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# IMPROVING THE EFFICIENCY, SAFETY, AND UTILITY OF WOODBURNING UNITS

Special Cresote Report

By
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December 15, 1979

Work Performed Under Contract No. EC-77-S-05-5552

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**U. S. DEPARTMENT OF ENERGY**

**Division of Buildings and Community Systems**

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# IMPROVING THE EFFICIENCY, SAFETY AND UTILITY OF WOODBURNING UNITS

## SPECIAL CREOSOTE REPORT

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Department of Mechanical Engineering

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Auburn, Alabama
36830

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# ABSTRACT

## STUDY OF CREOSOTE PHENOMENA IN WOODBURNING APPLIANCES

This study was undertaken to determine the amount of creosote formed by a woodburning stove under various test conditions. Eighteen different tests were perfromed using three different types of wood (hickory, oak, and yellow pine), each with three different geometries. Tests were also performed using different moisture levels.

To carry out the study, a special double wall stainless steel test chimney was constructed. A spectrophotometer was used to determine the relative concentration of the creosote-water solution. The wood type, moisture content and geometry did affect the creosote formation by the stove used in these tests. Wet wood produced more creosote than fire brands. Fire brands with larger piece sizes produced more creosote than the standard brands. Hickory generated more creosote than oak. Oak generated more creosote than yellow pine.

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## I. INTRODUCTION

Wood is a renewable resource; fossil fuels are not renewable. It has been estimated that the total world consumption of wood, as fuel, is about 2300 million tons a year [1]. This is equivalent to about 1300 million tons of coal or about 15 percent of the world's commercial fuel consumption. It is a surprisingly large total and a reason for considerable apprehension about the future. In heating value, wood compares favorably with other fuels. Seasoned hardwood can produce as much heat per cord as a ton of high BTU coal or 200 gallons of fuel oil.

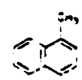
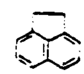
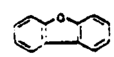
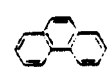
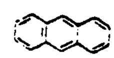
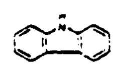
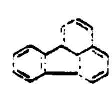
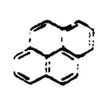
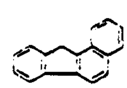
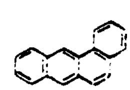
It is possible that package boilers designed for oil or gas can be adapted to use a suspension burner for pulverized wood [2]. A replacement or alteration of fossil-fuel-burning boilers is required to accomodate a wood-fired burner.

The use of wood for heating or perhaps electrical generation is increasing mainly because of the rising cost of conventional forms of equipment used to convert wood into heat for residential use. Today there are fireplaces, woodburning stoves and woodburning furnaces available for homeowners. In addition there are many accessories for the basic units; accessories to improve the performance, to make units safer and to improve the performance. Hence heating with wood in residences is gaining popularity. Along with the interest in burning wood, there is also growing concern over the safety and efficiency of wood heating equipment. For example, the chimney fire, air pollution and corrosion are problems of concern in modern woodburning equipment.

In a fireplace or an ordinary stove, fresh fuel placed on top of glowing coals will first lose water and then distill the volatile matters (pyrolysis), leaving charcoal behind. These stages occur more or less simultaneously in woodburning equipment. It is the volatile matter that gives rise to the long flame from burning wood, and if not completely burned, will be carried up the chimney as smoke. If the temperature of the exhaust gases is reduced to the dew point, these volatile matters will be deposited on the inside surface of the chimney as pyroligneous acid. The acid drips down the chimney walls and dries into creosote, a sticky black substance that is highly flammable.

It is observed that creosote is acidic with a PH value of about 4 and a heating value slightly less than that of wood tar, which is 10,000 BTU per pound. Creosote is corrosive to iron, steel and even galvanized steel. Also, flaky creosote has a significant insulating effect which reduces the heat output to the room when formed on the heat transfer surfaces. The majority of the compounds in creosote are polycyclic aromatic hydrocarbons. Only a limited number of them - less than 20 - are present in amounts greater than one percent [3]. The major components of creosote, listed in Table 1, generally comprise at least

# Table 1. Major Components in Creosote

| Peak No. | Component | Whole Creosote | Boiling Point[1] | Melting Point[1] | Structural Formula | Molecular Weight |
|---|---|---|---|---|---|---|
| | | Approx. Pct. ±0.7% | °C.760 | °C. | | |
| 1 | Naphthalene | 3.0 | 218 | 80.55 |  | 128.2 |
| 2 | 2-Methylnaphthalene | 1.2 | 241.05 | 24.58 |  | 142.2 |
| 3 | 1-Methylnaphthalene | .9 | 244.64 | -22 |  | 142.2 |
| 4 | Biphenyl | .8 | 255.9 | 71 |  | 154.2 |
| 5 | Dimethylnaphthalenes | 2.0 | 268 | 7.66, 105 | — | 156.2 |
| 6 | Acenaphthene | 9.0 | 279 | 96.2 |  | 156.2 |
| 7 | Dibenzofuran | 5.0 | 287 | 86-87 |  | 168.2 |
| 8 | Fluorene | 10.0 | 293-295 | 116-117 |  | 166.2 |
| 9 | Methylfluorenes | 3.0 | 318 | 46-47 | — | 180.2 |
| 10 | Phenanthrene | 21.0 | 340 | 101 |  | 178.2 |
| 11 | Anthracene | 2.0 | 340 | 216.2-.4 |  | 178.2 |
| 12 | Carbazole | 2.0 | 355 | 247-248 |  | 167.2 |
| 13 | Methylphenanthrenes | 3.0 | 354-355 | 65-123 | — | 192.2 |
| 14 | Methylanthracenes | 4.0 | 360 | 81.5-209.5 | — | 192.2 |
| 15 | Fluoranthene | 10.0 | 382 | 111 |  | 202.3 |
| 16 | Pyrene | 8.5 | 393 | 156 |  | 202.3 |
| 17 | Benzofluorenes | 2.0 | 413 | 189-190 |  | 216.3 |
| 18 | Chrysene | 3.0 | 448 | 255-256 |  | 228.3 |

[1]Values from Handbook of Chemistry and Physics, 1971-72, 52nd ed., Chemical Rubber Publishing Co., Cleveland, Ohio.

75 percent of the creosote. The exact compostion of creosote depends on the conditions under which it is formed and the temperature at which it is deposited.

To reduce or eliminate the formation of creosote in woodburning appliances, one must first understand the factors affecting creosote formation. The objective of this study is to determine the amount of creosote formed under various test conditions. The parameters that affect creosote formation include:

a. Species of wood,

b. Geometry of the wood,

c. Moisture content of the wood,

d. Flue gas temperature,

e. Chimney wall temperature,

f. Height of chimney,

g. Roughness of chimney wall,

h. Firing rate,

i. Air-fuel ratio (air setting),

j. Combustion temperature,

k. Type of stove,

l. Ambient temperature and humidity,

m. Exhaust gas flow rates, and

n. Ratio of primary to secondary combustion air.

The parameters of interest in this study are: type of wood, moisture content of wood, size of wood, and combustion process (air fuel ratio, distribution of air within furnace zone, and temperature of furnace walls).

## II. DESCRIPTION OF APPARATUS

A special test chimney was constructed to carry out a study of the formation of creosote. In order to withstand the pressures (steam and water) and resist corrosion, the test chimney was made of 1/16 inch thick, type 304 stainless steel, and had a double wall construction. This double construction provides a jacket of cooling water or steam to control the chimney wall temperature during a test and to reheat the chimney wall when a test is completed. The test chimney was comprised of three sections of double wall pipe. A six-inch diameter inner pipe and an eight inch diameter outer pipe was used to form the test section. Figure 1 shows the details of one section of the test chimney. Four water/steam manifolds(1/32 inch type 304 stainless steel) were connected to the bottom and top of each test section. The water enters at the bottom of each test section and exits at the top to ensure that the water jacket is always full. The steam enters at the top of each section and exits at the bottom to ensure that section contains only steam during the heating period. Also, it can be seen in Figure 1 that an inverted cone was placed inside the chimney to collect the creosote-water solution that condensed. This mixture was diverted through a 1/32 inch diameter tube to the outside of the eight-inch diameter pipe. The tube was connected to a collection beaker. Two different size flanges were welded on each

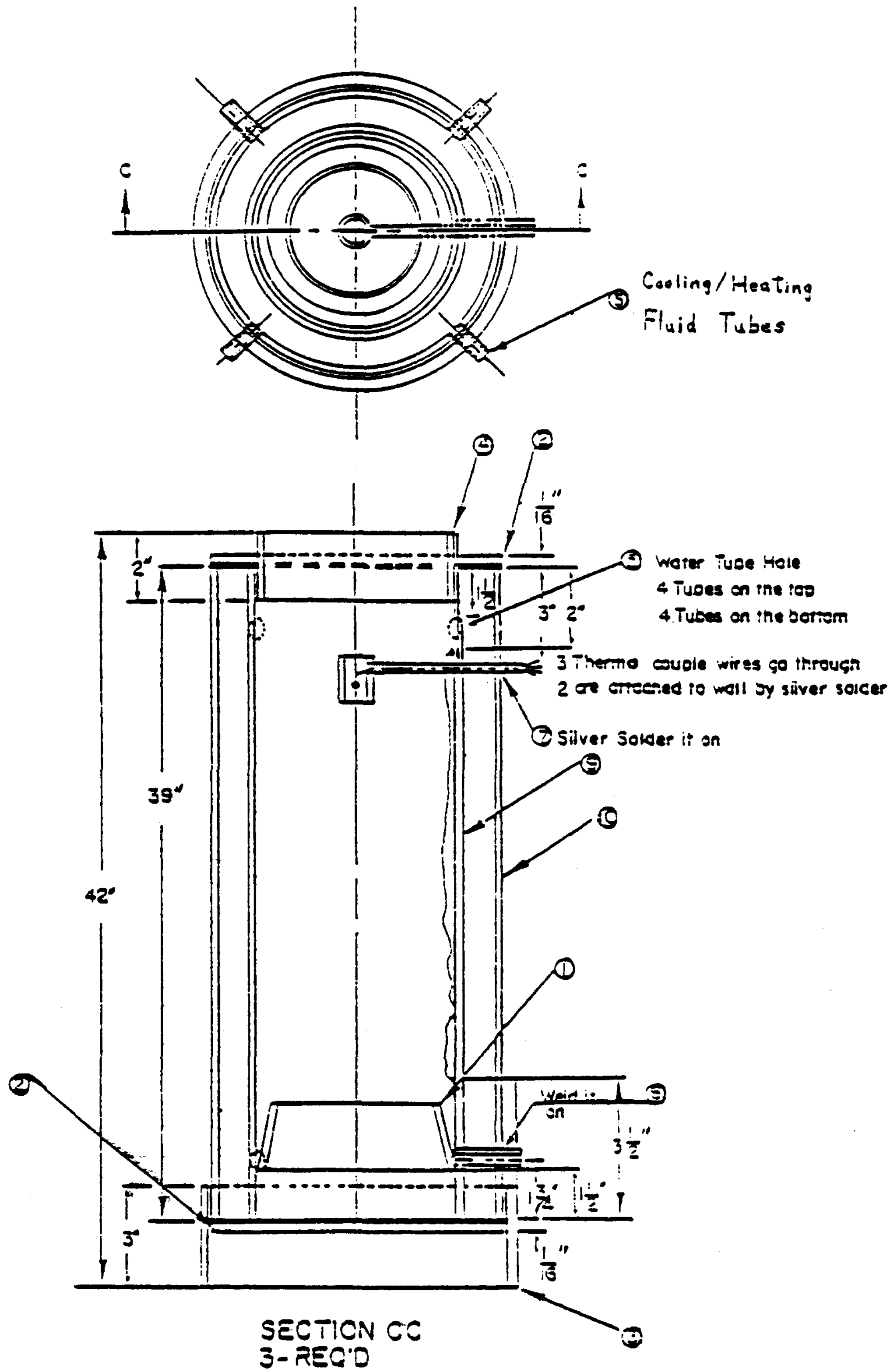



Figure 1. Details of Test Section

end of a chimney section to facilitate connecting the sections together. Figure 1 also shows that three type K thermocouples were placed at various locations to monitor the chimney wall and flue gas temperatures. Shielded thermocouples (Figure 2) were necessary to measure the flue gas temperature. The shield slows the transient response of the thermocouple from "seeing" the cooler flue pipe walls.

The entire assembly is shown in Figure 3. Figure 4 shows the water/steam circulation and control system. The apparatus used in this study is shown in Figures 5 and 6 and the stove in Figure 7. Figure 8 shows the damper setting (1/4 open, position 1) of the stove. Figure 9 shows the connection of the test sections. A closer look at the creosote-collection tubes and the water manifolds on the middle and bottom test sections are shown in Figure 10 and 11. Figure 11 also shows a length of 1/4 inch copper tube in which five type K thermocouples were inserted and projected from five different position holes. A schematic of the five thermocouples is shown in Figure 12. This section was placed between the stove exit and bottom test section to measure the flue gas temperature.

All temperatures were recorded automatically by a data acquisition system (see Figure 13). The test chimney was set up on a radiant type stove and the entire apparatus was situated on a digital balance (see Figure 14) so that the weight of wood consumed could be monitored. A hydraulic gas sample collector and Orsat gas analyzer (Figure 15 and 16) were used to collect flue gas samples and analyze the $CO_2$, $O_2$, and CO contents of the gas. Figure 17 shows a standard spectrophotometer

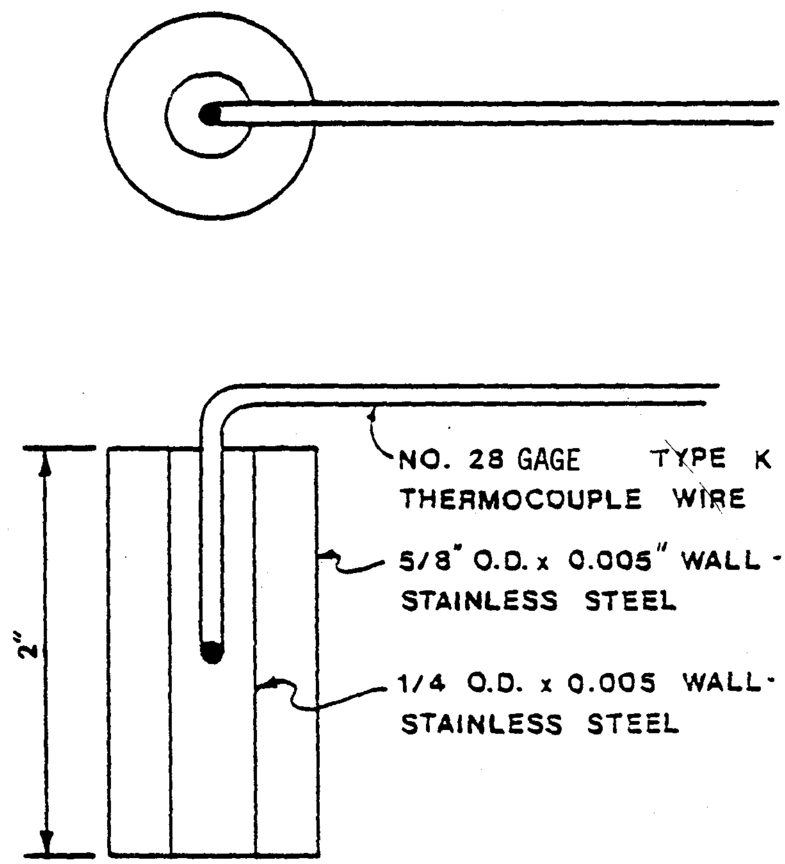
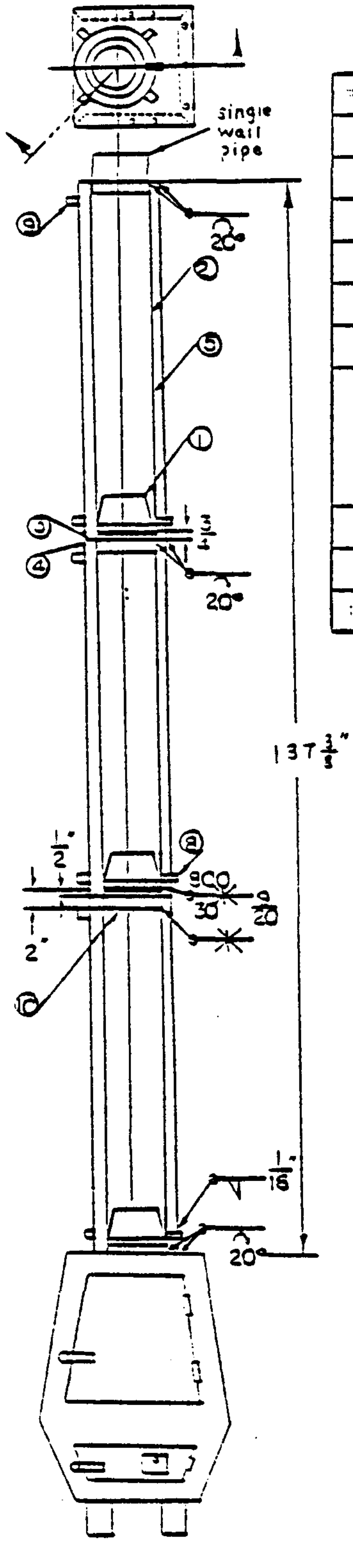



Figure 2. Shielded Thermocouple




| NO. | NAME | | MATERIAL | PC. |
|---|---|---|---|---|
| 1 | Creosote Collector | | 1/16" thickness, SS304 | [illegible] |
| 2 | S.W. Stove Pipe | | 1/16" thickness, SS304 | [illegible] |
| 3 | Separation Plate | | 1/16" thickness, SS304 | [illegible] |
| 4 | Fitting | | 1/16" thickness, SS304 | [illegible] |
| 5 | S.W. Water Jacket | | 1/16" thickness, SS304 | [illegible] |
| 6 | Elbow | | 1/16" thickness, SS304 | [illegible] |
| 7 | Supporter | Angle Bar | 1 1/4 x 1 1/4 x 1/8 | |
| | | Steel Plate | 1/8" thickness, SAE 1025 | [illegible] |
| | | Bolt & Nut | 1/4 - 5/8(L) UNC - 2A x 4 hexagonal head | 7 |
| 8 | 1 3/8" Long Creosote Tube | | [illegible] O.D. .035" thickness SS304 | [illegible] |
| 9 | [illegible]" Long Water Tube | | 3/4 O.D. .035" thickness SS304 | [illegible] |
| 10 | Connector | | 1/16" thickness SS304 | 2 |

