PROCESS VARIABLE STUDY OF INCINERATION USING TANGENTIAL OVERFIRE AIR

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Introduction

The expanding operations of the Atomic Energy Commission and the growing off-site uses of radioisotopes are making more urgent than ever the need for safe, convenient, and economical means for disposing of contaminated combustible solids that are incidental to these activities.

It is generally agreed that incineration offers the best chance of meeting such criteria as convenience and economy, since the waste can be disposed of at its source, and a very considerable reduction in volume of waste is achieved. However, unlike industrial furnaces for heat and power, incinerators are required to handle materials that are physically heterogeneous and liable to vary widely in composition, depending upon the sources of the wastes. Moreover, incinerators are generally charged batchwise because the charge cannot conveniently be delivered continuously with automatic stoking equipment. These characteristics make incinerator design very difficult, and it might be said in general that little or no sound engineering information is available as a basis for design. The approach in the case of domestic and industrial incinerators is largely of the cut-and-try variety, and it is the rule rather than the exception that these units do not consume the charges completely, with the result that considerable quantities of particulate matter and tarry distillation products are discharged from the stack. This is particularly bad where the cleaning system must be confined to the use of dry filters, as in off-site operations, where wet scrubbing of the gases is not desirable.

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Anticipating the problems that would arise in connection with incineration of contaminated combustible wastes, particularly in congested off-site areas where the health and safety of the operating personnel and of the community must be considered, the Atomic Energy Commission contracted with the Bureau of Mines to develop an incinerator for low-level wastes composed mainly of cellulosic materials, animals, and miscellaneous solids from laboratories.

Such a unit, or for that matter any incinerator, must achieve complete combustion of its charge with minimum space requirements per unit weight of charge burned per unit time, and with minimum concentration of solids and condensable vapors in the products of combustion. Also to be considered are safe means for removing and disposing of the grate residue, a simple gas-cleaning system, and low cost of the equipment.

These specific requirements for such equipment indicated that no rational design of a prototype incinerator could be made without some knowledge of certain fundamental factors unique to the incineration process. While it is conceivable that a preliminary unit could be constructed from educated guesses concerning the optimum grate area and furnace heat release rates, and later modified on the basis of its performance, this approach is generally expensive, tedious, and unsatisfactory. The widely varying chemical and physical properties of the materials comprising incinerator charges indicate that certain conventional practices used in connection with the design of coal-burning equipment must be modified to achievo efficient burning of such diverse mixtures as rubbish and animal tissue .

Therefore, a small incinerator, approximately 1/5 scale, was constructed and extensive burning tests were made with a <u>uniform</u> fuel under a variety of controlled operating conditions. In this manner it was possible to evaluate certain process parameters in relation to the combustion efficiency and the burning capacity of the unit, and therefore to secure data for the design of the prototype unit.

Owing to certain desirable characteristics of free vortex flow, that is, flow with constant angular momentum, it was decided to introduce all of the combustion air through tangential ports located above the level of the charge. This made it possible to control both the direction and the velocity of the air with respect to the fuel bed, and to correlate the burning characteristics of the fuel in terms of parameters such as the air rate, the dimensions of the air ports, and the height of the ports above the fuel bed. It will be obvious that these are independent variables of primary importance to the designer.

The object of this paper is to describe the experimental methods that were used, and some of the results and conclusions obtained in this phase of the investigation.

Scope of Investigation

As stated previously, the tests were designed to correlate the burning characteristics with independent variables such as the air flow rate through the tangential ports, the discharge area of the ports, and the height of the ports above the fuel bed. For these purposes, tests were made with three different air flow rates, and for each of these rates three different discharge areas and four different heights of the ports were used.

The principal observations were: (a) the time required to burn a given weight of charge completely, (b) the composition and the temperature of the products of combustion, (c) the composition of the gases at various locations within the combustion chamber, (d) the smoke and tar in the products of combustion, and (e) the temperature distribution over the metal shell of the incinerator.

The quantities used to characterize the performance of the unit were: (a) the observed burning rate, that is, the pounds of charge consumed per hour as denoted by the elapsed time between ignition and complete burn out of the charge, (b) the calculated burning rate, derived from the gas analyses and the mass flow rate, and representing only that part of the charge which is burned to carbon dioxide and water, (c) the fuel-air ratio, derived from the calculated burning rate and the air-flow rate.

A series of tests was also made to determine the distribution of tangential velocity in the incinerator for various air flow rates, port areas, and port heights. The object of this study was to establish the relationship between the flow conditions in the incinerator and the flow conditions in the tangential ports. These tests were made with cold air and without combustion.

In order to eliminate the composition of the fuel as a process variable, wood sawdust of relatively uniform composition and size consist was used for all of the burning tests. Its bulk density was about 10 pounds per cubic foot and its proximate analysis on the as-fired basis was nominally 8 percent moisture, 75 percent volatile matter, 17.5 percent fixed carbon, and 0.5 percent ash. The heating value was 8200 Btu per pound, gross.

