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Design of a Municipal Solid Waste Incinerator Based on Hierarchical Methodology

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A municipal waste inicnerator has been analysed in the post-graduated program on Engineering and Applied Sciences (PICA-UAEM) as an alternative for integral management of municipal solid wastes. In Mexico, incineration exists since end of the seventies, before actual regulations controlling hazardous waste were established. Today there are 35 authorized companies in Mexico for incineration of hazardous wastes some of them having more than one incinerator, which results in 43 operating equipments. 85 % of them are used with biological-infected waste ant the rest for the incineration of hazardous waste (ISWA, 2002). As of today, incineration is not applied as treatment method for municipal solid waste on industrial scale. Incineration prevents continuous use of landfills reducing drastically methane emissions and their great contribution to green house effect. Besides that, it replaces the use of fossil fuels in electricity production.
A hierarchical method for synthesizing process flow sheet of a municipal solid waste incinerator for the city of Cuernavaca has been applied. The procedure is evolutionary in nature and proceeds through a hierarchy of decision levels (Douglas, 1985), where more fine structure is added to the flow sheet at each decision level. Heuristics are used to obtain some of the structural elements of the process flow, and other heuristics are used to make some of the decisions required at the various decision levels. In many cases, no heuristics are available, so that process alternatives are generated.

1. Introduction

Most incinerators used to burn garbage are mixed waste incinerators, usually referred to as MWS incinerators. The hot gases created by this burning process are sent through an energy recovery boiler just downstream of the furnace. The hot gases from the burning process surround the boiler pipes, which contain water. This makes the water boil, creating steam. The steam is then used for space heating or put through steam turbines to create electricity. Most of the size and expense of the incinerator is dedicated to the

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pollution control equipment. In most cases, the first component of the pollution control equipment is the stage at which ammonia is injected into the gases produced from the burning process; this removes the oxides of nitrogen. Then activated carbon is injected into the gases; the primary purpose of this stage is to remove mercury. Finally, most incinerators have a baghouse or electrostatic precipitator; the purpose of this stage is to capture particulate and toxics attached to those particles before the gases are discharged to the air through the incinerator's stack. In addition to creating large volumes of gases, the incineration process creates ash. Two kinds of ash are formed during the incineration process. The first kind is called bottom ash. This is the ash that falls through the grates during the actual burning process. The second kind of ash is called fly ash. This is the ash that is created and captured during each stage when the gases are being treated to avoid releasing gases to the air. The fly ash usually makes up about 10% of the total ash created in an incinerator. The combined weight of the fly and bottom ash is usually about one-third of the weight of the waste that was put into the incinerator to be burnt. The ash is in a much more concentrated form than the wastes that were put into the incinerator. Therefore, if measured by volume, the ash is only 10% of the volume of the garbage that went into the incinerator.

1.1 Conceptual design of the incinerator

As with all other energy generation facilities, waste-to-energy facilities are designed in accordance with the specific properties of the fuel. Waste is far more complex than conventional fuels. If the facility is a combined heat and power plant (CHP), the boiler is a steam boiler. The steam produced is led to a steam turbine, which drives a power generator. The residual heat of the steam is recovered for the production of district heating. The flue gas generated is cleaned of dust, heavy metals, acid gasses (HCl, HF and SO_2), nitrogen oxides (NOx) and dioxins. The emission limit values are stipulated in the environmental permit of the facilities, which in turn is based on the Norma Oficial Mexicana NOM-098-SEMARNAT-2002 "Protección Ambiental – Incineración de Residuos, especificaciones de operación y límites de emisión de contaminantes".

When incinerating 1 Ton of waste approx. 2 MWh district heating and approx. 0.67 MWh electricity are produced. Where no electricity is produced, all the energy is recovered in the form of district heating. 4 Ton of waste substitutes 1 Ton of oil or 1.6 Ton of coal. The greater proportion of the waste is biomass, but it does also contain fossil materials such as plastics. Approx. 20 per cent of the waste consists of non-combustible parts such as glass, iron and other metals. These fractions exit the facility in the bottom ash, which is recycled.

2. Methodology

The hierarchical heuristic method is an extension of the purely heuristic approach and combines heuristics with an evolutionary strategy for process design. Douglas (1988) has proposed a hierarchical heuristic procedure for chemical process design where heuristic rules are applied at different design levels to generate the alternatives. The hierarchical heuristic method consists of the following steps:

Step 1. Batch vs. continuous.