Figure 3. Assembly of Test Facilities

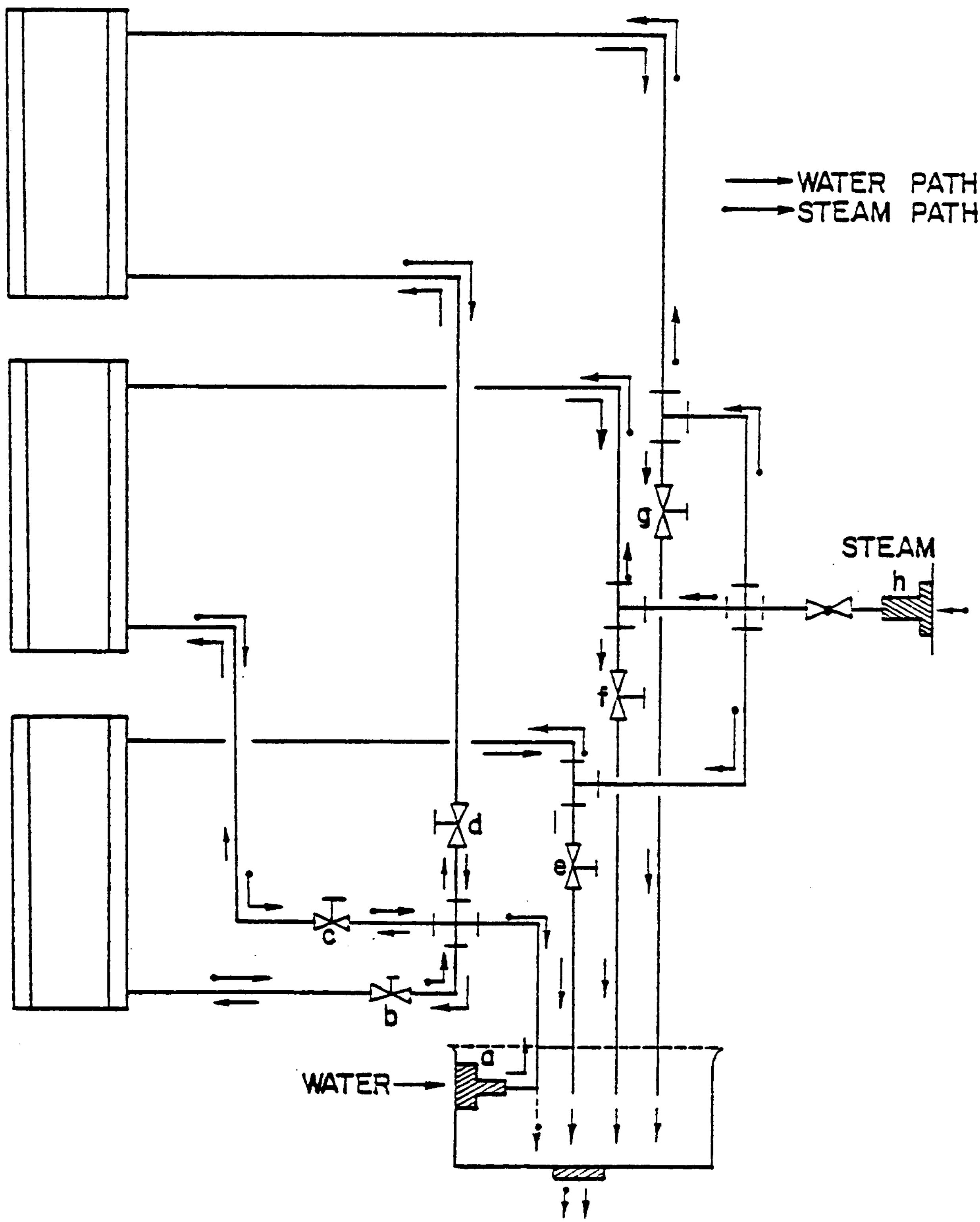



Figure 4. Water/Steam Circulation and Control System

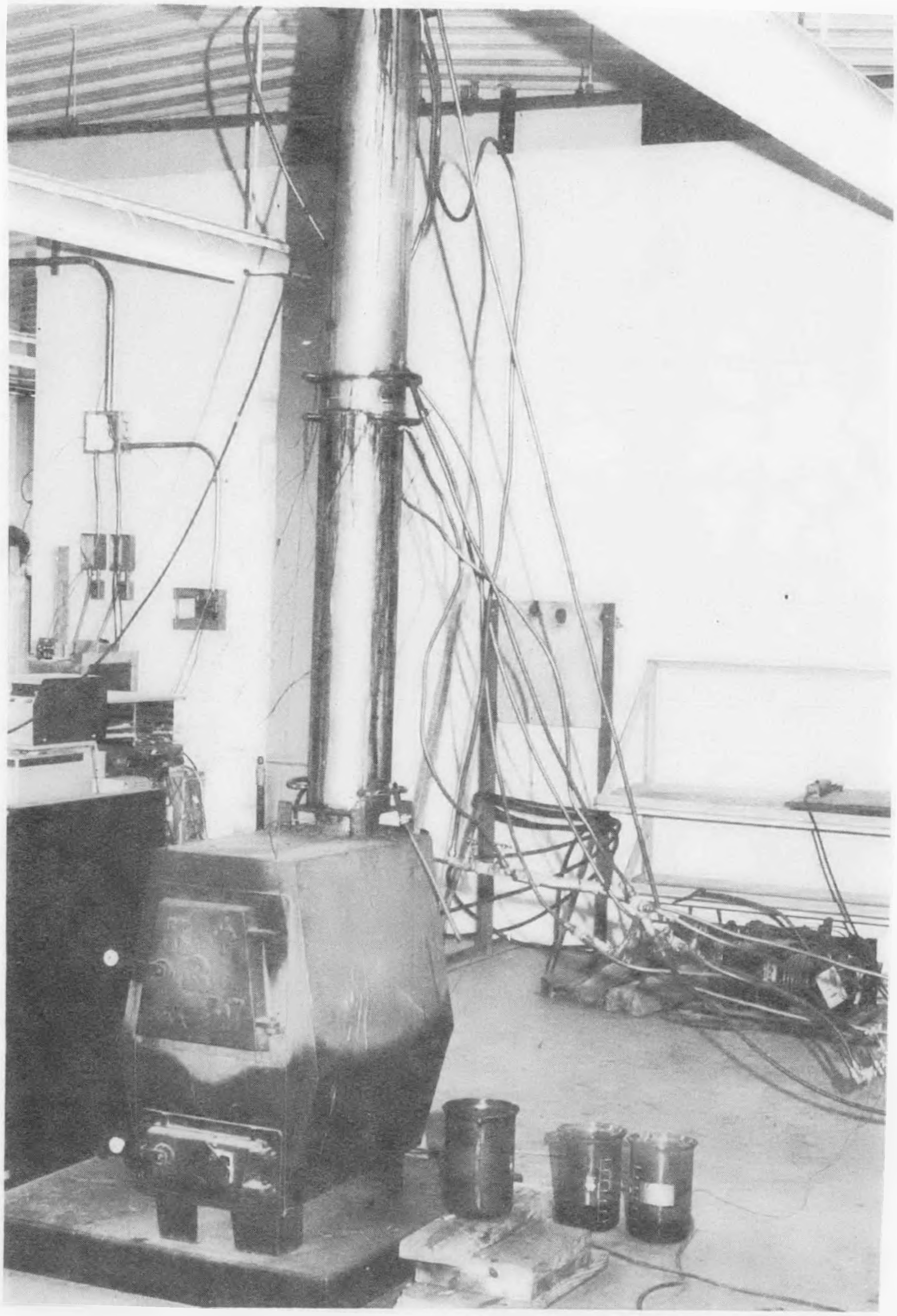


Figure 5. Test Installation

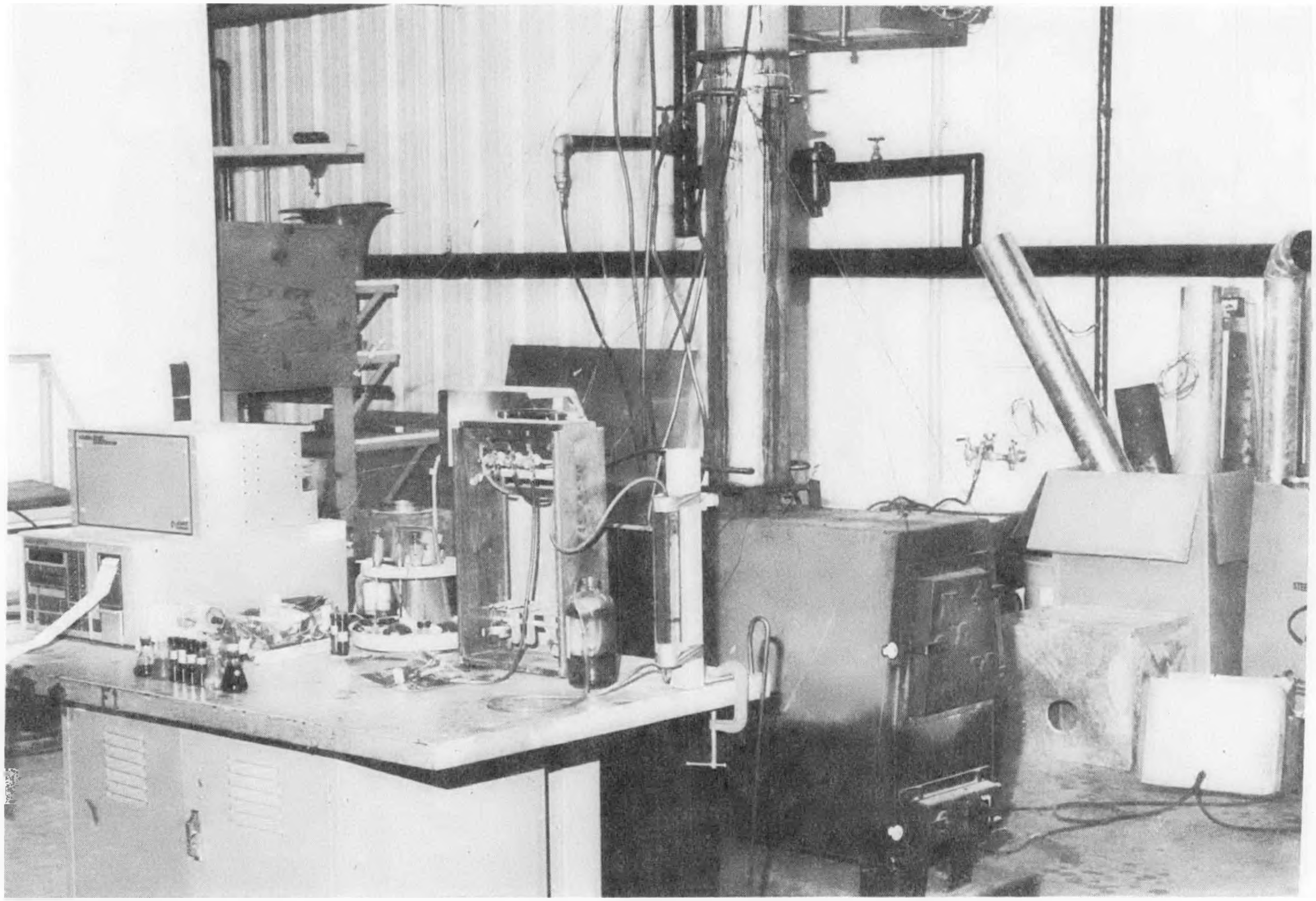


Figure 6. Entire Test Facilities

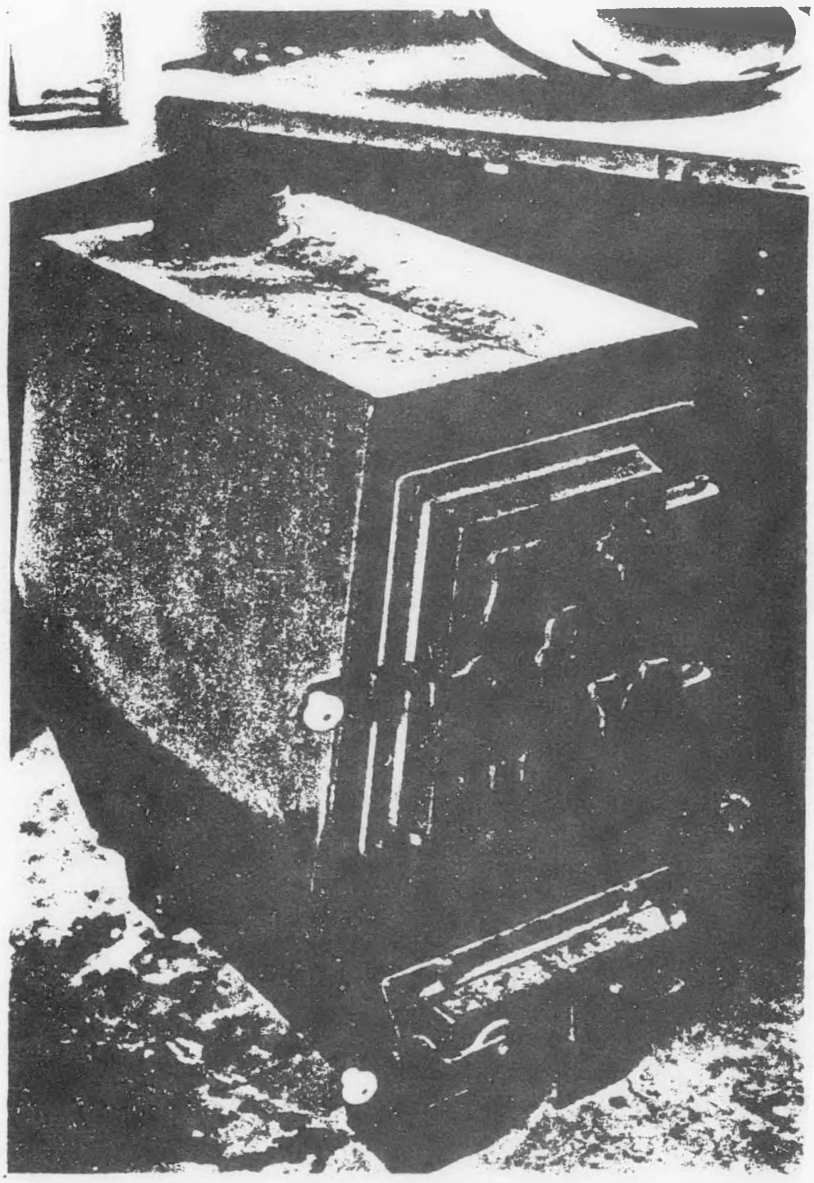


Figure 7. Test Stove

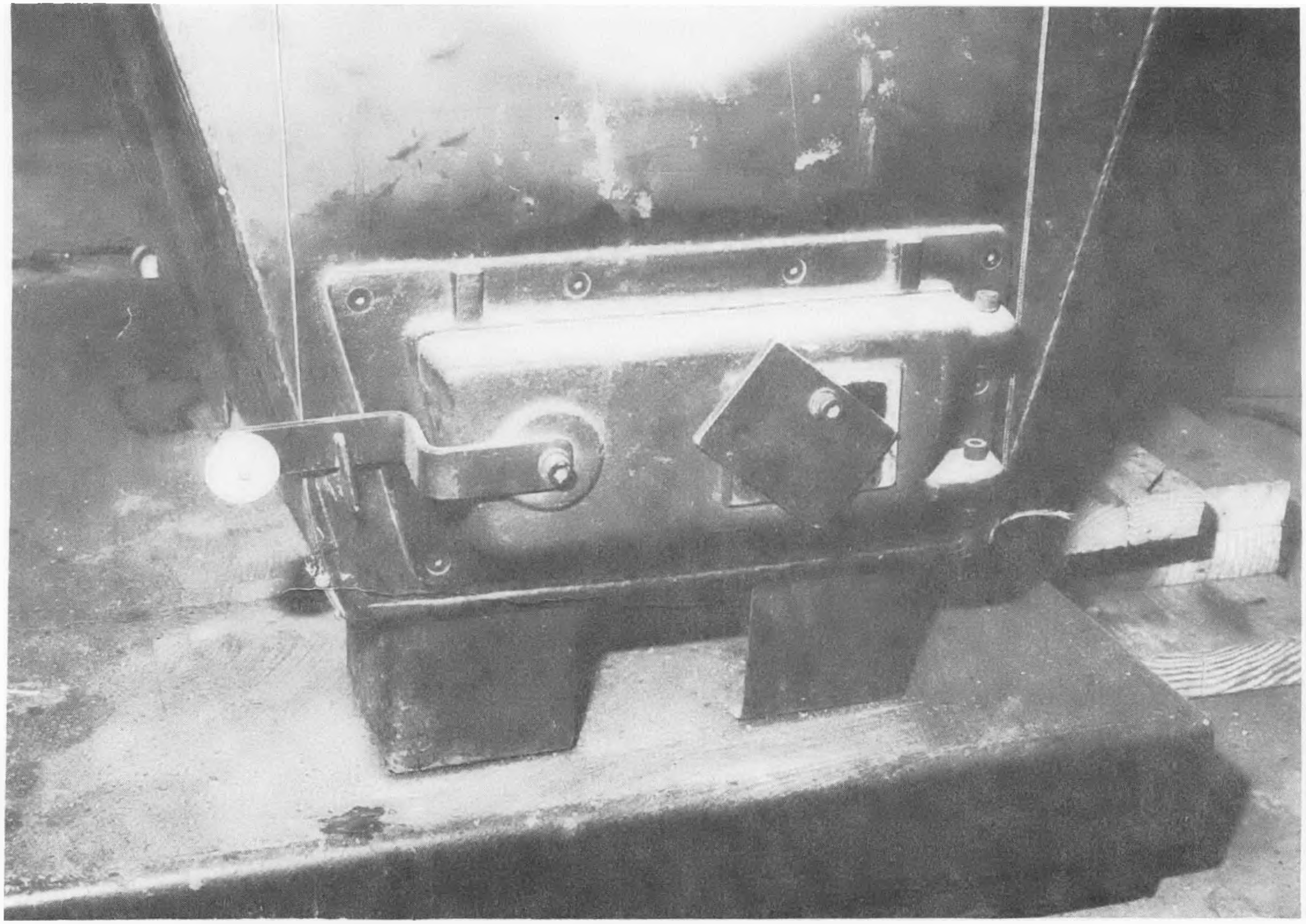


Figure 8. 1/4 Open Damper Setting

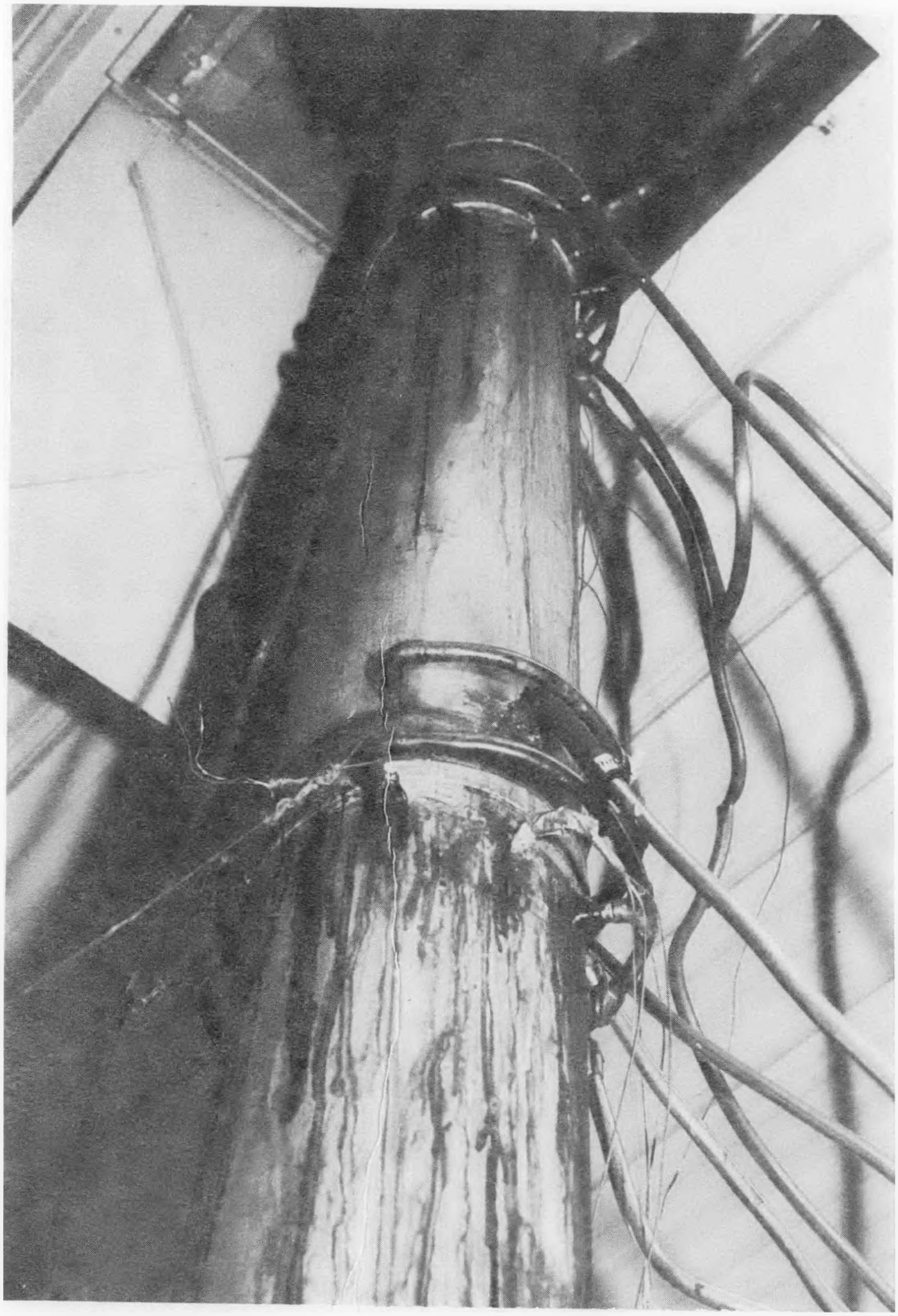


Figure 9. Connection of Test Sections

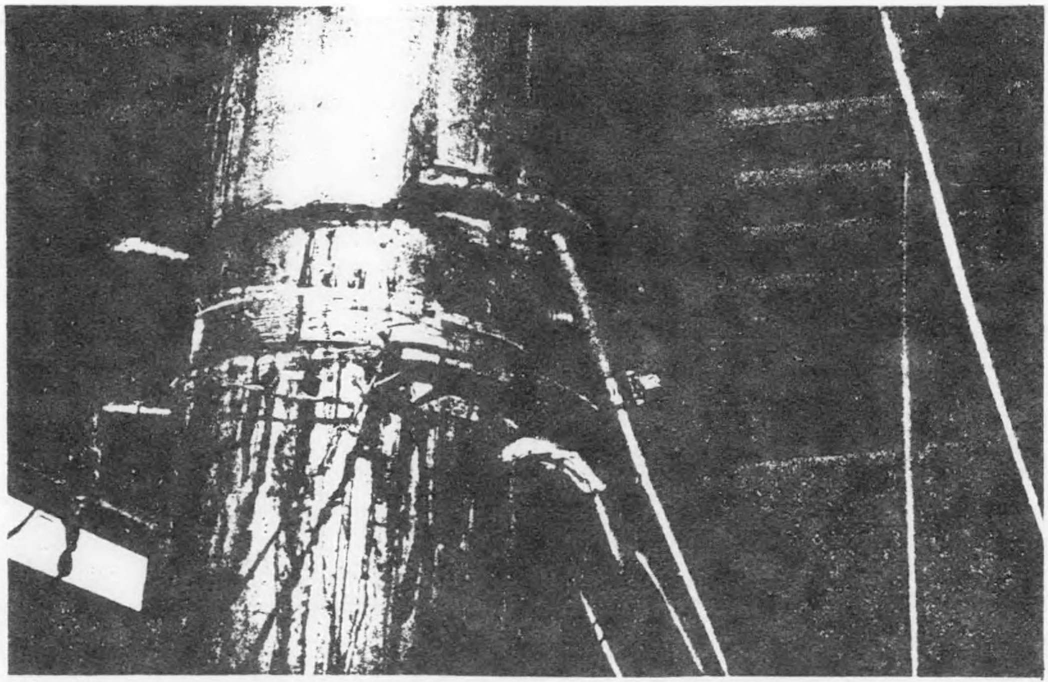


Figure 10. Collection Tube and Water Manifolds in Middle Section

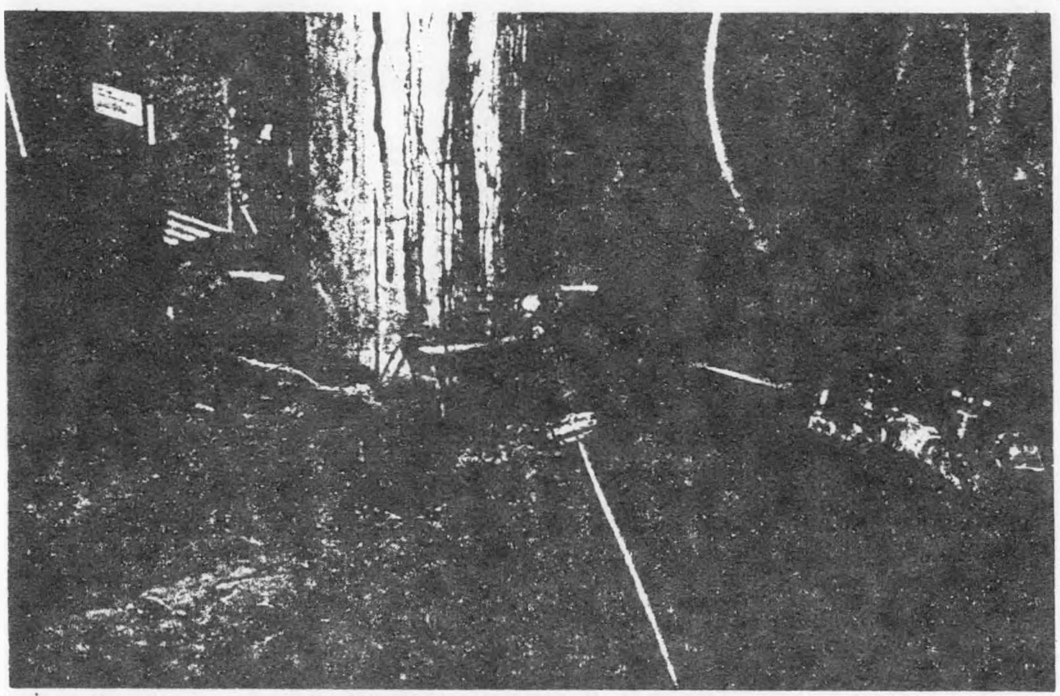


Figure 11. Collection Tube and Water Manifolds in Bottom Section

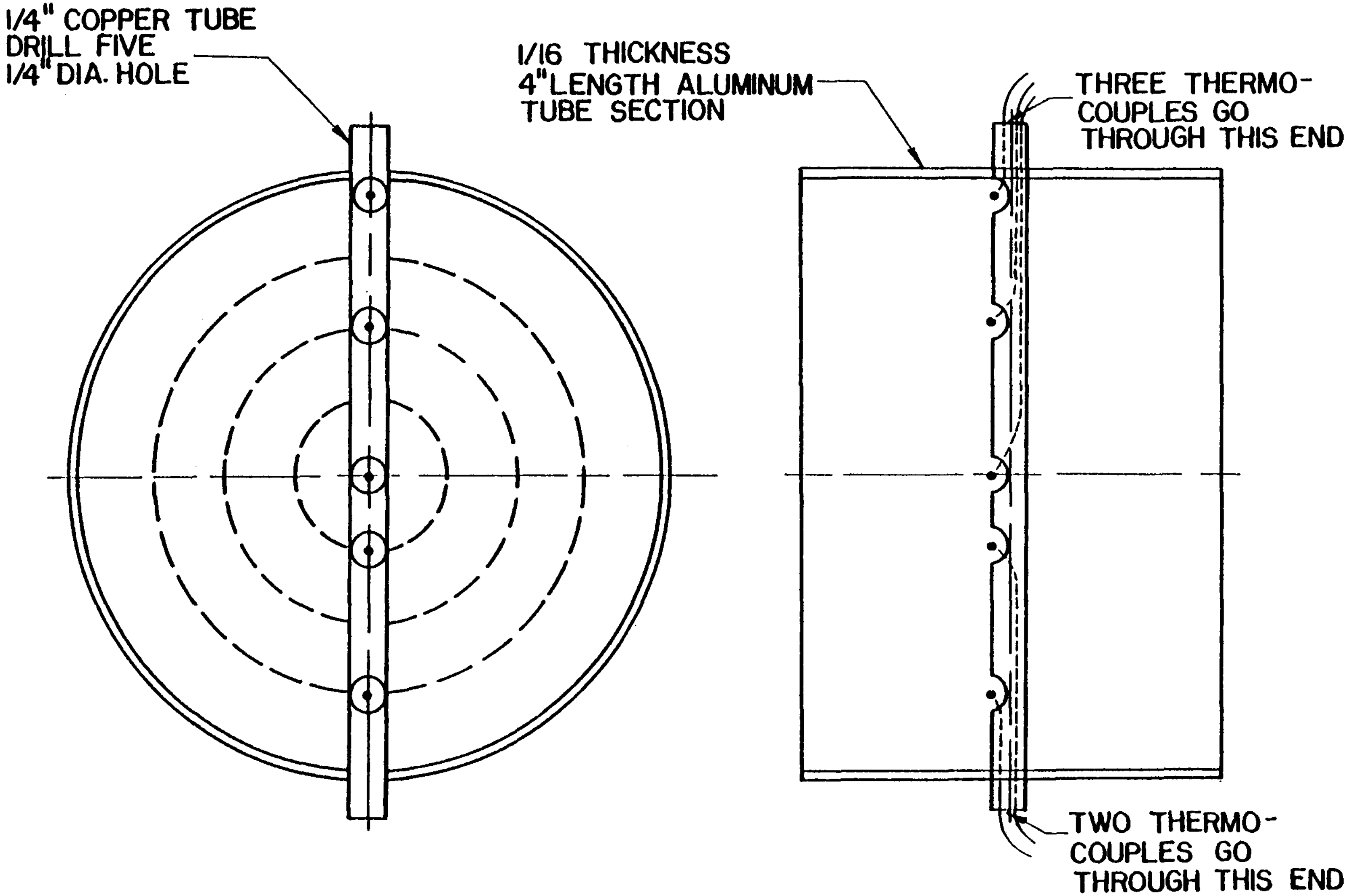



Figure 12. Design of Temperature Measurement at Stove Exit

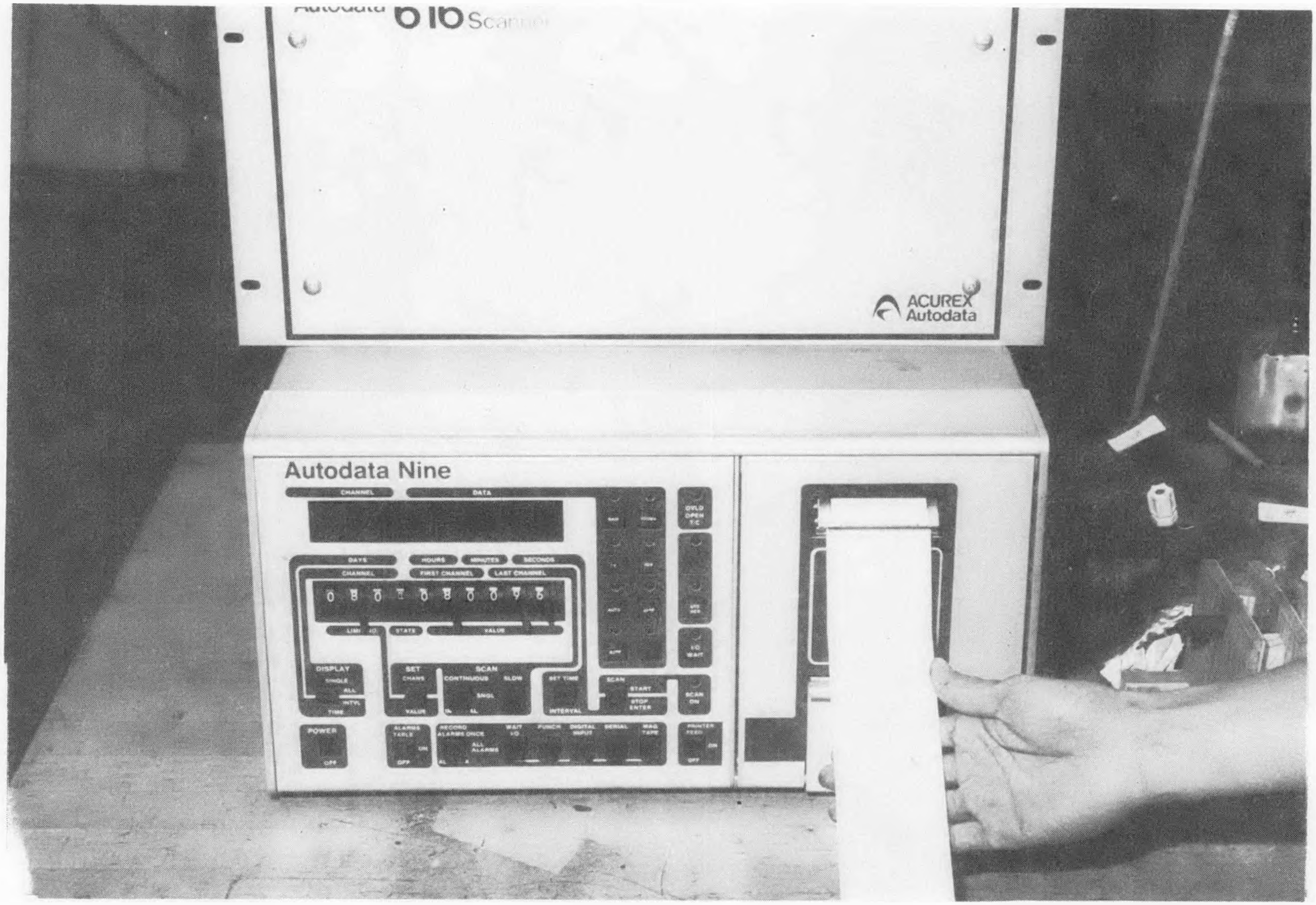



Figure 13. Automatic Data Aquisition System

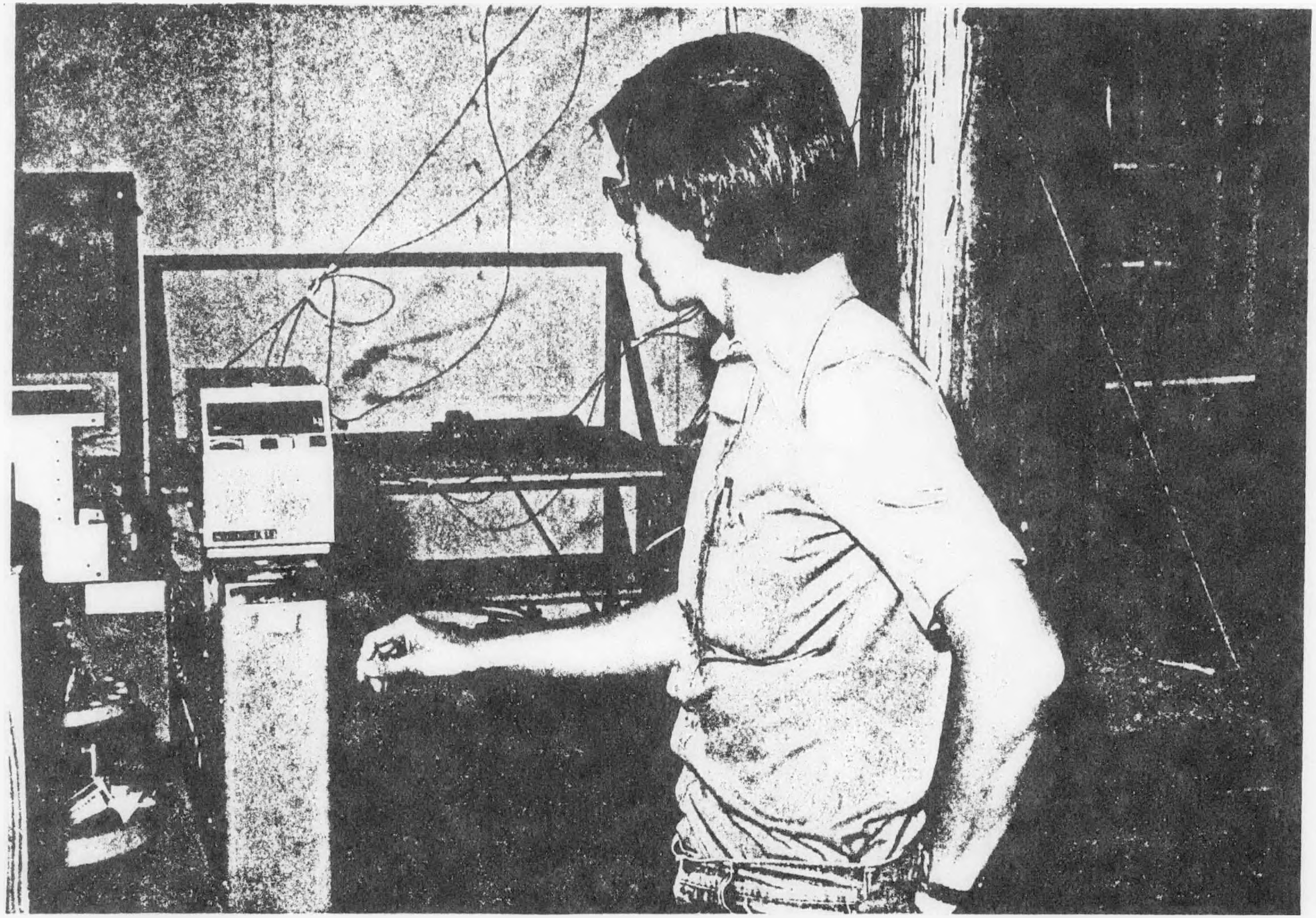


Figure 14.  Digital Balance

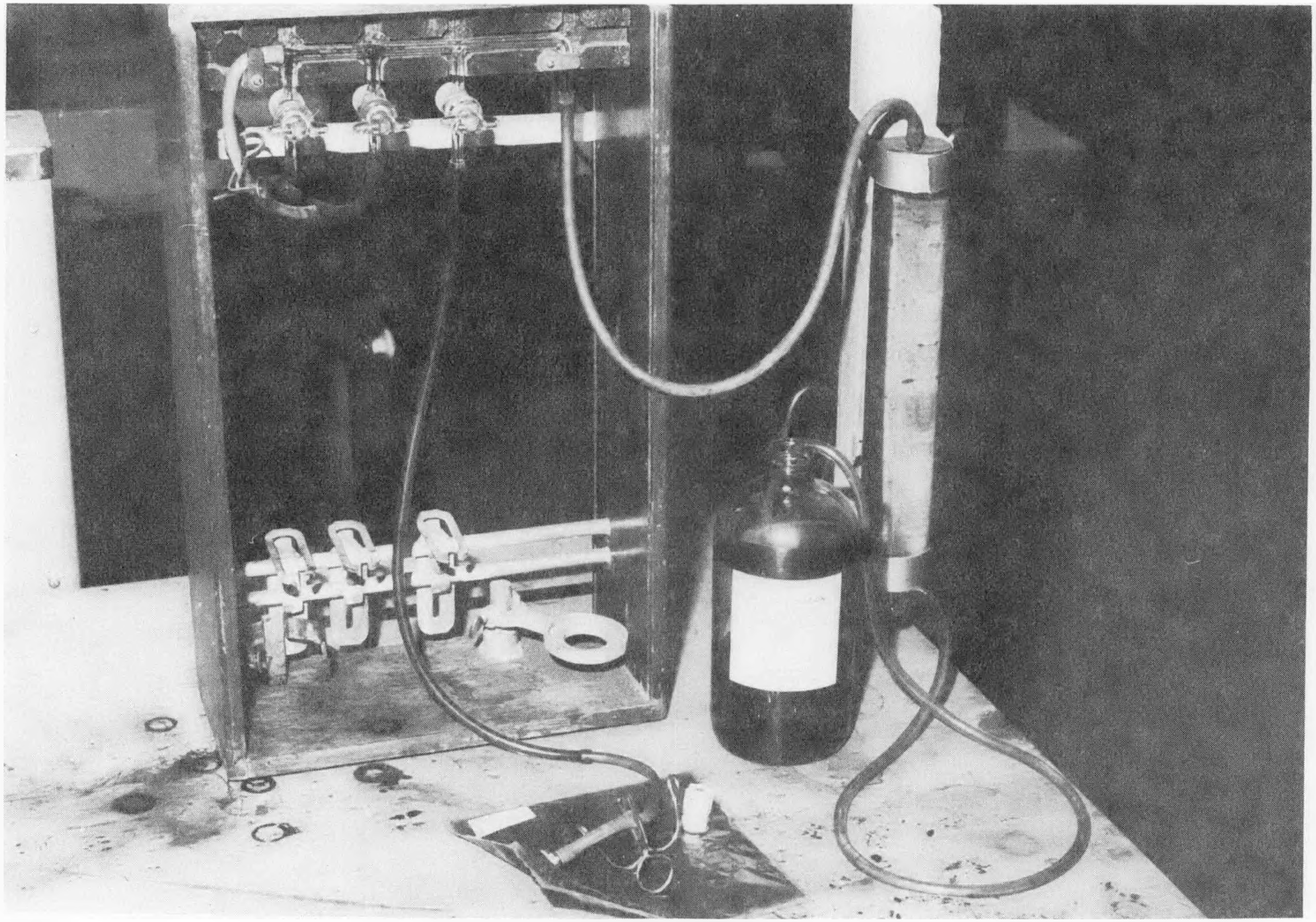


Figure 15. Hydraulic Gas Sample Collector

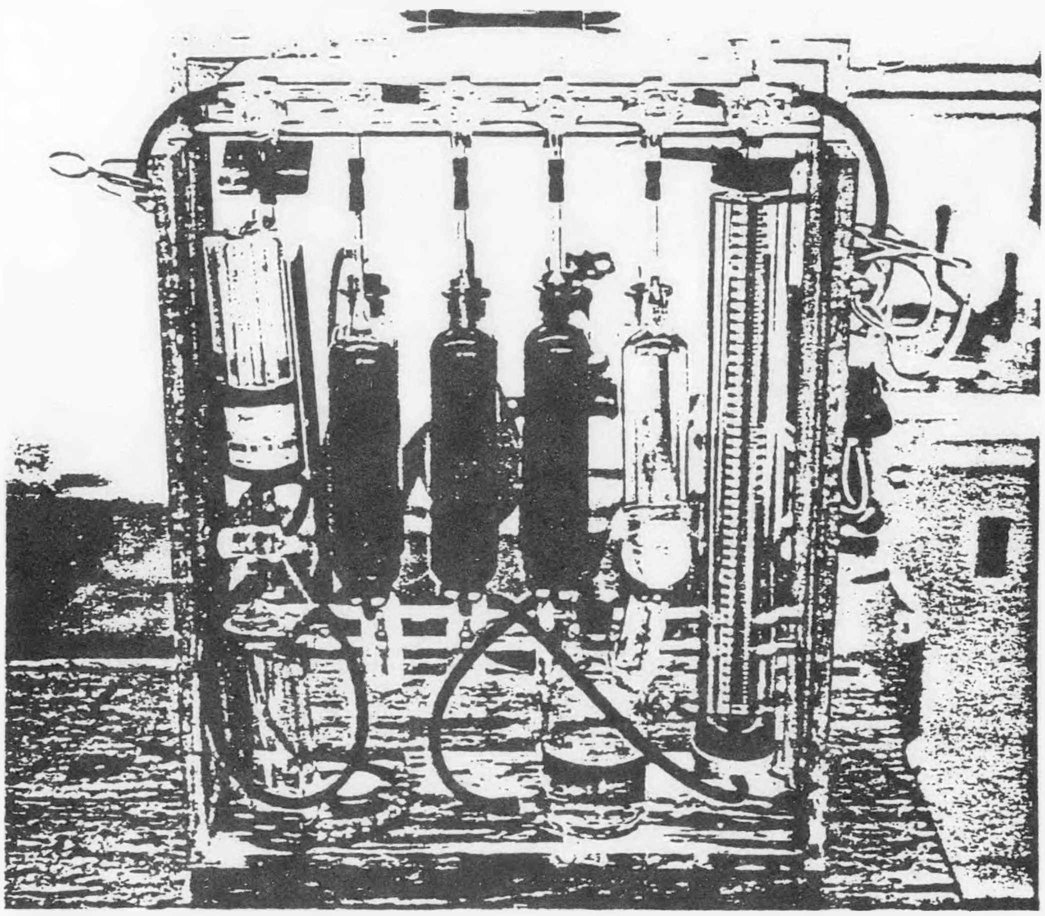


FIGURE 16. Orsat Gas Analyzer

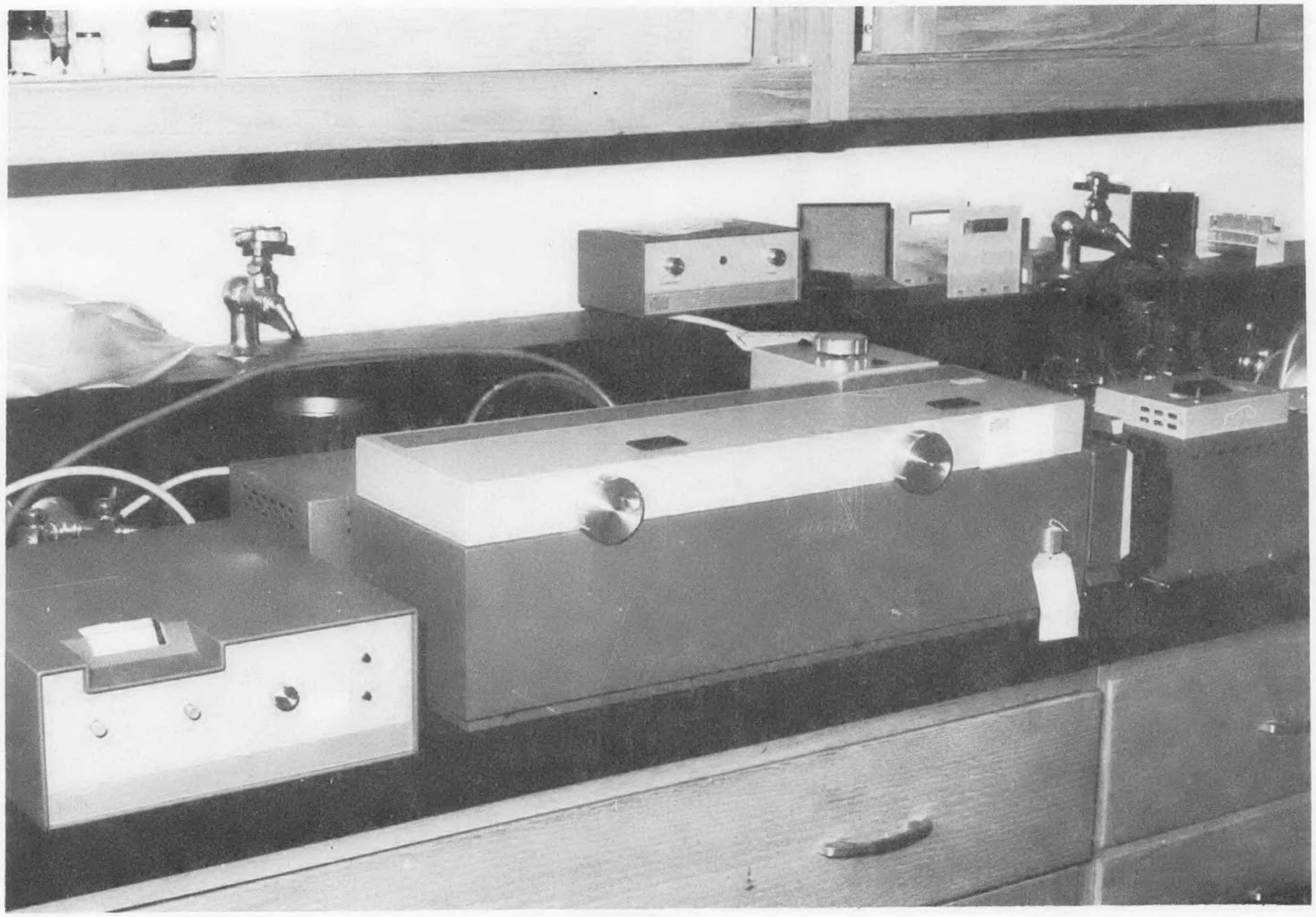


Figure 17. Spectrophotometer

which was provided by the Chemistry Department. The spectrophotometer was used to determine the concentrations of the creosote-water mixture collected during the tests. A description of equipment used in this study is shown in Appendix D.

Tests were performed with yellow pine, oak and hickory. Each wood was tested at two different moisture contents and with three different geometries. Figure 18a shows the standard configuration brand used in the test. It was made of 3/4 inch by 3/4 inch strips located on one inch centers. A type B brand is shown in Figure 18b. These brands were made of 3/4 inch by 1 3/4 inch strips located on 2 1/4 inch centers. Figure 18c shows the split logs. Each split log had an average surface area of about 280 square inches.

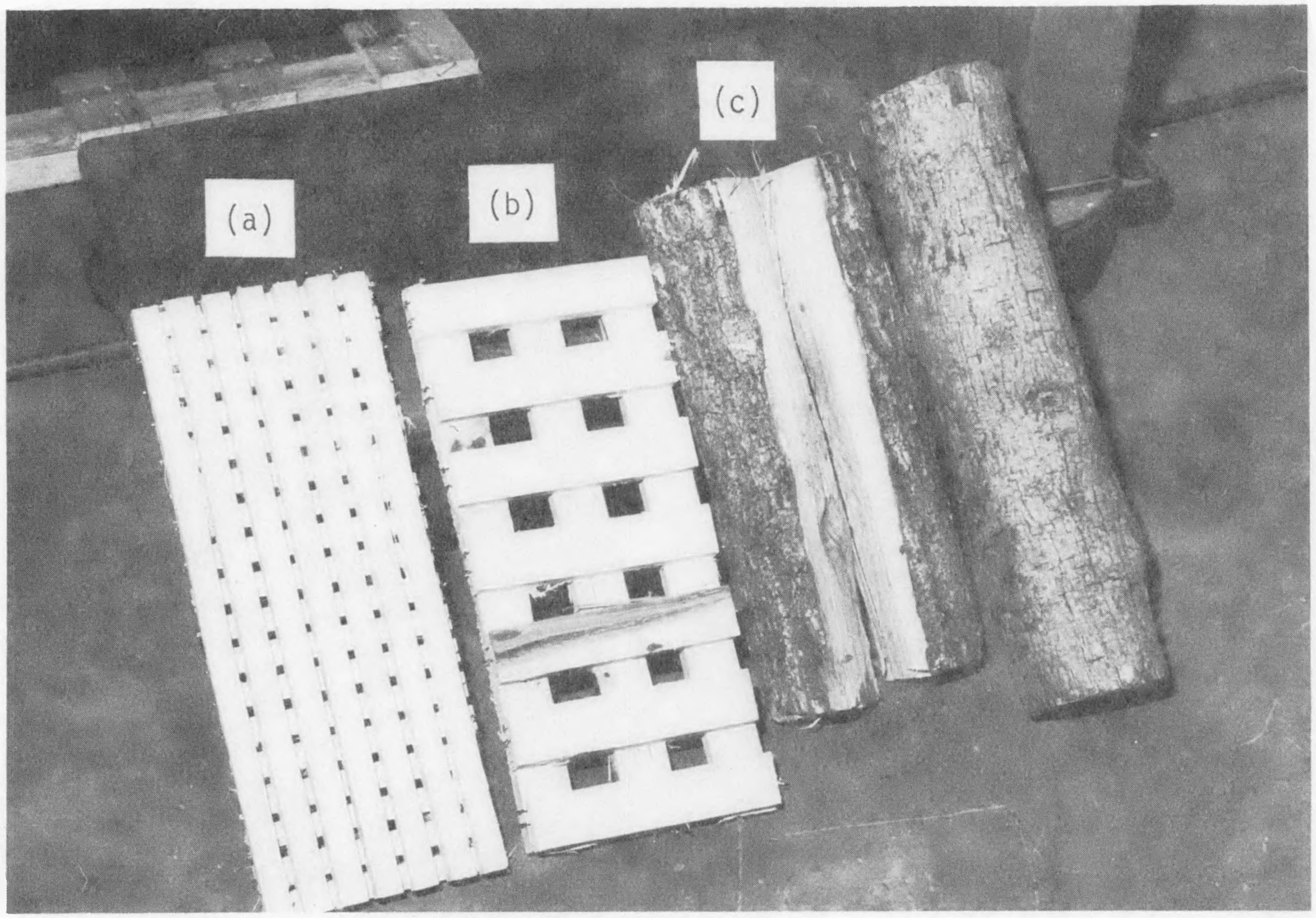



Figure 18. (a) Standard Brand, (b) Brand B, (c) Logs

## III. EXPERIMENTAL PROCEDURE

The first task was to prepare the wood of desired species, geometry and moisture content for the testing program. Nine test runs were performed with oven dry wood. The brands and logs were placed in an oven and maintained at 212$^{o}$F for about 72 to 168 hours (longer times may be needed for the larger pieces of wood). The exact time in the oven was determined when no measurable weight change was detected. The moisture contents of the fuels for the remaining nine test runs were determined by oven drying a known weight of sample from the fuel and reweighing the sample after drying.

The procedure used to conduct test runs is outlined below:

(1) Connect water/steam pipes to chimney. Check water and steam control valves.

(2) Set Auto Data (temperature readouts equipment),Orsat gas analyzer and gas sample collector, ready for testing.

(3) Fire stove to build up bed of charcoals. This generally required a half hour of operating time to bring the system to an equilibrium state.

(4) Set air inlet to desired position.

(5) Open and adjust water valves to obtain the same flow rates in the three sections of the chimney.

(6) Read initial weight of stove and load fuel charge.

(7) Begin data collection. Temperature data and weight readings were recorded on five minute intervals on all readouts. Orsat data of flue gases was taken ever ten minutes.

(8) When the wood was consumed, the test was considered complete.

(9) Close water valves. Open steam valves to reheat dry creosote left in test section.

(10) Close steam valves after twenty minutes of reheating.

(11) Measure volumes of creosote-water mixture collected from each chimney section.

(12) Stir mixtures and take samples for spectrophotometer analysis.

(13) Pour out the mixture, measure the amounts of heavy creosote deposited on the bottom of the beakers.

This procedure yielded the efficiency data and was used to collect the creosote-water solutions condensed on the chimney wall during the test. The efficiency data was processed by the standard procedure described in earlier Quarterly Reports. The final results (relative amount of creosote) were obtained by using a spectrophotometer to analyze the relative concentration of each creosote sample. The procedure of this analysis is shown in Appendix A.

## IV. DATA COLLECTION AND ANALYSIS

The three types of wood used in the testing program were yellow pine, oak and hickory. Yellow pine is a softwood with a relative density of about 29 pounds per cubic foot (dry basis), and hickory are hardwoods with relative densities of about 41 and 44 pounds per cubic foot (dry basis), respectively. The standard brand had a surface area of approximately 610 square inches, brand B had a surface area of 414 square inches, and the split log had an average surface area of about 280 square inches. The moisture contents of the fuels used in the eighteen test runs are shown in Table 2.

The efficiency of the unit is defined as the percent of the energy released from the wood that is used to heat the room. The measurements needed to determine the efficiency are the flue gas temperature, the flue gas composition and the fuel consumed. A shielded thermocouple and an automatic data acquisition system were used to measure the flue gas temperature. Weight readings were taken manually as needed. An Orsat gas analyzer was used to obtain the percent $CO_2$, $O_2$ and CO in the gas leaving the unit. By applying mass and energy balances using the data taken as described above, the efficiency of the unit (both instantaneous and average) was computed.

TABLE 2. Moisture Contents of Test Woods

| No. | Wood Kind | Geometry | Moisture Content(%) |
|---|---|---|---|
| 1 | P | S | 0.0 |
| 2 | P | B | 0.0 |
| 3 | P | L | 0.0 |
| 4 | P | S | 8.3 |
| 5 | P | B | 8.3 |
| 6 | P | L | 42.0 |
| 7 | O | S | 0.0 |
| 8 | O | B | 0.0 |
| 9 | O | L | 0.0 |
| 10 | O | S | 28.0 |
| 11 | O | B | 28.0 |
| 12 | O | L | 26.0 |
| 13 | H | S | 0.0 |
| 14 | H | B | 0.0 |
| 15 | H | L | 0.0 |
| 16 | H | S | 27.0 |
| 17 | H | B | 27.0 |
| 18 | H | L | 25.0 |

P: Yellow Pine S: Standard Brand

O: Oak B: Brand B

H: Hickory L: Log

The flue gas temperatures and cooling surface temperatures at various locations in the chimney were recorded automatically to aid in understanding the characteristics of the system during condensations of the creosote. The flue gas temperatures at various positions of the stove exit to the chimney are different. The temperature drops significantly at positions near the wall of the stove exit. Flue gas temperatures at the stove exit were measured every five minutes and an average temperature was calculated.

Finally, the relative concentrations of creosote mixtures were measured with a spectrophotometer. The Beer-Lambert Law [4] states that light absorption is proportional to the number of molecules of absorbing substance through which the light passes. Thus, if the absorbing substance is dissolved in transparent solvent (e.g., water), the absorption of the solution is proportional to its molar concentration. Hence a formula $A = Ecl$ states the absorption of a given compound at constant conditions is related to the unique extinction coefficient, E, of the compound, the concentration of the compound, c, and the length of the light path, l. The mixture samples were diluted in water at nine times the volume of a sample. The optical densities (i.e., absorption) of the dilute samples of eighteen test runs were then analyzed by a selected wavelength of 450 nm. To quantitize the relative amounts of creosote formed, a Creosote Number is defined below.

$$\text{Creosote Number} = \frac{(\text{Relative Optical Density})\ (\text{Volume of Mixture})}{(\text{lbm of Wood Consumed})}$$

Table 3 shows the results of the spectrophotometer analysis. The Creosote Number gives a relative comparison of the amount of creosote formed. The Creosote Number increases with the amount of creosote formed.

Table 3. Results of Spectrophotometer Analysis

| Test No. | Fuel | Volume of Mixture (ml) 1-sec | 2-sec | 3-sec | Optical Density (450nm) 1-sec | 2-sec | 3-sec | Wood Consumed (lbm) | Creosote Number |
|---|---|---|---|---|---|---|---|---|---|
| 1 | WP S | 1500 | 700 | 225 | 0.579 | 0.425 | 0.432 | 16.2 | 73 |
| 2 | WP B | 1400 | 800 | 500 | 0.524 | 0.374 | 0.394 | 14.1 | 37 |
| 3 | DP B | 1160 | 560 | 300 | 0.707 | 0.520 | 0.467 | 13.2 | 95 |
| 4 | DP S | 1240 | 655 | 380 | 0.406 | 0.515. | 0.442 | 13.0 | 73 |
| 5 | DP L | 1790 | 1000 | 625 | 0.128 | 0.084 | 0.088 | 17.7 | 21 |
| 6 | WO S | 3810 | 1875 | 1065 | 0.133 | 0.108 | 0.100 | 25.6 | 33 |
| 7 | WO B | 3940 | 1440 | 810 | 0.081 | 0.101 | 0.100 | 21.3 | 25 |
| 8 | WH B | 4600 | 1530 | 900 | 0.083 | 0.147 | 0.084 | 20.2 | 34 |
| 9 | WH S | 4220 | 1630 | 980 | 0.087 | 0.103 | 0.117 | 22.3 | 29 |
| 10 | DO S | 3340 | 1280 | 690 | 0.251 | 0.224 | 0.152 | 15.7 | 73 |
| 11 | DH S | 2160 | 930 | 510 | 0.590 | 0.378 | 0.454 | 13.3 | 102 |
| 12 | DO B | 2000 | 970 | 625 | 0.312 | 0.368 | 0.356 | 12.1 | 99 |
| 13 | DH B | 2100 | 990 | 590 | 0.453 | 0.515 | 0.450 | 12.2 | 142 |
| 14 | WP L | 4300 | 2230 | 2780 | 0.012 | 0.002 | 0.040 | 17.0 | 10 |
| 15 | WH L | 4530 | 2190 | 2250 | 0.044 | 0.228 | 0.050 | 15.8 | 51 |
| 16 | WO L | 4600 | 2470 | 2125 | 0.027 | 0.033 | 0.004 | 14.4 | 14 |
| 17 | DH L | 2600 | 2500 | 1380 | 0.208 | 0.195 | 0.243 | 8.3 | 154 |
| 18 | DO L | 3010 | 1490 | 1250 | 0.213 | 0.438 | 0.344 | 11.7 | 147 |

## V. DISCUSSION OF RESULTS

The results of the experiments are presented in two separate groups. The first group shows the test results graphically so as to compare effects of variations in the parameters of moisture content of wood, type of wood, and geometry of wood. The summary of test data is shown in Tables 4 and 5 and a discussion of each individual test is given for the second group (see Appendix C).

First, the three parameters that were chosen in the eighteen experimental tests are discussed below.

### a. Effect of Moisture Content of Wood

According to the results of the tests, dry wood produced more creosote than wet wood under the same test conditions (see Figure 19). There are two main reasons to explain this phenomena:

(1) The water vapor dilution effect. The first effect of heating during a test is to drive out moisture present in the wood. This endothermic process consumes energy to evaporate the water (latent heat of water is 1050 BTU/lbm at 77$^{o}$F, plus about 100 BTU/lbm of heat to break the hygroscopic bond between water and wood). Additional water, carbon monoxide, carbon dioxide, hydrogen, formic acid, acetic acid, ethylene, benzol, and other volatile matters are distilled out of the wood at temperatures below 540$^{o}$F [5]. This reaction also absorbs heat. Above

## Table 4. Summary of Test Data (1)

| No. Fuel | Moist. Cont. | HHV (BTU/LB) | Eff. | Test Time (Min) | Cooling Water Temp (F) | Average Heat Released (BTU/HR) | Average Heat Output (BTU/HR) | Damper Setting (Position) | Ambient Temp (F) | Fuel Consume (LB) | Average Flue Gas Temp (F) Leaving Chimney | Creosote Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 W P S | 8.3% | -8058.9 | 55.0% | 130 | 61 | 52415.3 | 23950.4 | 1 | 69 | 16.2 | 101 | 78 |
| 2 W P B | 8.3% | -8038.9 | 55.2% | 98 | 57 | 69823.2 | 38540.0 | 1 | 70 | 14.1 | 112 | 87 |
| 3 D P S | 0.0% | -8821.0 | 43.0% | 90 | 59 | 77524.7 | 33411.0 | 1 | 75 | 13.2 | 117 | 95 |
| 4 D P S | 0.0% | -8821.0 | 38.3% | 95 | 59 | 72425.0 | 27751.3 | 1 | 66 | 13.0 | 120 | 73 |
| 5 D P L | 0.0% | -8821.0 | 58.7% | 190 | 60 | 52043.9 | 30553.3 | 2 | 33 | 17.7 | 123 | 21 |
| 6 W O S | 28.0% | -6351.1 | 44.9% | 215 | 61 | 45373.5 | 20365.9 | 1 | 71 | 25.6 | 105 | 33 |
| 7 W O B | 28.0% | -6351.1 | 39.7% | 180 | 61 | 45092.9 | 17909.1 | 1 | 79 | 21.3 | 93 | 25 |
| 8 W H B | 27.0% | -6439.3 | 42.7% | 205 | 61 | 38070.6 | 16244.0 | 1 | 79 | 20.2 | 107 | 34 |
| 9 W H S | 27.0% | -6439.3 | 41.3% | 190 | 62 | 45346.4 | 18724.3 | 1 | 77 | 22.3 | 112 | 29 |
| 10 D O S | 0.0% | -8821.0 | 43.0% | 195 | 63 | 42512.2 | 18329.5 | 1 | 70 | 15.7 | 115 | 79 |
| 11 D H S | 0.0% | -8821.0 | 32.1% | 120 | 64 | 80712.1 | 25892.0 | 1 | 73 | 18.3 | 109 | 102 |
| 12 D O S | 0.0% | -8821.0 | 42.4% | 90 | 63 | 71156.1 | 30172.7 | 1 | 77 | 12.1 | 110 | 99 |
| 13 D H B | 0.0% | -8821.0 | 31.9% | 85 | 62 | 75964.4 | 24226.7 | 1 | 76 | 12.2 | 112 | 142 |
| 14 W P L | 42.0% | -5116.2 | 51.1% | 175 | 66 | 29820.0 | 15224.4 | 2 | 33 | 17.0 | 119 | [illegible] |
| 15 W H L | 25.0% | -6615.7 | 45.8% | 160 | 66 | 39198.3 | 17965.1 | 2 | 37 | 15.8 | 113 | 51 |
| 16 W O L | 25.0% | -6627.5 | 37.3% | 160 | 67 | 35248.7 | 13312.9 | 2 | 34 | 14.4 | 101 | 14 |
| 17 D H L | 0.0% | -8821.0 | 34.5% | 105 | 67 | 41836.7 | 14414.1 | 2 | 31 | 9.3 | 95 | 164 |
| 18 D O L | 0.0% | -8821.0 | 40.1% | 100 | 63 | 61923.4 | 24818.0 | 2 | 35 | 11.7 | 92 | 147 |

W: Wet
D: Dry

P: Pine
O: Oak
H: Hickory

S: Standard Brand
B: Brand B
L: Log

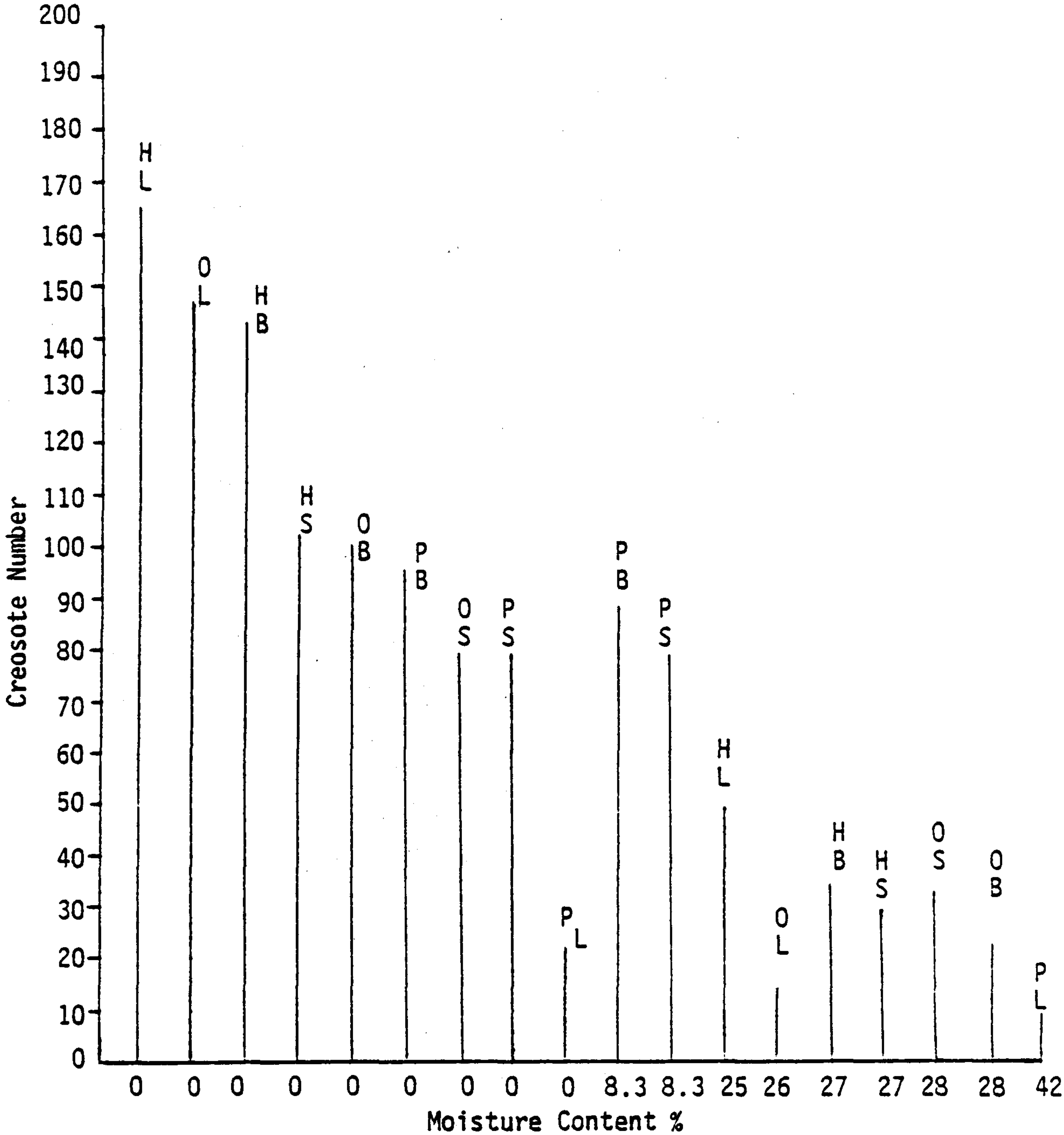
Table 5. Summary of Test Data (2)

| No. | Fuel | Moisture Content (%) | Amount of Pure Creosote |
|---|---|---|---|
| 1 | PS | 8.3 | 2 |
| 2 | PB | 8.3 | 2 |
| 3 | PB | 0.0 | 3 |
| 4 | PS | 0.0 | 3 |
| 5 | PL | 0.0 | 1 |
| 6 | OS | 28.0 | 0 |
| 7 | OB | 28.0 | 0 |
| 8 | HB | 27.0 | 0 |
| 9 | HS | 27.0 | 0 |
| 10 | OS | 0.0 | 3 |
| 11 | HS | 0.0 | 4 |
| 12 | OB | 0.0 | 4 |
| 13 | HB | 0.0 | 4 |
| 14 | PL | 42.0 | 0 |
| 15 | HL | 25.0 | 1 |
| 16 | OL | 26.0 | 0 |
| 17 | HL | 0.0 | 4 |
| 18 | OL | 0.0 | 4 |

H - Hickory
O - Oak
P - Pine

S - Standard Brand
B - Brand B
L - Log

*Amount of pure creosote is measured on a scale of 0-4. Zero signifies essentially no pure creosote. 4 signifies maximum amount of pure creosote.




H - Hickory
O - Oak
P - Pine

S - Standard Brand
B - Brand B
L - Log

FIGURE 19. Effect of Moisture Content of Wood

$540^{o}F$; the main pyrolysis and distillation of the volatile matters continues, with the evolution of some heat even if no additional air is supplied. Large amounts of gases, volatile matters and tar are generated. These include carbon monoxide, carbon dioxide, methane, methonal, water vapor, hydrogen, benzol, phenol, phlorylic acid, creosote and many other compounds. Due to incomplete combustion, a certain amount of these substances may escape from the combustion chamber and go up the chimney. By the time the temperature of the wood reaches about $900^{o}F$, pyrolysis is essentially complete and charcoal is left behind.

The water vapor formed during combustion together with the large amount of distilled water vapor driven from the wet wood reduces the partial pressure of the creosote constituents (dilution effect). Thus, the dew-point temperature of the creosote constituents is reduced. Figure 20 shows a simple explanation of this phenomenon [6]. Thus, creosote is harder to condense and deposit on the chimney wall.

In a normal wood fire, the inside of a piece of wood may not even be dry while the outside is charred and burning. The water dilution effect may occur at any time before all the wood becomes charcoal.

(2) The water-gas reaction. The volatile matters and water vapor generated in the inner portion of the wood must pass through the surface layers on their way out of the wood. It is possible that water vapor can react with charcoal when it passes through the external layers of wood to produce carbon monoxide and hydrogen gases. These additional combustible gases can result in a secondary combustion [7]. This

Dew Point (creosote): Temperature of the saturated creosote vapor at partial creosote pressure.

*Dew point temperature decreases with the reduction of partial creosote pressure.

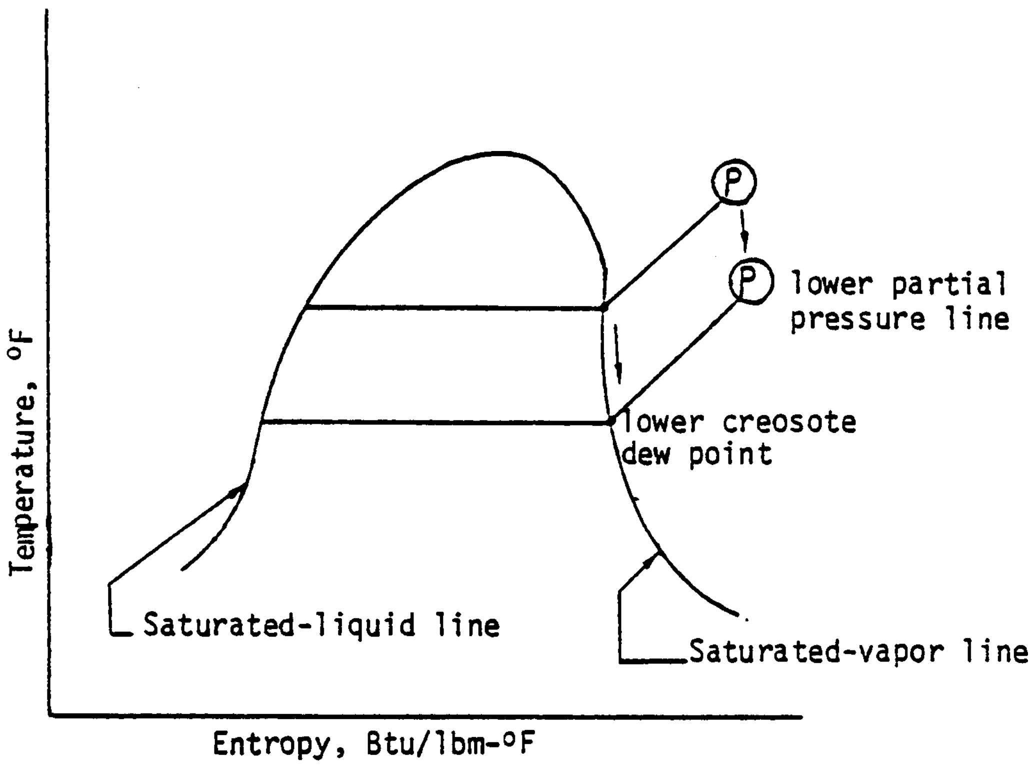



FIGURE 20. Lower Creosote Dew Point

reaction has little effect on the thermal efficiency, for when water reacts with charcoal, it consumes heat (endothermic) to produce gases. However, when these gases react with oxygen, they produce heat (exothermic) and also water and carbon dioxide. It is possible that this additional secondary combustion can aid in the break down and burning of the heavier volatile matters or creosote. This reaction also renders a more complete combustion of wood.

b. Effect of Geometry of Wood

Wood geometry is a factor that affects the amount of creosote formed. Three different wood geometries were used in the test program. The difference in amount of creosote formed in burning the wet wood is hard to discern because of the abundance of water the creosote-water solution. However, in burning dry wood, the amounts of creosote formed were different for the three geometries used in the test program. Figure 21 shows that split logs can generate more creosote than the brands under the same test conditions. Brand B generated more creosote than the standard brand. It was observed (see Appendix C for each dry wood test data) that an abundance of unburned gases or volatile matters were collected in the chimney during the first forty minutes of the test. The reason for this incomplete combustion is directly related to the burning rate, surface area and air supply. It has been shown that as the burning rate is decreased, the efficiency increases [8]. A conclusion is made that as either the surface area of the wood becomes larger or as the spacing between the wood pieces that make up the brands becomes more narrow, the efficiency of the woodburning stove improves under the

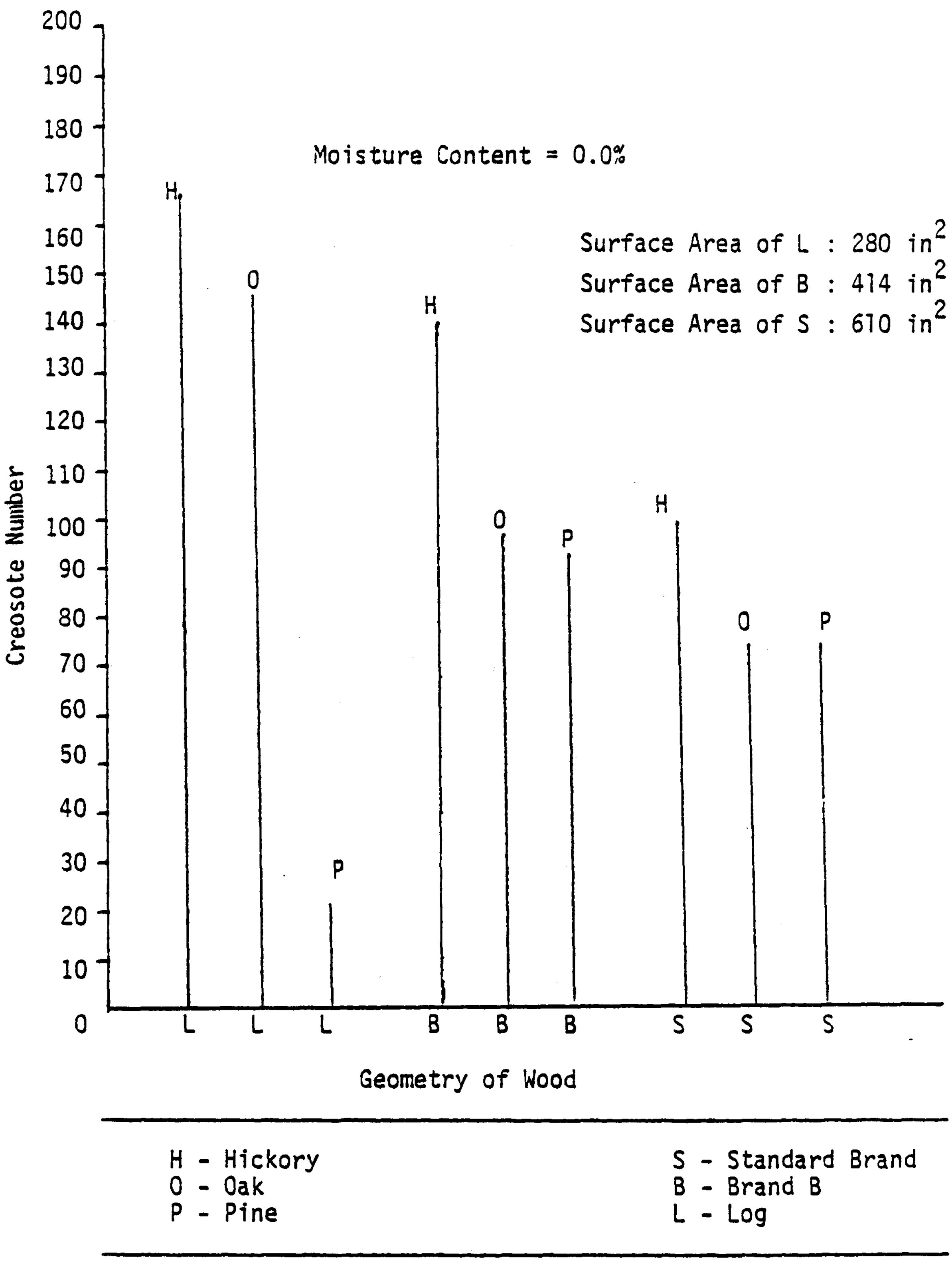


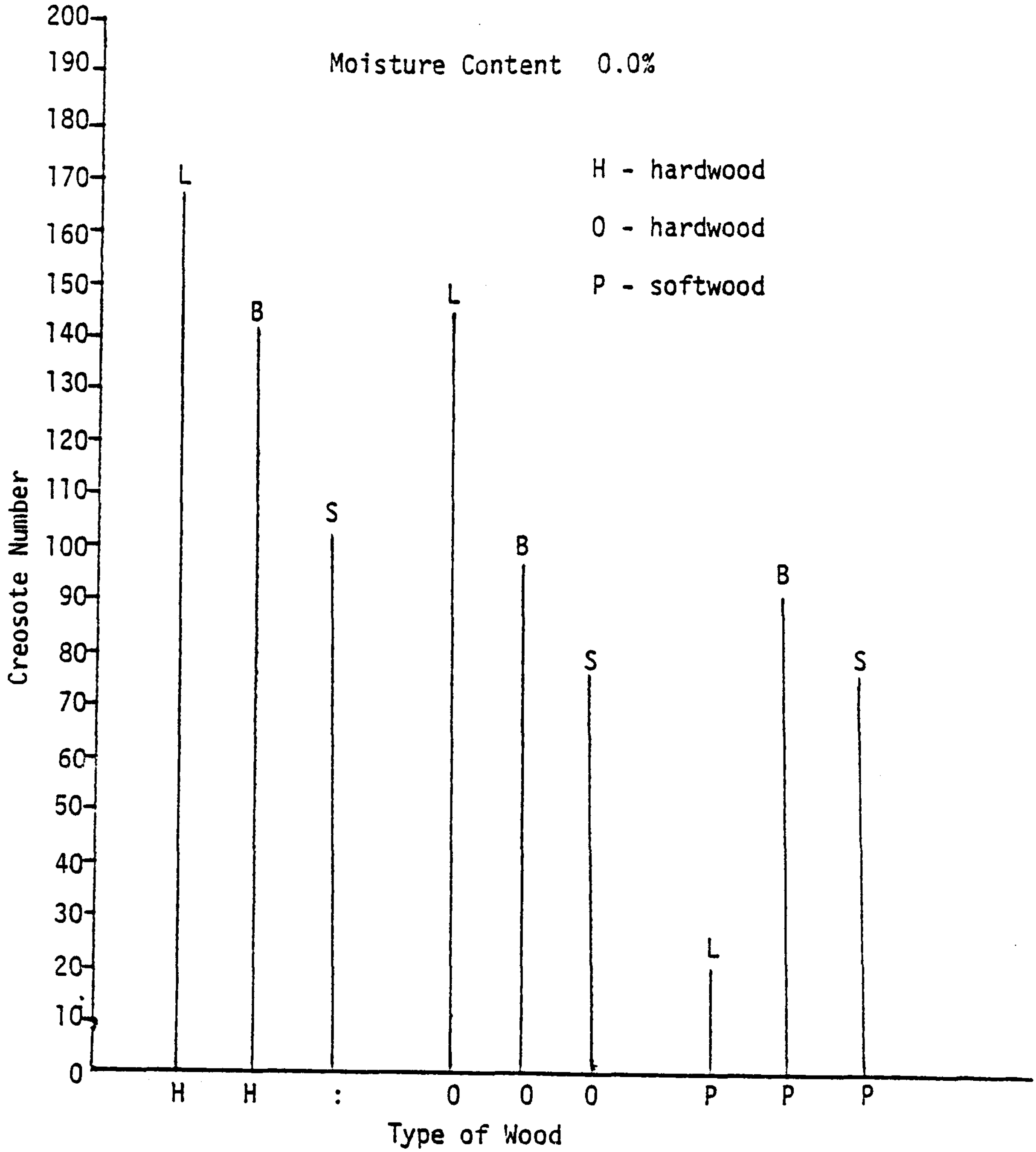

FIGURE 21. Effect of Geometry of Wood

conditions of these tests. Both the brand B and standard brand have a large surface area, (standard brand-610 $in^2$; brand B-414 $in^2$), also, the standard brand has a smaller spacing between the wood pieces. When small wood pieces are spaced close together, not enough oxygen can get in between the closely spaced pieces to burn the gases as fast as they are produced. Thus, a significant portion of the gases are burned well above the solid wood, such that the flame does not heat the wood as much as if the combustion process occurred between the wood pieces. The wood pyrolyzes or produces combustible gas at a rate which is dependent on the wood temperature.

