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LABORATORY TESTS OF ORCHARD HEATERS*

A. H. HOFFMAN†

Field studies of the economic phases of orchard heating have been made by Young,^(9, 10, 11, 12) Young and Cate,⁽¹³⁾ Schoonover, Hodgson and Young,⁽⁶⁾ West and Edlefsen,⁽⁸⁾ Webber et al.,⁽⁷⁾ Garcia and Fite,⁽¹⁾ and others. Tests to determine the effectiveness of different orchard heaters to stay the fall of temperature have been made in large number and variety by Young,^(9, 10, 11, 12) West and Edlefsen,⁽⁸⁾ O'Gara,⁽⁴⁾ and others. Aside from some measurements of radiation made by Kimball and Young,⁽³⁾ exact measurements of the performance of the individual heaters have in general been lacking and are needed for the guidance of both the user and the manufacturer. At the urgent request of the Citrus Growers' Department of the Southern California Farm Bureaus and others the work here reported was undertaken. In general it has been found that the methods which mechanical engineers commonly use in testing the performance characteristics of steam-boiler furnaces and the like are inapplicable to orchard heaters for the reason that the latter, burning in the open, present an entirely different problem. Hence it has been found necessary to devise new methods and apparatus.

THE IDEAL ORCHARD HEATER

Those who have made the most thorough study of the subject are generally agreed that the following characteristics in an orchard heater are desirable for reasons obvious or specified.

1. It should be able to burn fuel (and hence to produce heat) at rates that will enable the fruit grower to control the temperature of his orchard within the necessary limits. The only practical method yet found for preventing frost damage in orchards is by adding heat to the air.

2. It should burn the fuel completely so that all the heat contained may be liberated.

* The purpose of this bulletin is to make the results of these studies immediately available to the user and to the manufacturer of orchard heaters. The test methods will be explained in a later publication.

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3. Its radiation above the horizontal plane should not be excessive.
4. The gases rising from the stacks should be discharged at a level close to the ground and should not have too great an upward velocity or they may be shot so high that they may not effectively warm the orchard.
5. The higher the temperature of the heater surfaces and of the gases rising from the stacks the greater will be the rate of radiation and the higher the upward velocity. It follows therefore that very high temperatures are undesirable and that as much cold air as possible should be mixed with the products of combustion before they are discharged from a heater.
6. An orchard heater should not smoke, since smoke is a general nuisance to all persons in the region. It damages ripe fruit by blacking it and rendering washing necessary, and wastes a small portion of the heat content of the fuel.
7. All the foregoing desirable characteristics should be embodied in a heater (*a*) that can be produced at a reasonable cost, (*b*) that can be operated with a minimum of skill, labor and care, (*c*) that will have a low up-keep expense and a satisfactory length of life, and (*d*) that will burn available fuel.

THE PROBLEMS TO BE SOLVED

The following items are the principal objectives sought in this study:

1. What are the characteristic burning or fuel consumption rates of the different heaters?
2. How efficiently do they convert fuel into heat?
3. What per cent of the heat is lost by radiation?
4. How fast do the hot gases rise from the stacks of the heaters?
5. What temperatures are attained by the gases and by the heater surfaces?
6. How much smoke is produced by each heater and how may a visible record of the smokiness be obtained?
7. What characteristics are necessary in a satisfactory fuel for orchard heating?

THE HEATERS STUDIED

A total of nineteen heaters, figure 1, and table 1, were included. Extra stacks and "spiders" for placing over lard-pail type to reduce the burning rate (see Nos. 6s and 8s as typical spiders) brought the actual number of heaters tested up to twenty-six. Six of these are of the briquet or solid fuel burning type, two are non-distilling, and

Fig. 1.—Names of the heaters tested: 1. Pomona. 2. Kittle. 3. Scheu Jumbo Cone Louvre. 4. Scheu Baby Cone Louvre. 5. Scheu Double Stack. 6. Bolton. 6s. Bolton (with spider). 7. Troutman. 8. Canco. 8s. Canco (with spider). 9. Diamond. 10A. Dunn (10 in the illustration). 10C. Dunn (with 30-inch stack; not shown). 11A. Citrus, 9-gal. low stack. 11B. Citrus, 9-gal. medium stack. 11C. Citrus, 9-gal. high stack. 12A. Citrus, 6-gal. low stack. 12B. Citrus, 6-gal. medium stack. 12C. Citrus, 6-gal. high stack. 13. Karr. 14. Jessen (large). 15. Jessen (medium). 16. Jessen (small). 17. Low Delivery. 18. Baby Double Stack. 19. Citrus Gas Flame.

eighteen distilling oil burners. Four additional heaters were received too late for test. Three of these are Citrus heaters and similar to Nos. 11B, 11C, and 19. They differ from those illustrated in that each has a baffle plate inside the reservoir and a filler tube and filler cap in the cover, and the one similar to 11B also has the stack height reduced from 31 inches to 18 inches. The fourth is the new Scheu-National Jumbo Cone Louvre heater and differs from heater No. 3 of the tests in the following particulars: weight 18.3 pounds; over-all height 44 inches; stack, height $22\frac{1}{2}$ inches, top diameter 7 inches, bot-

TABLE 1
IDENTIFICATION OF ORCHARD HEATERS TESTED
(See also fig. 1)

No.	Name	Made by	Type*	Weight ^a , pounds	Over-all ^a , inches		Stack, inches		Reservoir, inches		Material
					Ht.	Length by width (or diameter)	Ht.	Diameter (top and bottom)	Ht.	Length x width, top and bottom (or diameter, top and bottom)	
1	Pomona.....	Pomona Valley Orchard Protec- tion Association, Pomona.....	Brqt.....	6.6	19	10				9	G. I. & C. I.
2	Kittle.....	Kittle Mfg. Co., Los Angeles.....	N. ds. oil.....	30.0	45.5	23 x 22	40	7.8 & 9	9	19 x 21 & 16 x 18	G. I. & Sht. St.
3	Scheu Jumbo Cone										
4	Louvre.....	American Can Co., Los Angeles	Ds. oil.....	22.3	53	20	29	6.8 ^b	10	19.4 & 17	Sht. St.
	Scheu Baby Cone										
5	Louvre.....	American Can Co., Los Angeles	Ds. oil.....	16.5	49	20	24	5.5 ^b	10	19.4 & 17	Sht. St.
6	Scheu Double Stack	American Can Co., Los Angeles	Ds. oil.....	11.7	27.5	20	15	6 & 8†	10	19.4 & 17	Sht. St.
6s	Bolton (lard pail).....	W. R. Ames Co., San Francisco	Ds. oil.....	2.1	10	10.5			9.3	9.5 & 8.6	Sht. St.
7	Bolton (with spider)	W. R. Ames Co., San Francisco	Ds. oil.....	2.3	10	10.5			9.3	9.5 & 8.6	Sht. St.
	Troutman (modified										
	lard pail).....	P. H. Troutman, Denver, Colo.	Ds. oil.....	2.2	11.5	7.5			8.8	7.4 & 7	Sht. St.
8s	Canco (lard pail).....	American Can Co., San Francisco	Ds. oil.....	2.1	9	10			8.8	9.8 & 8.8	Sht. St.
9	Canco (with spider)	American Can Co., San Francisco	Ds. oil.....	2.3	9	10			8.8	9.8 & 8.8	Sht. St.
	Diamond.....	Phillips Orchard Heater Co., Covina.....	Brqt.....	6.9	24	9.5			19	9	G. I. & C. I.
10A	Dunn.....	No longer manufactured, but many still in use.....	Ds. oil.....	12.0	26	17	12	5 & 6	10.2	16 & 14	Sht. St.
10C	Dunn (30 in. x 6 in. stack).....	No longer manufactured, but many still in use.....	Ds. oil.....	15.8	5.5	17	41	5 & 6	10.2	16 & 14	Sht. St.
11A	Citrus 9-gal. (low stack).....	Riverside Sheet Metal Works, Riverside.....	Ds. oil.....	11.4	18.5	16.5 x 16.5	6	5.5	10.5	15.5 x 15.5 & 13 x 13	G. I.
11B	Citrus 9-gal. (med- ium stack).....	Riverside Sheet Metal Works, Riverside.....	Ds. oil.....	14.2	31.5	16.5 x 16.5	15	6	10.5	15.5 x 15.5 & 13 x 13	G. I.