Experimental Apparatus

The model incinerator used for these tests is shown in Figure 1. It was constructed from a 55-gallon stainless steel drum. Two tangential air ports, 180 degrees apart, were located at four different levels, each being valved and connected to a manifold so that any pair or combination of pairs could be used at any time. The discharge area of the ports could be changed by means of machined inserts to areas of 0.00166, 0.003 or 0.006 square feet, or approximately in the ratio of 1:2:4.

The observation hole was of sample size to observe about one-half of the fuel bed and to make time-lapse photographs.

Access holes, not shown in the figure, were located at three elevations on one side. Water-cooled probes were inserted through these holes to secure gas samples radially and vertically during the tests.

A thermocouple was inserted through the stack, with the hot junction approximately flush with the inlet to the stack. Owing to its location, this couple provided only a rough indication of the gas temperature and was used primarily for control purposes.

A water-cooled gas-sampling line also was located in the stack to provide a continuous gas sample for a CO_2 recorder, and an average sample for complete orsat analysis.

A Bacharach smoke indicator in the stack drew a measured volume of stack gas through a paper disc, and provided a relative measure of smoke and tars in the gases at any selected time. A continuous tape-type smoke recorder was tried during the investigation, but condensation of water on the tape caused considerable trouble and its use was abandoned.

Several thermocouples were welded to the outside of the shell to provide a continuous record of the shell temperature at selected positions.

Figure 2 shows the general arrangement of the test equipment. A temperature recorder, of the multi-point variety, was used to obtain a continuous record of the gas temperatures and the shell temperatures.

The velocity surveys mentioned previously were made with an airfoil pitometer designed by the Harvard School of Public Health and loaned to the Bureau by Dr. Leslie Silverman.

Experimental Results

Although it is not possible at this time to present the experimental results in detail, some of the more significant observations will be discussed.

First, let us consider the effect of various parameters on the observed burning rate, that is, the time required to consume a given weight of charge. It should be emphasized that this quantity represents the material that disappears in a given time and does not show the amount of combustibles in the products of combustion.

The observed burning rate was found to increase almost linearly with the air flow rate, and for a given air flow rate it increased as the area of the port decreased. Qualitatively, this is shown in Figure 3.

The regions in which tars and other combustibles are discharged are shown at the extremities of the family of curves. Of course, these regions actually are not as sharply delineated as indicated by the curves.

It is obvious that for a fixed port area the linear velocity of the air in the tangential ports increases with air rate. Since the observed burning rate is a function of both the mass flow rate and linear velocity of the air, the burning rate was plotted as a function of the Reynolds number of the air in the tangential ports. This relationship is shown in Figure 4.

The lower curve is the calculated burning rate, which represents the amount of the charge that burns completely tc CO_2 and H_2O. The spread between these curves is approximately the amount of unburned material in the form of CO, H_2, tars, or carbon. The significance of this lies in the fact that there is an optimum range of Reynolds numbers in which the combustion efficiency is greatest. This is clearly indicated by Figure 5 which shows the ratio of the calculated burning rate to the observed burning rate as a function of the Reynolds number of the air in the tangential ports. Evidently, the optimum Reynolds number is of the order of 15,000.

The effect of air velocity on the oxygen distribution and the burning conditions in the combustion chamber can be characterized by the composition of the hot gases sweeping the surface of the burning charge. Figure 6 shows the composition of the gases inside the incinerator when burning sawdust at constant air rate, but at two different air velocities. The left-hand figures are for a port velocity of 35.8 feet per second and right-hand figures are for a port velocity of 130.8 feet per second. The Reynolds number corresponding to these conditions is 19,000 for the former and 29,000 for the latter. It will be noted that at the low air velocity excess oxygen was always present; however, when the velocity was increased, the oxygen disappeared about four inches from the center of the fuel bed, and the overall result was the formation of carbon monoxide over a relatively large portion of the fuel bed. While Figure 6 suggests that low air velocities are preferable, it should be indicated that below some optimum value appreciable quantities of tarry products are formed and leave the incinerator unburned. Smoke deposits obtained by filtering a measured volume of the gases leaving at the various operating conditions suggest that at low air velocities the combustible losses are primarily unburned tars, while at high air velocities these losses consist primarily of carbon monoxide and hydrogen. The operating range in which efficient burning can be achieved is roughly that indicated by the unshaded region shown in Figure 3.

This is by no means a complete analysis of the many factors that were investigated in connection with the model studies. For example, the effects of such variables as the geometry of the ports and the height of the ports above the fuel have not been discussed. Nor have the results been given of the velocity traverses made to establish the relationship between the flow conditions in the incinerator to the flow conditions in the tangential ports. These data are now being correlated, and it is too early to discuss the final results. However, in this connection Figure 7 shows the fuel-air-ratio as a function of the tangential velocity of the gases at a radius corresponding to the circle to which the tangential ports are tangent. The maximum in this curve corresponds to the minimum excess air, and suggests that the optimum tangential velocity close to the wall of the incinerator is about 14 feet per second. In addition, the data indicate that below some minimum port area the transfer of linear momentum of the air to angular momentum is zero regardless of the linear velocity in the tangential ports. This is suggested by Figure 8, where the ratio of the tangential velocity to the linear velocity is plotted as a function of height of the ports above the fuel bed and the area of the tangential port. Thus, for any given height it is evident that the energy losses involved in the transfer of momentum increase as the port area decreases.

