CALIFORNIA
AGRICULTURAL EXTENSION SERVICE

CIRCULAR 111
April, 1939

PROTECTION OF ORCHARDS AGAINST FROST

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Coöperative Extension work in Agriculture and Home Economics, College of Agriculture, University of California, and United States Department of Agriculture coöperating. Distributed in furtherance of the Acts of Congress of May 8, and June 30, 1914. B. H. Crocheron, Director, California Agricultural Extension Service.

THE COLLEGE OF AGRICULTURE
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA

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PROTECTION OF ORCHARDS AGAINST FROST[1]

WARREN R. SCHOONOVER,[2] F. A. BROOKS,[3] AND H. B. WALKER[4]

INTRODUCTION

THE PROTECTION of orchards against frost damage is a major problem in many California orchard districts. Almost one third of the entire California citrus acreage now has heater equipment, a second third does not suffer from frost damage often enough to warrant heating systems, and in the other third the need for heaters is marginal. At present 92,000 acres of citrus orchards are equipped with heaters to prevent frost damage.[5] Four million orchard heaters are in service. Each one must be individually lighted and regulated and all except 160,000 pipe-line heaters must be individually filled. During the severe freeze of 1937 about two million barrels of fuel oil and 17,000 tons of solid fuel (coal, coke, wood, and rubber tires) were burned during approximately 15 nights from January 5 to 27. The gas oil consumed in these three weeks drained all southwestern storage, emptied outbound tankers, and required large emergency shipments from distant refineries. The total quantity burned in three weeks was about 3 per cent of the whole United States annual refinery output of this grade of fuel. The available supply of solid fuel was adequate for only a small acreage.

Although, in 1937, there was a local shortage in fuel oil of the desired 27+° A.P.I. (American Petroleum Institute) gravity Diesel grade, oil is the only fuel which can be considered for the general practice of orchard heating. Because the refiners cannot carry adequate stocks, many growers have installed ranch storage, ranging in capacity from 350 to 3,000 gallons per heated acre. Mr. Floyd Young, in the statistical study just cited, reports a total ranch storage of about 61,000,000 gallons which,

[1] This publication is a revision of and supersedes Extension Circular 40, *Frost Protection in California Orchards*, by Warren R. Schoonover, Robert W. Hodgson, and Floyd D. Young; it is not a report of the research project in orchard heaters and heating now being carried on by the Agricultural Engineering Division of the University of California in the laboratories at Davis and in the field at the Citrus Experiment Station at Riverside. This project is not complete but some of the new observations will be cited at their appropriate places in the text to clarify the general questions of orchard heating.

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[5] Young, Floyd D. California orchard heater statistics. California Citrograph 23(9):371, 386, 388. July, 1938.

with 25,000,000 gallons stored at packing-houses, is equal to the 1937 usage.

Orchard heating is used for producing a rather small modification of outdoor temperature, namely, counteracting local cooling to maintain a safe minimum temperature, and raising the temperature of inflowing air near the ground a maximum of about 10° Fahrenheit. Whether orchard heating should be used more extensively than at present is primarily an economic problem. In general, heating should be avoided if there is any doubt as to its being worth while. It seems likely that present heating equipment will still be in use when fuels will have changed somewhat in quality and when they will probably be higher in cost.

ECONOMIC CONDITIONS UNDER WHICH ORCHARD HEATING MAY BE JUSTIFIED

Frost damage has occurred with sufficient frequency in California orchards so that frost protection is now recognized as an essential orchard-management practice in many of the orchard districts. The losses vary from minor crop losses or impaired quality of part of the fruit to severe tree damage which may result in decrease of crops for several seasons in the case of the more tender subtropical fruits.

Past experience in the citrus industry has led to the installation of frost-protection equipment on about one-third of the acreage in the state. Deciduous-fruit orchards and vineyards have, on the whole, less loss expectancy and are not as fully protected. It is probable that most of the citrus acreage on which protection is justified is already equipped, although often inadequately so, against severe frosts. There is evidence that heating is practiced in some orchards where it is not economically sound.

The question of when or under what conditions it becomes advisable for the grower to install orchard-heating equipment in all or part of his orchard is difficult if not impossible to answer positively, since there are so many variable factors such as differences in frost hazard, production costs, possible net returns with and without heating, and other considerations. In the last analysis this question must be decided by each grower. Certain factors entering into the decision may be determined with some degree of accuracy.

There is every reason to believe that over wide areas in the fruit-producing sections of the state the occurrence of temperatures occasioning severe damage is so infrequent that the savings effected by the use of heaters would not in the long run equal the costs of installing and operating the heating equipment. It is also probable that there are certain localities planted to fruits where frost damage is so extensive and so frequent in occurrence that over a period of years the cost of heating would exceed the value of the crops saved. Orchards so situated should be top-worked to varieties that are more resistant to frost damage, that bloom later, or that mature earlier. Unless this is possible, it is doubtful whether such orchards should be maintained, and in most cases they must eventually be abandoned or replaced by other crops.

It is unsafe to make a decision concerning the advisability of installing orchard heaters from the experience of only one season. The question should be given careful study and a decision reached only when it is apparent from local experience over a number of years that orchard heating is not only necessary to obtain satisfactory crops but that it will probably pay returns on the investment in capital and labor involved in its installation and operation.

The primary factors which should determine the advisability of orchard heating are the *overhead and operating costs involved,* and the *probable additional income* which may result. The overhead costs of orchard heating can be determined with some degree of accuracy from the extensive experience at hand, as can also the operating costs provided the average number of hours of heating per year required to save the crop is known. In many districts frost-hazard data can be supplied by the local representative of the Fruit Frost Service of the United States Weather Bureau or by the county farm advisor. Many of the farm advisors, in addition, can supply local data on overhead and operating costs as reported to them by coöperators in their enterprise-efficiency studies. Cost estimates should be based on available data and in all cases should be liberal.

Probable Additional Income from Heating.—The income from saved fruit is difficult to compute since this is determined by the production per acre which may be expected under the methods of management in use and the average price which may be expected for the fruit saved. It is necessary, therefore, to estimate the volume of fruit per acre that is likely to be saved from frost damage over a twenty-year period and the average price for this production. A fair allowance should also be made for protection against tree damage.

The factors of *production per acre* and *average price* received for the fruit are of great importance in determining the probable profits from orchard heating. It is clear that where both average yields and prices are low, heating is likely to result in a loss.

Probable Costs of Orchard Heating.—Orchard-heating costs should be divided into overhead costs and operating costs. The overhead costs will depend upon the type of equipment chosen and the care given to it. Operating costs depend mainly upon the fuel consumption which in turn is proportional to the degree-hours[6] of temperatures below the danger point and to the general atmospheric conditions prevailing during the period of heating.

The cost of satisfactory equipment for locations of average frost hazard is approximately $175 per acre for oranges, $280 per acre for lemons and avocados, and $80 per acre for deciduous fruits. These costs are based on new equipment which is adequate but which is not the most expensive nor the cheapest available. Costs will be higher for areas affected by the more rigid smoke abatement ordinances or places having extreme frost hazards. Where heating is practiced generally over an extensive acreage there is a marked effect on temperatures over the whole area so that the amount of equipment required can be reduced 10 to 20 per cent with a corresponding reduction in the above-estimated costs.

An adequate supply of fuel in storage will cost, at present prices, about $60 per acre for oranges, $100 for lemons and avocados, and $30 for deciduous fruits. The total investment will be about $235 per acre for oranges, $380 for lemons and avocados, and $110 for deciduous fruits. An annual charge of 10 per cent should be ample to cover normal depreciation, interest, and ordinary fuel losses, making annual overhead costs $23.50, $38.00, and $11.00 per acre for the respective classes of fruits.

Operating costs fall into two classes: first, those costs which are incurred every year whether heaters are lighted or not; and second, cost of fuel and labor for firing and refilling. The first group includes placing heaters in the field, the initial filling, removing from the field, ordinary repairs, painting, etc. Minimum costs for good practices will run about $6 per acre for oranges and deciduous fruits and $10 for lemons and avocados. The costs in the second group vary widely according to conditions.

The orchards of the Citrus Experiment Station at Riverside are typical of a relatively large area of moderate frost hazard. In January, 1937, there was general heating for 11 nights. Several of the nights were severely cold but all of the equipment was used on only 2 nights. Only *half* of the heaters were lighted on the remaining 9 nights. Oil consumption on the entire 150 acres heated averaged a little over 12 gallons per acre per hour, taking the elapsed time from the beginning of lighting to the shutting-down of the last heater. This amounted to 0.42 gallon per heater per hour burned. The cost of fuel was 4.5 cents per gallon and the total cost for fuel and labor averaged 81 cents per acre per hour.

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[6] Further discussion of degree-hours is to be found in the section, "Temperature in Relation to Frost Damage."

The Division of Agricultural Engineering and the Agricultural Extension Service coöperated in conducting an orchard-heating survey during the summer of 1937. The results of this survey indicate that costs vary from the above as an approximate minimum to three or four times as much. In extreme cases oil consumption exceeded 100 gallons per acre per hour for short periods.

The survey data indicate that, on the average, with distilling types of oil-burning heaters of 9 gallons capacity, the cost of lighting is about one-sixth of the total operating cost, the cost of refilling another sixth, and the cost of fuel two-thirds of the total operating cost. In addition to normal depreciation on containers there is faster depreciation on stacks and covers, and extra work for cleaning that should be covered by a charge of 10 per cent of the combined fuel and labor cost. Assuming three typical cases with an average number of hours of heating per acre per year and average fuel consumption rates, the costs may be summarized as shown in table 1.

TABLE 1

TYPICAL COSTS OF ORCHARD HEATING PER ACRE

Items	Oranges	Lemons and avocados	Deciduous fruits
	dollars	*dollars*	*dollars*
Interest and normal depreciation	23.50	38.00	11.00
Care and handling of heaters (no heating)	6.00	10.00	6.00
Heating, 20 hours	16.00	.....	.....
Heating, 30 hours	.....	36.00	.....
Heating, 10 hours	.....	.....	10.00
Extra depreciation and maintenance	1.60	3.60	1.00
Total	47.10	87.60	28.00

These costs are presented merely as a guide for the grower who must decide whether to heat or not. The method of making these estimates is indicated in the text. Each grower who can secure data for his immediate locality can estimate his probable costs using the probable number of hours of heating required for his location and adjusting the interest and depreciation item in accordance with the cost and type of the equipment he contemplates purchasing. These probable costs should be weighed against probable additional income. The additional income depends, as stated above, upon the extent of probable frost losses which are to be prevented by heating, the yield of the orchard, and the price of fruit. Orchard-heating costs are likely to go up in the future rather than down. Heating should be undertaken only where a carefully estimated balance sheet indicates the probability of a profit.

ATMOSPHERIC CONDITIONS ON FROST NIGHTS

In the citrus districts located in areas not subject to subfreezing temperatures in the daytime, the *frost* damage is due primarily to the nocturnal loss of heat by radiation to the cold sky. The air itself does not lose much heat by radiation, but becomes chilled because of contact with the cold ground or other exposed surfaces, principally plant leaves, which radiate energy to the sky. Even in the cases of so-called "freezes" when a cold air mass of polar origin invades the citrus districts, it is the

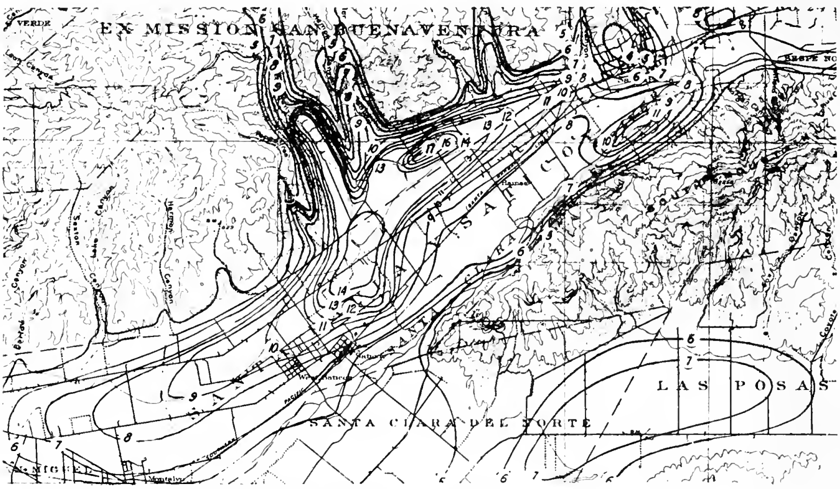


Fig. 1.—The effect of topography and the drift of cold air. The numbered lines are essentially isotherms expressed as the average number of nights per season during which heating was required. (From unpublished data compiled in 1930 by the Fruit Frost Service of the U. S. Weather Bureau, and supplied through the courtesy of Floyd D. Young, Senior Meteorologist.)

regional chilling of this air at night which is most damaging. The cooled air is more dense than the warmer air above and remains close to the ground, getting colder as long as the surface temperature of the earth continues to fall. Topographical air drainage produces "cold spots" and there is large variation in heating requirements of different localities. The map of the Santa Paula district, California (fig. 1), shows broadly the topographical effect in terms of number of nights of heating. This is not a frost-hazard map because it does not indicate degree-hours of low temperature nor does it show local variations found in individual orchards.

Radiation of Heat from the Ground to the Cold Sky.—Since the primary factor in the formation of a frost hazard is the loss of heat from the ground and other surfaces by radiation to the cold sky, it is of interest to note the net rate at which this radiation proceeds. The rate of radiation of energy from exposed surfaces to space varies from about 120 B.t.u.[7] per square foot per hour, when the ground temperature is 60° F, to about 90 B.t.u. after the ground has cooled to 20° F. Incoming radiation from the water vapor and carbon dioxide in the atmosphere will vary greatly with the dryness and temperature of the air overhead, but during radiation frosts 80 B.t.u. per square foot per hour can be assumed for a rough estimate. The *net* loss of heat from the ground to the sky would under these assumptions vary from 40 to 10 B.t.u. per square foot per hour between sunset and sunrise. When the ground temperature approaches the danger point the net radiation loss is about 20 B.t.u. per square foot per hour, or about 900,000 B.t.u. per acre per hour. This net radiation loss is equivalent to the perfect utilization of the heat of combustion of 6½ gallons of oil per acre per hour.

Because the lower horizons of the ground are warmer than the surface during frost, heat flows out of the ground and supplies part of the net radiation demand. The thermal efficiency of artificial heating varies with many factors so no definite figure can be cited as to the fuel requirements to counteract the net radiation loss in the tract. Furthermore, additional heat sources exist in the cooling process of the air in contact with the ground surface or foliage and also in the condensation of water vapor (dew) and sometimes in the latent heat of freezing (white frost).

Flow of Cold Air.—Air movement is one of the major factors in determining the effectiveness of artificial heat in raising orchard temperatures. The air chilled by ground contact is heavier than warmer air and hence will slowly flow downhill, underrunning the warmer air. The filling of ground depressions by cold air from neighboring slopes increases the frost hazard in low spots, and conversely the frost hazard is less on hill slopes where air drainage prevents the accumulation of chilled air.

If an inflow of cold air (sometimes 2 to 3 miles per hour) is to be warmed 10° F or an average of 5° for the full depth from ground up to say 40 feet, the total border-heating requirement is about 5,000,000 B.t.u. per hour for each 100 feet of windward frontage, needing roughly one row of heaters spaced every 10 feet plus 8 rows with heaters every 20 feet. This shows why it is difficult to warm small isolated tracts when there is any air drift. In the so-called "mass heating" of large areas the air-drift effect diminishes and the main requirement is to add to the heat given up by the ground enough artificial heat to counteract the normal local cooling, so that the temperature will not fall below the danger point.

[7] B.t.u., a British thermal unit, is the quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit.

Classification of Atmospheric Conditions on Frost Nights.—Because of the two factors contributing to frost hazard, namely, radiation cooling and inflow of cold air, it seems proper to consider atmospheric conditions on frost nights under four separate headings, as follows:

A. Clear winter day and calm, clear night, atmosphere drier than average. Strong local nocturnal radiation cooling to frost temperatures occurs with slow air drainage (typical radiation frost).

B. Cold wind by day, calm clear night. The daytime wind prevents ground temperatures from rising normally; then the ground heat lost in even moderate radiation cooling at night drops the surface temperature enough to produce a frost.

C. Light rain in the daytime or early evening, calm clear night. Evaporation cooling lowers the temperature of the ground surface. The effect is similar to that of type B.

D. Cold night wind and clear sky. Local and regional nocturnal radiation cooling lowers further the already cold air temperatures at night. (Usually known as a "freeze.")

In all cases except during a rare freeze occurring under clouds the air is cooled by contact with the colder ground or leaf surface. When there is no wind, the chilled air will accumulate near the ground and the air at higher elevations will be warmer than near the ground. There will not be much mixing of the colder ground air with the warmer air overhead, as long as the wind velocity at 8 to 10 feet above the tree tops is less than 6 miles per hour. If the air above is sufficiently warm, this inversion is an important factor in orchard-heating practice in that it restricts the rise of air warmed by the heaters.

Air Temperature Inversion and "Ceiling."—Figure 2 indicates the change of temperatures throughout the night at four different levels on a hill slope. This shows the gradual nocturnal cooling and also that it is more pronounced on the low ground than at higher elevations. Figure 3 illustrates another example of temperature variation with altitude observed by a captive balloon at the Citrus Experiment Station in Riverside, January 27, 1938, and by airplane sounding at San Diego, 90 miles south. The balloon soundings cover a period of 3 hours during which there was progressive cooling as indicated in the shaded band. This record is for much higher ground temperatures than that of figure 2, but it is of interest in showing a temperature inversion point at 125 feet. Above this point there was on that night no appreciable decrease in air temperature up to an elevation of about 2,000 feet, and in the next 2,000 feet there was a decrease of only about 6° F.

Under steady weather conditions there is little fluctuation of air temperature above the inversion level, hence the overhead air temperature at night can be estimated from daytime soundings. The elevation at which the maximum temperature occurs, or in other words, the point of inversion, is the upper limit of the "ceiling." From an orchard-heating standpoint the height of the "ceiling" is thought of as the distance above ground to a natural temperature warm enough to restrict the rise of di-

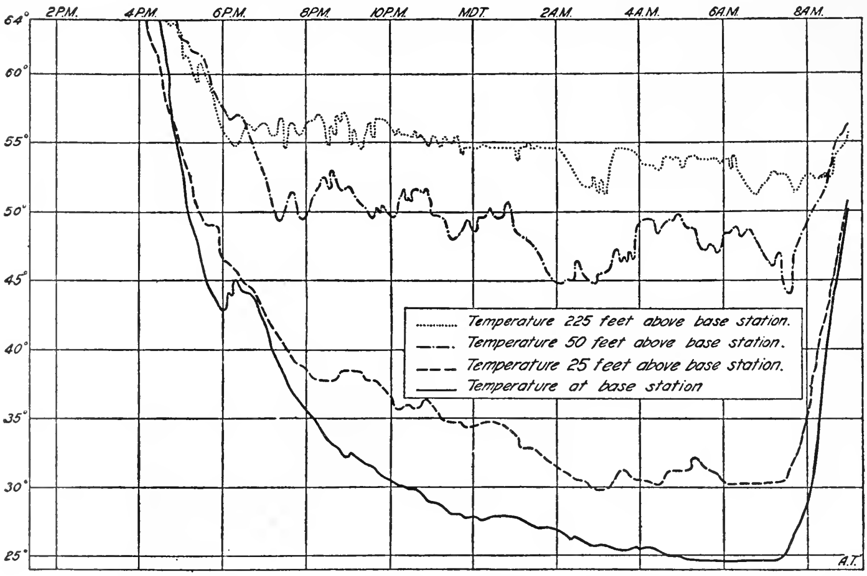


Fig. 2.—Temperature records taken at four different levels on a hill slope during a frosty night. (From: Young, Floyd D. Frost and the prevention of damage by it. U. S. Dept. Agr. Farmers' Bul. 1096:1–48. 1922.

luted hot products of combustion. For instance, with cold dry air, under frost conditions (type B) there might be a low-level inversion point and yet the absence of warm air overhead would make heating difficult.

Other balloon observations showed that the inversion point might be at 250 feet as on February 13, 1938, where the air was only 5° to 8° F warmer than at the surface; or it might be as low as 60 feet, as observed February 26, 1938, when there was a temperature difference of 25° in this height. These figures of course do not agree with the hillside observations, but represent the maximum and minimum observations by balloon during the winter of 1937–38 which was relatively warm.