TABLE 1—(Concluded)

No.	Name	Made by	Type*	Weight ^a , pounds	Over-all ^a , inches		Stack, inches		Reservoir, inches		Material
					Ht.	Length by width (or diameter)	Ht.	Diameter (top and bottom)	Ht.	Length x width, top and bottom (or diameter, top and bottom)	
11C	Citrus 9-gal. (high stack).....	Riverside Sheet Metal Works, Riverside.....	Ds. oil.....	18.0	60	16.5 x 16.5	43.5	5 & 6	10.5	15.5 x 15.5 & 13 x 13	G. I.
12A	Citrus 6-gal. (low stack).....	Riverside Sheet Metal Works, Riverside.....	Ds. oil.....	9.1	15	16.5 x 16.5	6	5.7	7.5	15.5 x 15.5 & 14 x 14	G. I.
12B	Citrus 6-gal. (medium stack).....	Riverside Sheet Metal Works, Riverside.....	Ds. oil.....	11.9	23.3	16.5 x 16.5	15	6	7.5	15.5 x 15.5 & 14 x 14	G. I.
12C	Citrus 6-gal. (high stack).....	Riverside Sheet Metal Works, Riverside.....	Ds. oil.....	15.7	56.8	16.5 x 16.5	43.5	5 & 6	7.5	15.5 x 15.5 & 14 x 14	G. I.
13	Karr.....	Western Steel Products Co., Duluth, Minn.....	Brqt.....	6.2	29.5	10	.....	.....	29.5	10 & 8	Sht. St.
14	Jessen (large).....	Jessen Sheet Metal Works, Los Angeles.....	Brqt.....	7.0	30	9	.....	.....	26	9	G. I. & C. I.
15	Jessen (medium).....	Jessen Sheet Metal Works, Los Angeles.....	Brqt.....	6.0	24	9	.....	.....	19.8	9	G. I. & C. I.
16	Jessen (small).....	Jessen Sheet Metal Works, Los Angeles.....	Brqt.....	5.5	20	9	.....	.....	16	9	G. I. & C. I.
17	Low Delivery.....	Kittle Mfg. Co., Los Angeles.....	N. ds. oil.....	21.0	36	30 x 20	30	8	8	17 x 17 & 14 x 14	G. I. (Stack "Duriron")
18	Baby Double Stack	Scheu-National Orchard Heater Co., Covina.....	Ds. oil.....	5.6	22	15.4	15.2	6 & 7†	5.5	15 & 12.5	Sht. St.
19	Citrus Gas Flame....	Riverside Sheet Metal Works, Riverside.....	Ds. oil.....	13.9	25.8	17 x 17	13	6†	10.5	15.8 x 15.8 & 13 x 13	G. I.

* "Brqt." means briquet; "Ds. oil," distilling oil; "N. ds. oil," non-distilling oil.

^a Weights and over-all heights include cover and deflector, if any. Where stacks or reservoirs flare the diameter (or length and width) at top is given first.^b Measured above cone.

† Diameter of outer part of the double stack.

‡ "G. I." means galvanized iron; "C. I.," cast iron; "Sht. St.," sheet steel.

tom diameter 9 inches. The cone is larger at the top than that of No. 3. A self-contained lighting cup is placed at the top of the down-draft tube. With the exception of the Dunn heater (no longer manufactured but many still in use), all the heaters studied were supplied by courtesy of the manufacturers. In each case the maker was asked to supply any directions for use which he had found necessary to give the buyers of his product. In the tests such instructions were followed as closely as possible.

The heaters studied are of three types or classes, (1) those that burn solid fuel, especially briquets, (2) those that burn oil in a burner separate from the fuel reservoir, and (3) those that burn oil within the reservoir itself. The names in common use for these three types, briquet, non-distilling oil, and distilling oil, are used in reporting this work, although the last two terms do not seem entirely fitting since condensation is not a feature in the operation of either type. In the so-called non-distilling heater the oil is metered through a suitable device in flowing from the reservoir to the burner. The fuel left in the reservoir after a night's burning of the heater is practically the same in quality as before lighting. In the so-called distilling type heater the fire inside the reservoir causes the more volatile portions of the oil to be vaporized and burned first. Hence, after some hours of burning, the oil remaining in the reservoir of such a heater may be considerably denser (lower Baumé number) than the original fresh oil.

Briquet heaters are not so easy to extinguish as the oil burners. They are usually left until the complete charge of fuel has burned out. Though some fuel might be saved by emptying the contents of the heaters upon the ground, generally the labor cost would be too great.

THE LABORATORIES USED

In order that the conditions under which the heaters were placed during test might be comparable with those in practice, the laboratory chosen for the bulk of the tests was a tilled field about 50 yards wide flanked on the east by a deciduous orchard and on the west by a vineyard. The only building near was a small shed built to shelter the necessary instruments. Here the tests were run at night and only when the wind speed, measured at a height of 18 feet 10 inches above the ground was less than about 5.5 miles per hour. The speed at the level of the heaters was much less. Higher wind speeds caused too great variations in the burning rates and made it impossible to obtain

satisfactory measurements of the quantities under study. The air temperatures during the testing were not so low as is desirable but were the best available at Davis. However, it is believed that a re-running of the tests at temperatures between 18° F and 28° F would not change the relative positions of the heaters as to the measurements. Since colder air is denser and therefore contains more oxygen per cubic foot it would be expected that for a given adjustment and kind of fuel a heater would burn faster at the colder air temperature. A test indicated that this was true. An open lard-pail heater was burned four times at night and thrice in the daytime using 17 pounds of No. 2 oil (see table 7) for each test. The wind speeds were nearly the same for all tests. The average day burning time was 3 hours 0 minutes and air temperature 48.7° F; the average night time 2 hours 29 minutes and air temperature 36.3° F. See curves "8 (day)" and "8" in figure 2.

In general at least two tests in the field laboratory were made on each heater, one at "high adjustment" and one at "low adjustment, meaning, respectively, about as high as a grower would ordinarily burn his heaters if he feared he might not be able to hold a safe air temperature, and about as low as the heater could be made to burn properly. In some cases it was found later that adjustments had been somewhat too high or too low. It was not always possible to re-run the test.

To make sure that the comparative records of smoke and of upward velocities of the gases were correct it was decided to make a "normal adjustment" run indoors so that wind effects might be entirely eliminated. The indoor tests were made in daytime in a large room which was ventilated after each test, the heaters being lighted and warmed up outside and brought in on a small flat-car.

