Concepts and Behavior of the Controlled Air Incinerator

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ABSTRACT

The concepts and behavior of the controlled air, grateless incinerator are discussed in detail. This type of incinerator is equipped with a well-balanced air distribution system and burner arrangement which provide the flexibility in incinerator design to meet present and future air pollution control requirements.

INTRODUCTION

The enactment of new and more stringent air pollution control codes has given impetus to the development and improvement of incinerators employing the controlled air concept as a method of disposing of solid wastes. It is the purpose of this paper to show that a properly designed controlled air incinerator can operate below the limits established by the various air pollution control authorities without the need of employing auxiliary air pollution control devices.

Controlled air incineration is not a totally new concept since it employs all the various parameters normally considered in combustion processes. However, the controlled air concept permits a level of control of these parameters so that the combustion process can proceed under conditions of extremely low stack emissions.

Conceptually the controlled air incinerator attempts to carry out the combustion process in two steps, the first of which is to initiate the burning process under less than stoichiometric air conditions. The heat released in this limited combustion is partially utilized in the volatilization and gasification of the various hydrocarbons contained within the waste. The second step in the process is to carry the combustion products, together with the gaseous hydrocarbons into a second chamber where the injection of additional air permits the gases to go to complete combustion either spontaneously or by ignition with an afterburner. It is this two-step process that allows low stack emission since the only source of particulate emission is from the first chamber which, because it is operating under starved air conditions, will not have the high turbulent combustion which encourages the entrainment of particulates into the gas stream.

Essentially, the incinerator requires two chambers to complete the two-step combustion process. Erroneously the term “multi-chamber” has become symbolic of any incinerator that physically has more than one chamber regardless of its performance. The stepwise development of the combustion theory in this paper will clearly show that the “clean” incineration process in the controlled air incinerator essentially requires a well designed combustion chamber, an afterburner section (whether it be stack or second chamber) and a judicious approach to the introduction of the combustion variables. This requires a complete knowledge of combustion technology as well as empirical facts derived from experimental work. In short, the design of a controlled air incineration system is both an art and a science.

BASIC CONCEPTS

In order to develop the basic concepts of controlled air incineration on a generalized basis, the combustible material to be burned will be referred to only as waste.
There will be no specific reference to any actual waste material since the basic concept should hold for any combustible material regardless of its chemical composition, physical states, water content, and ash content. In the following discussion, stoichiometric air is referred to as the total air required to completely oxidize the fixed mass of waste. The concepts presented here represent more than three years of both analytical and experimental studies.

Under idealized adiabatic conditions, and perfect mixing of air and waste the combustion of a fixed mass of waste will result in a theoretical combustion temperature which is dependent on the total air supplied for combustion. The maximum theoretical combustion temperature is achieved when the total air supplied reaches slightly less than 100 percent of the stoichiometric requirements. Beyond the point where the air supplied equals the stoichiometric requirements further additions of air serve to cool and dilute the exhaust products.

In a practical sense, combustion cannot be carried out under the ideal conditions as discussed above. Because of departures from the idealized adiabatic and mixing conditions, the maximum theoretical combustion temperature will be substantially reduced. A further degradation in the theoretical combustion temperature occurs in the case where the air supplied is less than the stoichiometric requirements. Under such a condition there will be only partial combustion carried out and accompanied by the generation of gaseous hydrocarbons. The volatilization and gasification of these hydrocarbons will absorb a considerable amount of the heat released by the combustion process. The curves shown in Fig. 1 reflect the combustion process as discussed above.

Part A of Fig. 1 shows that the generation of hydrocarbon gases increases as the total air supplied increases, reaching a peak at an air supply of somewhat less than 50 percent of stoichiometric. The hydrocarbon gases then decrease to zero as 100 percent stoichiometric air is reached. In other words, when the stoichiometric air quantity is reached, the full utilization of the air is producing full combustion of the waste material. After this point is reached, further air supplies do not increase the waste burned or gases generated, but only serve to cool and dilute the exhaust gases.

The relationships between the waste oxidized and waste volatilized but unburned reflect the response of the total waste material under the controlled air conditions of high temperature combustion as shown in Fig. 1-B. The solid line in Fig. 1-A represents total waste phase change as a function of total air supplied. Of particular significance is the demonstration that the 100 percent phase change of the waste can be achieved with less than 50 percent of stoichiometric air. This represents one of the basic foundations for the design and operation of controlled air incinerators.

