INCINERATION OF COMBUSTIBLE WASTES USING TANGENTIAL OVERFIRE AIR

By

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INTRODUCTION

At the request of the U. S. Atomic Energy Commission, the Bureau of Mines initiated a systematic investigation of incineration. The ultimate purpose of this investigation was to design a packaged incinerator for disposal of radioactive combustible wastes incidental to operations at off-site research laboratories.

The prime requisites of any incinerator are: (1) maximum combustion efficiency, so that smoke, tar, and malodorous constituents are not discharged to the atmosphere; (2) maximum retention of particulate matter within the combustion chamber to obtain the lowest possible dust-loading in the stack gases; (3) maximum reduction of charge volume, so that the least amount of residue must be handled.

Knowledge of the complex heat-and-mass transfer processes which control combustion in solid-fuel-fired furnaces, is meager. Consequently, design of efficient combustion chambers is generally empirical, particularly in the field of incineration. No sound engineering data have yet been published relating such factors as temperature, gas residence or contact time, and turbulence to the burning process of solid fuels.

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ports, 180 degrees apart, located at different levels of the drum. Figure 1 is a schematic diagram of the model incinerator.

The principal objective of the model studies was to establish the relationship of the various process parameters to the burning performance of the incinerator. The variables studied were: (1) air rate, (2) port area, and (3) height of ports above the grate. All tests were made with sawdust whose proximate analysis on the as-fired basis was nominally 8 percent moisture, 74 percent volatile matter, 17.5 percent fixed carbon, and 0.5 percent ash. The gross heating value of the sawdust was approximately 8200 Btu per pound.

The unit was charged at the beginning of each test with 10 pounds of sawdust, ignited, and operated at various predetermined conditions. Each test was considered completed when the last embers were seen to burn out.

The principal observations in each test were: (a) the time required to burn the charge completely; (b) the composition and the temperature of the stack gases, and (c) the relative quantity of smoke and tar in the products of combustion.

Four quantities were used to characterize the performance of the unit: (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; (b) the calculated burning rate, derived from the mass air flow rate and the composition of both the charge and the stack gases; (c) the combustion efficiency which is the ratio of the calculated to the observed burning rate; (d) the relative smoke content of the stack gases.

In designing the incinerator for disposal of radioactive wastes several factors, such as handling the residue and the design of the gas-cleaning system had to be considered. However, the most urgent need was to achieve high combustion efficiency and maximum retention of particulate matter, consistent with a reasonable burning capacity.

Generally, incinerators are required to perform satisfactorily over a wide range of operating conditions. For example, the refuse charged generally consists of different kinds and proportions of solids and semi-solid wastes whose heat of combustion and burning characteristics vary widely. Moreover, when charged randomly, as it is normally done, the flow rate and distribution of air through and above the burning charge vary radically. Observations of various types and sizes of incinerators have clearly indicated that unsatisfactory performance is largely the result of inadequate control of the quantity and distribution of undergrate and overfire air.

The investigation comprised three phases: (1) Disposal of ash residues by fluxing them in molten Na(OH). This has been completed and reported upon. (2) Evaluation of the process parameters with a model incinerator. (3) Design and evaluation of the performance of a prototype unit, based on the results obtained with the model incinerator.

The objective of this paper is to discuss the operation and performance of the prototype incinerator.

MODEL INCINERATOR STUDIES

Before discussing the results obtained with the prototype unit, it is necessary to review briefly the studies made with the model incinerator.

The model incinerator consisted of a 55-gallon steel drum with a small axial stack at the top of the drum and four pairs of tangential

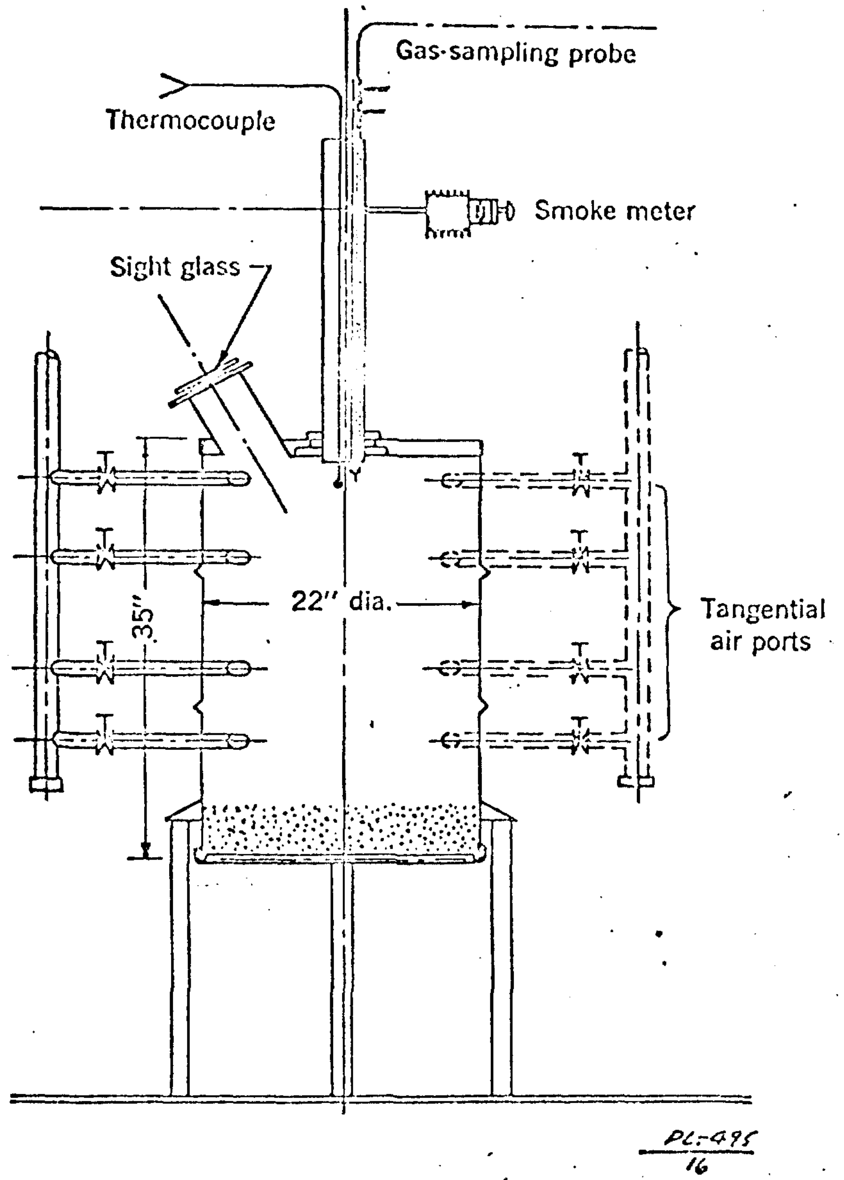
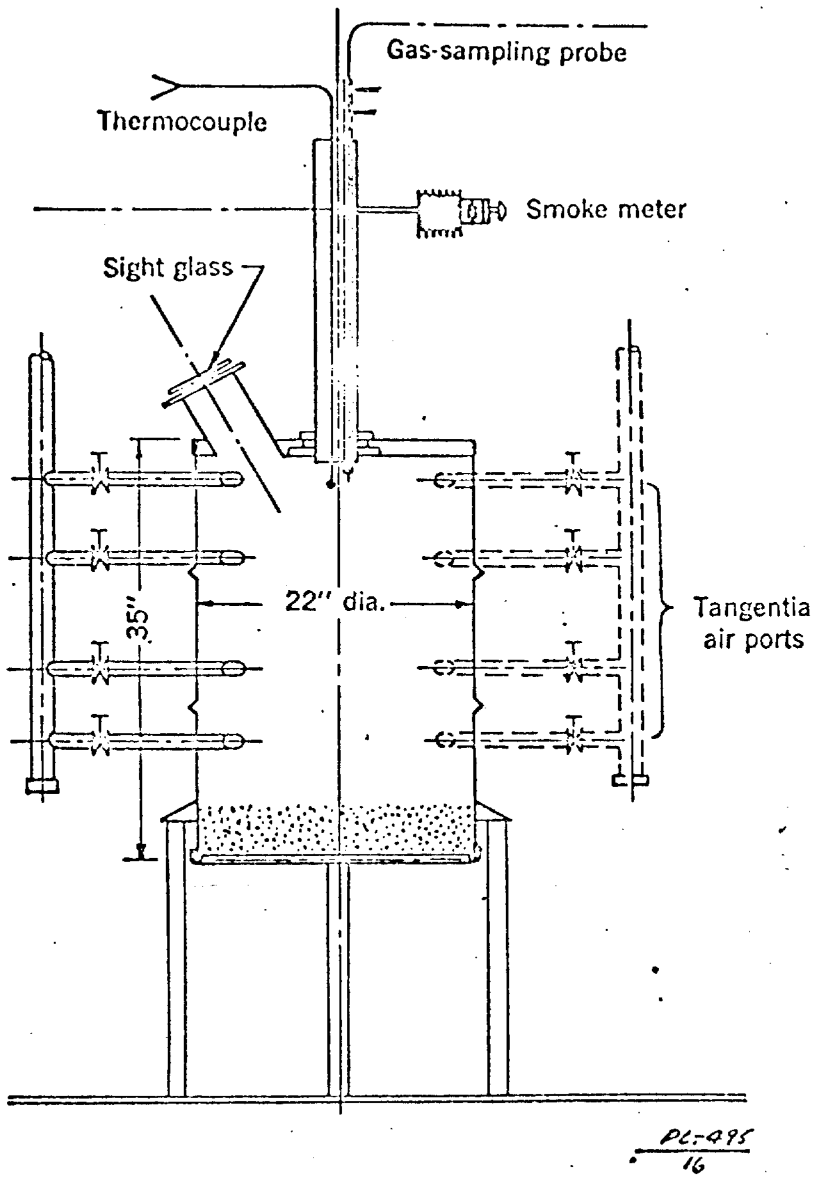


