metal and acidic gas. A recent research focused on 110 French incinerators using life cycle approach by Antoine Baylot et *al.,*[44] found that the climate change impact potential of the incineration of 1 tonne of waste varies from a benefit of 58 kg CO_2-eq to 408 kg CO_2-eq, with 294 kg CO_2-eq as the average impact. Rabl et *al.,* [45] compared the environmental impact of landfilling and incineration and found that the damage cost of incineration ranged from about 4 to +21 €/tonne of waste, whereas that of landfills, around 10 to 13 €/tonne of waste. Several studies found that the adverse health effects caused by incinerators on areas of proximity included increased twinning in births, incidences of primary liver cancer, laryngeal cancer, soft-tissue sarcoma and lung cancer [46-48]. Arguments against the adverse health effects caused by incinerators are also found [49]. Due to these environmental concerns, a number of regulations on the incinerator emissions by various agencies and countries are seen [50]. Also, the handling and treatment of fly ash, bottom ash, FGT residue, etc., is often legally debated and regulated [51]. It is now seen that preference of incineration over recycling and reuse is being debated and many government policies are now being aimed to support the latter, in various countries [52-54]. However policies supporting incineration because of its polygeneration capability are also found [55].

COMPARISON WITH OTHER WTE TECHNOLOGIES

The main waste-to-energy (WTE) technologies are incineration, pyrolysis, anaerobic digestion and gasification. The description and the working process of these technologies are given by a number of articles [56, 57]. A recent work by Lombardi et *al.,* [58] reported that incineration and gasification are the two leading WTE technologies for energy recovery from waste. Also, Out of the two, it was found that gasification process is more complex and expensive, more difficult to operate and maintain and less reliable than the incineration, for large capacity systems of comparable size and steam cycle technology. Research conducted by Münster et *al.,* [59] suggested biogas and thermal gasification technologies as the alternatives for incineration. In a recent report [60], it is shown that for the same capacity, the Air-fed RDF Gasification technology is the best option available for energy recovery, followed by incineration. Consonni et *al.,* [61] pointed out that the parameters that highly influence the thermal efficiency of the WTE systems are the scale and the temperature of steam inlet into the power generating turbine. The environmental impact of the WTE's can be seen in previous research [62].

RECENT DEVELOPMENTS AND FUTURE SCOPE

As seen in the earlier sections, some of the government policies continue to support the incineration technologies for waste disposal (UK, for example) whereas some promote alternative technologies. Recently, innovative methods [63] for low pollutant and economically efficient waste combustion were patented by KIT Germany. Incineration is considered to be a proven technology in Europe [64] and it can be seen that the latest directives support incinerators with growing control on emissions. It can be seen that for a developing country like China, urban expansion, increase in population, proper MSW management and public concerns are the factors to be considered for the application of incineration, which is still an advanced technology for developing countries [65]. Estimates [66, 67] by ecoprog, Germany shows that about 200 plants with a total annual capacity of 60 million tons were constructed between 2009 and 2013. It is expected that about 500 plants with a total annual capacity of 150million tons will be commissioned in the coming 10 years. Much of this will be from the developing countries, led by China.

The future scope of waste incineration plants lies in the integrated and polygenerative perspective. Integration of the incineration technology with renewable energy technologies like Solar or Wind energy can serve multiple purposes in a more environmental friendly manner. Geothermal and Solar technologies can be used for the pretreatment of the waste. Low grade heat required for incineration and waste treatment purposes can be supplied from renewable energy sources to get more efficient and cleaner operation. Also, polygenerative plants with integration of district heating, desalination, refrigeration, etc., can satisfy the growing needs of the developing world.

SUMMARY

The authors have made an attempt to review the various incineration technologies through its working process steps. The types of wastes, their handling are discussed at first. The various incinerators developed are explained along with emphasis on their characteristics. The emissions produced are discussed in detail with focus on their treatment and handling. Also, handling, treatment and uses of incineration products are also conversed. Comparison of the incineration technology with the other WTE's is done to give an insight into the significance of incineration in energy recovery. Discussions on the environmental impact and government policies have done to seek out the position of incineration technology in the environmental platform. In the end, a brief outline of the recent developments in the incineration technology, trends as well as its future scope are done.

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Fig. 1 Solar cooling paths.

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