FUEL CONSUMPTION RATES

From the utility standpoint the burning or fuel consumption rates are of the utmost importance since to produce heat in large quantities is the prime object. The heat produced equals the number of pounds of fuel burned times the heat content per pound, assuming complete combustion. The heat content of a fuel is generally expressed in British thermal units (abbreviated B.t.u.) per pound. Its value is about 20,000 for oil, 16,000 for coke, and 13,000 for coal. A B.t.u. is

Fig. 2.—Characteristic burning rates. Each curve, except “8” and “8 (day),” is the record of a single test on the heater of the corresponding number. The fuel reservoirs were full at lighting. The only draft adjustments, if any, were made immediately after lighting. All briquet heaters were top lighted. The deviations from smooth curves are due principally to wind variations. Briquet type heaters vary more than the oil burners (curves 1, 9, 9', and 13). Curve 9' shows a typical case of imperfect lighting (heater No. 9). The dotted line curve “8 (day)” is the average of three tests run in daytime and shows how higher air temperature slows the burning rate. Curve “8” is the average of 4 tests all run at night. See figure 1 and table 1 for identification of heaters.

the heat required to warm one pound of pure water one degree Fahrenheit. It is comparatively easy to measure burning rates. For the field tests the scales used were sensitive to one-fourth ounce and were set into the ground so that the bottom of each heater was on a level with the ground surface. Readings of weights were taken at 30-minute intervals in the field laboratory and at 10-minute intervals indoors. It was found that the burning rates of distilling type oil burning, and of briquet burning heaters were greatly affected by slight changes in wind speed. The two non-distilling heaters tested were of course unaffected, since in these heaters the fuel is metered into the burner; however such heaters are sensitive to temperature effects, especially when the oil used is of such nature that it thins rapidly on being warmed, for example, oils A, B, C, and L in figure 11 (see also table 6). The oil burning heaters have characteristic burning rate curves, a few of which are shown in figure 2.

It should be emphasized that in the tests in which data for these curves were obtained the only draft adjustments were made immediately after lighting. Also no fuel was added during test. Frequent regulation is essential in practice to secure the desired results. Generally the adjustment will be for a low burning rate at lighting when only a little heat is needed. Towards morning when the temperature may tend to go very low a much higher burning rate may be required; this would necessitate re-regulation and, in lard-pail and briquet heaters, re-fueling, or lighting of reserve heaters. It should be noted that all briquet type heaters tested were lighted at the top. Bottom lighting causes the fuel to burn out in a shorter time.

The peaks that are found on curves 3 and 8 (fig. 2) at points about one hour after lighting are evidently caused by the warming of the oil and consequent more rapid vaporization. The later falling off of the burning rates is no doubt due to the oil level becoming lower in the reservoirs and to the fact that the more volatile portions of the fuel burn first leaving the heavier, more slowly vaporizing portions. In some heaters clogging with soot undoubtedly tends to slow the rate of burning.

Most of the deviations from smooth curves are due to the effects of variations in wind speed and air temperature; some may be the result of errors in the readings. It will be noted (fig. 2) that the burning rates of briquet type heaters are often much more erratic than those of the oil burners. The method and skill used in kindling and in lighting and also the character of the material used for kindling

have a considerable effect upon the promptness with which the heater will come up to its maximum burning rate for a given adjustment. Curves 9 and 9' show variations that may be expected. Curve 9' is a typical case of slow starting which may be caused by using too little or poor quality kindling, by improper placing of the kindling, or by unskillful application of the oil from the lighting torch. For briquet heaters two jute balls (fig. 3) filled with paraffin and placed under the top layer of briquets proved to be very satisfactory kindling. No deterioration of the kindling would occur even if the unlighted heater were left standing several years. Pieces of old automobile casing were found to serve well except for the smoke and odor. A quart of dried peach pits similarly placed was also satisfactory. Short pieces of seasoned wood thoroughly soaked with refuse crank-case oil served the purpose though they were less pleasant to handle.

Fig. 3.—A satisfactory kindling for briquets. Balls of jute waste $2\frac{1}{2}$ inches in diameter dipped into melted paraffin. Two are placed under the top layer of briquets. They are unaffected by weather or time and start readily when lighted with fuel from a lighting torch.

Another factor that influences greatly the burning rate of a given heater under given conditions is the volatility of the fuel used. If light oil is used the rate of burning will be more rapid.

In these tests the briquet heaters burned up to nearly 5 pounds of fuel per hour (table 4), and the oil burning heaters up to nearly 15 pounds per hour (table 5). It is understood, of course, that the oil burning heaters other than lard-pail type could have been adjusted so as to consume at considerably more than the highest rates given in the summaries, but in general it would have been at the penalty of higher upward velocities and higher radiation rates. Also such excessively high adjustment would have greatly increased the smoke nuisance.

FUEL-TO-HEAT CONVERSION EFFICIENCY

To find out how efficiently the several heaters converted fuel into heat it was necessary to analyze the hot gases arising from them to find the per cent of carbon monoxide gas and to determine the weight of smoke (carbon) per unit volume of the hot gases. It was found necessary to take the samples of the gases just above the tip of the flame. If taken too low, considerable amounts of unburned oily vapors and much larger amounts of carbon would be drawn. If taken too high, there was greater danger of taking some fresh air. Hence good results could be obtained only when the wind was nearly still. Especially sensitive apparatus was used to determine the per cent of carbon monoxide. This was in no case found to be greater than five-hundredths of one per cent even when the gas sample had been taken a little too close to the flame. The heat loss represented by the unburned carbon in the smoke of some of the smokiest heaters was only about one-tenth of one per cent of the heat value of the fuel used. We must conclude therefore that *the fuel-to-heat conversion efficiency of all the heaters tested was practically 100 per cent.* That is to say, the heaters tested got out of the fuel used practically all the heat there was in it. This takes no account of fuel left unburned in the reservoirs, or else assumes that the drafts in distilling type heaters are opened sufficiently at the last to burn out completely the asphaltic residues. In practice this latter would not usually be done on account of the danger of warping and of burning holes in the bottoms of the reservoirs. In the tests here reported only fresh oil was used. In practice it is customary to add enough fresh oil to refill the partially emptied reservoirs after each night's use. Thus the heavier residues may accumulate. Cases have been reported where from this cause near the close of a long period of freezing weather lighting became very difficult and large quantities of tarry or asphaltic matter were left when the fires would no longer burn with the ordinary draft regulations. (For further discussion of smoke measurements see p. 17, and of fuels, p. 27.)

RADIATION FROM HEATERS

Heat that passes out in straight lines from a hot object as a center does not appreciably warm the air or other medium through which it passes. It is only when the heat ray strikes some opaque object and is absorbed that it is able to warm the air in the neighborhood. For these reasons that portion of the heat that is radiated upwards

from an orchard heater is largely lost to the sky. Whatever heat is radiated along lines that fall below the horizontal will of course be absorbed by the soil and be effective in warming the air. Also any rays that strike leaves, twigs, branches, and stems of trees would be saved. Hence more of the radiant heat would be lost in a deciduous orchard than in a citrus grove.

Fig. 4.—Apparatus for measuring radiation from orchard heaters. Four heaters placed on scales set in an arc of a circle were tested in succession by swinging the radiometer from one to another. Readings were taken at seven positions from 0° angle (horizontal) up to 90° angle (vertical). The radiometer was connected electrically to a sensitive galvanometer in the instrument shelter.

The higher the temperature of the hot gases and of the heater surfaces the greater will be the radiation loss. Evidently the radiation rate will vary as gas and surface temperatures change. A flaming heater radiates more than one that is too cool to emit light.

Apparatus was devised for measuring the heat radiated above the horizontal plane through the effective radiation centers of the several heaters (fig. 4). The total heat radiated upward was in some cases nearly 5 per cent of the total heat in the fuel burned (see summaries of night tests, tables 4 and 5).