In conclusion, it can be seen that the frost damage is due primarily to the loss of heat from the ground and trees, and therefore the most effective protection is to supply heat artificially to counteract the natural loss. In terms of heat, a common firing rate of 25 gallons gives about 3,500,000

B.t.u. per acre per hour, which is nearly four times the radiation loss discussed previously.

Effect of Atmospheric Moisture and Smoke.—The rate of nocturnal loss of heat by radiation varies with the moisture content of the atmosphere and its temperature, particularly in the lower layers. This is be-

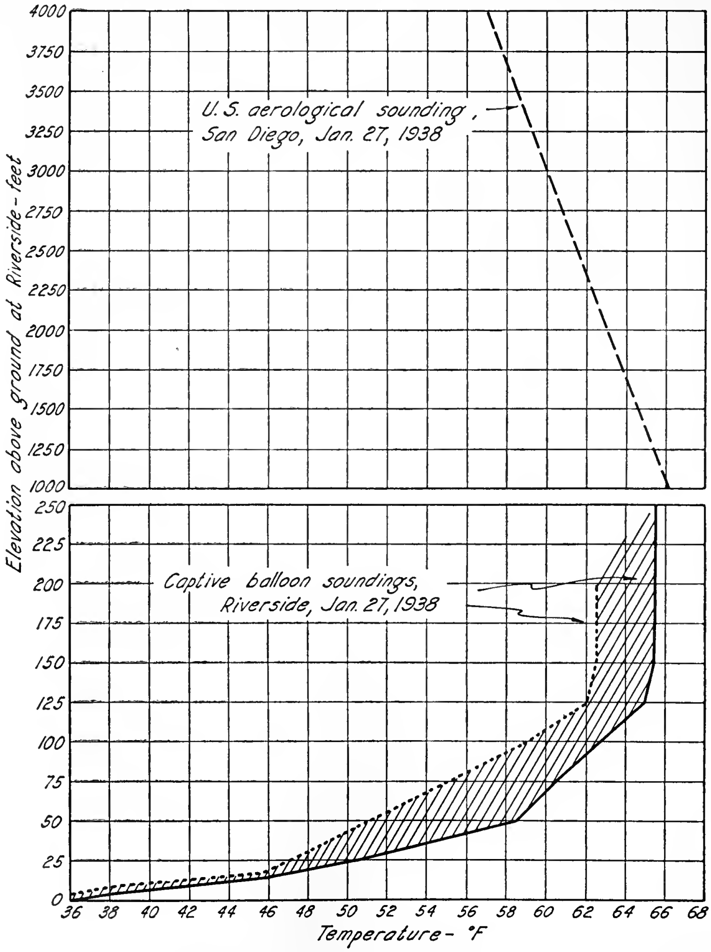


Fig. 3.—Balloon and airplane observations of air temperatures at Riverside and San Diego, January 27, 1938. Note change of scale in the upper half of the figure.

cause the radiation from the water vapor of the atmosphere coming toward the earth is dependent upon the amount of moisture in the air and its temperature. There is some transparency through the water vapor, but the net rate of radiation from the ground to the sky depends on the rate of radiation back to the ground from the moisture in the air.

The smoke output from orchard heaters has no advantage in an economic sense even to the grower. There is an opinion that a smoke screen shielding the fruit from the early-morning sun decreases frost damage, and there is some laboratory evidence of the advantage of slow thawing. Thermally there is a disadvantage in smoke intercepting solar energy during the day. The lighter frost damage which is sometimes observed in sections of orchards shaded by windbreaks or buildings might be explained by restricted radiation cooling at night. However, with adequate heating there will be no frost damage. The smoke is a serious nuisance to the general public, so orchard heating should be made virtually smokeless as soon as possible.

TEMPERATURE IN RELATION TO FROST DAMAGE

The literature dealing with the effect of low temperatures on plants, blossoms, and fruits is extensive, and no attempt will be made to give a general review of this literature here. Temperatures which will be endured without damage depend upon many variable factors, such as:

1. Duration and degree of the low temperature.
2. The amount of air movement.
3. The amount of moisture in the air.
4. The degree of exposure of the plant parts to direct radiation.
5. The cell-sap concentration of the plant part under consideration.
6. The heat capacity of the fruit or plant.
7. The degree of insulation.
8. The extent to which the fruit cools below the freezing point without the formation of ice crystals—namely, "undercooling."

The present concepts of these factors, influencing the freezing of fruit, are as follows:

1. The duration of temperatures below some critical point is the most important factor in determining the degree of frost damage. A convenient way of expressing duration of damaging temperatures is degree-hours below the freezing point of the juice, or below some critical temperature which field experience has indicated results in practically no damage. By degree-hours is meant the total exposure to cold expressed as an integration of the product of degrees below the danger point and hours, for each hour below that point. A rough estimate of the damage to ripe oranges may be secured from a record of the degree-hours below 26° F to which the fruit has been exposed. Past experience indicates that 4 degree-hours will cause very little damage, 6 to 8 degree-hours serious reduction in grade, and 10 or more degree-hours almost complete loss of

crop.[8] This should not be taken as an exact or sole criterion because the degree-hours of low temperature represent only one of eight important factors determining injury.

2. Other factors being equal, fruit or plant parts will freeze more quickly in moving cold air than in still air. There are two reasons for this effect: first, the movement of the air substitutes forced convection for free convection and thus greatly increases the rate of loss of the heat stored in the fruit; and second, undercooling of the fruit does not occur to the same extent when the air is moving as it does in calm air.

3. For equal temperatures the amount of damage to fruit or plants will be greater on nights of high dew point than on nights of low dew point. The reasons for this are not fully understood but it is known that undercooling occurs to a greater extent on dry nights. The greatest amount of undercooling occurs when the temperature of the dew point is so low that no frost forms on the fruit. Nights of high dew point are not usually as dangerous as nights of low dew point because the temperature does not fall as rapidly nor as far, but if the temperature does happen to go down very low on nights of high dew point, the damage will be excessive. Artificial humidification of small areas retards the fall in temperature very little and may contribute seriously to frost injury.

4. Fruit and plant parts become cooled through contact with cold air and also through radiation of heat to the sky. Fruit on the inside of a tree will often have a temperature of 2° or 3° F higher than the fruit which is fully exposed to sky radiation. Trees near buildings or dense windbreaks are sheltered from part of the sky exposure. Often there is very little damage to fruits on these trees when nearly all of the fruit may be lost on trees further out in the orchard.

5. The concentration of the cell sap or the freezing point of the fruit juice is a most important factor in determining the temperatures which will be endured. Dissolved substances lower the freezing point of water. If atmospheric and soil conditions have been favorable for rapid growth immediately preceding a frost, the sap concentration is likely to be low and frost damage may occur at relatively high temperatures. If the plants have been exposed to low temperatures unfavorable for growth for a period of several days or several weeks, plants and fruits will endure very low temperatures for relatively long periods of time.

The actual damage which occurred during the freeze of January 1937

[8] This formula should not be confused with the so-called "Dezell" formula used by the California Fruit Growers Exchange in estimating losses. The Dezell formula is based on a simple product of the number of hours below 26° F and the number of degrees that the minimum temperature is below 26°. The figures obtained in this manner are about twice those obtained by summation of the degree-hours.

was very much less than would have been expected from previous experience with similar temperatures. For example, one orchard of eight-year-old Fuerte avocados survived a minimum of 14° F with 6 hours below 20°. The trees were severely damaged but the trunks and main framework branches remained alive so that it has been possible to rehabilitate the orchard. In previous freezes similar trees have been killed outright by temperatures of 20°. Citrus trees and fruits in general suffered much less damage in 1937 than occurred with higher temperatures in 1922 and with similar temperatures in 1913. The experience of 1937 cannot be considered a dependable guide regarding temperatures which will be endured.

6. Full-grown oranges, grapefruit, and lemons will endure more degree-hours below the actual freezing point of the juice than will small fruits and blossoms. This is because the rate of cooling by free convection is less for larger size, and the mature fruit has a greater heat capacity. Fruits become warmed during the daytime and then cool more slowly than the surrounding air when the temperature falls at night. When the temperature is falling rapidly on a frosty night following a warm day, the interior of the fruit may be as much as 6° to 7° F warmer than the surrounding air, and the temperature inside the fruit may lag from an hour to an hour and a half behind the air temperature. For these reasons many growers use fruit thermometers as a means of determining when to start lighting orchard heaters. The use of fruit thermometers will be discussed in another section.

7. Another reason why mature citrus fruits freeze slowly is because of the insulation value of the thick pithy rind. This principle is applied artificially to protect young trees against frost damage. A layer of corn stalks, tules, or other porous insulating material 2 or 3 inches in thickness tied tightly around the trunks of young trees will retard heat loss from the trees and protect them from injury even though temperatures go to exceedingly low points.

8. Undercooling, sometimes called supercooling, is the name used for the physical phenomenon of cooling a liquid below its freezing point without the occurrence of actual solidification or change of state.[9] When a liquid is undercooled, it is in an unstable condition and will freeze rapidly if anything causes a rearrangement of the molecules to start, so that freezing or crystallization may occur. A sudden jar or the addition of a small crystal as a source of inoculation for crystal formation will often cause instantaneous freezing of the whole mass of liquid. Such

[9] Dorsey, N. Ernest. Supercooling and freezing of water, Jour. Research National Bureau of Standards (Research Paper 1105) 20(6):799–808. June, 1938.

freezing is accompanied by a rise in temperature to the freezing point. Fruits such as oranges frequently cool as much as 3 degrees below the freezing point of the juices and are in an unstable undercooled condition. No damage will occur if fruit in this condition becomes warmed above the freezing point without actual freezing having occurred. Undercooling explains the lack of damage on many severely cold nights. It is most likely to occur on nights which are dry, and particularly on nights which are both dry and relatively calm.

In view of the many variables which influence the extent of frost injury it is difficult to specify temperatures which will be safe for various kinds of fruit and below which damage will occur. However, the fruit grower needs some specification as a guide to his orchard-heating operations. The suggestions in this circular are believed to be conservative and safe. They are based upon extensive experimental work and field observations by the Fruit Frost Service of the United States Weather Bureau under the direction of Floyd D. Young, Senior Meteorologist, Pomona, California.[10] The table for deciduous fruits and suggestions in the text are based on a standard reference point, which is the temperature indicated by a tested thermometer exposed in a satisfactory shelter at a height of 5 feet from the ground. If a grower follows the recommendations, he will inevitably light his heaters many times when no damage would have occurred without heat. On the other hand, unusual conditions may occur when fruits might be injured at higher temperatures than those indicated in tables which are based upon past experience. If heating costs go up and fruit prices go down, growers will wish to supplement the tables with their own experience, and not maintain higher temperatures than are actually necessary to prevent damage. No grower should be guided by the experience of only one season. For example, during 1937 green Valencia oranges withstood lower temperatures without damage than mature navel oranges. This experience is contrary to that of some previous years so one should not conclude that it is safe to allow Valencias to reach lower temperatures than navels.

In order to save expense, growers may decide to take certain chances, and not try to save all of the fruit. More small lemons will be saved by maintaining orchard temperatures above 30°F than by maintaining them above 28°. For some locations, however, it is better from an economic standpoint to permit the freezing of some of the small lemons and to save expense by allowing temperatures to go as low as 28°, before starting to light heaters. Some growers allow the most exposed oranges

[10] Young, Floyd D. Frost and the prevention of frost damage. U. S. Dept. Agr. Farmers' Bul. 1588:1–62. 1929.

on trees to start freezing before lighting their orchard heaters. This will result in a slight amount of damage but may materially reduce the cost of heating. Other growers will look upon heating as insurance and endeavor to maintain safe temperatures at all times, being guided by the slogan, "It is better to be safe than sorry."

Safe Temperatures for Citrus Fruits.—Safe temperatures for citrus fruits depend upon the variety, the degree of maturity, and the atmospheric conditions. The freezing point of the juice of green oranges varies from 28.5° to 29.5° F; for half-ripe oranges and grapefruit from 28° to 29°; and for ripe oranges and grapefruit from 27° to 28°. The time at which lighting should occur may be determined by using air temperatures indicated by properly sheltered thermometers or fruit temperatures or a combination of the two as a guide. When air tempertures are falling, fruit temperatures will usually lag. Therefore, the temperature of exposed fruits obtained with fruit thermometers will be a valuable aid in determining the time of lighting. Fruit temperatures should be taken only in oranges of more than average sky exposure. If the air temperature is below the freezing point of the juice, it is not safe to delay heating operations after the fruit temperature has dropped to the freezing point of the juice, or after the fruit has reached a temperature near this point and remained at a constant temperature for about half an hour.

When a fruit is cooled its temperature falls to the freezing point of the juice and then if the fruit starts to freeze, its temperature will remain constant at the freezing point until the fruit is frozen, even though the air temperature continues to fall. The leveling-off of temperature in an individual fruit surrounded by air which is falling in temperature indicates that the freezing point of that particular fruit has been reached even though the temperature is above the supposed freezing point for the variety and stage of development. If the fruit undercools, the temperature will drop below the freezing point.

Air Temperatures at Which Heaters Should be Lighted in Citrus Orchards.—For those growers who do not wish to use fruit temperatures in conjunction with air temperatures, the following suggestions issued by the Fruit Frost Service of the United States Weather Bureau[11] will be useful. They are based on the use of sheltered thermometers and anticipate completing first lighting of heaters within 30 minutes.

On cold nights following warm days (highest temperature 60° F or over) with steady temperature fall to the danger point:

Fire ripe oranges or grapefruit when the air temperature reaches 26°.

Fire green or half-ripe oranges and grapefruit at 27°.

[11] Placards printed by the California Fruit Growers Exchange.

On cold nights following cool days (highest temperature 59° or lower) with very slow temperature fall near danger point:

Fire ripe oranges or grapefruit at 27°.

Fire green or half-ripe oranges or grapefruit at 27.5°.

Keep the shelter thermometer up to 28° or higher on both types of night after firing is begun.

Damp nights are more dangerous than dry nights, *with similar temperatures.* Citrus fruits begin to freeze at a higher temperature when they are covered with ice than when they are dry. The temperature fall is usually slow and steady on damp nights. On dry nights look out for sudden and rapid drops in temperature.

If the air temperature fluctuates rapidly, owing to wind, take the average of the high and low points as the effective temperature.

During November the navels in most districts are in the half-ripe stage and will freeze at a temperature about 1° higher than they will later in the winter.

Similar suggestions apply to lemons except that higher temperatures need to be maintained. The temperature at which heating is begun for the protection of lemons will depend on whether it is desired to save the blossoms and small "button" lemons, or only the mature fruit. If blossoms and small fruits or "button" lemons are to be protected, the temperature must be held at 30° F or higher, while the larger lemons will not be injured with an air temperature of 28° for several hours. Even though lighting is delayed until the temperature reaches 28° it is usually desirable afterward to maintain the temperature of lemon orchards around 30°. The small green fruits are more susceptible to damage by frost than the blossoms.

In the protection of avocados the general recommendations for "button" lemons should be followed.

Safe Temperatures for Deciduous Fruits.—The data in respect to deciduous fruits are not adequate. The recommendations do not cover all of the stages of growth and should be considered merely as a guide which will be safe but which may result in burning unnecessary amounts of fuel. It is very difficult to forecast damage to a deciduous fruit crop from a severe frost at any stage prior to the young green-fruit stage. This is because blossoms will withstand different temperatures at different stages of development, and not all of the blossoms on the trees are in the same stage of development. In California, owing to warmer winters than in many other fruit-growing regions, the rest period of deciduous trees is not completely broken. The prolongment of the rest period results in the lengthening of the blossoming season. Severe frosts have often been observed to kill a large percentage of the blossoms without subsequent reduction in crop. A second, lighter frost may cause a complete loss of crop if it occurs when fruits which missed the first frost are in a tender stage. It is therefore necessary for the deciduous fruit grower to become a careful student of temperature conditions as related to frost injury in order to secure adequate protection without unnecessary expense.

Table 2 indicates the temperatures in degrees Fahrenheit which will be endured for 30 minutes or less by deciduous fruits in various stages of development.

Orchard heating is often of considerable benefit during severe freezes even though it has been impossible to prevent air temperatures from dropping far below those ordinarily considered safe. The thermometer in

TABLE 2

TEMPERATURES ENDURED FOR THIRTY MINUTES OR LESS BY DECIDUOUS FRUITS*

Kind of fruit	Stage of development		
	Buds closed but showing color	Full bloom	Small, green fruits
	°F	°F	°F
Apples	25	28	29
Peaches	25	27	30
Cherries	28	28	30
Pears	25	28	30
Plums	25	28	30
Apricots	25	28	31
Prunes	23	27	30
Almonds	26	27	30
Grapes	30	31	31
Walnuts, English	30	30	30

* Temperatures determined from sheltered thermometers.

Source of data:
Young, Floyd D. Frost and the prevention of frost damage. U. S. Dept. Agr. Farmers' Bul. **1588**:1-62. 1929.

the standard shelter may indicate complete failure when some fruit may have been protected by radiation from heaters which did not register upon the thermometer. Often the hot products of combustion blow directly through trees and do not affect thermometers out away from the trees. There may be other reasons also for the benefits which result from heating even though thermometers have not indicated that fruit would be saved. A grower who is unable to maintain satisfactory temperatures by using all of his equipment at reasonable burning rates should not become discouraged and stop his heating operations as a result of finding that his thermometer records dangerously low temperatures.

METHODS OF ADDING HEAT TO ORCHARDS

Use of Orchard Heaters.—As previously described, orchard heaters are successful in counteracting nocturnal radiation cooling and in warming the inflowing cold air mainly because of the usual temperature inversion which confines the artificial heat to a relatively shallow depth of air near the ground.

The nocturnal atmospheric condition is very different from that of the daytime in that a cold ground surface stabilizes the air, whereas a warm ground surface promotes circulation. In the daytime air need be warmed only a few degrees above normal to become less dense than the air overhead and rise almost without limit. At night when the ground is colder than the air overhead, the ground air uniformly warmed a few degrees will still be heavier than the even warmer air overhead and hence will rise only a short distance before it reaches a balance.

With this in mind it is evident that the ideal method of orchard heating is the use of a very large number of small heating units distributed over the area to be protected. Experience in 1937 showed that the minimum number of heaters of any kind is about 35 per acre to afford reasonable protection; and of course more units would have been more efficient in frost protection. Larger combustion units might be more efficient as heat producers, but in an orchard the advantage in small units seems to lie in the more uniform radiant and convective energy distribution.

Border Heating.—When there is an inflow of cold air on an exposed frontage it is necessary to bank the heaters on the upwind side to protect the first rows of trees. If the heaters are located one or two per tree on the exposed side, the radiant energy from the heaters and possibly also the products of combustion will warm the near trees directly and thus afford protection although the heat output of this first bank of heaters is not adequate to warm the entire depth of incoming air stream to the height where the air temperature due to inversion naturally is the same as that of the dispersed products of combustion. Hence, several rows of heaters inside the border also serve to warm the incoming air in addition to counteracting radiation cooling, and the incoming air will not all be warmed to the height of natural safe temperature until it has passed many tree-rows in from the exposed border. Under these conditions one would expect the need for heat per unit area to gradually taper off down-wind from close border-row spacing until only radiation cooling need be counteracted.

Mass Heating.—The "mass-heating" requirement to counteract only radiation cooling is usually low, and at most is equivalent to the heat of combustion from 35 heaters per acre burned at the rate of ⅓ gallon per hour. Not all the heat output of heaters is available but some of the heat needed comes naturally from the ground, so even lower burning rates are often used successfully on calm nights when radiation cooling is moderate.

This low burning rate to counteract radiation cooling in the center of large heated areas no doubt explains why certain orchards with inadequate protection have suffered little frost damage. Furthermore, the general practice of orchard heating in some districts has now altered the local conditions so that the frosts at control stations do not appear as severe as in the past during similar general weather conditions.

Where most of the frost damage occurs in localized "cold spots" much fuel can be saved by noting temperature differences in each acre or two so that firing will be regulated to suit the need of the areas threatened.

Wind Machines or Blowers.—Because under ordinary nocturnal radiation cooling there is a large quantity of warm air overhead, a great many installations of blowers have been made to artificially mix the ground air with the higher warm air.

Large blowers or fans mounted on towers as high as 50 feet above the ground have been used in California for twenty years. Some of these are driven by electric motors and others by gas engines, varying in size from a Ford V-8 engine to a 425-hp. airplane engine. The greatest use of this equipment has been in the central California citrus district, but the practice has been extended to other areas, and a few installations have been made in walnut, apricot, and pear orchards.