Figure 1. Schematic diagram of model incinerator.



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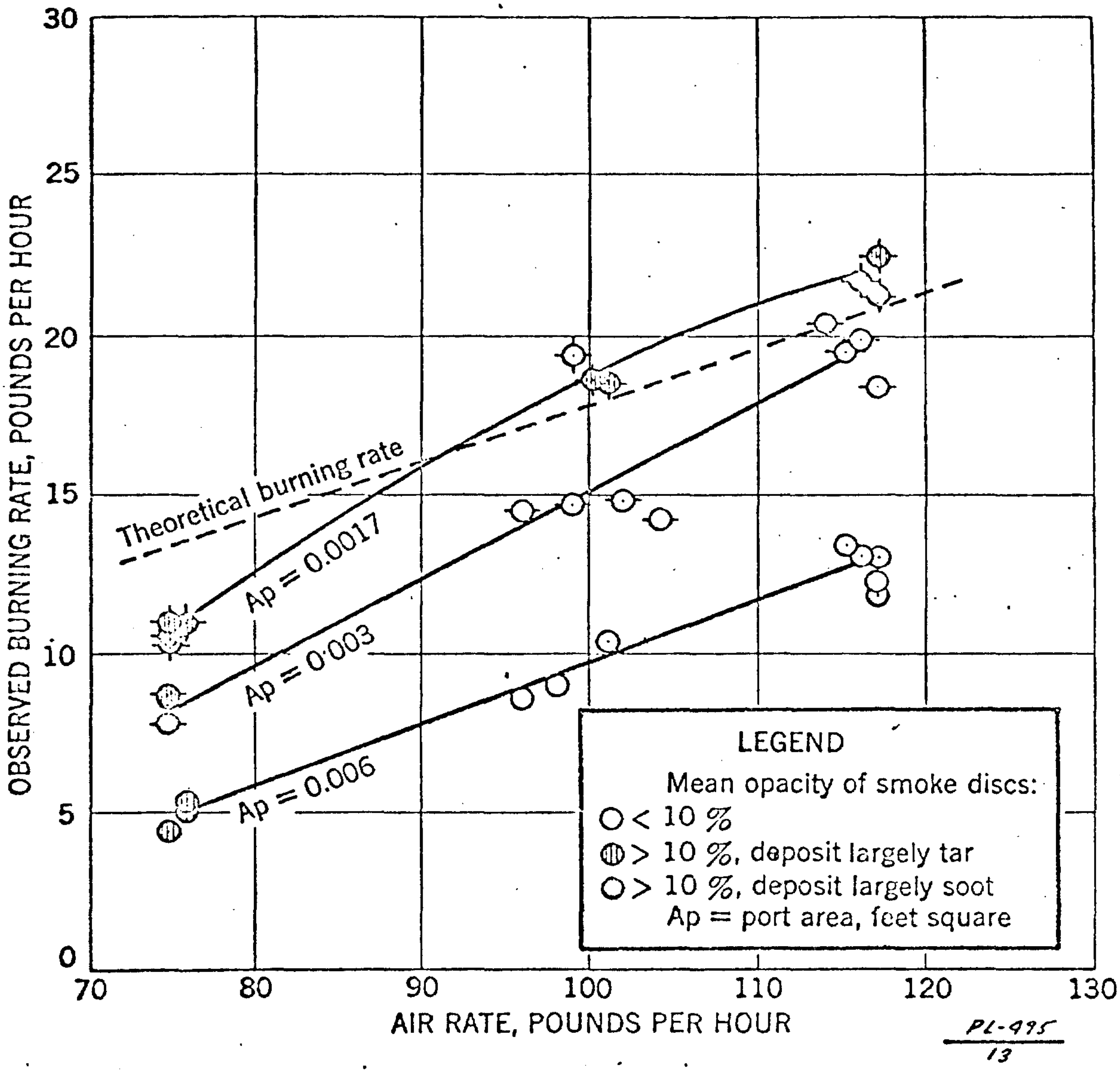


Figure 2. Average observed burning rate as a function of air rate and port area.