A number of attempts were made to reduce the radiation loss by the use of screens of various shapes. All of these proved effective in some degree. The most practicable form of radiation screen found (though far from being the most effective) was a simple flat baffle plate placed a few inches above the stack. Figure 5 shows graphically the effect.

Fig. 5.—How a deflector affects radiation to the sky. Distances out from center are proportional to the intensity of radiation. The space between the two curves indicates roughly the heat saved by the use of an 18-inch square deflector placed on a Scheu Jumbo Cone Louvre heater burning 10.63 pounds of No. 1 oil per hour.

UPWARD VELOCITY OF THE WARM GASES

The warm gases rising from an orchard heater should not rise too rapidly or they may not spread out horizontally and come to rest at a sufficiently low level. If shot out at high velocity and high temperature they may instead “penetrate the temperature-equilibrium ceiling” above the orchard and in some degree become ineffective as far as warming the orchard is concerned. Measurement of the upward velocity of the hot gases was accomplished by use of a high-temperature anemometer especially designed and built for the purpose. Calibration was made to enable interpretation of its readings in terms of feet per second. A further study is to be made to find out how high gases starting at 14 feet per second will normally rise in an orchard.

Fig. 6.—High-temperature anemometer as set ready for use in out-of-doors tests. This measures the upward velocity of the hot gases. The revolutions are recorded electrically on the chronograph roll seen on the right.

Figure 6 shows the high-temperature anemometer in position for use in a field laboratory test. In the field tests the anemometer was placed in line with the center line of the stack and partly within the top to lessen wind effects. In the indoor tests it was placed as in figure 7, in the region of highest velocity of the gases. In a few cases,

Fig. 7.—Anemometer placing in indoors tests. The region of highest velocity is generally found at about two diameters distance above the stack in still air.

especially of low or medium stack heaters, slightly higher velocities (and sometimes higher gas temperatures also) were found at low burning rate adjustment than at higher adjustment in the same heater. These apparent discrepancies were in general due to the fact that the column of rising gases in some cases did not fill the whole area of the stack but was concentrated in a portion of the space. As will be seen in the summaries, tables 2, 3, 4, and 5, the velocities range from less than 2.5 feet per second (below which the anemometer would not run satisfactorily) to about 5 feet per second for briquet burning heaters, and from the same low limit up to about 14 feet per second for oil burners.

The same flat baffle plate that was found practicable to reduce radiation to the sky may be used satisfactorily above many of the heaters now in use. Its use will stop the rapid rise of a concentrated stream of high temperature gases and send them out horizontally at greatly reduced speed, at the same time mixing them more effectively with the cold air. It was found that the upward velocity of the gases from heaters Nos. 2 and 17 was less than 2.5 feet per second when the regular baffles were in place but about 8 and 6 feet per second, respectively, when the baffles were removed.

TEMPERATURE OF GASES AND HEATER SURFACES

It was found very simple and easy to measure these temperatures by use of electrical pyrometers designed to work at the temperatures involved. Measurement was made just at the top of the stacks. Luminous flames were found very hot, in some cases running about 1400° F. The temperatures of the heater surfaces were found to vary considerably, depending upon the distribution of the fires inside. In briquet burning heaters lighted at the top large and very irregular variations were found. Hot spots develop and move as the fire spreads through the fuel. As before indicated, excessively high surface temperatures are undesirable because they tend to increase radiation losses. They also tend to cause rapid destruction of the heaters.

SMOKE FROM ORCHARD HEATERS

While, as before indicated (under "Efficiency," p. 13), the smoke from orchard heaters does not represent an appreciable heat loss, it is nevertheless a great nuisance to the fruit grower and his helpers and to everybody else within its range, and does not itself appreciably lessen the danger of frost damage.⁽³⁾

In the study of smoke two things were sought: (1) to weigh the smoke in a given volume of the gases and, (2) to secure a visible record by which relative smokiness might be compared. Some difficulties were encountered, but satisfactory methods and apparatus were finally evolved. The weights of smoke were found to be exceedingly small (summaries, tables 2, 3, 4 and 5).

TABLE 2

SUMMARY OF DAYTIME TESTS BRIQUET BURNING HEATERS*

No.	Heater	Fuel charge, pounds	Fuel, pounds per hr.	Time since lighting,		Heat in fuel ^a , B.t.u. per hr.	Maximum upward velocity ^b , feet per second	Temperature of gases ^c , degrees F.	Smoke, pound per 1000 cu. ft. gas
				Hr.	Min.				
1	Pomona.....	24	2.94	1	00	39,590	4.7	690	.0085
		20	2.81	2	00	37,839	4.4	305	.0062
		17	1.41	5	20	18,987	2.7	485	Clear
9	Diamond.....	19	3.44	1	55	35,281	2.6	600	Trace
		13	2.06	4	17	27,740	3.0	415	Clear
13	Karr.....	22	4.31	2	00	58,038	5.1	460	.0145
14	Jessen, large.....			No	day	run			
15	Jessen, medium			No	day	run			
16	Jessen, small....	18	3.28	1	30	44,169	Less than 2.5†	645	.0044
		12	1.78	3	55	17,477	Less than 2.5	335	Trace

* All tests made indoors with No. 3 briquets (see table 7).

^a Product of pounds fuel per hour by heat content per pound as obtained by bomb calorimeter.

^b Measured at region of maximum velocity.

† Measured at top of stack.

‡ Regular lid in place. Without lid, 4.8.

For making a visible record of relative smokiness of all the heaters the same volume of gases for each, taken from just above the tip of the flame, was passed at the same rate through a circle 3 inches in diameter in the center of a 5-inch square of white felt. For the speed at which the gases passed through, the felt used made a practically perfect filter. Because of its long bill or tube (for cooling the gases before they reached the felt) the device in which the square of felt was clamped was termed the 'smoke mosquito.' Figure 8 shows it in use in an indoor test. The record of smoke in the out-of-doors tests is shown in figure 9 and in tables 4 and 5. Series of records were taken on two briquet heaters (Nos. 1 and 14, fig. 9) to show the behavior with the passage of time. Where in the summaries (tables 2, 3, 4 and 5) the