The gases discharging from the combustion chamber under less than stoichiometric conditions (starved air) are not necessarily clean, since they are heavily laden with hydrocarbon gases and/or aerosols and particulate matter as shown in Fig. 1-C. If these gaseous or liquid hydrocarbons were to be discharged into the atmosphere, they would be generally referred to as smoke.

The carry-over of particulate matter from a combustion chamber depends primarily on the gas velocities within the chamber, together with the intensity of the combustion process. Both the gas velocity and intensity of combustion increase with increasing amounts of total air; therefore, the flyash discharging from a combustion chamber can be expected to increase with an increase in the total air. The order of the flyash discharging from the combustion chamber as a function of total air is shown in Fig. 1-C. After the total air reaches 100 percent stoichiometric, we can expect the intensity of the combustion process to decrease, hence, the flyash decreases. But, since the gas velocities continue to increase, there should be a continual particulate carry-over from the combustion chamber.

![Fig. 1 Chamber behavior as function of chamber air supplied when burning constant mass of waste.](image-url)
The discharged gases from the main chamber subsequently enter the afterburner section where additional air is injected. If the gases are at a sufficiently high temperature, they will ignite spontaneously; otherwise, they can be ignited with an afterburner. The combustion temperature in this afterburner section is established by the amount of air injected and closely follows the relationship shown in Fig. 1-B. The temperature and retention time have to be sufficient to completely burn the hydrocarbon gases and to also burn any solid combustible material exhausting from the main combustion chamber.

The afterburner section functionally serves as the final combustion chamber requiring good mixing of air and gases, critical temperature level and sufficient retention time. All of these requirements can be achieved by a well designed secondary combustion chamber or an afterburner-stack section.

**CONTROLLED AIR INCINERATOR OPERATION**

The basic concepts of controlled air incineration described in the previous section can now be related to the actual combustion process occurring in an incinerator. The objectives of this section are to show that there is a unique relationship between the variables of air supply and waste charged into a controlled air incinerator and that deviations in these variables will result in a less than optimum incinerator. The critical relationships in such an incinerator will be followed by assuming that the quantities of air distributed to the main combustion chamber and the afterburner stack section have been fixed and are invariant.

The relationship between combustion temperature, chamber emissions, and total burning and volatilization of waste within the chamber as a function of waste charged is shown in Fig. 2.

It should be noted in Fig. 2 that the abcissa has been changed from total chamber air supplied to waste charging rate. In order to understand this, it should be recalled that in the previous section the concept is developed that if the chamber air is less than 50 percent of the stoichiometric requirement, a complete phase change of all the waste in the primary chamber can be achieved. In this context, phase change refers to the physical change of the waste from solid state to gaseous state, through combustion and pyrolysis. With reference to the curve in Fig. 2-A, it can be seen that optimum volatilization can be realized by increasing the waste charging rate to a value above 200 percent of the stoichiometric burning rate. Furthermore, it can also be seen that if less waste is supplied, the emission level of the gases leaving the chamber will increase without a proportionate increase in burning rate.

The relationships shown in Fig. 3 illustrate the behavior of the gases exhausting from the main combustion chamber to the afterburner section. The afterburner section has been designed to yield a temperature of 1600 F to 1800 F with a retention time of 0.7 sec to 1.0 sec at a waste charging rate of 200 percent of stoichiometric air supplied to chamber. To illustrate this point, in Fig. 3-B, it can be seen that the optimum stack incineration temperature is achieved at the chamber charging rate of about 200 percent of the stoichiometric air supplied to the chamber. The shaded areas shown on the left and right side of the optimum points of the stack combustion temperature curve reflect a chamber burning rate that can result in the discharging of hydrocarbon gases into the atmosphere that can be referred to as smoke. In order to eliminate this smoke at these conditions, the stack incineration temperature must be elevated above that resulting from the combustion process of the exhaust gases to the optimum level. This will require additional heat input from a separately fired burner. The additional costs for
supplying fuel to the afterburner in these zones are one of the primary reasons why the 200 percent region has been selected as the optimum operating conditions for the controlled air incinerator.