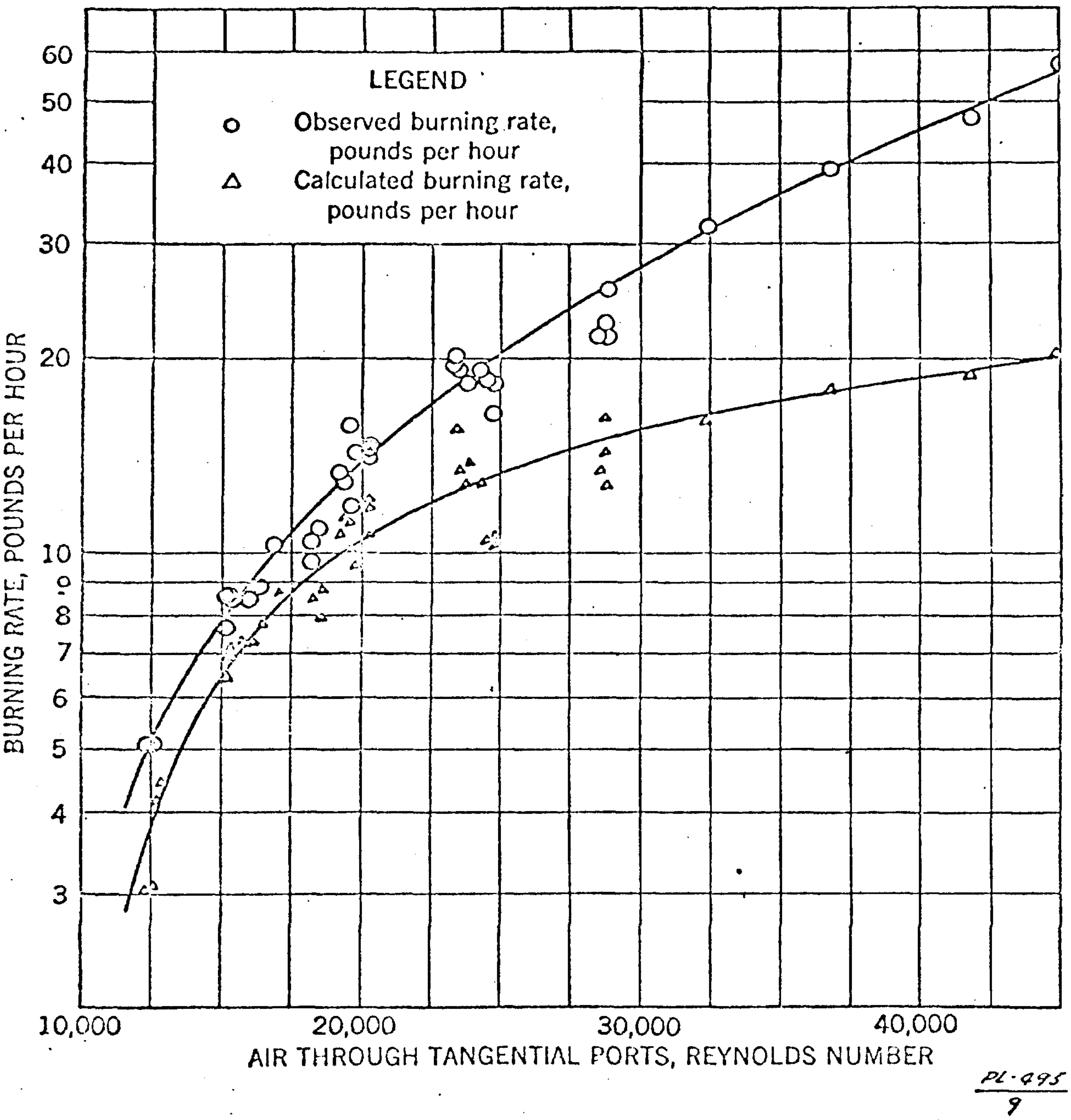


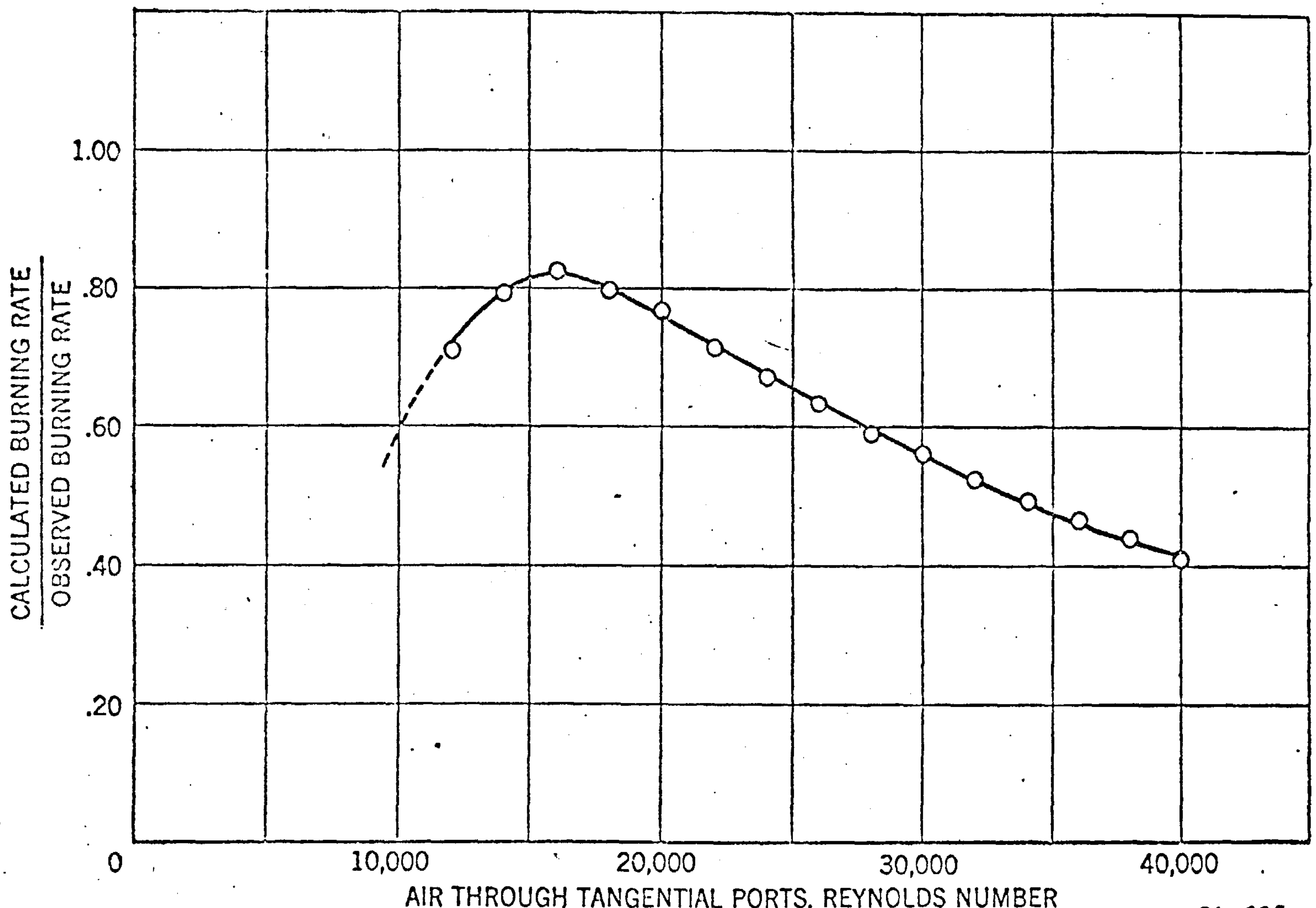
Figure 3. Burning rate as a function of Reynolds number of air in tangential ports.

RESULTS AND DISCUSSION OF RESULTS

Correlation of the results showed that the observed burning rate increased almost linearly with the air rate, and for a given air rate, the burning rate also increased as the port area was decreased. Figure 2 shows the observed burning rate as a function of air rate and port area. Since the observed burning rate is based on the time required to consume the weighed charge, it does not show the amount of combustibles in the stack gases. The theoretical burning rate, shown as a broken line, is the rate at which the sawdust would burn completely to CO_2 and water vapor for a given air rate, if no excess air were necessary, and serves as a guide in comparing the burning rates achieved. When combustion is complete, the burning rates lie on or below this line, and the distance below it is a relative measure of the excess air. It is possible, however, to have unburned combustibles in the presence of excess air. Although the data failed to show a marked effect of the port height, it will be shown later that this variable does have a small effect on the performance of the prototype unit. In general, higher combustion efficiencies were attained when using the uppermost ports.

The results shown in figure 2 suggested that the burning rates could be correlated with a dimensionless parameter characterizing the flow conditions in the tangential ports. Accordingly, the results were plotted as a function of the Reynolds number of the air in the tangential ports. The effect of Reynolds number on both the observed and calculated burning rate is shown in figure 3.

Since the observed burning rate represents all of the fuel that is consumed, and the calculated burning rate only the portion that burns



PL-495
12

Figure 4. Combustion efficiency as a function of Reynolds number of air in tangential ports.