Summary

The following conclusions can be drawn from this work:

1. Efficient combustion of low ash, high volatile wastes can be obtained using only tangential overfire air. Smoke, tars, and other products of incomplete combustion, which might impair the efficiency of the gas-cleaning system, can be maintained at very low concentrations by controlling the Reynolds number of the air in the ports. Undergrate air can be used if it is desired to increase the burning rate per square foot of grate area, but it should be a relatively small fraction of the total combustion air.

2. The incinerator can be operated efficiently with about 40 percent excess air, which is an important factor in designing the gas-cleaning system.

3. Owing to the characteristics of this type of incineration, it appears that the concentration of solids in the effluent gas will be very low -- other things being equal.

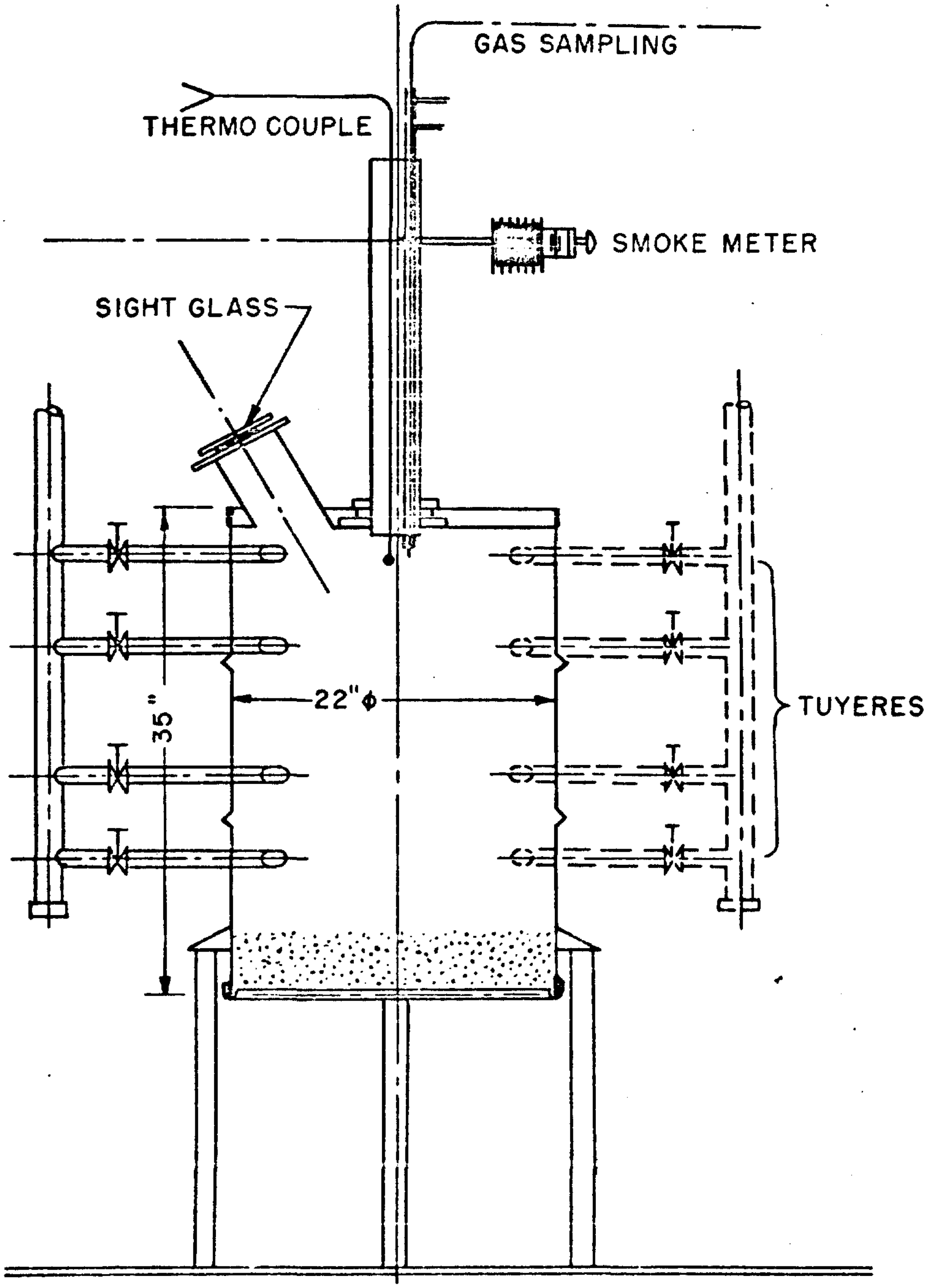

Fig. 1—Cross-sectional view of model incinerator.