In order to ignite the split logs (surface area: 280 $in^2$), a hot bed of coals and larger amount of air (air inlet position 2) were needed in the tests. These special conditions increased the burning rate and resulted in a high production of CO and combustibles during the early period of a test. Large amounts of unburned combustibles went up the flue and resulted in a low efficiency. A condensation of creosote occurred if the chimney wall temperatures dropped below about 300$^{o}$F. There was an exception in burning the dry pine logs due to slow the burning rate (see the individual test discussion, page 98 ).

c. Effect of Type of Wood

No wood type tested prevented the generation of creosote in a stove under certain conditions. Hardwood generates more creosote than the softwood (see Figure 22). Undoubtedly, different species of wood have slightly different compositions [7]. Hardwood have a larger relative density (specific gravity) than softwood. Hardwood can burn longer, but




H - Hickory

O - Oak

P - Pine

S - Standard Brand

B - Brand B

L - Log

FIGURE 22. Effect of Type of Wood

it also generate more creosote. Of the three kinds of wood that were used, hickory generated more creosote than oak; oak generated more creosote than yellow pine.

# VI. CONCLUSION AND RECOMMENDATION

Based on this study, the following conclusions are made:

1. Moisture content within the wood is the most important factor affecting the amount of creosote produced during the tests. Dry wood produced more creosote than wet wood under the same test conditions. This means that the water within the wood does help in eliminating the formation of creosote.
2. Wood geometry does affect the amount of creosote formed. In burning the dry brands the smaller the spacing between the wood pieces, or the larger the surface area of the wood, the more complete the combustion and the less the amount of creosote formed. Split logs produced more creosote than the brands. Geometry of wood has no obvious effect of the amount of creosote formed in burning the wet wood.
3. Type of wood has an affect on the formation of creosote. Hardwood can produce more creosote than softwood. It depends on the composition and the relative density of the wood. The higher the relative density of the wood the more the amount of creosote constituents within the wood. Hardwood produces more creosote than softwood.

4. It was observed from this study that small sized semi-seasoned (25 - 35% moisture content) softwoods have a reputation of producing the least amount of creosote.

For purposes of further study, the following recommendations are present:

1. As mentioned in the Introduction, fourteen parameters can affect creosote formation. Among them, the chimney wall temperature, firing rate, air inlet setting, combustion temperature, type of stove and exhaust gas flow rate are recommended to be the parameters that affect creosote formation for further study by using the same test facilities.
2. Further studies of the characteristics of creosote will help to determine ways to prevent the creosote formation on chimneys.
3. More accurate data collection or new method to collect creosote deposits on the chimney is needed to determine the amount of pure creosote formed in the different test conditions.
4. A gas sampling system which can provide accurate samples near the stove exit, and a gas chromatography technique which can directly measure the compositions of volatile matters which are generated from the wood, are needed for the future study.

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## APPENDIX A

## OPERATION PROCEDURE OF MEASURING THE CONCENTRATION BY SPECTROPHOTOMETER

First, turn on the photometer and allow it to warm up for thirty minutes while its internal electronic components heat up to uniform levels of stable output. While the instrument is warming up, select and thoroughly clean several sample tubes or cuvettes, and then fill one tube (a blank) with $H_2O$ and fill the other tubes with a colored solution (e.g., dilute creosote solution). Next, select some suitable wavelength in the visual range (e.g., 450 nm) and with no cuvette in the system and no light passage through the instrument, adjust the instrument to 0% transmission (infinite absorbance, i.e., the limit value just above absorbance = 2.0). This adjustment control is frequently called the "dark current" control. Then place the blank in the instrument and with light passage through the blank, adjust the other controls (i.e., not the dark current control) to obtain 100% transmission and 0 absorbance. This adjustment is made by either a single slit control, or a single sensitivity control, or both, depending upon the make and model of photometer or spectrophotometer. These adjustments define the limits of the photometry range at 450 nm. Finally, confirm the uniformity of all of the sample tubes or cuvettes at 450 nm by testing to see that tubes containing to colored solution yield nearly identical absorbance values. [10]

APPENDIX B

Description of Equipment

| TYPE | MODEL | MANUFACTURER | RANGE | ACCURACY |
|---|---|---|---|---|
| Automatic Data Logger | A900 | Auto Data | -328 - 2472°F | ±1°F |
| Scanner | 616 | Auto Data | 100 channels | |
| Digital Scales | K12 | Sauter | 0-1200kg | ±0.1kg |
| Orsat Gas Analyzer | 39-246 | Burrell Corporation | $CO_2$,$O_2$,CO | ±1% |
| Boiler | Eclipse | Lookout Co. | 20Hp, 125psi: W.P. | |
| Spectrophotometer | 250 | GIL | 185-800nm | ±0.001A |
| Balance | P-1000 | Mettler | 0-1300 gm | ±0.1 gm |

# APPENDIX C

## DISCUSSION OF EACH INDIVIDUAL TEST

WOOD BURNING TEST RESULTS

TEST NUMBER : A-02/28/79

DATE OF TEST : FEB. 28,1979

AMBIENT TEMPERATURE : 69 DEG F

DAMPER SETTING :
POSITION 1

FUEL : WET #2 YLW. PINE STANDARD BRAND,6

MOISTURE CONTENT 8.3 % HHV= -8088.9

| TIME | | LBS WOOD | FLUE GAS TEMP (F) | %CO2 | %O2 | %CO | %COM | %EFF | A/F RATIO | THEO AIR | HEAT RISE BTU/HR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 17.2 | 285.0 | | | | | | | | 0. |
| 5 | 0 | 14.3 | 206.0 | | | | | | | | 291492. |
| 10 | 0 | 13.6 | 148.0 | 9.2 | 10.8 | 2.6 | 2.8 | 48.8 | 7.07 | 5.66 | 67946. |
| 15 | 0 | 12.3 | 136.0 | | | | | | | | 126186. |
| 20 | 0 | 11.4 | 126.0 | 10.1 | 9.1 | 3.9 | 3.1 | 48.4 | 5.97 | 5.66 | 87360. |
| 25 | 0 | 10.6 | 131.0 | | | | | | | | 77653. |
| 30 | 0 | 10.1 | 133.0 | 9.2 | 10.4 | 2.5 | 1.9 | 57.2 | 7.74 | 5.66 | 48533. |
| 35 | 0 | 9.7 | 136.0 | | | | | | | | 38827. |
| 40 | 0 | 9.5 | 141.0 | | | | | | | | 19413. |
| 45 | 0 | 8.8 | 147.0 | 8.6 | 11.2 | 1.9 | 1.4 | 61.5 | 8.95 | 5.66 | 67946. |
| 50 | 0 | 8.6 | 150.0 | | | | | | | | 19413. |
| 55 | 0 | 8.1 | 147.0 | | | | | | | | 48533. |
| 60 | 0 | 7.7 | 148.0 | 10.3 | 9.7 | 2.7 | 3.1 | 49.4 | 6.38 | 5.66 | 38827. |
| 65 | 0 | 7.5 | 143.0 | | | | | | | | 19413. |
| 70 | 0 | 6.8 | 145.0 | | | | | | | | 67946. |
| 75 | 0 | 6.6 | 148.0 | 9.6 | 10.2 | 2.6 | 2.4 | 52.6 | 7.09 | 5.66 | 19413. |
| 80 | 0 | 6.2 | 141.0 | | | | | | | | 38827. |
| 85 | 0 | 5.7 | 136.0 | | | | | | | | 48533. |
| 90 | 0 | 5.3 | 131.0 | 8.0 | 11.1 | 2.7 | 1.0 | 63.0 | 9.13 | 5.66 | 38826. |
| 95 | 0 | 4.6 | 123.0 | | | | | | | | 67946. |
| 100 | 0 | 4.4 | 129.0 | | | | | | | | 19413. |
| 105 | 0 | 3.5 | 145.0 | 10.0 | 9.6 | 2.3 | 1.7 | 60.5 | 7.53 | 5.66 | 87360. |
| 110 | 0 | 3.1 | 144.0 | | | | | | | | 38826. |
| 115 | 0 | 2.6 | 143.0 | | | | | | | | 48533. |
| 120 | 0 | 2.2 | 148.0 | 9.1 | 10.3 | 2.2 | 1.0 | 65.3 | 8.64 | 5.66 | 38827. |
| 125 | 0 | 1.8 | 147.0 | | | | | | | | 38826. |
| 130 | 0 | 1.7 | 147.0 | | | | | | | | 9707. |
| 135 | 0 | 1.6 | 147.0 | 8.1 | 11.3 | 2.4 | 1.2 | 61.2 | 9.11 | 5.66 | 9707. |
| 140 | 0 | 1.3 | 152.0 | | | | | | | | 29120. |
| 145 | 0 | 1.1 | 151.0 | | | | | | | | 19413. |
| 150 | 0 | 1.0 | 150.0 | 8.2 | 10.9 | 2.2 | 0.3 | 72.0 | 10.08 | 5.66 | 9707. |

REMARKS

AVERAGE HEAT RELEASED: 52415.8 BTU/HR

AVERAGE HEAT OUTPUT : 28850.4 BTU/HR

AVERAGE EFFICIENCY : 55.0 %

COOLING WATER TEMP= 51 F TEST BY JOE JUGER

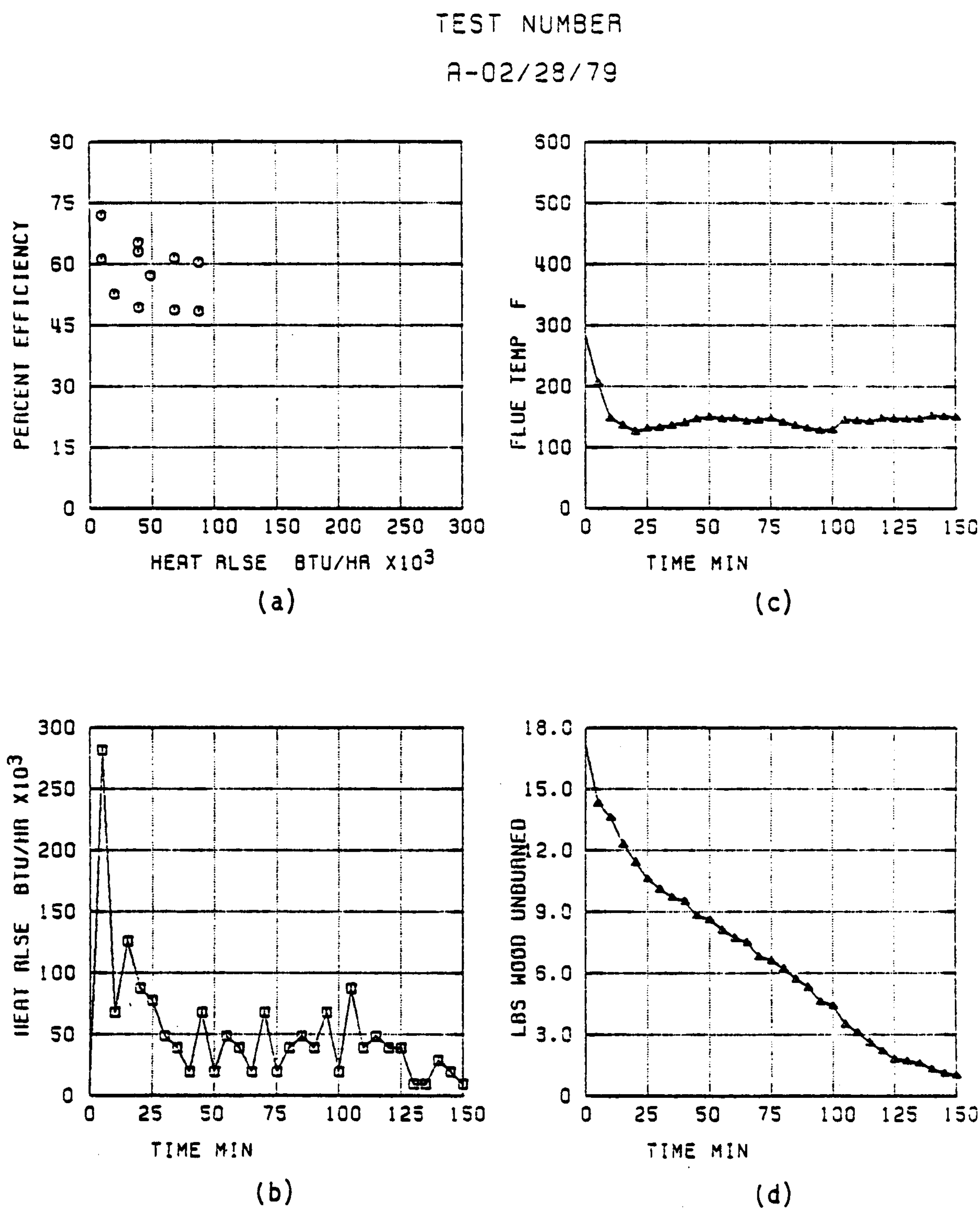



Figure 23. Test Data of Wet Pine Standard Brand

TEST NUMBER

A-02/28/79

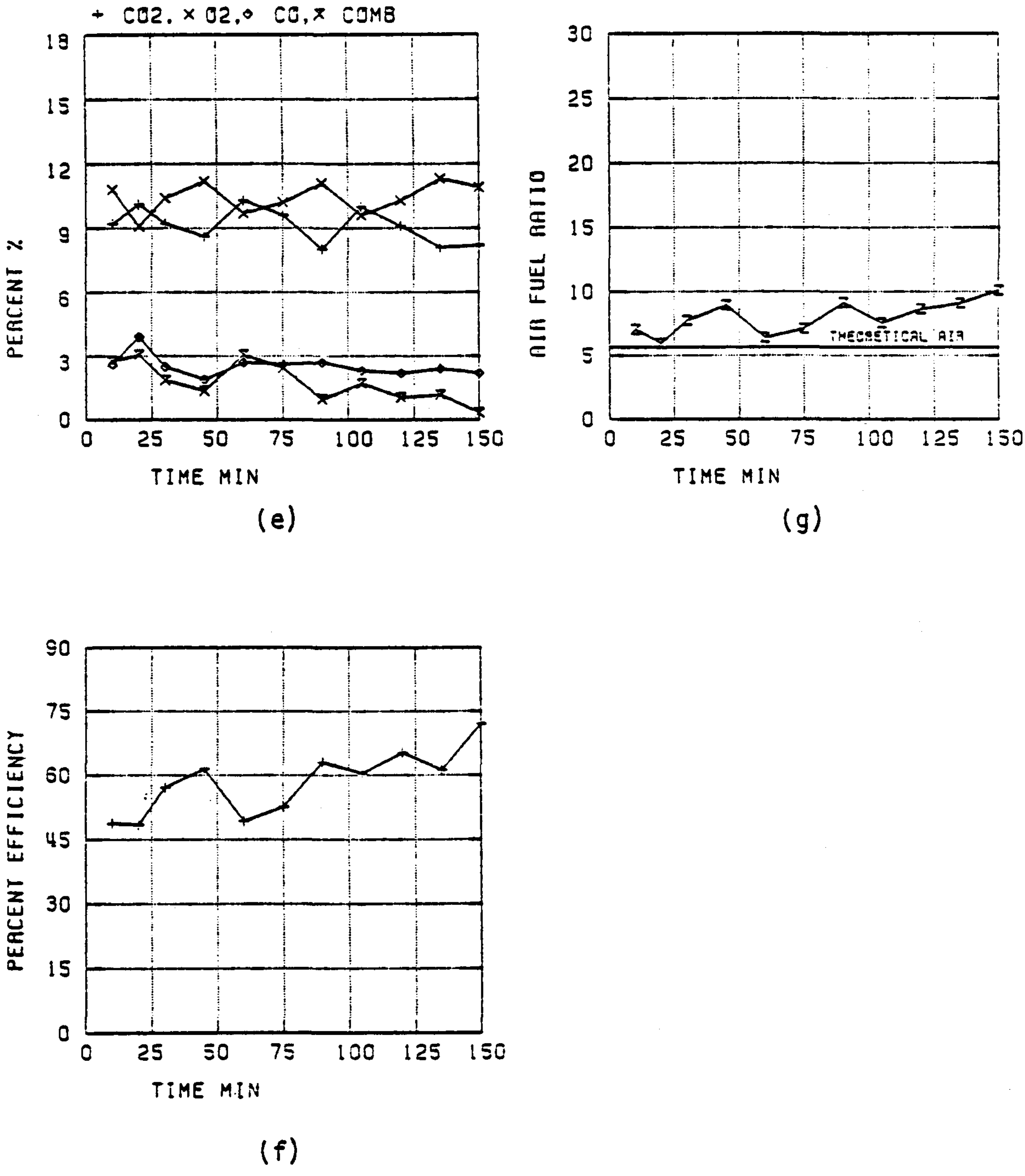



Figure 23. Continued

TEST NUMBER

A-02/28/79

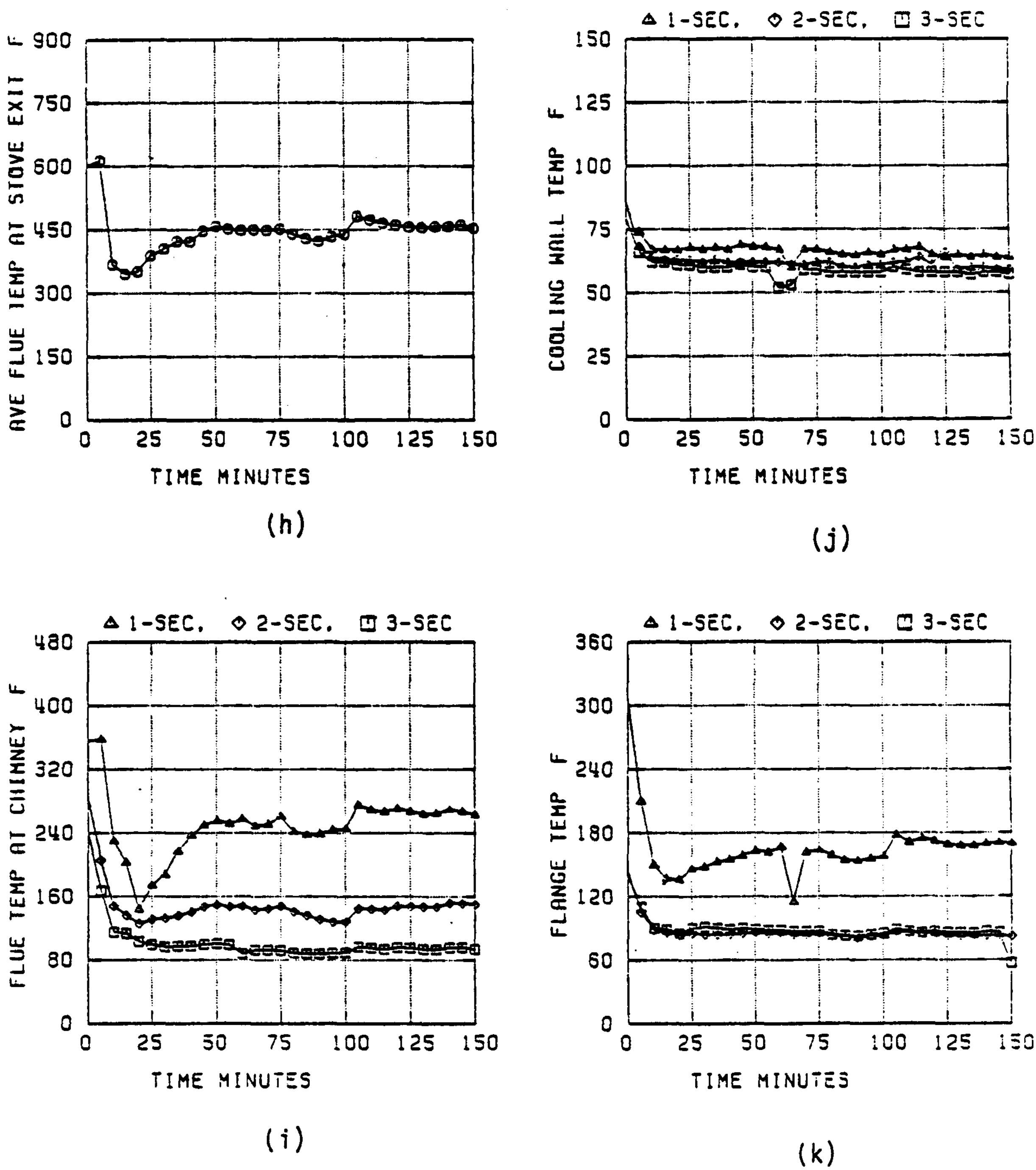



Figure 23. Continued

DISCUSSION OF TEST A-02/28/79 (Wet Pine Standard Brand)

Six kiln dry yellow standard brands with low moisture levels (8.3%) were tested using low levels of undergrate air (i.e. air inlet position 1). The fire started easily with the initial temperature of 805°F (measured at the stove exit). A very stable temperature was kept until the end of the test. The low burning rate (see Fig 23d) cause a good efficiency (55.0%) and a higher air-fuel ratio (Figure 23g) during the test. Figure 23e shows that the amount of $CO_2$ and $O_2$ were always around 10.0% and the percent of combustibles varied with the percent of CO in the flue gases. It is observed that the amount of creosote formation varied depending on the percent of combustibles in the flue gases. Yellow pine (soft wood) with largest surface area (standard brands) but with the moisture level of 8.3% can still produce creosote in the chimney. The amount of water vapor distilled from the wood did not produce a successful dilution effect. It was observed that the thicker creosote was still formed in the chimney.

The average flue temperature at the stove exit was about 450°F (Fig. 23h). In the top of the first test section, the temperature had dropped to about 250°F. This means that some of the compounds in the flue have not yet condensed. The temperature dropped to about 95°F in the top of the third test section. All the heavy volatile matters which were not condensed in the first section condensed in the second and third sections. Since the temperatures of the flue gases leaving the chimney (shown in Figure 23) were below 110°F, and it is shown in Table 1 that the boiling temperature of the naphtalene has the lowest boiling point within the creosote components is 218$^{o}$C (424$^{o}$F). A test showed that the creosote starts to condense at the cooling surface temperature of 300$^{o}$F.

WOOD BURNING TEST RESULTS

TEST NUMBER : A-03/01/79

DATE OF TEST : MARCH 01,1979

AMBIENT TEMPERATURE : 70 DEG F

DAMPER SETTING :
POSITION 1

FUEL : WET #2 YLW. PINE BRAND 3,6

MOISTURE CONTENT 8.3 % HHV= -8088.9

| TIME | | LBS WOOD | FLUE GAS TEMP (F) | %CO2 | %O2 | %CO | %COM | %EFF | A/F RATIO | THEO AIR | HEAT RLSE BTU/HR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 15.4 | 350.0 | | | | | | | | 0. |
| 8 | 20 | 14.6 | 209.0 | | | | | | | | 46592. |
| 16 | 40 | 12.1 | 208.0 | 11.7 | 7.8 | 4.6 | 4.8 | 40.0 | 4.65 | 5.55 | 145599. |
| 25 | 0 | 10.8 | 169.0 | | | | | | | | 75712. |
| 33 | 20 | 9.6 | 164.0 | | | | | | | | 128127. |
| 41 | 40 | 5.2 | 155.0 | 11.0 | 8.4 | 2.6 | 1.8 | 60.5 | 6.80 | 5.66 | 139775. |
| 50 | 0 | 4.4 | 156.0 | 10.4 | 9.3 | 2.0 | 1.6 | 63.0 | 7.59 | 5.66 | 104832. |
| 58 | 20 | 4.0 | 149.0 | 10.0 | 10.0 | 1.7 | 1.7 | 61.7 | 7.90 | 5.66 | 23296. |
| 64 | 40 | 3.3 | 159.0 | 9.6 | 10.4 | 1.6 | 1.5 | 62.7 | 8.36 | 5.66 | 53642. |
| 73 | 0 | 3.1 | 154.0 | | | | | | | | 11648. |
| 81 | 20 | 2.2 | 157.0 | 8.8 | 10.9 | 1.7 | 0.9 | 67.1 | 9.38 | 5.66 | 52416. |
| 89 | 40 | 1.8 | 162.0 | | | | | | | | 23296. |
| 98 | 0 | 1.3 | 130.0 | | | | | | | | 29120. |

REMARKS

AVERAGE HEAT RELEASED: 69828.2 BTU/HR

AVERAGE HEAT OUTPUT : 38540.0 BTU/HR

AVERAGE EFFICIENCY : 55.2 %

COOLING WATER TEMP= 51 F TEST BY JOE JUGER

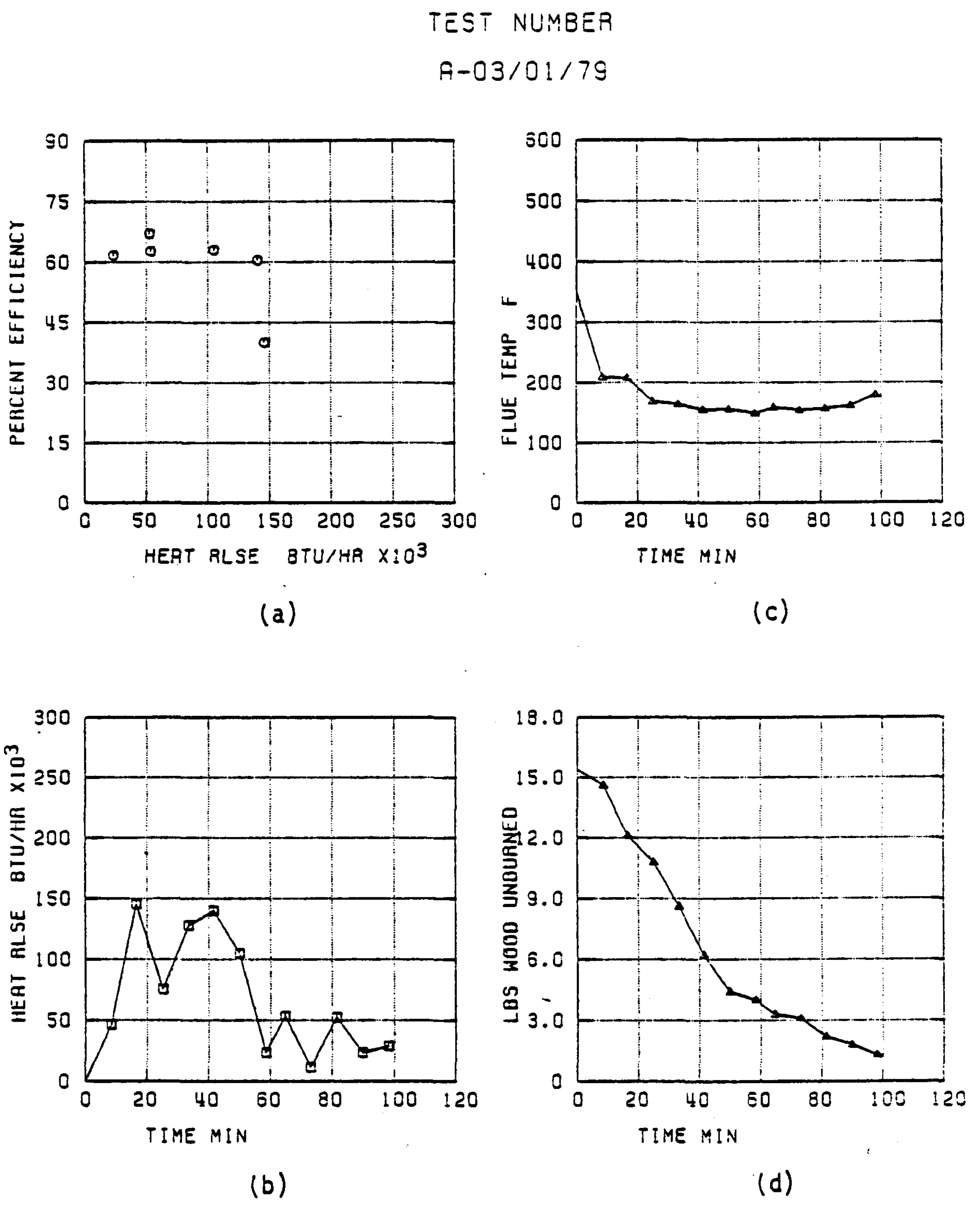
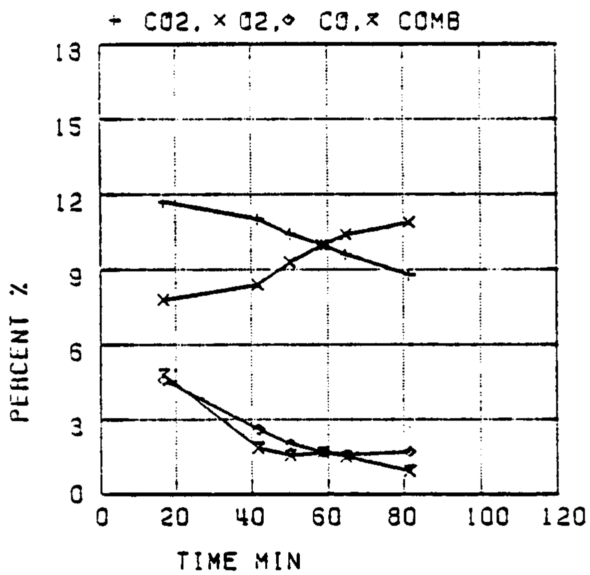


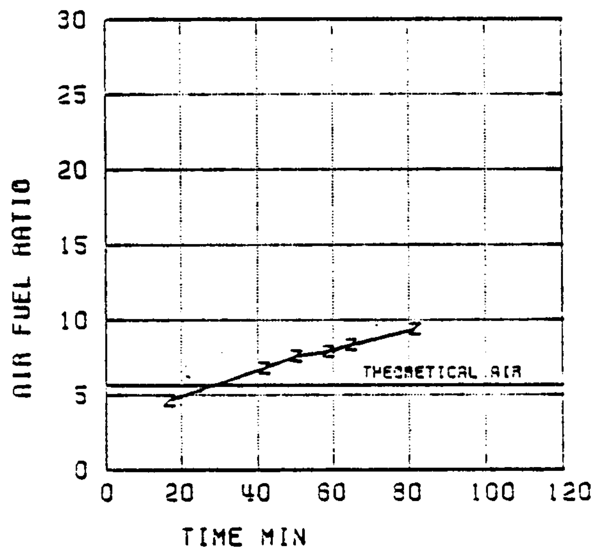

Figure 24. Test Data of Wet Pine Brand B

TEST NUMBER

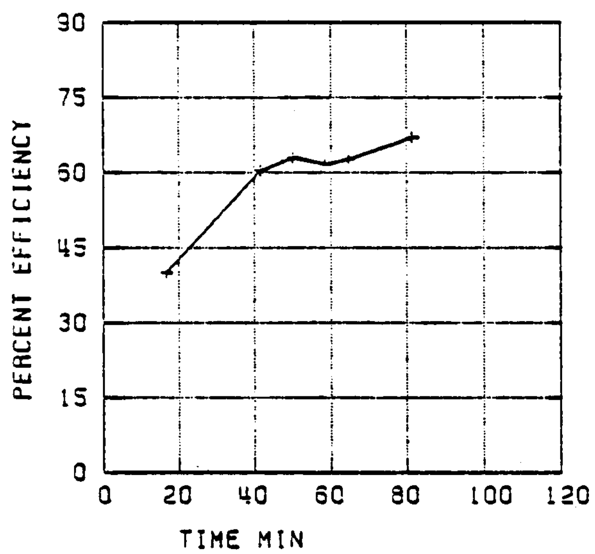
A-03/01/79




(e)




(g)




(f)

Figure 24. Continued

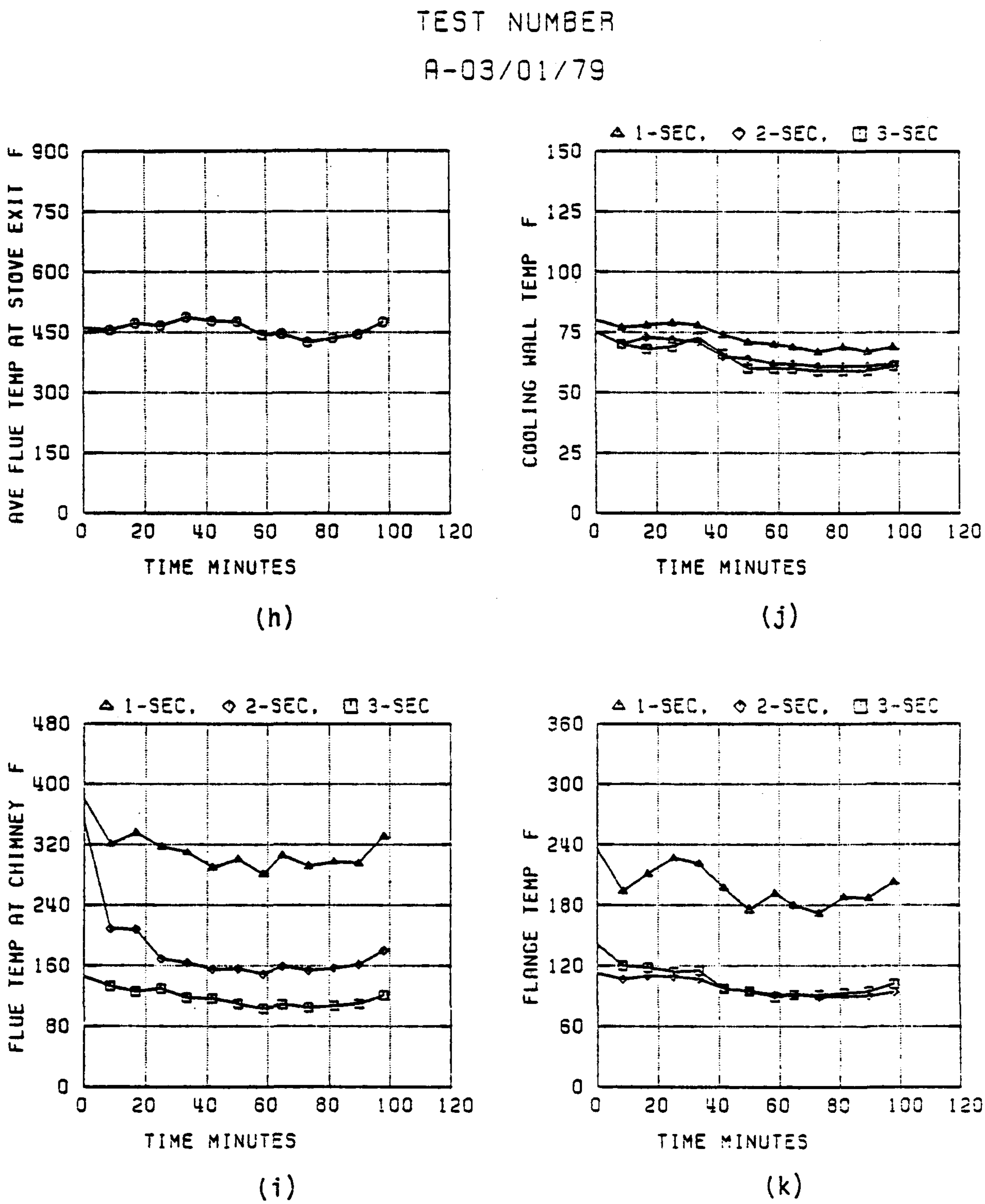



Figure 24. Continued

DISCUSSION OF TEST A-03/01/79 (Wet Pine Brand B)

Data for this test were taken every eight minutes and twenty seconds. The burning rate (Fig. 24d) increased during the first forty minutes and the average flue temperature at the stove exit was about 450 $^{o}$F. The flue temperature at the first section was higher than that of the last test (A-02/28/79). Figure 24e shows that the percent of CO was decreasing from 6.0% to 2.6% in the first forty minutes. It was observed that the amount of creosote generated depended on the percent of CO or combustibles measured. Test time was fifty minutes shorter than that of the last test, but the efficiencies were alsmost the same. It seems that the test was still accurate with a faster burning rate. The amount of creosote formation showed by Creosote Number was about 10% more than that of the last test.

WOOD BURNING TEST RESULTS

TEST NUMBER : A-04/06/79

DATE OF TEST : APRIL 06,1979

AMBIENT TEMPERATURE : 75 DEG F

DAMPER SETTING :
POSITION 1

FUEL : DRY #2 YLW. PINE BRAND 3,6

MOISTURE CONTENT 0.0 %  HHV= -8821.0

| TIME | | LBS WOOD | FLUE GAS TEMP (F) | %CO2 | %O2 | %CO | %COM | %EFF | A/F RATIO | THEO AIR | HEAT RLSE BTU/HR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 13.9 | 324.0 | | | | | | | | 0. |
| 5 | 0 | 13.4 | 182.0 | 12.6 | 7.4 | 5.5 | 7.1 | 33.8 | 3.99 | 6.13 | 52926. |
| 10 | 0 | 12.8 | 169.0 | | | | | | | | 63511. |
| 15 | 0 | 11.2 | 161.0 | 12.6 | 8.0 | 5.6 | 8.4 | 29.1 | 3.67 | 6.13 | 169363. |
| 20 | 0 | 9.5 | 164.0 | | | | | | | | 179948. |
| 25 | 0 | 7.3 | 172.0 | 11.5 | 8.7 | 4.9 | 6.6 | 33.5 | 4.45 | 6.13 | 232874. |
| 30 | 0 | 5.3 | 168.0 | | | | | | | | 211704. |
| 35 | 0 | 4.2 | 161.0 | 11.6 | 8.0 | 3.4 | 3.4 | 51.1 | 5.98 | 6.13 | 116437. |
| 40 | 0 | 2.9 | 162.0 | | | | | | | | 137508. |
| 45 | 0 | 2.6 | 174.0 | 12.0 | 7.2 | 2.0 | 0.8 | 74.0 | 7.88 | 6.13 | 31756. |
| 50 | 0 | 2.4 | 175.0 | | | | | | | | 21170. |
| 55 | 0 | 2.2 | 174.0 | 10.4 | 9.0 | 1.4 | 0.2 | 80.9 | 9.87 | 6.13 | 21170. |
| 60 | 0 | 2.0 | 174.0 | | | | | | | | 21170. |
| 65 | 0 | 1.8 | 174.0 | 9.7 | 9.9 | 1.4 | 0.5 | 76.4 | 10.15 | 6.13 | 21170. |
| 70 | 0 | 1.3 | 176.0 | | | | | | | | 0. |
| 75 | 0 | 1.5 | 164.0 | 9.1 | 10.4 | 1.4 | 0.2 | 79.6 | 11.04 | 6.13 | 31756. |
| 80 | 0 | 1.1 | 158.0 | | | | | | | | 42341. |
| 85 | 0 | 0.9 | 156.0 | 8.8 | 10.7 | 1.5 | 0.3 | 77.9 | 11.13 | 6.13 | 21170. |
| 90 | 0 | 0.7 | 160.0 | | | | | | | | 21170. |

REMARKS

AVERAGE HEAT RELEASED: 77624.7 BTU/HR

AVERAGE HEAT OUTPUT : 33411.0 BTU/HR

AVERAGE EFFICIENCY : 43.0 %

COOLING WATER TEMP= 59 F  TEST BY JOE JUGER

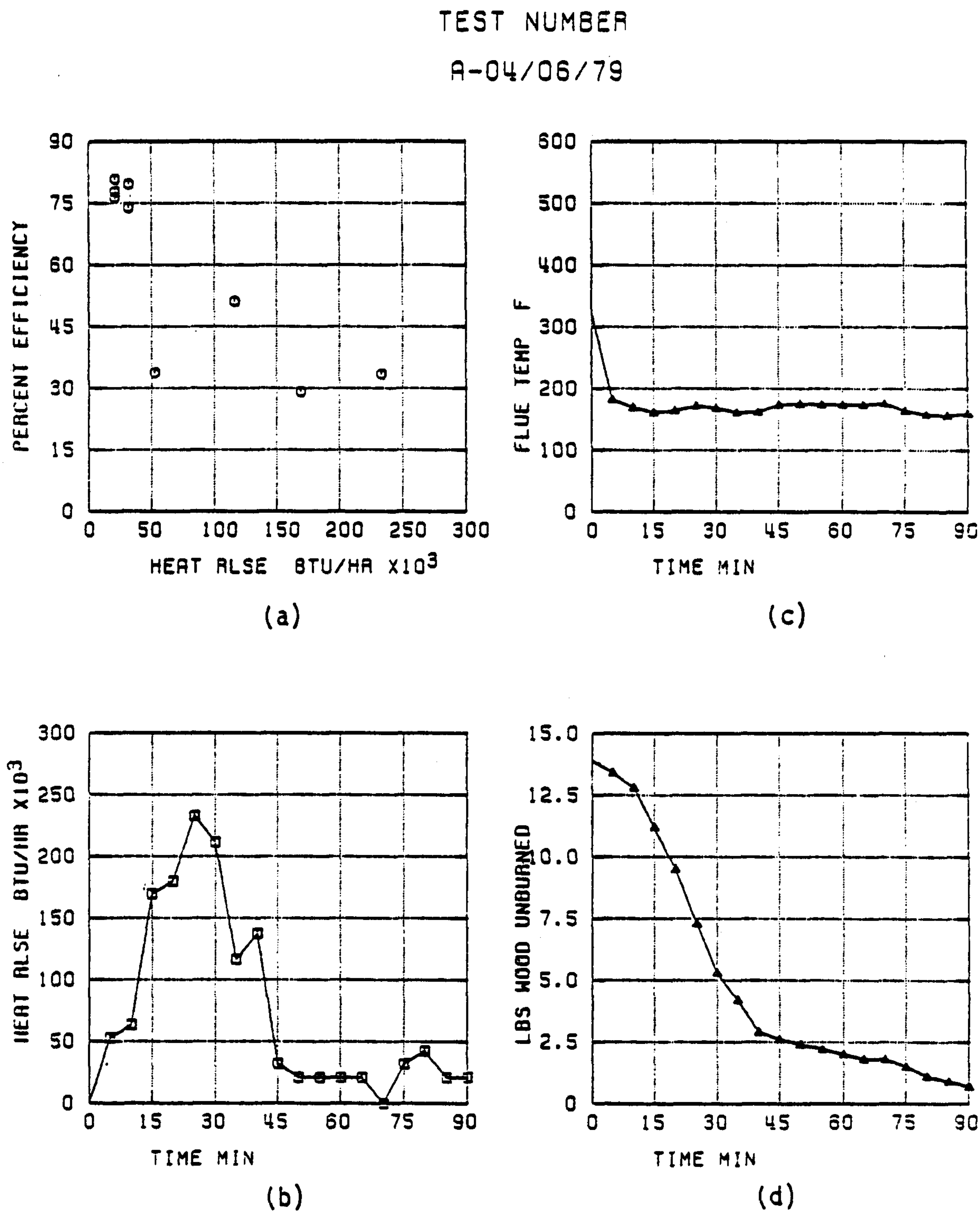



Figure 25. Test Data of Dry Pine Brand B

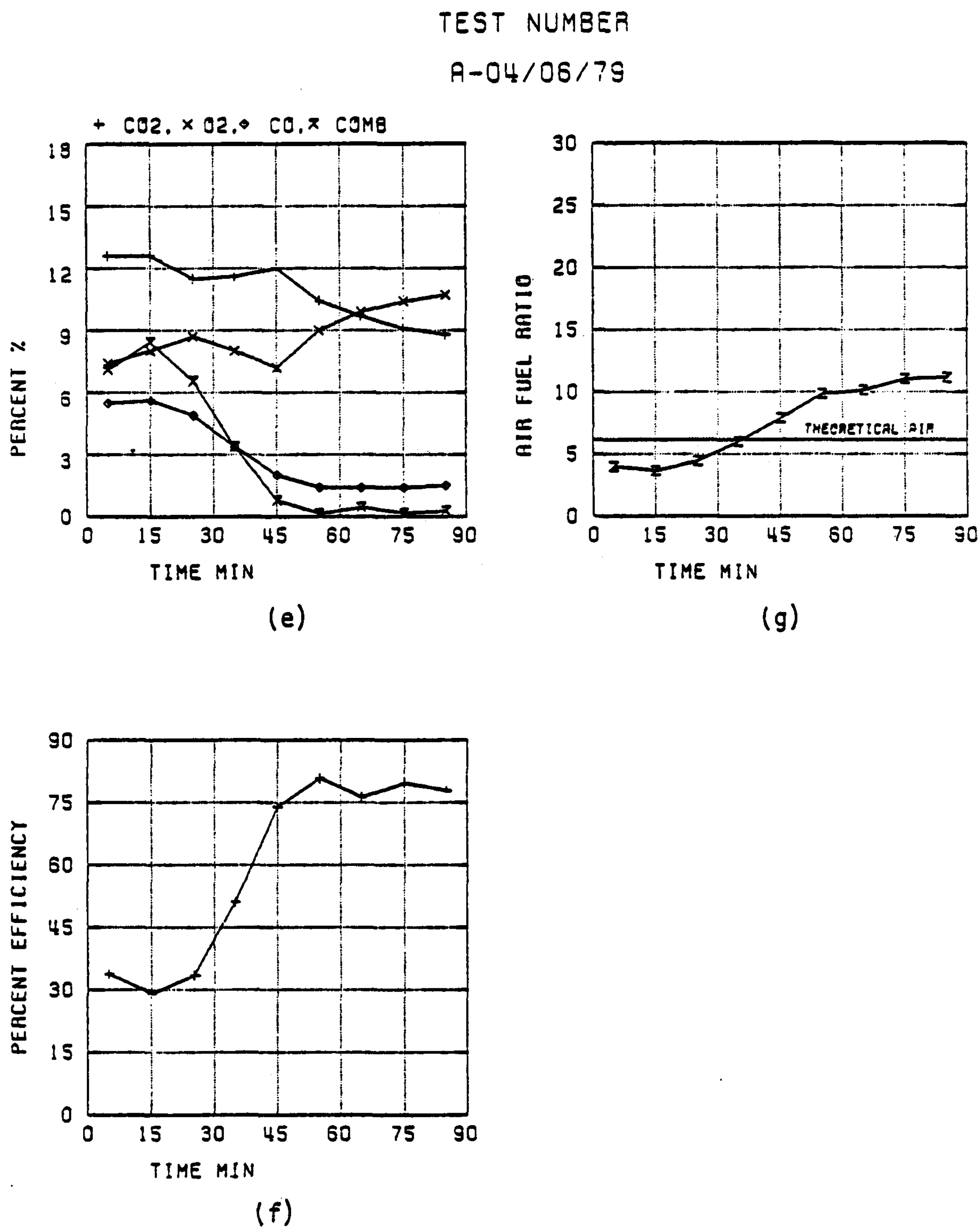



Figure 25. Continued

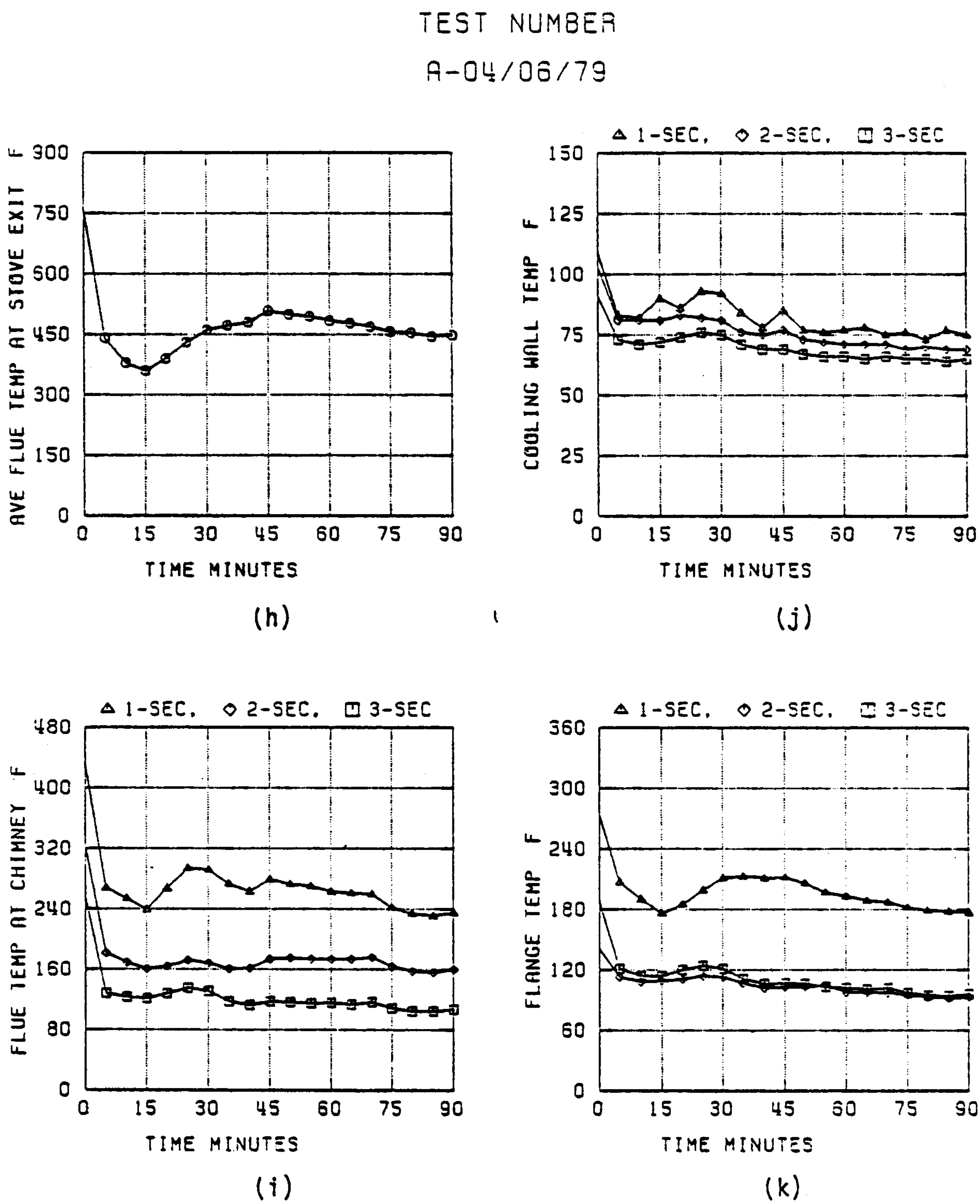



Figure 25. Continued

<u>DISCUSSION OF TEST A-04/06/79</u> (Dry Pine Brand B)

The test conditions used to generate the data of this test were kept the same as that of last test (A-03/0]/79) with the exception of using oven dry (0.0% moisture) brand B's in stead of using the brands with 8.3% of moisture content. This test with an efficiency (43.0%) 12% lower than that of last test. Starting with very low efficiency (see Fig. 25f) of the test, most of the pyrolysis reactions were completed before the 45th minute and leaving charcoal behind (see Fig. 25d). Figure 25e and 25g show that large amount of unburned gases (CO, $CH_4$, etc.) in the condition of low air fuel ratio passed through the surfaces of the wood and go up the chimney. It was observed that most of the creosote was formed during the early stage of burning. Total volume of the mixture is less than that of last test because of 0.0% of moisture content in the wood. However, the optical densities are relatively higher. Hence the amount of the creosote formation in this test is 9.0% higher than that of last test.