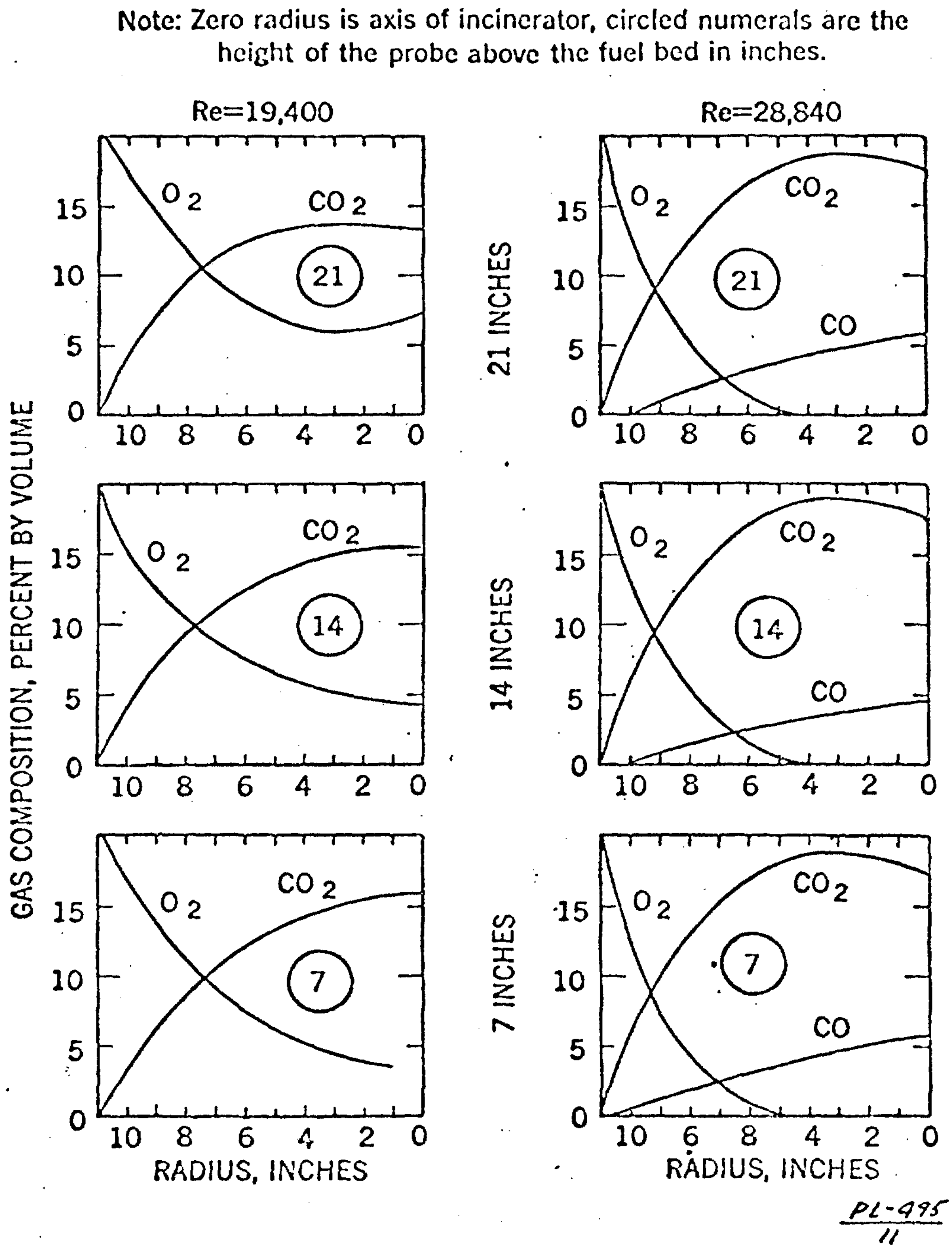
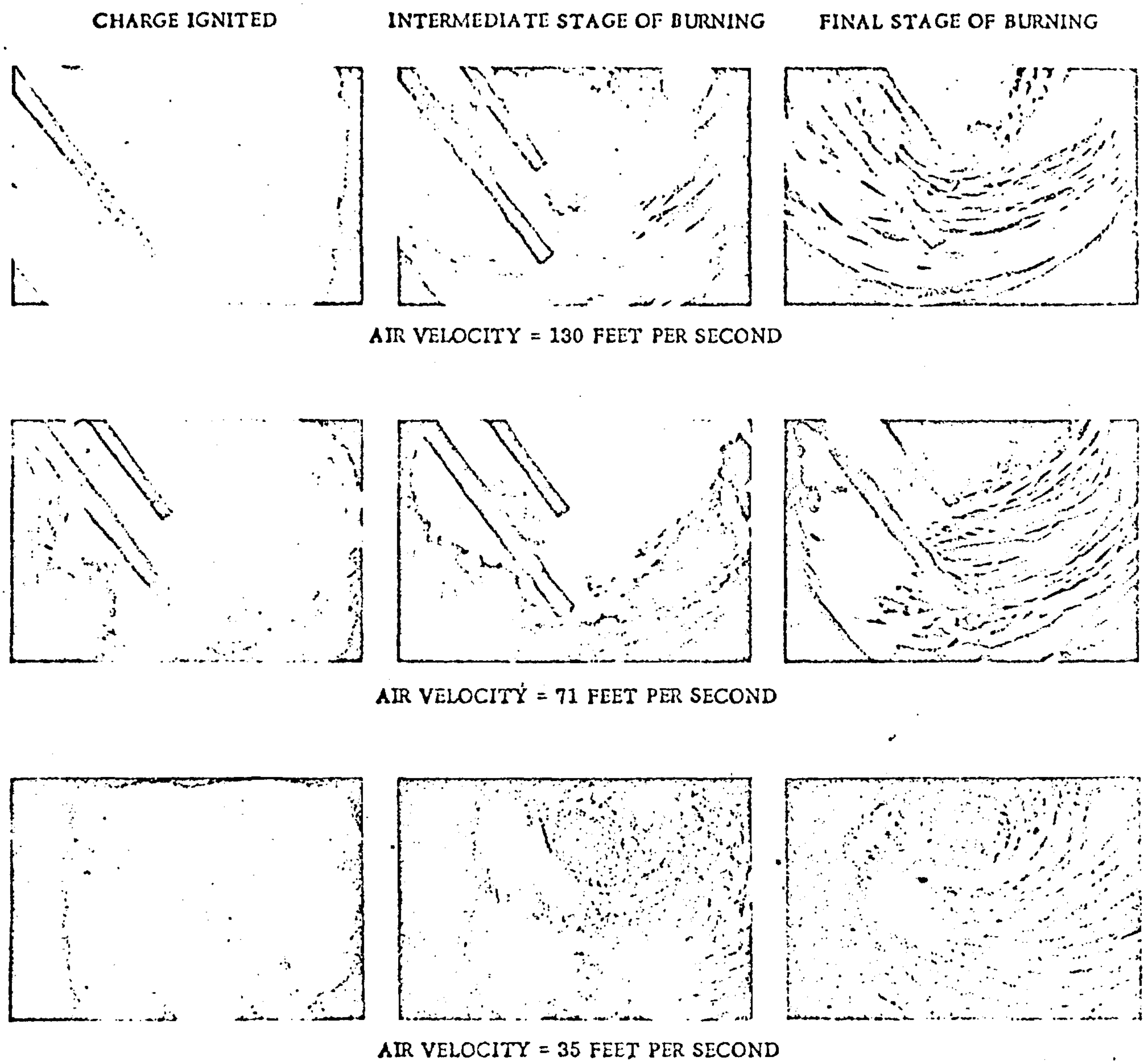


Figure 5. Composition of gases within incinerator for different Reynolds numbers. Air mass flow rate constant at 117 pounds per hour.



TIME LAPSE PHOTOGRAPHS OF BURNING IN MODEL INCINERATOR TO SHOW EFFECT OF AIR VELOCITY UPON FLOW PATTERN OF GASES AND BURNING PARTICLES. AIR RATE = 115 POUNDS PER HOUR.

Figure 6.

