Reprinted from chemical plants + processing

Incinerators

German Kurz, Heinrich Güthoff

Caloric GmbH - Lohenstr. 12 - 82166 Graefelfing (near Munich / Germany)
Phone +49 (0) 89-89 819-0 - Fax +49 (0)89 - 89 819-104
email: info@caloric.de - www.caloric.com

Plants for the disposal of fluid wastes

Incinerators

German Kurz, Heinrich Güthoff

The definition incinerator relates to plants designed for the thermal disposal of gaseous and liquid wastes as they are produced as by-product or out-of-spec product during the production or treatment of chemicals or pharmaceuticals. It is the intention of G. Kurz and H. Güthoff to provide potential users of incinerators with basic information about aspects of different wastes, the state-of-the-art of incinerators as well as their problems and possibilities for applications.

In incinerators those wastes can be disposed which can be converted into environmentally acceptable substances by combustion with or without after-treatment of the combustion products. For the combustion process the chemical analysis of the wastes is decisive. The design and execution of the plant also requires careful consideration of physical data.

- Hydrocarbons: The disposal remains relatively simple as long as the waste is pure hydrocarbon without fixed nitrogen, halogens or metals and also not mixed with inorganic components like salts. At sufficient excess oxygen, turbulence, temperature and residence time, all hydrocarbon will turn into carbon dioxide and water vapour. The flue gas quality will be equal to conventional heating systems.
- Wastes containing fixed nitrogen or ammonia:

The chemical NO_x, also called "Fuel-NO_x", is decisive for the NO_x level whilst burning organics with fixed nitrogen or ammonia. Depending on type and concentration of the nitrogen compound, up to 85 % of the fixed nitrogen will be transformed into NO_x in a one-step combustion. The formation of chemical NO_x can be suppressed by a two-stage combustion as long as a reducing atmosphere with parts of CO and H_2 is maintained in the first combustion stage at a sufficient residence time, and free oxygen is present only in the second oxidising combustion step.

- Chlorinated hydrocarbons: Due to the highly negative impact of different chlorinated hydrocarbons to nature, chlorinated wastes are of specific significance. In a competently designed and instrumented plant, the amount of chlorine from organic compounds will be converted totally into HCl and Cl_2. While HCl might be recovered or neutralised to NaCl, this is not possible for Cl_2. Therefore it is the target of the combustion process to minimise the formation of Cl_2. This is achieved according to the Deacon equilibria by applying high combustion temperatures, high amounts of water vapour and a limited surplus of oxygen. At an optimised operation, up to 99.9 % of the chlorine will be transformed to HCl.
- Waste containing sulphur: During combustion more than 95 % of the sulphur from wastes is transformed into SO_2 and less than 5% into

SO_3. If the amount of SO_2 and SO_3 exceeds the permitted massflow or the emission limits, desulphurisation of the flue gas becomes necessary. In an incinerator plant this is normally achieved by a scrubber which uses an aqueous sodium hydroxide or soda solution. The Na_2SO_3 formed in the scrubber, which has a reducing character will be converted into neutral Na_2SO_4 in an additional wet oxidation step.

- Brine wastes: Inorganic salts such as NaCl, KCl, Na_2SO_4 quite often occur with the organic wastes, requiring special considerations during combustion, as well as in the following downstream process steps. Due to the low vapour pressure, molten salt (slag) will be generated even at low salt concentrations in the waste. The major part of this slag will accumulate on the incinerator walls, and therefore a vertical or at least declined combustion chamber arrangement with an outlet for molten salt at its lowest point is required. Commonly, the salt slag will be dissolved in water and discharged as aqueous solution. The flue gas will also carry salt vapour and small droplets, which turn into fine crystals while the flue gas is cooled down. For their removal, special separators such as venturi scrubbers become necessary.

Heating value of wastes

It is normally the case that wastes are part of a mixture, and quite often they are just the impurities of a carrier stream like water, air or inert gas. In such a case, the concentration of the waste determines whether the required combustion temperature will be achieved without additional fuel. If additional fuel is required, quite often it can be substituted by additional wastes with a high calorific value. In this event, liquid waste offers the advantage of easy storage and the possibility to compensate fluctuations in the massflow and concentration of other waste streams.

