DESIGN CONSIDERATIONS FOR LOW LEVEL RADIOACTIVE WASTE COMBUSTORS

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INTRODUCTION

In a previous paper and presentation, (1) we presented data that showed the need for low level radioactive waste (LLRW) incinerators, presented the amounts of waste that such systems will have to process, and introduced C-E/WIS, the Combustion Engineering Waste Incineration System for LLRW.

The main design objective of a low level radioactive waste incineration system is maximum volume reduction. The best firing and combustion techniques for maximum volume reduction are suspension firing in an excess air atmosphere, which are the techniques used in the C-E Waste Incineration System (C-E/WIS). Suspension firing as opposed to bulk firing is also safer.

COMBUSTION TECHNIQUES

First, a review of four generic combustion techniques will help to show why excess air suspension combustion is the best kind of the combustion for maximum volume reduction. It is helpful to categorize combustor designs according to the type of atmosphere created and sustained within the combustion vessel, that is, how the ratio of fuel and oxygen. The four combustion techniques that are used for LLRW incinerators are pyrolysis, starved air, stoichiometric, and excess air combustion.

Pyrolysis

Pyrolysis is the thermal degradation or decomposition of a combustible material in the total absence of oxygen. The process liberates volatile

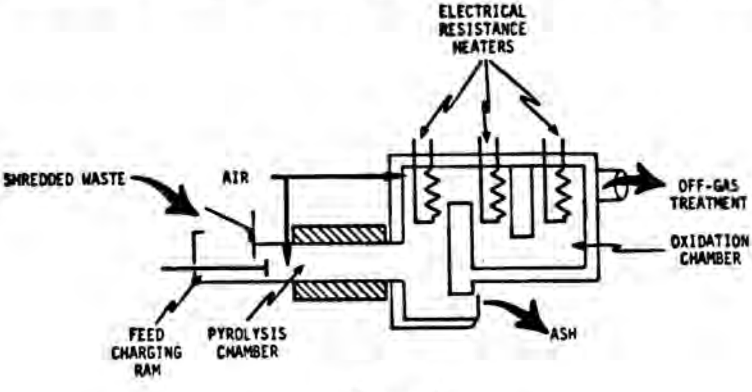

Figure 1
Fig. 1. Typical Pyrolysis Combustor (2)

portions of the waste fuel as gaseous hydrocarbons commonly known as "fuel gas" which is high in calorific value. To recover the heat from the fuel gas there is generally a secondary chamber following the pyrolysis chamber (Fig. 1) in which fuel gas is burned. It is generally used when there is some interest in recovering the heat in the fuel gas. Because there is considerable combustible material (mostly carbon) left plus the mineral matter originally present in the fuel, pyrolysis does not provide maximum volume reduction.

In the pyrolysis chamber, the normal means of feed is in bulk by ram charging. One disadvantage is that, at times, large masses of LLRW are in the combustor (burning on the hearth) and sophisticated control is required to maintain a safe situation should an upset occur.

Starved Air Combustion

Starved air combustion is an alternative to pyrolysis for producing a clean fuel gas. Like pyrolysis, starved air combustion is the thermal decomposition of a fuel in an atmosphere containing less than the stoichiometric oxygen quantity, but unlike pyrolysis, some oxygen is used and therefore limited combustion does take place. The fuel gas is combustible, although of less calorific value than pyrolysis fuel gas and the ash/char still contains significant combustible material. Again, maximum volume reduction has not been achieved. System safety considerations are the same as with pyrolysis because bulk feeding and hearth burning are required. Figure 2 depicts a typical starved air incinerator. Note that as with pyrolysis, a secondary chamber is required for burning the fuel gas.

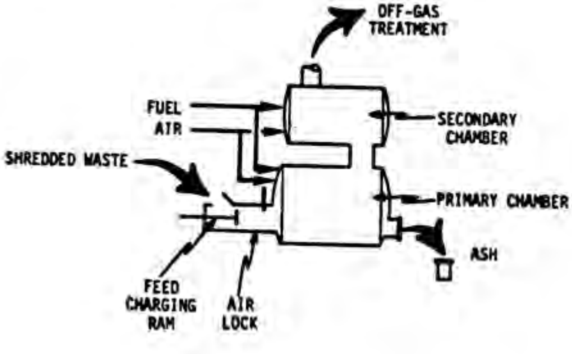

Fig. 2. Typical Starved Air Combustor (2)

Stoichiometric Combustion

Stoichiometric combustion is the burning of a fuel with the theoretically correct amount of oxygen required for the fuel and is most nearly achieved when burning some gaseous fuels. Stoichiometric combustion requires good mixing of the fuel and air and every particle of waste fuel must be in contact with combustion air. Even with preconditioning of LLRW by shredding and atomization, fuel to air mixing is not sufficient for stoichiometric combustion.