TABLE 3
SUMMARY OF DAYTIME TESTS, OIL BURNING HEATERS*

No.	Name and type	Fuel charge, pounds, approx.	Fuel, pounds per hour	Heat in fuel ^a , B.t.u. per hr.	Maximum upward velocity, ft. per sec.	Temperature of gases, ° F.	Smoke, pound per 1000 cu. ft. gas
2	Kittle, non-distilling.....	36	3.38	66,748	Less than 2.5	665	Trace† .0053† .0053† .0053
17	Low delivery, non-distilling..	44	1.97	38,904	Less than 2.5	460	.0107 Trace
17	Low delivery, non-distilling..	41	3.72	73,463	Less than 2.5	715	Trace Trace .0044
3	Scheu Jumbo Cone Louvre, distilling.....	32	6.67	131,719	10.9	955	Clear Clear
4	Scheu Baby Cone Louvre, distilling.....	31	5.44	107,429	11.8	865	.0124 .0329
4	Scheu Baby Cone Louvre, distilling.....	30	3.00	59,244	9.7	645	.0062 Trace
5	Scheu Double Stack, distilling.....	35	3.56	70,303	8.0	1,060	.0062 .0071
5	Scheu Double Stack, distilling.....	34	2.91	57,467	6.9	655	Trace Trace
6	Bolton, distilling.....	12	3.94	77,807	4.7	670	.0338 .0373
6s	Bolton, spider on, distilling...	11	0.85	16,786	Less than 2.5	286	.0115 .0115
7	Troutman, distilling.....	8	1.56	30,807	3.5	.....	.0364 .0409
8	Canco, distilling.....	12 10 9	5.63 5.83 6.04	109,838 115,131 192,779	4.8 5.7	1,020 940	.0364 .0267 .0249
8s	Canco (spider on) distilling...	13	1.03	20,340	Less than 2.5	310	.0178 .0187 .0275
10A	Dunn, distilling.....	24	4.25	83,929	8.0	1,420	.0249
10C	Dunn, with 30" x 6" stack, distilling.....	22	4.50	88,866	8.8	830	.0364 .0382
11A	Citrus, 9-gal., low stack, distilling.....	31	3.09	61,021	7.7	1,160	.0151 .0124
11B	Citrus, 9-gal., medium stack, distilling.....	29	4.98	98,345	8.1	1,125	.0187 .0222
11C	Citrus, 9-gal., high stack, distilling.....	25	10.78	212,883	14.1	1,140	.0293 .0213 .0231
12A	Citrus, 6-gal., low stack, distilling.....	34	2.69	53,122	6.0	885	.0258 .0258 .0258
12B	Citrus, 6-gal., medium stack, distilling.....	31	5.0	98,740	9.8	1,160	.0187 .0240
12C	Citrus, 6-gal., high stack, distilling.....	28	10.0	197,480	.....	1,115	.0115 .0142
18	Baby Double Stack, distilling	13	3.00	59,244	4.3	1,010	Trace .0178
18	Baby Double Stack, distilling	12	1.60	31,597	6.3	1,070	Clear Clear
19	Citrus Gas Flame, distilling..	22	3.94	77,807	4.0	850	Trace Trace

* All tests made indoors with No. 2 oil (see table 7).

^a Product of pounds fuel per hour by heat content per pound of fuel as obtained by bomb calorimeter.

† Determinations of smoke density were sometimes made in duplicate or in triplicate.

TABLE 4
SUMMARY OF NIGHT TESTS, BRIQUET BURNING HEATERS

No.	Name	Time since lighting,		Fuel charge, (approx.) pounds	Fuel,		Heat in fuel,* B.t.u. per hr.	Heat radiated, ^a		Maximum upward velocity, ^b ft. per second	Temperature of gas, [†] degrees F.	Temperature surface, [‡] degrees F.	Smoke, pound per 1000 cu. ft. of gas
		Hr.	Min.		No.	Pounds per hour		B.t.u. per hr.	Per cent				
1	Pomona.....	0	45	15	3	2.18	29,356			3.6	600		Trace
		1	15	14	3	2.20	29,625						Trace
		2	15	10	3	1.80	24,239						
		2	45	9	3	2.04	27,471						
		4	10	8	3	1.68	22,623	1,013	4.5				
9	Diamond.....	0	40	13	3	3.44	46,323	1,564	3.4	4.4	860	556, 575, 50	Trace
		1	40	10	3	2.50	33,665	1,326	4.1	3.5	665	418, 560, 60	Clear
13	Karr.....	0	35	34	3	4.13	55,615	1,633	2.9	4.4	1,030	732, 50, 50	Trace
		2	35	27	3	3.75	50,496	1,697	3.4	Less than 2.5	317	248, 334, 589	Trace
14	Jessen, large.....	0	50	29	4	1.63	26,377	406	1.5				
		1	30	28	4	1.50	24,273	579	2.4				
		2	30	26	4	4.63	74,923			Less than 2.5	494	378, 356, 197	0.0053
		5	45	18	4	2.75	44,501	1,529	3.4				
		0	32	28	3	2.88	38,782	1,024	2.6	Less than 2.5†	490	690, 352, 50	0.0124
		3	30	19	3	2.86	38,513			Less than 2.5†	477		Trace
15	Jessen, medium.....	1	25	24	4	1.38	22,331	400	1.8				
		4	53	18	4	1.80	29,128			Less than 2.5	335	422, 476, 360	Clear
		5	42	16	4	2.04	33,011	1,089	3.3				
16	Jessen, small.....	0	50	19	4	1.42	22,978	267	1.2				
		1	25	18	4	2.60	42,073	474	1.1				
		5	05	13	4	1.08	17,477			Less than 2.5	627	453, 615, 489	Clear
								631	3.4				
		5	43	12	4	1.14	18,447						

* Practically equal to heat delivered per hour.

^a Only that part above horizontal plane through radiation center of heater.

^b measured at top of stack.

† When regular lid was in place. With lid off, 4.6 maximum.

‡ Temperatures are top, middle and bottom, respectively.

TABLE 5
SUMMARY OF NIGHT TESTS, OIL BURNING HEATERS

No.	Name and type of heater	Fuel charge, pounds, (ap-prox.)	Fuel,		Heat in fuel*, B.t.u. per hr.	Heat radiated ^a ,		Maximum upward velocity†, ft. per second	Temperature of surface, degrees F.	Smoke, pound per 1000 cu. ft. of gas			
			No.	Pounds per hr.		B.t.u. per hr.	Per cent				Top	Mid.	Bot.
2	Kettle, distilling.....	55	2	7.13	140,803	4,894	3.5	Less than 2.5	589	658	1,071	.0124	
		51	2	5.25	103,677	2,641	2.5	Less than 2.5	467	547	800	.0107	
		47	2	3.25	64,181	926	1.4	Less than 2.5	248	292	422	Trace	
17	Low delivery, non-distilling.....	35	2	3.25	69,118	899	1.3	Less than 2.5	206	249	414	Trace	
		33	2	1.25	24,685	267	1.1	Less than 2.5	59	77	150	Trace	
3	Scheu, Jumbo Cone Louvre, distilling..	29	2	10.75	212,291	.....	.....	10.0	.....	.....	.....	.0133	
		23	2	5.5	108,614	.....	.....	7.5	.....	.....	.....	Clear	
		59	1	10.63	209,943	9,470	4.62	When 18" square deflector was used, radiation fell to 3.85%	715	830	978	.0195	
		54	1	10.38	205,005	.....	.....	11.0	.....	.....	.....	Trace	
		34	1	3.82	75,379	2,111	2.8	8.8	792	.....	.....	.0231	
		35	3	14.88	303,329	10,715	3.5	10.3	1,287	.....	.....	Clear	
4	Scheu, Baby Cone Louvre, distilling....	27	3	6.75	137,599	5,127	3.7	9.2	884	.....	.....	.....	
		56	2	7.09	139,947	5,598	4.0	11.0	1,255	.....	.....	.0280	
		48	2	3.82	75,339	2,411	3.2	8.7	816	283	325	400	Trace
		56	1	4.64†	91,640†				1,285	530	580	700	
5	Scheu, double stack.....	32	3	6.88	140,249	4,987	3.6	.....	.....	.....	.....	.....	
		20	3	4.25	86,636	2,305	2.7	.....	.....	.....	.....	.....	
		39	1	11.51	227,224	9,089	4.0	5.6	839	547			.0200
		32	1	8.00	158,000	5,885	3.7	5.3	834				.0213
		33	1	4.25	83,938	2,167	2.6	4.8	769	467			.0133
		42	2	4.88	96,370	.....	.....	7.0	.....	.....	.....	Trace	
		38	2	3.38	66,748	.....	.....	6.8	.....	.....	.....	Trace	

* Practically equal to heat delivered per hour.

† Only that part above horizontal plane through radiation center of heater.

† Measured at top of stack.

‡ Averages for 7½ hours.