# WOOD BURNING TEST RESULTS

TEST NUMBER : A-04/09/79

DATE OF TEST : APRIL 09,1979

AMBIENT TEMPERATURE : 66 DEG F

DAMPER SETTING :
POSITION 1

FUEL : DRY #2 YLW. PINE STANDARD BRAND.6

MOISTURE CONTENT 0.0 % HHV= -8821.0

| TIME | | LBS WOOD | FLUE GAS TEMP (F) | %CO2 | %O2 | %CO | %COM | %EFF | A/F RATIO | THEO AIR | HEAT RLSE BTU/HR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 15.7 | 226.0 | | | | | | | | 0. |
| 5 | 0 | 14.8 | 191.0 | 12.0 | 7.8 | 4.7 | 5.6 | 38.9 | 4.69 | 6.13 | 95267. |
| 10 | 0 | 14.1 | 211.0 | | | | | | | | 74096. |
| 15 | 0 | 13.2 | 198.0 | 12.0 | 7.9 | 5.5 | 6.3 | 33.2 | 4.16 | 6.13 | 95267. |
| 20 | 0 | 11.7 | 199.0 | | | | | | | | 158778. |
| 25 | 0 | 10.1 | 171.0 | 11.7 | 9.2 | 5.0 | 8.1 | 27.8 | 3.98 | 6.13 | 169363. |
| 30 | 0 | 8.4 | 158.0 | | | | | | | | 179948. |
| 35 | 0 | 7.5 | 169.0 | | | | | | | | 95267. |
| 40 | 0 | 5.6 | 161.0 | | | | | | | | 95267. |
| 45 | 0 | 4.2 | 151.0 | 10.9 | 9.5 | 3.0 | 4.3 | 44.0 | 5.92 | 6.13 | 254045. |
| 50 | 0 | 3.7 | 155.0 | | | | | | | | 52926. |
| 55 | 0 | 3.3 | 157.0 | 12.1 | 6.9 | 2.9 | 1.6 | 65.5 | 6.88 | 6.13 | 42341. |
| 60 | 0 | 3.2 | 161.0 | | | | | | | | 10585. |
| 65 | 0 | 3.1 | 164.0 | 11.4 | 7.7 | 1.5 | 0.0 | 83.5 | 9.15 | 6.13 | 10585. |
| 70 | 0 | 3.0 | 166.0 | | | | | | | | 10585. |
| 75 | 0 | 3.0 | 164.0 | 9.0 | 11.0 | 1.3 | 1.0 | 59.1 | 10.25 | 6.13 | 0. |
| 80 | 0 | 2.9 | 165.0 | | | | | | | | 10585. |
| 85 | 0 | 2.8 | 165.0 | 9.9 | 9.8 | 1.1 | 0.3 | 80.3 | 10.45 | 6.13 | 10585. |
| 90 | 0 | 2.7 | 166.0 | | | | | | | | 10585. |
| 95 | 0 | 2.7 | 165.0 | | | | | | | | 0. |

REMARKS

AVERAGE HEAT RELEASED: 72425.0 BTU/HR

AVERAGE HEAT OUTPUT : 27761.3 BTU/HR

AVERAGE EFFICIENCY : 38.3 %

COOLING WATER TEMP= 59 F TEST BY JOE JUGER

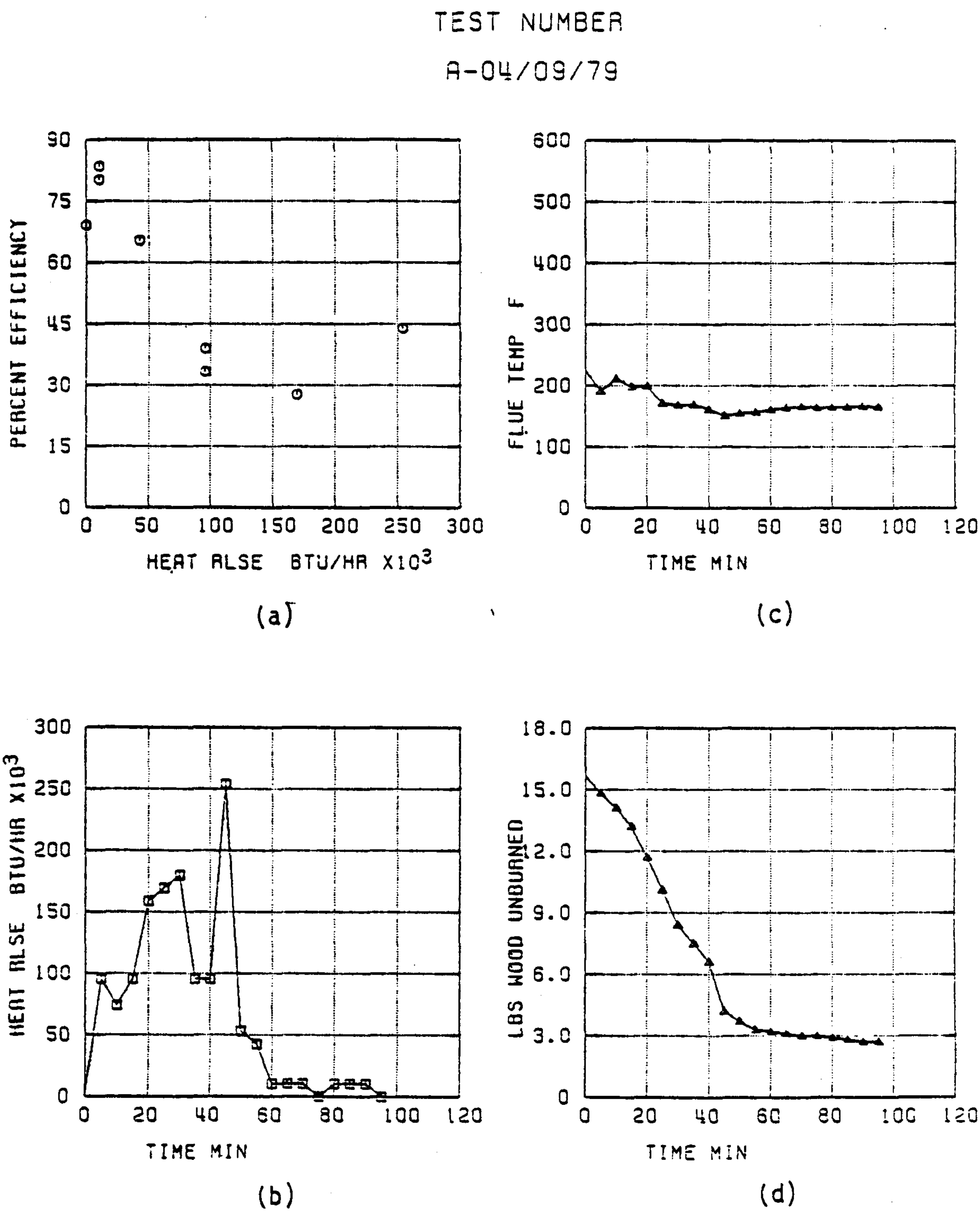



Figure 26. Test Data of Dry Pine Standard Brand

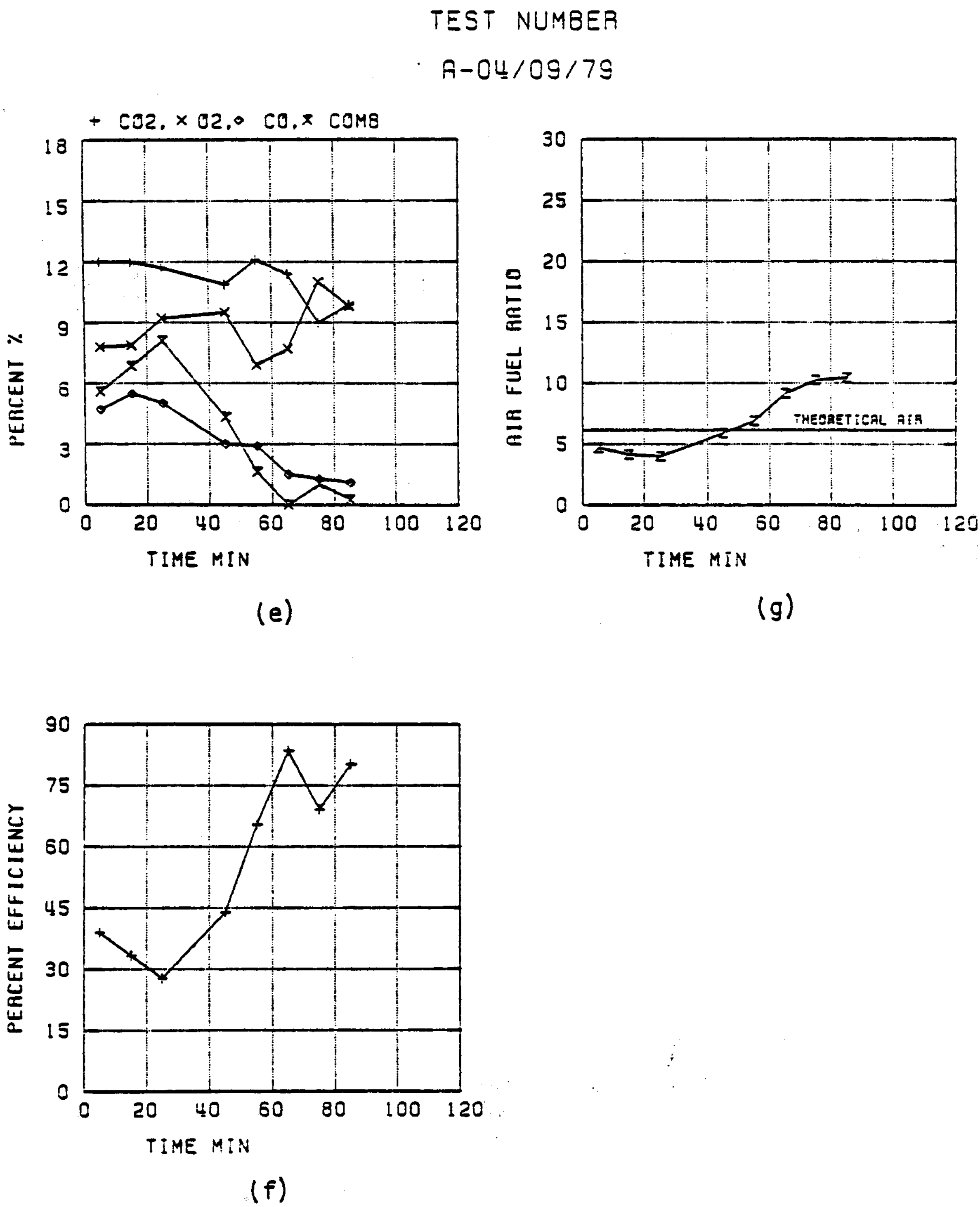



Figure 26. Continued

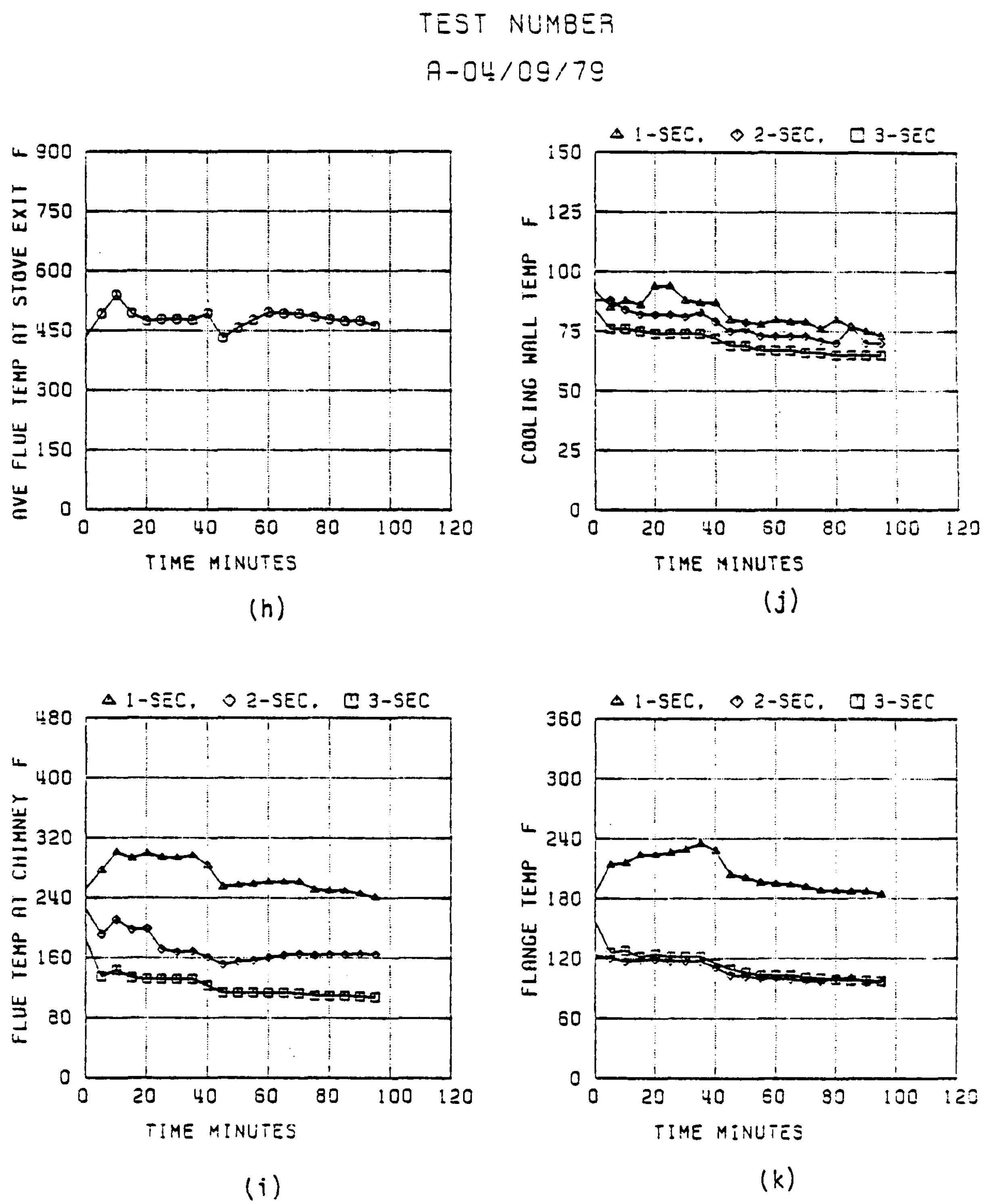



Figure 26. Continued

DISCUSSION OF TEST A-04/09/79 (Dry Pine Standard Brand)

It is interesting to compare all the Figures of this test with that of the last test (A-04/06/79). They are all similar. The test was being controlled so well that one can easily tell the difference in the amount of creosote formed in this test and in the last test. All the conditions of this test are similar to that of the last test with the exception of the geometry of the brand (standard brands were loaded). It was marked that the amount of creosote formation is 18% less than that of the last test (A-04/06/79).

It was observed in the previous test runs that the geometry of wood does affect the formation of creosote. However, there was not much difference in the formation of creosote when burning oven dry wood or kiln dry wood.

# WOOD BURNING TEST RESULTS

TEST NUMBER : A-04/11/79

DATE OF TEST : APRIL 11,1979

AMBIENT TEMPERATURE : 33 DEG F

DAMPER SETTING :
POSITION 2

FUEL : DRY YLW. PINE LOG,3

MOISTURE CONTENT 0.0 % HHV= -8821.0

| TIME | | LBS WOOD | FLUE GAS TEMP (F) | %CO2 | %O2 | %CO | %COM | %EFF | A/F RATIO | THEO AIR | HEAT RLSE BTU/HR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 22.5 | 305.0 | | | | | | | | 0. |
| 5 | 0 | 22.3 | 118.0 | 7.0 | 13.5 | 1.6 | 2.1 | 51.4 | 10.57 | 6.13 | 21170. |
| 10 | 0 | 22.0 | 94.0 | | | | | | | | 31756. |
| 15 | 0 | 21.8 | 136.0 | | | | | | | | 21170. |
| 20 | 0 | 21.6 | 130.0 | 10.0 | 10.6 | 2.8 | 4.3 | 42.0 | 6.30 | 6.13 | 21170. |
| 25 | 0 | 21.4 | 169.0 | | | | | | | | 21172. |
| 30 | 0 | 20.7 | 228.0 | | | | | | | | 74096. |
| 35 | 0 | 20.5 | 197.0 | 10.9 | 9.7 | 1.9 | 3.3 | 50.8 | 6.91 | 6.13 | 21170. |
| 40 | 0 | 20.1 | 138.0 | | | | | | | | 42340. |
| 45 | 0 | 19.6 | 131.0 | | | | | | | | 52926. |
| 50 | 0 | 19.0 | 186.0 | 10.6 | 10.0 | 1.7 | 3.0 | 52.9 | 7.32 | 6.13 | 63512. |
| 55 | 0 | 18.5 | 182.0 | | | | | | | | 52926. |
| 60 | 0 | 18.1 | 194.0 | | | | | | | | 42340. |
| 65 | 0 | 17.2 | 195.0 | 11.7 | 8.9 | 1.6 | 3.0 | 55.3 | 6.87 | 6.13 | 95268. |
| 70 | 0 | 16.5 | 194.0 | | | | | | | | 74096. |
| 75 | 0 | 15.7 | 185.0 | | | | | | | | 84682. |
| 80 | 0 | 15.2 | 193.0 | 11.7 | 8.7 | 1.6 | 2.6 | 58.3 | 7.10 | 6.13 | 52926. |
| 85 | 0 | 14.3 | 204.0 | | | | | | | | 95267. |
| 90 | 0 | 13.4 | 218.0 | | | | | | | | 95267. |
| 95 | 0 | 12.8 | 225.0 | 12.4 | 7.9 | 1.7 | 2.6 | 58.6 | 6.74 | 6.13 | 63511. |
| 100 | 0 | 11.9 | 242.0 | | | | | | | | 95267. |
| 105 | 0 | 11.5 | 228.0 | | | | | | | | 42341. |
| 110 | 0 | 11.2 | 202.0 | 11.4 | 9.0 | 1.6 | 2.5 | 57.8 | 7.26 | 6.13 | 31756. |
| 115 | 0 | 10.8 | 194.0 | | | | | | | | 42341. |
| 120 | 0 | 9.9 | 205.0 | | | | | | | | 95267. |
| 125 | 0 | 9.0 | 213.0 | 12.0 | 8.0 | 2.0 | 2.4 | 59.6 | 6.90 | 6.13 | 95267. |
| 130 | 0 | 7.9 | 223.0 | | | | | | | | 116437. |
| 135 | 0 | 6.8 | 228.0 | | | | | | | | 116437. |
| 140 | 0 | 5.7 | 223.0 | 10.8 | 9.1 | 1.4 | 1.2 | 68.4 | 8.64 | 6.13 | 116437. |
| 145 | 0 | 5.6 | 193.0 | | | | | | | | 10585. |
| 150 | 0 | 5.5 | 187.0 | | | | | | | | 10585. |
| 155 | 0 | 5.3 | 190.0 | 7.7 | 11.8 | 1.2 | 0.0 | 80.5 | 13.20 | 6.13 | 21170. |
| 160 | 0 | 5.2 | 189.0 | | | | | | | | 10585. |
| 165 | 0 | 5.1 | 185.0 | | | | | | | | 10585. |
| 170 | 0 | 5.0 | 178.0 | 7.2 | 12.5 | 1.3 | 0.2 | 76.9 | 13.58 | 6.13 | 10585. |
| 175 | 0 | 4.9 | 172.0 | | | | | | | | 10585. |
| 180 | 0 | 4.8 | 168.0 | | | | | | | | 10585. |

REMARKS

AVERAGE HEAT RELEASED: 52043.9 BTU/HR

AVERAGE HEAT OUTPUT : 30555.8 BTU/HR

AVERAGE EFFICIENCY : 58.7 %

COOLING WATER TEMP= 60 F TEST BY JOE JUGER

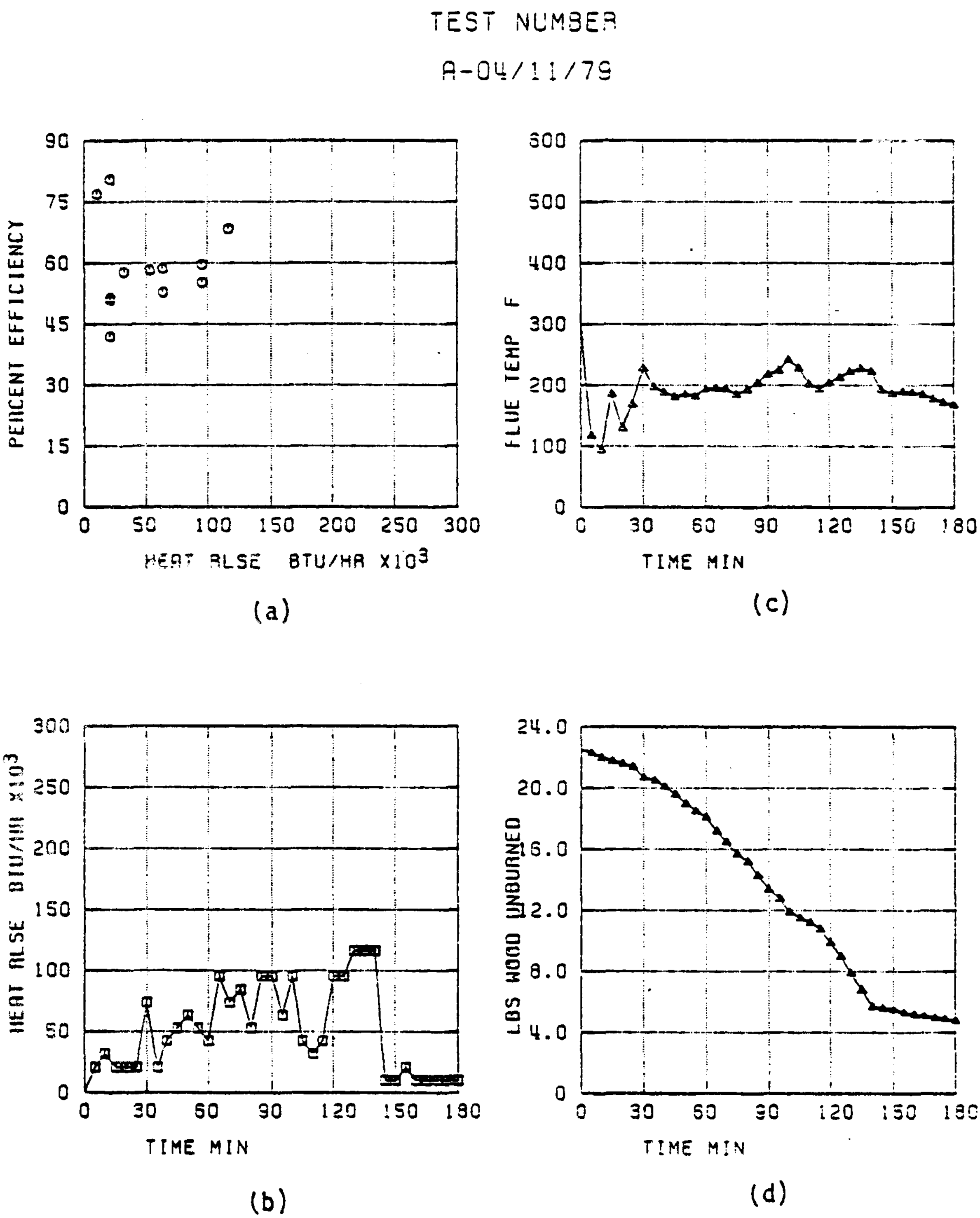
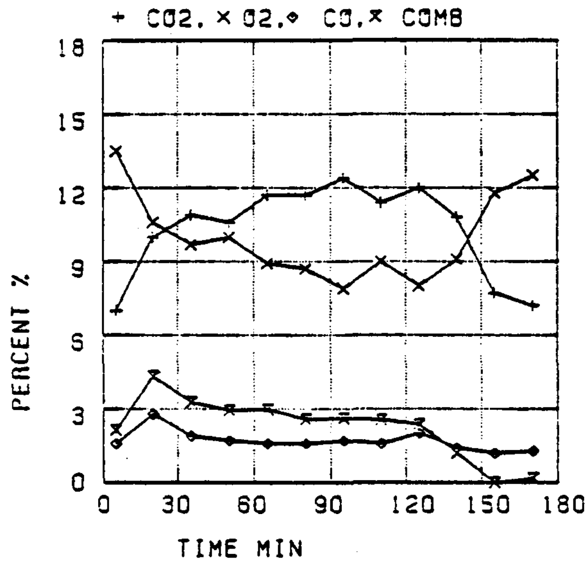


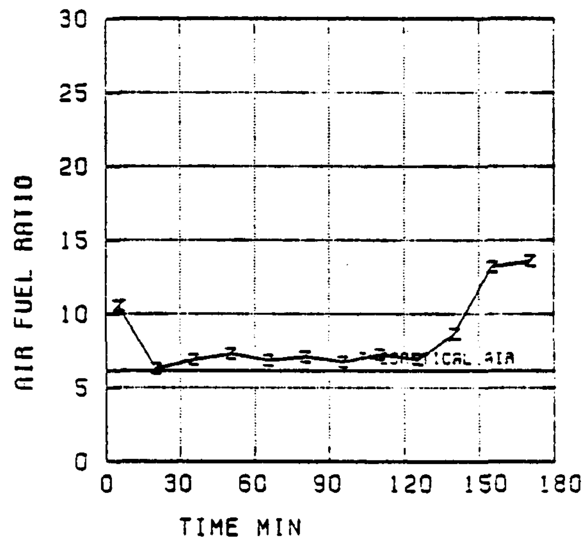

Figure 27. Test Data of Dry Pine Log

TEST NUMBER

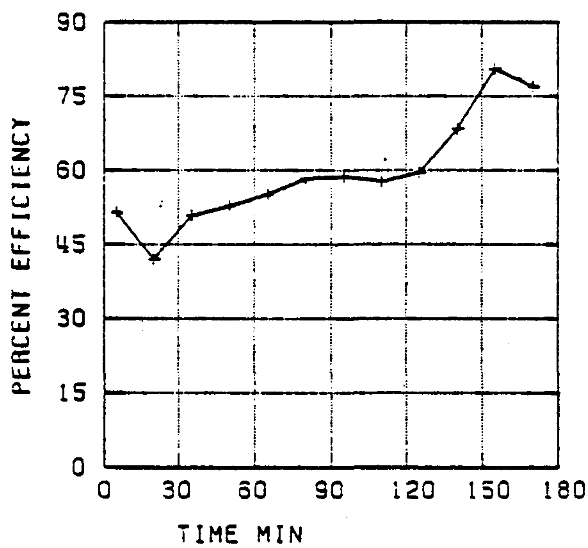
A-04/11/79




(e)




(g)




(f)

Figure 27. Continued

TEST NUMBER
A-04/11/79

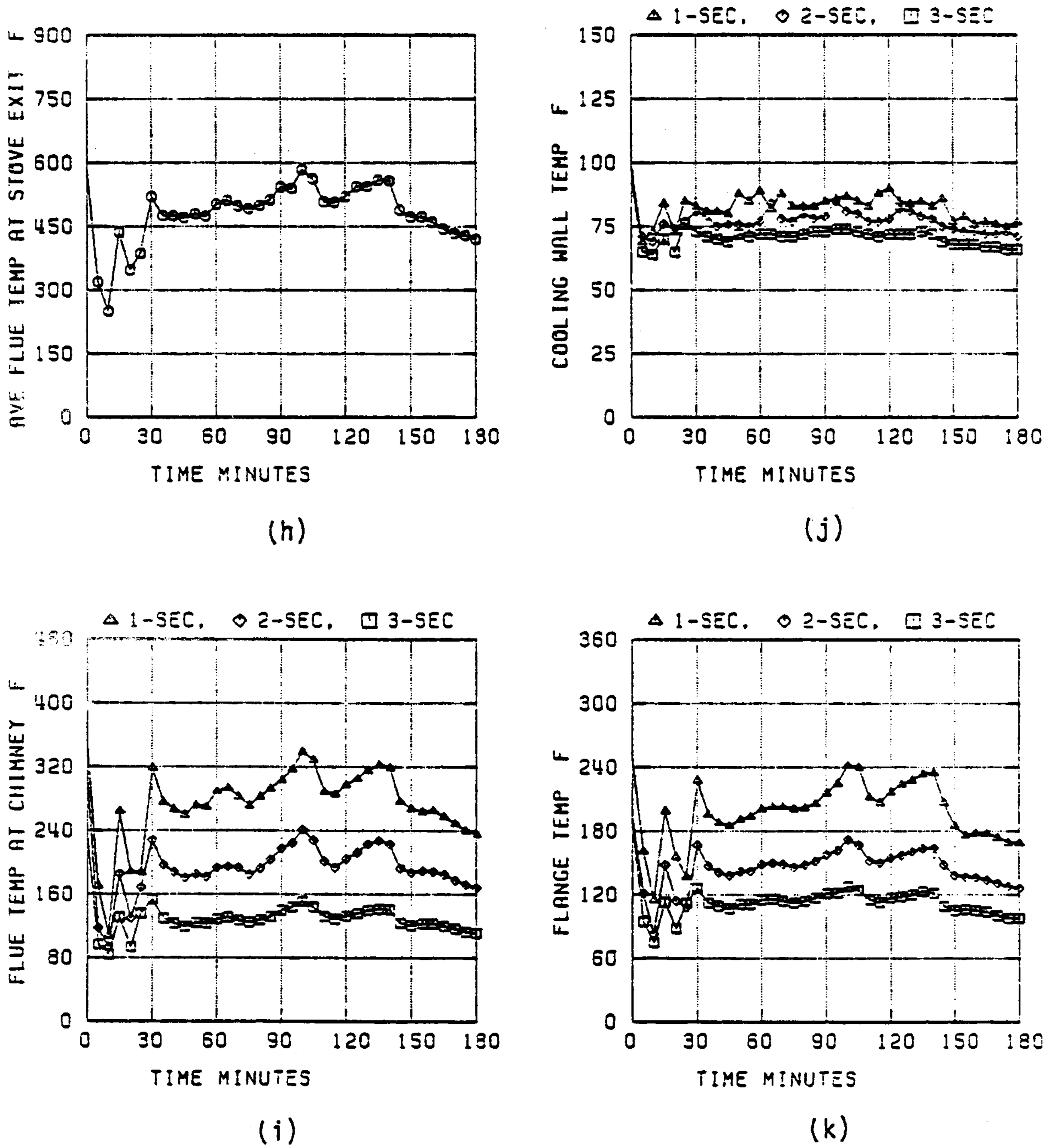



Figure 27. Continued

DISCUSSTION OF TEST A-04/11/79 (Dry Pine Log)

In order to determine the influence of wood geometry, split logs (the third geometry) with about 280 $in^2$ surface area were used. The combustion results of burning logs under the same condition still vary a lot depending on how the logs are fed in. Note that 4.8 pounds of wood were not burned in this test. Air was always sufficient (see Fig. 27g) with low burning rates (Fig. 27d). Pine logs which were used in this test had been dried about twenty days. 45% of moisture and even some volatile matters or resin in the wood were driven off. Since logs are hard to ignite or start the fire, a good bed of hot coal was prepared. Air in-let damper was adjusted to the position 2 to make sure that sufficiency oxygen was supplied. Note that the position 1 is about 1/4 open, while position 2 is 1/3 open. The combustion efficiency in this test was high as compared with the other tests. Less Creosote or other volatile matters passed through the surfaces of logs and went up the chimney. Most of them were burned out because of the slow gases generation and the sufficient air supply (complete combustion).

## WOOD BURNING TEST RESULTS

TEST NUMBER : A-04/13/79

DATE OF TEST : APRIL 13,1979

AMBIENT TEMPERATURE : 71 DEG F

DAMPER SETTING :
POSITION 1

FUEL : WET OAK STANDARD BRAND,6

MOISTURE CONTENT 29.0 % HHV= -6351.1

| TIME | | LBS WOOD | FLUE GAS TEMP (F) | %CO2 | %O2 | %CO | %COM | %EFF | A/F RATIO | THEO AIR | HEAT RLSE BTU/HR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 30.0 | 206.0 | | | | | | | | 0. |
| 5 | 0 | 29.0 | 204.0 | 4.2 | 16.7 | 0.7 | 1.3 | 39.0 | 13.67 | 4.52 | 76213. |
| 10 | 0 | 28.4 | 211.0 | | | | | | | | 45729. |
| 15 | 0 | 27.8 | 136.0 | 5.4 | 15.0 | 1.1 | 1.0 | 53.3 | 11.33 | 4.52 | 45727. |
| 20 | 0 | 27.6 | 108.0 | | | | | | | | 15242. |
| 25 | 0 | 26.9 | 129.0 | 7.2 | 13.1 | 1.7 | 1.9 | 47.5 | 7.77 | 4.52 | 53350. |
| 30 | 0 | 26.5 | 114.0 | | | | | | | | 30485. |
| 35 | 0 | 25.6 | 154.0 | 8.9 | 11.3 | 2.3 | 2.7 | 43.1 | 5.91 | 4.52 | 68592. |
| 40 | 0 | 24.3 | 168.0 | | | | | | | | 99078. |
| 45 | 0 | 22.7 | 192.0 | 11.5 | 8.4 | 3.0 | 3.4 | 43.5 | 4.52 | 4.52 | 121942. |
| 50 | 0 | 21.4 | 211.0 | | | | | | | | 99078. |
| 55 | 0 | 20.5 | 142.0 | 10.0 | 10.3 | 2.7 | 3.6 | 39.9 | 4.96 | 4.52 | 68592. |
| 60 | 0 | 19.6 | 133.0 | | | | | | | | 68592. |
| 65 | 0 | 18.7 | 128.0 | 9.3 | 10.5 | 2.9 | 2.8 | 44.1 | 5.47 | 4.52 | 68593. |
| 70 | 0 | 18.1 | 125.0 | | | | | | | | 45727. |
| 75 | 0 | 17.2 | 132.0 | 9.8 | 10.5 | 2.8 | 3.7 | 38.7 | 4.94 | 4.52 | 68593. |
| 80 | 0 | 16.3 | 137.0 | | | | | | | | 68592. |
| 85 | 0 | 15.7 | 135.0 | 10.5 | 9.7 | 2.8 | 3.6 | 41.3 | 4.73 | 4.52 | 45728. |
| 90 | 0 | 15.0 | 128.0 | | | | | | | | 53349. |
| 95 | 0 | 14.3 | 123.0 | 7.4 | 13.0 | 1.6 | 2.0 | 47.6 | 7.63 | 4.52 | 53349. |
| 100 | 0 | 13.9 | 119.0 | | | | | | | | 30485. |
| 105 | 0 | 13.4 | 118.0 | 8.4 | 11.3 | 1.9 | 1.1 | 59.5 | 7.44 | 4.52 | 38107. |
| 110 | 0 | 13.0 | 116.0 | | | | | | | | 30485. |
| 115 | 0 | 12.6 | 114.0 | | | | | | | | 30485. |
| 120 | 0 | 12.1 | 113.0 | 7.5 | 12.4 | 1.9 | 1.4 | 54.2 | 7.83 | 4.52 | 38107. |
| 125 | 0 | 11.9 | 111.0 | | | | | | | | 15243. |
| 130 | 0 | 11.5 | 111.0 | | | | | | | | 30485. |
| 135 | 0 | 11.2 | 110.0 | 6.8 | 13.4 | 1.7 | 1.6 | 49.7 | 8.31 | 4.52 | 22864. |
| 140 | 0 | 10.8 | 108.0 | | | | | | | | 30485. |
| 145 | 0 | 10.6 | 107.0 | | | | | | | | 15243. |
| 150 | 0 | 10.1 | 107.0 | 7.4 | 12.6 | 2.0 | 1.7 | 50.2 | 7.55 | 4.52 | 38107. |
| 155 | 0 | 9.9 | 105.0 | | | | | | | | 15243. |
| 160 | 0 | 9.7 | 105.0 | | | | | | | | 15243. |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 165 | 0 | 9.3 | 106.0 | 7.5 | 12.5 | 2.4 | 2.3 | 44.3 | 6.82 | 4.52 | 30485. |
| 170 | 0 | 6.6 | 115.0 | | | | | | | | 38107. |
| 175 | 0 | 8.2 | 122.0 | | | | | | | | 45728. |
| 180 | 0 | 7.7 | 124.0 | 6.3 | 14.2 | 2.0 | 2.5 | 36.6 | 7.61 | 4.52 | 38107. |
| 185 | 0 | 7.3 | 124.0 | | | | | | | | 30485. |
| 190 | 0 | 6.8 | 125.0 | | | | | | | | 38107. |
| 195 | 0 | 6.2 | 170.0 | 9.6 | 10.9 | 1.3 | 2.1 | 52.1 | 6.46 | 4.52 | 45728. |
| 200 | 0 | 5.3 | 273.0 | | | | | | | | 68592. |
| 205 | 0 | 4.9 | 137.0 | | | | | | | | 30485. |
| 210 | 0 | 4.6 | 122.0 | 8.3 | 11.6 | 2.5 | 3.4 | 38.6 | 5.54 | 4.52 | 22864. |
| 215 | 0 | 4.4 | 111.0 | | | | | | | | 15243. |

REMARKS

AVERAGE HEAT RELEASED: 45373.5 BTU/HR

AVERAGE HEAT OUTPUT : 20365.9 BTU/HR

AVERAGE EFFICIENCY : 44.9 %

COOLING WATER TEMP= 61 F TEST BY JOE JUGER

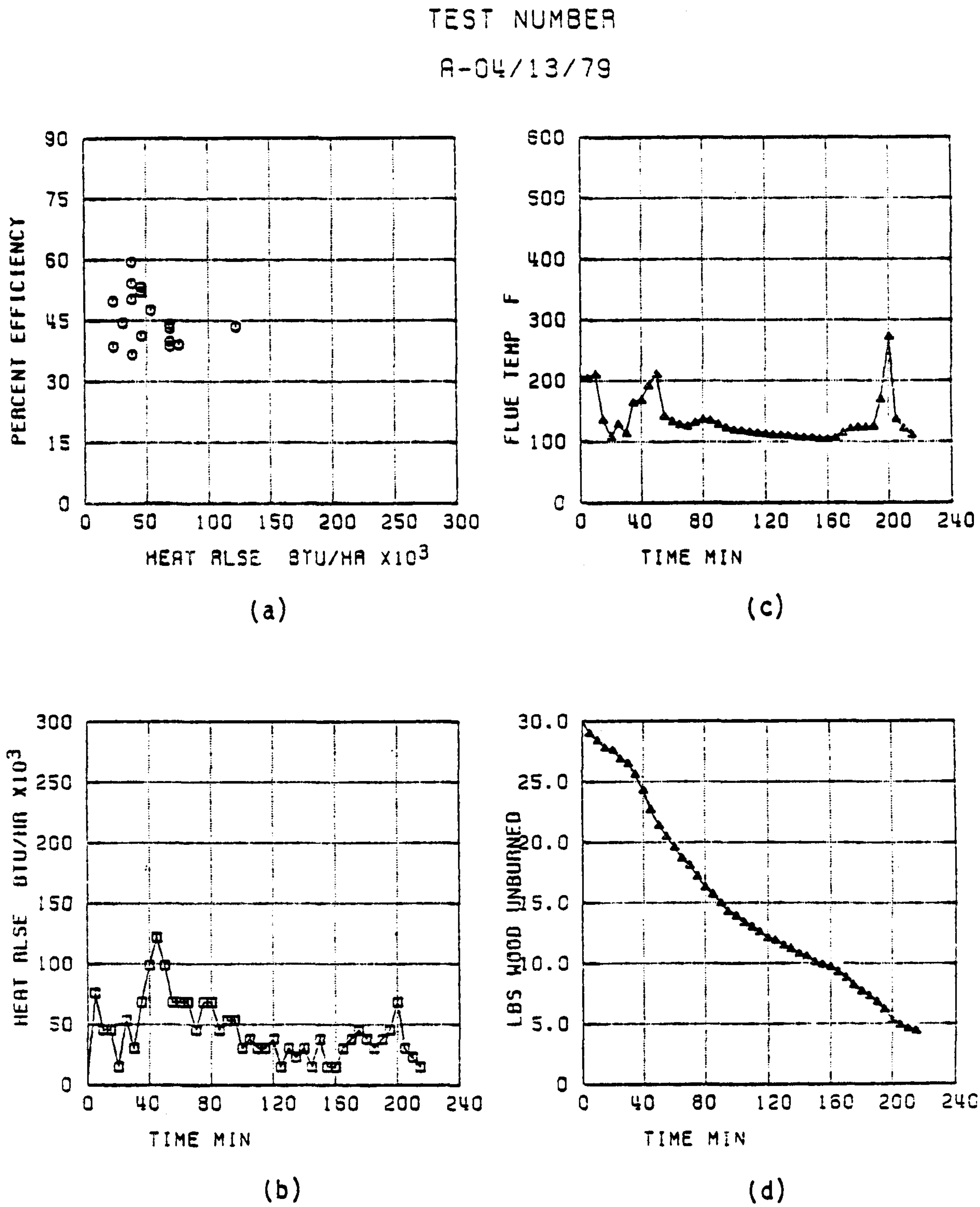



Figure 28 Test Data of Wet Oak Standard Brand

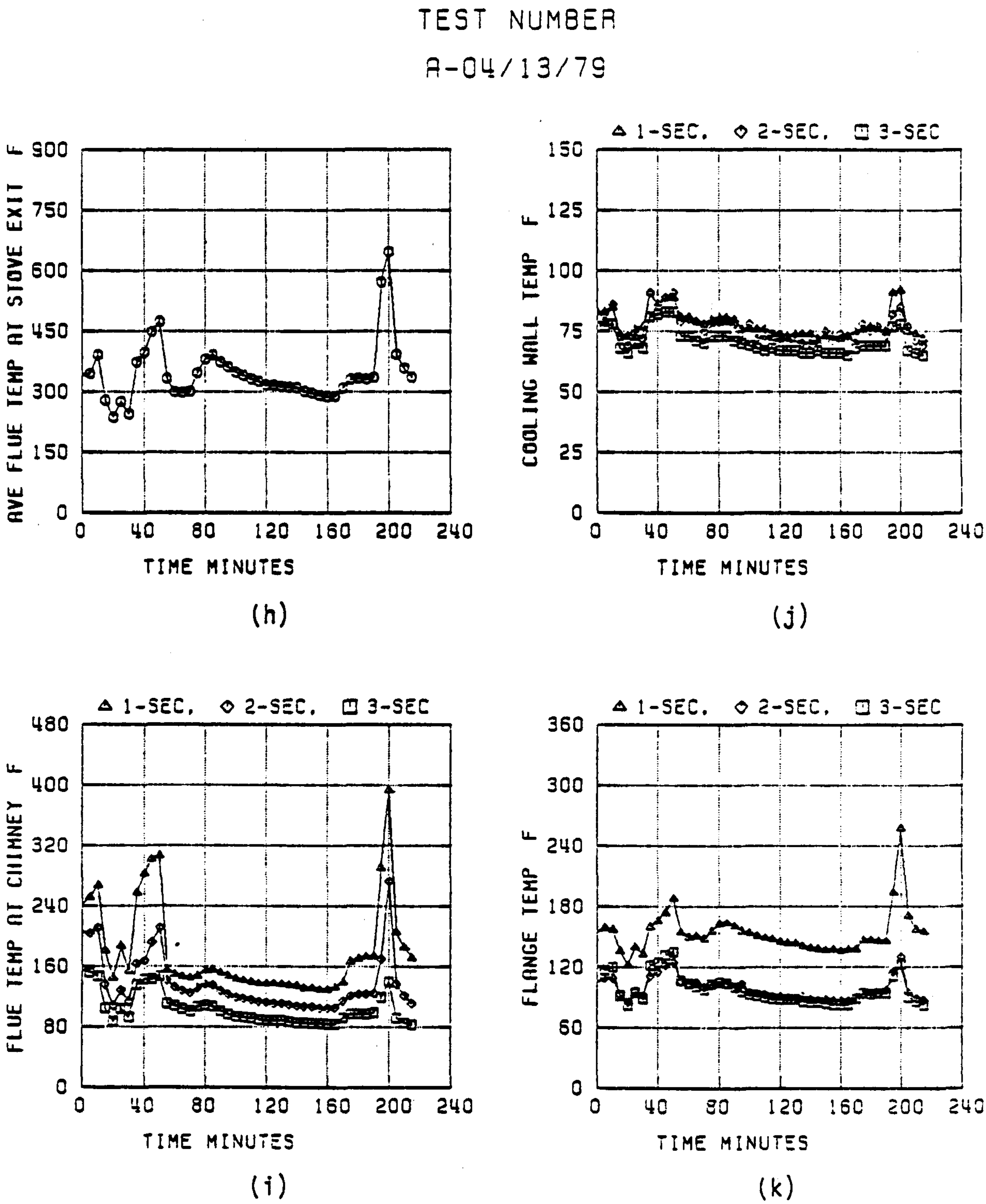
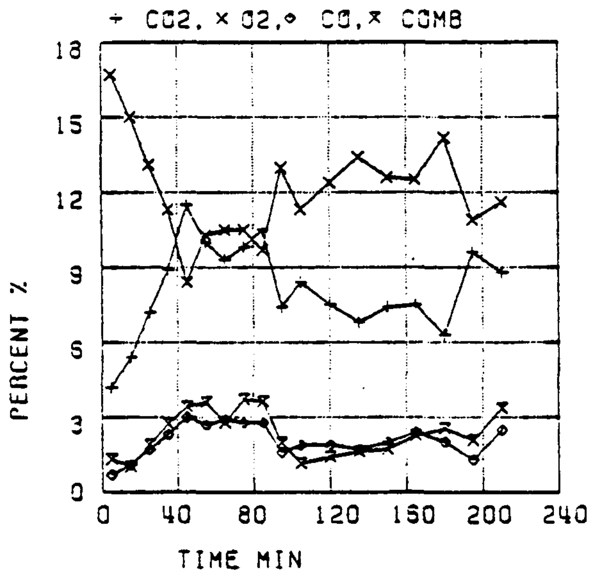


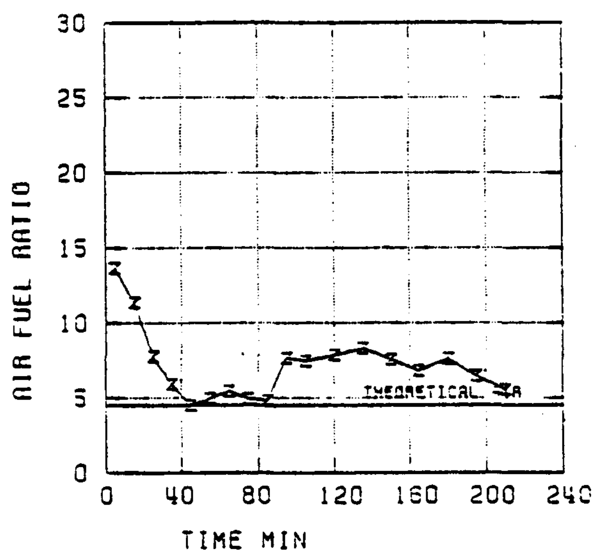

Figure 28. Continued

TEST NUMBER

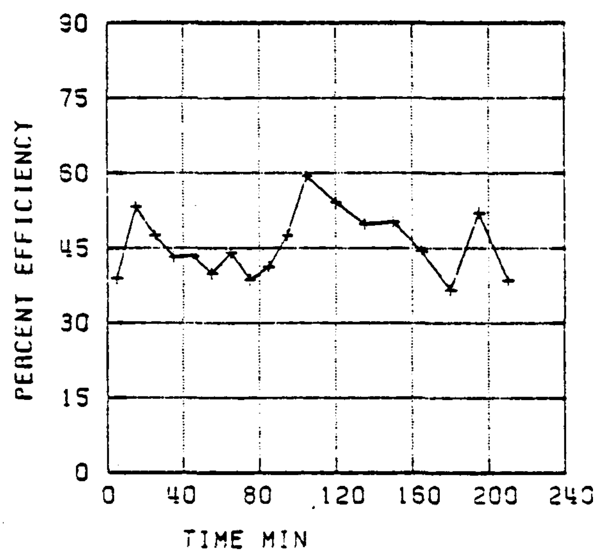
A-04/13/79




(e)




(g)




(f)

Figure 28. Continued

DISCUSSION OF TEST A-04/13/79 (Wet Oak Standard Brand)

The following eight test runs have several apparent results so that one can tell the differences of amount of creosote formation from different moisture content, wood geometry and kind of wood.