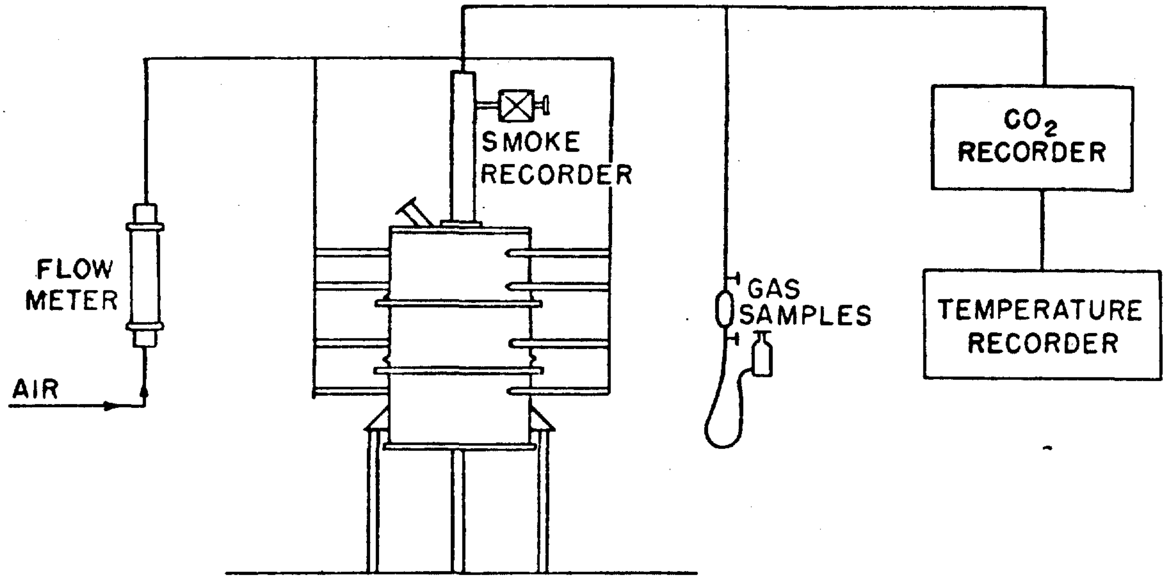

Fig. 2—Schematic diagram of test equipment.

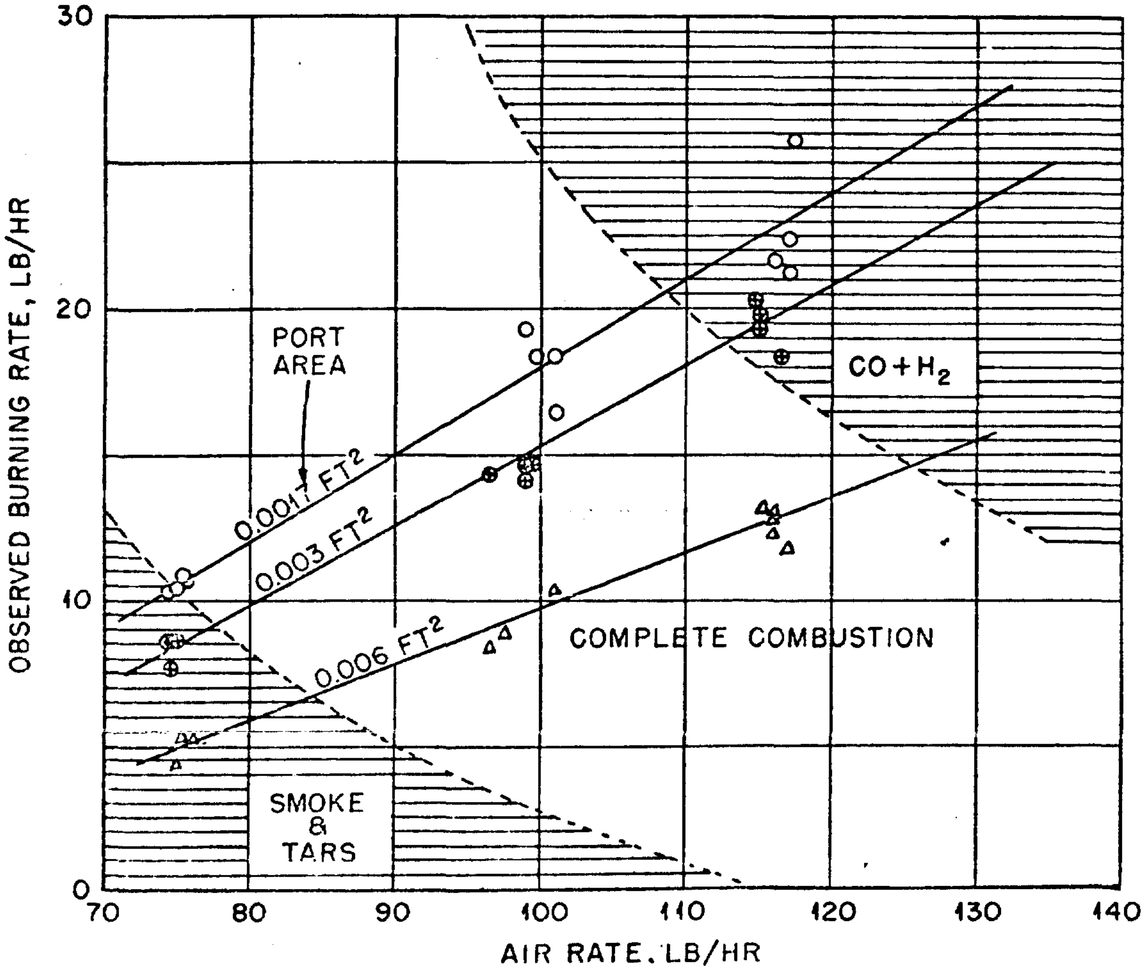

Fig. 3—Variation of observed burning rate with air rate and port area.