Observations and the experiences of owners of typical wind machines indicate that under certain conditions blowers have reduced frost damage. Temperature observations in some orchards when there was a temperature inversion of 10° F in 50 feet have shown the air to be about 3° warmer in the area near the blowers than that outside. The effectiveness of blowers is not apparent beyond approximately 300 feet for small machines and about 500 feet for large ones. In the winter of 1934–35 when the oranges in two orchards were graded for frost injury, it was evident that the fruit nearest the blower was damaged least, and that the damage increased with the distance from the blower.[12] Similar results were later obtained in a walnut orchard.

Growers cannot expect protection from such equipment if there is no warm air available overhead. In a typical freeze there is no warm layer above if there are no orchard heaters in the neighborhood. However, there is some evidence that a few blowers operated near heated areas decreased the frost damage during the 1937 freeze. The combination of a large furnace with a revolving blower has not yet been proved successful. The blown furnace air, being much hotter than the orchard air, does not carry well into the trees before rising.

[12] Moses, Ben D. Blowers for frost protection. Agricultural Engineering. 19(7): 307–08. 1938.

The explanation of the occasional apparent success of this type of frost protection in spite of observed low temperatures is obscured by highly complicated physiological factors of the trees and fruit, such as dormancy, so no specific limits can be stated. If blowers are used, experience indicates that they should be started before the temperature drops to 32° F. If an increase in air temperature cannot be obtained, the wind machine should be stopped at the freezing temperature of the fruit to avoid forced cooling.

If the grower is satisfied with partial frost protection, a blower may be considered because of its convenience and smokelessness. However, partial protection by heaters would be normally more economical. A favorable place for blowers is in narrow canyons where insufficient natural air drainage can be artificially increased so that the formation of cold air pockets is prevented. Again, this use does not afford protection against freezes.

Use of Water.—If the orchard is irrigated at night, just before an expected frost hazard, the water will provide extra heat, first in the cooling from its original temperature to the freezing point, and second in the giving up of latent heat when forming ice. The amount of heat delivered by a cubic foot of water in cooling from 56° F to the freezing point is approximately 1,500 B.t.u., and the amount of heat liberated when a cubic foot of water changes to ice is about 9,000 B.t.u. Hence, the total available heat from a cubic foot of water at 56° is about 10,500 B.t.u. when transformed to ice. Maximum nocturnal radiation alone for 6 hours would cool a 2-inch layer of water to the freezing point or cool and freeze a 3/8-inch layer. Ice does not form rapidly except at temperatures below 26° so the latent heat of freezing does not afford satisfactory frost protection.

If water and ice remain throughout the next day, the orchard will start cold the following night; but if there is another radiation frost, a second flooding could be resorted to. The limitation of this method of frost protection is the availability of enough water, and its effect on the root system. If ice is allowed to form, it must be flooded frequently to prevent its temperature from dropping much below 32° F. Of course, flooding will not protect against low-temperature winds as in freezes, but water on the ground can be used as a partial substitute for artificial heat.

The water should never be sprayed on the trees because the ice load is likely to break the trees. Furthermore, the introduction of water by spray promotes evaporation which absorbs heat from the air rather than supplying heat. The belief that an ice coating will prevent the fruit from going below 32° F is not correct, because ice does not remain at 32° if the loss of heat continues. A layer of ice has some thermal insulation value, but there is evidence that the presence of ice on the outside of the fruit affects the physiological condition of the fruit so that there might actually be more damage than if the surface were dry.

Use of Steam.—If steam could be liberated throughout an orchard so that it would warm the air before rising above the trees, a large quantity of heat could be carried by a small quantity of water. The steam in condensing (forming a fog or drizzle) gives up about 65,000 B.t.u. for each cubic foot of condensed water. The cooling and freezing of condensed steam would add another 20,000 B.t.u. per cubic foot of water. However, steam heating has not been considered practical for orchards because of the high cost of the steam plant and distribution piping.

Mr. W. H. Hutchinson, of Sonora, proposed in 1933 that the steam be generated without a boiler by injecting water directly into a furnace. All the products of combustion plus the extra water vapor were to be distributed throughout the orchard by a blower and large ducts. The heat output of such a central heating system would include the steam values mentioned previously and in addition those obtained from the cooling of the air and products of combustion. The pertinent question of such a system is whether the hot fog could be confined to the orchard displacing the heavier colder air, and whether the central heating and distributing system would be too expensive. If the protection is not adequate, there would be greater frost damage with wet fruit. Previous attempts at steam heating have been abandoned.

Use of Central Heating.—A few installations have been made in small orchards of central heating with warm air piped to each tree. In these cases it is intended to warm the trees but not the spaces between trees. Single-tree experiments at Riverside show this to be difficult of accomplishment unless the air is so quiet that smoke from the usual orchard heater rises straight up. The apparent economy of this type of installation may be partly due to adjacent mass heating. Installation costs seem to be high.

Nocturnal Heat from the Ground.—There is an advantage in having a moist soil during frost periods in that with the ground damp the rate of heat transfer into and out of the ground will be greatly facilitated, and hence the diurnal temperature range of the wet ground surface will be less than if the surface were dry. In other words, a dry surface soil will obstruct the flow of heat into the ground when the sun is shining and will also obstruct the flow of heat from the ground at night. Hence, when the energy discharged by radiation at night is drawn from the ground, the temperature gradient in dry ground must be much greater than in wet ground, and the surface temperature will fall much lower with dry soil than moist. This is extremely important in typical radiation frosts because the air is largely cooled by the ground. Late spring frosts seldom occur when the spring rains have been so spaced that the soil over the countryside is always somewhat moist.

The heat discharge from moist soil at night is complicated by evaporation which absorbs energy day and night so the above general statement cannot be made specific for a given orchard without detailed studies of the local soil and air conditions.

HEATING EQUIPMENT

The necessary items of equipment for orchard heating, which will be discussed in this section, are heaters, filling equipment and torches, thermometers, thermographs, and frost alarms.

Heaters must use fuel that is available. The commonest usage at present is of 27+° Diesel oil which is the "heart cut" of the crude oil and for which there is growing demand in the production of gasoline.

Heaters.—Many types of heaters have been put on the market during the last twenty-five years. New and improved types are brought out nearly every year but no present heater meets all of the requirements of a good orchard heater. According to the generally accepted ideas as to the more important specifications of an ideal oil-burning heater, it should:

1. Hold sufficient fuel to burn all night without refueling, or else be piped for continuous fuel supply.

2. Be capable of sufficient regulation to give its greatest heat just before sunrise even though the fuel in the bowl is low by this time (ordinary burning rates are from ⅓ to ⅔ gallon an hour).

3. Be able to burn any of the ordinary grades of heating fuels on the market without objectionable smoking and without leaving troublesome residues.

4. Be rain-proof so that water will not enter the oil container.

5. Deliver the heat and products of combustion near the ground, but without excessive heating of the ground.

6. Be easy to light and regulate by inexperienced labor under all weather conditions.

7. Be capable of being lighted with the control set as required for normal burning.

8. Burn at a uniform rate without frequent regulation.

9. Be readily extinguished by merely closing the regulator and capping the stack or by closing a valve.

10. Burn several nights if possible without the necessity of cleaning.

11. Be so designed that the oil can be burned to the bottom of the heater bowl without damage.

12. Avoid excessive oil condensation on the stack or cover. (A little condensation may be beneficial in preserving the stack and cover.)

13. Be easily filled without removing stack or cover.

14. Be of reasonable cost. (See p. 6 for average installed cost per acre.)

15. Be made of good material and show small annual depreciation.

16. Be easy to take apart, clean, and store.

New heaters being installed for use near populated districts should be as smokeless as possible and old heaters should be modernized so as to reduce their smokiness.

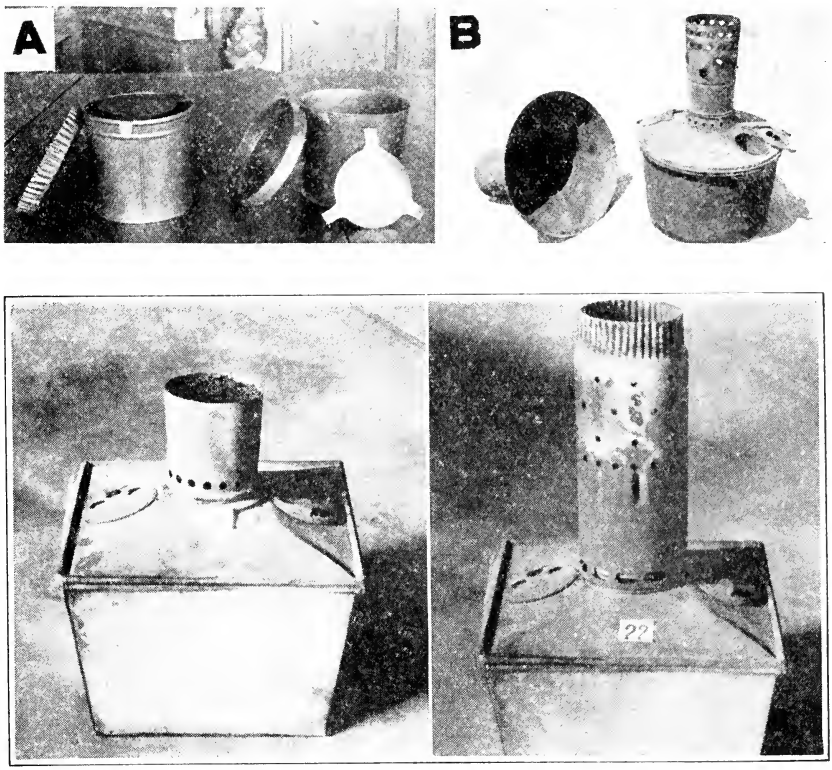
Open Pails for Heating Deciduous Fruits.—The simplest type of orchard heater is an ordinary pail with a close-fitting cover. So-called "lard pails" of 5-, 8-, and 10-quart capacity are manufactured especially for deciduous orchard heating. Growers also use secondhand paint pails, powder cans, no. 10 tin cans, and garbage pails of from 5- to 12-gallon capacity. Garbage pails need to be of especially good construction or they will leak after soldered seams have been exposed to heat. Other simple types consist of square or rectangular pans with sliding covers.

These simple heaters or "smudge pots" are effective from a frost-protection standpoint provided burning rates are controlled properly. Burning rates depend upon the surface area of oil exposed in relation to depth to the oil level in the container. A 5-quart lard pail with full surface exposed will burn about 2½ hours and a 10-quart pail the same length of time, giving average burning rates of one-half and 1 gallon per hour respectively. The burning rate is far from uniform, however, being very high the first hour and low the last. The burning rate may be partially controlled by the spider, which is a device for partially covering the top of the pail (fig. 4, *A*). The spider should be left in place until the pail has burned half empty and then be removed. The larger pails and the pans have the burning rates controlled by sliding metal covers.

These simple heaters are not recommended for citrus orchards because the excessive smoke soots up the fruit and reduces its value. In thickly settled areas they create a smoke nuisance which is intolerable. Under these conditions all such heaters should be discarded.

For deciduous-fruit growers who are away from the cities and in districts where the hours of operation are so few that no general smoke nuisance is created, such heaters are satisfactory and economical. The smoke does no damage to the blossoms of deciduous fruits and does not interfere with pollination.

Early Smudge Pots for Citrus.—The next development in heaters was the smudge pot of large capacity, usually 7 to 9 gallons. Such heaters include the Dunn, the Riverside or Citrus, with stub stack, or with 15-inch stack (fig. 4, *B, C* and *D* respectively), and several models of the Hamilton. These heaters are effective but are ordinarily too smoky for use in the citrus districts. The smoke output often exceeds that of the lard-pail



C *D*

Fig. 4.—"Smudge pot" orchard heaters. *A*, Lard-pail heaters of the Bolton and Canco types; *B*, Dunn heater with the umbrella cover removed; *C*, Citrus Regular, stub stack; and *D*, Citrus, 15-inch stack. (*A* and *B* from Bul. 398; *C* and *D* from Bul. 536.)

types. These heaters can be modernized by fitting collars onto the covers and using "lazy-flame" stacks of recent design. In the lazy-flame type, the stack serves as a mixing chamber for the petroleum gases and air, and the combustion is mostly above the stack. In many cases it will not be worth while to modernize old Riverside or Hamilton heaters with loose-fitting covers or old Dunn heaters which have been in use for twenty years or more. Such heaters should be discarded.

Early Orchard Heaters.—Other equipment which needs modernizing includes the Baby Cone, the 5½-inch Exchange stack, the National and

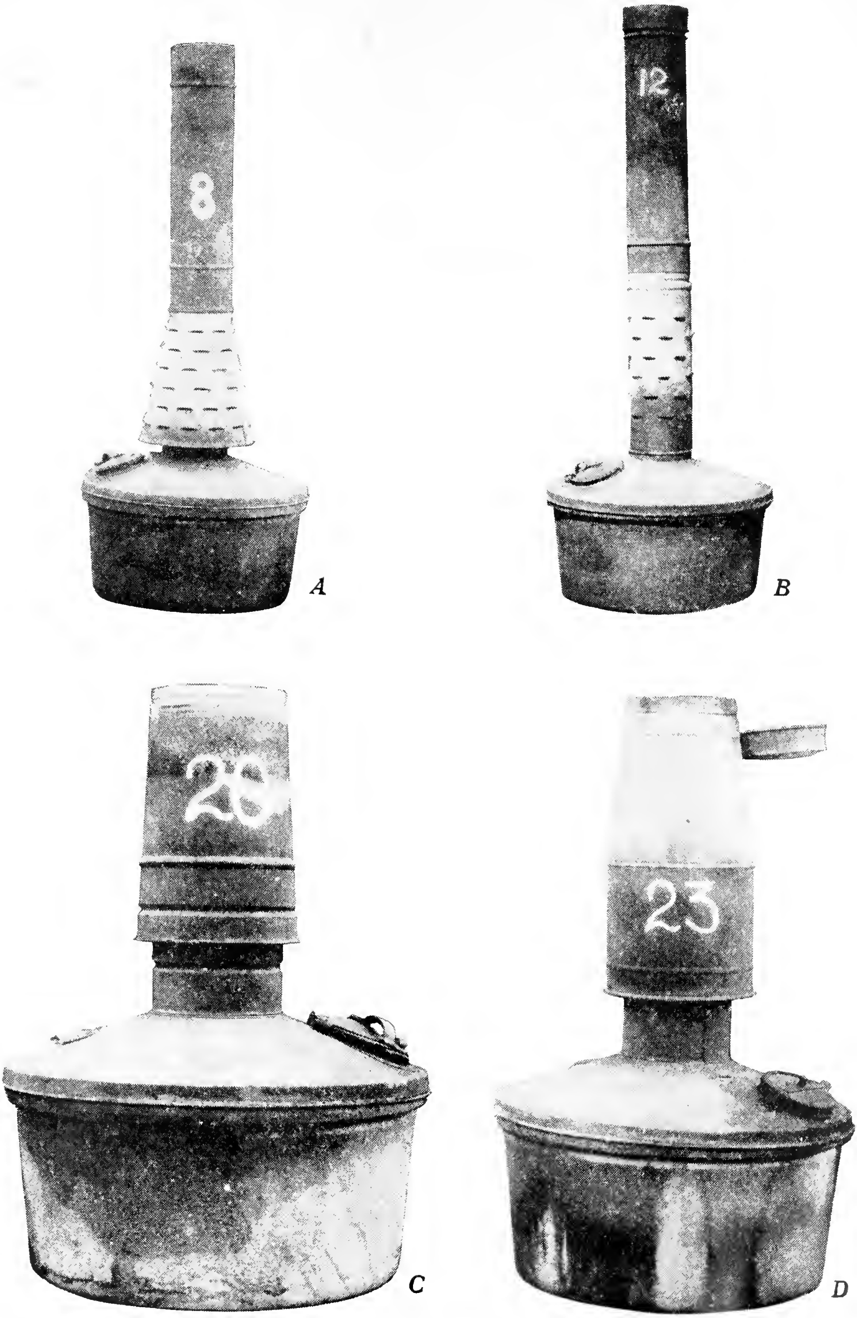


Fig. 5.—Early types of orchard heaters. *A,* National Baby Cone; *B,* National Exchange model, 5½-inch stack; *C,* National, double stack; and *D,* Hy-Lo double stack. These heaters are all of 9-gallon capacity; the illustrations are not of the same scale. (From Bul. 536.)

Hy-Lo double-stack heaters (fig. 5). The last two heaters can be modernized by placing adapters under the present stacks, but the Baby Cone and 5½-inch Exchange stack should be replaced by new stacks of better design. The Baby Cone is an example of a heater which burns reasonably well at one burning rate, which rate cannot be maintained without regulating the heater at frequent intervals. This difficulty can be overcome in part by pounding down (closing) the second, third, and fourth rows of louvres, starting from the top. There are many old models of stacks with combustion chambers which can be operated with reasonable freedom from smoke if great care is exercised to keep them within the range of burning rates for which they are designed. Heater manufacturers should be consulted regarding modernization of old models.

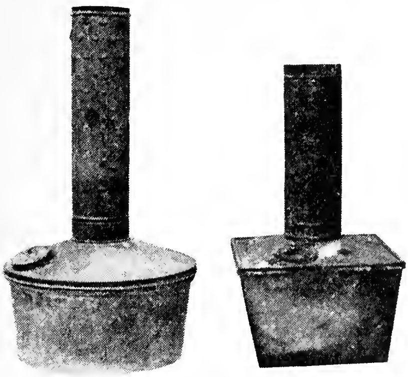


Fig. 6.—Round- and square-bowl orchard heaters of the "lazy-flame" type.

Heaters with combustion chambers in the stacks are satisfactory only if there is a favorable air-fuel ratio in the combustion chamber, if good mixing takes place, and if the capacity of the combustion chamber is not exceeded. If the burning rate is too high for the size of the combustion chamber, a portion of the fuel vapor becomes overheated before it can burn; and cracking takes place, causing excessive smoke production. All combustion-chamber heaters are sensitive to regulation. Other factors such as air-fuel ratio and mixing being equal, the larger the combustion chamber the wider the range of burning rate and the easier the regulation. The grower should make burning tests to determine the range of burning rates over which his heaters will burn without appreciable smoke and should regulate them accordingly. Other heaters especially sensitive to regulation are the Apollo, the Beacon, and the 6-inch Exchange stack.

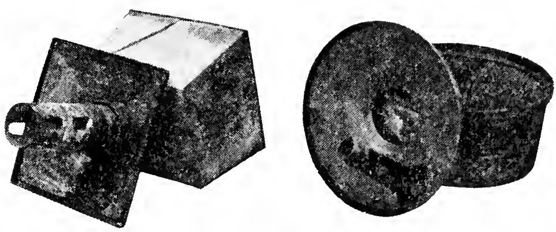


Fig. 7.—Covers equipped either with down draft tubes (right) or internal chimneys (left).

Choice of Heaters.—The grower purchasing heaters today has four general types from which to choose:

1. Distilling type or bowl heater: These may be obtained with round or square bowls (fig. 6). Observed differences in carbon-residue formation due to bowl shape or interior parts have not been sufficiently significant to justify recommendations for any particular type of bowl if the covers fit tightly. Field experience indicates that square-bowl heaters must be

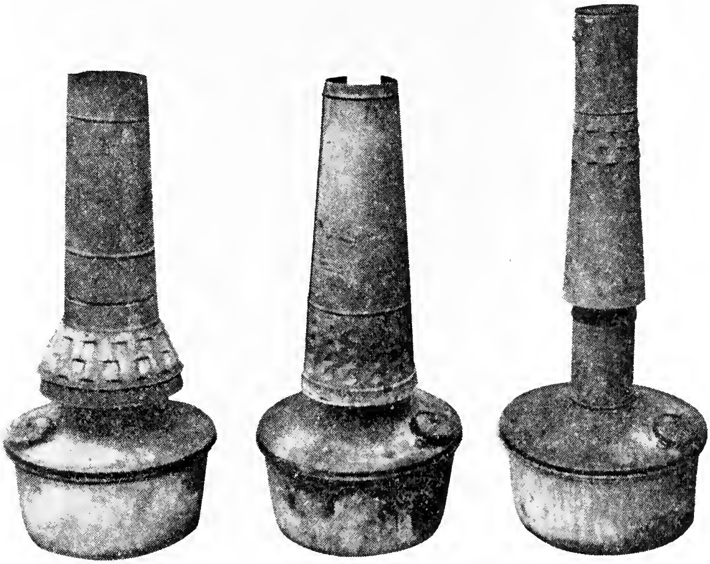


Fig. 8.—Combustion-chamber heaters. *A,* Jumbo Cone, *B,* Lemora; and *C,* Hy-Lo, No. 148 Special

handled more carefully than round-bowl heaters to maintain the cover fit sufficiently airtight to permit proper control of the burning rate. Stack performance is almost independent of bowl designs now in use.