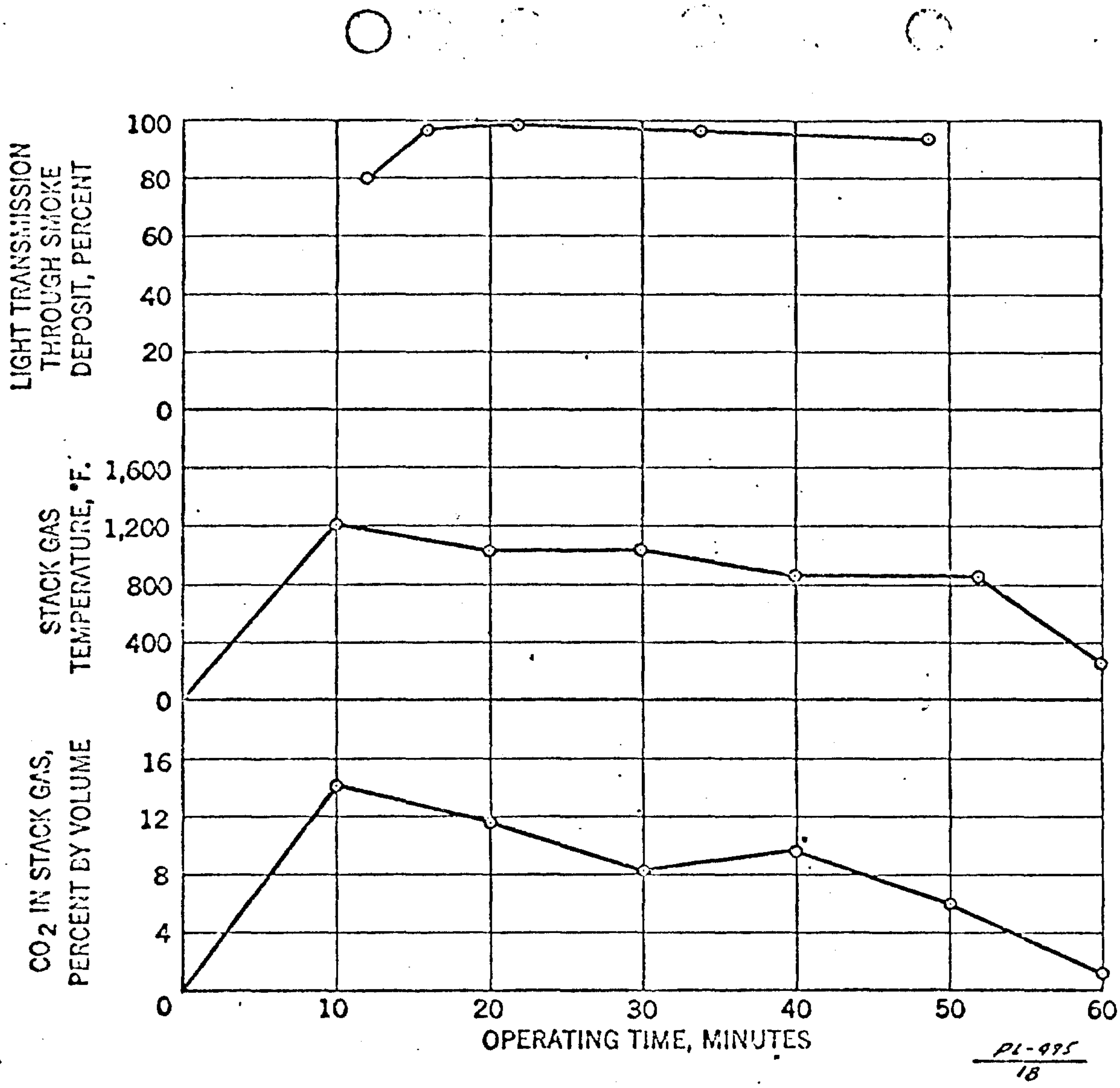


Figure 7. Operating conditions for a Reynolds number of 19,400, air rate = 117 pounds per hour.

to CO_2 and water, the spread between these curves is related to the amount of combustible material in the stack gases. The least spread between the two curves was found at a Reynolds number of approximately 15,000. This is shown more clearly in figure 4.

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 5 shows the composition of the gases at different elevations inside the chamber for a fixed air rate of 117 pounds per hour but for two different Reynolds numbers, 19,400 and 28,840.

It is evident from these data that at the lower Reynolds number excess oxygen was present throughout the chamber, but at the higher Reynolds number the oxygen disappeared at a radius of approximately 4 inches, and CO was formed. Figure 6 shows three stages of the actual burning conditions in the chamber for a fixed mass flow rate of 115 pounds per hour but at three different linear velocities in the ports. These flow conditions correspond to Reynolds numbers of 56,700, 23,500, and 19,400. The angular path of the incandescent particles is clearly evident from these photographs. Comparing the final stage of burning at 35 and 130 feet per second, it will be noted that the average radius of the path of the particles is greater at the higher velocity, which, of course, is to be expected.

In figure 7, the operating conditions for a Reynolds number of 19,400 are given. Special attention is called to the smoke data at the top of the figure. The gray circles are reproductions of the smoke discs, which were taken at the time indicated on the abscissa. Their densities agree quite well with the corresponding photometer results.

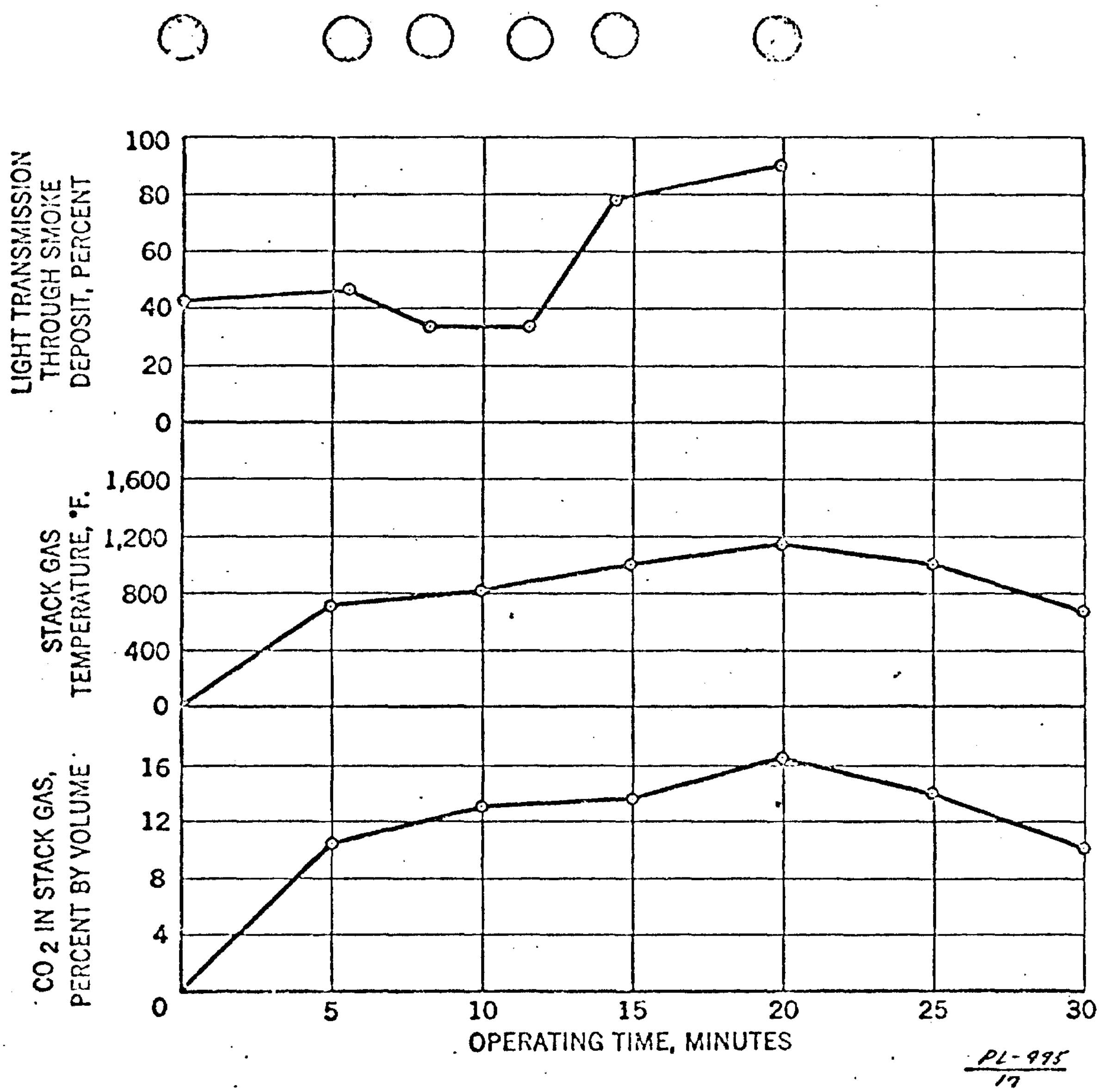


Figure 8. Operating conditions for a Reynolds number of 29,000, air rate = 117 pounds per hour.