TABLE 5—(Continued)

No.	Name and type of heater	Fuel charge, pounds, (approx.)	Fuel, No.	Pounds per hr.	Heat, in fuel, B.t.u. per hr.	Heat radiated ^a ,		Maximum upward velocity [†] , ft. per second	Temperature of surface, degrees F.			Smoke, pound per 1000 cu. ft. of gas
						B.t.u. per hr.	Per cent		Top	Mid.	Bot.	
6 6s	Bolton, lard pail, distilling.....	9	2	5.32	105,059	4,060	3.9	4.2	1,069			.0802
		10	2	1.6	31,597	1,738	5.5	3.3	817			.0258
7	Troutman, modified lard pail, distilling	6	1	1.88	37,130	1,564	4.2	3.7	833			.0267
		8	2	2.00	39,496			4.8	1,019			.0320
8 8s 8s	Canco, lard pail, distilling.....	7	1	4.88	96,380	4,761	4.9	4.0	1,062			.0262
		5	1	1.50	29,625	626	2.1	2.7	645			.0142
		12	2	5.96	117,698			5.1	1,039			.0302
		8	2	3.28	64,773			3.2	702			.0204
10A	Dunn, distilling.....	41	2	6.00	118,488	4,605	3.9	7.9	1,445	837	930	.0213
		35	2	3.00	59,244	2,044	3.5	7.1	1,070	689	792	.0240
10C	Dunn, 30-in. stack added, distilling....	35	2	7.50	148,110	6,035	4.1	11.9	1,175	733	1,005	.0329
		31	2	4.25	83,929	2,984	3.6	9.9	783	466	618	.0293
11A	Citrus, 9-gal., low stack, distilling.....	40	1	9.38	185,255	6,621	3.6	5.5	1,036	745		.0204
		36	1	7.88	155,630	4,199	2.7	5.1	1,045	415		.0231
		51	2	10.25	202,417	7,785	3.8	5.6	1,165	732		.0293
		46	2	5.63	111,181	4,356	3.9	5.3	1,157	724		.0142
11B	Citrus, 9-gal., medium stack, distilling	31	1	13.00	256,750	10,021	3.9	7.6	1,157	690	475	.0222
		25	1	9.00	177,750	6,744	3.8	7.5	1,122	900	835	.0204
		42	2	8.25	162,921	7,605	4.7	7.3	1,191	882	858	.0249
		38	2	5.25	103,677	2,230	2.2	6.7	1,261	875	775	Trace

* Practically equal to heat delivered per hour.

^a Only that part above horizontal plane through radiation center of heater.

† Measured at top of stack.

TABLE 5—(Concluded)

No.	Name and type of heater	Fuel charge, pounds, (ap-prox.)	Fuel,		Heat in fuel*, B.t.u. per hr.	Heat radiated ^a ,		Maximum upward velocity†, ft. per second	Temperature of surface, degrees F.	Smoke, pound per 1000 cu. ft. of gas		
			No.	Pounds per hr.		B.t.u. per hr.	Per cent				Top	Mid.	Bot.
11C	Citrus, 9-gal., high stack, distilling	16	1	7.75	153,063	3,128	2.0	12.9	645	733	758	.0160
		8	1	3.26	64,385	1,031	1.6	10.1	334	316	307	Clear
		35	2	13.50	266,598	8,144	3.1	12.3	732	775	900	.0142
12A	Citrus, 6-gal., low stack, distilling	25	1	8.00	158,000	6,418	4.1	4.8	1,029			.0213
		23	1	4.42	87,295	2,994	3.4	4.7	1,113			.0160
12B	Citrus, 6-gal., medium stack, distilling	21	1	9.26	182,885	7,632	4.2	7.9	1,234			.0258
		19	1	4.96	97,980	3,522	3.6	8.1	1,183			.0204
12C	Citrus, 6-gal., high stack, distilling	13	1	6.68	131,330	3,702	2.8	11.5	1,144			.0142
18	Baby double stack, distilling	14	2	4.38	86,496	3,279	3.8	4.3	1,090	283	85	Trace
		11	2	1.22	24,093	622	2.6	4.6	880	188	111	Clear
19	Citrus, gas flame, distilling	40	2	5.38	106,244	3,674	3.5	4.6	860	387	163	Trace
		37	2	2.25	44,433	909	2.0	3.3	840	248	133	.0124
		23	2	3.94	77,807						124	Trace

* Practically equal to heat delivered per hour.

^a Only that part above horizontal plane through radiation center of heater.

† Measured at top of stack.

“smoke, pound per 1000 cu. ft. of gas” is given as “clear,” no sign of smoke was visible on the felt. Where “trace” is recorded a faint circle was visible but the quantity caught was too small to be weighed.

In the indoors tests a pair of smoke records were taken in the test of each heater. Figure 10 shows these pairs and indicates how closely the smoke records check. The conditions of burning rates, etc., when the indoors smoke records were taken, may be found in tables 2 and 3.

Fig. 8.—The “smoke mosquito” in use. A measured volume of the gases is drawn from just above the tip of the flame through a square of white felt. Note pyrometer (left) measuring the temperature of the gases.

In practically all the heaters clearer burning was obtained at low burning rates than at high. Nearly all oil burning heaters smoked badly when burned at maximum capacity. A comparative study of all the heaters tested indicated that in some cases a very slight difference in design apparently caused a large difference in smokiness. While absolute smokelessness under all conditions seems not feasible under present conditions of available fuel and equipment, still a great improvements could be made by the elimination, especially in the citrus growing districts, of the lard-pail and all other open type heaters; by redesign of some of the other heaters; by more care in the production of the fuels used; and especially by more care on the part of the user to regulate more frequently and to avoid burning at too high rates. In justice to the user it should be added that poorly designed or constructed heater covers sometimes make it impossible to regulate the burning rate.

Fig. 9.—Smoke records, out-of-doors tests. Equal volumes of gases at the same rate were drawn through all these felts. The darker the circles the more smoky the heater. Note (right) how two briquet heaters varied in smokiness as burning proceeded. (The card of heater No. 4 appears slightly below its proper place in the photograph.)

EFFECT OF ORCHARD HEATING ON THE PUBLIC HEALTH

Considerable complaint has been heard that gaseous products injurious to the health of residents in the citrus growing districts are given off by the heaters. Bronchial and pulmonary affections apparently caused by the smoke or by the gases have been mentioned repeatedly. No exhaustive study of this matter was made but the following facts are determined. Comparison with data given by Henderson, Haggard, Teague, Prince and Wunderlich⁽²⁾ and by Sayers, Meriwether and Yant⁽⁵⁾ of the U. S. Bureau of Mines shows

Fig. 10.—Smoke records, indoor tests. At least 2 daytime tests were made on each heater; note the close agreement between the records in each pair. The same fuels (No. 2 oil and No. 3 briquets) were used for all the indoor tests. Wind effects were eliminated in this portion of the test by running indoors. See tables 2 and 3 for rates of fuel consumption, etc.

that the per cent of carbon monoxide given off by orchard heaters is too small to produce any appreciable effect. In fact very much higher concentrations of carbon monoxide are found where automobile traffic is heavy in some of the streets of our cities than would ever be present under the worst conditions in a heated orchard. Some of the fuels sold for orchard heating in this state are rather high in sulphur content (table 7). This sulphur is almost completely changed to sulphur dioxide, a gas which, while not dangerous to the same degree as carbon monoxide, is very disagreeable and irritating to the nasal passages, throat and lungs. No method was found to determine

whether smoke of itself had any effect upon the health. Removal of sulphur from the fuels sold for orchard heating would certainly be highly desirable. Along with this, of course, should go reduction of smoke to a minimum.