Heaters are usually equipped with downdraft tubes or internal chimneys (fig. 7). Each serves to distribute primary air, makes starting easier, and makes it possible to burn the oil to the bottom. Field experience indicates that with downdraft tubes starting is somewhat easier than with internal chimneys. Both devices tend to clog with soot. This soot is usually washed out of the downdraft tubes at each refilling, but slots in the internal chimney must be cleaned (usually with a stick) to keep the holes open and to maintain the full burning rate. Wicks facilitate the starting of new or cleaned heaters, but if left in place apparently increase carbon residue.

Until a few years ago, the cover of the 9-gallon round bowl was furnished with a lighting cup underneath the draft opening. A V-type deflector, fluted deflector, or downdraft tube was fitted into the lighting cup. Some of the cups had two holes pointing toward the base of the stack, some had one hole, and some were without holes. These holes cause a great increase in smokiness for all stacks placed on such covers and the holes should be plugged with small sheet-metal disks which can be obtained for this purpose.

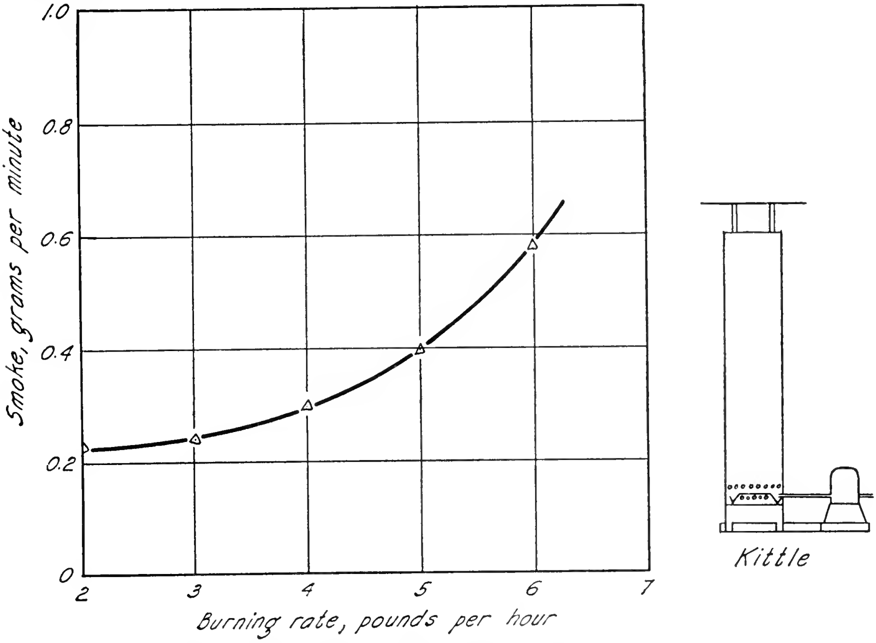


Fig. 9.—Smokiness of the Kittle drip-type heater.

Two general types of stacks are available for use on these bowls. These are the lazy-flame or short stacks (fig. 6), and the combustion-chamber stacks (fig. 8).

Field experience indicates a preference for short stacks of the lazy-flame type. The main reasons advanced are that the heat is liberated close to the ground; the stacks are easily cleaned; the stacks last longer because the metal is not overheated; and they are easier to light and regulate. The lazy-flame stacks have a narrower range of burning rate than some of the more expensive stacks of the combustion-chamber type. However, the maximum burning rate for good operation is adequate if enough heaters are provided per acre, and it is preferable to burn more heaters at rates for which operation is satisfactory than to burn fewer heaters at excessive rates.

2. Drip-type heater: The Kittle is the only drip-type heater in general use at the present time. It differs from the distilling type heater in hav-

ing fresh oil fed constantly to the burner, either from a reservoir at one side or from an oil line connected with a small reservoir in which the oil level is controlled by a float (fig. 9). The operation of this heater is satisfactory at burning rates of ⅓ to ½ gallon per hour, with a possible maximum of ¾ gallon. The smokiness when burning a good grade of the Marine Diesel fuel is also shown in figure 9. It is essential that the fuel trough in the burner be kept level and that the residue be scraped out from time to time. The usual difficulty is that the trough fills with coke

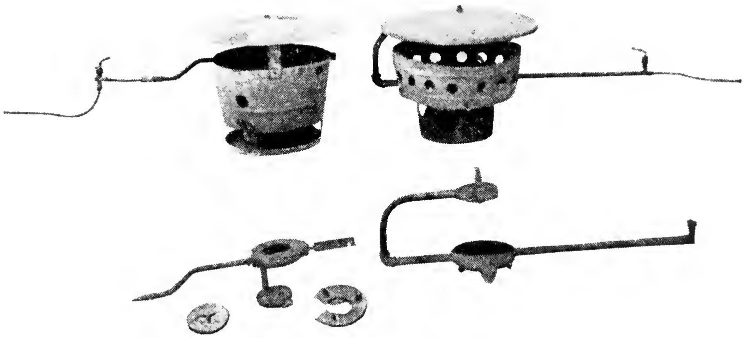


Fig. 10.—Generator-type heaters. The Fugit is shown at the left; the California at the right. (1937 models.)

and then the oil overflows into the base pan where it ignites and causes a great deal of smoke. High burning rates aggravate this difficulty. Poor-quality fuels leave more residue and cause the trough to fill up in a short time. Some samples of Marine Diesel fuel, bunker grade (27+° A.P.I.) can be burned successfully if the trough is frequently cleaned. If one wants to be sure of avoiding difficulty with samples which may be delivered in any one main grade of fuel, it will be best to specify fuels of the "kero-distillate" type.

3. Generator-type heaters: In generator-type heaters, commonly known as "pipe-line" heaters (fig. 10), the fuel is passed through a small evaporation chamber in which the fuel is volatilized. The fuel vapor then issues from an orifice, as a vapor jet, where it burns in a self-induced draft. Special fuel is essential for the heaters now in use and the range of burning rate is very limited. The minimum burning rate is too high for the best utilization of the heat in an orchard. The cost of installation is so high that there is a tendency to install too few heaters per acre and burn them at relatively high burning rates. They are likely to be wasteful of fuel, especially on nights which are only moderately cold. These heaters are popular because they avoid the necessity of hauling oil through the orchard. They have many advantages, but have not yet been developed to

the point where they can be operated without systematic regulation and attention during the night.

4. Solid-fuel heaters: Less than 10 per cent of the orchard heating is done with heaters burning petroleum coke, or briquettes made from coke, carbon black, or other materials. Briquette heaters are of two types: a small-sized heater (fig. 11) in which the burning rate is difficult if not

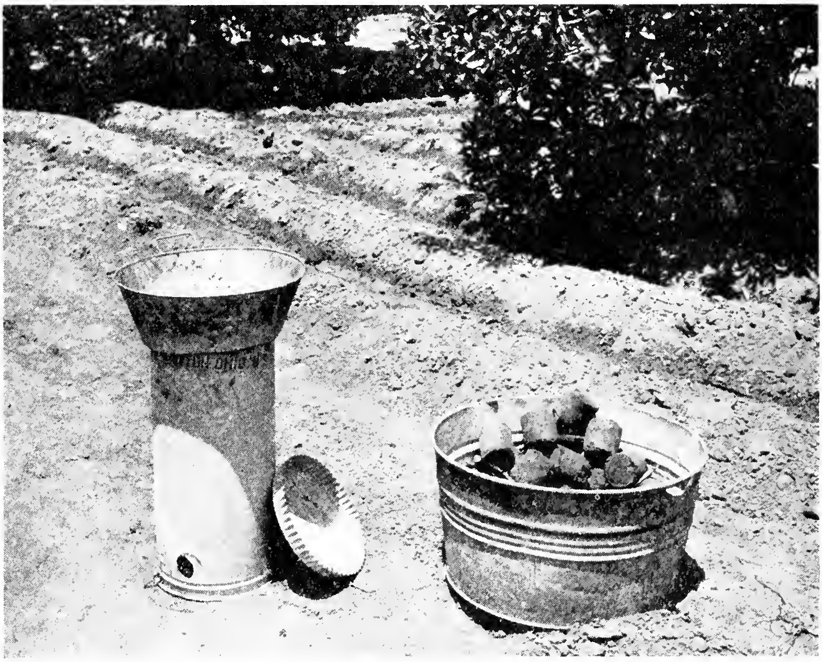


Fig. 11.—Briquette heater with funnel to facilitate filling, and tub for fuel storage. (From Bul. 398.)

impossible to control, and which varies between 1½ and 3 pounds of fuel per hour; and a larger type with some control of burning rate and a maximum burning rate of about 5 pounds per hour. The amount of heat available from 5 pounds of briquettes or coke is approximately equal to that developed from burning ½ gallon of oil. Therefore, a large-sized briquette heater at its maximum burning rate will produce heat equivalent to that produced by an oil heater at average burning rates, and some of the small briquette heaters may produce heat at a rate as low as one-third of this. The number of heaters required will be inversely proportional to the average burning rate of the kind selected, and will vary between 50 and 100 per acre. The first cost of satisfactory equipment for frost protection is less if solid-fuel heaters are used than in the case of oil heaters.

The former deteriorate much more rapidly under use than the latter. They may, however, be a good choice where the frost hazard is not great and where general fixed charges are a more important item of total cost than operating expense.

There is no practicable method of extinguishing most of the briquette heaters and they must be kept refueled until sunrise, after which time the remaining fuel burns out without being useful. Therefore, some waste

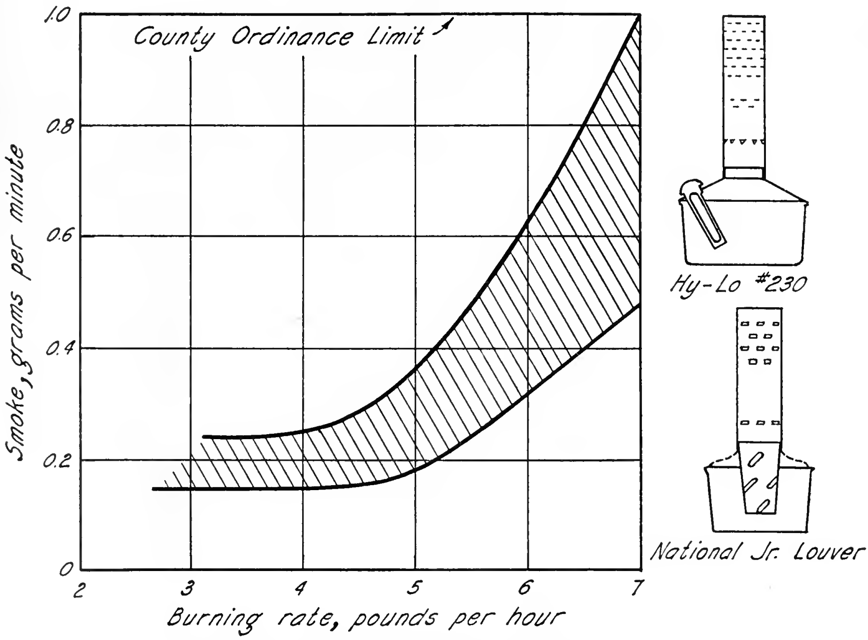


Fig. 12.—Smokiness of cleaned lazy-flame stacks; the band combines the performance characteristics of all stacks of this type.

of fuel is inevitable and operating expense is higher than with oil heaters. Solid fuel can be more easily handled than oil by growers who do not have horses, trucks, or tractors available.

Heat and Smoke Output of Oil-burning Orchard Heaters.—The total heat output of all orchard heaters is practically the same for a given weight of oil burned, but there is a large difference in the ratio of total to sensible heat—manifested by the feeling of warmth—because the proportion of radiant heat is greatest in a horizontal plane from large, tall, hot stacks. The smoke output from different heaters varies greatly and the operating characteristics differ. The choice of heaters and stacks, therefore, should be based mainly on minimum smokiness and on reliable operation.

Figure 12 shows a band covering the normal smoke production of reasonably clean stacks of the lazy-flame type when operated in calm air. The figure combines the performance characteristics of all stacks of the lazy-flame type now available on the market. The Riverside Junior Louver 18-inch stack exhibits cycles of smokiness especially if burned at rates above or below the optimum, which is about ½ gallon per hour. It will therefore show a smoke output considerably above the indicated band for

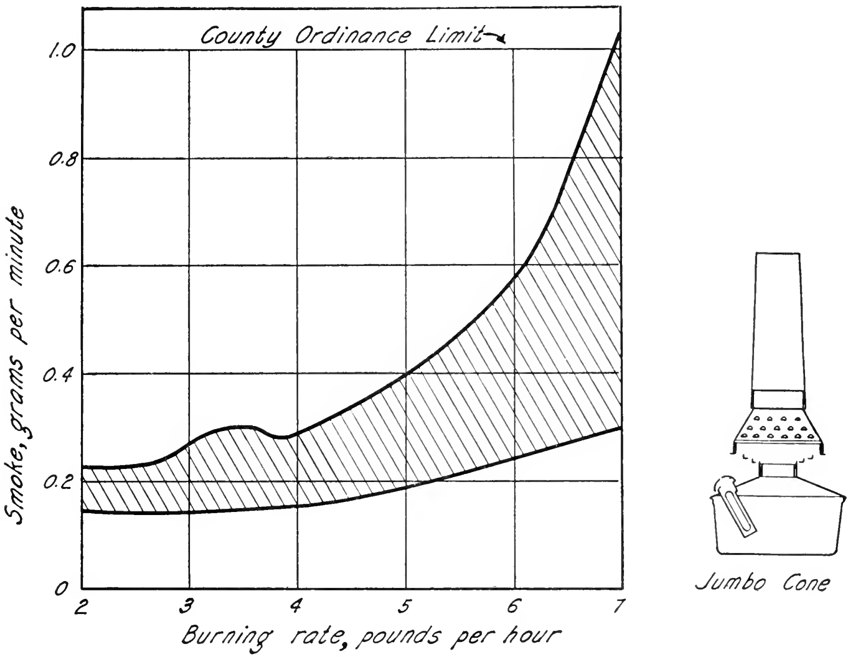


Fig. 13.—The normal band of smoke output for reasonably clean stacks of the combustion-chamber type of heater.

brief periods when in a smoky cycle. All lazy-flame stacks are smoky whenever low burning rates or soot accumulations cause the flame to drop to the lowest row of holes or louvres in the stack.

Stacks with combustion chambers are usually designed for a wider range of burning rate than is possible with lazy-flame stacks. As combustion-chamber size is increased, the mixing of the oil vapors with air becomes more of a problem, so stacks have been built with sharp conical sections and with internal gadgets such as flame spreaders to aid in the mixing. Such changes have not been wholly beneficial since they have increased the difficulty of cleaning the stacks. All combustion-chamber stacks must be kept clean and the burning rate must not be allowed to exceed the capacity of the combustion chamber. These stacks show a very rapid increase in smokiness when the capacity of the combustion chamber is exceeded, at which time the performance may be as bad as that of ordinary smudge pots.

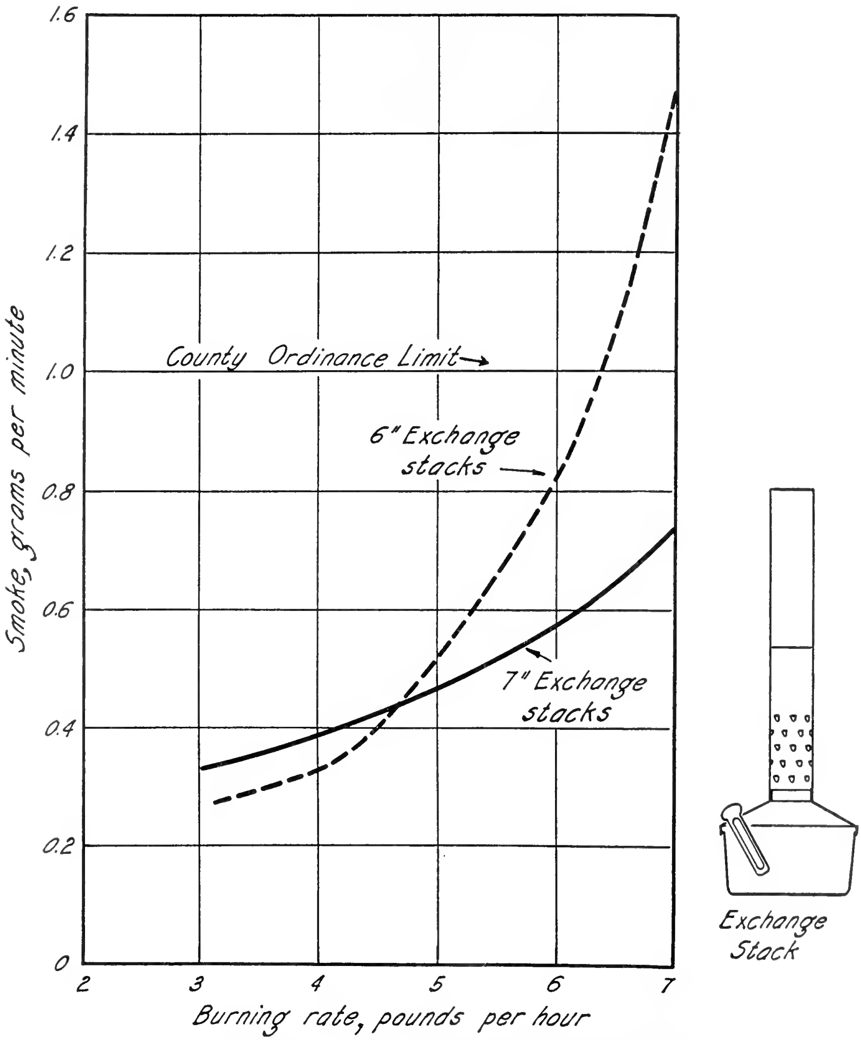


Fig. 14.—Smokiness of 6- and 7-inch Exchange Stacks.

Figure 13 indicates the normal band of smoke output for reasonably clean stacks of the combustion-chamber type now available on the market operated in calm air. The Hy-Lo 148 Special operates as a combustion-chamber stack at low and moderate burning rates, and at high burning rates assumes the characteristics of the lazy-flame stack. At the higher burning rates its smoke output is normally near the lower edge of the band and it is responsible for the bump in the curve of figure 13 at 3½ pounds per hour. The 6-inch and 7-inch straight stacks (Exchange type) are more erratic in their performance than the stacks with conical chambers such as the Jumbo Cone, the Lemora, and the Hy-Lo 148 Special.

The 6-inch straight stack is easily cleaned and if clean is satisfactory up to about ¾ gallon per hour. The diagram and smoke output with a clean stack is shown in figure 14. The same stack after being operated 20 hours without cleaning showed a smoke output too high to be plotted on figure 14. The actual performance was as follows:

Burning rate, pounds per hour	Smoke, grams per minute
3.6	2.1
4	2.4
5	3.4
6	4.0 (or more)

This stack overheats and deteriorates rapidly unless kept at burning rates below 4 pounds per hour.

The 7-inch straight stack, Exchange type, will operate satisfactorily over a wider range of burning rates than the smaller ones, as shown in figure 14. It also requires frequent cleaning and is subject to rapid deterioration at high burning rates.

Number of Heaters Required.—The number of heaters per acre, and the best way of using the different types will vary somewhat with their operating characteristics. The grower should not get away from the basic principle of a large number of small fires per acre. The number of heaters usually installed is 50 bowl-type heaters for oranges and 60 to 80 for lemons and avocados. The number may be reduced about 20 per cent if large areas are heated, and must be increased, especially around the borders of orchards, in cold spots, and in colder areas.

For deciduous fruits the grower should be prepared to maintain fires at from 40 to 50 locations per acre under severe conditions. This would require a minimum installation of 40 heaters per acre having a capacity of 5 or more gallons per heater or about 100 to 150 of the small containers which burn empty in so short a time that some must be held in reserve for burning later in the night. Solid-fuel heaters are not well adapted to the heating of deciduous orchards because blossoms and small fruits freeze quickly. When a drop in temperature is sudden, it is impossible to develop heat rapidly enough with solid-fuel heaters unless excessive amounts of kindling are used.