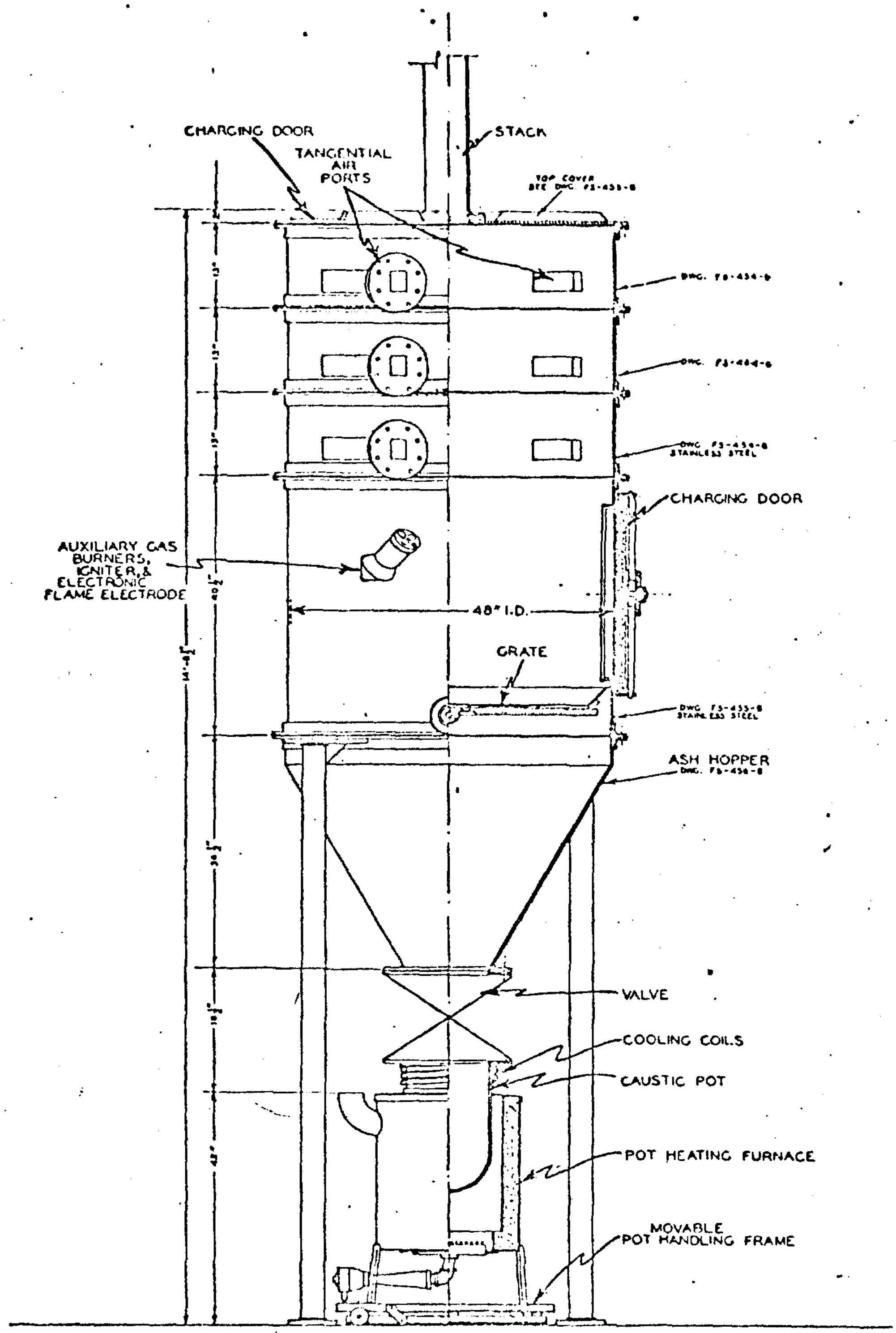


Figure 9. Schematic diagram of prototype incinerator.

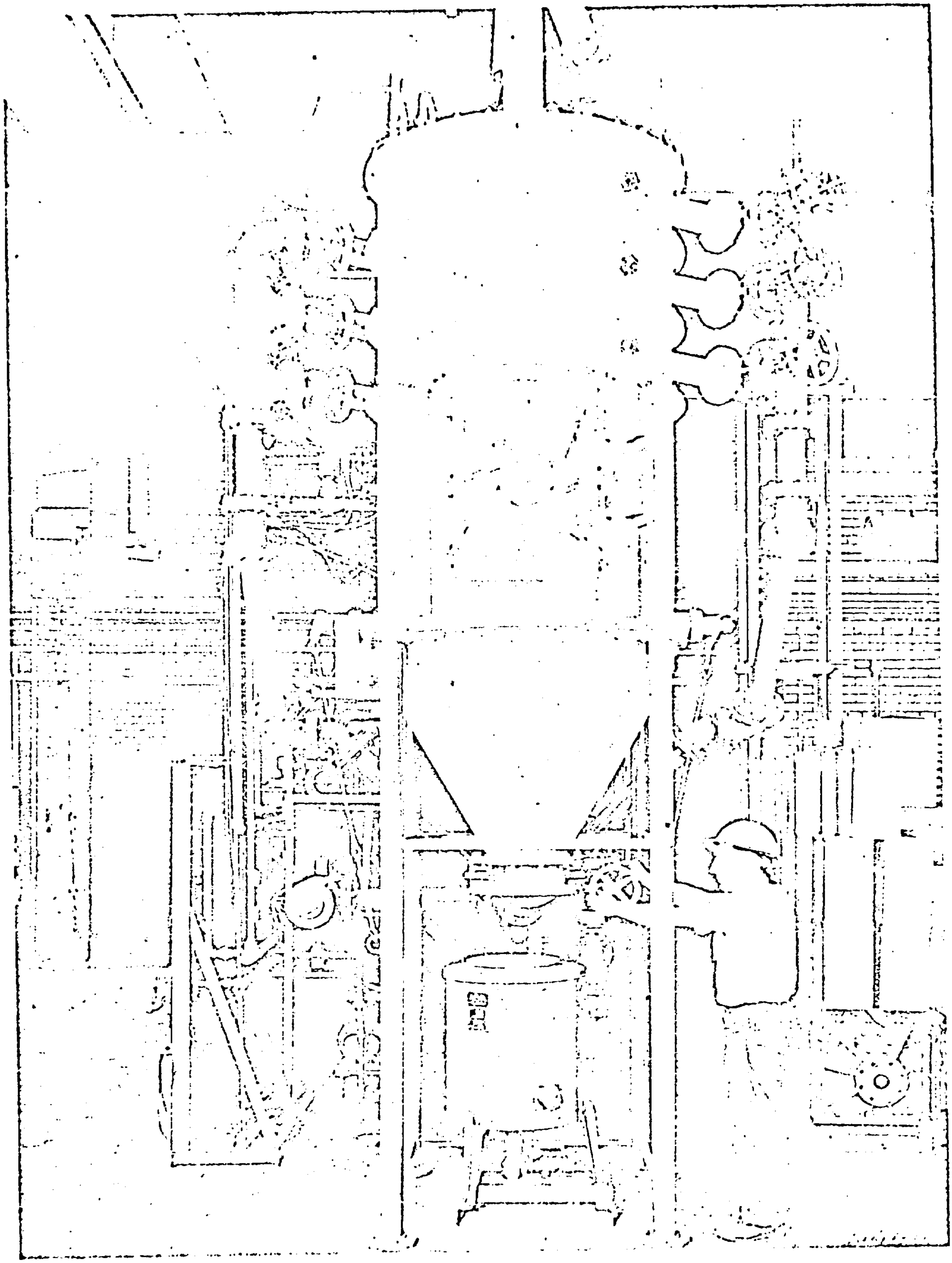


Figure 10. Photograph of prototype incinerator.

In figure 8, the results are given for a Reynolds number of 29,000. The discs for this test were generally darker than for the test at the lower Reynolds number.

PROTOTYPE INCINERATOR

On the basis of these results a prototype unit approximately five times as large as the model was designed. It consists of a cylindrical combustion chamber with an axial stack at the top and a conical ash hopper flanged to the base of the combustion chamber. Figure 9 shows a schematic diagram of the incinerator and the ash-fluxing pot-furnace when assembled for operation. Air to the incinerator is admitted through three pairs of rectangular tangential ports, 180 degrees apart, located at three different levels of the chamber. The ports are valved and connected to a manifold so that any pair or combination of pairs can be used. The area of each port can be varied by means of retractable inserts located in the rectangular section of the ports. The grate consists of two semicircular, cast iron plates hinged in the center, and counter-balanced for ease of manipulation. Two quick-closing doors, one for overhead charging and one for side-charging, were installed for use during the investigation. However, the final unit will be provided with a charge-bin sealed by a guillotine-type door; similar to the Los Alamos unit. Figure 10 is a photograph of the prototype incinerator.

An auxiliary gas burner, with safety interlock devices, is used to ignite the charge.

The total cost of this unit including installation was approximately \$10,000. A commercial model of similar size could be constructed for somewhat less by eliminating auxiliary test equipment, which is not required for satisfactory commercial operation.