Step 2. Input-output structure of the flowsheet.

Step3. Recycle structure of the flowsheet.
Step 4. Separation system synthesis.
Step 5. Heat recovery network.
The hierarchical heuristic method emphasizes the strategy of decomposition and screening. It allows for the quick location of flowsheet structures that are often ‘near’ optimal solutions. However, the major limitation of this method, due to its sequential nature, is the impossibility to manage the interactions between different design levels. For the same reason there are problems in the systematic handling of multi-objective issues within hierarchical design. The hierarchical heuristic method offers no guarantee of finding the best possible design. Smith (2005) has proposed an onion model similar to the hierarchical heuristic model for decomposing chemical process design into several layers. The design process starts with the selection of the reactor and then moves outward by adding other layers – the separation and recycle system (Powers, 1972).In this work, an improvement of the hierarchical heuristic method is achieved applying it to the design of a municipal waste incinerator adapted to the specific needs of our community.

3. Results

3.1 Batch vs. Continuous

According to the guidelines from the Douglas methodology applied to the conceptual design of a municipal solid waste incinerator, it is concluded that this process should operate on a batch basis.
The incinerator is designed to be operated 8-16 h/d so that ash removal and certain maintenance can be performed during the shutdown. Besides that, the incinerator in Cuernavaca will complement a Municipal Waste Management Program which includes a recently built landfill. Also, the incinerator will have an auxiliary solar energy operated evaporator. This fact limits the operation of the incinerator to a maximum of 8 h/day. Annual planned capacity of the incineration plant is 36500 t/y, flexibility is guaranteed by a batch operation.

3.2 Flowsheet structure of a Municipal Solid Waste Incinerator

In the Figure 1 we show the preliminary flowsheet of a municipal waste incinerator based on Douglas methodology.

3.3 Recycling structure

As from the presented flowsheet (Figure 1), it can be seen that the bottom ash which leaves the waste treatment unit can be returned to the process for further incineration, in order to reduce the volume to be landfilled to the maximum possible.

3.4 Separation systems

3.4.1. Particulate

Reported values for particulate emissions from uncontrolled starved-air, staged combustion incinerators vary from 0.012 to 0.212 grains/dscf at 12 % CO_2. Starved-air incinerators have the ability to operate with particulate emission rates consistently below 0.08 grains/dscf at 12 % CO_2. Other technologies have much higher uncontrolled levels.

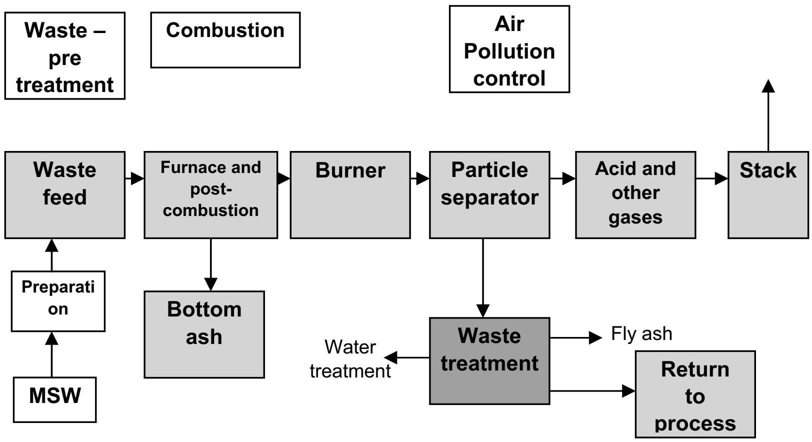

Figure 1: Flowsheet of a municipal waste incinerator including environmental control system.

3.4.2 Acid Gases.

Based on the limited literature available, an average uncontrolled SO_2 emission rate of 45-87 ppm can be expected from our municipal waste incinerator. In normal SO_2 scrubbing systems for solid fuel boiler systems, an actual operating removal efficiency of 90-95 % can be assumed.