Six wet oak standard brands were tested using low level of undergrate air (position 1). Damper was fully opened in the first eight minutes because that these brands were hard to ignite with 28% of moisture content. This is a very slow and low temperature (see Fig.28 d,28 h) combustion. Figure 28e shows that percent of CO always below 3.0, and there was no back puffing in the test. Very small amount of black creosote droplets flew out with the mixture from the thirtieth minute to the sixtieth minute. Huge amount of mixture was collected, but most of it is water, hence the optical density are very low. It is hard to compare with the amount of creosote formation of different kind of wood or different size of wood by using wet wood (25% or above in the moisture content).

# WOOD BURNING TEST RESULTS

TEST NUMBER : A-04/17/79

DATE OF TEST : APRIL 17,1979

AMBIENT TEMPERATURE : 79 DEG F

DAMPER SETTING :
POSITION 1

FUEL : WET OAK BRAND 3,6

MOISTURE CONTENT 23.0 %  HHV= -6351.1

| TIME | | LBS WOOD | FLUE GAS TEMP (F) | %CO2 | %O2 | %CO | %COM | %EFF | A/F RATIO | THEO AIR | HEAT RLSE BTU/HR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 23.9 | 330.0 | | | | | | | | 0. |
| 5 | 0 | 22.0 | 259.0 | 7.3 | 13.3 | 1.2 | 1.6 | 44.9 | 3.15 | 4.52 | 137134. |
| 10 | 0 | 20.5 | 193.0 | | | | | | | | 114320. |
| 15 | 0 | 19.8 | 167.0 | 10.2 | 10.4 | 2.7 | 4.2 | 35.7 | 4.66 | 4.52 | 53349. |
| 20 | 0 | 18.3 | 198.0 | | | | | | | | 114320. |
| 25 | 0 | 17.2 | 141.0 | 9.6 | 11.2 | 2.8 | 4.7 | 31.7 | 4.63 | 4.52 | 83335. |
| 30 | 0 | 16.1 | 138.0 | | | | | | | | 83834. |
| 35 | 0 | 15.0 | 138.0 | 10.0 | 11.0 | 3.8 | 6.5 | 23.5 | 3.74 | 4.52 | 83335. |
| 40 | 0 | 13.9 | 137.0 | | | | | | | | 83835. |
| 45 | 0 | 12.8 | 135.0 | 11.4 | 8.9 | 3.0 | 4.2 | 39.6 | 4.29 | 4.52 | 83835. |
| 50 | 0 | 11.9 | 135.0 | | | | | | | | 68592. |
| 55 | 0 | 11.0 | 126.0 | 11.0 | 9.5 | 3.1 | 4.7 | 36.0 | 4.21 | 4.52 | 68592. |
| 60 | 0 | 10.4 | 120.0 | | | | | | | | 45728. |
| 65 | 0 | 9.7 | 117.0 | 11.4 | 9.1 | 2.8 | 4.3 | 39.4 | 4.30 | 4.52 | 53349. |
| 70 | 0 | 9.0 | 113.0 | | | | | | | | 53349. |
| 75 | 0 | 8.6 | 113.0 | 11.0 | 9.3 | 2.4 | 3.4 | 45.2 | 4.86 | 4.52 | 30485. |
| 80 | 0 | 8.2 | 110.0 | | | | | | | | 30485. |
| 85 | 0 | 7.7 | 106.0 | 10.4 | 9.8 | 2.1 | 2.7 | 49.4 | 5.45 | 4.52 | 38107. |
| 90 | 0 | 7.5 | 105.0 | | | | | | | | 15243. |
| 95 | 0 | 7.1 | 105.0 | 8.8 | 11.4 | 2.1 | 2.4 | 47.2 | 6.21 | 4.52 | 30485. |
| 100 | 0 | 6.6 | 107.0 | | | | | | | | 38107. |
| 105 | 0 | 6.4 | 109.0 | 9.3 | 11.1 | 2.3 | 3.2 | 42.2 | 5.53 | 4.52 | 15243. |
| 110 | 0 | 6.0 | 109.0 | | | | | | | | 30485. |
| 115 | 0 | 5.5 | 107.0 | 11.4 | 8.7 | 2.9 | 3.7 | 43.6 | 4.49 | 4.52 | 38107. |
| 120 | 0 | 5.1 | 107.0 | | | | | | | | 30485. |
| 125 | 0 | 4.9 | 107.0 | 10.5 | 9.5 | 2.5 | 2.8 | 47.9 | 5.20 | 4.52 | 15243. |
| 130 | 0 | 4.6 | 109.0 | | | | | | | | 22864. |
| 135 | 0 | 4.4 | 109.0 | 9.8 | 10.1 | 2.6 | 2.7 | 47.3 | 5.47 | 4.52 | 15243. |
| 140 | 0 | 4.2 | 107.0 | | | | | | | | 15243. |
| 145 | 0 | 4.0 | 107.0 | 10.0 | 9.5 | 2.6 | 1.9 | 54.2 | 5.77 | 4.52 | 15243. |
| 150 | 0 | 3.7 | 107.0 | | | | | | | | 22864. |
| 155 | 0 | 3.5 | 111.0 | 9.9 | 9.7 | 2.7 | 2.2 | 51.0 | 5.61 | 4.52 | 15243. |
| 160 | 0 | 3.4 | 109.0 | | | | | | | | 7621. |
| 165 | 0 | 3.2 | 110.0 | | | | | | | | 15243. |
| 170 | 0 | 2.9 | 117.0 | | | | | | | | 22864. |
| 175 | 0 | 2.6 | 117.0 | | | | | | | | 22864. |
| 180 | 0 | 2.5 | 120.0 | | | | | | | | 7621. |

REMARKS

AVERAGE HEAT RELEASED: 45092.9 BTU/HR

AVERAGE HEAT OUTPUT : 17909.1 BTU/HR

AVERAGE EFFICIENCY : 39.7 %

COOLING WATER TEMP= 61 F  TEST BY JOE JUGER

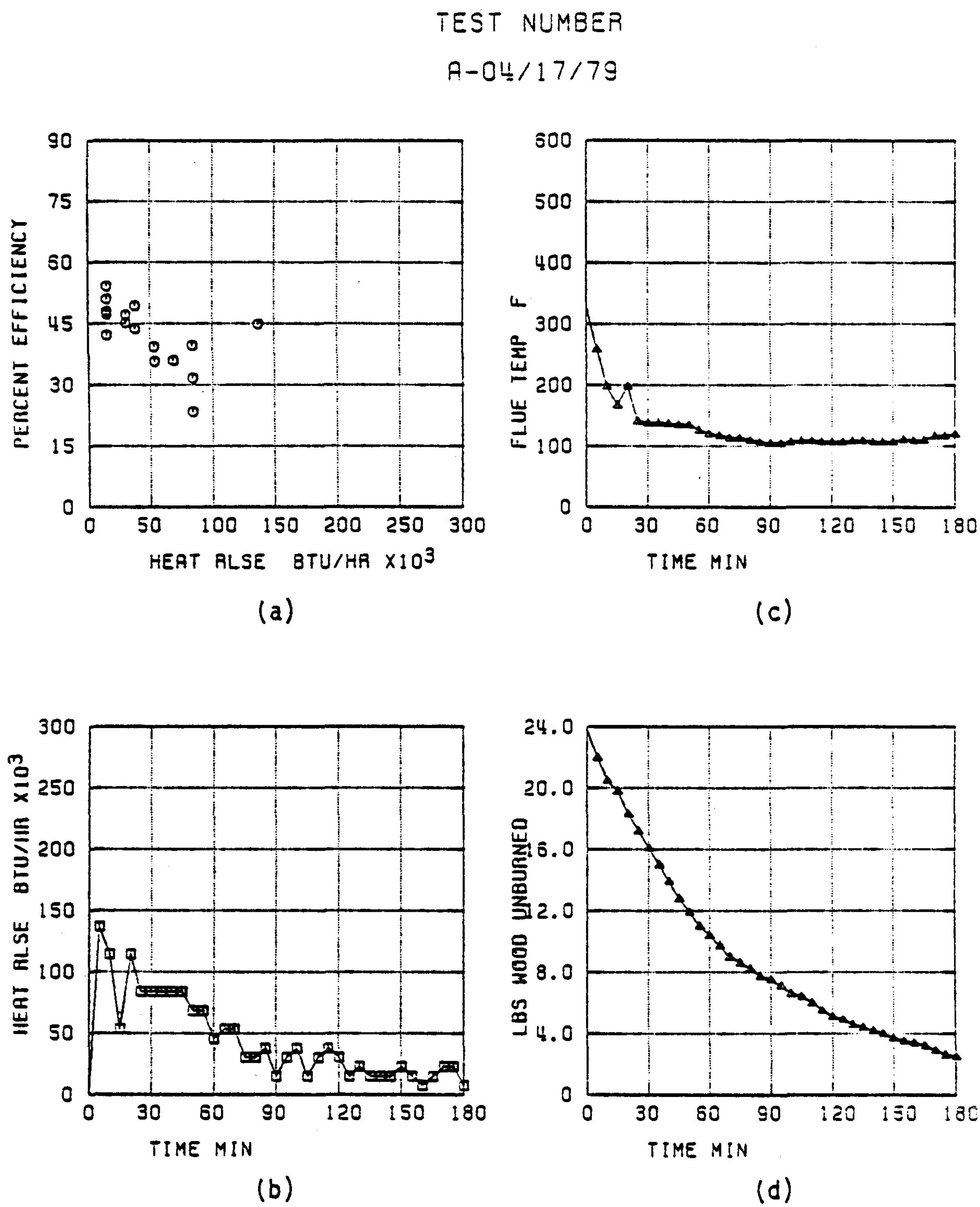



Figure 29. Test Data of Wet Oak Brand B

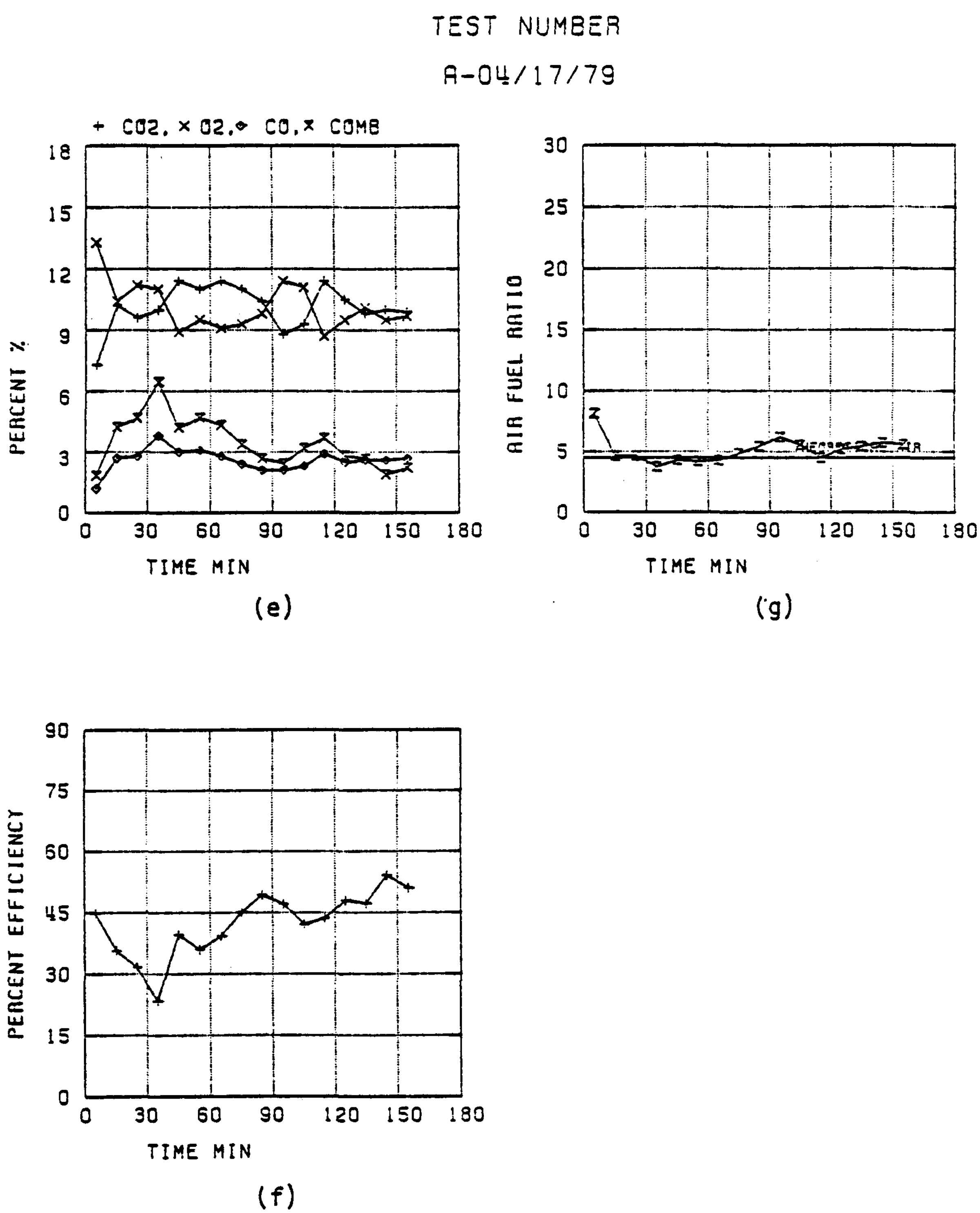



Figure 29. Continued

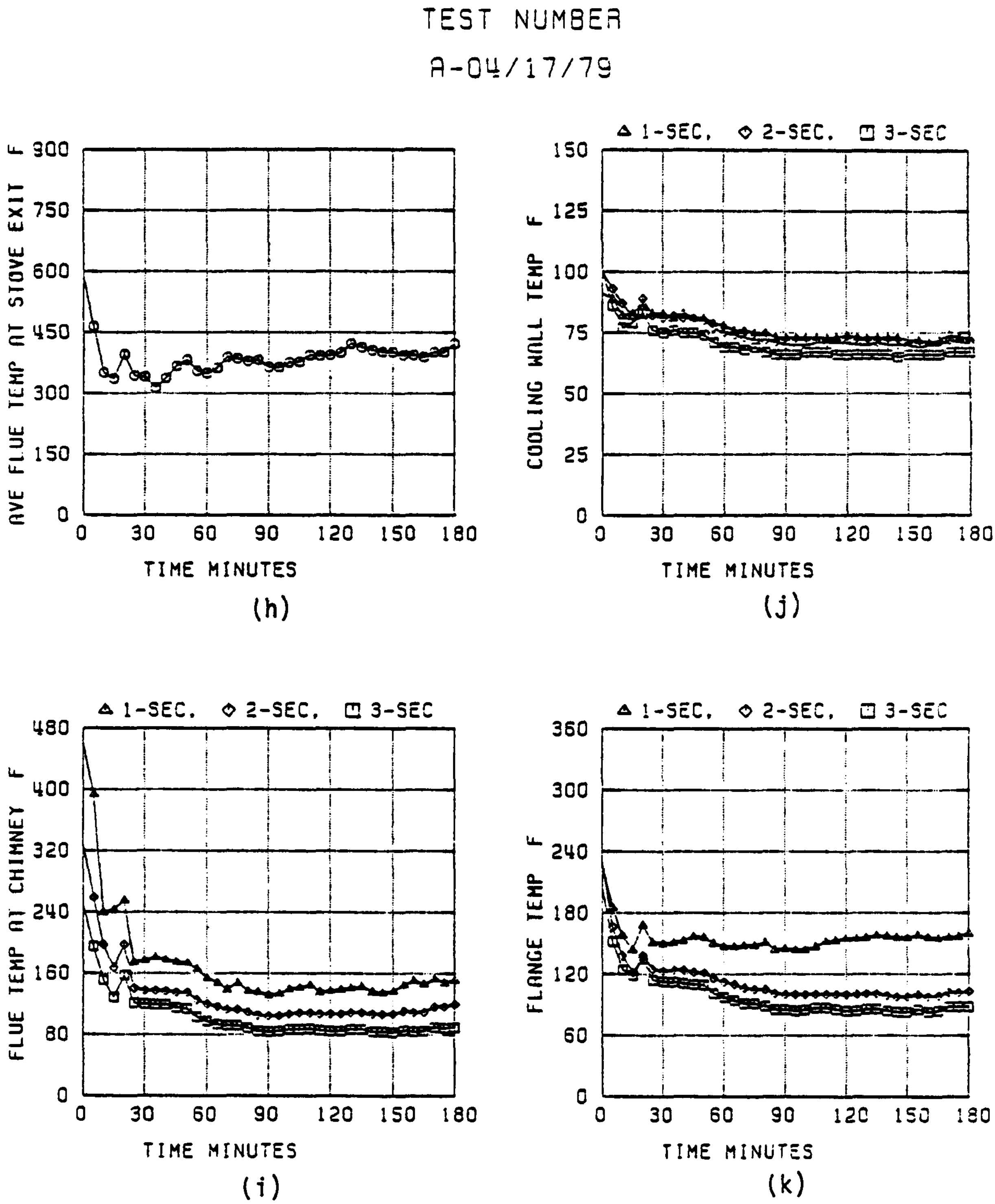



Figure 29. Continued

DISCUSSION OF TEST A-04/17/79 (Wet Oak Brand B)

All conditions and results in this test are similar to the last test (A-04/13/79) except using wood of brand B geometry. Figure 29g shows that air-fuel ratios were always around theoretical line (4.52). One can obtain a very good combustion result under this situation. Burning rate is slow with a very stable flue temperature. Figure 29h, 29i, 29k, 29j show that all temperatures in this test are stable. Percents of CO are always below 3.0 except the 35th minute, and there was no back puffing too. No thicker creosote droplet was coming out after reheating the chimney by steam.

## WOOD BURNING TEST RESULTS

TEST NUMBER : A-04/18/79

DATE OF TEST : APRIL 18,1979

AMBIENT TEMPERATURE : 79 DEG F

DAMPER SETTING :
POSITION 1

FUEL : WET HICKORY BRAND 8,6

MOISTURE CONTENT 27.0 % HHV= -6439.3

| TIME | | LBS WOOD | FLUE GAS TEMP (F) | %CO2 | %O2 | %CO | %COM | %EFF | A/F RATIO | THEO AIR | HEAT RLSE BTU/HR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 24.5 | 338.0 | | | | | | | | 0. |
| 5 | 0 | 22.9 | 293.0 | 8.3 | 12.3 | 1.8 | 2.8 | 37.9 | 6.49 | 4.58 | 123635. |
| 10 | 0 | 21.6 | 217.0 | | | | | | | | 100453. |
| 15 | 0 | 20.9 | 153.0 | 9.5 | 11.0 | 2.7 | 3.9 | 36.2 | 5.04 | 4.58 | 54091. |
| 20 | 0 | 20.3 | 130.0 | | | | | | | | 46362. |
| 25 | 0 | 19.6 | 129.0 | 10.3 | 10.3 | 3.3 | 5.0 | 32.1 | 4.25 | 4.58 | 54090. |
| 30 | 0 | 19.0 | 128.0 | | | | | | | | 46364. |
| 35 | 0 | 18.3 | 124.0 | 9.0 | 11.5 | 2.3 | 3.3 | 40.0 | 5.63 | 4.58 | 54090. |
| 40 | 0 | 17.9 | 133.0 | | | | | | | | 30909. |
| 45 | 0 | 17.0 | 139.0 | 9.8 | 10.8 | 2.3 | 3.6 | 39.7 | 5.21 | 4.58 | 69544. |
| 50 | 0 | 16.1 | 136.0 | | | | | | | | 69544. |
| 55 | 0 | 15.4 | 132.0 | 9.7 | 11.1 | 2.3 | 4.0 | 36.9 | 5.08 | 4.58 | 54091. |
| 60 | 0 | 14.8 | 123.0 | | | | | | | | 46363. |
| 65 | 0 | 14.3 | 115.0 | 10.3 | 10.5 | 2.0 | 3.7 | 41.5 | 5.12 | 4.58 | 38636. |
| 70 | 0 | 13.9 | 114.0 | | | | | | | | 30909. |
| 75 | 0 | 13.7 | 115.0 | 9.4 | 11.6 | 1.8 | 3.7 | 38.9 | 5.50 | 4.58 | 15454. |
| 80 | 0 | 13.2 | 114.0 | | | | | | | | 38636. |
| 85 | 0 | 13.0 | 114.0 | 9.4 | 11.5 | 2.0 | 3.8 | 38.3 | 5.39 | 4.58 | 15454. |
| 90 | 0 | 12.8 | 113.0 | | | | | | | | 15454. |
| 95 | 0 | 12.3 | 125.0 | 9.0 | 11.5 | 1.5 | 2.3 | 50.0 | 5.62 | 4.58 | 38636. |
| 100 | 0 | 11.7 | 128.0 | | | | | | | | 46363. |
| 105 | 0 | 11.2 | 119.0 | 9.6 | 11.4 | 2.2 | 4.3 | 35.3 | 5.04 | 4.58 | 38636. |
| 110 | 0 | 10.8 | 123.0 | | | | | | | | 30909. |
| 115 | 0 | 10.4 | 126.0 | 9.5 | 11.6 | 2.6 | 5.0 | 30.1 | 4.66 | 4.58 | 30909. |
| 120 | 0 | 9.9 | 132.0 | | | | | | | | 38636. |
| 125 | 0 | 9.5 | 129.0 | 8.4 | 12.4 | 1.8 | 3.2 | 39.5 | 6.20 | 4.58 | 30909. |
| 130 | 0 | 9.0 | 127.0 | | | | | | | | 38636. |
| 135 | 0 | 8.6 | 128.0 | 8.0 | 12.7 | 2.0 | 3.2 | 37.8 | 6.27 | 4.58 | 30909. |
| 140 | 0 | 8.3 | 129.0 | | | | | | | | 23182. |
| 145 | 0 | 7.9 | 134.0 | 8.0 | 12.6 | 1.6 | 2.5 | 44.6 | 6.97 | 4.58 | 30909. |
| 150 | 0 | 7.5 | 136.0 | | | | | | | | 30909. |
| 155 | 0 | 7.3 | 134.0 | | | | | | | | 15454. |
| 160 | 0 | 7.1 | 136.0 | 7.4 | 13.2 | 1.2 | 1.8 | 49.7 | 8.16 | 4.58 | 15454. |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 165 | 0 | 5.6 | 138.0 | | | | | | | | 38636. |
| 170 | 0 | 5.2 | 140.0 | | | | | | | | 30909. |
| 175 | 0 | 5.7 | 138.0 | 3.0 | 12.5 | 1.3 | 1.9 | 51.2 | 7.63 | 4.58 | 38636. |
| 180 | 0 | 5.3 | 143.0 | | | | | | | | 30909. |
| 185 | 0 | 4.9 | 148.0 | | | | | | | | 30909. |
| 190 | 0 | 4.6 | 145.0 | 7.4 | 13.6 | 0.2 | 1.3 | 59.1 | 9.73 | 4.58 | 23182. |
| 195 | 0 | 4.5 | 145.0 | | | | | | | | 7727. |
| 200 | 0 | 4.4 | 147.0 | | | | | | | | 7727. |
| 205 | 0 | 4.3 | 149.0 | | | | | | | | 7727. |

REMARKS

AVERAGE HEAT RELEASED: 38070.6 BTU/HR

AVERAGE HEAT OUTPUT : 16244.0 BTU/HR

AVERAGE EFFICIENCY : 42.7 %

COOLING WATER TEMP= 61 F TEST BY JOE JUGER

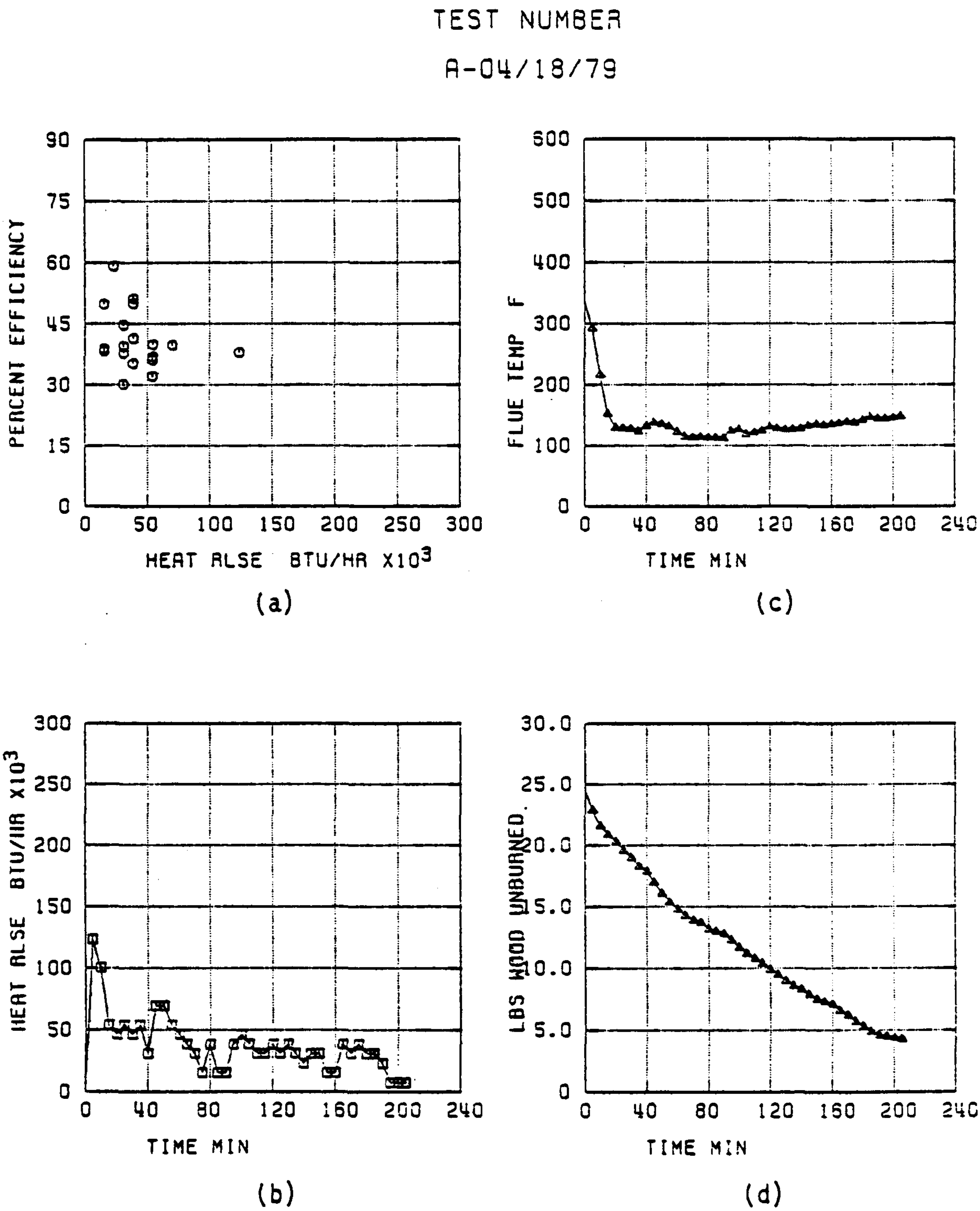



Figure 30. Test Data of Wet Hickory Brand B

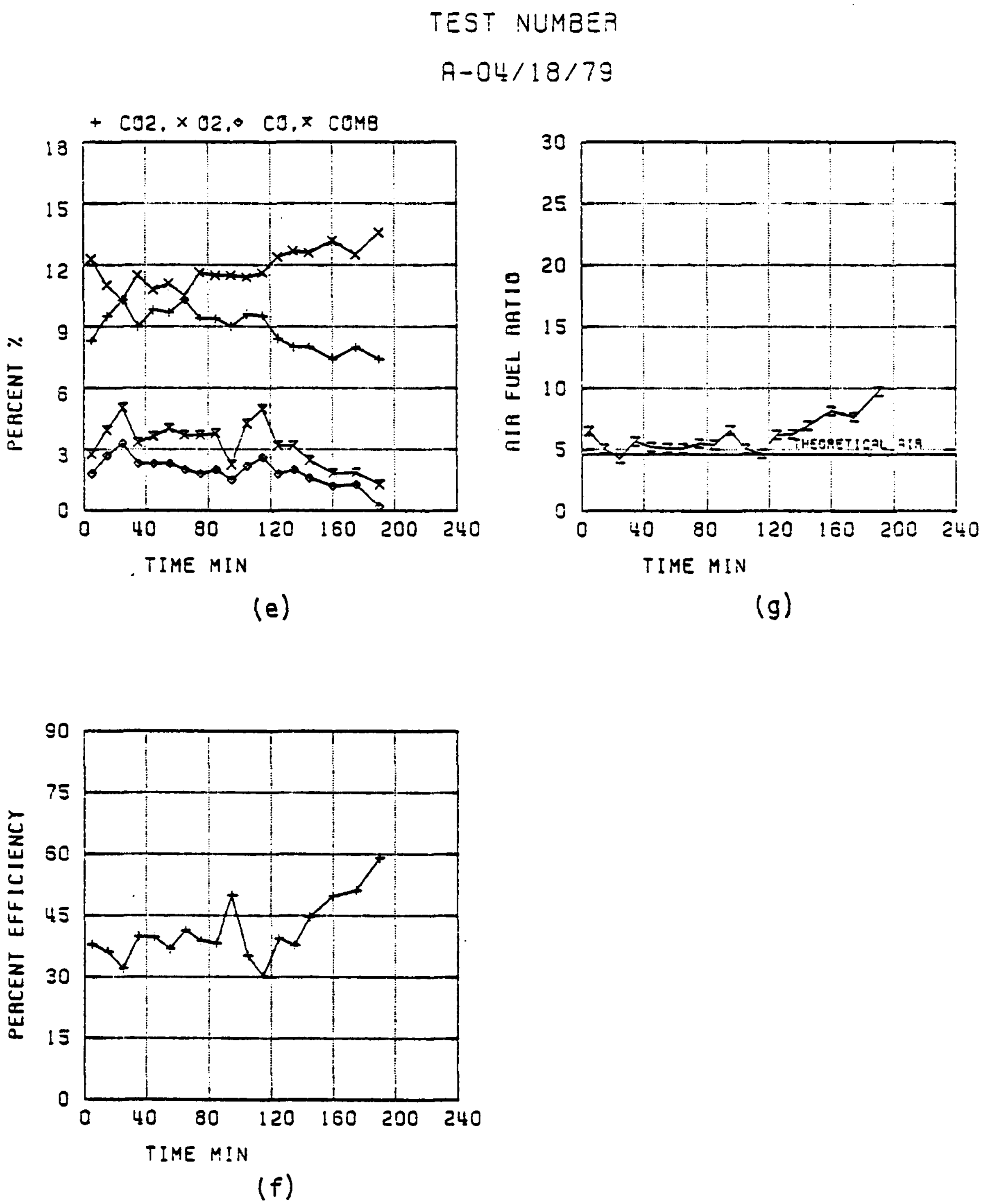



Figure 30. Continued

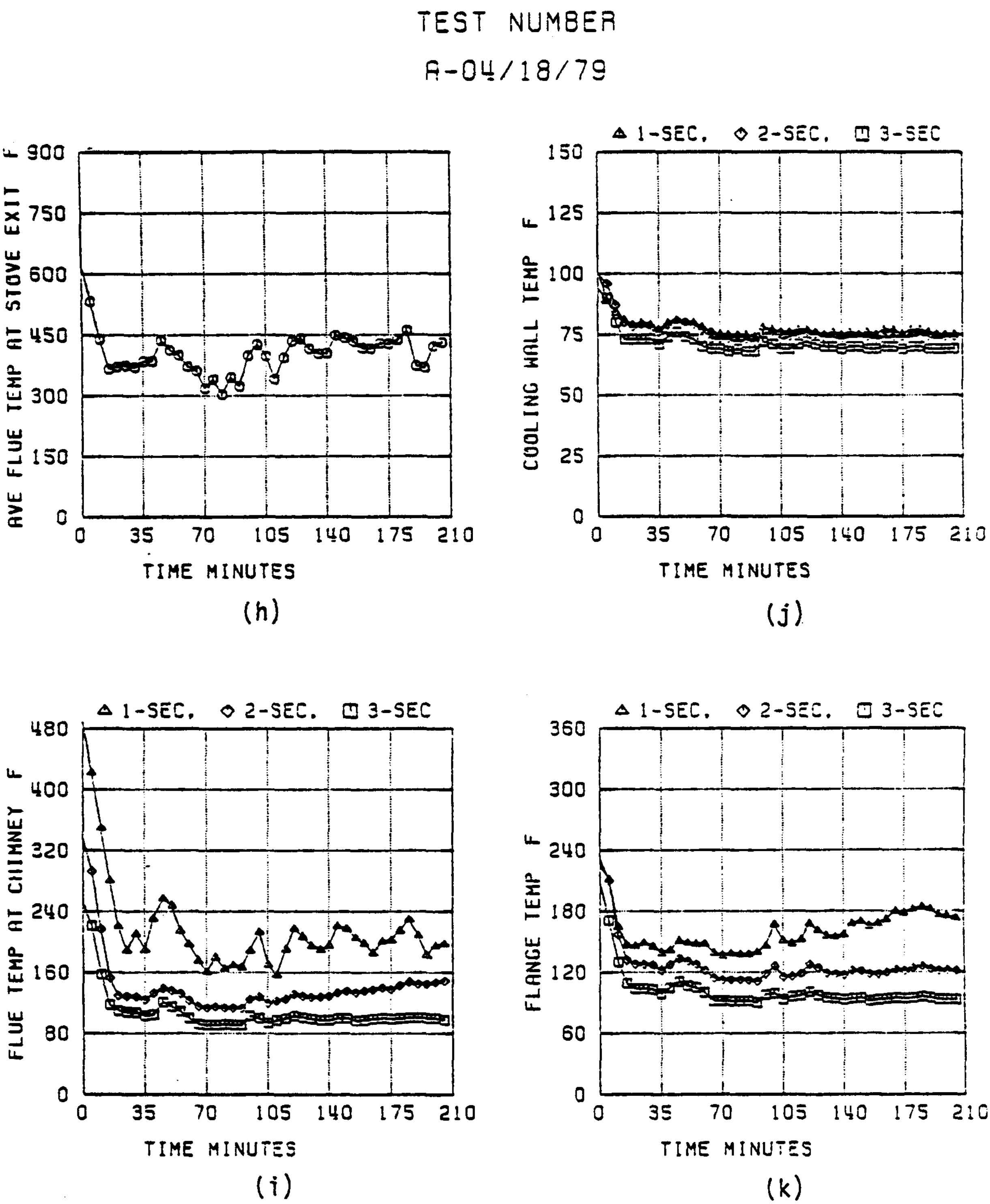



Figure 30. Continued

DISCUSSION OF TEST A-04/18/79 (Wet Hickory Brand B)

To understand the characteristics of different kind of wood as a fuel, hickory was introduced in the test. Still huge amount of water with the creosote mixture and a relatively low optical density of it. Low burning rate, stable cooling wall temperature, but unstable flue temperature at stove exit and in first section. Test started with high temperature, there is a pit on the Figure30g and a peak on the Figure 30e at 25th minute, show that there is not enough air to burn the combustibles, gases fled from wood surface up to the chimney. Three big black puffings with blue smoke happened at 115th minute, probably due to slow stream, too much carbon monoxide reacted to the oxygen, a pit and a peak can be found on the Figure 30g and30e at the 115th minute. Note the amount of the creosote generated is proportional to the percent of carbon monoxide in the flue.

# WOOD BURNING TEST RESULTS

TEST NUMBER : A-04/19/79

DATE OF TEST : APRIL 19,1979

AMBIENT TEMPERATURE : 77 DEG F

DAMPER SETTING :
POSITION 1

FUEL : WET HICKORY STANDARD BRAND,6

MOISTURE CONTENT 27.0 % HHV= -6439.3

| TIME | | LBS WOOD | FLUE GAS TEMP (F) | %CO2 | %O2 | %CO | %COM | %EFF | A/F RATIO | THEO AIR | HEAT RISE BTU/HR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 27.6 | 348.0 | | | | | | | | 0. |
| 5 | 0 | 26.2 | 256.0 | 10.4 | 9.8 | 2.4 | 3.1 | 42.6 | 5.23 | 4.58 | 108181. |
| 10 | 0 | 24.9 | 204.0 | | | | | | | | 100454. |
| 15 | 0 | 24.0 | 162.0 | 11.6 | 9.0 | 3.6 | 5.6 | 31.9 | 3.76 | 4.58 | 69544. |
| 20 | 0 | 23.1 | 150.0 | | | | | | | | 69544. |
| 25 | 0 | 22.3 | 135.0 | 10.4 | 10.6 | 2.8 | 5.2 | 31.6 | 4.31 | 4.58 | 61818. |
| 30 | 0 | 21.6 | 131.0 | | | | | | | | 54090. |
| 35 | 0 | 20.3 | 165.0 | 10.2 | 9.3 | 3.0 | 3.4 | 41.1 | 4.93 | 4.58 | 100454. |
| 40 | 0 | 19.2 | 157.0 | | | | | | | | 85000. |
| 45 | 0 | 18.3 | 136.0 | 11.5 | 8.9 | 3.4 | 4.9 | 35.7 | 4.01 | 4.58 | 69544. |
| 50 | 0 | 17.6 | 120.0 | | | | | | | | 54090. |
| 55 | 0 | 17.2 | 120.0 | 9.4 | 11.2 | 2.3 | 3.6 | 39.4 | 5.37 | 4.58 | 30909. |
| 60 | 0 | 16.5 | 119.0 | | | | | | | | 54090. |
| 65 | 0 | 16.1 | 118.0 | 9.5 | 11.3 | 2.0 | 3.6 | 39.9 | 5.44 | 4.58 | 30908. |
| 70 | 0 | 15.7 | 133.0 | | | | | | | | 30909. |
| 75 | 0 | 15.0 | 145.0 | 11.2 | 9.3 | 1.9 | 3.1 | 47.5 | 5.13 | 4.58 | 54090. |
| 80 | 0 | 14.1 | 157.0 | | | | | | | | 69545. |
| 85 | 0 | 13.4 | 155.0 | 11.0 | 9.6 | 1.6 | 2.9 | 48.9 | 5.40 | 4.58 | 54090. |
| 90 | 0 | 13.0 | 161.0 | | | | | | | | 30909. |
| 95 | 0 | 12.3 | 170.0 | 10.2 | 10.6 | 1.4 | 2.9 | 46.6 | 5.77 | 4.58 | 54090. |
| 100 | 0 | 11.9 | 153.0 | | | | | | | | 30909. |
| 105 | 0 | 11.2 | 179.0 | 11.2 | 9.5 | 1.4 | 2.8 | 49.3 | 5.43 | 4.58 | 54090. |
| 110 | 0 | 10.8 | 233.0 | | | | | | | | 30909. |
| 115 | 0 | 10.4 | 147.0 | 9.5 | 11.7 | 2.2 | 4.6 | 31.8 | 4.91 | 4.58 | 30909. |
| 120 | 0 | 9.9 | 123.0 | | | | | | | | 38636. |
| 125 | 0 | 9.5 | 126.0 | 9.2 | 12.0 | 2.4 | 4.9 | 29.8 | 4.85 | 4.58 | 30909. |
| 130 | 0 | 9.0 | 125.0 | | | | | | | | 38636. |
| 135 | 0 | 8.8 | 122.0 | 10.0 | 10.7 | 2.0 | 3.5 | 42.2 | 5.33 | 4.58 | 15454. |
| 140 | 0 | 8.6 | 122.0 | | | | | | | | 15454. |
| 145 | 0 | 8.4 | 121.0 | | | | | | | | 15454. |
| 150 | 0 | 7.9 | 129.0 | 9.0 | 11.6 | 1.8 | 2.9 | 44.1 | 5.10 | 4.58 | 38536. |
| 155 | 0 | 7.7 | 129.0 | | | | | | | | 15454. |
| 160 | 0 | 7.1 | 123.0 | | | | | | | | 46363. |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 165 | 0 | 5.8 | 123.0 | 3.6 | 12.3 | 1.3 | 3.4 | 38.3 | 5.98 | 4.58 | 23132. |
| 170 | 0 | 6.4 | 131.0 | | | | | | | | 30909. |
| 175 | 0 | 6.0 | 135.0 | | | | | | | | 30909. |
| 180 | 0 | 5.9 | 136.0 | 3.0 | 12.8 | 1.6 | 2.8 | 40.9 | 6.70 | 4.58 | 38636. |
| 185 | 0 | 5.4 | 138.0 | | | | | | | | 7727. |
| 190 | 0 | 5.3 | 136.0 | | | | | | | | 7727. |

REMARKS

AVERAGE HEAT RELEASED: 45346.4 BTU/HR

AVERAGE HEAT OUTPUT : 18724.8 BTU/HR

AVERAGE EFFICIENCY : 41.3 %

COOLING WATER TEMP= 62 F TEST BY JOE JUGER

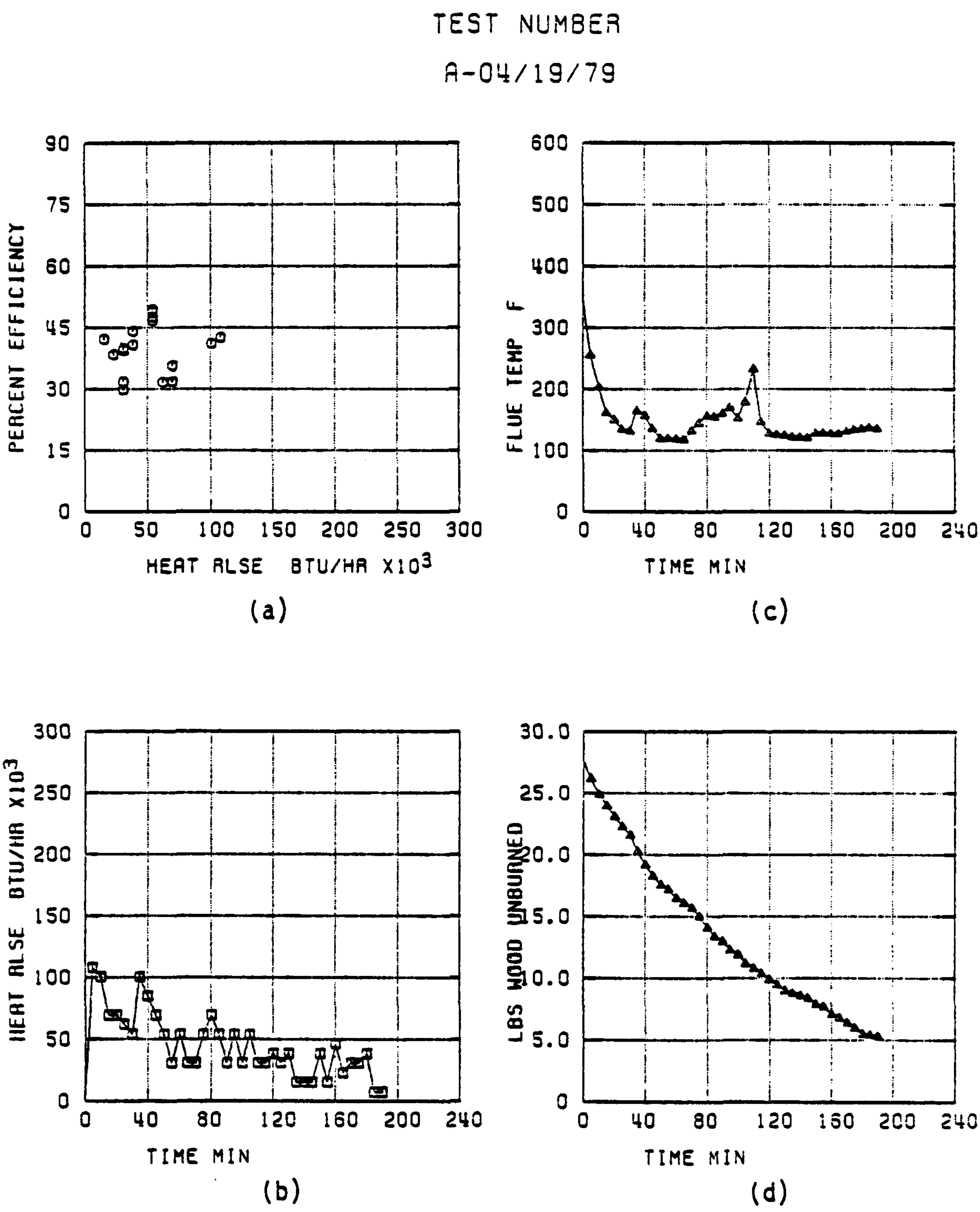
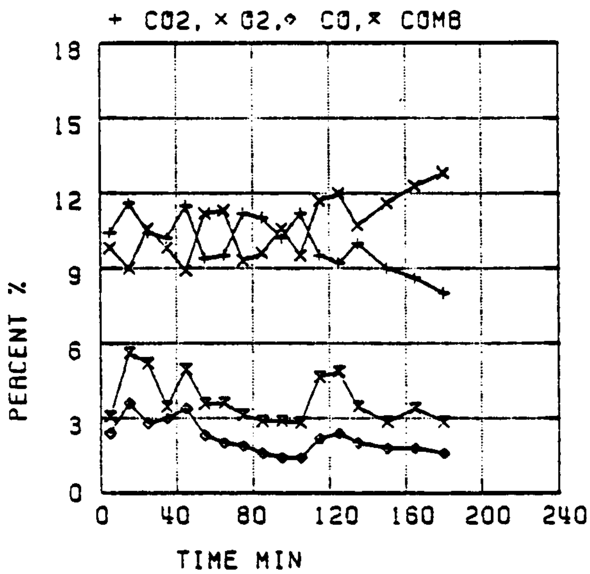


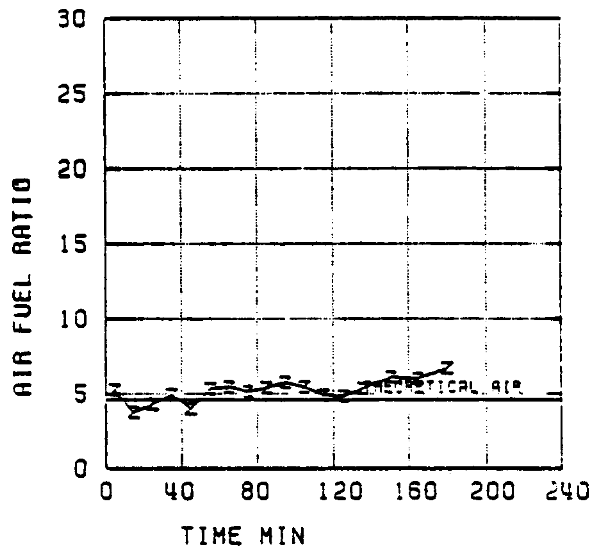

Figure 31. Test Data of Wet Hickory Standard Brand

TEST NUMBER

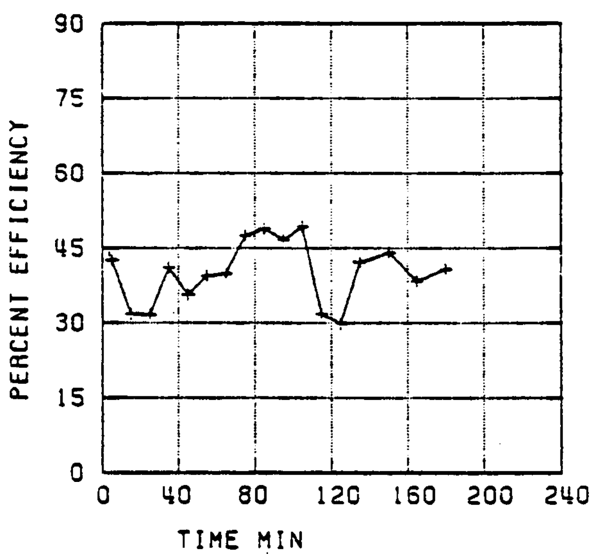
A-04/19/79




(e)




(g)




(f)

Figure 3I. Continued

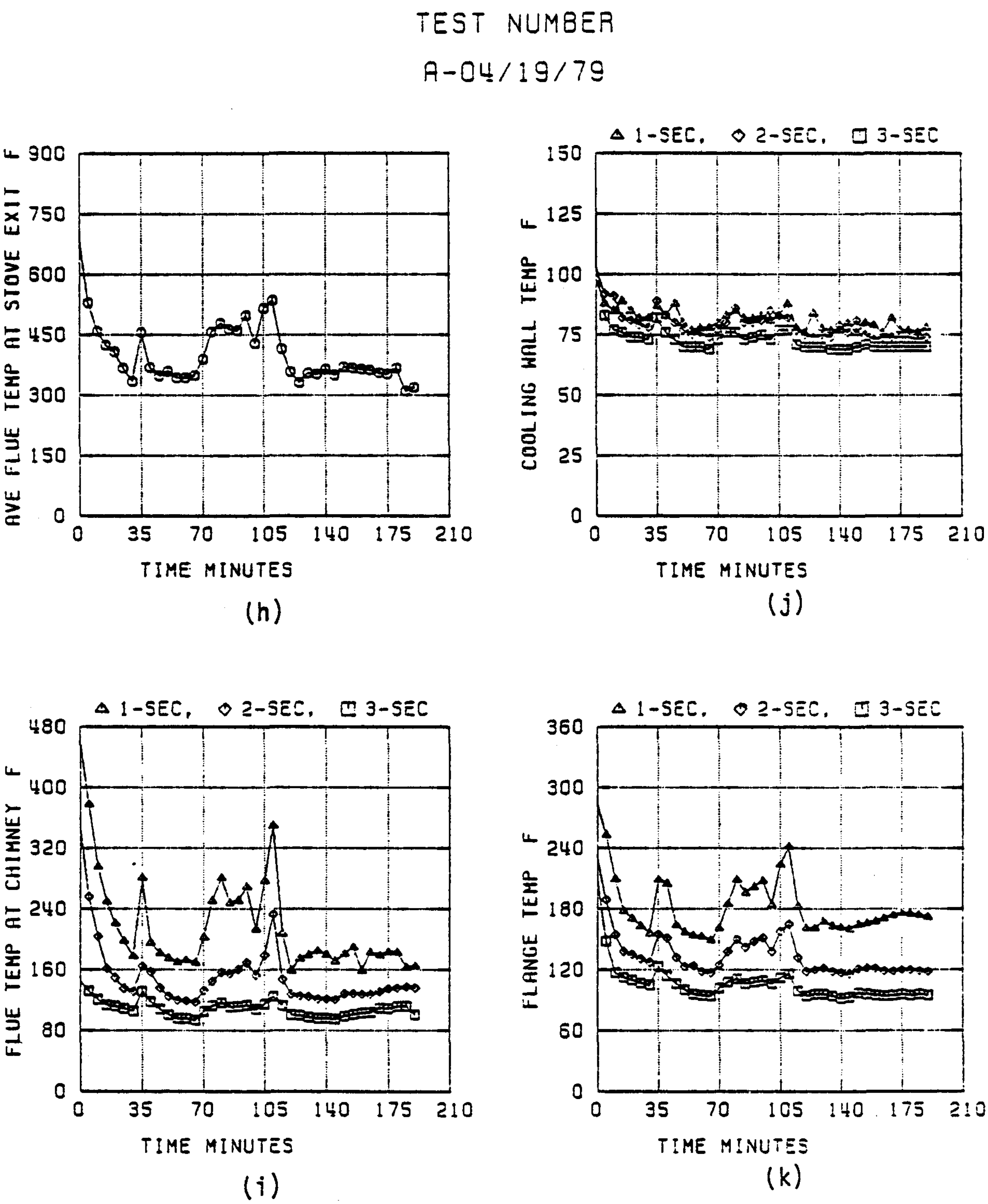



Figure 31. Continued

DISCUSSION OF TEST A-04/19/79 (Wet Hickory Standard Brand)

Having generated the data indicated in Figure 31, it must be emphasized that this test can not tell too much difference from last test. This is due to high levels of moisture content of the wood. Water vapor dilution effect were apparent in these tests (A-04/13/79, A-04/17/79, A-04/19/79, A-04/19/79). Creosote number of these test vary from 26 to 34. It is estimated that the thicker creosote will not be formed if the creosote number is below 60. It is important that under the conditions tested, the level of moisture content has large influence on the creosote formation. The flue temperatures of the test A-04/18/79 and A-04/19/79 are apparently more unstable than that of the test A-04/13/79 and A-04/17/79 (see Figure 28, 29, 30, 31). It seems that hickory is more active in the combustion than the oak.