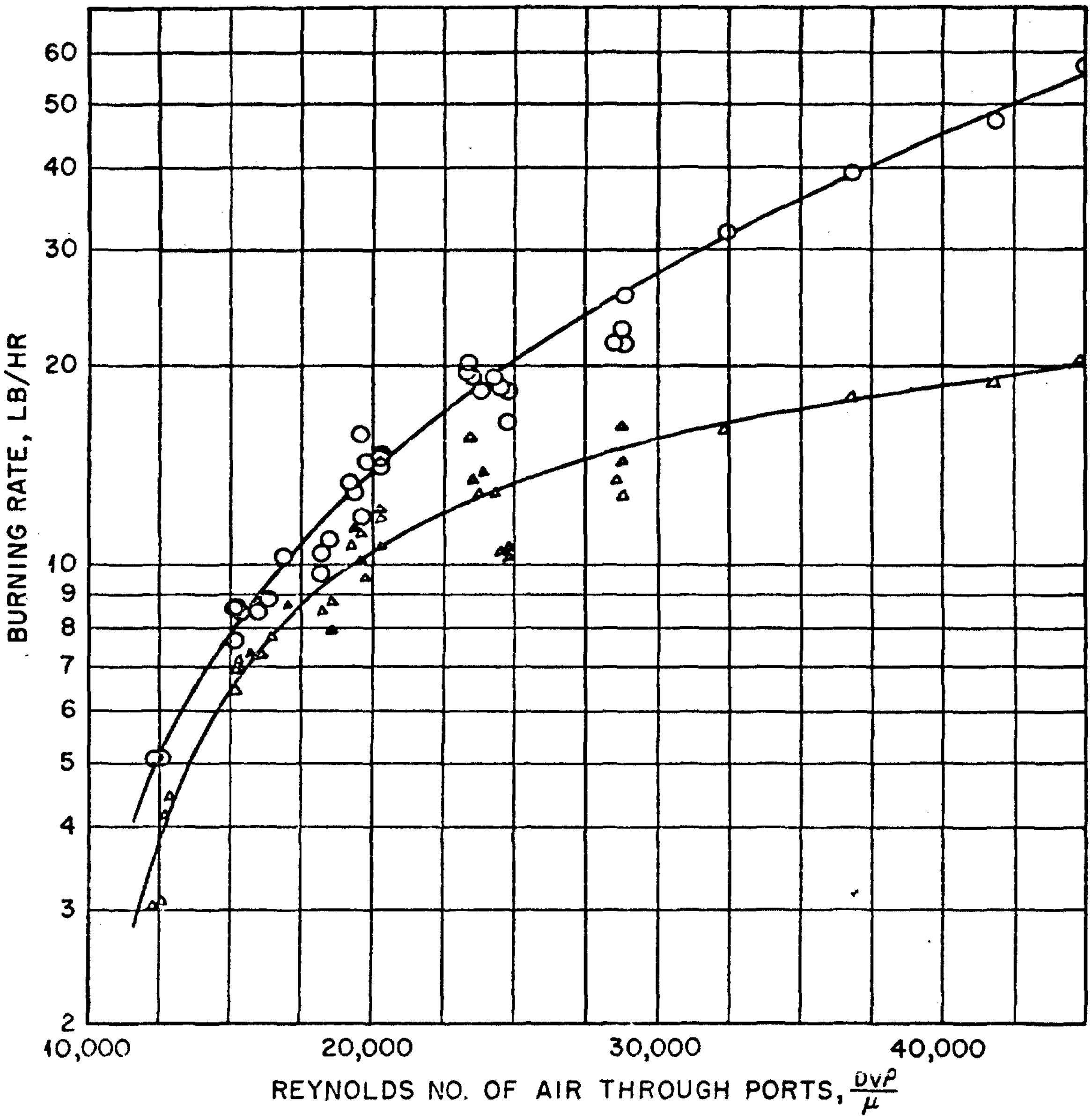

Fig. 4—Variation of burning rate with Reynolds no. of air through ports. ⊙, observed burning rate, lbs/hr; Δ, calculated burning rate, lbs/hr.