HCl emissions from burning municipal waste in starved-air or excess-air incinerators have ranged from 53-724 ppm before the exhaust gas is treated, but HCl emission levels vary widely and reflect variations in feed stock. Plastics and paper have been found to be the major contributors, while food waste and untreated wood products are minor contributors of HCl. Typically, food waste and wood products make up only 8 % of the source of chlorine. An aggressive paper and plastic recycle program can drastically reduce the source of chlorine and reduce HCl emissions to the low end of the 50-725 ppm HCl range for an incinerator with a materials recovery facility. Because PVC plastics contain 40 % chlorine, removal of all PVC plastics from the waste delivered to the incinerator may be a significant factor in helping achieve low HCl emissions.

3.4.3 Nitrogen Oxides.

NOx emissions come from two separate sources during combustion. The first source is oxidation of nitrogen in the fuel (fuel NOx); the second source is the high temperature oxidation of atmospheric nitrogen (thermal NOx). The amount of NOx generated is highly dependent upon the furnace heat release rates and residence time. NOx emission rates increase with increasing furnace temperatures and excess air. These conditions combine to produce minimal thermal NOx. Rates of NOx formation are affected by nitrogen availability as well as temperature. Waste containing a high nitrogen-content, such as leaves and grass clippings, will increase the fuel NOx. An uncontrolled NOx emission rate between 258-327 ppm can be expected from the incinerator, it can be reduced by the injection of ammonia or urea. Injection is accomplished using either steam or compressed air.

3.4.4 Carbon Monoxide.

Maintenance on the natural gas burners and their temperature controllers, in the primary and secondary chambers, will assure that temperatures in these chambers are maintained above the ignition temperature of CO. Bag house and scrubber systems have no effect on CO emissions. High CO emissions reflect inefficiency in the combustion process, incomplete destruction of organic compounds, and loss of energy that should have been released in the combustion process.

3.4.5 Dioxins and Furans.

Chlorinated dibenzo-dioxins (PCDD) and dibenzo-furans (PCDF) can be generated with small amounts of chlorine present. The formation of these complex chlorinated hydrocarbons can occur in the combustion process and during the combustion gas cool-down process. The quantity of PCDD and PCDF is a function of the combustion process efficiency. The secondary combustion process has a significant affect on the "polishing" of the combustion gas. The temperature must be maintained above 800 °C to assure rapid destruction of the PCDDs and PCDFs formed at lower temperatures in the primary combustion process.

3.4.6 Heavy Metals.

The best control alternative is a fabric-filter system. As the flue gases cool, the vaporized heavy metals condense on particulates. Due to their small size (less than 10 μ), heavy metal particulates are not collected effectively by scrubbing systems (less than 50 % effective). Fabric-filter systems with "seeded" bags create a tortuous path that effectively controls release of fine particulates.

3.5 Heat exchanger networks

Typically the steam or hot water produced in the energy recovery system is matched to the existing space-heating power plant conditions. The incinerator is used as a base-load generator due to its need to burn waste at a constant rate of throughput. This inflexibility in operating the incinerator means that the existing fossil-fueled, space-heating plant will be swingloaded to follow changes in the daily demands (Griffith et al., 2005). It is desirable to equip the incinerator plant with a steam turbine to produce electricity or do other mechanical works (e.g., pump water, run air compressors) (Li and Kraslawski, 2004).

3.5.1 Steam turbines

There are available that use steam at pressures as low as 300 psig, perform mechanical work, and exhaust the steam at 150 psig or lower.

3.5.2 Electricity Generation.

Electrical generation rates of 400 kWh from a 50-tpd incinerator plant and more than 1,600 kWh from a 200-tpd plant can be expected, despite the relatively low overall plant efficiencies (i.e., 10-12 %).

4. Conclusions

The incineration process as a complementary alternative for the Municipal Waste Management Program is innovative for Mexico and the city of Cuernavaca, where

landfill space is reduced and also since incineration process is not used as a treatment method. The use of the hierarchical methodology for synthesizing the process flowsheet of the municipal solid waste incinerator was effective.
Mexico has ratified the Kyoto protocol and in this connection committed itself to reducing the total emission of greenhouse gases. Waste incineration makes a significant contribution to this reduction. Landfills for waste are extremely space consuming, so when the waste is incinerated instead, landfill areas are saved. When incinerated, the waste is reduced as follows: by weight by 80-85 per cent and by volume by 95-96 per cent. Finally, incineration makes it possible to recycle the mineral components of the waste (the bottom ash).

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