FUELS USED IN ORCHARD HEATERS

Various complaints have been made concerning the oils sold for orchard heating purposes in this state. Several samples of orchard heater oils were secured and subjected to such tests as seemed likely to indicate how satisfactory they might prove in use. Since usually in non-distilling heaters the rate at which the oil will run through a small opening determines the burning rate, tests of viscosity were made on eleven oils (table 6). The California residue test (later

TABLE 6
OILS TESTED FOR VISCOSITY AND PER CENT OF RESIDUE*

No.	Source	Residue, by California test, per cent
1	Same as No. 1 used in the heater tests (Table 6).....	6.83
2	Same as No. 2 used in the heater tests (Table 6).....	0.201
3	Same as No. 3 used in the heater tests (Table 6).....	0.206
A	Ventura Oil Co., bought at Ventura.....	0.924
B	Seaside Oil Co., bought near Ventura.....	0.935
C	Ventura Oil Co., bought at Fillmore.....	1.206
D	Union Oil Co., bought at Lindsey.....	0.277
E	Standard Oil Co., "27+," bought at Lindsey.....	0.639
K	Standard Oil Co., bought at Winters.....	0.741
L	From ranch of P. G. Rhodes, near Winters.....	2.586
M	Standard Oil Co., "27+," bought at Los Angeles.....	(Sample too small)

* All from 1925-26 season supply. The viscosities are given in figure 11.

described) was also made and the results for some of the oils compared with results obtained for the same oils by use of the regular Conradson carbon test and Holde hard asphalt test. Figure 11 shows graphically the results of the viscosity tests. Evidently the samples that show nearly straight vertical lines (that is, that maintain their free flowing character almost constant from 100° F down to well below the freezing temperature of water) would run satisfactorily in a non-distilling type heater. On the other hand an oil like C, B, or L, if lighted and the burning rate properly adjusted at 25° F, would flow very much faster after the fuel in the reservoir came up to 35° F or 40° F. Oil A was solid at 12° F and oil L at 16° F. Oil L would hardly flow at all below 25° F.

To study the effect of settling, two samples of oil No. 1 were taken, one from the top and the other from the bottom of a 50-gallon drum after it had stood undisturbed for three weeks. The bottom oil was found to be 0.5° Beaumé heavier than the top, but both showed the same viscosity curve as that of the composite sample of oil No. 1. Possibly longer settling might have made a noticeable difference. Also other oils might have behaved differently. Oil No. 1 was chosen principally because it was very dark in color and on being burned left much asphaltic residue.

Fig. 11.—As the oils thicken on becoming colder, longer times are required for a standard unit quantity of oil to flow through the standard opening in the Saybolt test apparatus. The straighter lines show oils that thicken less rapidly on cooling. See table 6.

The accumulation of heavy residues in the reservoirs of distilling type heaters and in the burners of the non-distilling type has been a frequent cause of trouble. In extreme cases the heaters would operate very unsatisfactorily or could scarcely be made to burn at all. It seems that these asphaltic residues are not necessarily merely so much asphalt that was present in the original oil, but are probably produced by what the oil chemist calls “cracking of the molecules” of oil when heated. In the “cracking” process a molecule of the oil may be regarded as breaking up and then reassembling its component parts to

make two new molecules different from each other and from the original molecule. Thus the heat to which the oil in the reservoir is subjected may change some of the oil into two new kinds of oil, one that vaporizes easily and therefore burns readily, and one that is very heavy and hard to vaporize and hence is liable to fail to mix with the oxygen of the air and so be left unburned. Some oils will "crack" much more readily than others.

An attempt was made to find a simple test that would show whether a given oil would "crack" badly or not. The apparatus used consists of a sheet copper burner bowl A (fig. 12), a pedestal B on

Fig. 12.—California residue test for orchard heater oils. Ten grams of the oil to be tested is placed in bowl A. Bowl is placed on pedestal B and draft pipe C placed over as in figure 13. Lighting is by an alcohol swab burned under one edge of the bowl. The residue remaining when the fire dies is weighed. See data in tables 6 and 7.

which to support it, and a draft pipe, C. A 10-gram sample of oil is weighed in the burner bowl, the bowl placed level on the pedestal and the draft pipe placed over it (fig. 13). Lighting is accomplished by the use of a swab soaked in alcohol burned under one edge of the bowl until the fuel ignites. A pasteboard screen to prevent air currents is placed around the apparatus. When the fire dies out the residue is found by weighing the bowl on a sensitive analytical balance. Table 7 gives the results obtained on the oils used in the heater tests and a few other oils, together with results of other standardized tests for oils. It will be noted that there is a rather close parallel between the new California residue test and the Conradson carbon and Holde hard asphalt tests. Since the per cents of residue are considerably larger in the new test than in the Conradson, higher accuracy should be obtained by the California test, with the same degree of care and sensitiveness of instruments. The Conradson test results given were obtained from two companies engaged in commercial oil testing. It will be noted that the results differ somewhat. The Holde tests were made by the Chemistry Division staff at Davis.

A very simple test with inexpensive apparatus (fig. 14) may be made by the rancher himself to try orchard heater oils for residue. This is a modification of the California test but is less accurate and gives only a visual instead of a numerical comparison. However, the results obtained are sufficiently definite for all ordinary purposes.

Fig. 13

Fig. 14

Fig. 13.—California residue test apparatus (assembled). When in use, a pasteboard screen (not shown) surrounds the apparatus to reduce the effects of air currents. The balance shown is used to weigh the 10 grams of oil. A delicate analytical balance is used for the bowl and residue.

Fig. 14.—Modified form of California residue test apparatus. This enables making a residue test without expensive or delicate apparatus. Half-pint samples of the oils are burned in small tin pans and the residues compared.

Equal volumes ($\frac{1}{2}$ pint) or equal weights ($\frac{1}{2}$ lb.) are taken of the several oils to be tested. Instead of the small copper burner A of figure 12, an ordinary tin pan $5\frac{1}{4}$ inches inside diameter at the top, $4\frac{1}{2}$ inches at the bottom and $1\frac{1}{2}$ inches deep is used. It is well to have as many pans as there are oils to be tested, so that the results may be kept for comparison. An empty tomato can placed bottom end up may be used as a pedestal. The draft tube is not necessary. The oil may be lighted by placing a 2-inch diameter asbestos swab soaked in torch oil (gasoline and kerosene equal parts) under an edge of the pan. If preferred the pan of oil may be heated on top of a stove until it will ignite readily when a lighted match is applied.

Fig. 15.—Residues from orchard heater oils obtained by use of the apparatus shown in figure 14. Upper, oil No. 1 unsatisfactory; lower, oil No. 2 more satisfactory.

After lighting, a screen to keep off air draughts should be placed around if the test is made out-of-doors. A carton about 2 feet square and 3 feet high from which the top and bottom have been removed makes a satisfactory screen.

An unsatisfactory oil will leave a residue that is very noticeable though it may weigh less than half an ounce. Usually such a residue will consist of two parts, a thin layer of black, shiny, asphaltic material on the bottom of the pan, and above it a hard, flaky crust consisting mostly of carbon. A satisfactory oil will have no noticeable asphaltic residue and very little of the crusted carbon.

Since the temperature of the pan and contents during the burning determines in a large measure how much residue will be left, it is essential that all the conditions that might affect this temperature should be alike in all tests, if the results are to be compared. This refers especially to the method of lighting and the level placing on the pedestal. Using an asbestos pad between the burner pan and the pedestal in some of the tests and not in the rest, would make the results of doubtful value. Differences of 5°F or 10°F in the air temperatures when the tests are run will not appreciably affect the results. Figure 15 shows the residues obtained by this test on oils Nos. 1 and 2 (for other data of these oils see table 7). Oil No. 1 produced quite a drip of asphaltic material from the burners of the non-distilling type heaters tested. At intervals the crusted carbon left in the burners by this oil had to be removed. Oil No. 2 burned much more satisfactorily. The briquets used were in general satisfactory. The sulphur fumes were noticeably worse from the coal dust briquets as would be expected from the high sulphur content (table 7). The relatively large ash residues from the coal dust briquets sometimes partially clogged the grates and so reduced the burning rates. The coke and carbon briquets used had less sulphur and left no noticeable ash. They were however less satisfactory to handle because of their tendency to blacken anything they touched and to break into pieces.