Most solid and liquid fuels become a gas before they burn and this phenomenon occurs to some extent with LLRW fuels. With liquid fuels, the lighter fractions evaporate and burn as gases while the heavier fractions burn like solids. Atomization speeds evaporation because, with the tiny particles, there is a greater surface area for evaporation. When solid fuels are burned, the process becomes more complicated because of the mass transport phenomenon in which oxygen moves toward the surface while carbon monoxide moves away from the surface of the fuel. Shredding facilitates the burning of solid fuels by increasing the surface area for mass transfer. Shredding dry solid waste improves air contact, but other variations such as density and heating value must also be accounted for. Dry solids such as shredded paper and cloth may have a 20 lb ft^3 density and 6000 Btu/lb heating value whereas dewatered ion exchange resin beads are much heavier at 65 lbs ft^3 and have a high heating value, over 18,000 Btu/lb. If liquid wastes, such as inorganic salt concentrate or contaminated water are to be processed, the combustor must have sufficient atomization and thermal capacity to evaporate the liquids and dry the salts. Although atomization and shredding improve the potential for the successful combustion of LLRW, these processes are usually not efficient enough to allow complete stoichiometric combustion, so maximum volume reduction is not achieved.

Excess Air Combustion

Excess air combustion will result in the most complete oxidation of a waste fuel; it exposes the fuel to as much as three times the stoichiometric amount of air which gives the fuel extra time to evaporate and mix with sufficient oxygen for complete combustion to take place. Although combustion efficiency suffers because excess air has to be heated, this form of burning renders the ash and flue gas more inert and provides for maximum volume reduction.

These four generic combustion techniques define the potential for developing incinerator designs. Of special interest are those designs capable of processing more than one type of waste stream. Such versatility is inherent in the C-E/WIS excess air suspension combustor as depicted in Fig 3.

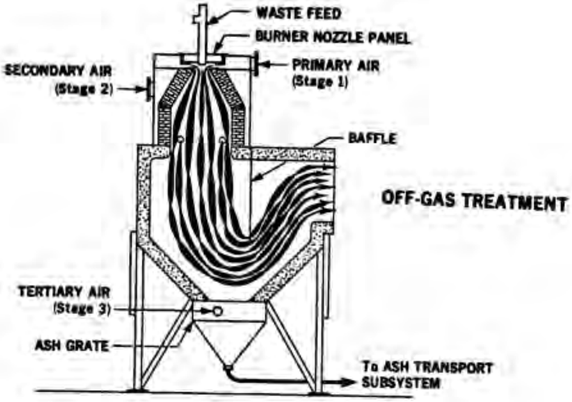

Fig. 4. C-E/WIS Combustor.

C-E/WIS COMBUSTOR

The incineration technology used in the C-E/WIS combustor is constant, excess air, controlled fuel, suspension burning. As the name implies, the combustion chamber is always maintained in an excess air condition, with the fuel--both waste and supplemental--modulated to maintain key process output variables at their desired setpoints. The excess air (never less than 11% excess O_2 for any LLRW throughput) mode of operation eliminates the fuel rich/fuel lean zones common to batch fed pyrolysis and starved air designs which can be subject to "flash back", resulting in pressure excursions and in some cases explosions. Minimum ignition temperature and sufficient air is continuously provided to burn the LLRW feed throughout the entire combustor under all modes of operation, including startup.

The incineration process in the combustor takes place in three stages. The first stage is designed to thoroughly mix the waste stream with combustion air, raise the mixture to the ignition temperature and initiate ignition. This stage is supported by the primary combustion air supply as well as an auxiliary ignitor operating on a commercial fuel such as natual gas or oil. During steady state operation, direct flame radiation and refractory glow will also help preheat the waste/air mixture. The auxiliary ignitors' heat release is modulated in response to selected, key process output variables, such as the combustor exit flue gas temperature, in order to support the combustion process as required; providing more energy for wastes of lower heating value and less energy for wastes of higher heating value.