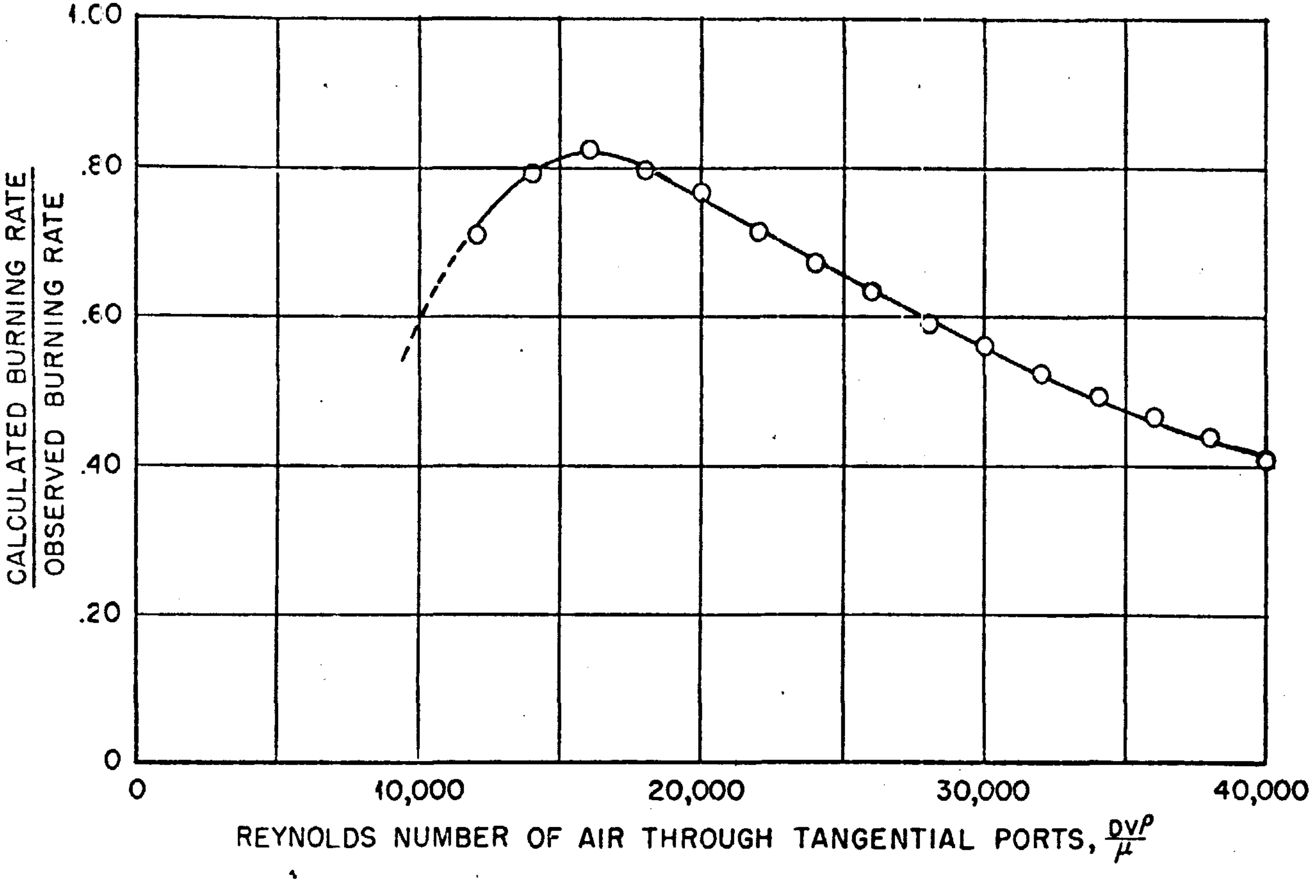

Fig. 5—Ratio of calculated to observed burning rate as a function of Reynolds number of air through tangential ports.