Usually older trees are easier to protect than young. It is important from the standpoint of effective heating to have enough heaters so that it is unnecessary to exceed the range of burning rates over which they operate best. The most efficient burning rate from the standpoint of heat conservation in the orchard is probably from ⅓ to ½ gallon of oil (2⅓ to 3½ pounds) per heater per hour. A number of heaters, including all of the present generator heaters and the Jumbo Cone heater, will not burn satisfactorily at rates as low as ½ gallon per hour. Such heaters are more effective for border protection and for severely cold nights. One large lemon orchard is equipped with heaters having stacks of large combustion chambers and lazy-flame stacks alternating. The lazy-flame heaters are used under ordinary conditions and the heaters with combustion chamber stacks are used when conditions become more severe and higher burning rates are desired. Some growers have found it practical to equip their orchards with generator heaters at the rate of about 20 per acre and to fill in between with 20 bowl heaters. The 20 generator-type heaters take care of ordinary nights, and since the bowl heaters are not used very often the hauling of oil will not be very difficult. This method of operating has the disadvantage that it utilizes heaters of high burning rate on nights when lower burning rates would be more desirable and more economical of fuel.

Filling Equipment.—Facilities must be provided for refilling the heaters after each night of burning. Oil is ordinarily distributed in tanks which may be horse-drawn if the capacity is 400 to 500 gallons; 600- to 800-gallon sizes may be mounted on a light truck; and those of even greater capacity may be on a trailer pulled by a tractor. In some instances these trailers have track treads instead of wheels. While the average oil consumption will be less than 100 gallons per acre per night, the maximum oil consumption may be around 400 gallons per acre per night. It is therefore essential that everything be provided which will speed up the refilling operations. Oil is distributed to the heaters from the tanks either through 1½-inch to 2-inch hoses or carried in 5-gallon pails. Some operators have both hose and faucets connected to the tank, filling heaters near the drive from the hose and heaters in the second row by carrying the oil in pails. Data from a limited number of records taken in an orchard-heating survey conducted in 1937 show that 45 per cent of the growers used pails and distributed an average of 131 gallons per man per hour; 28 per cent used hose and distributed 180 gallons per man per hour; and the remaining 27 per cent used the combination system and distributed 139 gallons per man per hour. Table 3 shows the details as reported from the various counties. The table indicates that the range of performance for any one method is much greater than the differences between the methods, so it is difficult to draw conclusions as to what method will be most effective for a given set of conditions. The table is valuable as an indication of field experience in filling. Inasmuch as equipment is more difficult to obtain than hand labor, the amount of oil distributed per tank and crew, per hour, is a more important consideration than the amount distributed per man per hour. In order to keep the tanks working to the best advantage, outlet pipes and fittings from elevated storage tanks and pumps from underground storage tanks should be of

TABLE 3

METHODS OF FILLING HEATERS REPORTED IN ORCHARD-HEATING SURVEY OF 1937

County	Pails			Hose			Pails and hose		
	Number of records	Gals. per man-hr.		Number of records	Gals. per man-hr.		Number of records	Gals. per man-hr.	
		Range	Av.		Range	Av.		Range	Av.
Los Angeles....	20	52–266	130	7	109–350	225	8	73–350	171
Orange.........	2	75–125	100	3	100–185	150	6	90–165	114
Riverside......	19	60–183	115	11	44–194	127	20	52–186	105
San Bernardino	24	60–207	136	11	89–216	162	10	28–200	106
Tulare.........	9	100–280	184	21	110–400	205	4	125–205	168
Ventura........	8	78–150	105	..	....	...	..	....	.....

large capacity so that truck tanks can be filled rapidly. Discharge outlets from wagon or truck tanks should be sufficiently large so that all of the faucets on a discharge line can run simultaneously without diminishing the flow. Some growers even mount pumps driven by small gasoline engines on their truck tanks in order to speed up discharge rates. For sloping land it is desirable to have outlets from the front of the tank as well as the rear. This precaution is necessary in order to remove all of the oil when going down hill.

The fuel for briquette heaters is usually carried loose in a cart, truck, or trailer; and scoop shovels and large funnels are used to fill the heaters. In other cases briquettes are distributed during the summer time and stored in the field in apple boxes, old tubs, or other containers. Filling is then done by hand by pouring from the container into the heater through a large funnel, as is shown in figure 11. Refueling at night is done by taking fuel from boxes or other containers by hand. Kindling is carried in a separate container and is placed in the heater at the time of filling.

Considering the field troubles with tank wagons and the heavy work of carrying pails of oil over muddy ground, the most promising improvement in filling technique seems to lie in piping the fuel oil from the ranch storage tank to well-placed hydrants from which all heaters can be reached by hose.

Hydrant-Hose Filling Systems.—It appears that one man can distribute about twice as much oil per hour from a pipe-line system as he can as a member of a crew distributing from a tank.

A brief investigation of hose-filling operations showed that filling was much faster with a short hose handled by one man than with two men

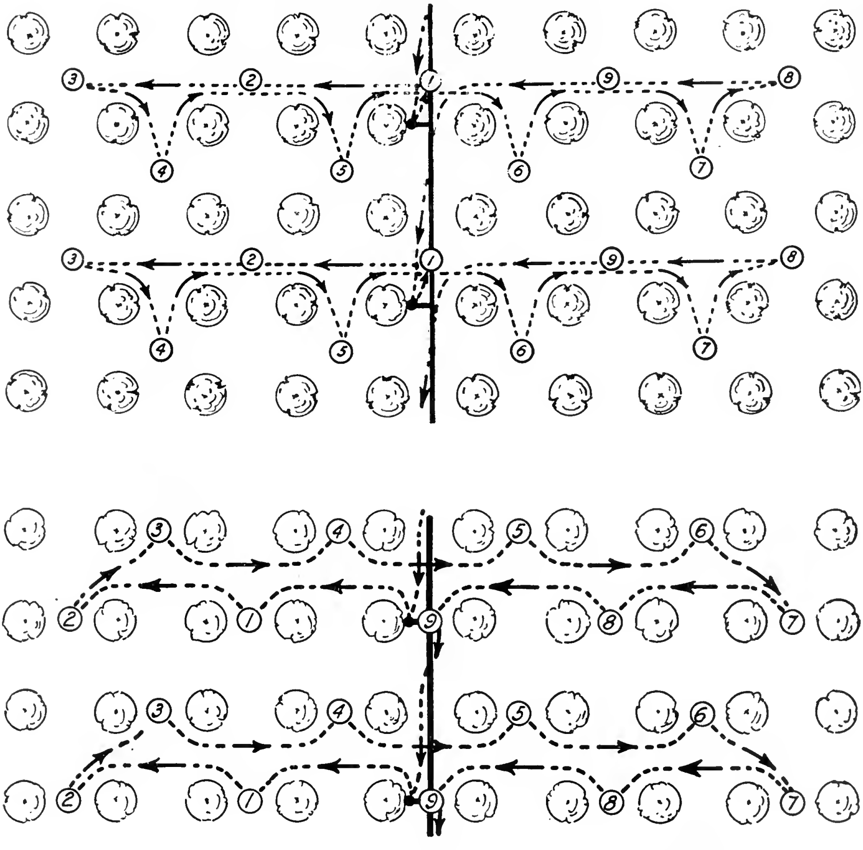


Fig. 15.—Suggested work pattern for filling heaters from hydrants.

on a long hose. A ¾-inch hose 100 feet long was as much as any one man could handle effectively, and then only if the filling pattern followed was regular and with no danger of displacing heaters while dragging the hose from one location to another. Figure 15 shows a suggested work pattern for filling heaters spaced every other tree in every row. With hydrants every two rows there will be no interference between heaters and hose if the route indicated is followed for either heaters in the tree spaces as shown in the upper part of figure 15 or for heaters in the tree rows as shown in the lower part of the diagram. In moving the hose from hydrant

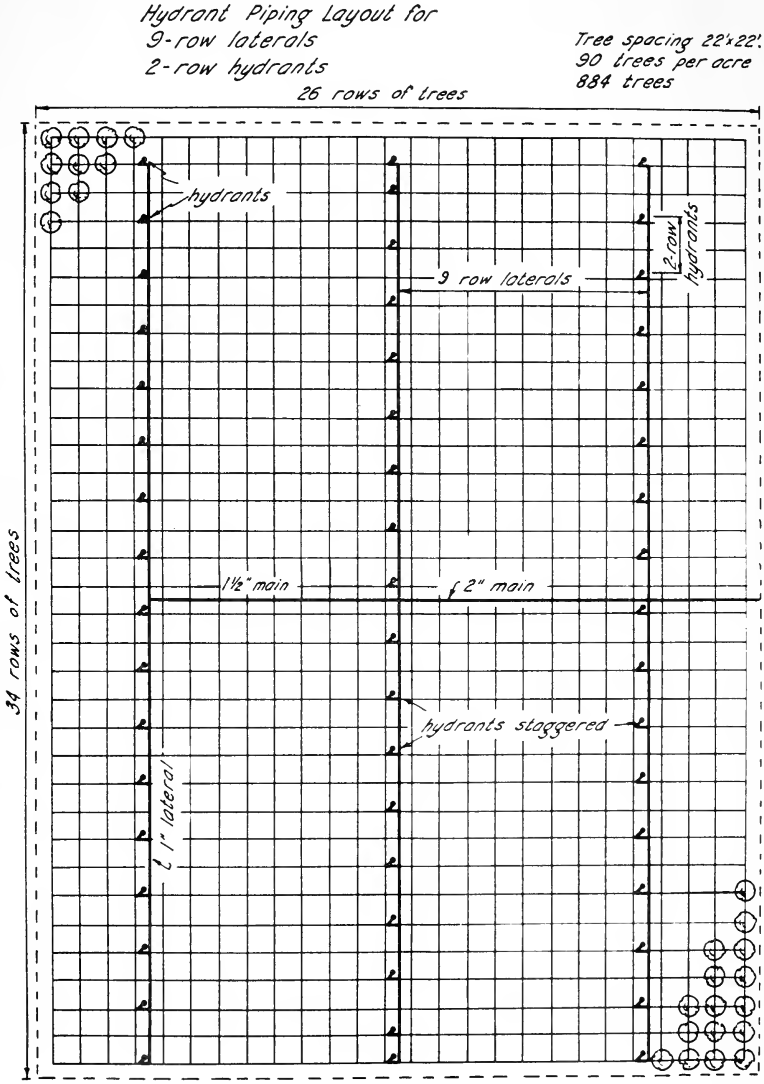


Fig. 16.—Suggested layout for piping to hydrants in orchard heating.

to hydrant both ends are hauled together and care must be taken always to pass between the heater nearest the hydrant and the last one to be filled. When filling is started the hose must be dragged around the first heater so as to lie in the space between heater rows as filling proceeds.

A rate of oil flow of 10 gallons per minute is easily managed with a hose equipped with a hand valve at the nozzle. About half the time would be spent in moving from heater to heater. The fuel output per man in one such system installed late in 1937 was well over 400 gallons per hour.[13]

A typical hydrant layout for 10 acres for 9-row hydrants is shown in figure 16. The recommended method of connecting the pump to the storage tank is shown in figure 17. The important difference from common

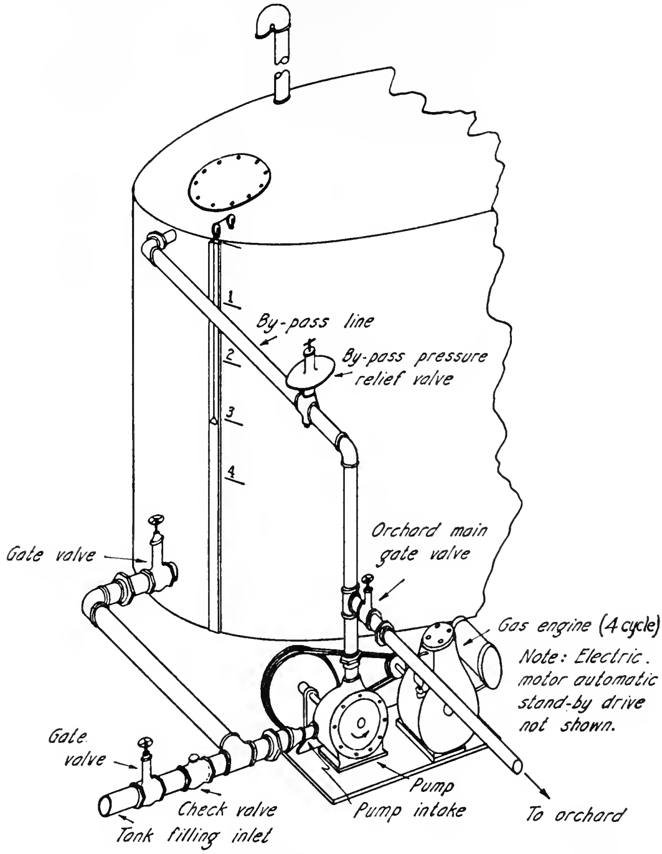


Fig. 17.—Diagram of connections and fittings of orchard pipe-line systems to pressure pumps and storage tanks.

practice is that the by-pass is carried back into the tank to prevent overheating and foaming of the oil when the pump is running but no oil is being used.

The material cost for such a hydrant system is high, and the system should not be installed unless definite savings can be foreseen.

Piped-Heater Systems.—The engineering principles of piping oil to heaters have been studied and mimeographed recommendations are

[13] Daybell, Frank. A pipeline system for filling orchard heaters. California Citrograph 23(6):251. April, 1938.

available.[14] Numerous field installations have already been made in which fuel is piped to each heater for both drip and generator types.[15]

Lighting.—Lighting is accomplished by the use of torches which drip burning torch fuel into the heaters. A torch consists of a container with a spout, a wick, and a wire gauze in the base of the spout. The wick is made of asbestos, usually wrapped in a piece of screen or a wire spiral. It is placed either directly in the spout, loosely enough so that the fuel will flow freely through it, or in a slot close to the end of the spout. In either case the wick must be so arranged that the fuel leaving the spout flows over or through it. The lighted wick ignites the torch fuel as it flows out.

The most important feature of the torch is the protective wire gauze at the base of the spout and under no circumstances should a grower use a torch in which the wire gauze is lacking or defective. Fatal explosions have occurred with homemade torches. The usual gauze fire screen is of a fine mesh brass or copper screen and is generally soldered into the base of the spout. It works on the same principle as the miner's safety lamp. Slight explosions sometimes occur in the spout where there may be enough air to make an explosive mixture. The spout should screw tightly into the container against a metal gasket. A long, small tube for the air intake to the container helps to preserve a fuel-vapor atmosphere inside too rich to burn. Torches which are nearly empty should be refilled before further use. An electric flashlight is the safest light to use when filling torches at night.

The most commonly used torch fuel is a fresh mixture of equal parts of gasoline and kerosene. This mixture will carry fire clear to the ground if poured from a burning torch held 3 feet from the ground.

Oily clothes worn by the operators are dangerous during lighting operations or near open-flame heaters.

Thermometers.—An adequate supply of accurate thermometers is an essential part of orchard-heating equipment. Temperatures vary several degrees in different parts of even small orchards. It would seem advisable to have one thermometer for each two acres on the small properties, and one for each four or five acres on the large properties. The thermometers should be distributed through the orchard in some relatively uniform pattern, with the locations marked in such a way that they can be easily found at night. One thermometer should always be placed outside of the orchard or on the upstream edge with respect to the air drift.

[14] Division of Agricultural Engineering. Oil distribution systems for orchard heating. Division of Agricultural Engineering, University of California. 33 p. 1937. (Mimeo.) Available at farm advisors' offices.

[15] McCracken, J. H., and K. B. Low. Centralized orchard heating system as installed at the Limoneira Ranch. California Citrograph 23(6):246, 267. April, 1938.

The horizontal alcohol- or toluene-filled minimum thermometer, which indicates the lowest temperature reached, is the most satisfactory type. The minimum temperature is marked by a glass indicator which is set at the top of the liquid column by turning the thermometer upside down. The thermometer is then placed with the bulb about 1 inch lower than the top of the stem and as the temperature falls the glass indicator is pulled down by surface tension. When the temperature goes up again the liquid flows past the glass indicator leaving it in such position that the top end indicates the lowest temperature reached since the last setting. Thermometers of this type, designed by the United States Weather Bureau especially for orchard-heating work, cost about $3.00 each. One or two of these in an orchard may be supplemented by somewhat cheaper vertical short-range instruments, designed especially for orchard use. Even carefully constructed thermometers are sometimes inaccurate, so it is advisable to have all thermometers tested when purchased, and before each danger season. The Fruit Frost Service of the United States Weather Bureau performs this service free of charge in all districts where they have field men. If there is no local representative of the Service in the district, the county farm advisor sometimes arranges to test thermometers or have them sent to the nearest place where tests are made.

If thermometers are so placed in the orchard that the bulbs are exposed to the sky they will lose heat by radiation, the amount depending on the type of instrument used, and the temperature indicated therefore will not be correct. This may vary as much as 3 or 4 degrees from the true air temperature. To provide accurate reading, thermometers must be placed in shelters which shade them from the sky. A very satisfactory shelter may be made from two 1-inch boards about 8 inches wide and 16 inches long. One board is placed at right angles to the other, one constituting the back of the shelter, the other furnishing a cover for the thermometer. The cover is hinged so the indicator can be set, which is done by elevating the bulb end of the instrument (fig. 18, *B*) or lowering the stem. Recently growers have been using a small double-roof shelter with ventilated back and ends (fig. 18, *A*). This shelter provides for adequate air movement and protection against radiation. The standard exposure is at a height of 4½ to 5 feet from the ground with the shelter facing north so as to prevent the sun from striking any part of the thermometer. All thermometer shelters should be painted white. The best thermometers for orchard use are graduated to a short range and may be injured by extreme heat. During the summer they should be removed from the shelters and stored with the bulb ends down, in a cool place.

An open flame from match or torch should never be used to read a thermometer; the only safe light is that from an electric flashlight. The reading should be made quickly and the observer must take care not to breathe on the bulb of the thermometer.

If the minimum thermometer is roughly handled or improperly exposed, the column of liquid may separate. The thermometer can sometimes be put back into condition by attaching a 3-foot length of stout

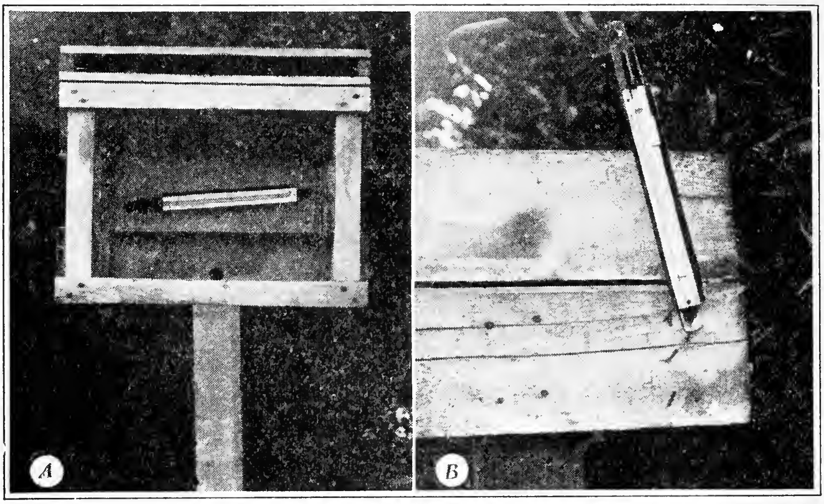


Fig. 18.—*A*, Minimum thermometer in a simple shelter. *B*, Detail showing setting of the indicator.

string to the top end and whirling it rapidly. Repairs should be made by a United States Weather Bureau representative if possible.

The U-tube type of thermometer which reads both maximum and minimum is less reliable and is not recommended for use in connection with orchard heating.

Fruit thermometers as shown in figure 19 are very valuable when used in conjunction with air-temperature thermometers in deciding the proper time to light orchard heaters. A satisfactory fruit thermometer should be filled with mercury. It should not have a metal shield to protect the bulb because the metal will conduct heat away from the fruit. Instead, the fruit should be pierced with a nail before inserting the thermometer. Fruit thermometers should always be of the short-range type, preferably calibrated to half degrees and with the marks far enough apart so that accurate readings can be made. It is important that fruit thermometers be carefully tested and all which are inaccurate be discarded. Two or three fruits should have thermometers inserted and be used together to avoid misinterpretation.

Thermographs.—Many growers have thermographs so that they have a continuous record of the temperatures they have maintained in the orchards. The temperature record charts shown in figure 2 are taken directly from an orchard thermograph record. The thermograph should be checked daily against a tested thermometer in the same shelter, with due allowance for time lag if the temperature is changing rapidly.