Explosive mixtures

If air is the carrier for organic wastes, the mixture might be considered as explosive within a defined limit of concentration. As the flame in the incinerator has to be considered as a continuous ignition source, the wasteline has to be equipped with flame arrestors. Three independent safe guard systems, normally consisting of a flash back safe burner and two flame arrestors, are presently considered state-of-the-art. If the mixture becomes explosive only occasionally or in case of failure at the waste source, less than three safe guard steps are sufficient.

The requirements for a complete combustion of wastes are high turbulence, sufficient temperature and residence time and oxygen.

Flow pattern in the combustion chamber

The combustion chambers of incinerators are preferably cylindrical in shape, as this offers the advantage to maintain a controlled turbulence in the combustion chamber during operation. The tangential intake of combustion air results in a strong rotation in the combustion chamber with the recycling of gas in the centre of the vortex back towards the air inlet.

The disadvantage of this principle of mixing is the separation due to the centrifugal force which results from the rotation. Heavy particles accumulate on the wall of the combustion chamber, resulting in incomplete combustion and a short life of the refractory lining. This problem can be countered by introducing the combustion gas of the support burner, or a secondary combustion air stream at a given angle. The additional semi-tangential introduction of gas forces the particles from the wall back into the centre of the combustion chamber.

Atomisation

Even an optimised flow pattern with high turbulence in the combustion chamber cannot compensate an inferior atomisation of liquid waste. Pure atomisation results in large droplets, which again have a long lifetime as a result of the Leidenfrost phenomena. The lifetime will exceed the residence time in the combustion chamber, and the droplets will either escape unburnt or will hit the incinerator wall, where they may be cracked instead of being burnt. Wastes containing particles and the corrosivity of wastes are a specific challenge on atomising nozzles. Nozzles, specially developed for such purposes allow the unobstructed passage of the liquid waste at low pressure through a wide central boring. The atomisation takes place outside the nozzle in a nodal point of ultrasonic frequency, generated by steam or compressed air. This atomising principle, together with an unobstructed passage, makes it possible to atomise even such liquids into aerosols which are highly viscose or contaminated with solids.

Parameters of incineration

Good mixing and atomisation provided, the combustion temperature, residence time and excess oxygen still remain as parameters for the optimisation of the incinerator. Whilst for the disposal of organics in air, from the painting or printing industry, with a low concentration of organics an incineration temperature of 800°C is sufficient, this temperature rises with increasing molecular weight. For the incineration of PCB-containing waste, a minimum combustion temperature of 1200°C has been defined and will be required by regulations. This also applies for the residence time. While for the combustion of light hydrocarbons a residence time of 0.3 s is sufficient, the required time for a complete combustion of highly chlorinated hydrocarbons or organically loaded brine will multiply Regulations defining a minimum oxygen might be considered as a relic from early times of incineration technology, and no longer apply in most of the industrial countries. In order to minimise fuel consumption and the formation of Cl_2 in the combustion of chlorinated hydrocarbons, a low but sufficient and controllable oxygen content is the target. The limit is given rather by the controllability than by combustion.

Combustion chamber design

Basically, there is the possibility to select a metallic or a refractory lined combustion chamber. The advantages of a non-refractory lined combustion chamber are relatively low production costs. The disadvantages of metal combustion chambers relate to the general problems of welded high temperature sheet metal and the limited operating temperature. Therefore, metallic combustion chambers are restricted in their application mainly to the disposal of air loaded with solvents as derived from painting or printing processes. For the disposal of wastes from chemical and pharmaceutical production, refractory-lined combustion chambers are common. As they tolerate high combustion temperature, they offer a potential possibility for the optimisation of the combustion process. Additionally, the refractory lining avoids the high temperature corrosion of metals by halogens.

Heat recovery

The energy of the hot offgas from incinerators can be recovered with a high efficiency. The investment for the required heat recovery equipment will pay back in most cases in less than two years of operation. Incinerators not incorporating a waste heat recovery have become the exception.