WOOD BURNING TEST RESULTS

TEST NUMBER : A-04/25/79

DATE OF TEST : APRIL 25,1979

AMBIENT TEMPERATURE : 70 DEG F

DAMPER SETTING :
POSITION 1

FUEL : DRY OAK STANDARD BRAND,6

MOISTURE CONTENT 0.0 % HHV= -8821.0

| TIME | | LBS WOOD | FLUE GAS TEMP (F) | %CO2 | %O2 | %CO | %COM | %EFF | A/F RATIO | THEO AIR | HEAT RLSE BTU/HR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 19.0 | 353.0 | | | | | | | | 0. |
| 5 | 0 | 18.3 | 155.0 | 9.3 | 11.6 | 4.1 | 7.6 | 24.2 | 4.65 | 6.13 | 74096. |
| 10 | 0 | 17.9 | 128.0 | | | | | | | | 42342. |
| 15 | 0 | 17.6 | 76.0 | 12.1 | 8.5 | 3.2 | 5.2 | 43.6 | 5.19 | 6.13 | 31754. |
| 20 | 0 | 17.2 | 137.0 | | | | | | | | 42342. |
| 25 | 0 | 16.5 | 105.0 | 15.0 | 7.6 | 5.6 | 12.7 | 22.0 | 2.65 | 6.13 | 74096. |
| 30 | 0 | 15.0 | 198.0 | 15.6 | 6.0 | 6.4 | 11.9 | 24.7 | 2.65 | 6.13 | 158778. |
| 35 | 0 | 13.4 | 143.0 | | | | | | | | 169363. |
| 40 | 0 | 12.6 | 133.0 | 14.4 | 7.8 | 5.6 | 11.3 | 22.8 | 2.83 | 6.13 | 84682. |
| 45 | 0 | 11.5 | 128.0 | | | | | | | | 116437. |
| 50 | 0 | 10.8 | 137.0 | 14.3 | 7.1 | 5.0 | 9.4 | 29.6 | 3.34 | 6.13 | 74096. |
| 55 | 0 | 10.1 | 131.0 | | | | | | | | 74096. |
| 60 | 0 | 9.7 | 126.0 | 10.8 | 9.8 | 2.8 | 4.4 | 43.6 | 5.97 | 6.13 | 42341. |
| 65 | 0 | 9.3 | 125.0 | | | | | | | | 42341. |
| 70 | 0 | 9.0 | 125.0 | 12.6 | 7.4 | 2.4 | 3.0 | 57.6 | 6.20 | 6.13 | 31756. |
| 75 | 0 | 8.6 | 126.0 | | | | | | | | 42341. |
| 80 | 0 | 8.4 | 127.0 | 12.6 | 7.4 | 2.2 | 2.7 | 59.7 | 6.40 | 6.13 | 21170. |
| 85 | 0 | 8.2 | 128.0 | | | | | | | | 21170. |
| 90 | 0 | 7.9 | 128.0 | 12.7 | 7.4 | 2.1 | 2.8 | 59.4 | 6.37 | 6.13 | 31756. |
| 95 | 0 | 7.5 | 129.0 | | | | | | | | 42341. |
| 100 | 0 | 7.3 | 130.0 | 12.6 | 7.5 | 2.1 | 2.8 | 59.3 | 6.41 | 6.13 | 21170. |
| 105 | 0 | 7.1 | 130.0 | | | | | | | | 21170. |
| 110 | 0 | 6.8 | 130.0 | 11.4 | 8.7 | 2.1 | 2.6 | 58.2 | 6.97 | 6.13 | 31756. |
| 115 | 0 | 6.6 | 129.0 | | | | | | | | 21170. |
| 120 | 0 | 6.4 | 128.0 | 10.4 | 9.8 | 1.9 | 2.4 | 58.0 | 7.67 | 6.13 | 21170. |
| 125 | 0 | 6.3 | 130.0 | | | | | | | | 10585. |
| 130 | 0 | 6.2 | 129.0 | 9.6 | 10.2 | 2.1 | 1.8 | 61.5 | 8.47 | 6.13 | 10585. |
| 135 | 0 | 6.0 | 129.0 | | | | | | | | 21170. |
| 140 | 0 | 5.8 | 128.0 | | | | | | | | 21170. |
| 145 | 0 | 5.7 | 131.0 | 9.0 | 10.8 | 2.4 | 2.1 | 56.5 | 8.39 | 6.13 | 10585. |
| 150 | 0 | 5.6 | 126.0 | | | | | | | | 10585. |
| 155 | 0 | 5.5 | 125.0 | | | | | | | | 10585. |
| 160 | 0 | 5.3 | 124.0 | 8.1 | 11.8 | 2.4 | 2.2 | 53.5 | 8.92 | 6.13 | 21170. |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 165 | 0 | 4.9 | 123.0 | | | | | | | | 42341. |
| 170 | 0 | 4.6 | 123.0 | | | | | | | | 31756. |
| 175 | 0 | 4.4 | 125.0 | 8.6 | 11.2 | 2.4 | 2.0 | 56.1 | 3.69 | 6.13 | 21170. |
| 180 | 0 | 4.2 | 128.0 | | | | | | | | 21170. |
| 185 | 0 | 4.0 | 128.0 | | | | | | | | 21170. |
| 190 | 0 | 3.7 | 128.0 | | | | | | | | 31756. |
| 195 | 0 | 3.3 | 130.0 | | | | | | | | 42341. |

REMARKS

AVERAGE HEAT RELEASED: 42612.2 BTU/HR

AVERAGE HEAT OUTPUT : 13329.5 BTU/HR

AVERAGE EFFICIENCY : 43.0 %

COOLING WATER TEMP= 63 F TEST BY JOE JUGER

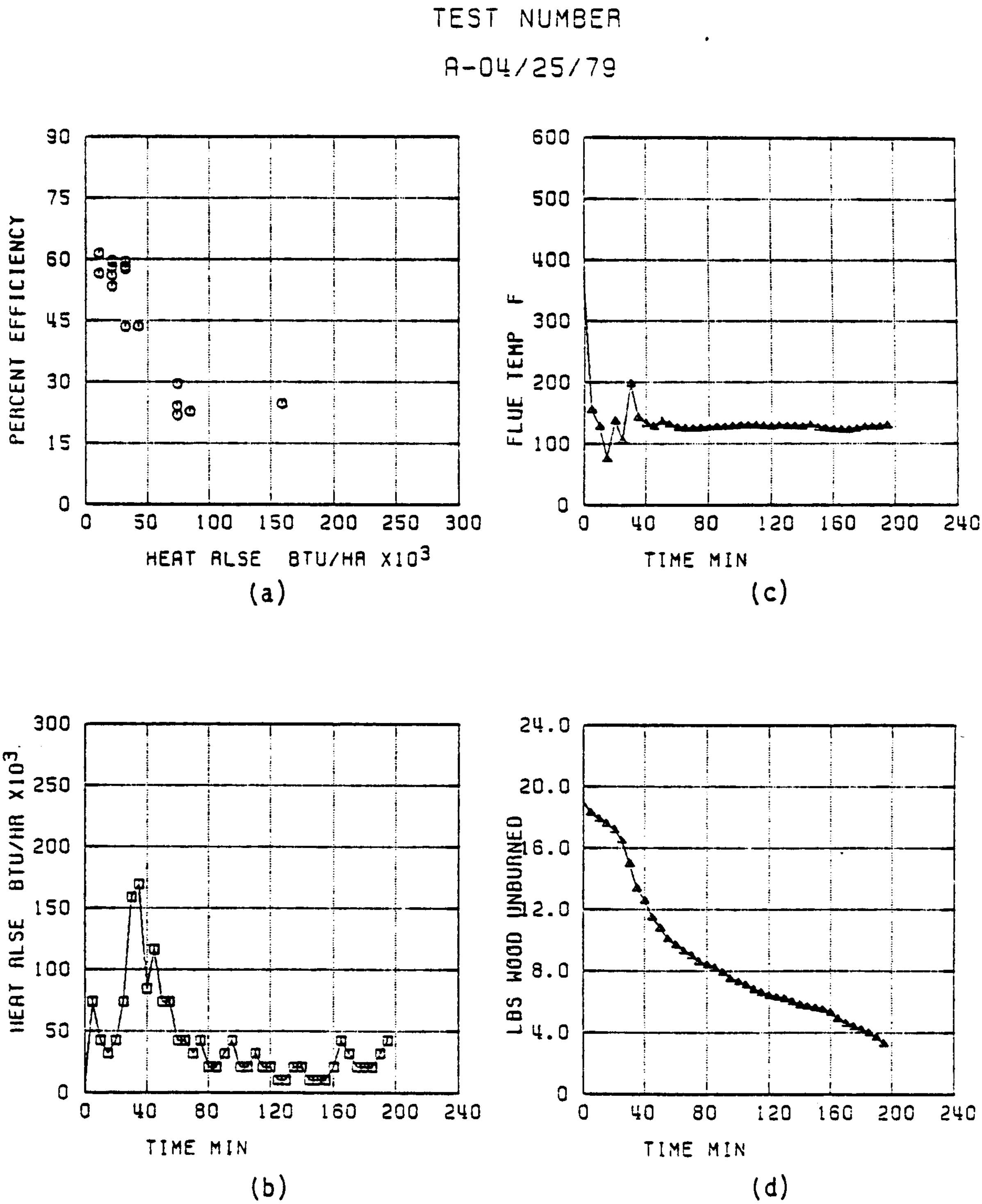



Figure 32. Test Data of Dry Oak Standard Brand

TEST NUMBER

A-04/25/79

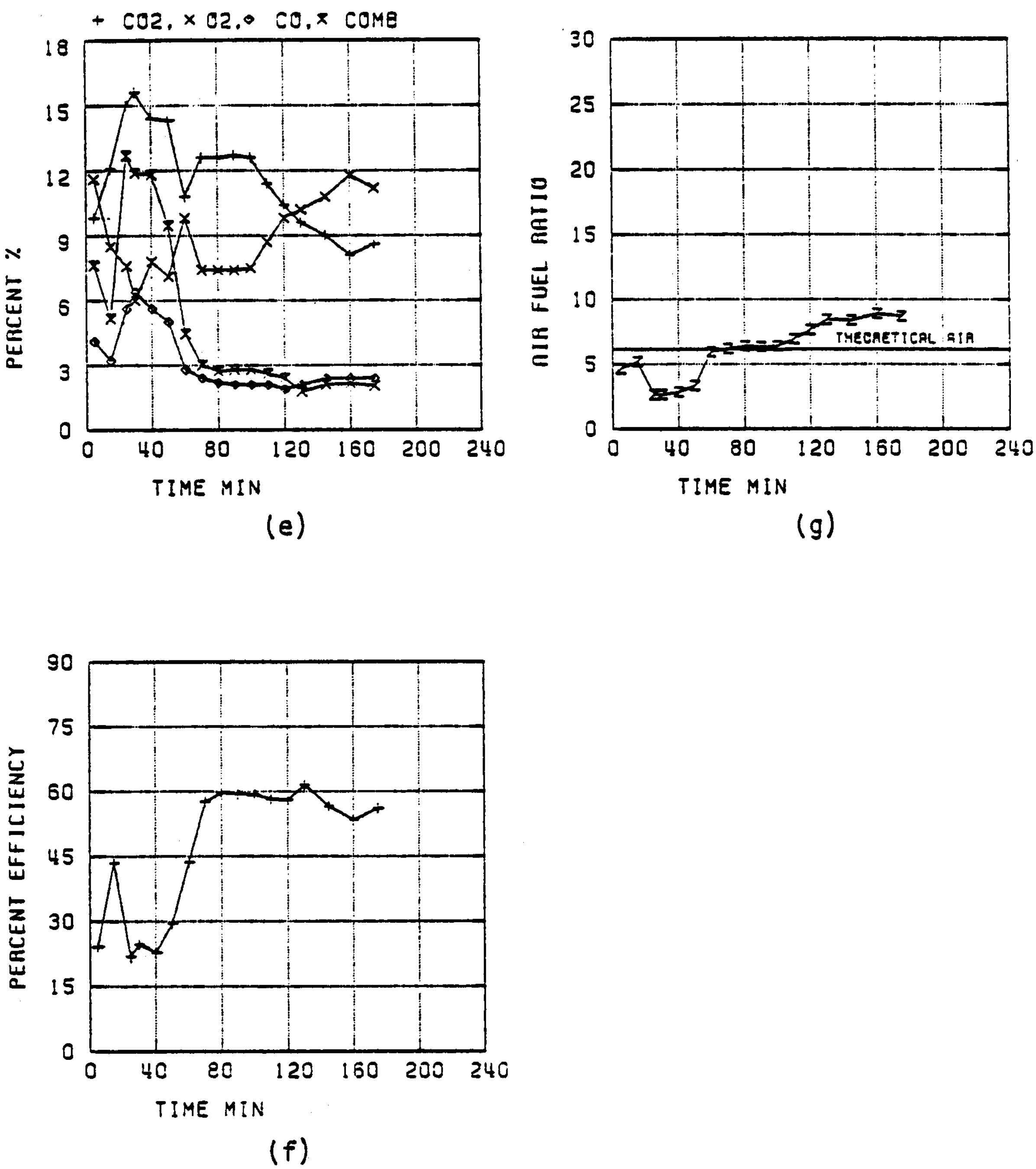



Figure 32. Continued

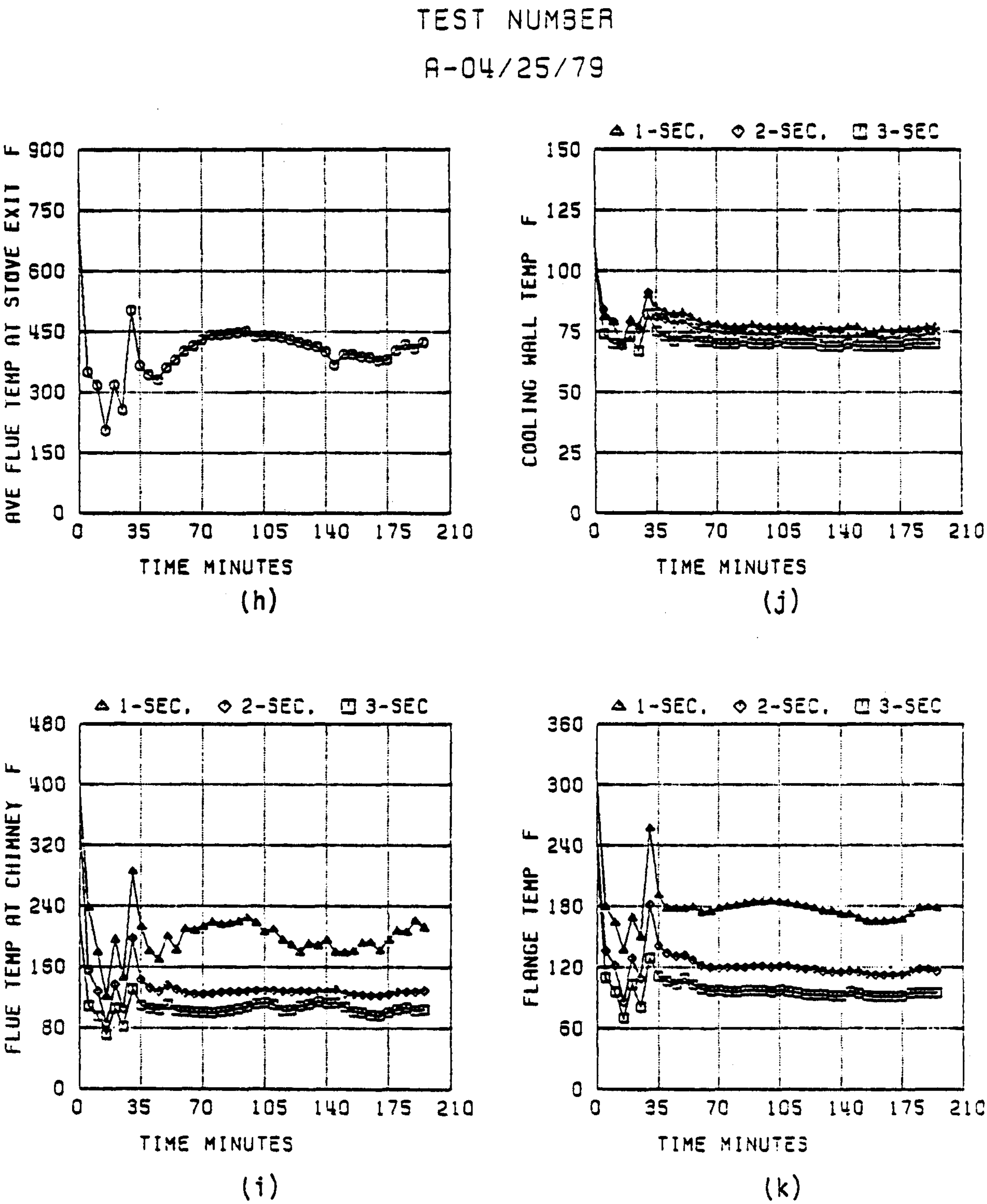



Figure 32. Continued

DISCUSSION OF TEST A-04/25/79 (Dry Oak Standard Brand)

The brands of these following four tests were in the oven dry condition (0.0% moisture content). One of the objectives of this overall research effort is to determine the effects of the moisture content of wood on their combustion characteristics and creosote formation in the chimney.

Six dry oak standard brands were tested in this run. From Figure 32b, 32e, 32f, 32g it can be concluded that for the first fifty five minutes, a lot of creosote or volatile matters were driven from the wood and fled to the chimney. No sufficient oxygen was supplied in these higher burning rate period. Therefore, the combustion efficiency is very low comparing with the latter period of the test run. Creosote mixture getting thicker and darker from 10th minute to 80th minute. Real creosote droplets flew out with thinner mixture. Thicker creosote then gathered together, first floated on the surface of the mixture, then, getting heavier and deposited to the bottom of the breaker. This happened only on the first section of the chimney. Relative optical density of this test higher than that of last four tests (wet brand tests). More distinct phenomenon will be seen in the latter three tests.

# WOOD BURNING TEST RESULTS

TEST NUMBER : 3-04/27/79

DATE OF TEST : APRIL 27,1979

AMBIENT TEMPERATURE : 73 DEG F

DAMPER SETTING :
POSITION 1

FUEL : DRY HICKORY STANDARD BRAND,6

MOISTURE CONTENT 0.0 % HHV= -8821.0

| TIME | | LBS WOOD | FLUE GAS TEMP (F) | %CO2 | %O2 | %CO | %COM | %EFF | A/F RATIO | THEO AIR | HEAT RLSE BTU/HR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 22.0 | 211.0 | | | | | | | | 0. |
| 5 | 0 | 20.9 | 184.0 | 11.6 | 10.8 | 6.9 | 13.6 | 11.8 | 2.66 | 6.13 | 116438. |
| 10 | 0 | 20.1 | 134.0 | | | | | | | | 84680. |
| 15 | 0 | 19.4 | 135.0 | 15.0 | 7.6 | 5.6 | 12.7 | 21.6 | 2.65 | 6.13 | 74098. |
| 20 | 0 | 17.6 | 229.0 | | | | | | | | 190532. |
| 25 | 0 | 16.5 | 155.0 | 13.8 | 8.4 | 4.8 | 10.7 | 24.2 | 3.18 | 6.13 | 116438. |
| 30 | 0 | 15.4 | 145.0 | | | | | | | | 116437. |
| 35 | 0 | 14.3 | 135.0 | 12.9 | 9.4 | 4.3 | 10.7 | 22.1 | 3.26 | 6.13 | 116437. |
| 40 | 0 | 13.0 | 137.0 | | | | | | | | 137608. |
| 45 | 0 | 11.5 | 141.0 | 15.7 | 5.6 | 5.4 | 10.0 | 30.8 | 3.05 | 6.13 | 158778. |
| 50 | 0 | 10.1 | 148.0 | | | | | | | | 148193. |
| 55 | 0 | 8.8 | 152.0 | 17.9 | 3.1 | 5.5 | 9.8 | 35.2 | 2.86 | 6.13 | 137608. |
| 60 | 0 | 7.7 | 150.0 | | | | | | | | 116437. |
| 65 | 0 | 6.6 | 143.0 | 14.4 | 5.4 | 4.4 | 5.5 | 45.2 | 4.32 | 6.13 | 116437. |
| 70 | 0 | 6.2 | 140.0 | | | | | | | | 42341. |
| 75 | 0 | 5.7 | 153.0 | 11.8 | 7.4 | 2.9 | 2.0 | 62.3 | 6.31 | 6.13 | 52926. |
| 80 | 0 | 5.5 | 157.0 | | | | | | | | 21170. |
| 85 | 0 | 5.3 | 152.0 | 11.7 | 7.9 | 1.8 | 1.3 | 70.1 | 7.32 | 6.13 | 21170. |
| 90 | 0 | 5.1 | 153.0 | | | | | | | | 21170. |
| 95 | 0 | 4.6 | 148.0 | 11.3 | 6.2 | 1.5 | 1.7 | 67.4 | 7.67 | 6.13 | 52926. |
| 100 | 0 | 4.4 | 148.0 | | | | | | | | 21170. |
| 105 | 0 | 4.2 | 143.0 | 12.5 | 7.6 | 1.8 | 2.4 | 62.4 | 6.79 | 6.13 | 21170. |
| 110 | 0 | 4.0 | 145.0 | | | | | | | | 21170. |
| 115 | 0 | 3.9 | 140.0 | | | | | | | | 10585. |
| 120 | 0 | 3.7 | 138.0 | | | | | | | | 21170. |

REMARKS

AVERAGE HEAT RELEASED: 80712.1 BTU/HR

AVERAGE HEAT OUTPUT : 25892.0 BTU/HR

AVERAGE EFFICIENCY : 32.1 %

COOLING WATER TEMP= 64 F TEST BY JOE JUGER

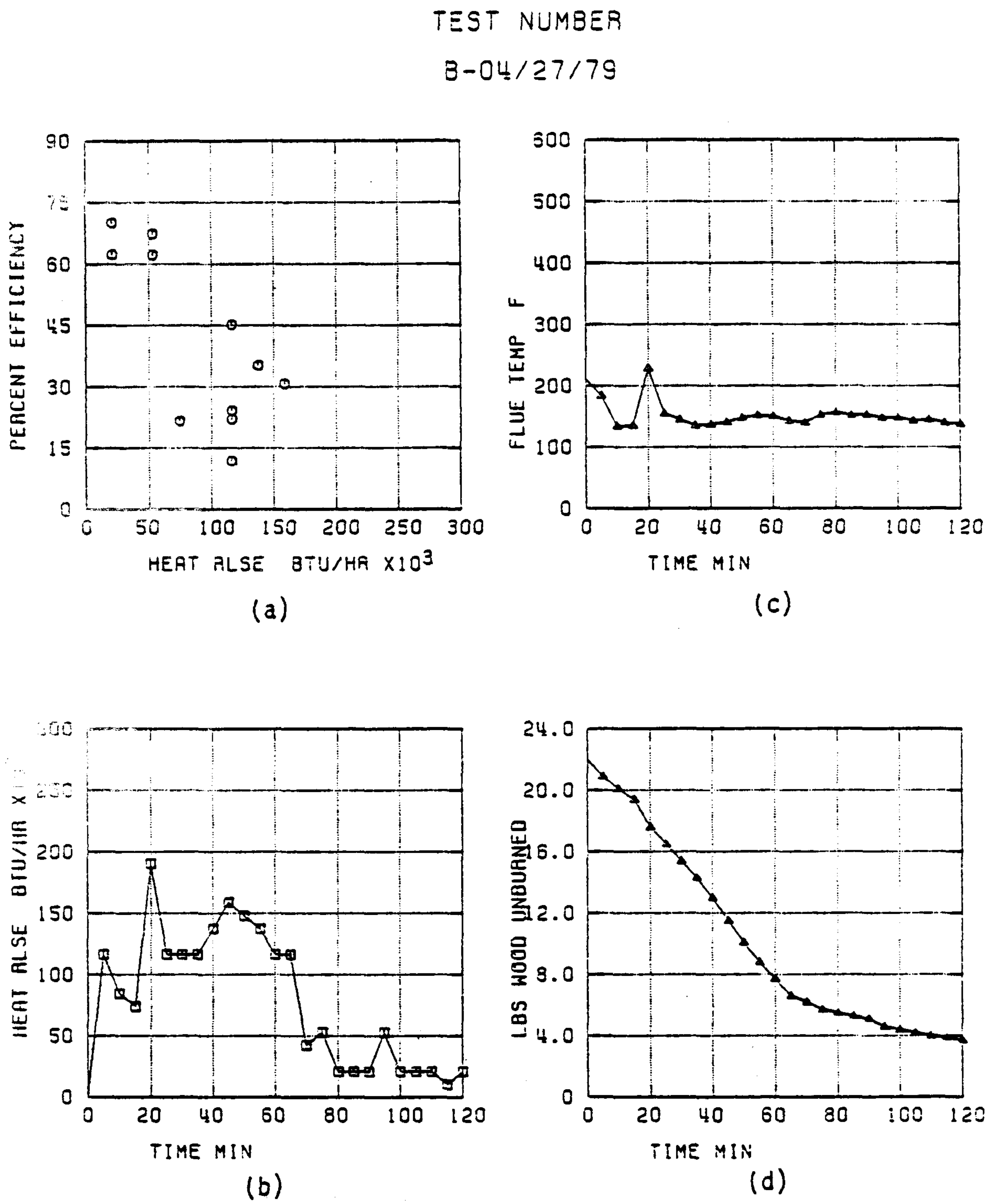
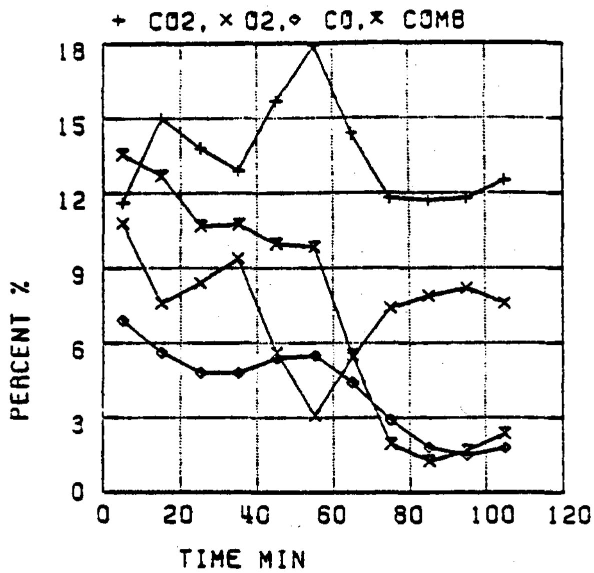


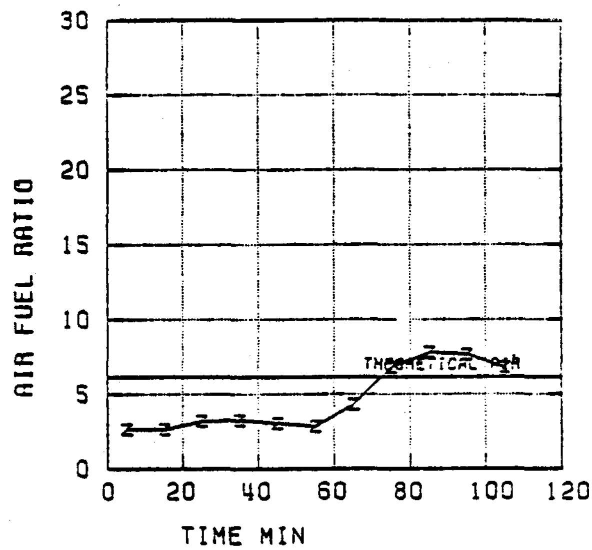

Figure 33. Test Data of Dry Hickory Standard Brand

TEST NUMBER

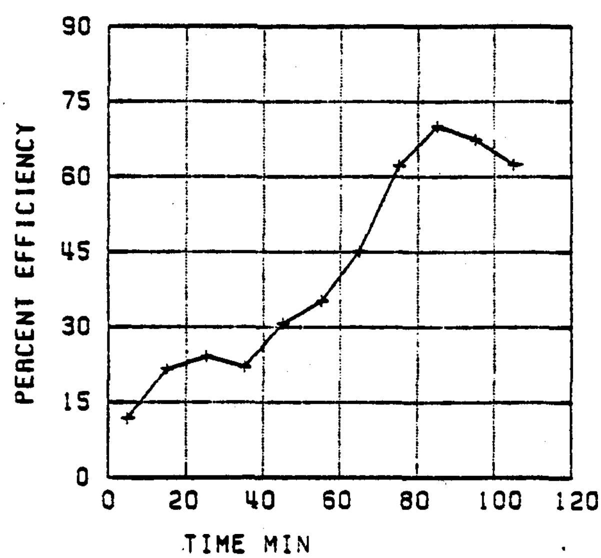
B-04/27/79




(e)




(g)




(f)

Figure 3.3. Continued

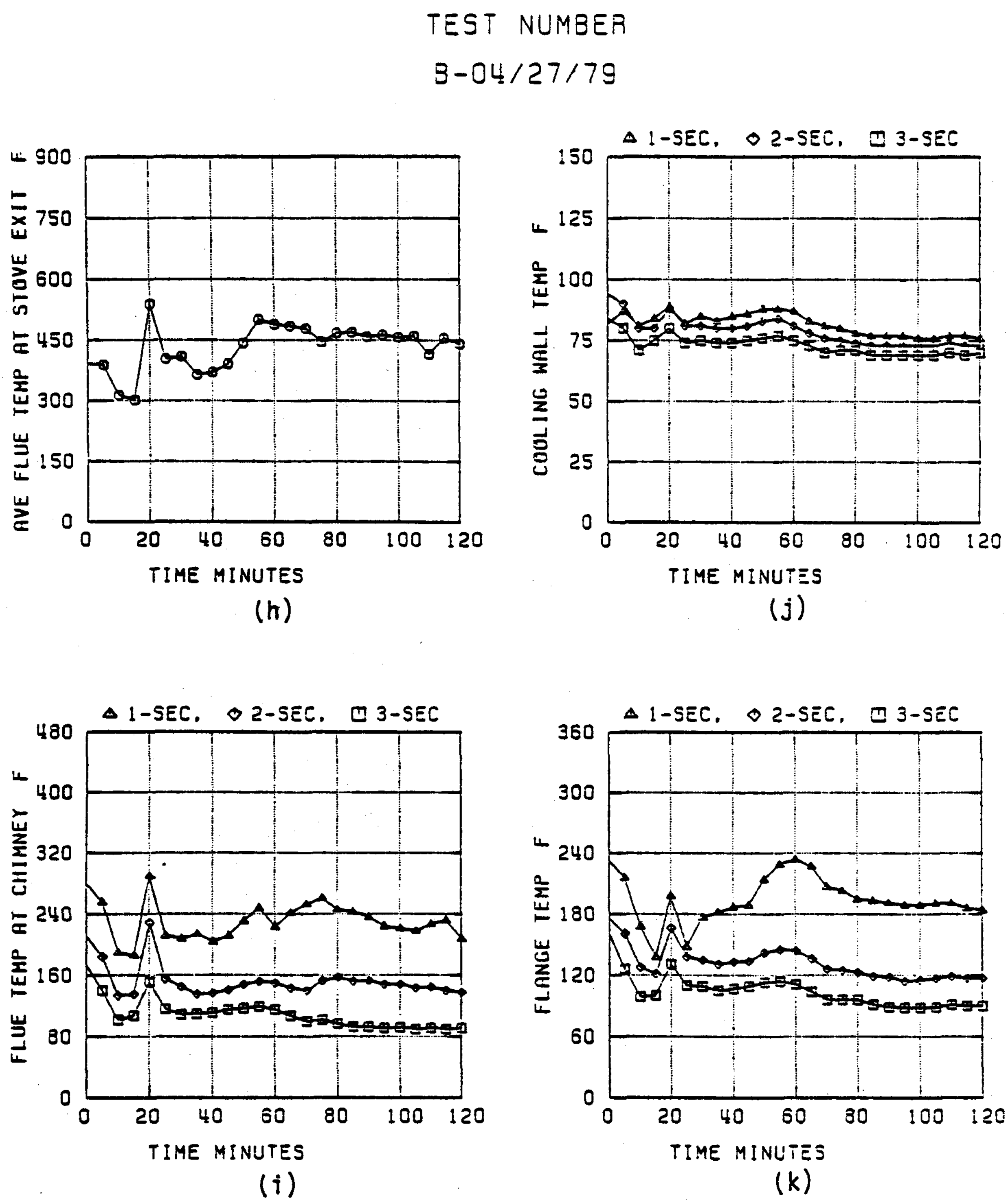



Figure 33. Continued

DISCUSSION OF TEST A-04/27/79 (Dry Hickory Standard Brand)

The test data shown in Figure 33 were for combustion of six dry hickory standard brands, so that one can tell the difference of amount of creosote formation in the chimney between burning the oak and the hickory. Burning rate of this test is higher than that of last test. There were about fifteen little back puffings every five minutes beginning at 40th minute ending at 70th minute. Huge amount of thicker creosote were formed in this period, due to large amount of thick smoke with high partial pressure of the creosote. The effect of combustion water dilution on the creosote formation was very small. As noted in Figure 33b, 33e, 33f, 33g, the first seventy minutes of the test was in higher heat release, low efficiency, very low air fuel ratio and with high contents of carbon monoxide, unburned combustibles and volatile matters in the flue. These are the good conditions for the creosote formation in the chimney. After the test was finished, reheating the chimney, large amount of pure creosote (highly combustible) flew out and quickly sank to the bottom of the beaker in the first section. It is concluded that the amount of creosote formation of burning the hickory is 30% [illegible] than that of burning the oak.

# WOOD BURNING TEST RESULTS

TEST NUMBER : C-04/29/79

DATE OF TEST : APRIL 23,1979

AMBIENT TEMPERATURE : 71 DEG F

DAMPER SETTING :
POSITION 1

FUEL : DRY OAK BRAND 8,6

MOISTURE CONTENT 0.0 % HHV= -8821.0

| TIME | | LBS WOOD | FLUE GAS TEMP (F) | %CO2 | %O2 | %CO | %COM | %EFF | A/F RATIO | THEO AIR | HEAT RLSE BTU/HR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 17.1 | 301.0 | | | | | | | | 0. |
| 5 | 0 | 14.8 | 311.0 | 17.7 | 3.2 | 4.8 | 8.7 | 36.6 | 3.15 | 6.13 | 243460. |
| 10 | 0 | 12.8 | 221.0 | | | | | | | | 211704. |
| 15 | 0 | 11.0 | 191.0 | 13.2 | 4.5 | 4.7 | 12.1 | 28.5 | 2.58 | 6.13 | 190534. |
| 20 | 0 | 9.0 | 190.0 | | | | | | | | 211704. |
| 25 | 0 | 7.7 | 192.0 | 14.3 | 5.6 | 3.9 | 5.0 | 46.7 | 4.58 | 6.13 | 137608. |
| 30 | 0 | 7.1 | 166.0 | | | | | | | | 63511. |
| 35 | 0 | 6.6 | 165.0 | 10.3 | 9.8 | 0.9 | 0.9 | 74.4 | 9.68 | 6.13 | 52926. |
| 40 | 0 | 6.4 | 155.0 | | | | | | | | 21170. |
| 45 | 0 | 6.2 | 155.0 | 10.8 | 9.0 | 1.4 | 1.0 | 72.3 | 8.80 | 6.13 | 21170. |
| 50 | 0 | 6.1 | 155.0 | | | | | | | | 10585. |
| 55 | 0 | 6.0 | 158.0 | 9.6 | 10.2 | 1.2 | 0.6 | 76.1 | 10.30 | 6.13 | 10585. |
| 60 | 0 | 5.8 | 154.0 | | | | | | | | 21170. |
| 65 | 0 | 5.7 | 153.0 | 10.1 | 9.5 | 1.4 | 0.5 | 76.9 | 9.76 | 6.13 | 10585. |
| 70 | 0 | 5.5 | 154.0 | | | | | | | | 21170. |
| 75 | 0 | 5.3 | 148.0 | 9.2 | 10.4 | 1.4 | 0.4 | 77.5 | 10.69 | 6.13 | 21170. |
| 80 | 0 | 5.2 | 147.0 | | | | | | | | 10585. |
| 85 | 0 | 5.1 | 147.0 | | | | | | | | 10585. |
| 90 | 0 | 5.0 | 144.0 | | | | | | | | 10585. |

REMARKS

AVERAGE HEAT RELEASED: 71156.1 BTU/HR

AVERAGE HEAT OUTPUT : 30172.7 BTU/HR

AVERAGE EFFICIENCY : 42.4 %

COOLING WATER TEMP= 63 F TEST BY JOE JUGER

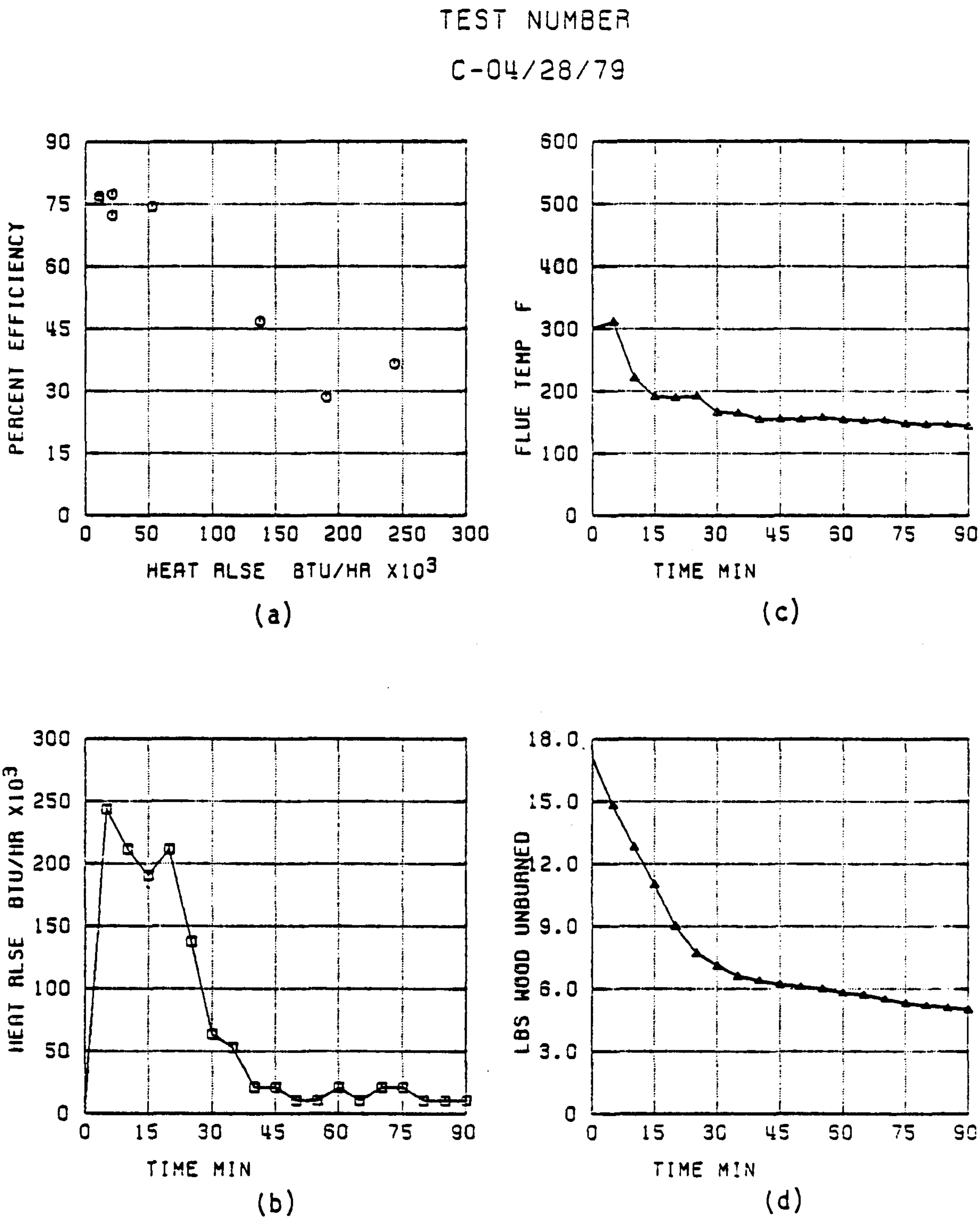
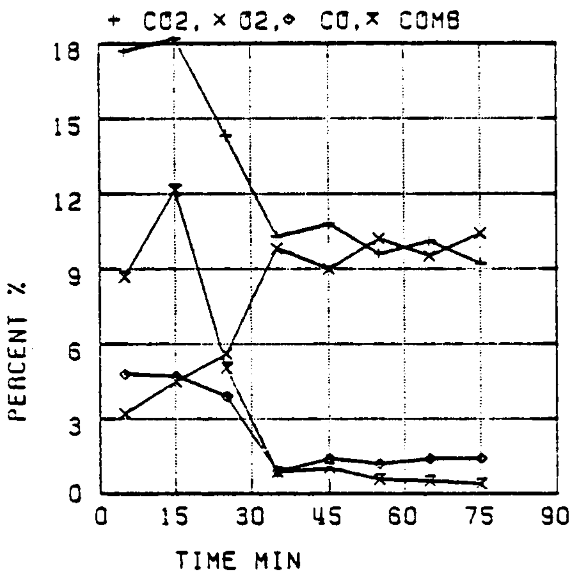


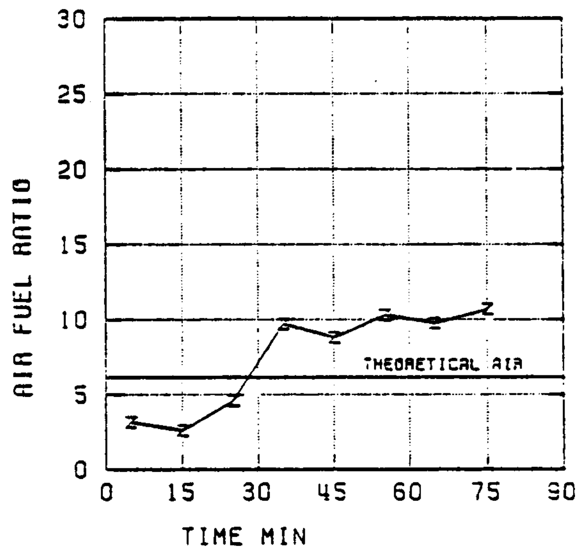

Figure 34. Test Data of Dry Oak Brand B

TEST NUMBER

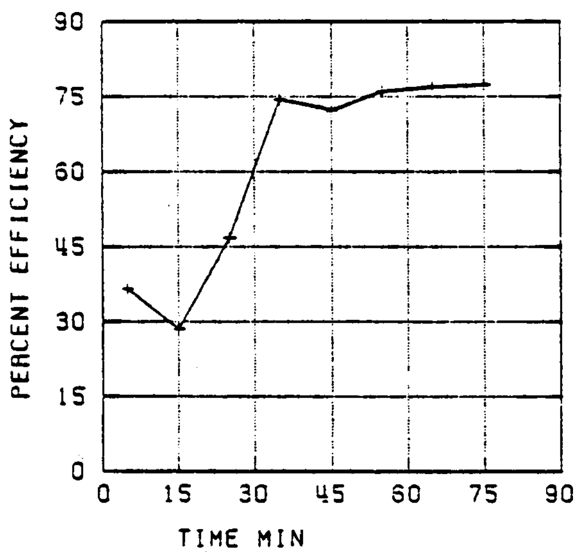
C-04/28/79




(e)




(g)




(f)

Figure 34. Continued

TEST NUMBER
C-04/28/79

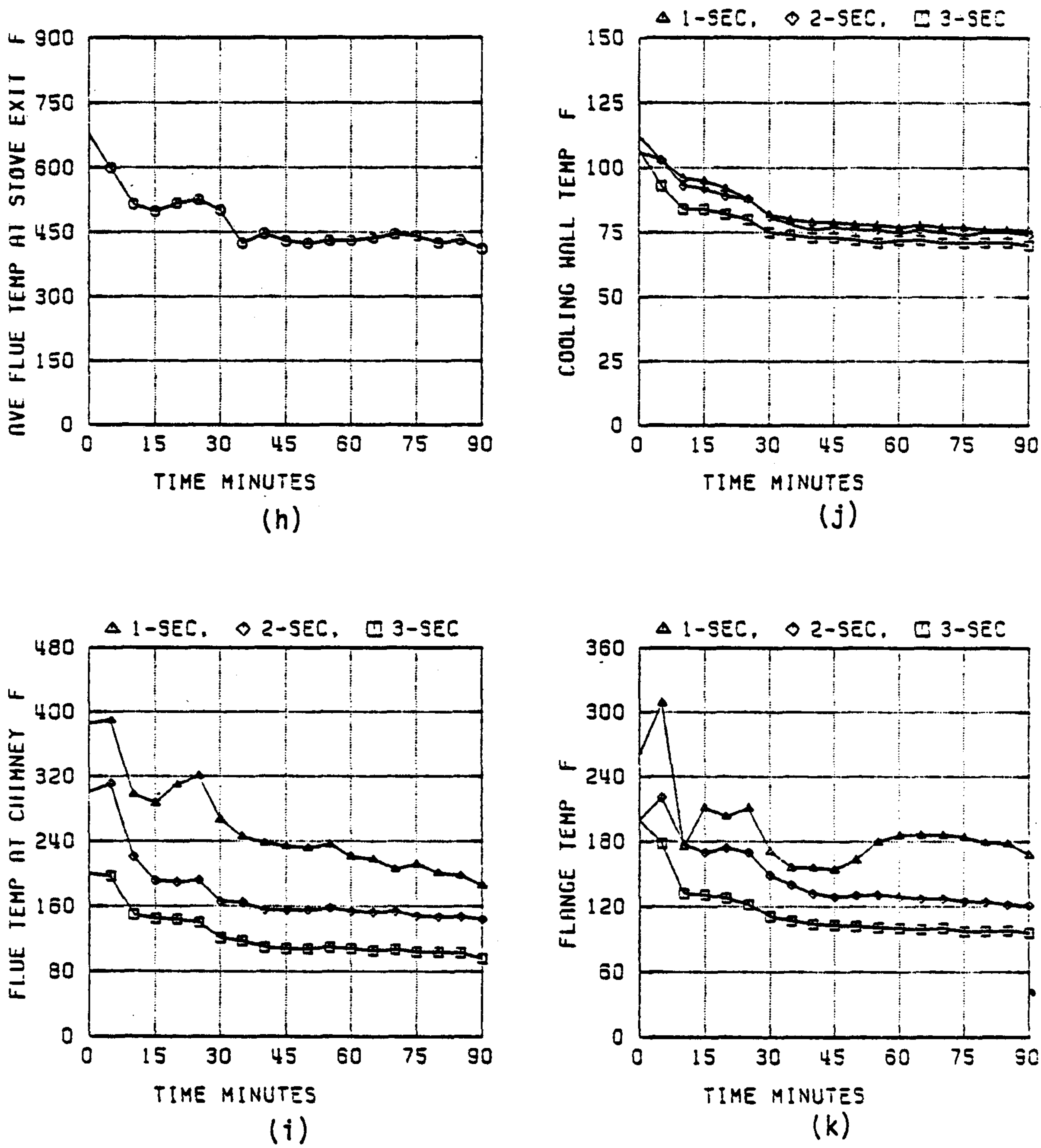



Figure 34. Continued

DISCUSSION OF TEST C-04/28/79 (Dry Oak Brand B)

The conditions which were used to generate the data shown in Figure 34 were repeated except that standard brands were changed to brand B's. There were two interesting phenomenon in this test, one phenomena was that there were two huge back puffings (explosions) which binded the stove and made two distinct curves on the surface of the left side of it. All temperatures in this test are relatively higher than that of the last two tests, probably due to frequency of back puffing. Temperature was getting higher every time after back puffing. Figure 34b, 34d show that the burning rate was very high in the first thirty minute, also in Figure 34e and 34g, it is shown that huge amounts of combustible gases, carbon monoxide and volatile matters were generated and fled to the flue. Smoke was changed from thick and brown color to thin and light blue color at 35th minute. It is concluded that the amount of creosote formation of burning the brand B (surface area 414 $in^2$) is 27% more than that of burning the standard brand (surface area 610 $in^2$).