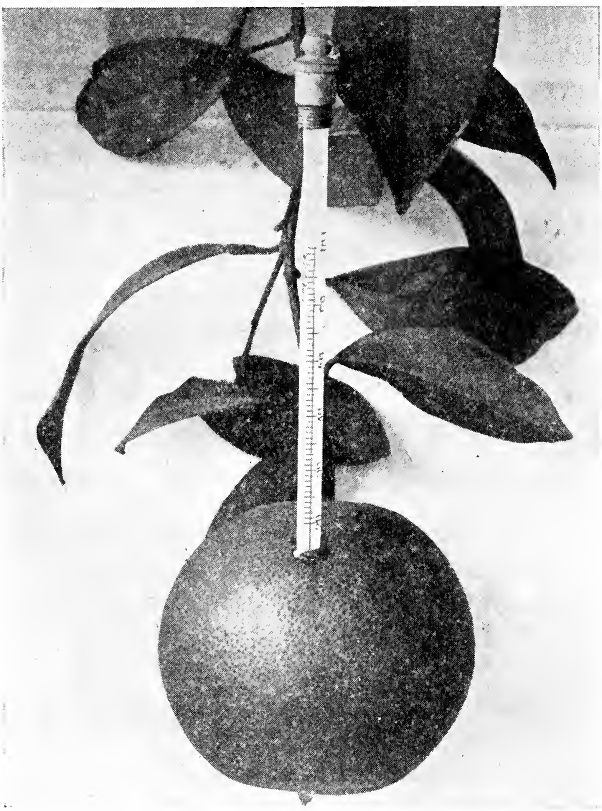


Fig. 19.—A fruit thermometer inserted in an orange.

Frost Alarms.—Many growers use frost alarms to sound a warning when the temperature reaches the danger point. Unfortunately, there are many frost alarms in use which are not dependable. The essential requirements of a good frost alarm are as follows:

1. It should operate on a closed circuit, attached either to a 110-volt lighting circuit or to a battery. (Different types of relays will be required for the different sources of power.)

2. It should have a dependable relay which will close the bell circuit

when the current from the orchard unit is broken. The bell circuit should always be battery-operated, and if batteries are used on the orchard circuit, a separate battery should be used for the bell circuit.

3. The orchard unit should consist of a carefully constructed large-bore mercury-filled thermometer with a fixed alarm contact point sealed in. Such alarm units are not adjustable. One thermometer unit must be purchased for each alarm temperature desired. Some first-class mercury thermoregulators are in use which can be reset at the factory. There is no dependable frost alarm at present on the market which can be adjusted by the grower.

All frost alarms should be tested each night during the danger season by breaking the orchard circuit with a switch provided for making the test. The thermometer unit should be placed in the coldest part of the orchard in an instrument shelter. More than one thermometer can be attached to the same alarm box. This makes it easy to have the alarm ring at different temperatures; a switch in the house may be set for any selected unit to ring the alarm. Two wires run from the thermometer unit to the alarm box. Each additional thermometer requires an additional wire, the ground wire from the first unit serving the second unit also.

FUELS AND FUEL STORAGE FOR ORCHARD HEATING

Fuels for Bowl- or Distilling-Type Heaters.—More than 90 per cent of all orchard heating is done with fuel oil and most of the oil-burning heaters are of bowl or distilling type that use gas oil generally known as bunker grade marine Diesel fuel of 27+° A.P.I., selected for low pour point. The refiners list this grade of oil as Pacific Standard 200. Such a specification necessarily has rather broad limits so some selection should be made, first to get fuel with a pour point of 0° F or lower (as stated in Commercial Standard No. 3); second, to favor a low carbon residue; and third to favor a high degree of A.P.I. gravity.

Table 4 lists the specification values for Pacific Standard 200 and the corresponding Commercial Standard No. 3[16] and also includes typical values as shown by regular stock samples of the former from seven California refineries, drawn in May 1938.

A special carbon-residue test is included in table 4 which is practically a miniature lard-pail heater—the regular Conradson crucible—being left uncovered and the oil burned from a free surface without external application of heat. This test (described in the Appendix) is simpler than

[16] United States Department of Commerce. Fuel oils, commercial standard CS 12–38, (4th ed.) U. S. Dept. Commerce Natl. Bur. Standards. 1938.

the Conradson on 10 per cent residuum, and appears to be as useful for judging orchard-heater fuel oils, although it is not an official test of the American Society for Testing Materials.

In bowl- or distilling-type heaters the fuel is evaporated from a large free oil surface. The presence of a flame in the bowl atmosphere of fuel vapor causes the release of carbon regardless of the nature of the fuel.

TABLE 4

STANDARD LIMITS OF THE DIESEL-FUEL GRADES REPRESENTED BY PACIFIC STANDARD 200 AND COMMERCIAL STANDARD NO. 3.

Characteristics	Pacific Standard 200 and suggested limits		Commercial Standard No. 3		7 samples of Pacific Standard 200, May 1938 observed range
	Maximum	Minimum	Maximum	Minimum	
Gravity at 60°/60° F, ° A. P. I. (American Petroleum Institute)	..	27*	..	..	34.5 to 30.3
Viscosity at 100° F, seconds Saybolt Universal	55	35	55	..	39.7 to 35.7
Viscosity at 35° F, seconds Saybolt Universal	80*	..	..	..	79.5 to 54.5
Pour point, ° F	0*	0†	..	..	+5 to −45
Pour point on 25 per cent bottoms, ° F	..	..	..	..	+60 to −10
Open crucible self-burning residue, per cent by weight	..	..	..	..	1.21 to 0.76
Conradson carbon, per cent by weight	..	..	0.15	..	0.073 to 0.016
Conradson carbon on 10 per cent residuum, per cent by weight	1.00*	..	..	..	0.60 to 0.08
Flash point, Pensky-Martens, closed cup, ° F	..	150	230	110	214 to 172
Distillation, American Society for Testing Materials, D158–28: Initial boiling point, ° F	..	..	..	..	438 to 370
10 per cent by volume, ° F	..	425	..	..	485 to 440
50 per cent by volume, ° F	..	..	..	..	542 to 498
90 per cent by volume, ° F	..	600	675	600‡	668 to 603
End-point, ° F	..	..	..	..	732 to 661
Distillation residue at 700° F, per cent	..	..	..	..	6 to 2
Water and sediment, per cent	0.10*	..	0.10	..	......
Sulfur, per cent	0.75*	..	0.75§	..	......

* Additional limits suggested by the authors (not listed in the general standard) for orchard-heater fuel, pending further studies.

† Specification limit when low pour point is required.

‡ Minimum distillation of 600° may be waived if A.P.I. gravity is 26° or lower.

§ Specification limit when low sulfur content is needed.

However, there are other types of residue formed in the bowl, the amount of which will vary with the nature of the fuel, probably being greater for the oils higher in naphthenes. The smoke output from free-surface burning would also be greater for the oils higher in naphthenes, hence the oils with higher paraffin tendencies seem more desirable for bowl heaters.

The paraffinic or naphthenic tendency in a fuel oil can be judged somewhat by the relation between the 50 per cent distillation temperature and the open crucible self-burning residues. Figure 20 shows the test results of all bowl-type heater fuel oils tested by the special self-burning open crucible method in relation to 50 per cent distillation temperatures. The 50 per cent temperature is chosen as being the most reliable indicator of the distillation characteristics. The temperatures are higher for the more paraffinic oils; the burning residues are greater for the more naphthenic oils. A 50 per cent distillation temperature of 530° F appears from field reports to be the maximum acceptable for the more paraffinic fuel oils.

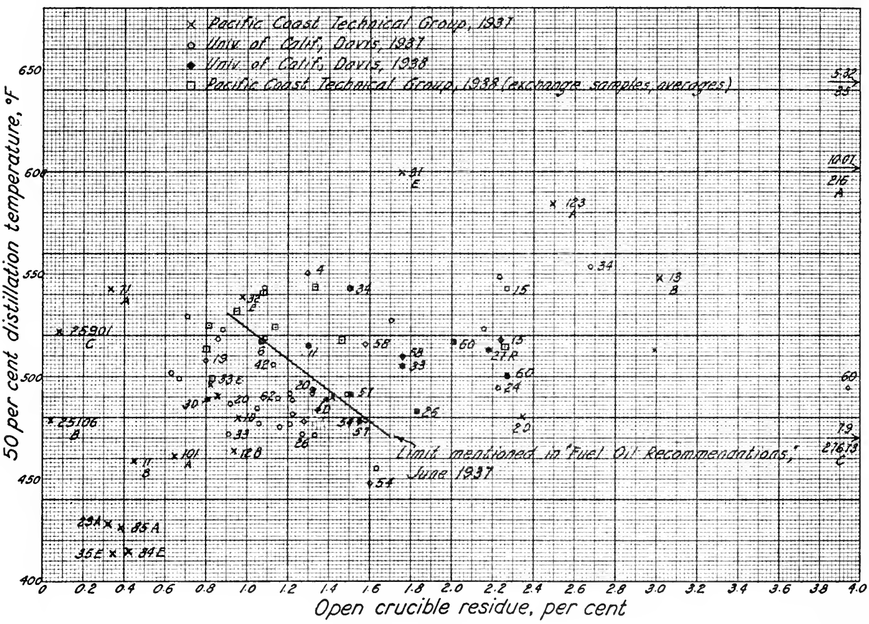


Fig. 20.—Relation of open-crucible residue to 50 per cent distillation temperatures for samples of Diesel oil for bowl-type orchard heaters.

Those more naphthenic might be excluded by limiting the burning residue to 0.9 per cent maximum. The more naphthenic fuels with much higher burning residues up to about 1.7 per cent maximum have been used by growers without unusual trouble, but the 50 per cent distillation temperatures of these oils are low. A maximum temperature of about 470° appears to be a fair limit for oils with 1.72 per cent residue. Most of the fuels tested (which were not complained of in the field) show a burning residue of less than 1.3 per cent and a 50 per cent distillation temperature below 500°. Fuels with the lower residues and low distillation temperatures are preferred. The present field data are not sufficient to indicate whether the saving in heater trouble would warrant the payment of a higher price for fuel oil, but it seems evident that extra troubles in orchard heating should be expected when using oils with higher self-burning residues than shown below for the corresponding 50 per cent distillation temperatures:

Open-crucible self-burning residue, per cent	50 per cent distillation temperature, °F
0.9	530
1.3	500
1.7	470

For intermediate values of burning residue, intermediate distillation temperatures would be expected.

The characteristics of the samples of fuel oils for which trouble was reported in January, 1937, are given in table 5, arranged in the decreasing order of self-burning residue.

Fuels for Drip-Type Heaters.—The best fuel for the Kittle heater comes under Pacific Standard 100, but satisfactory operation can be obtained from Pacific Standard 200 if specific lots are carefully chosen for higher quality than average.

In this type of heater, burning is from a small free oil surface but under a strong draft and excess air. In the Kittle there is very little space for residue accumulation so the main service requirement is to clean out the burner trough frequently to prevent overflow.

Although many operators mentioned fuel trouble with Kittle heaters, only one of the oil samples received in 1937 was identified with drip heaters. This was said to burn well (self-burning residue 0.8 per cent). The manufacturer specifies fuel of the 32° A.P.I. gravity or better, and judging by the samples included in this group a maximum open-crucible burning residue of 1.0 would exclude most of the undesirable oils.

No recommendation for an upper limit for the 50 per cent distillation temperature can be made at present because of the lack of adequate data.

Fuels for Generator-Type Heaters.—In these heaters the fuel is evaporated in a small closed chamber. Ideally, the temperature of the generator, when the heater is in regular operation, should be high enough to volatilize the fuel, but below that at which cracking will occur. These heaters can operate with generator temperatures a little lower than the end boiling point because the vaporized portion can carry some liquid out through the orifice. Present experimental information is insufficient to specify fuel characteristics, but in general the fuel should be a straight-run distillation product. Generator fuels are generally marketed as kerosene distillate or stove oil, and come under Pacific Standard 100 or Commercial Standard No. 1. (See footnote 16, p. 46.) Table 6 gives the

TABLE 5

CHARACTERISTICS OF FUEL OILS REPORTED UNSATISFACTORY FOR BOWL-TYPE HEATERS

Project oil No.	Gravity, °A.P.I. at 60°/60° F	Color	Viscosity, seconds Saybolt Universal			Pour point, A.S.T.M. maximum, ° F*	Open-crucible self-burning residue, per cent	Conradson carbon on 10 per cent residuum, per cent	Flash point A.S.T.M., open cup, ° F	Fire point A.S.T.M., open cup, ° F	Distillation temperature, A.S.T.M., ° F		
			100° F (observed)	35° F (observed)	35°F (extrapolated)						10 per cent by volume	50 per cent by volume	90 per cent by volume
35	25.2	Black	98	No flow	875	+65	5.3	16.8	265	280	516	624	634†
34	31.9	Black	43	85	85	+20	2.7	4.6	210	255	483	543	622
24	31.1	Black	39	59	57	−25	2.2	4.5	205	235	439	499	610
23	31.9	Black	41	68	68	+10	1.7	3.1	220	255	465	522	634
4	32.1	Black	44	400	78	+35	1.3	1.2	225	245	472	551	665

* Analyses made by Curtis and Tompkins, San Francisco.

† Cracked at this temperature—before 90 per cent distillation.

standardized limits for these specifications and also includes typical values of regular stock from three California refineries in April, 1937.

Because it is desirable to have as wide a difference as possible between evaporation temperatures and cracking temperatures (cracking inside the generator chamber produces coke in the passage) fuels of the more paraffinic type are to be preferred. Of the 20 field samples of fuel for

TABLE 6

STANDARD LIMITS OF THE STOVE OIL GRADES REPRESENTED BY PACIFIC STANDARD 100 AND COMMERCIAL STANDARD No. 1

Characteristics		Pacific Standard 100		Commercial Standard No. 1		3 samples of Pacific Standard 100, April 1937 observed range
		Maximum	Minimum	Maximum	Minimum	
Gravity at 60°/60° F, ° A. P. I. (American Petroleum Institute)		..	..	..	..	38.3 to 37.0
Viscosity at 100° F, seconds, Saybolt Universal		..	..	..	..	34 to 31
Pour point, ° F		..	..	0*	..	0 to −20
Conradson carbon, per cent by weight		..	..	..	..	0.02 to 0.01
Conradson carbon on 10 per cent residuum, per cent by weight		..	..	0.12†	..	....
Flash, Pensky-Martens, closed cup, ° F		165	110 (or legal)	165	100 (or legal)	180 to 145
Distillation, American Society for Testing Materials,	Initial boiling point, ° F	..	..	..	..	381 to 359
	10 per cent by volume, ° F	420	350	410	..	405 to 383
	50 per cent by volume, ° F	..	..	..	..	451 to 429
	90 per cent by volume, ° F	550	450	..	..	520 to 495
	End-point, ° F	..	..	590‡	..	600 to 558
Distillation residue, per cent		..	..	..	..	2.0 to 1.5
Water and sediment, per cent		..	..	trace	..	trace
Sulfur, per cent		..	..	0.5§	..	....

* Limit when low pour point is needed.
† Limit is 0.05 per cent for sleeve-type blue-flame household burners.
‡ Limit is 560° F for sleeve-type blue-flame household burners.
§ Limit when oil of low sulfur content is needed.

generator heaters analyzed in 1937, a maximum acceptable self-burning residue of 0.5 per cent would insure getting oils of paraffinic tendencies. This limit would exclude only 1 of the 20 samples received and that one was reported as having given trouble.

To recommend an upper limit for the 50 per cent distillation temperature is not feasible at present. Field troubles have been reported on samples with the 50 per cent distillation temperatures throughout the range of all the samples (435° to 485° F). The design of most generators has been altered from year to year, so that no consistent behavior is evident. Field tests have shown that close attention is required to operate the generator-type heater at a proper burning rate, hence many of the field

TABLE 7

CHARACTERISTICS OF TWENTY FUEL OILS FOR GENERATOR-TYPE HEATERS

Project oil No.	Gravity, ° A.P.I. at 60°/60° F	Color	Viscosity, seconds Saybolt Universal		Pour point A.S.T.M. maximum, ° F*	Open-crucible self-burning residue, per cent	Conradson carbon on 10 per cent residuum, per cent	Flash point, A.S.T.M., open cup, ° F	Fire point, A.S.T.M., open cup, ° F	Distillation temperature A.S.T.M., ° F		
			100° F	35° F						10 per cent by volume	50 per cent by volume	90 per cent by volume
29	35.6	Light brown	36	47	−25	0.53	0.10	200	245	447	483	528
36	36.4	Light brown	36	46	−30	.49	.20	175	215	434	476	519
41	36.8	Dark brown	36	44	−35	.49	.37	180	195	404	467	526
25	37.4	Light brown	36	47	−25	.47	.07	200	240	444	479	544
53	38.0	Dark reddish brown	35	41	−40	.46	.38	155	190	389	449	523
48	36.8	Light brown	36	49	−35	.45	.27	205	225	441	485	517
51	36.8	Yellow	35	46	−40	.43	.07	195	220	436	473	509
45	37.0	Light yellow	35	45	−25	.43	.07	185	215	428	472	508
39	38.0	Dark yellow	35	44	−30	.43	.08	175	205	402	467	530
40	38.2	Light brown	35	42	−30	.43	.31	165	195	395	450	526
49	37.0	Yellow	35	44	−30	.42	.20	175	200	420	472	514
38	37.8	Dark yellow	35	42	−40	.42	.17	155	175	393	456	525
37	37.2	Brown	36	45	−40	.41	.16	190	215	443	470	504
9	37.8	Light yellow	35	40	−45	.40	.10	135	145	352	433	505
5	36.8	Very light yellow	36	45	−60	.38	.21	165	180	401	455	496
44	37.8	Yellow	34	41	−30	.38	.13	150	175	378	449	536
6	37.4	Light yellow	35	41	−60	.38	.09	145	155	374	443	508
50	39.0	Yellow	36	41	−15	.38	.06	175	195	414	447	489
17	37.6	Light yellow	36	41	−30	.37	.19	150	165	384	449	528
55	38.4	Dark yellow	36	41	−35	0.37	0.38	155	185	390	450	520

* Analyses made by Curtis and Tompkins, San Francisco.

complaints may be due to faulty operation or obsolete generators. Table 7 gives the entire 1937 list of field fuel samples for generator-type heaters, arranged in order of self-burning residue. Field complaints were made about fuels Nos. 29, 25, and 53.

Pour-back Oil.—In bowl-type heaters the character of the oil changes as burning from the surface proceeds because the lighter fuel fractions are burned more readily than the heavier and some polymerization occurs in the bowl. As an indication of the magnitude of this change figure 21 gives the distillation curves for the original poor oil and after burning

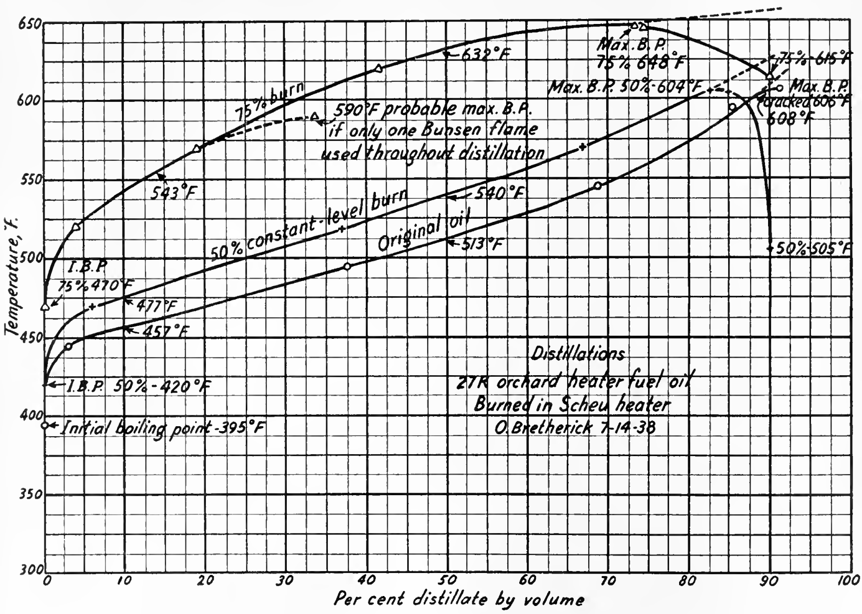


Fig. 21.—Change of distillation characteristics after burning a poor oil down one-half and three-quarters in a bowl-type heater.

down half and three-quarters. In the case of a good oil the 50 per cent distillation temperature for the original of 493° F increased 58° to 551° after the lazy-flame heater had burned off 4½ gallons of the original 6 gallons of fuel. The viscosity at 35° F for this same sample changed from 54 to 115 seconds. Another fuel with an original pour point of —15° was found to have a +40° pour point after similar burning down from 6 gallons to 1½ gallons. These large changes explain the field difficulties of pour-back oil and show the importance of keeping the pour-back separate from the new oil storage.