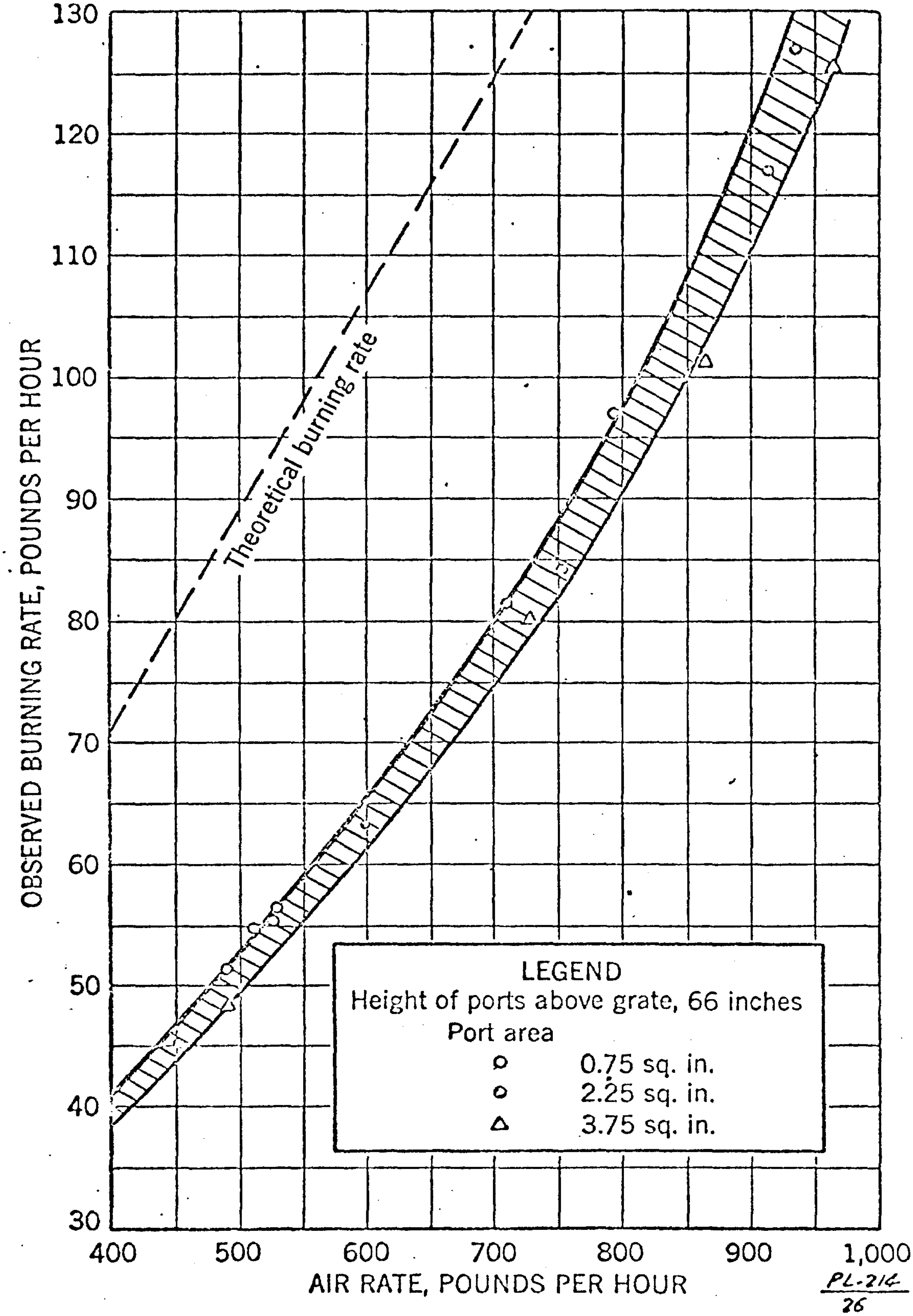


Figure 11. Average observed burning rate as a function of air rate.

EXPERIMENTAL CONDITIONS

The unit is charged batchwise with 100 pounds of sawdust packaged in cylindrical cardboard containers. Fifteen cartons comprise a charge for each test. To ignite the charge the gas burner is turned on for one and one-half minutes and then turned off for the remainder of the test. Each test is considered completed when the last embers are seen to burn out. The burning conditions in the chamber were noted through an observation port located at the top of the chamber.

Several tests were made at air rates ranging from 500 to 1000 pounds per hour, using each pair of ports at the different elevations of the chamber, and various tangential port areas. In addition, some preliminary tests were made with sawdust containing as much as 40 percent moisture.

DISCUSSION OF RESULTS

Since the factors that were varied with the prototype were the same as those for the model incinerator, similar parameters were used to correlate the results. Figure 11 shows the relationship between the observed burning rate and air rate for three different port areas. The ports were located 66 inches above the grate in each case. These data show that the observed burning rate increases with air rate. However, varying the port area at a fixed air rate had little effect. In the model unit the port area had a much more pronounced effect upon the burning rate.

Similar trends were found with ports located at 53 and 40 inches above the grate.

This difference between the model and the prototype suggests that the gas-flow pattern established in the larger unit depends largely on the total quantity of air used, and only to a minor extent on the linear velocity of the air in the ports. These results are in marked contrast with those from the model studies, in which port area had a pronounced effect upon incinerator performance. One possible explanation for this inconsistency may be the differences in geometric relationships between the diameter of both the ports and incinerator, which would affect the transfer of linear momentum of the air in the ports to angular momentum in the chamber. That is, the expansion losses are greater in the prototype unit than they are in the model.

The effect of varying the port height on the burning performance of the prototype incinerator is shown in figure 12. It is significant to note that both the observed and calculated burning rates decreased when the port height was decreased. Moreover, a lower combustion efficiency was achieved when the ports closest to the fuel bed were used. This is better illustrated in figure 13, which is a plot of the ratio of the calculated to the observed burning rate as a function of air rate. It is evident from these results that higher capacities, as well as higher combustion efficiencies, are attainable when all the air is admitted through the uppermost ports.

Since occasionally wet charges are incinerated, some preliminary tests were made using sawdust containing up to 40 percent moisture. No difficulties were encountered in burning the wet charge, except that it was necessary to operate the gas burner somewhat longer

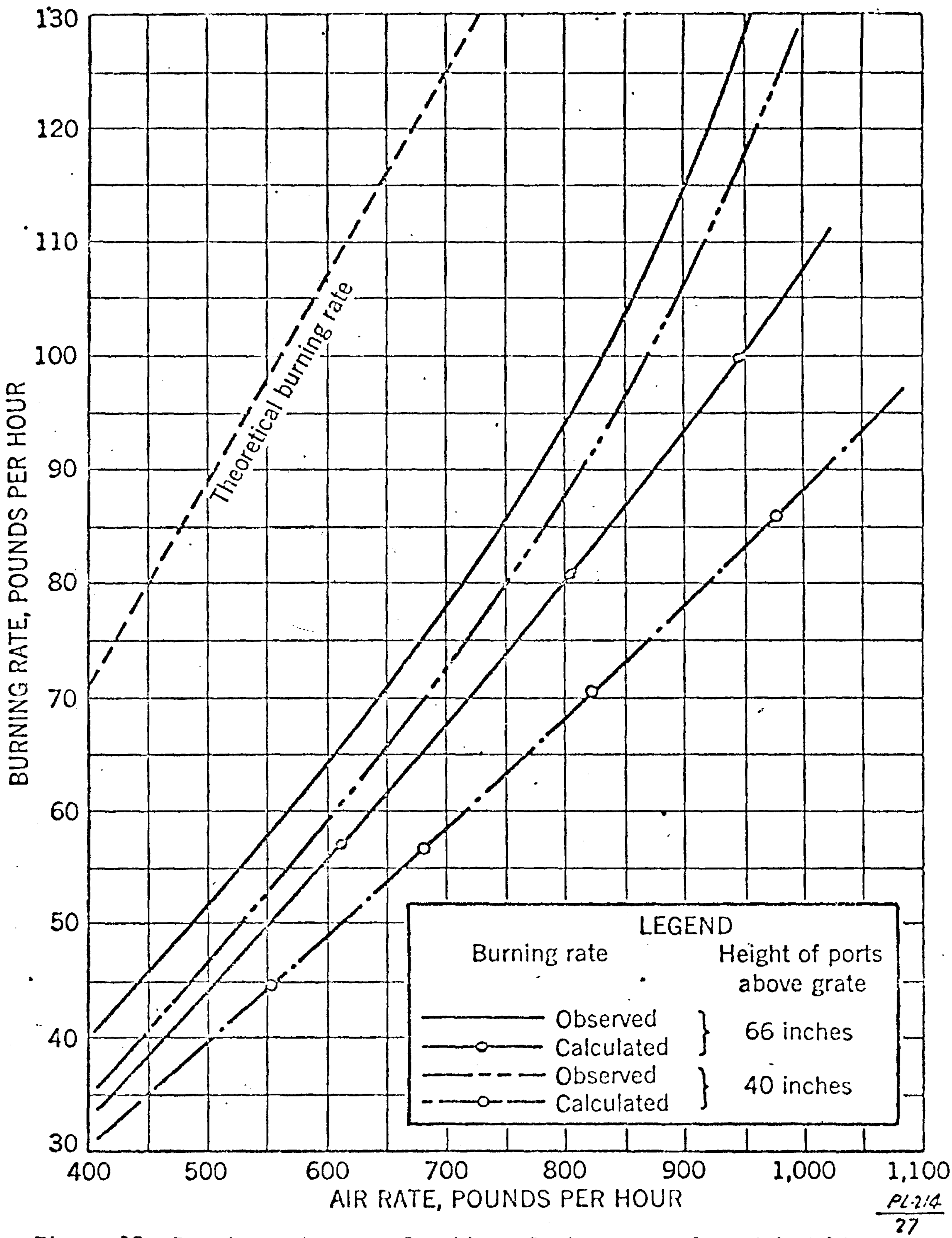


Figure 12. Burning rate as a function of air rate and port height.