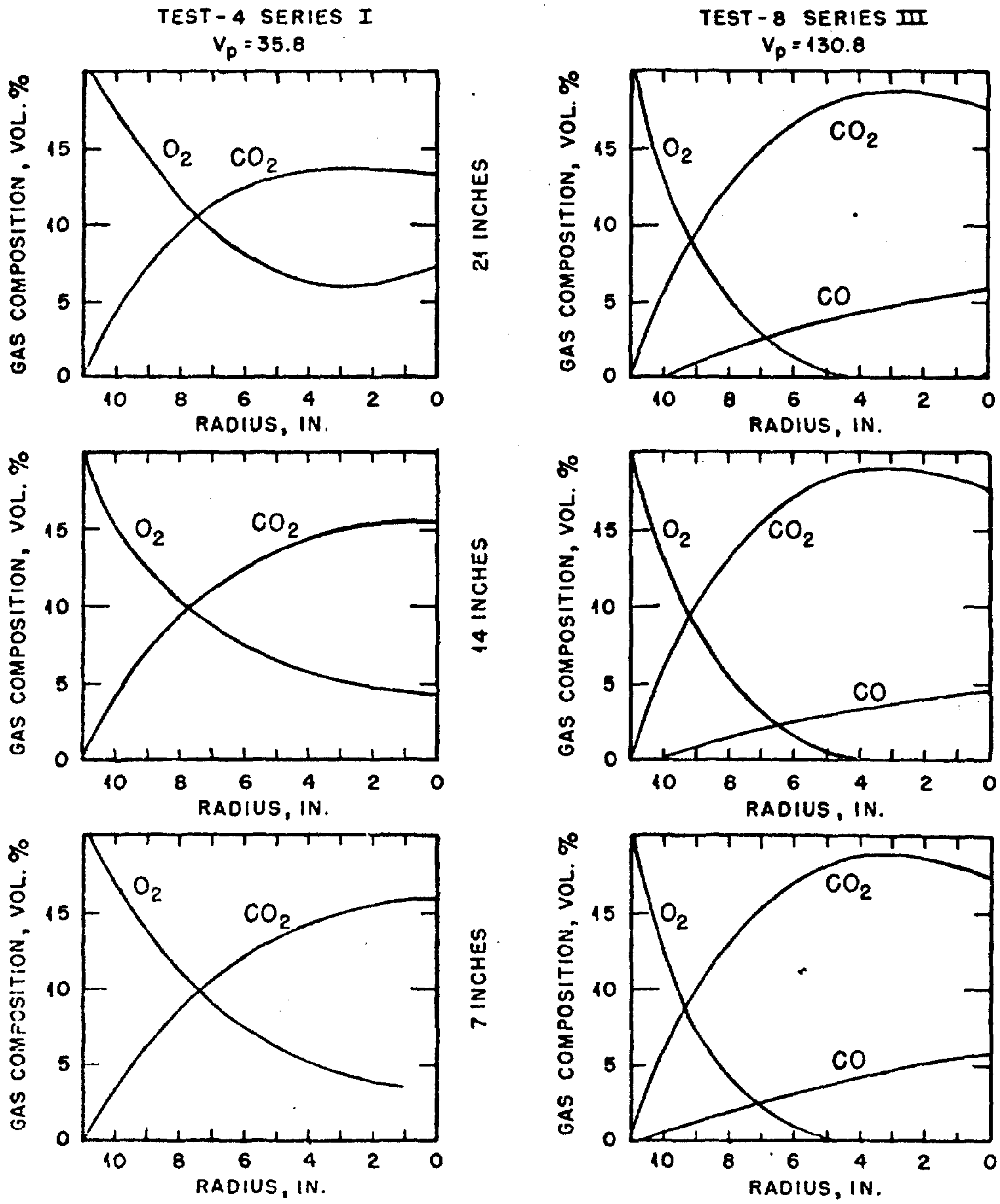

Fig. 6—Composition of hot gases in the incinerator at 7, 14, & 21 incnes above the ignited fuel.