Storage of Fuel Oil.—Fuel-oil storage for orchard heating is justified partly to minimize the risk of shortage during a severe freeze, as occurred in January 1937 when regional oil stocks were exhausted; partly to permit selection of the proper quality of fuel which is not always available; and partly to take advantage of off-season prices. Storage of fuel oil introduces extra problems of leakage loss, soil damage, etc., but the greatest difficulty is the formation of water sludge in the bottom of the tank. This sludge is jellylike and often is found 6 inches or a foot deep on the bottom of the reservoir and thus constitutes a serious hazard to the withdrawal of fuel during a frost. It is essential, therefore, that the water sludge be removed from tanks every few years. The accumulation of water cannot well be prevented because it enters the air vent as a vapor and at night condenses on the inside walls of the tank. The water sinks below the oil and therefore cannot re-evaporate.

The total amount of oil storage in the communities and on the ranches should be at least equal to the maximum seasonal usage.

Location of Oil-Storage Tanks.—Oil-storage tanks should be located so that oil supplies can be delivered from an all-weather road and with due regard for fire and theft hazards, discovery of leakage, and convenience for management. Where pipe-line distribution systems are contemplated, consideration should be given also to land elevation, economy of pipe-line layouts, electrical service, and similar factors.

Capacity.—The storage capacity in no case should be less than 1,000 gallons per acre protected. A safer rule is 30 gallons per heater used. Higher minimum storage capacities are recommended for heaters requiring fuels of better grade than commercially available bunker-grade marine Diesel fuel.

Foundations.—The foundations should be adequate to provide a full uniform bearing in a horizontal plane. Commercial metallic tanks should be erected in accordance with the manufacturer's recommendations. Bearings for footings under normal field conditions should not exceed 1 ton per square foot.

Materials for Tanks.—Tanks should be of fire-resistant materials and constructed in conformity with local building ordinances. The container must be tight and free from leakage or seepage of any sort. Only first-class materials and construction should be considered.

Marine Diesel fuel oil (27+° A.P.I.) to be used in pipe-line systems should not be stored in galvanized tanks because unneutralized oils react with zinc and produce zinc soaps which make trouble in pumps and small valves.

Concrete Tanks.—Concrete tanks should be steel-reinforced and made from properly designed and selected materials. These should be preferably of vibrated, monolithic construction poured as a continuous unit.

Lighter fuel oils (above 30° A.P.I.) have a tendency to penetrate concrete walls unless the surface is treated with sodium silicate, boiled linseed oil, or other suitable processes. In general, pipe openings through the base and sides of concrete tanks should be avoided.

Metal Tanks and Protection from Rust.—All metal tanks should be painted with a rust-proofing paint, aluminum preferred. Protective treatments should be applied to tank bottoms before placing on the foundations.

Tank Covers, Vents, and Manholes.—All tanks should be tightly covered to prevent excessive evaporation losses. Covers should be vented in accordance with the insurance underwriter's requirements. Manholes with covers should be installed as the service may require.

Float Gauge.—Tanks should be equipped with float gauges and outside indicators to show plainly the fuel level in the tanks.

Pipe-Line Outlets.—Service outlets should be provided for the withdrawal of the tank contents by gravity or pumping as the installation may require. In no case should the outtake (pump suction intake or gravity outlet) be below the sludge level of the tank. For flat-bottomed tanks this should be not less than $\frac{1}{20}$ of the tank height. A shut-off valve should be placed in the outlet pipe (pump suction intake or gravity outlet) as near the tank as practicable.

Filling Inlet.—An inlet of adequate size should be provided for filling the tank. The location of this inlet will depend upon the type of tank used, its elevation, method of filling, and other local factors. The inlet should be equipped with a shut-off valve located near the tank exterior.

By-Pass Inlet.—A by-pass inlet must be provided for storage tanks used in connection with pumping plants for pipe-line pressure systems.

Provision for Sludge Removal.—Provision should be made to withdraw accumulations of sludge from the tank floor through sumps, floor outlets, or other suitable devices. A shut-off valve should be provided in the drain line near the tank exterior.

Protection with Embankments.—All tanks constructed aboveground should be surrounded by an earthen embankment with the enclosed volume in excess of the maximum holding capacity of the tanks to confine the oil in case of tank failure.

HEATING VALUES OF FUELS

Although oil is the only fuel available in sufficient quantity for the major part of orchard heating, other fuels are in limited use and are discussed in the following pages. Some of these fuels require less expensive and others more expensive heaters than the usual bowl type, and operating costs are different. The following tabulation gives the quantity of various fuels whose heat value equals that of one gallon of oil (140,000 B.t.u.):

Fuel	Quantity	
Carbon briquettes	9–10	pounds
Coal briquettes	10–11	pounds
Dry white-pine wood	24	pounds
Dry yellow-pine wood	15	pounds
Dry oak wood	25	pounds
Rubber tires	11	pounds (variable)
Butane-propane	1⅓	gallons
Natural gas	130	cubic feet
Electricity	41	kilowatt-hours

Coke and Briquettes.—Coke and briquettes are the usual solid fuel. Solid-fuel heaters are especially designed for a particular kind of fuel and any change in the nature of the coke or briquette may lead to considerable operating difficulty. A heater for solid fuel must be so designed that it can be easily lighted from the top and will burn at a reasonably uniform rate for several hours. It is expected that there will be no visible smoke except in starting and that the ash will not cause operating difficulties. The daily supply of petroleum coke and briquettes is limited, and ample ranch storage for the season's use is a necessity. The heating value is approximately 15,000 B.t.u. per pound. Hence, if the heating efficiency of coke can be made to equal that of oil, a price of $12.00 per ton corresponds to oil at 5½ cents per gallon.

Wood.—Wood fires are sometimes used for frost protection. The heating value of white pine is about 5,900 B.t.u. per pound and for a cord of 2,200 pounds, the heating value per cord is about 13,000,000 B.t.u. or slightly less than that of 100 gallons of oil. In other words, the cost of cordwood in dollars (about $12) should be compared with the price of oil in cents per gallon. All kinds of firewood except yellow pine and hemlock have about the same heat value per pound as white pine, but many have 50 per cent greater heat value per cord owing to greater density.

Rubber Tires.—Such large use was made of old rubber tires for burning in January, 1937, that the ordinary price of about $6.00 per ton rose to over $30.00. The heat of combustion of rubber might be compared with that of coal, but the canvas and wire in old tires decrease the heat value so at the ordinary price they are more expensive than oil. This material produces a large amount of smoke, which is objectionable in citrus plantings and near populated centers, and therefore the use of rubber tires for heating should be avoided.

Butane-Propane Mixtures.—There are a few installations of butane orchard-heating systems, and these have functioned satisfactorily. They are, however, inherently more expensive than oil-fired heaters because the entire season's fuel must be stored under pressure. Some propane is added to the butane to insure adequate pressure for operating in subfreezing weather. The pipe lines to invidual heaters are designed to carry the fuel in liquid form (low volumetric flow required) and the fuel vaporizes at the heater which burns the gas without smoke. The price per gallon of about 5 cents is for a heat content of only 70 per cent of that of oil, so the 5-cent price corresponds to oil at 7 cents per gallon. The claim for higher efficiency of heating by butane has not been demonstrated; but the cleanness, low labor cost, and easy regulation over a wide range of burning rates are important advantages.

Natural Gas.—The existing municipal gas-distributing systems are limited in their storage capacities and the pipe sizes are usually inadequate to carry a sudden excessive demand as would occur if used for orchard heating. The domestic demand is also greatest during the winter. Hence, natural gas for orchard heating could only be used by those growers near enough to gas wells, usually capped, that could be drawn upon without interfering with domestic demand. To use natural gas in the orchard would require extensive orchard piping of the gas or else of warmed air from a central heating plant. There is no published price quoted by the large utility companies in southern California for orchard heating by natural gas. An adequate supply would not be available, however, because the domestic demand has priority. If the gas price were 5 cents per 100 cubic feet for 1,100 B.t.u. per cubic foot, this would be equivalent to 6.4 cents per gallon of oil.

Electricity.—Electricity is not a fuel, but efforts are being made to use it for frost protection. The electric generating capacity of the country is utterly inadequate to support any general use for orchard heating. There are no published rates for orchard heating, and noninterruption could not be guaranteed. The minimum commercial annual charge for electric heating is $4.50 per kilowatt of connected load. The minimum heater installation estimating 1 kilowatt per tree without tree enclosures and 100 trees per acre is 100 kilowatts per acre indicating a minimum annual cost of $450.00 per acre, which is unthinkable. The wiring cost would be about $200.00 per acre. Furthermore, the magnitude of the energy demand is so large that special substations would be required for electric heating of even a few acres. Incidentally, a substation minimum energy price of 1 cent per kilowatt-hour is equivalent to a fuel-oil price of 40 cents per gallon, and the load factor for sudden demand on only a few nights per year is about the worst imaginable. The only load feature that is favorable for electric heating is that the requirement usually falls in the off-peak period between 11:00 p.m. and 6:00 a.m. A longer heating period, which often is necessary, would conflict with the morning and evening domestic peak loads. Hence, it seems self-evident that without tree enclosures electric heating of orchards is impractical.

ROUTINE PRACTICES OF ORCHARD HEATING

Complete success in orchard heating is not attainable without an adequate number of heaters of sufficient fuel capacity and proper accessory equipment. Equipment itself, however, merely renders success possible but does not assure it. The individual whose personal efficiency is high may save his crop with rather inferior equipment while his neighbor with much better equipment may fail. *The essentials of success are sufficient heat at the proper time and in the proper place.* To provide the necessary heat the grower must be fully prepared at all times during the period of possible danger and must understand how to handle the firing under his own conditions with the type of heaters at his disposal. Suggestions are offered in this section as to operating methods but each grower must learn how to solve his local heating problems by actual experience. An excellent precautionary practice is the lighting of a few heaters after they are in the field and supposedly ready for emergency use. The technique of lighting different makes varies. The grower should learn by experiment which methods of wicking and lighting will enable him to light his heaters most quickly.

For citrus orchards, heaters should be placed in the field not later than November first, and for deciduous orchards well in advance of the first indications of swelling of the buds. As pointed out previously, the orchard-heating problem consists in part of replacing the heat lost to the drifting air and in making up for losses from radiation cooling. It is advisable to have a row of heaters, one or two to a tree, outside of the orchard on the side from which the air is drifting. Figure 22 shows an orange orchard banked with one heater of large capacity outside each tree. In some districts it is advisable to bank two sides in this way and in cold locations two outside rows may need to be banked with a heater to each tree. Inasmuch as radiation cooling to the cold sky occurs uniformly throughout the orchard, heaters should be placed so as to give a uniform distribution of heat.

The ideal manner of lighting the heaters would be to leave no dark or unlighted rows. For this reason it is better to have a heater to every other tree in every row than to place them one to a tree in alternate rows. Convenience and speed in firing and ease of filling must be taken into consideration, however, in placing the heaters. When the heaters have been placed in the field the thermometers should be set up, torches filled, and placed together with a reserve supply of torch fuel in a convenient location. An extra supply of well-mixed torch fuel should be kept in some tight container such as a 5-gallon can or a 15-gallon oil drum in the field. It is a wise precaution to fill torches only by electric light or flashlight.

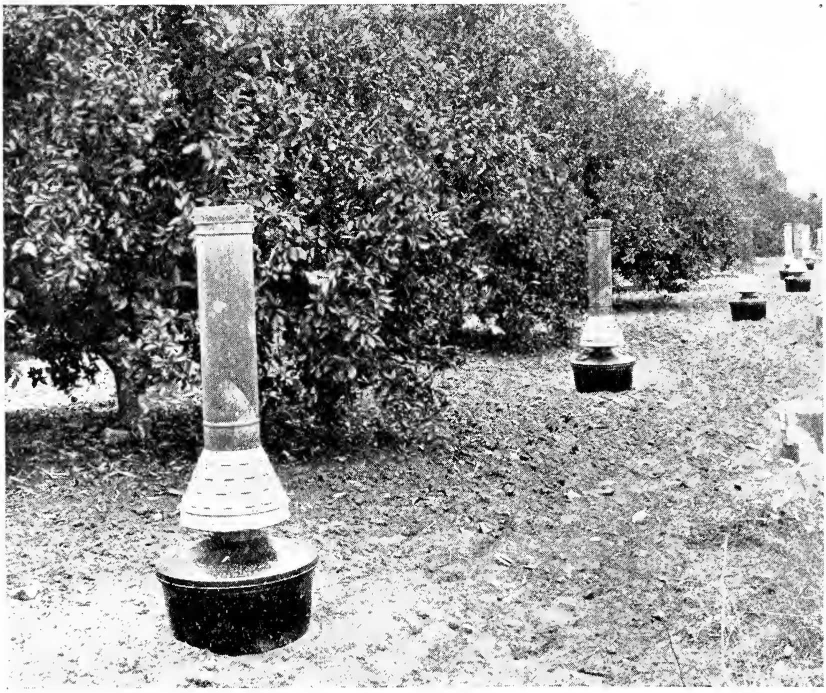


Fig. 22.—Citrus orchard banked with heaters on the windward side; one large-capacity heater per tree. (From Bul. 398.)

Accurate information concerning weather conditions is helpful in determining firing plans. The forecasts issued by the United States Weather Bureau every evening (where a local Fruit Frost Service representative is available) include an estimate of the minimum temperature likely to be reached, information as to the probable dew point, wind conditions, and the character of temperature inversion at a certain key station. A forecast of this kind provides the grower with the information necessary for determining approximately how difficult the heating problem is likely to be for any given night. If local Fruit Frost Service forecasts are not available, special evening forecasts may be had sometimes from a district office of the Weather Bureau. The county farm advisor should be consulted concerning the frost forecasting service available in the district.

If a severe and early drop in temperature is expected, lighting should begin at a higher temperature than if the duration of cold is expected to be only for a short time. If the temperature drop has been rapid and occurs late in the night, the fruit temperature will lag behind the air temperature and lighting may be delayed somewhat. (See section, "Temperature in Relation to Frost Damage.")

When temperatures begin to approach dangerous levels, systematic reading of the thermometers should start and the temperatures should be carefully noted on a card. Information obtained in this manner will show the rate of temperature fall and to what extent fluctuations are taking place. Growers who have thermographs will find that they provide very useful records of the rate of change in temperature.

Lighting Procedure.—The danger point as previously explained varies according to the type and severity of the frost expected, but when it is reached the grower should take steps to make heat available at once over the entire acreage. The first heaters lighted should be the border rows, especially on the windward side, and heaters in so-called "frost pockets" or "cold spots." Then about one-fourth of the number of heaters should be lighted throughout the orchard. It is better to light one-fourth of the heaters in each row or alternate heaters in alternate rows rather than all of the heaters in every fourth row. Periodic inspections of the thermometers should be made and temperatures recorded as was done before lighting. If the temperature continues to drop, more heaters should be lighted, this operation being repeated as often as may be necessary. The greatest economy in fuel usage may be had by maintaining the temperature just above the danger point rather than by allowing it to fluctuate greatly. This is accomplished in two ways: first, by varying the number of heaters burning per acre; and second, by controlling the rate of fuel consumption through heater regulation. When a marked fall in temperature occurs, the most efficient way to increase the heat is to light more heaters and regulate all of them to a moderate fire. This procedure is in harmony with the basic principle of a relatively large number of small fires per acre which provides for the most uniform distribution of the heat generated. If still more heat is required after all of the heaters are lighted, it may be provided by opening the drafts and increasing the burning rate. If safe temperatures cannot be maintained without excessive burning rates which produce objectionable smoke, more heaters per acre should be provided.

The thermograph records from heated and unheated orchards shown in figures 23, 24, and 25 illustrate satisfactory as well as unsatisfactory temperature control. Figure 23 shows superimposed thermograph rec-

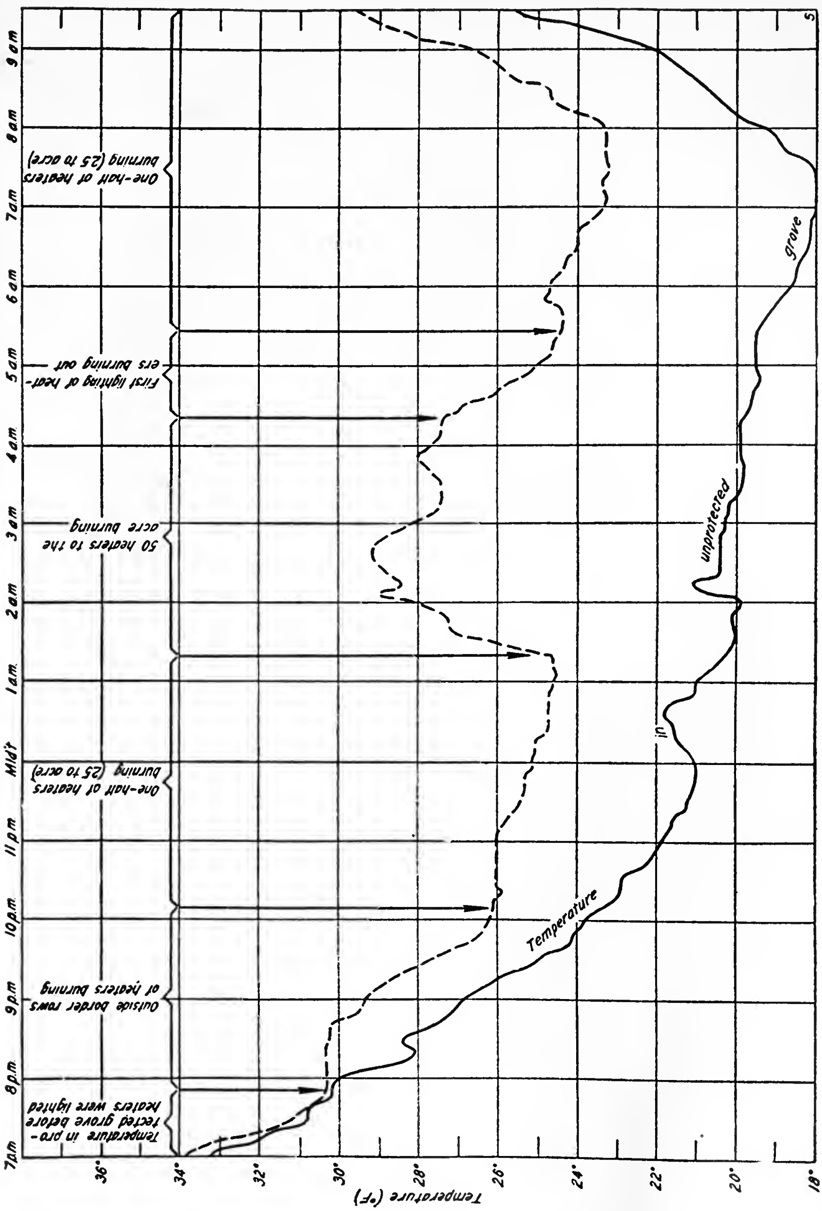


Fig. 23.—Thermograph records for the same night from neighboring heated and unheated navel-orange orchards. (From: Young, Floyd D. Notes on the 1922 freeze in southern California. Monthly Weather Review 51:484. 1923.)

ords from instruments located in neighboring heated and unheated navel-orange orchards the same night. The solid line shows the temperature in the unprotected grove, and the dotted line the temperature record for a grove protected with fifty 7-gallon oil heaters per acre. The following facts should be noted: (1) The heat from the border rows of heaters merely delayed the fall in temperature of the heated orchard with the outside temperature steadily falling; (2) the burning of 25 heaters per

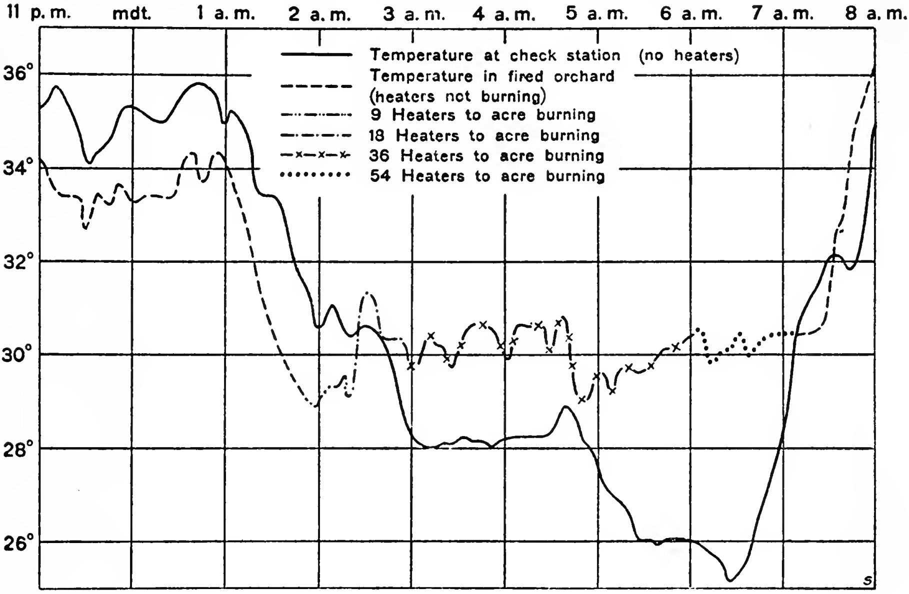


Fig. 24.—Temperature records in a heated orchard and at an outside check station on the night of April 13–14, 1919. (From: Young, Floyd D., and C. C. Cate. Damaging temperatures and orchard heating in the Rogue River Valley, Oregon. Monthly Weather Review 51:617–31. 1923.)

acre from 10:00 p.m. until 1:00 a.m. did not maintain a safe temperature even though these heaters were burned at the maximum rate; (3) fifty fires per acre did maintain a satisfactory temperature as long as they were kept burning; (4) failure to provide sufficient field fuel capacity by having heaters of larger size or some unlighted heaters in reserve, coupled with the waste of oil early in the night from improper regulation, was responsible for the severe drop in temperature starting at 4:15 a.m. when the first lighted heaters burned dry. The loss of fruit in this orchard was not great but if fifty properly regulated heaters had been kept burning from 9:30 p.m. until 8:00 a.m., a much more satisfactory temperature control would have been obtained.