The second stage provides the excess air necessary to permit the combustion processes to complete. It also enhances the turbulent vortex flow of waste/air and flue gases generated in the first stage to expose the combustibles to the maximum amount of oxygen available in the combustion chamber. Figure 4 shows the degree of the turbulence in the various regions of the C-E/WIS combustor relative to residence time. Note that the increased volume of the combustor in Stage 3 and the baffle reduce turbulence for increased residence time and waste burnout.

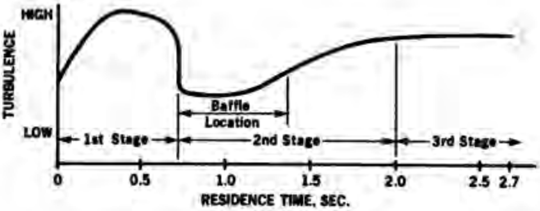

Fig. 4. C-E-WIS Turbulence vs. Residence Time.

The third stage is designed to provide the residence time for any of the heavier particles suspended in the flue gas to burn completely. These particles are removed from the flue gas by inertial separation in a "U" shaped corridor as the gas passes through the third stage. The particles fall on the grate and continue to burn supported by tertiary air injected just below the grate. Third stage combustion is sustained strictly by refractoy glow and indirect flame radiation. Average particle residence time is 2.7 seconds which as shown in Fig. 5 meets the United States Environmental Protection Agency hazardous waste destruction requirement of 2 seconds at 1832°F. Suspended shredded or atomized waste fuel particles are exposed to the maximum amount of oxygen available in the combustion chamber. Unlike other solid waste fuel fired furnaces where the fuel particles lie on a stoker or grate, suspension burning literally immerses the fuel particles in a turbulent sea of air and gases. This ensures and enhances heat and mass transfer associated with solid fuel combustion.

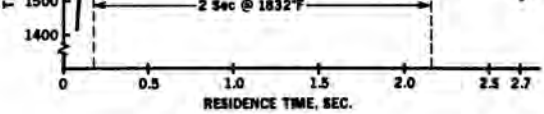

Fig. 5. C-E-WIS Temperature vs. Residence Time.

Supsension burning incinerators such as the C-E/WIS design can burn solid, liquid and gaseous waste fuels. Unlike grate or bed combustion, where large waste masses are periodically charged to the combustor and held there for burning which sometimes result in hard to control stoichiometric changes, the inventory of waste in a suspension combustor is low (less than 1/4 lb in suspension) which simplifies control and improves system safety by minimizing the potential for uncontrolled release of waste in process during system upset. Use of the C-E/WIS combustor for LLRW provides the best techniques for the complete volume reduction of these wastes. Volume reductions in excess of 200:1 have been attained when incinerating dry active waste (See Reference 4).

Since the combustion of LLRW (liquid concentrates, resin slurries, and dry solids) can be endothermic or exothermic depending on the heat of vaporization of liquids vs. the high heating value of solids, complete oxidation of this spectrum of wastes presented a challenge in balancing sufficient combustion air, supplemental fuel, and waste input at all times to maintain a safe incinerator environment. The problem was solved by treating the combustion chamber as a calorimeter. By using a well insulated combustion chamber in combination with a constant and known air flow, the combustor outlet temperature is an accurate indicator of the total heating value of the waste fuel. The system is capable of increasing or decreasing supplemental fuel feed to maintain a constant outlet temperature assuring minimum ignition energy with sufficient air to insure complete combustion. The relatively large mass of the refractory and insulation provide sufficient thermal inertia to absorb transients due to rapid changes in waste fuel heating values and thereby stabilize the thermodynamic process. Figures 6 and 7 show this stability for typical incineration runs at the C-E/WIS prototype. Note that as waste fuel is introduced, there is a decrease in primary (Stage 1) temperature but the secondary (Stage 2) and combustor outlet temperatures remain steady. Supplemental fuel flow also adjusts automatically to maintain the constant combustor outlet temperature.