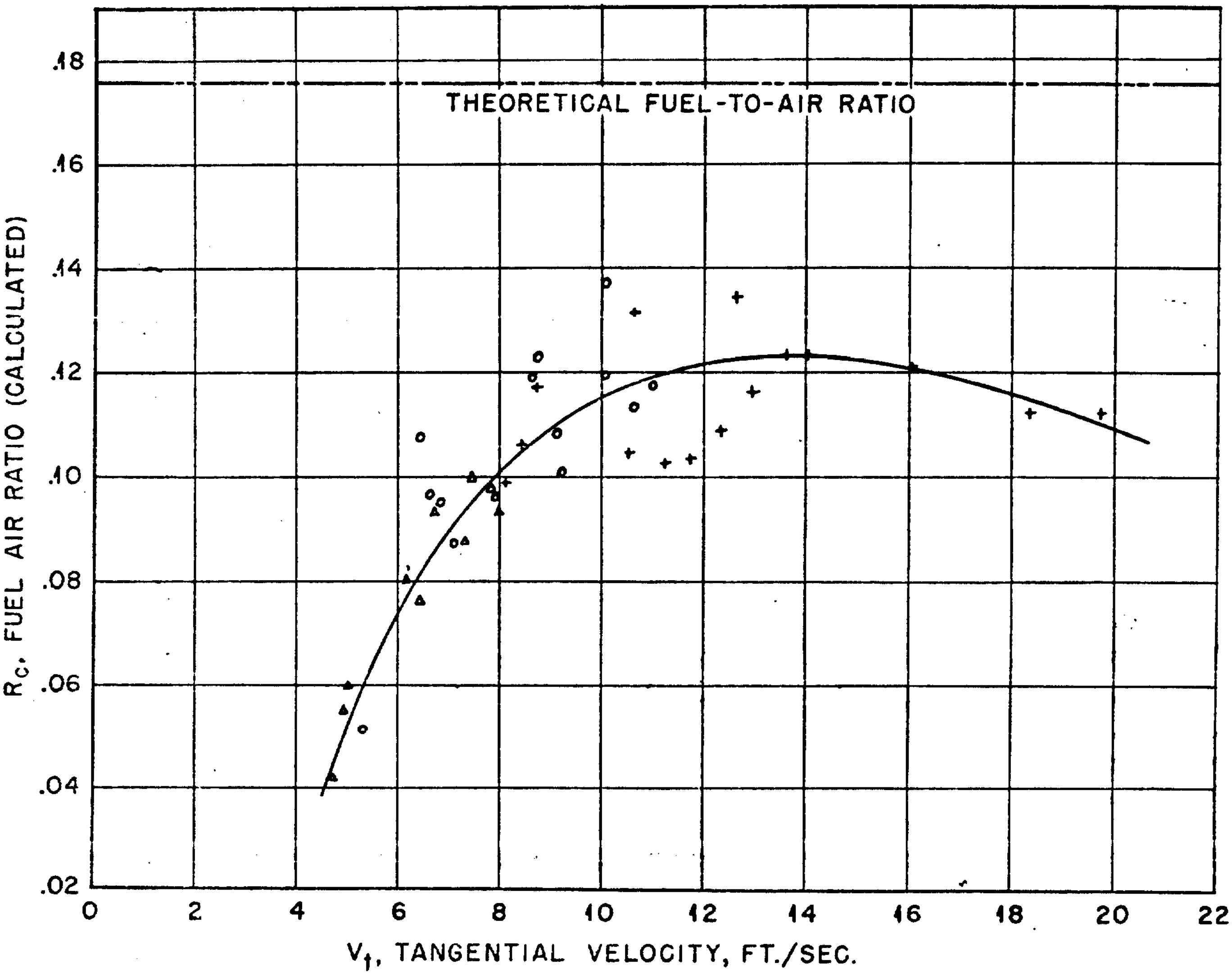

Fig. 7—Plot of the calculated fuel–air ratio as a function of tangential velocity. +, 0.00166 ft.^{2} port area, ○, 0.003 ft.^{2} port area, △, 0.006 ft.^{2} port area.

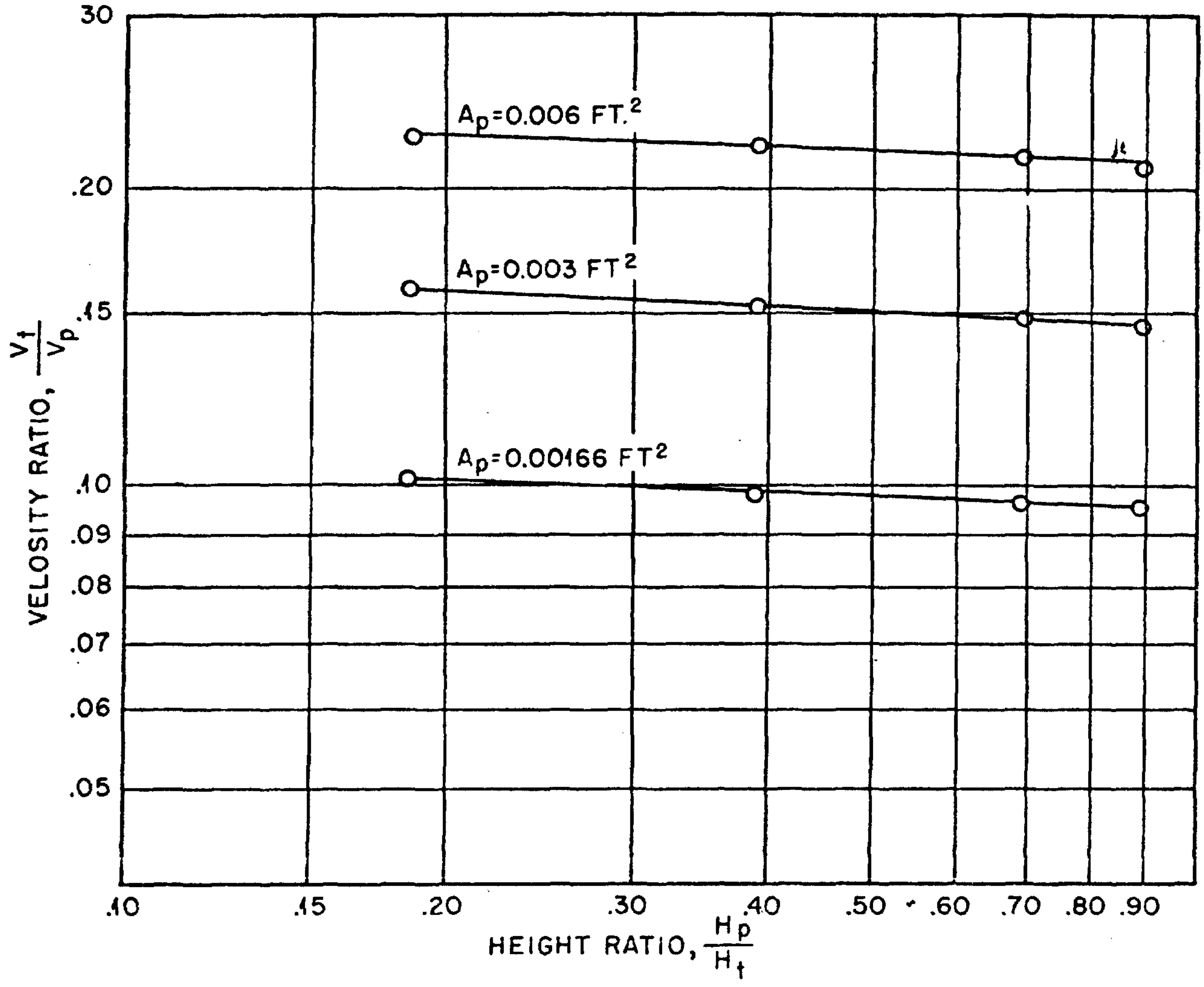

Fig. 8—Velocity ratio $(V_t)/V_p)$ as a function of H_p/H_t at different port areas.