Although not immediately obvious from this discussion, it should be pointed out that care must be exercised in selecting the capacity of the afterburner in regard to its potential for elevating the exhaust gas temperature. Assuming that the afterburner is an on-off unit, then a practical capability of the afterburner should be to raise the stack gas temperature differential of no greater than 300 to 400°F. If the capacity is greater than this, then excessive cycling of the afterburner will occur about the setpoint. Our experience has indicated that this cycling and hunting about the preset temperature may create objectional puffs of smoke. The curves shown in Fig. 3-A reflect the emission expected from the incinerator. Of the two curves shown, the solid line reflects the emission that can be experienced without the heat input from the afterburner; the dotted lines show the emission under conditions where the afterburner supplies the additional heat to the system. It is significant to note that with the afterburner heat input, little additional pollution emissions can be expected as the charging rates exceed the optimum range. However, the operation at these levels is uneconomical because at no increase in waste burned, there is an associated cost of fuel supplied to the afterburner. At charging rates below the optimum range, the emission level will increase. Here the burning within the chamber is being carried out at near stoichiometric conditions and the violence of this combustion process will result in a high carryover of particulate to the stack. In addition, the cost of fuel to the afterburner will also make operation at this point uneconomical.

Our experience has, therefore, suggested that the optimum burning rate is in the range of more than 200 percent of the stoichiometric air supplied to the chamber. A charging rate greater or less than this rate will require additional heat input to the afterburner section with little increase in burning rate, but additional fuel cost to the afterburner. A charging rate below this optimum rating will likewise require additional heat input and will also result in greater air pollution emissions.

**DISCUSSION**

The description of the controlled air incinerator contained in this paper is highly generalized and is intended to show only the concepts which must be considered in such a design. There is no basic theory which can replace experimental work in finalizing and refining the design. Patterns and trends can be predicted with these concepts...
which then can be used to interpret experimental work. However, waste burning rate as a function of chamber geometry can only be characterized accurately with actual tests on the specific geometry.

The chamber air has been treated very simply; however, the actual application of the concepts requires test work to properly establish the distribution of air throughout the waste and to properly allocate the amounts of underfire air and overfire air to optimize the burning rates and emissions.

The afterburner section likewise requires experimental work to properly distribute the injected air and to establish the capacity and location of the afterburner. The temperature and retention time requires many experimental burns with careful sampling and analysis of stack emissions.

Wastes vary as to density, moisture and heating value and each have unique values in regard to the parameters mentioned above.

The controlled air incinerator marketed under the name Combustall* by the Air Preheater Company employs a stack as the afterburner section. An afterburner section of this design, as shown in Fig. 4, can operate as effectively as any other type of secondary chamber.

Finally, we need to emphasize the need for proper operation of the incinerator to achieve the minimal pollution emissions. Despite all the engineering design efforts involved in producing a clean burning incinera tor, the final responsibility for proper operation must rest with the user. Economy measures such as shutting off the afterburner prematurely will inevitably result in a smoking stack. Likewise, sloppy operation such as leaving the charging door open, over charging and under charging produces similar results.

The recent introduction of well designed controlled air incinerators has demonstrated the responsibility that today's industry is prepared to assume. The ultimate user must also accept his responsibility to properly operate the equipment to achieve the results made possible by responsible industry.

**CONCLUSION**

Based on our knowledge of the controlled combustion principle and operation of the controlled air incinerator and our experience with numerous types of solid waste, the following may be concluded with a high degree of confidence:

1. The principle of the controlled combustion as applied to the controlled air incinerator design has been proven to be practical and economical. This design is able to completely incinerate all organic waste materials and to meet the most stringent incinerator emission standards without using auxiliary air pollution control equipment. The various incinerator codes which treat the multimultichamber incinerator as the only acceptable design for low
stack emissions should be revised to reflect the successful results with the primary chamber-afterburner-stack design.

(2) The controlled air incinerator can be operated continuously, intermittently or in batch using various temperature and air distribution controls. Because of the flexibility in design, new incinerators capable of burning 100 percent plastics or other high heating value waste [1] have been evolved and marketed.

(3) This incinerator not only can serve isolated industrial establishments and institutions for on-site waste disposal, but also can be grouped in multiple units to economically serve commercial centers, suburbs, and small communities for commercial and/or municipal waste disposal. Due to its modular sizes, several groups of this multiple unit can be strategically located around the community to minimize the high hauling cost and to spread the garbage truck traffic concentration in more routes. It also simplifies operation, maintenance, and even facility expansion procedures.

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REFERENCES