Comparison of California residue test results with specific gravities (table 7) shows that the latter do not give any indication of the probable behavior of an oil with respect to asphaltic residue.

It was found that the asphaltic residues from some oils collected in and under the burners of the non-distilling heaters tested. Sometimes these residues spread over the ground around the heater. With some oils at certain adjustments the residues burned out automatically at intervals or could be made to burn out without apparent harm to the heater by applying a little fuel from the lighting torch to the base of the burner. The residues resulting from "cracking" of the fuel and

TABLE 7
ORCHARD HEATER FUELS

Fuel No.	Source and season bought	Specific gravity, ^a Beaume (at 60° F.)	Viscosity, seconds Saybolt,		B. t. u. per lb.	Sulphur, per cent	Carbon (Conradson test), per cent		Asphalt (Hofide hard asphalt test), ^a per cent	Residue (Calif. test), per cent
			20° F.	32° F.			A Co.	B Co.		
Oil 1.....	Citrus Exp. Sta., Riverside, 1925-1926.....	32.5	81	67	19,750	0.24	0.97	1.03	0.57	6.83
Oil 2.....	Union "Stove Oil," Davis, 1926.....	34.4	48	45	19,748	1.31*	0.02	Trace	None	0.201
Oil 3.....	Standard Oil Co., "27+," Winners, 1926.....	27.5	105	78	20,385	0.47		Trace	None	0.206
Oil 4.....	Richfield, "No. 2 straw distillate," 1927.....	36.1			19,723	0.31	0.04	0.015	None	0.144
Oil 15.....	General Petroleum Co., Covina, 1926-1927.....	32.6						0.53	0.26	2.80
Oil 16-17.....	Run of 1926-1927, sold to Cooperative Citrus Growers, Covina	32.5						0.30	0.25	2.83
Oil 18.....	Calpet, Fillmore Refinery, 1926-1927.....	27.4						0.85	0.23	3.36
Briquet 1.....	"Diamond" (coal dust), Pacific Coast Coal Co., Los Angeles, 1925-1926.....				13,046	0.84				
Briquet 2.....	Carbon, Fernholtz Machinery Co., Los Angeles, 1925-1926.....				16,315	0.46				
Briquet 3.....	"Diamond" (coal dust), 1926-1927.....				13,466	1.06				
Briquet 4.....	Coke, Shell Co., Los Angeles, 1926-1927.....				16,182	0.41				

* Determined by sulphur bomb method. The values for the other fuels were obtained by the bomb calorimeter method.

^a Hofide, David. The examination of carbon oils and of saponifiable fats and waxes. John Wiley & Sons, Inc. 2nd English Ed., p. 105-106 (method II), 1922.

from droppings of soot that accumulated in the reservoirs of the distilling heaters tested could be burned out in many cases by opening the drafts wide. Very high temperatures in the reservoirs would result. Whether this would rapidly destroy the heaters by burning out the bottoms was not determined by these tests. Growers report that reservoirs frequently burn through at the bottom of the down-draft tubes. No intensive study of orchard heater troubles was made in connection with the laboratory tests here reported. In general the test runs were of too short duration for characteristic troubles to develop fully. It is believed that these can be studied more satisfactorily in field tests such as are reported by Schoonover, Hodgson, and Young.⁽⁶⁾

It was found that refuse oil drained from crankcases of automobiles and tractors could be burned satisfactorily in several distilling type heaters.

CAUTION NECESSARY IN USE OF DATA

It is inadvisable to draw hard and fast conclusions as to the relative merits and demerits of the several heaters tested, using as a basis of comparison the data given in the summaries. This is particularly the case where the quantities measured were themselves very small. It should be remembered that the smaller the quantity, the less, in general, will be the degree of accuracy to which it can be measured. Also it should be borne in mind that the quantities measured were often changing appreciably from moment to moment. It was not in every case possible to take and to average a large number of readings for the reason that limited time was available when weather conditions were fit for making the tests. Nevertheless the data presented enable the making of a fair general comparison.

SUMMARY

New methods of testing were necessary because those used by mechanical engineers for testing furnaces were found inapplicable. Full description of methods is to be made in a later publication.

Nineteen heaters were studied and each was given a high and a low test in the open and a "normal" test indoors.

The burning rate was found important since it governs the rate of heat production. Each type of heater, if left without readjustment, was found to have a characteristic burning rate curve the shape

of which was altered by changes in wind speed and air temperature and in temperature and volatility of the fuel. The burning rate is adjustable in most heaters. Too high a rate was found undesirable since it tends to increase smoke and losses by radiation and by gases rising too high. It also tends to cause rapid scaling off and destruction of the stacks. Frequent and careful regulation is highly desirable as a means of overcoming the smoke nuisance as well as of securing the desired heat production.

It is customary in many orchards to light only a portion of the heaters at first and light others as the night grows colder. From the standpoint of heat distribution and reduction in the amount of smoke it is better to light all of the heaters and burn them at a low rate with frequent regulation. This frequent regulation will control the burning rates of the heaters in such a way as to save considerable fuel. With briquet heaters the most practical way of controlling the burning rate is to start with a relatively small fuel charge and refuel at about two-hour intervals throughout the night.

All the heaters were found practically 100 per cent efficient from the standpoint of converting fuel into heat, there being almost no carbon monoxide in the gases and the heat lost in the unconsumed carbon of the smoke being in every case less than one-tenth of one per cent of the total heat in the fuel used.

The heat radiated above the horizontal plane ranged from about one to nearly five per cent of the total heat in the fuel. Not all of this radiated heat is lost. The portion that strikes leaves, twigs, or other opaque objects and is absorbed serves to warm the air. Baffles for decreasing the radiation loss were found practicable.

High upward velocities and high temperatures tend to waste fuel by sending the hot gases to high levels above the orchard. The velocities found were satisfactorily low except in high stack heaters not equipped with a horizontal baffle plate. In some of these velocities as high as 14 feet per second were found.

Smoke is always a nuisance and of little or no benefit as a blanket to prevent radiation. The lard-paid heaters were the worst offenders. A number of the later oil burners were practically smokeless when burned at normal and low rates, but all smoked some when burning at very high rates. Satisfactory control of the burning rate was in some cases made difficult if not quite impossible by ill-fitting reservoir covers in distilling type heaters. Briquet heaters smoke considerably at lighting and for a time afterward but become clearer as burning progresses. Photographic smoke records were made.

No exhaustive study was made of orchard heater gases and smoke as affecting the public health. The concentrations of carbon monoxide are evidently too small to cause appreciable effects. Sulphur dioxide apparently caused annoyance to some of the workers. What part the smoke itself played was not determined.

Oils, being higher in heat content per pound, are more effective than solid fuels. The oils sold for orchard heating differ considerably in characteristics that affect their suitability. Oils that leave large asphaltic residues on burning are less desirable both for distilling and for non-distilling type heaters. A new method for determining per cent of residue is described. High sulphur content is objectionable. High viscosity and rapid increase in viscosity when temperature decrease make an oil unsuitable for non-distilling type heaters.

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