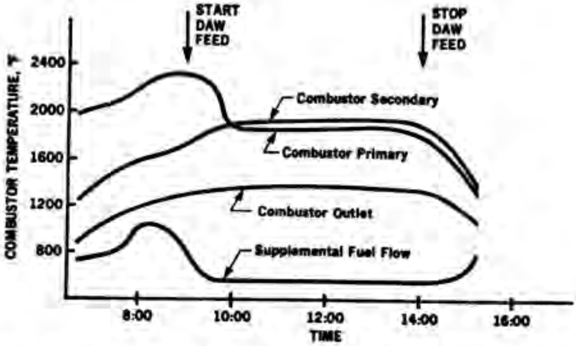

Fig. 6. C-E-WIS Combustor Temperature & Supplemental Fuel Flow vs. Time During Dry Active Waste (DAW) Burn.

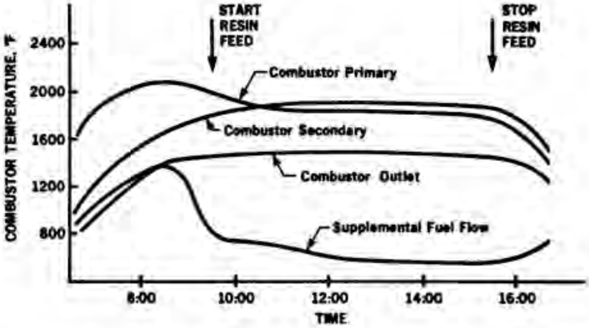

Fig. 7. C-E-WIS Combustor Temperature & Supplemental Fuel Flow vs. Time During Resin Burn.

To ensure the presence of a flame at all times, the supplemental ignitor is provided with a flame supervisory and safeguard system (FSSS)(TM). This system confirms the presence of a flame in the auxiliary ignitor by detecting voltage fluctuations in the support flame and is therefore unaffected by refractory glow, moisture, carbon dioxide and solids in the waste feed and combustion gases. The support fuel heat release is maintained at greater than 20% of the waste heating value, which assures enough energy will be available to combust any credible amount of waste in the combustor.

The combustor, and the entire WIS are maintained under a negative static pressure during all modes of operation. This limits fugitive emissions as well as preventing gaseous products of combustion from entering the operator area. An induced draft fan provides the negative static pressure for the entire system and eliminates the possibility of pressurizing the combustor or any part of the system during a draft control malfunction.

The C-E/WIS is operated remotely by a combinaton of digital and analog instrumentation. The digital control consists of a solid state programmable controller and functions as the "brain" for the entire system. The controller continuosusly monitors the combustion process and the other system parameters and trips the CE-WIS for any upset or significant transient condition. "Start" and "Stop" functions for all electrically operated equipment are provided by the controller. The analog instrumentation controls the sytem process, provides remote indication and provides input to the programmable controller on the system process parameters.

The two control systems are integrated to control and monitor the C-E/WIS with minimal operator action. Additionally, programmable logic prevents an operator from inadvertently operating portions of the C-E/WIS out of sequence. For example, the C-E/WIS cannot be restarted after a trip until a safety sequence has been assured (i.e. time delay, air for purge, valve positions, and component check).

CONCLUSIONS

The C-E/WIS uses suspension burning in an excess air atmosphere for maximum volume reduction and safety. Pyrolysis and starved air combustion, when applied to the incineration of radioactive waste materials must be considered with caution. All waste, from liquids through resin slurries to dry active wastes, cannot be handled effectively with these processes. The use of these designs result in less than maximum volume reductions and increase the potential for unsafe operation. The design of Combustion Enginering's Waste Incineration System (CE-WIS) combustor is unique in that it has been specifically designed to accommodate all the waste incineration requirements of an operating nuclear power plant. Full scale prototype tests of the C-E/WIS have demonstrated its capability to incinerate these wastes safely with the maximum reduction in volume. The results of more than 600 test hours are presented in Reference 4 and summarized below.

PERFORMANCE

a) Dry active waste and ion exchange resin slurries are incinerated separately in a common combustor vessel at volume reduction rates in excess of 100:1 and 20:1 respectively.

b) Concentrate waste solutions can be co-processed with dry active waste or ion exchange resin by spray drying in the system cooling tower.

c) System feed rates exceed 215 lbs/hr for dry active wastes, 150 lbs/hr for dewatered resin, and 2 gpm for concentrates.

d) The inherent thermal stability of the system allows feeding wastes with a wide range of compostion and varied heating values.

e) Excess air suspension burning minimizes the quantity off LLRW being processed through the combustor at any time thereby reducing the potential for release during system upset conditions.

ACKNOWLEDGEMENTS

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