Figure 24 shows superimposed thermograph records from neighboring pear orchards, one protected with small lard-pail-type heaters and the other unprotected. The records were taken during the night of April 13–14, 1919, when the temperature inversion was only 3° F in 35 feet and heating conditions were difficult. With no other regulation than an increase in the number of heaters burning per acre a satisfactory temperature was maintained all night with the exception of a few minutes

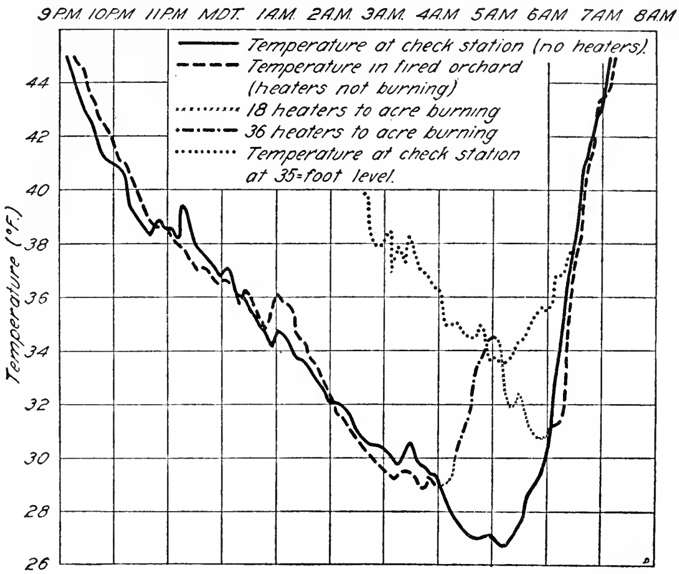


Fig. 25.—Continuous records of the temperature in a pear orchard on a calm, frosty night with considerable temperature inversion, showing the effect of orchard heating. Note that before the heaters were lighted at 4 A.M. the temperature at the check station ran practically the same as that in the orchard equipped with heaters. On this night the stratum of air heated was only about 35 feet in depth. The increase in temperature of 7.5° F at the 5-foot level in the fired orchard with only thirty-six 5-quart lard-pail oil heaters to the acre burning was unusually large, owing to the strong temperature inversion and lack of air movement. (From: Young, Floyd D. Frost and the prevention of frost damage. U. S. Dept. Agr. Farmers' Bul. 1588:1–62. 1929.)

following 4:40 a.m. when the first-lighted heaters burned dry. Reserve heaters were lighted until a total of 54 per acre were burning. Economy of fuel usage was obtained by keeping the temperature just above the danger point.

This pair of records should be contrasted with another pair (fig. 25) obtained in two pear orchards on the night of May 4–5, 1919, when weather conditions were almost ideal for heating and the temperature inversion was about twice as great as on the night of April 13–14. The burning of 36 heaters per acre of the 5-quart lard-pail type rapidly raised the temperature several degrees above the danger point. Less oil would have been consumed if the grower had lighted only 9 heaters per acre at the first firing and then more if necessary, as was done the night of April 13–14.

If the grower is to maintain a safe temperature with the minimum fuel consumption, it must be done by intelligent firing based on a careful check of actual temperatures at frequent intervals.

Lighting Methods.—Simple smudge pots are most readily lighted by removing the cover, or sliding it back to the required position, and then pouring burning torch fuel around the inside edge of the exposed portion of the container. Bowl-type heaters vary in their lighting characteristics. Especially after the heaters have been burned once, most of the lazy-flame types can be lighted successfully with the draft open only a little, if any, more than is required for normal operation. Most of the heaters with combustion-chamber stacks cannot be lighted without throwing the draft cover wide open. In this case it is necessary for a second member of the crew to follow the first and regulate the heaters about 3 minutes after lighting. The only way of avoiding this procedure is to equip heaters with automatic regulators. Drip heaters are lighted by merely adjusting the flow of oil to the burner and pouring burning torch fuel into the stack. Each type of generator or pipe-line heater should be lighted according to instructions supplied by the manufacturer.

Briquette heaters should be carefully prepared so that they may be lighted quickly. They are easily lighted if they are properly filled and provided with a sufficient quantity of good kindling. There should be one layer of briquettes or coke on top of the kindling. The best kindling is made by soaking, in crankcase drainings for several days, small blocks of wood, such as trimmings from 2 × 4's and smaller pieces of lumber. A few of these blocks per heater will provide sufficient kindling. Other types of kindling consist of oil-soaked shavings or wood briquettes, pieces of automobile tires about 2 or 3 inches long cut across the casing, or a large handful of peach pits. The heaters are lighted from the top with burning torch fuel. It may be advisable to replace part of the kerosene of the customary torch-fuel mixture with crankcase drainings when lighting briquette heaters. It is usually not worth while to attempt the regulation of burning rate of briquette heaters. They should usually be refueled at intervals of 1½ to 2 hours. It is best to add only one layer of fuel each time, so as not to depress the fire too much by the addition of cold fuel. Solid fuel heaters which have been in the field more than one season without burning should have the fuel sifted to free it from "fines" and dust.

Lighting heaters is a more difficult task on a cold night than on a warm day. If the night is damp, the covers may be frozen on and the drafts frozen shut when lighting should begin. Pliers and draft tools should always be at hand. Some growers with a large acreage to heat remove the caps and open the drafts before night, if the forecasts and general weather conditions indicate the probability of a need for rapid lighting.

Regulating the Burning Rate of Heaters.—Growers should be prepared to give careful and systematic regulation to their oil-burning heat-

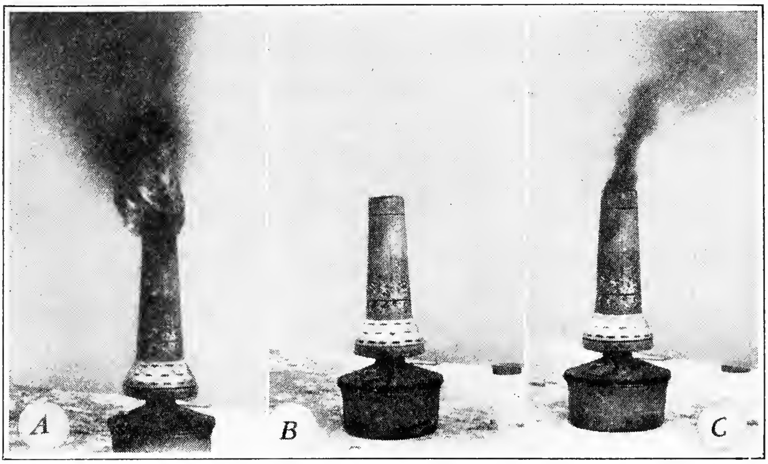


Fig. 26.—Smoke output of a heater capable of clear burning. *A*, Starting—the draft wide open; *B*, burning clear—properly regulated; *C*, burning smoky—at too high a rate.

ers throughout the night. This will save fuel and will avoid many difficulties which develop with heaters. It is usually necessary to open the drafts gradually as the oil level drops in the container.

"Smudge pots" or old orchard heaters which are inherently smoky have been replaced in many districts and in such districts are no longer the major source of smoke. The smoke nuisance is therefore primarily due to careless operation of heaters which can be burned without appreciable smoke if kept clean and regulated within the range of proper burning rates. Figure 26 shows clearly how a satisfactory heater can become a nuisance when the starting period is longer than necessary or when the burning rate is excessive or cleaning is neglected.

Extinguishing Heaters.—The time for extinguishing heaters should be determined from the temperature shown by the check thermometer situated outside the heated area, or if there is no check thermometer, by extinguishing a few heaters near a thermometer on the upstream side of the air drift and watching the temperature on that thermometer. The temperature is frequently below the danger point for an hour or more after sunrise, and the fires should not be put out too soon. It is necessary to keep briquette heaters refueled up to sunrise even though they cannot be put out and some loss of fuel will be inevitable. Most types of heaters are best extinguished by closing the drafts tightly and capping the stacks.

Refilling.—Refilling should begin as soon as the heaters are completely extinguished and should continue until all have been filled. Many losses have occurred through failure to refill after each night of burning, even though only a small part of the oil had been burned. If, for any reason, refilling is not completed, and lighting must start early, the full heaters from the reserve of the previous night should be lighted first the next night, so when the most fires are needed, usually about 4:00 or 5:00 a.m., there will be some fuel in all of the heaters.

Cleaning.—The necessary cleaning of stacks, drafts, internal chimneys, etc. should take place at the time of refilling. If stacks fit loosely enough, they should be removed from the covers for cleaning, so that the soot is not pushed down into the bowls.

The easiest way to clean the stack is to pass a wire brush through it. The best type of brush is made by attaching a wire buffing wheel to a rod. It is important that the 6-inch Exchange stack be cleaned after each night of burning; most of the lazy-flame stacks should be cleaned this often. It is absolutely essential to clean internal chimneys frequently. This is especially true of those types with narrow slots, like the ones found in the old-style Riverside heaters. If these slots become clogged with soot, the burning rate decreases until after a time such a heater will not burn at all.

Labor for Operations.—One man can light 2½ to 7 acres, according to the number and type of heaters and the amount of regulating required. Fruit pickers and high school and junior college students furnish the usual source of labor for orchard-heating operations.

Heaters should be kept serviced and in good order throughout the entire season. They should not be removed from the field until danger of frost is over. The fact that the frost forecasts are discontinued on February 15 does not mean that the danger season is over by then. Damaging frosts have occurred in the citrus districts as late as April.

Care of Orchard Heaters.—No systematic studies have been undertaken to determine the best method of caring for orchard heaters. Some growers give them very little care and others spend too much money on this item. The care given to heaters depends upon the method of handling during the summer. It seems that the most economical and probably the most satisfactory method is to leave oil in the heaters. The heaters can be left either under the trees, in selected parking spots within the orchard, or hauled from the orchard on sleds and stored along the edge. Full heaters can be easily moved with tools like those shown in figure 27. If the heaters are put under the trees, care must be taken to see that they rest in a level position. They should be at least a foot from the trunk of the tree to avoid oil seepage which might kill the tree. A leaky heater would damage the tree even at this distance, so they should be carefully inspected. Growers have usually, however, been unduly concerned about spilling

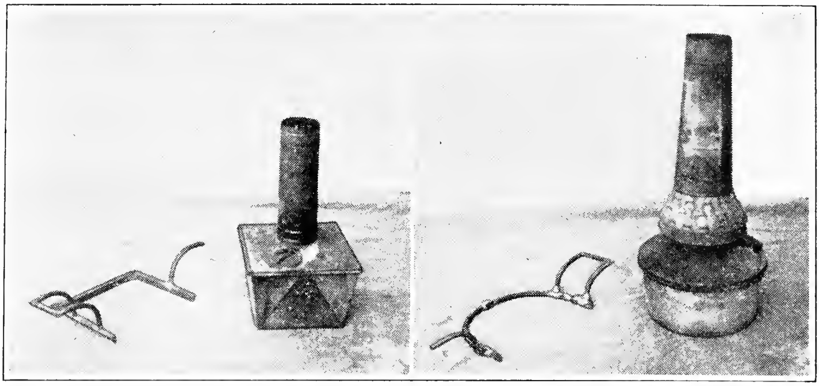


Fig. 27.—Tools for moving square- and round-bowl heaters while they are burning or while filled with oil.

oil in the orchard. The only place oil, even in considerable quantities, can do serious damage is under the tree, so that the trunk and root crown become oil-soaked sufficiently to kill the bark.

If the heaters are stored full of oil, the troublesome problem of pour-back oil is avoided although there may be new difficulties on account of water condensation in the heaters. Pour-back oil should in no case be mixed with fresh oil in the storage tanks. If growers do not wish to leave oil in the heaters, special storage should be provided for pour-back oil.

With most of the grades of fuel a residue will form in the bowl at the rate of 1 inch or more for each 25 gallons of oil burned. The residue results in part from impurities in the oil but mostly from soot which forms in the bowl and in the stack. This residue cuts down the capacity of the heater and should be disposed of from time to time to avoid this difficulty. One means of accomplishing this is to accumulate the residue in certain heaters and burn these at a rate higher than normal so that the residue is gradually consumed. If such heaters are burned dry or nearly dry, the remaining material can be dumped. It is unwise to burn these heaters dry if the draft must be opened wide in order to keep them burning. A wide-open draft would develop a sufficiently hot fire to damage the heater, and the smoke nuisance even with a good stack would be intolerable. Other means of handling the residue are to clean the heaters by pouring from one to another through a fine screen, and hauling the material which remains on the screen to the dump. A recent development is a machine which removes the oil and residue from the heater, cleans it by means of a centrifugal process, and returns it to the heater or to the storage tank. In some areas it is possible to hire this work done on a contract basis.

When the heaters are empty, either temporarily while pouring from one to the other for cleaning, or removed from the field for summer storage, they should be inspected for leaks, straightened out where bent, and repaired in any way that may be necessary.

It was at one time customary to dip the bowls in hot asphaltum before storing. Practically all new equipment at present comes in galvanized iron so that dipping is less necessary, although the life even of the galvanized bowls may be prolonged by dipping the bottom. The most rapid deterioration occurs in covers and stacks, which are subjected to a great deal more heat than the bowls. It is not worth while to use expensive paints but cheaper coatings will be found useful, such as cheap asphaltum-base roof paint, or that obtained by diluting melted asphalt with orchard-heater oil. No paint will remain on the heaters and be effective after they have been burned. A cheap paint applied at the end of the season will protect the metal against rust, and will be especially effective on those heaters which are not lighted again for one or more seasons.

No blanket recommendations can be offered concerning methods of care of orchard heaters. These must of necessity be determined by each grower for himself in accordance with the type of heaters he has, the amount of burning required, the humidity and rainfall in the district, and the most economical and efficient method of handling them in his orchard.

With good care the depreciation of heaters should not be excessive; the bowls and covers last from fifteen to twenty years, and the stacks from three to ten years.

APPENDIX:

OPEN-CRUCIBLE SELF-BURNING OIL RESIDUE TEST

The following method of residue test was found to give results more closely reproducible than the Hoffman California Residue Test[17] which was intended to indicate the general desirability of a fuel oil for the bowl-type orchard heaters. The determination may be carried out with parts of the usual standard Conradson[18] apparatus.

Scope.—This method of test is a means of determining the amount of residue on burning an oil under specified free-surface conditions and is intended to indicate the soot and asphaltic residue-forming propensities of the oil. This test is intended for orchard-heater fuel oils, usually of 27° to 38° A.P.I. Residues of 0.3 to 4.0 per cent have been found in 60 samples.

Apparatus.—The following pieces of the standard Conradson Carbon Residue Test apparatus (A. S. T. M. designation: D 189–36) are used:

1. Porcelain crucible—weight 12 to 14 grams.
2. Circular sheet-iron hood—5 inches bottom diameter.
3. Iron tripod (9¼ inches tall), to support the hood.

In addition, a wooden wind-screen (no holes in bottom) and crucible shelf are used (fig. 28). The height of the crucible shelf should be 7 inches measured from the base upon which the tripod rests. The dimensions of the wind-screen as shown can be changed slightly without altering results appreciably as long as all drafts are excluded. The whole apparatus is placed in a low-velocity laboratory draft hood.

Procedure.—The test is conducted as follows: The oil to be tested should be free from moisture or other suspended matter. Measure 12 cubic centimeters and weigh in a tared porcelain crucible; place on the asbestos-covered stand and center it to the hood tripod. Then add 1.5 cubic centimeters of high-test gasoline and ignite the mixture at the surface with a small flame. The oil is allowed to burn spontaneously. There should be no external application of heat to the crucible. The time for complete burning is usually from 30 to 40 minutes. When the fire dies out, remove the crucible and place in a desiccator to cool. When cool,

[17] Hoffman, A. H. Laboratory tests of orchard heaters. California Agr. Exp. Sta. Bul. 442:29–30. 1927.

[18] Committee D–2 on Petroleum Products and Lubricants, American Society for Testing Materials. Standard method of test for carbon residue of petroleum products (Conradson carbon residue), A.S.T.M. designation D 189–36. (*In:* A.S.T.M. standards on petroleum products and lubricants.) American Society for Testing Materials, Philadelphia, Pa.

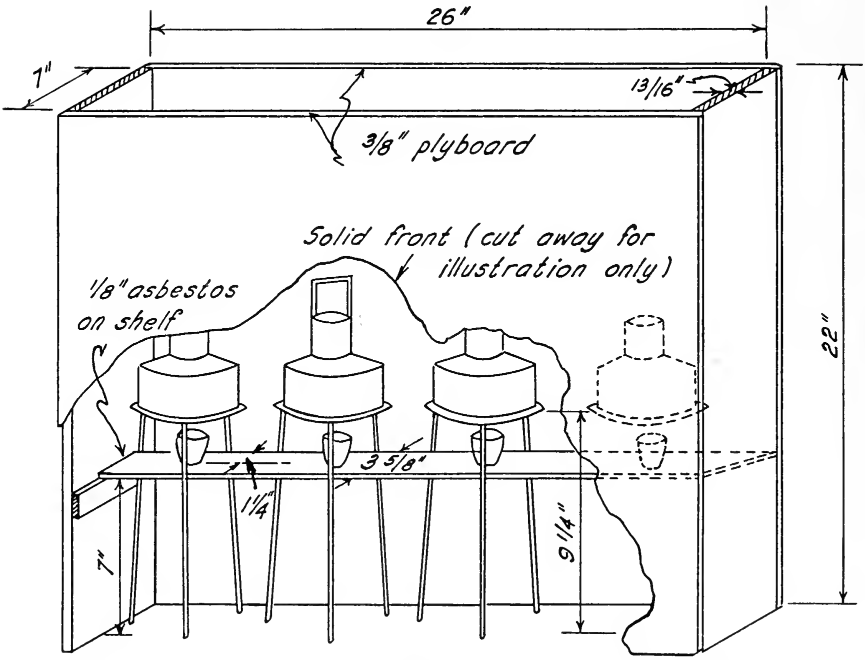


Fig. 28.—Diagram of open crucible self-burning residue apparatus.

weigh and express the residue as a weight percentage of the original sample.

Tolerances.—Weights of oil sample should be accurate to within 10 milligrams. The residue of 12 cubic centimeters of the high-test gasoline should not exceed 2.5 milligrams. Tests should be run in quadruplicate, and repeated if necessary, until the average departure of individual percentages of residue differ by not more than 5 per cent of the mean.

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