Steam production in waste heat boilers is the most common way of heat recovery, as steam is an uncritical energy carrier. By preselecting a sufficiently high steam pressure and the correct design of the waste heat boiler, corrosion is avoided, also whilst burning waste producing HCl and SO_2 containing offgas. Depending on the fluegas quantitiy and operating pressure of the waste heat boiler, fire-tube or water-tube boilers are used. If heat is required at a higher temperature level, the waste incinerator offgas might also be used for the calefaction of thermal oil. As the refractory lining of the combustion chamber has to be considered as a heat sink, special provisions have to be taken for emergency cases to prevent the thermal oil system from overheating. Preheating or vapourisation of wastes in heat exchange with the incinerator flue gas is in most cases not practical, as the characteristics of the waste, like cracking, polymerisation or corrosion, prevent this possibility.

Flue gas after-treatment

Combustion products resulting from inorganic compounds in the waste, such as SO_2, HCl, Cl_2, anorganic salts or metals, have to be removed to meet enviromental requirements if they exceed the tolerable massflow.

The economical combustion of chlorinated hydrocarbons can yield aqueous hydrocholorid acids or gaseous hydrochlorine. However, in most of the installations the quantity of HCl produced does not justify its recovery and therefore the HCl formed by combustion is transformed into sodium chloride in a wet scrubber by dosing sodium hydro-oxide or caustic soda.

Anorganic salts or metals as part of the waste turn into aerosols or fine particles in the fluegas. Depending on the size of particles and the surface structure, the removal of these particles requires different processes. Whilst salt crystals such as NaCl can be removed by a venturi scrubber, the removal of P_2O_5 or SiO_2 requires turbo agglomerators, textile filters or electrostatic precipitators.

Corrosion and material

The prevention of corrosion within an incinerator plant is essential for a trouble-free operation of the plant over a period of years. Savings in maintenance more than pay for higher investment for the right material in the beginning. Conceptual possibilities for avoiding corrosion are in maintaining corrosion-free operating conditions as well as the use of selected materials. Carbon steel, for example, is a very suitable material even in HCl, Cl_2 or SO_2 containing atmospheres as long as its operating temperature does not drop below the acid dewpoint and high temperature corrosion by the attack of HCl or Cl_2 is avoided. For waste lines and quench systems, special or even exotic materials such as Hastelloy, Titanium, Zirkonium or Graphite might become necessary. For the wet chemical part of flue-gas scrubbing systems, high quality FRP has proven to be most suitable.

Deterioration of an incinerator plant by corrosion can also be avoided when burning chlorinated hydrocarbons so long as operating conditions and materials have been selected wisely.

Optimisation of process and equipment

Data banks for most common wastes in connection with calculation programs will allow a process optimisation within a reasonable time. Regulations regarding acceptable emissions have to be considered with preference. The duty of an incinerator is the disposal of waste with a minimum of interference with the production. Therefore the overall concept has to be optimised. This requires an intensive dialogue with potential users of the incinerator in order to synchronise the requirements on flexibility and availability of the incinerator with system-imminent limitations, e. g. in the control system. The use of programmable process control systems offers the option to adapt the operation mode of the plant to future requirements without changing the hardware.

Theory and experience

The conceptual and mechanical design of incinerators requires a comprehensive file of data, as well as fundamental chemical and physical know-how plus comprehensive practical experience.

Requirements for process design such as classification of wastes, execution of combustion calculations, definitions of chemical equilibrias, calculation of heat and mass transfer and the separation of particles cover a fair range of chemical processing. Specialised data banks and computer programs permit the requirement to be fulfilled with the necessary accuracy and within a reasonable time. The process and reactions within an incinerator can only be partially predicted by theoretical considerations. Even though the mechanism of the formation of NO_x is well known, a quantitative prediction of the NO_x to be expected in a particular case is still only possible by practical experience and analogy. The same is true for the mechanical design of details where information regarding function and lifetime are mainly a result of the feed-back of practical experience.