# WOOD BURNING TEST RESULTS

TEST NUMBER : 0-04/30/79

DATE OF TEST : APRIL 30,1979

AMBIENT TEMPERATURE : 76 DEG F

DAMPER SETTING :
POSITION 1

FUEL : DRY HICKORY BRAND 8,6

MOISTURE CONTENT 0.0 % HHV= -8821.0

| TIME | | LBS WOOD | FLUE GAS TEMP (F) | %CO2 | %O2 | %CO | %COM | %EFF | A/F RATIO | THEO AIR | HEAT RLSE BTU/HR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 19.3 | 358.0 | | | | | | | | 0. |
| 5 | 0 | 17.0 | 238.0 | 17.9 | 4.4 | 5.5 | 12.4 | 27.0 | 2.50 | 6.13 | 243460. |
| 10 | 0 | 14.8 | 231.0 | | | | | | | | 232374. |
| 15 | 0 | 12.3 | 194.0 | 13.6 | 5.9 | 4.4 | 15.3 | 21.2 | 2.17 | 6.13 | 264630. |
| 20 | 0 | 10.4 | 184.0 | | | | | | | | 201119. |
| 25 | 0 | 9.0 | 151.0 | 13.7 | 6.7 | 4.7 | 7.0 | 37.2 | 4.00 | 6.13 | 148193. |
| 30 | 0 | 8.4 | 135.0 | | | | | | | | 63511. |
| 35 | 0 | 8.2 | 132.0 | 11.6 | 8.3 | 1.1 | 0.9 | 75.8 | 8.57 | 6.13 | 21170. |
| 40 | 0 | 7.9 | 132.0 | | | | | | | | 31756. |
| 45 | 0 | 7.8 | 132.0 | 11.4 | 8.0 | 1.6 | 0.6 | 77.7 | 8.64 | 6.13 | 10585. |
| 50 | 0 | 7.7 | 126.0 | | | | | | | | 10585. |
| 55 | 0 | 7.6 | 125.0 | 11.5 | 8.3 | 1.1 | 0.9 | 76.0 | 8.57 | 6.13 | 10585. |
| 60 | 0 | 7.5 | 126.0 | | | | | | | | 10585. |
| 65 | 0 | 7.4 | 124.0 | 11.2 | 8.8 | 0.9 | 0.8 | 77.5 | 9.08 | 6.13 | 10585. |
| 70 | 0 | 7.3 | 123.0 | | | | | | | | 10585. |
| 75 | 0 | 7.3 | 122.0 | 10.6 | 9.4 | 0.9 | 0.7 | 77.9 | 9.60 | 6.13 | 0. |
| 80 | 0 | 7.2 | 121.0 | | | | | | | | 10585. |
| 85 | 0 | 7.1 | 119.0 | | | | | | | | 10585. |

REMARKS

AVERAGE HEAT RELEASED: 75964.4 BTU/HR

AVERAGE HEAT OUTPUT : 24206.7 BTU/HR

AVERAGE EFFICIENCY : 31.9 %

COOLING WATER TEMP= 62 F TEST BY JOE JUGER

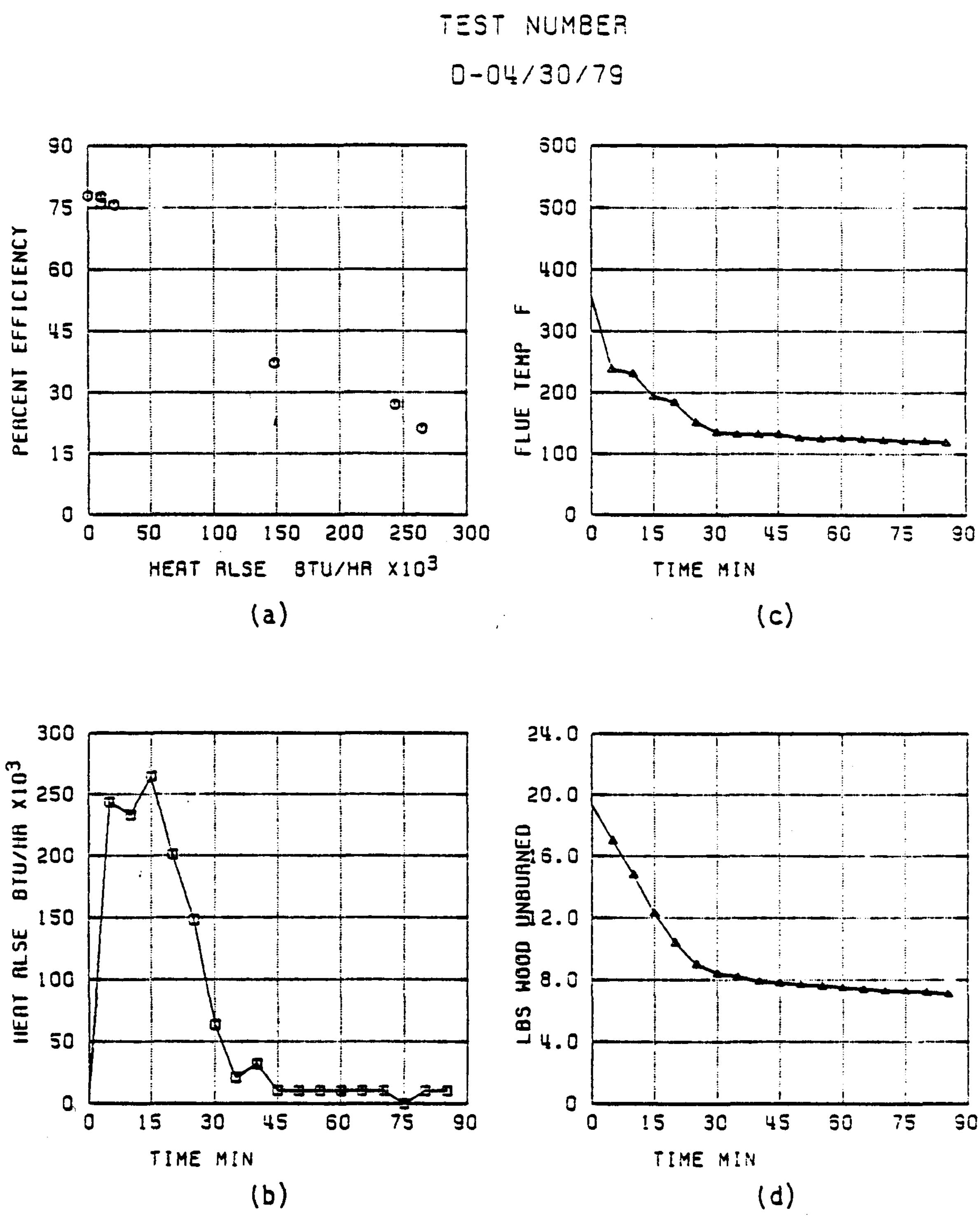



Figure 35. Test Data of Dry Hickory Brand B

TEST NUMBER

D-04/30/79

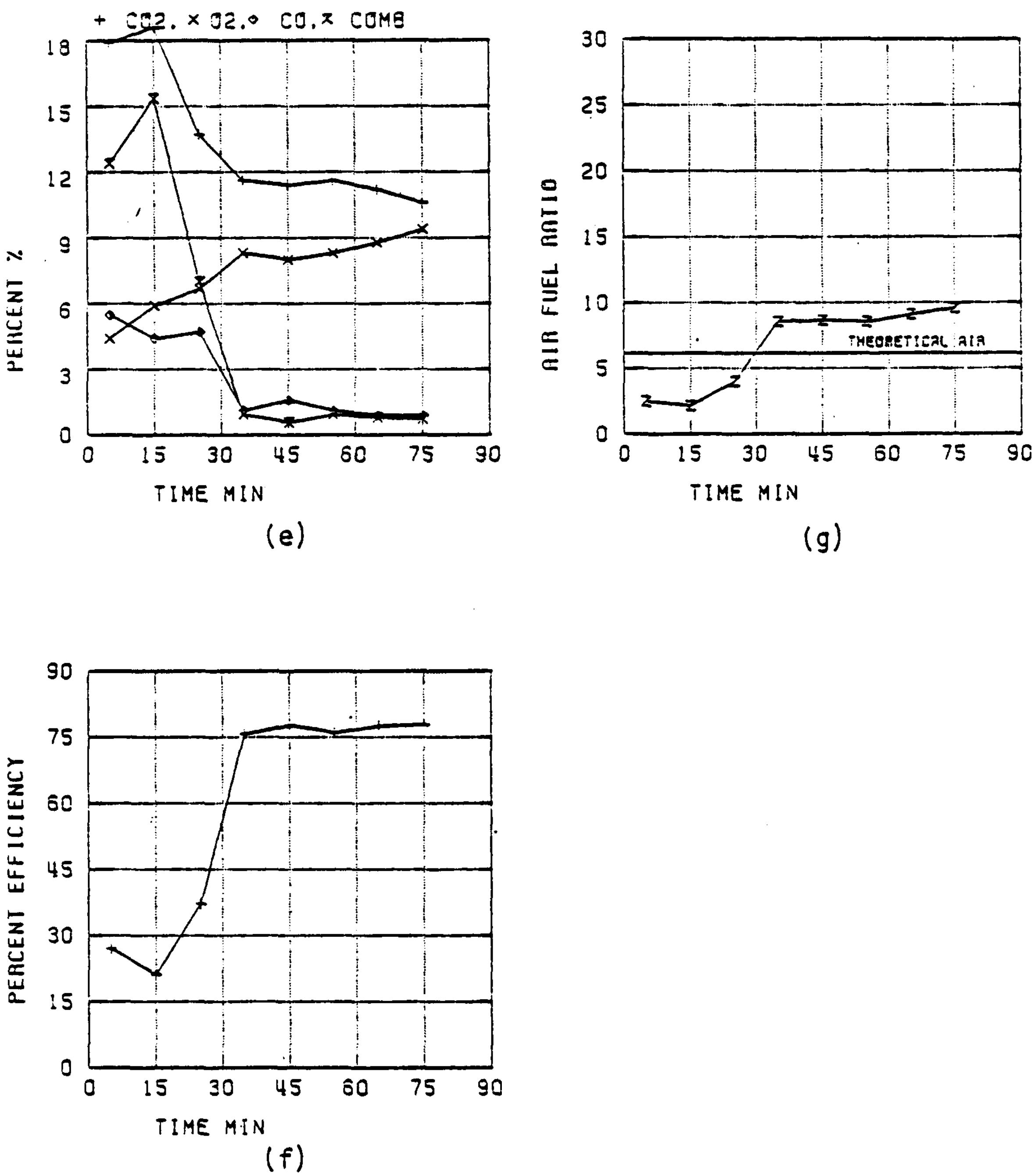



Figure 35. Continued

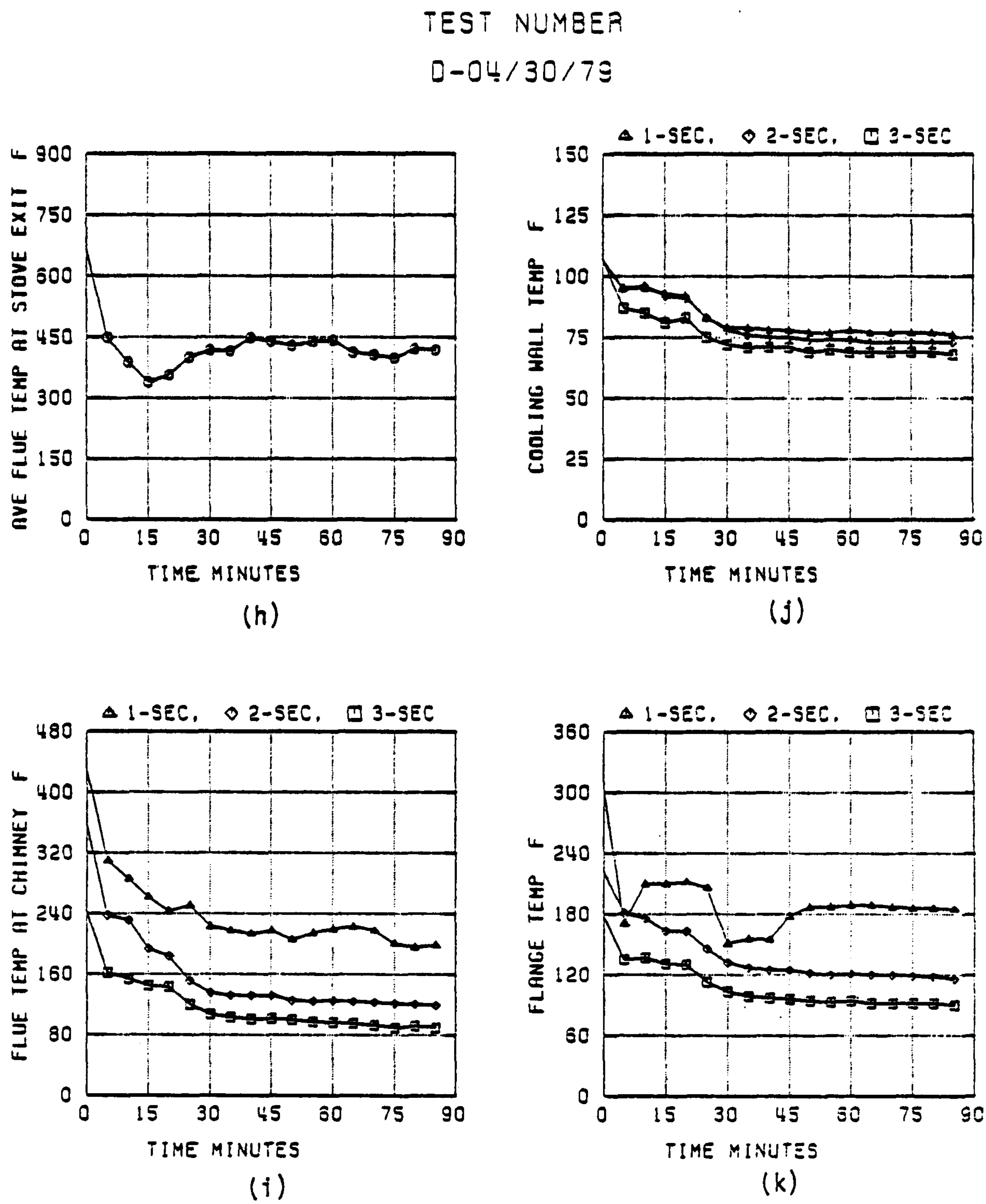



Figure 35. Continued

DISCUSSION OF TEST D-04/30/79 ( Dry Hickory Brand B)

Six dry Hickory Brand B's were tested in this run. Test started with good bed of coal, Figure 35b shows the burning rate in the first twenty five minutes was relatively much higher than that of latter test period. Most volatile matters were generated during the period of high heat release rate. There were a lot of little back puffings at the fifth minute and several big back puffings during the period of 20th to 25th minute, then, the pyrolysis stopped. Smoke became white and clean with low burning rate, but the temperature was kept very stable. Some of thick creosote was found in the beaker of middle section because of the higher flue gas temperature in the early burning stage. It is observed from these dry wood tests that the high volatile generation rate in the early burning stage causes the incomplete combustion. Thus, sufficient air supply is needed in the early burning period to help to burn out the volatile matters (creosote components).

WOOD BURNING TEST RESULTS

TEST NUMBER : A-05/09/79

DATE OF TEST : MAY 9,1979

AMBIENT TEMPERATURE : 63 DEG F

DAMPER SETTING :
POSITION 2

FUEL : WET YLW PINE LOG,3

MOISTURE CONTENT 42.0 %          HHV= -5116.2

| TIME | | LBS WOOD | FLUE GAS TEMP (F) | %CO2 | %O2 | %CO | %COM | %EFF | A/F RATIO | THEO AIR | HEAT RLSE BTU/HR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 24.5 | 149.0 | | | | | | | | 0. |
| 5 | 0 | 23.6 | 139.0 | | | | | | | | 55254. |
| 10 | 0 | 22.3 | 140.0 | | | | | | | | 79813. |
| 15 | 0 | 20.5 | 143.0 | 7.3 | 13.1 | 1.1 | 1.3 | 50.9 | 7.15 | 3.68 | 110510. |
| 20 | 0 | 20.3 | 138.0 | | | | | | | | 12279. |
| 25 | 0 | 19.8 | 138.0 | | | | | | | | 30697. |
| 30 | 0 | 19.4 | 132.0 | 6.0 | 13.9 | 1.0 | 0.6 | 58.9 | 8.35 | 3.68 | 24558. |
| 35 | 0 | 19.2 | 128.0 | | | | | | | | 12279. |
| 40 | 0 | 18.7 | 124.0 | | | | | | | | 30697. |
| 45 | 0 | 18.5 | 131.0 | 5.2 | 15.5 | 1.0 | 1.5 | 41.0 | 9.01 | 3.68 | 12279. |
| 50 | 0 | 17.9 | 133.0 | | | | | | | | 36837. |
| 55 | 0 | 17.2 | 132.0 | | | | | | | | 42976. |
| 60 | 0 | 16.8 | 128.0 | 5.0 | 15.6 | 0.6 | 0.7 | 55.3 | 11.13 | 3.68 | 24557. |
| 65 | 0 | 16.3 | 128.0 | | | | | | | | 30697. |
| 70 | 0 | 16.1 | 126.0 | | | | | | | | 12279. |
| 75 | 0 | 15.7 | 138.0 | 7.5 | 12.7 | 1.4 | 1.3 | 50.5 | 6.77 | 3.68 | 24558. |
| 80 | 0 | 15.0 | 134.0 | | | | | | | | 42976. |
| 85 | 0 | 14.6 | 130.0 | | | | | | | | 24558. |
| 90 | 0 | 14.1 | 129.0 | 5.5 | 15.2 | 0.8 | 1.2 | 46.6 | 9.21 | 3.68 | 30697. |
| 95 | 0 | 13.4 | 147.0 | | | | | | | | 42976. |
| 100 | 0 | 12.6 | 139.0 | | | | | | | | 49115. |
| 105 | 0 | 12.3 | 130.0 | 4.1 | 16.6 | 0.7 | 0.9 | 45.8 | 12.23 | 3.68 | 18418. |
| 110 | 0 | 12.1 | 118.0 | | | | | | | | 12279. |
| 115 | 0 | 11.7 | 134.0 | | | | | | | | 24558. |
| 120 | 0 | 11.2 | 132.0 | 5.7 | 15.2 | 0.7 | 1.5 | 43.1 | 8.71 | 3.68 | 30697. |
| 125 | 0 | 10.8 | 133.0 | | | | | | | | 24558. |
| 130 | 0 | 10.4 | 135.0 | | | | | | | | 24558. |
| 135 | 0 | 9.9 | 133.0 | 6.4 | 14.1 | 0.6 | 0.7 | 59.7 | 9.12 | 3.68 | 30697. |
| 140 | 0 | 9.7 | 126.0 | | | | | | | | 12279. |
| 145 | 0 | 9.5 | 128.0 | | | | | | | | 12279. |
| 150 | 0 | 9.0 | 134.0 | 6.9 | 13.8 | 0.5 | 1.0 | 55.9 | 8.28 | 3.68 | 30697. |
| 155 | 0 | 8.8 | 131.0 | | | | | | | | 12279. |
| 160 | 0 | 8.6 | 125.0 | | | | | | | | 12279. |
| 165 | 0 | 8.4 | 133.0 | 7.8 | 12.6 | 0.8 | 1.0 | 58.2 | 7.31 | 3.68 | 12279. |
| 170 | 0 | 7.9 | 134.0 | | | | | | | | 30697. |
| 175 | 0 | 7.5 | 130.0 | | | | | | | | 24558. |

REMARKS

AVERAGE HEAT RELEASED: 29820.0 BTU/HR

AVERAGE HEAT OUTPUT : 15224.4 BTU/HR

AVERAGE EFFICIENCY : 51.1 %

COOLING WATER TEMP= 66 F    TEST BY JOE JUGER

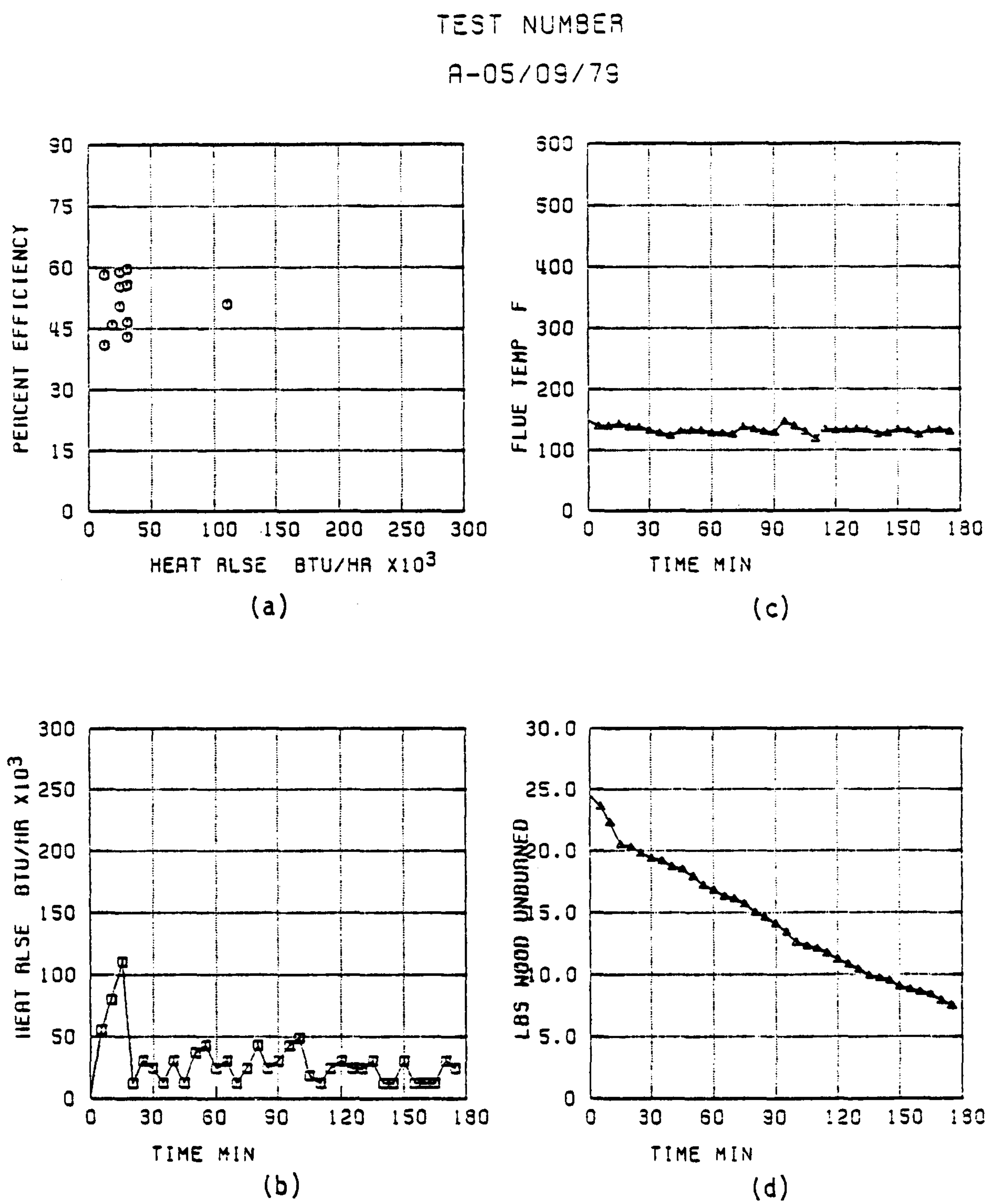



Figure 36. Test Data of Wet Pine Log

TEST NUMBER

A-05/09/79

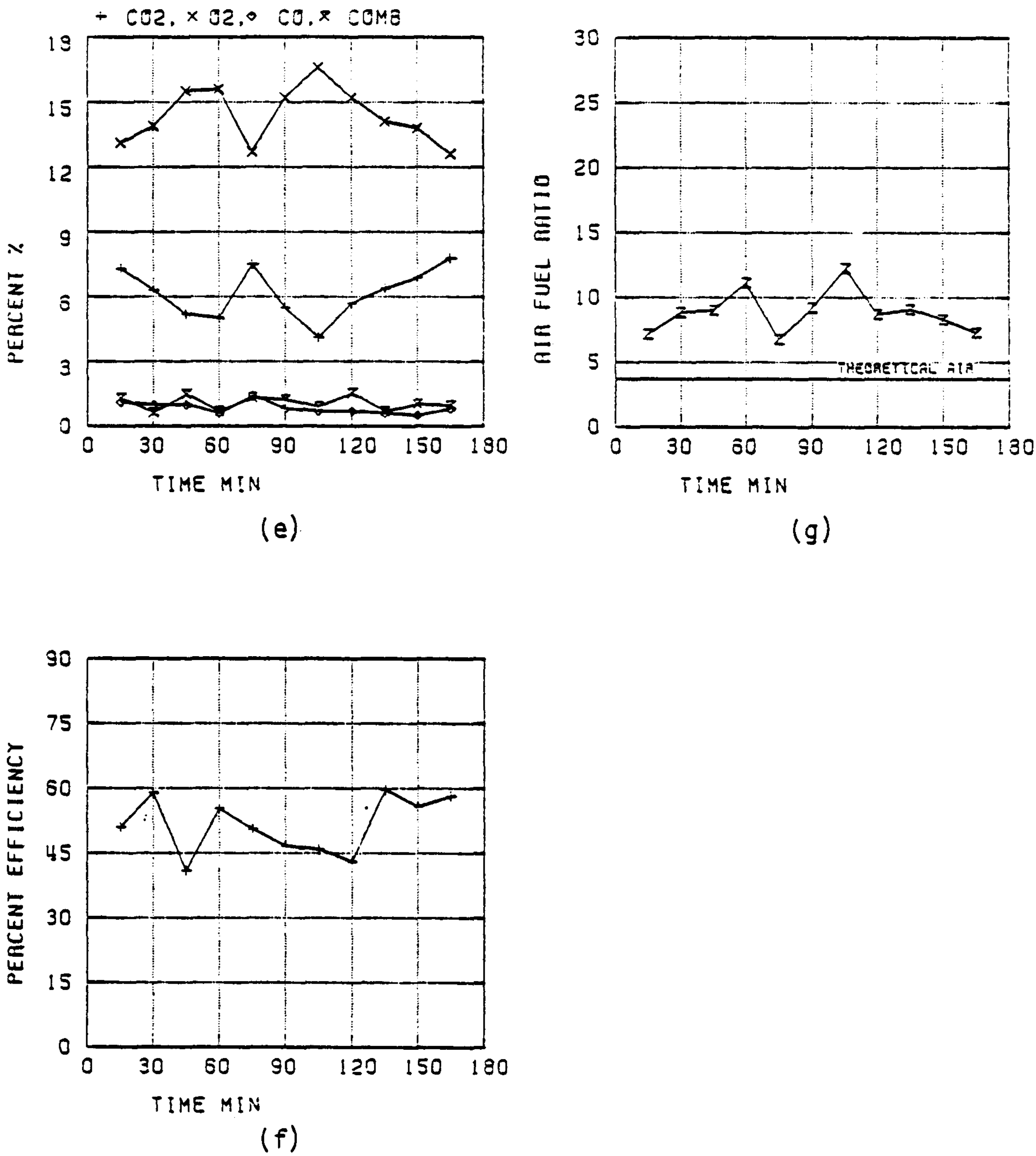



Figure 36. Continued

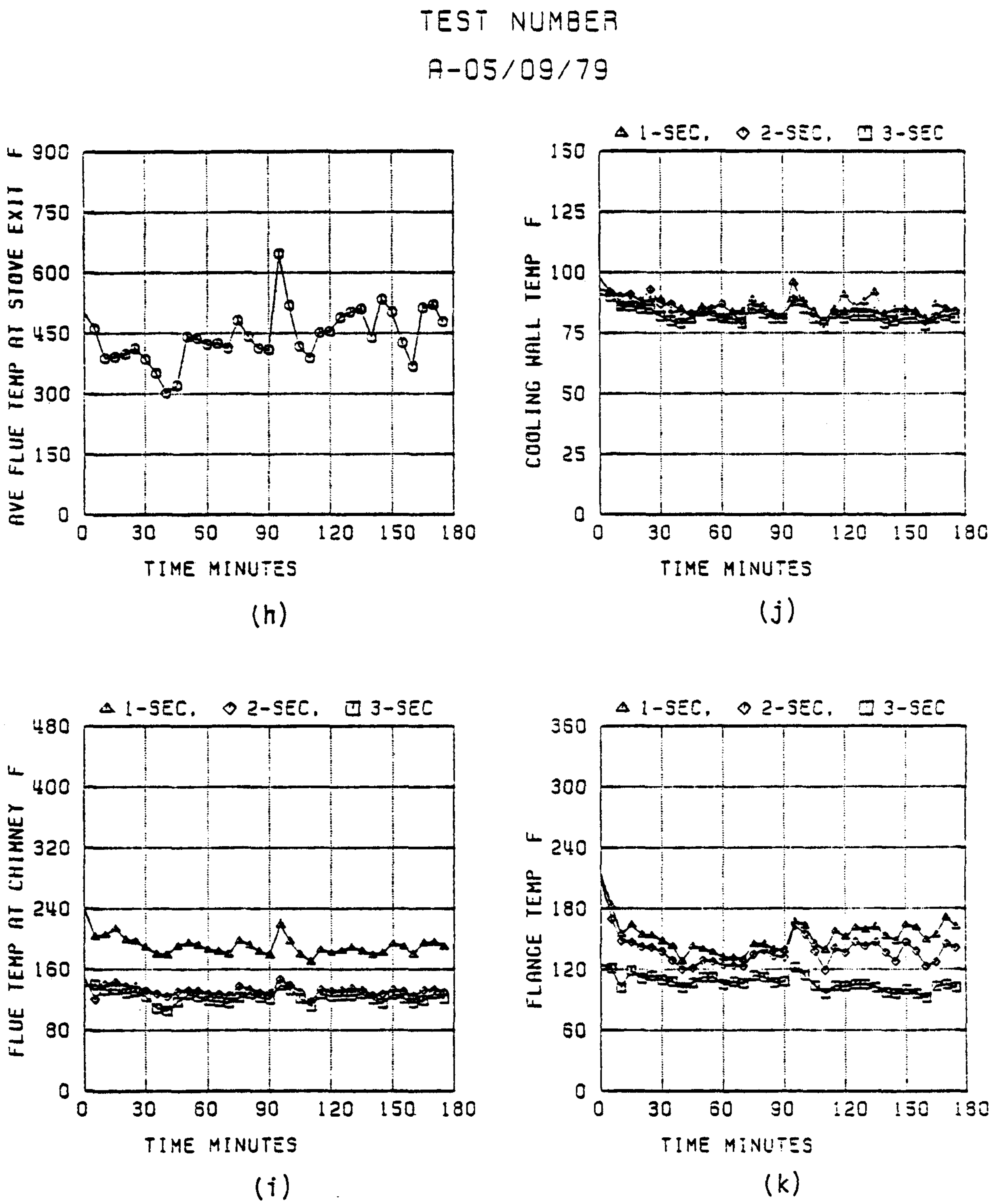



Figure 36. Continued

DISCUSSION OF TEST A-05/09/79 (Wet Pine Log)

The test data shown in the Figure 36 were for combustion of split yello pine logs. Figure 36 b and 36 c show that this test kept lower burning rate simply because of the heat loss in vaporizing the water within the logs (42% moisture content). Nevertheless, the combustion efficiencies were higher (Figure 36 a) in the whole test periods. Huge amount of water mixed with pyroligneous acid was collected. No thicker creosote was collected during the test or after reheating the chimney. Figure 36 e shows the low content of CO and combustibles in the flue gases. No pollution and creosote problems will happen in this test.

# WOOD BURNING TEST RESULTS

TEST NUMBER : 3-05/10/79

DATE OF TEST : MAY 10,1979

AMBIENT TEMPERATURE : 67 DEG F

DAMPER SETTING :
POSITION 2

FUEL : WET HICKORY LOG,3

MOISTURE CONTENT 25.0 % HHV= -6615.7

| TIME | | LBS WOOD | FLUE GAS TEMP (F) | %CO2 | %O2 | %CO | %COM | %EFF | A/F RATIO | THEO AIR | HEAT RLSE BTU/HR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 25.1 | 121.0 | | | | | | | | 0. |
| 5 | 0 | 24.5 | 133.0 | | | | | | | | 47634. |
| 10 | 0 | 23.8 | 136.0 | | | | | | | | 55572. |
| 15 | 0 | 23.1 | 139.0 | 10.2 | 10.0 | 2.8 | 3.6 | 41.5 | 5.07 | 4.69 | 55572. |
| 20 | 0 | 22.3 | 144.0 | | | | | | | | 63511. |
| 25 | 0 | 21.2 | 148.0 | | | | | | | | 87328. |
| 30 | 0 | 20.1 | 148.0 | 13.1 | 7.6 | 3.5 | 5.9 | 35.0 | 3.56 | 4.69 | 87327. |
| 35 | 0 | 19.0 | 146.0 | | | | | | | | 87328. |
| 40 | 0 | 18.1 | 150.0 | | | | | | | | 71450. |
| 45 | 0 | 17.0 | 145.0 | 13.7 | 5.8 | 3.0 | 3.0 | 52.9 | 4.34 | 4.69 | 87328. |
| 50 | 0 | 16.1 | 146.0 | | | | | | | | 71450. |
| 55 | 0 | 15.4 | 141.0 | | | | | | | | 55573. |
| 60 | 0 | 14.8 | 135.0 | 12.3 | 7.6 | 2.9 | 4.5 | 42.3 | 4.10 | 4.69 | 47633. |
| 65 | 0 | 14.3 | 129.0 | | | | | | | | 39695. |
| 70 | 0 | 13.9 | 130.0 | | | | | | | | 31756. |
| 75 | 0 | 13.4 | 133.0 | 11.8 | 8.7 | 2.2 | 3.6 | 46.0 | 4.80 | 4.69 | 39695. |
| 80 | 0 | 13.0 | 132.0 | | | | | | | | 31756. |
| 85 | 0 | 12.6 | 131.0 | | | | | | | | 31756. |
| 90 | 0 | 12.1 | 132.0 | 12.0 | 7.5 | 2.2 | 1.7 | 61.1 | 5.53 | 4.69 | 39695. |
| 95 | 0 | 11.9 | 131.0 | | | | | | | | 15878. |
| 100 | 0 | 11.5 | 130.0 | | | | | | | | 31756. |
| 105 | 0 | 11.2 | 128.0 | 11.4 | 8.6 | 1.3 | 2.0 | 57.8 | 5.73 | 4.69 | 23817. |
| 110 | 0 | 11.0 | 129.0 | | | | | | | | 15878. |
| 115 | 0 | 10.8 | 125.0 | | | | | | | | 15878. |
| 120 | 0 | 10.6 | 123.0 | 9.6 | 10.4 | 1.8 | 1.8 | 56.5 | 6.64 | 4.69 | 15879. |
| 125 | 0 | 10.4 | 121.0 | | | | | | | | 15878. |
| 130 | 0 | 10.1 | 128.0 | | | | | | | | 23817. |
| 135 | 0 | 9.9 | 129.0 | 9.1 | 11.2 | 1.6 | 2.0 | 53.0 | 6.35 | 4.69 | 15878. |
| 140 | 0 | 9.7 | 128.0 | | | | | | | | 15878. |
| 145 | 0 | 9.6 | 125.0 | | | | | | | | 7939. |
| 150 | 0 | 9.6 | 129.0 | 8.2 | 13.7 | 0.9 | 4.1 | 32.0 | 6.33 | 4.69 | 0. |
| 155 | 0 | 9.5 | 128.0 | | | | | | | | 7939. |
| 160 | 0 | 9.3 | 129.0 | | | | | | | | 15878. |

REMARKS

AVERAGE HEAT RELEASED: 39198.3 BTU/HR

AVERAGE HEAT OUTPUT : 17965.1 BTU/HR

AVERAGE EFFICIENCY : 45.8 %

COOLING WATER TEMP= 66 F TEST BY JOE JUGER

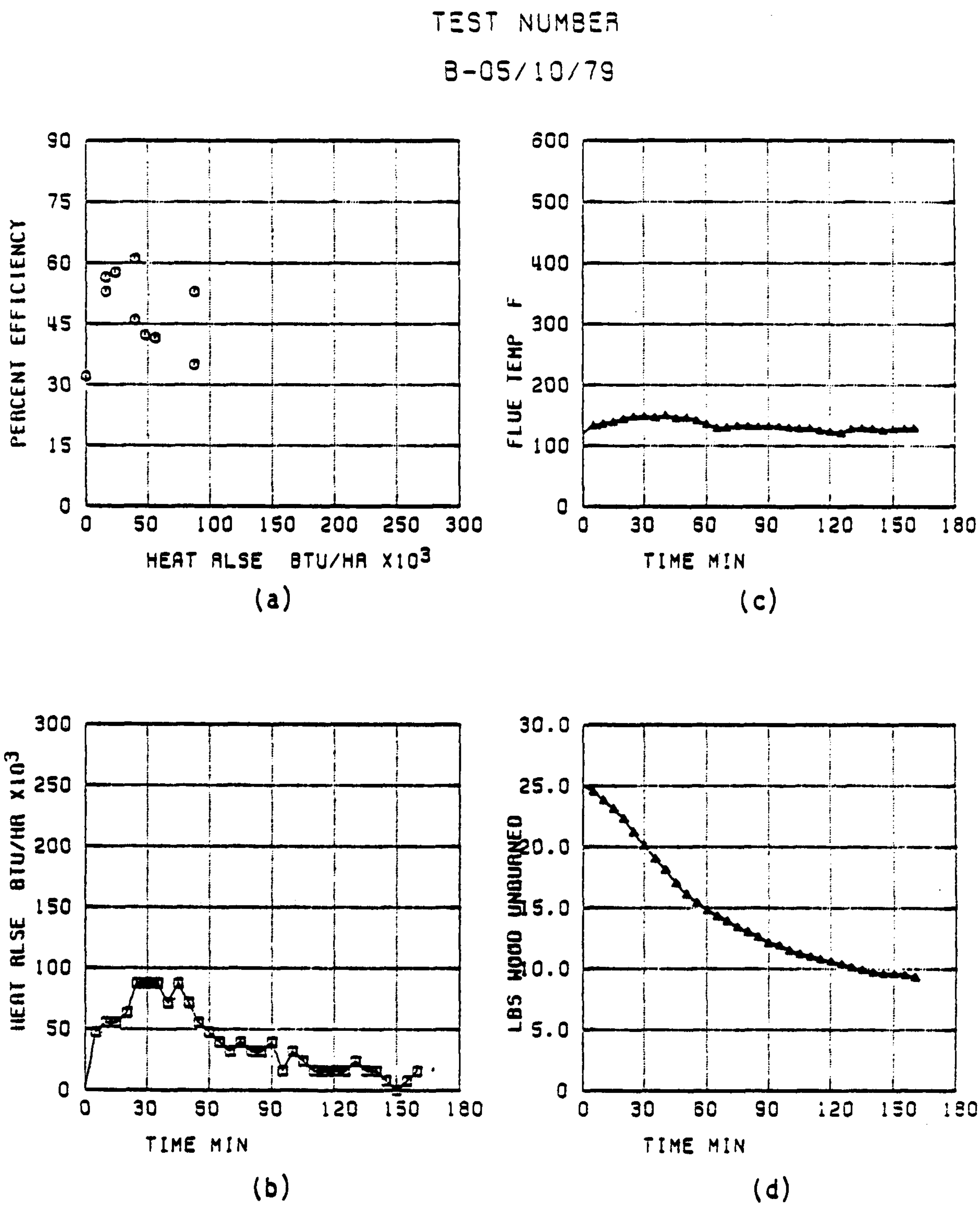



Figure 37. Test Data of Wet Hickory Log

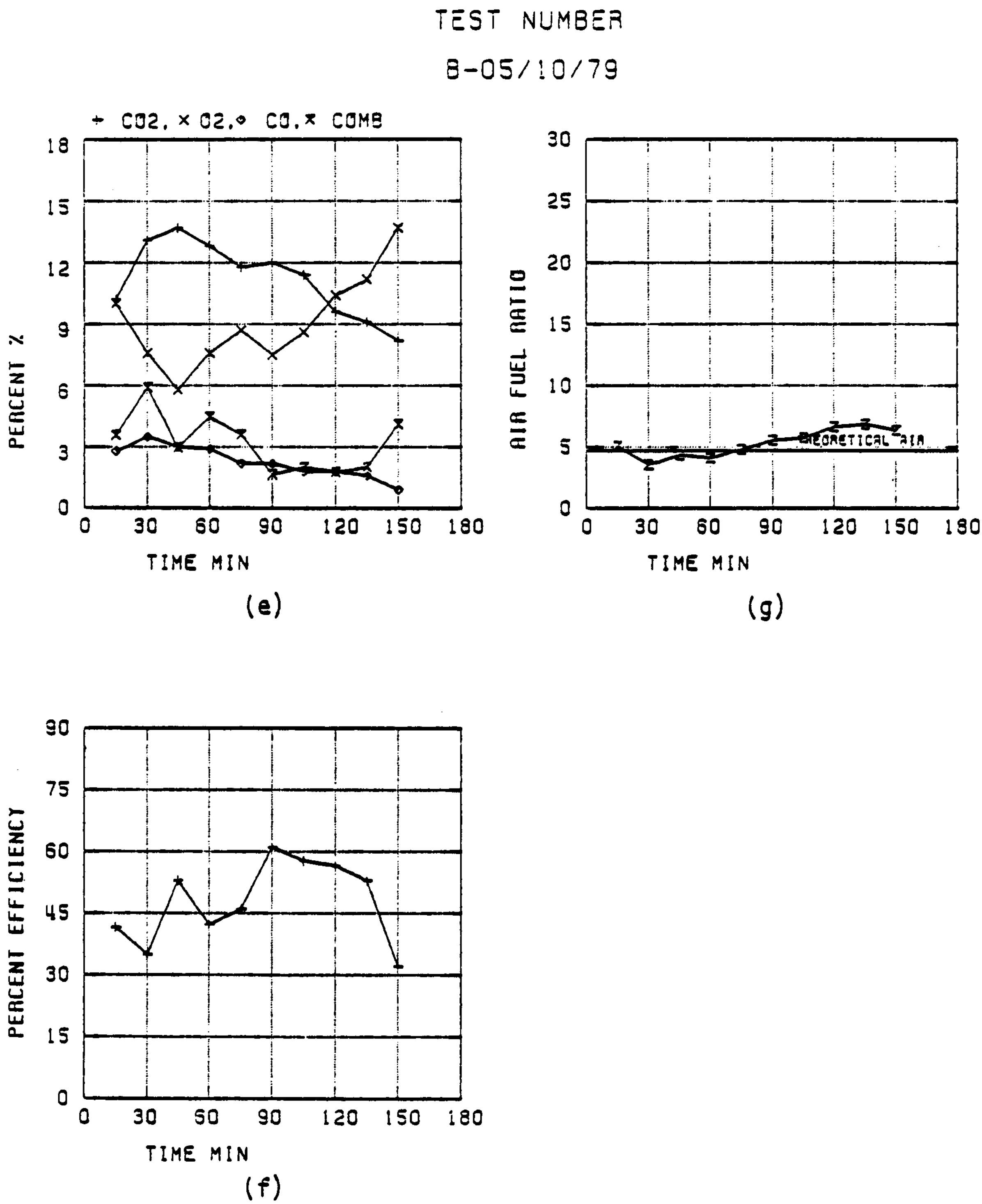



Figure 37. Continued

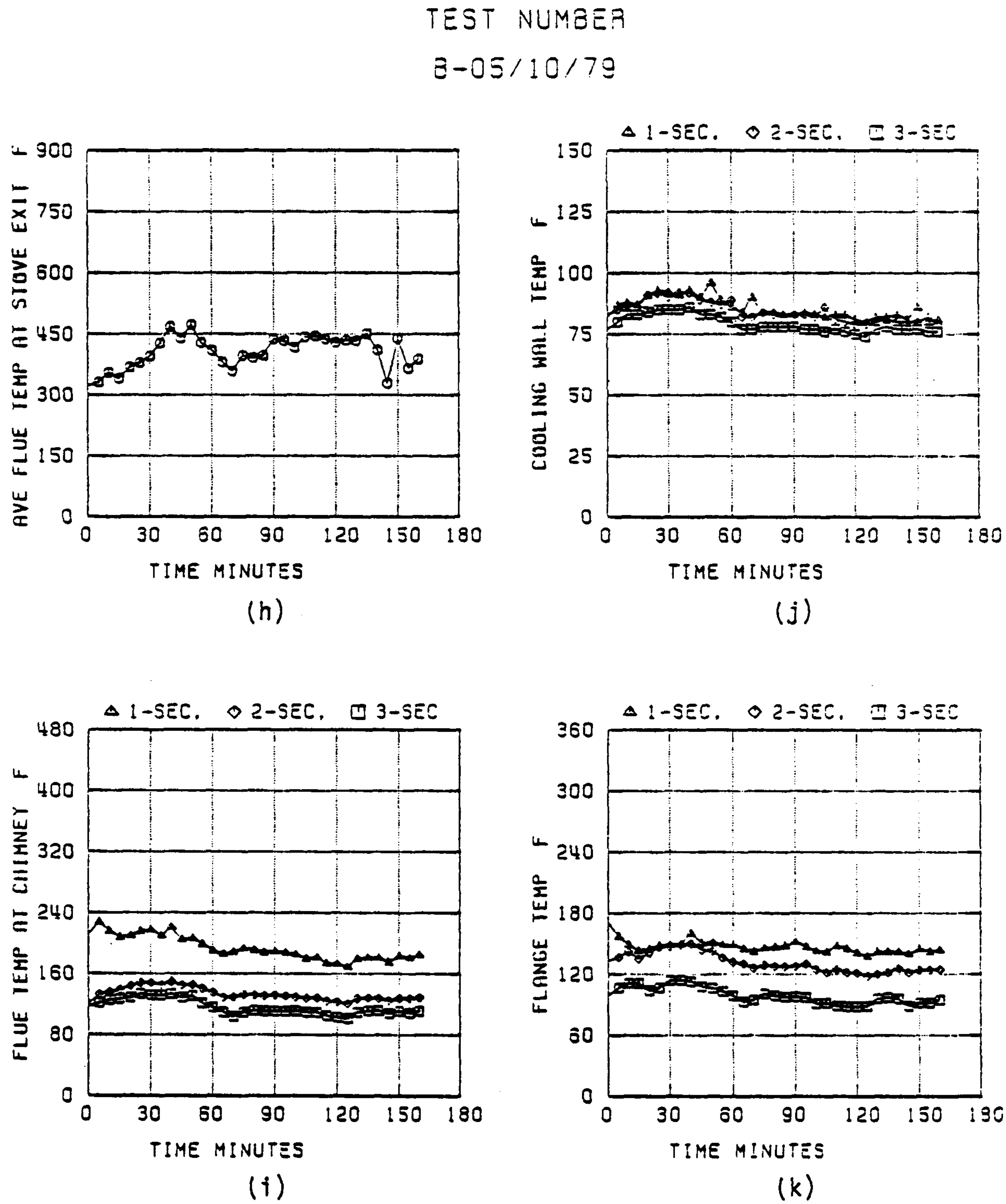



Figure 37. Continued

DISCUSSION OF TEST B-05/10/79 (Wet Hickory Log)

Split hickory logs with high moisture levels (25.0%) were tested using relative higher levels of undergrate air (i.e. air inlet position 2). The creosote number of this test is 51. It is observed from last fourteen tests that no thicker creosote will be formed if the creosote number is below 60. It may be found in Figure 37e that percents of CO and combustibles are higher than 3.0 in the first sixty minutes. This is the reason for the higher creosote number. Nevertheless, still no thicker creosote was collected after the reheating process.