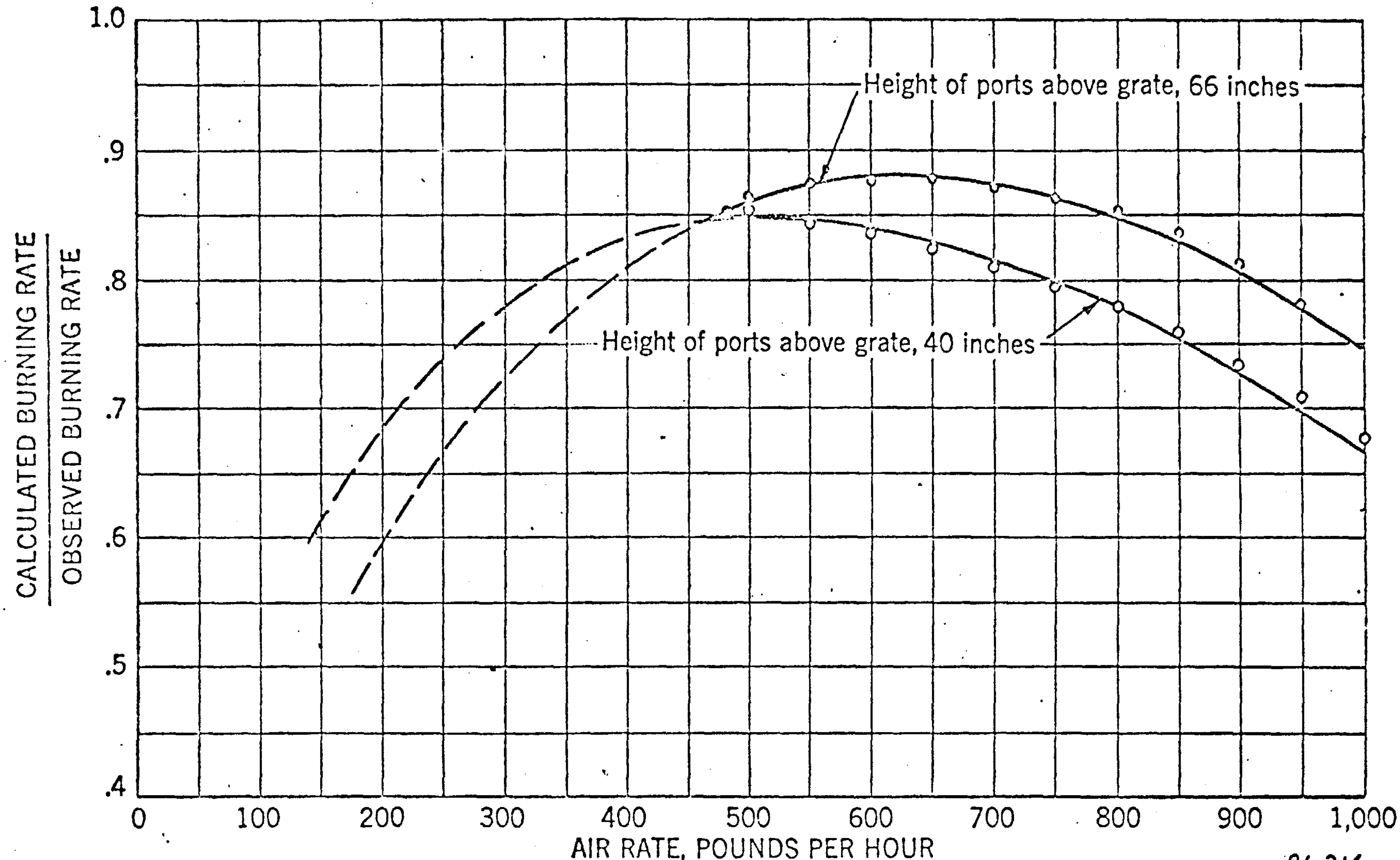


Figure 13. Combustion efficiency as a function of air rate.

PL-214
25

WASH-170

to attain satisfactory ignition. Table 1 shows the results of two tests using sawdust with 7.8 and 40.3 percent moisture. Comparing the data within the heavy boundary lines, it is seen that both the observed and the calculated burning rates do not vary appreciably. However, when the calculated rates are computed on the moisture-and-ash free basis, the charge containing 40.3 percent moisture showed a 25 percent decrease. It is significant to note that no auxiliary burner was used during the tests other than to ignite the charges at the beginning of each test.

CONCLUSIONS

Although a great deal remains yet to be done, the results obtained with the prototype are sufficiently conclusive to draw the following general conclusions:

1. Low ash, high volatile wastes with relatively high moisture content may be burned with high combustion efficiency in a cylindrical combustion chamber using only tangential overfire air. This confirms similar conclusions based upon the model studies. A commercial unit similar in size to the prototype incinerator will burn efficiently approximately 80 cubic feet of waste per day. This based on a bulk density of 10 pounds per cubic foot.

2. Variations of air mass flow rate showed approximately the same effect on the burning rate in the prototype unit as it did in the model unit.

3. The effect of port area and port height on the burning rate in the prototype unit was not consistent with the results obtained in the model studies. In the prototype unit, variations of port height had relatively greater effect than variations of port area, whereas, the opposite was true for the model incinerator.

Table 1.

Comparison Performance Tests of Prototype Incinerator Using Charges with Different Moisture Content

		Test No. 2	Test No. 3
Composition of charge burned:			
Proximate			
Moisture		7.80	40.30
Volatile matter		72.30	46.80
Fixed carbon		19.50	12.60
Ash		0.40	0.30
		100.00	100.00
Ultimate			
H		6.50	8.07
C		47.00	30.54
N		0.10	0.02
O		45.90	61.33
S		0.10	0.01
Ash		0.40	0.03
		100.00	100.00
Gross heating value, Btu/lb.		8070	5230
Operating conditions:			
Weight of charge,	lbs.	106.50	147.00
Approximate density of charge,	lbs/cu.ft.	10.65	14.70
Air rate,	lbs/hr.	854	872
Air temperature at the orifice,	°F	166.5	163.0
Linear air velocity in tangential ports,	ft/sec.	70.6	73.9
Reynolds number, in tangential ports,		49,800	51,000
Operating time,	minutes	62.0	82.0
Results:			
Observed burning rate,	lbs/hr.	103.0	107.5
Calculated burning rate (as charged)	lbs/hr.	87.2	99.0
Calculated burning rate (Moisture, Ash, Free basis)	lbs/hr.	80.0	59.0
Maximum stack gas temperature,	°F	1625	1385
Mean stack gas temperature,	°F	1270	1050
Maximum CO_2 content of stack gas,	percent	18.9	12.8
Mean CO_2 content of stack gas,	percent	11.6	8.4
Theoretical CO_2 content of stack gas,	percent	20.4	20.4
Pounds of residue,	lbs.	0.559	0.72

4. Both the combustion efficiency and burning capacity of the prototype unit were highest when using the uppermost set of ports. This confirms the results of the model studies with respect to combustion efficiency, but is in contrast with the results in the model with respect to burning capacity.

It should be emphasized that these conclusions are based on a limited investigation of only a few factors. The effect of such variables as the bulk density, chemical composition and moisture content of different waste materials has not been determined. It is evident that these factors must be investigated before a complete evaluation of the unit can be made.