# WOOD BURNING TEST RESULTS

TEST NUMBER : A-05/11/79

DATE OF TEST : MAY 11,1979

AMBIENT TEMPERATURE : 84 DEG F

DAMPER SETTING :
POSITION 2

FUEL : WET OAK LOG,3

MOISTURE CONTENT 26.0 % HHV= -6527.5

| TIME | | LBS WOOD | FLUE GAS TEMP (F) | %CO2 | %O2 | %CO | %COM | %EFF | A/F RATIO | THEO AIR | HEAT RLSE BTU/HR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 25.8 | 109.0 | | | | | | | | 0. |
| 5 | 0 | 25.6 | 132.0 | | | | | | | | 15666. |
| 10 | 0 | 24.9 | 141.0 | | | | | | | | 54832. |
| 15 | 0 | 24.0 | 149.0 | 10.4 | 11.1 | 2.7 | 6.0 | 26.9 | 4.12 | 4.63 | 70497. |
| 20 | 0 | 22.9 | 150.0 | | | | | | | | 86164. |
| 25 | 0 | 21.8 | 151.0 | | | | | | | | 86163. |
| 30 | 0 | 20.9 | 151.0 | 10.8 | 10.1 | 2.5 | 4.6 | 35.9 | 4.53 | 4.63 | 70498. |
| 35 | 0 | 20.1 | 149.0 | | | | | | | | 62663. |
| 40 | 0 | 19.2 | 147.0 | | | | | | | | 70498. |
| 45 | 0 | 18.5 | 144.0 | 10.9 | 9.1 | 2.9 | 3.4 | 44.0 | 4.84 | 4.63 | 54831. |
| 50 | 0 | 17.9 | 141.0 | | | | | | | | 46999. |
| 55 | 0 | 17.2 | 141.0 | | | | | | | | 54831. |
| 60 | 0 | 16.5 | 133.0 | 10.8 | 10.7 | 2.3 | 5.6 | 31.0 | 4.28 | 4.63 | 54831. |
| 65 | 0 | 16.1 | 133.0 | | | | | | | | 31332. |
| 70 | 0 | 15.7 | 127.0 | | | | | | | | 31333. |
| 75 | 0 | 15.4 | 128.0 | 10.0 | 10.8 | 1.7 | 3.3 | 44.1 | 5.61 | 4.63 | 23499. |
| 80 | 0 | 15.0 | 127.0 | | | | | | | | 31332. |
| 85 | 0 | 14.8 | 124.0 | | | | | | | | 15666. |
| 90 | 0 | 14.6 | 119.0 | 9.3 | 11.7 | 1.8 | 3.7 | 38.9 | 5.62 | 4.63 | 15666. |
| 95 | 0 | 14.3 | 121.0 | | | | | | | | 23499. |
| 100 | 0 | 14.1 | 120.0 | | | | | | | | 15666. |
| 105 | 0 | 13.7 | 121.0 | 8.2 | 12.9 | 1.6 | 3.5 | 36.9 | 6.29 | 4.63 | 31332. |
| 110 | 0 | 13.4 | 119.0 | | | | | | | | 23499. |
| 115 | 0 | 13.0 | 131.0 | | | | | | | | 31332. |
| 120 | 0 | 12.6 | 130.0 | 11.4 | 8.8 | 1.8 | 2.4 | 54.1 | 5.47 | 4.63 | 31332. |
| 125 | 0 | 12.3 | 125.0 | | | | | | | | 23499. |
| 130 | 0 | 12.1 | 122.0 | | | | | | | | 15666. |
| 135 | 0 | 11.9 | 120.0 | 8.6 | 12.2 | 1.4 | 2.7 | 45.6 | 5.70 | 4.63 | 15666. |
| 140 | 0 | 11.8 | 122.0 | | | | | | | | 7833. |
| 145 | 0 | 11.7 | 124.0 | | | | | | | | 7833. |
| 150 | 0 | 11.6 | 121.0 | 7.9 | 12.7 | 1.1 | 1.6 | 53.1 | 8.03 | 4.63 | 7833. |
| 155 | 0 | 11.5 | 120.0 | | | | | | | | 7833. |
| 160 | 0 | 11.4 | 119.0 | | | | | | | | 7833. |

REMARKS

AVERAGE HEAT RELEASED: 35248.7 BTU/HR

AVERAGE HEAT OUTPUT : 13312.9 BTU/HR

AVERAGE EFFICIENCY : 37.8 %

COOLING WATER TEMP= 67 F TEST BY JOE JUGER

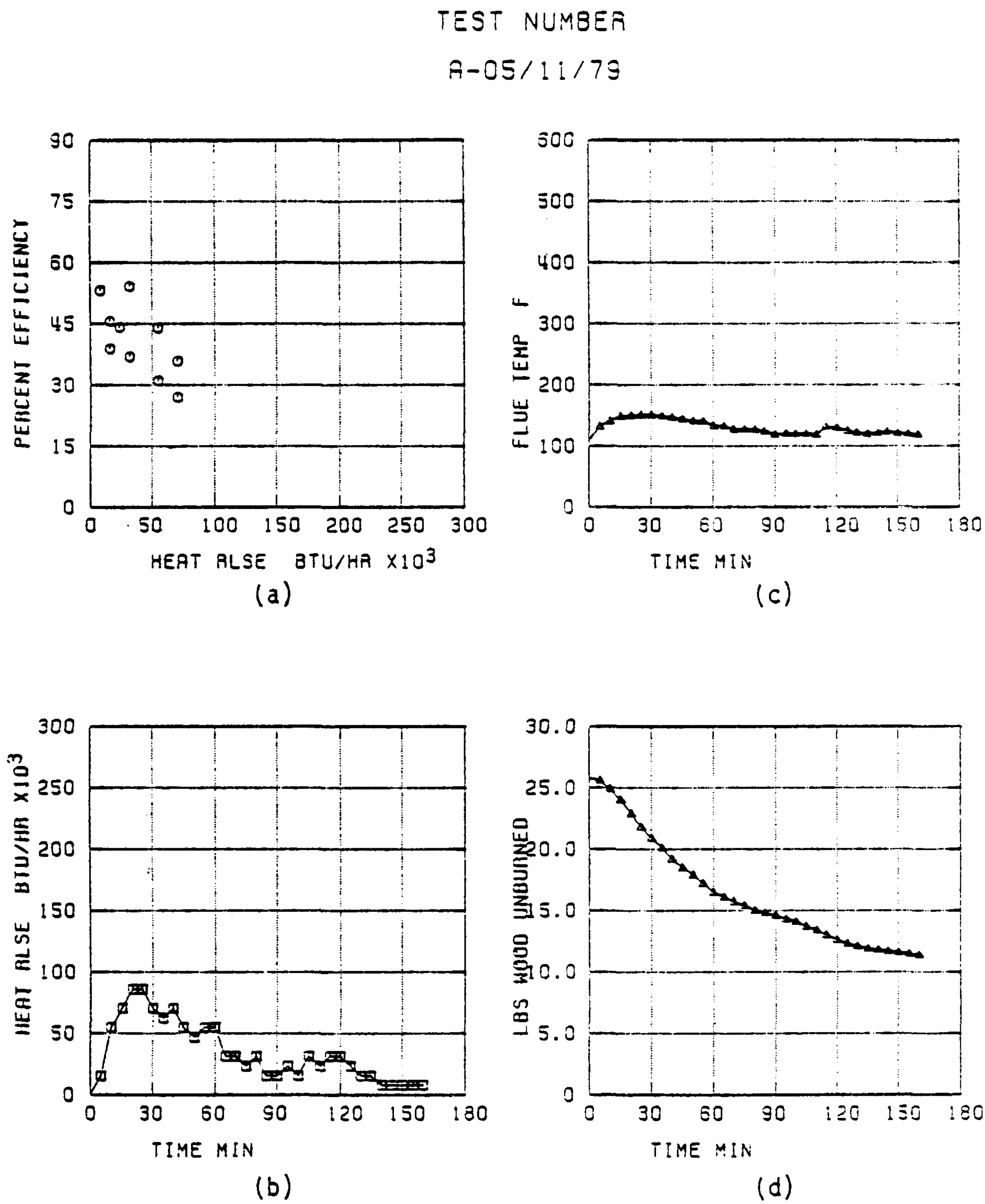



Figure 38. Test Data of Wet Oak Log

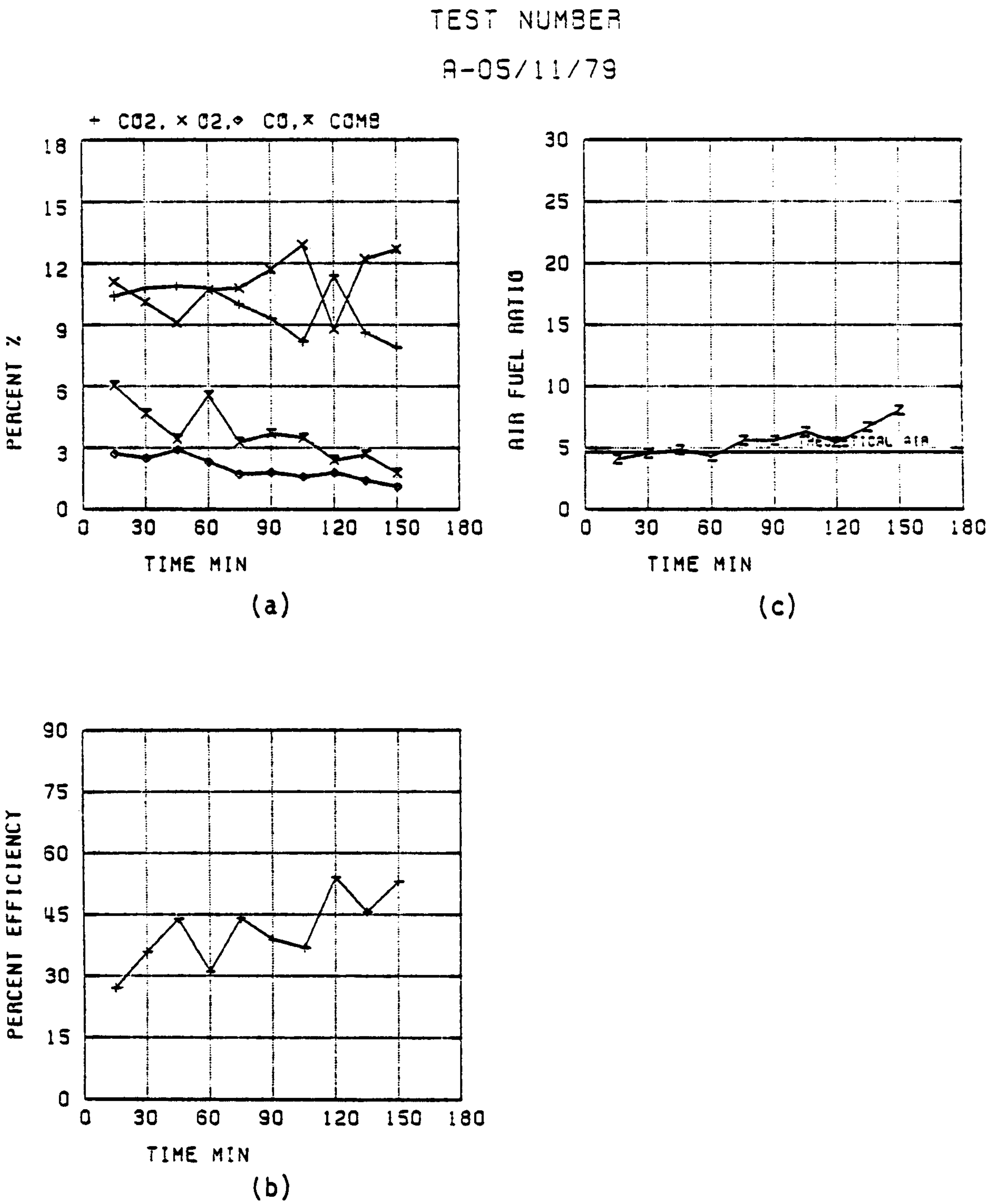



Figure 38. Continued

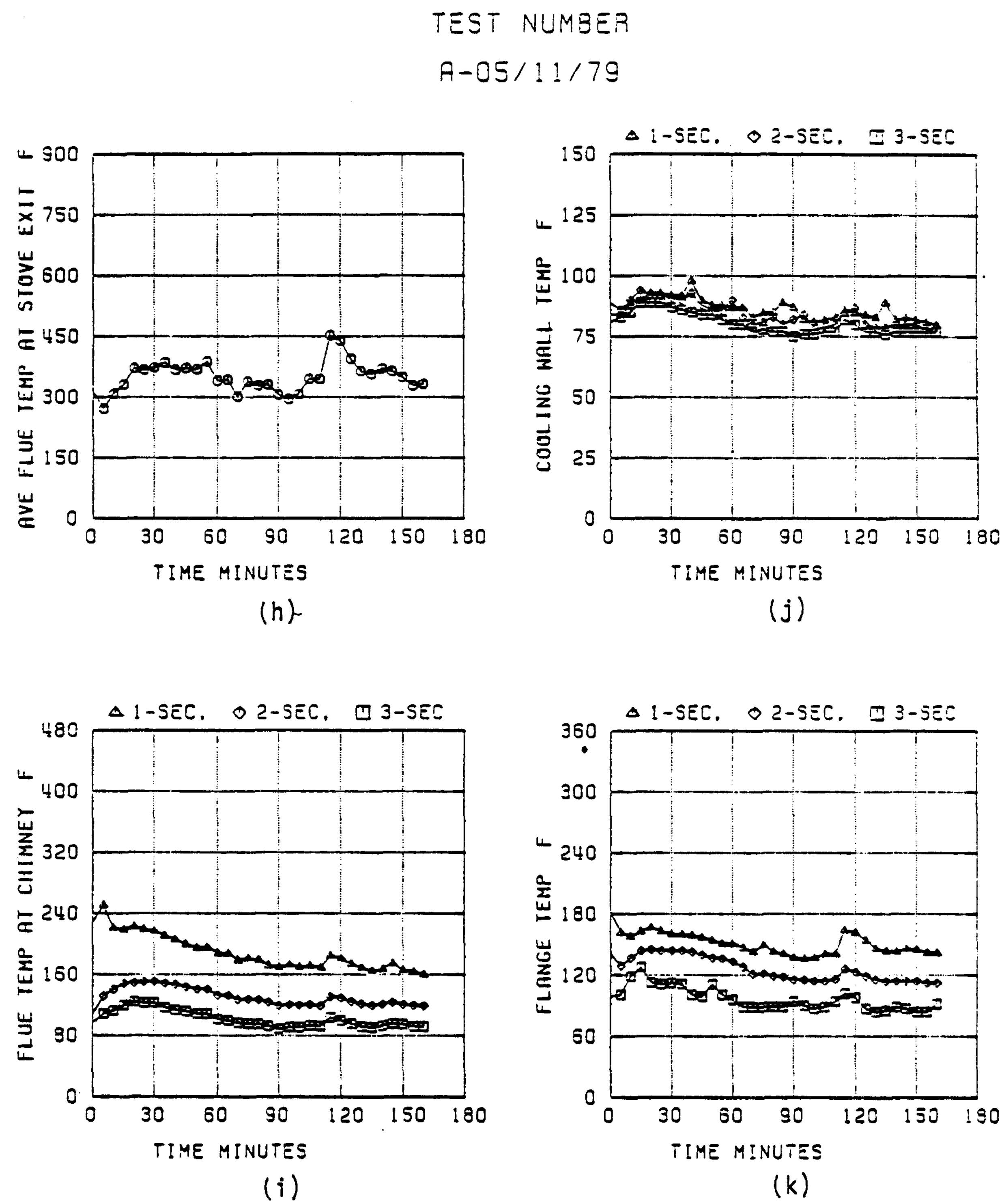



Figure 38. Continued

DISCUSSION OF TEST A-05/11/79 (Wet Hickory Log)

Comparing this test with the last test (B-05/10/79), one can see that these two tests were under the same conditions. However, the result of the amount of creosote formed is different. This test had a creosote number of 14. A conclusion can be made from these two tests that the burning characteristics of hickory and oak are very similar. Hickory can produce more creosote than oak.

# WOOD BURNING TEST RESULTS

TEST NUMBER : 6-05/12/79

DATE OF TEST : MAY 12,1979

AMBIENT TEMPERATURE : 81 DEG F

DAMPER SETTING :
POSITION 2

FUEL : DRY HICKORY LOG,3

MOISTURE CONTENT 0.0 % HHV= -8821.0

| TIME | | LBS WOOD | FLUE GAS TEMP (F) | %CO2 | %O2 | %CO | %COM | %EFF | A/F RATIO | THEO AIR | HEAT RLSE BTU/HR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 17.9 | 141.0 | | | | | | | | 0. |
| 5 | 0 | 17.2 | 139.0 | 14.8 | 7.7 | 6.4 | 13.5 | 19.4 | 2.48 | 6.13 | 74096. |
| 10 | 0 | 16.5 | 137.0 | | | | | | | | 74096. |
| 15 | 0 | 15.4 | 130.0 | 15.3 | 6.0 | 7.2 | 13.4 | 22.3 | 2.37 | 6.13 | 116437. |
| 20 | 0 | 14.3 | 142.0 | | | | | | | | 116437. |
| 25 | 0 | 13.4 | 139.0 | 15.9 | 5.2 | 6.6 | 11.2 | 27.8 | 2.71 | 6.13 | 95267. |
| 30 | 0 | 12.6 | 139.0 | | | | | | | | 84682. |
| 35 | 0 | 11.9 | 130.0 | 14.8 | 6.4 | 4.8 | 8.9 | 32.3 | 3.42 | 6.13 | 74096. |
| 40 | 0 | 11.7 | 121.0 | | | | | | | | 21170. |
| 45 | 0 | 11.5 | 117.0 | 11.3 | 8.8 | 2.4 | 3.0 | 55.0 | 6.67 | 6.13 | 21170. |
| 50 | 0 | 11.2 | 123.0 | | | | | | | | 31756. |
| 55 | 0 | 11.0 | 123.0 | 9.5 | 10.3 | 1.8 | 1.4 | 66.2 | 9.10 | 6.13 | 21170. |
| 60 | 0 | 10.8 | 128.0 | | | | | | | | 21170. |
| 65 | 0 | 10.6 | 135.0 | 10.3 | 9.5 | 1.9 | 1.6 | 64.8 | 8.30 | 6.13 | 21170. |
| 70 | 0 | 10.4 | 128.0 | | | | | | | | 21170. |
| 75 | 0 | 10.1 | 128.0 | | | | | | | | 31756. |
| 80 | 0 | 10.0 | 129.0 | 8.8 | 11.1 | 1.7 | 1.3 | 65.1 | 9.74 | 6.13 | 10585. |
| 85 | 0 | 9.9 | 123.0 | | | | | | | | 10585. |
| 90 | 0 | 9.8 | 126.0 | | | | | | | | 10585. |
| 95 | 0 | 9.7 | 124.0 | 8.5 | 11.8 | 1.0 | 1.1 | 68.7 | 10.90 | 6.13 | 10585. |
| 100 | 0 | 9.7 | 122.0 | | | | | | | | 0. |
| 105 | 0 | 9.6 | 122.0 | | | | | | | | 10585. |

REMARKS

AVERAGE HEAT RELEASED: 41336.7 BTU/HR

AVERAGE HEAT OUTPUT : 14414.1 BTU/HR

AVERAGE EFFICIENCY : 34.5 %

COOLING WATER TEMP= 67 F TEST BY JOE JUGER

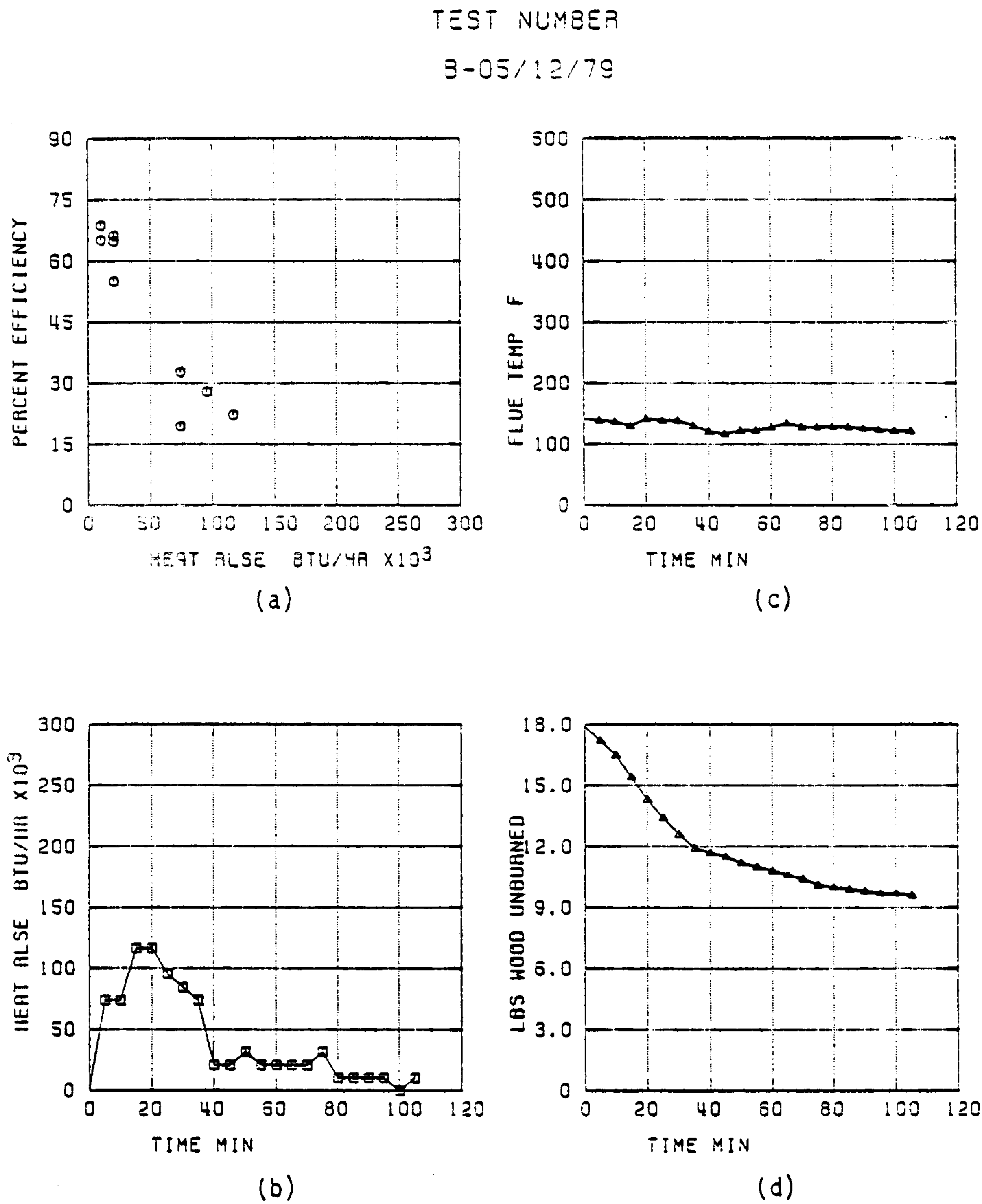



Figure 39. Test Data of Dry Hickory Log

TEST NUMBER

B-05/12/79

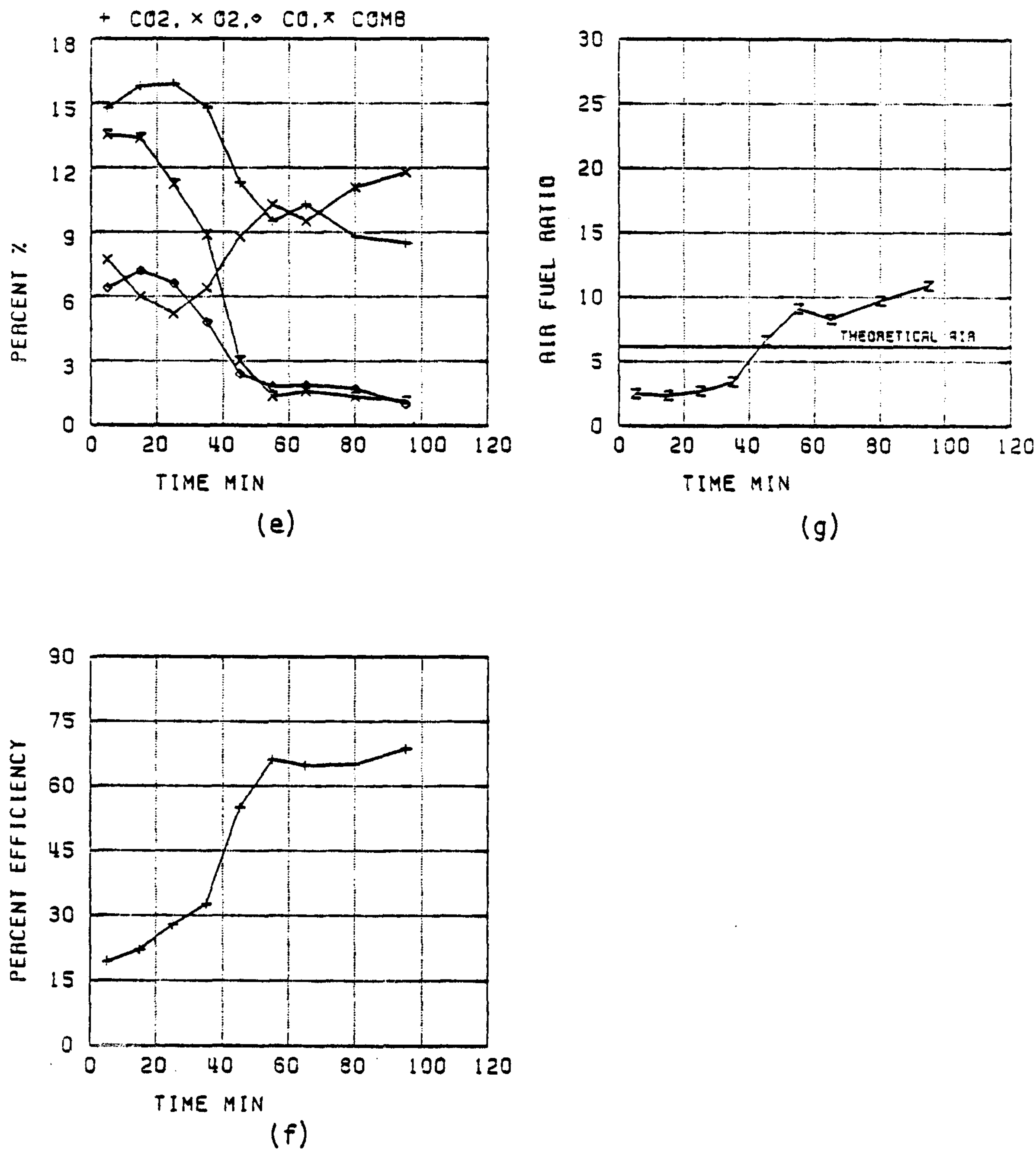



Figure 39 . Continued

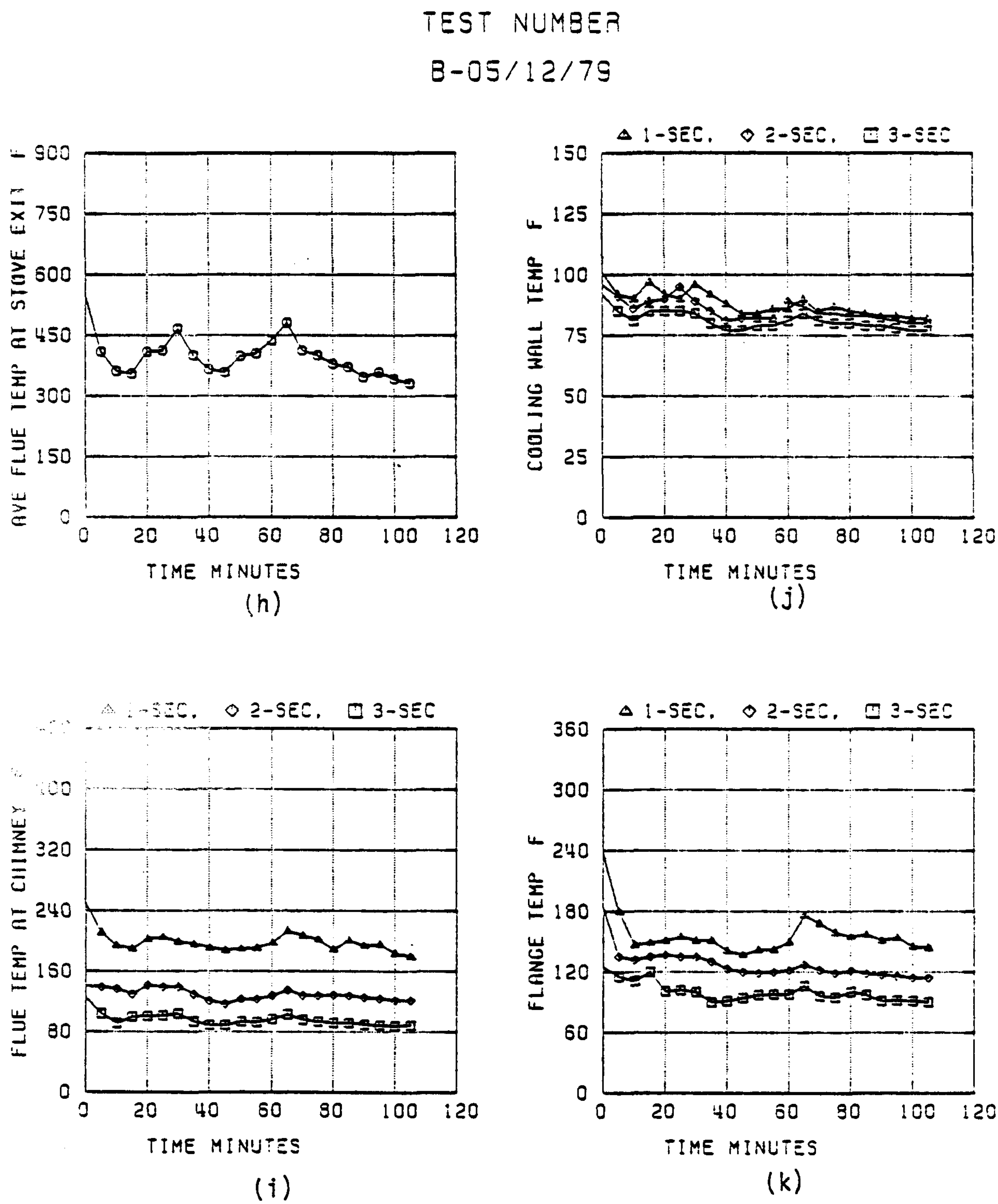



Figure 39. Continued

DISCUSSION OF TEST B-05/12/79 (Dry Hickory Log)

In order to determine the influence of moisture content of wood, split oven dry hickory logs were introduced in this test. Figure 39d shows that 17.9 pounds of wood were fed, but only 50% of it was consumed. Part of logs fell down to the corner of the combustion chamber and did not ignite. However, large amounts of CO and combustibles were measured within the flue gas during the early stage of combustion. Figure 39e shows the highest contents of CO and combustibles (volatile matters) in the flue gases were 7.2% and 3.5%, respectively. The creosote number in this run was the highest of the eighteen test runs (164).

WOOD BURNING TEST RESULTS

TEST NUMBER : A-05/21/79

DATE OF TEST : MAY 21,1979

AMBIENT TEMPERATURE : 36 DEG F

DAMPER SETTING :
POSITION 2

FUEL : DRY OAK LOG,3

MOISTURE CONTENT 0.0 % HHV= -8321.0

| TIME | | LBS WOOD | FLUE GAS TEMP (F) | %CO2 | %O2 | %CO | %COM | %EFF | A/F RATIO | THEO AIR | HEAT RLSE BTU/HR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 18.7 | 118.0 | | | | | | | | 0. |
| 5 | 0 | 17.6 | 151.0 | 14.9 | 5.9 | 5.2 | 8.6 | 33.6 | 3.40 | 6.13 | 116436. |
| 10 | 0 | 16.1 | 151.0 | | | | | | | | 158778. |
| 15 | 0 | 14.8 | 146.0 | 18.9 | 2.9 | 3.7 | 9.1 | 39.2 | 3.08 | 6.13 | 137608. |
| 20 | 0 | 13.4 | 144.0 | | | | | | | | 148193. |
| 25 | 0 | 12.3 | 138.0 | 17.8 | 4.0 | 4.6 | 10.2 | 34.0 | 2.91 | 6.13 | 116437. |
| 30 | 0 | 11.5 | 138.0 | | | | | | | | 84682. |
| 35 | 0 | 10.6 | 137.0 | 17.3 | 3.5 | 3.9 | 8.3 | 40.5 | 3.32 | 6.13 | 95267. |
| 40 | 0 | 9.7 | 135.0 | | | | | | | | 95267. |
| 45 | 0 | 9.0 | 133.0 | 16.7 | 4.3 | 4.3 | 8.1 | 39.3 | 3.43 | 6.13 | 74096. |
| 50 | 0 | 8.4 | 124.0 | | | | | | | | 63511. |
| 55 | 0 | 7.9 | 119.0 | 12.3 | 7.5 | 3.3 | 3.7 | 51.3 | 5.65 | 6.13 | 52926. |
| 60 | 0 | 7.7 | 115.0 | | | | | | | | 21170. |
| 65 | 0 | 7.5 | 113.0 | 11.3 | 7.1 | 2.7 | 1.1 | 70.7 | 7.40 | 6.13 | 21170. |
| 70 | 0 | 7.3 | 110.0 | | | | | | | | 21170. |
| 75 | 0 | 7.2 | 107.0 | 11.7 | 7.8 | 1.4 | 0.5 | 79.6 | 8.60 | 6.13 | 10585. |
| 80 | 0 | 7.2 | 105.0 | | | | | | | | 0. |
| 85 | 0 | 7.1 | 106.0 | 12.6 | 7.1 | 1.5 | 1.2 | 73.9 | 7.58 | 6.13 | 10585. |
| 90 | 0 | 7.1 | 107.0 | | | | | | | | 0. |
| 95 | 0 | 7.0 | 108.0 | 11.8 | 8.1 | 1.1 | 0.9 | 76.4 | 8.42 | 6.13 | 10585. |
| 100 | 0 | 7.0 | 107.0 | | | | | | | | 0. |

REMARKS

AVERAGE HEAT RELEASED: 61923.4 BTU/HR

AVERAGE HEAT OUTPUT : 24818.0 BTU/HR

AVERAGE EFFICIENCY : 40.1 %

COOLING WATER TEMP= 68 F TEST BY JOE JUGER

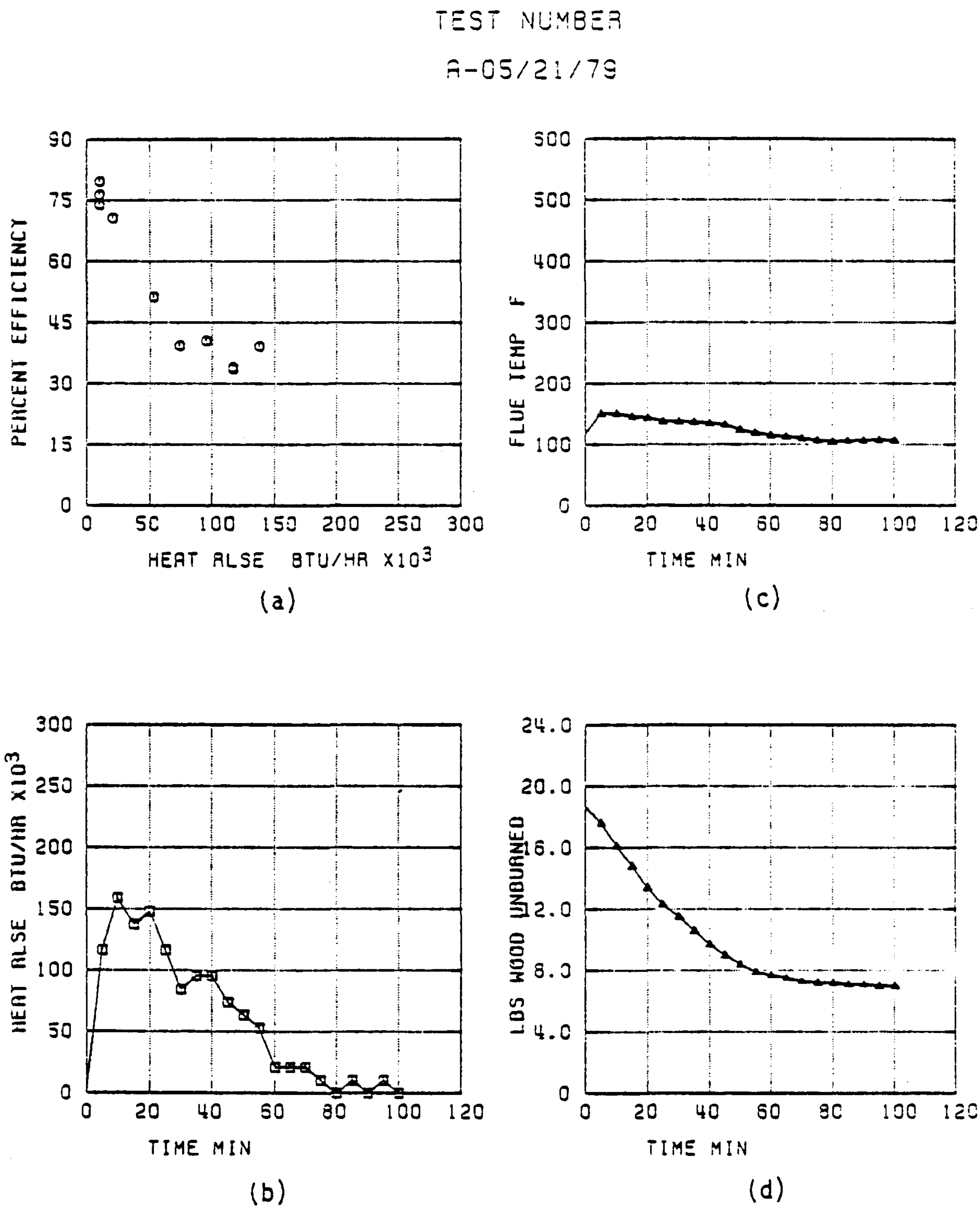



Figure 40'. Test Data of Dry Oak Log

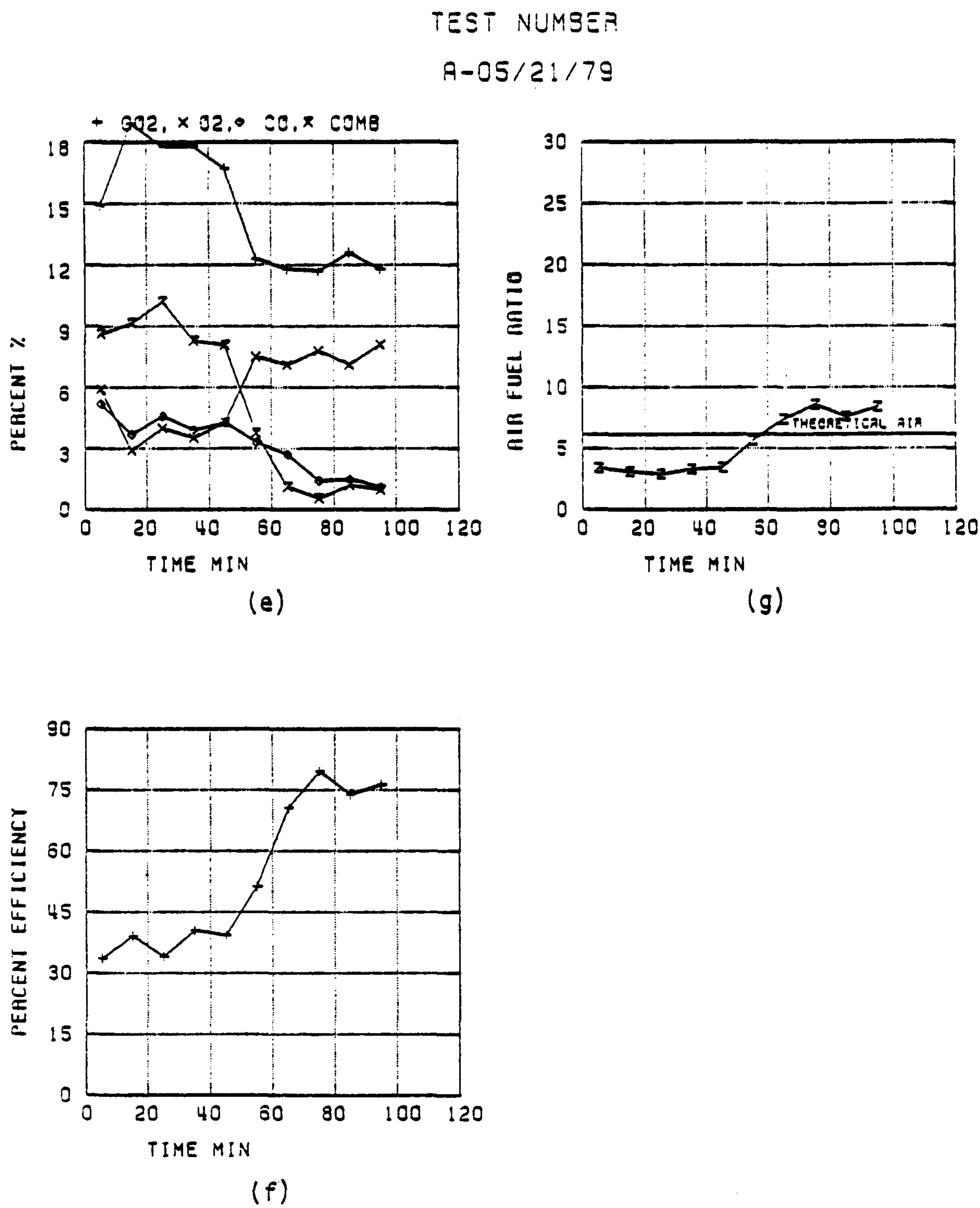



Figure 40. Continued

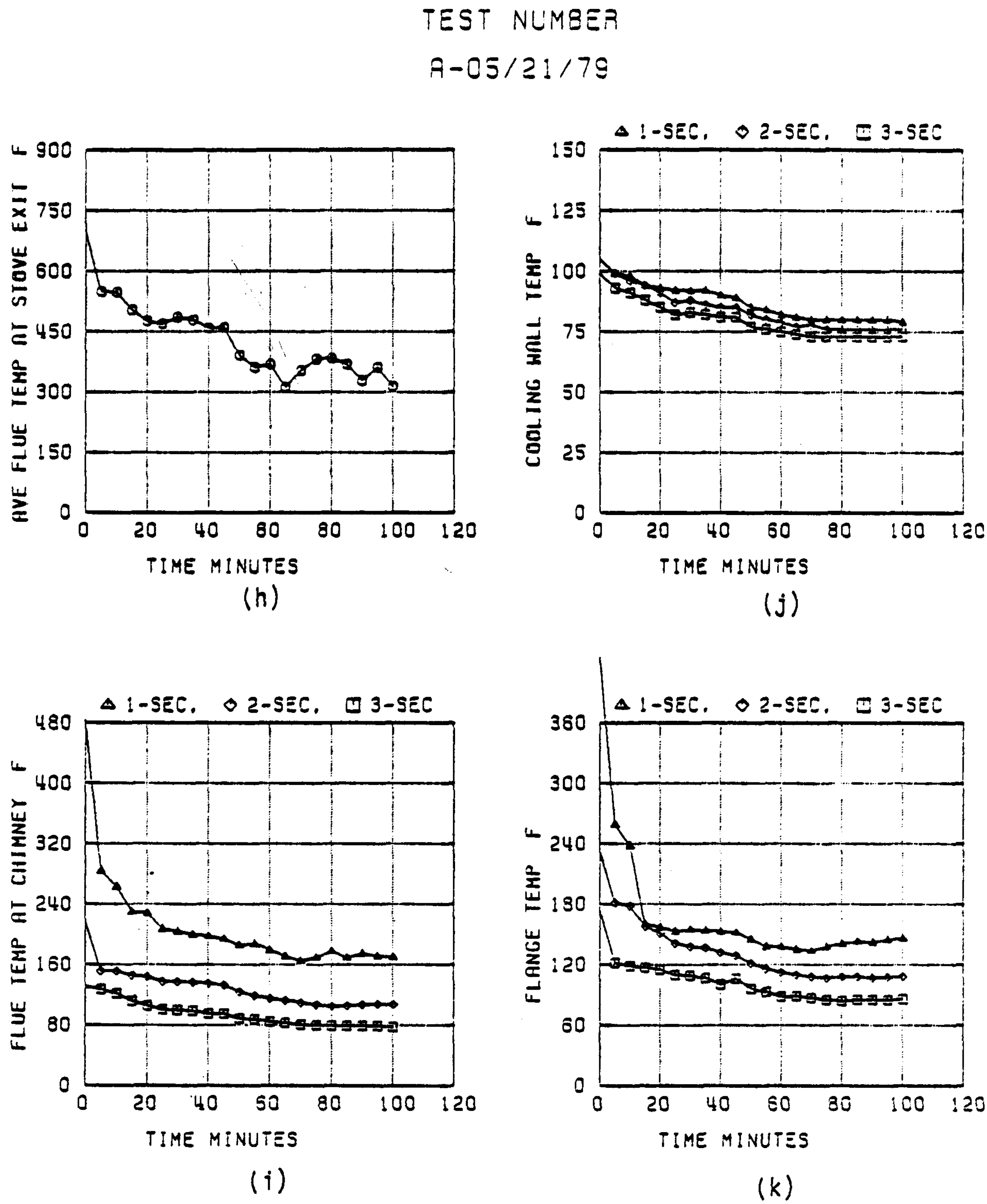



Figure 40. Continued

DISCUSSION OF TEST A-05/21/79 (Dry Oak Log)

Again, it is concluded from this and the last tests that hickory can generate more creosote than the oak. Split oak logs of 0.0% moisture content were used in this test. All figures of this test are similar to that of last test (B-05/12/79). Figure 40g shows a low air-fuel ratio during the first 45 minutes. It is observed that during this period of the test, the concentration of the pyroligenous acid was much higher than that of the burning latter period. Finally, it is also concluded that logs can produce more creosote than the brands.

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