UNIVERSITY OF CALIFORNIA
COLLEGE OF AGRICULTURE
AGRICULTURAL EXPERIMENT STATION
BERKELEY, CALIFORNIA

Investigations in the Sulfuring of Fruits for Drying

J. D. LONG, E. M. MRAK,
and C. D. FISHER

BULLETIN 636
July, 1940

UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA

CONTENTS

INVESTIGATIONS IN THE SULFURING OF FRUITS FOR DRYING[1,2]

J. D. LONG,[3] E. M. MRAK,[4] AND C. D. FISHER[5]

INTRODUCTION

THE PRODUCTION of dried fruit has been an important agricultural industry in California since the latter part of the nineteenth century. Prunes and raisins are the most important crops from the standpoint of production but the sulfured dried fruits have been more important from the standpoint of value per pound. The tonnage of dried sulfured fruits, consisting of apricots, peaches, nectarines, pears, apples, bleached raisins, and figs has totaled for the past few years about 90,000 tons annually, with an estimated total value of about fifteen million dollars. Dried sulfured fruits are produced in nearly all valleys of the state. The principal localities, varieties, and seasons are given in table 1. The season, yield, drying ratio, and values vary with the variety and locality as well as with the year. Detailed information concerning deciduous fruit statistics is given by Shear (1939).[6]

Sulfur dioxide has been used for the treatment of foods since ancient times. Fruits are so treated in order to preserve their natural color, flavor, and, in part, to protect certain nutritive values. Sulfuring also prevents enzyme and microbiological deterioration; repels insects to some extent during drying and storage; facilitates drying by plasmolyzing the cells; and is sometimes used to prevent losses during rainy drying seasons (see Bioletti and Way, 1919, and Cruess, 1921*a*). Years of scientific investigations and practical trials have failed to reveal another pretreatment agent equal to sulfur dioxide in preserving the desired qualities in cut, dried fruits.

When sulfur is burned in air it combines with the oxygen of the air to form sulfur dioxide, a colorless gas. The white fumes commonly seen in sulfur houses are due to the fogging of water vapor about particles of sulfur trioxide simultaneously produced, but which represent a small

[1] Received for publication January 11, 1940.

[2] Part of the nontechnical assistance was supplied by the Works Progress Administration, in Project No. 431, Northern California Section, Area 8.

[3] Assistant Professor of Agricultural Engineering and Assistant Agricultural Engineer in the Agricultural Experiment Station.

[4] Instructor in Fruit Technology and Junior Mycologist in the Experiment Station.

[5] Chief Chemist, Dried Fruit Association of California.

[6] See "Literature Cited" for complete citations which are referred to in the text by author and date of publication.

TABLE 1

VARIETIES, LOCALITIES, DRYING SEASONS, AND YIELDS OF SULFURED DRIED FRUITS IN CALIFORNIA

Fruits and principal varieties	Principal production localities	Drying seasons	Drying ratio	Yield of dried fruit per acre, tons
Apricots: Blenheim, Hemskirke, Moorpark, Royal. Tilton	Los Angeles, Riverside, San Benito, Santa Clara, Solano, and Ventura counties; Pajaro, Sacramento, and San Joaquin valleys	June 15 to August 15	4:1 to 7:1; average, 5:1	Low, 0.4; medium, 1.0; high, 2.4
Figs: Adriatic and Kadota	San Joaquin and Sacramento valleys	July 20 to November 1	1.5:1, or 3.5:1 when picked fresh	Adriatic: low, 0.5; medium, 1.0; high, 1.5. Kadota,* average 1.0
Nectarines: New Boy, Quetta, Stanwick	San Joaquin and Sacramento valleys	July 15 to August 30	3.5:1 to 5:1; average, 4.5:1	Low, 0.5; medium, 1.5; high, 2.7
Peaches (clingstone): Phillips Cling, Tuscan, and midsummer varieties	San Joaquin and Sacramento valleys	August 1 to Sept. 15	6.5:1 to 10:1; average, 9:1	Low, 0.5; medium, 1.1; high, 2.0
Peaches (freestone): Elberta, Lovell, and Muir	San Joaquin and Sacramento valleys	July 15 to Sept. 18	4:1 to 7:1; average, 5:1	Low, 1.0; medium, 2.0; high, 4.0
Pears: Bartlett	Lake, Los Angeles, Sacramento, Santa Clara, San Luis Obispo, Solano and Yuba counties	July 15 to Sept. 18	4:1 to 7:1; average, 5:1	Low, 0.6; medium, 1.5; high, 3.0
Raisins (golden bleach): Thompson Seedless	San Joaquin Valley	August 20 to October 20	3.8:1 to 4.3:1; average, 4:1	Low, 0.7; medium, 1.5; high, 3.0
Raisins (sulfur bleach): Thompson Seedless	San Joaquin Valley	August 20 to October 1	4:1 to 4.5:1; average, 4.2:1	Low, 0.7; medium, 1.5; high, 3.0

* Reliable data on Kadota figs are unavailable because this fruit is primarily a canning crop.

portion of the sulfur burned. According to B. Hatherell,[7] approximately 10 per cent of the sulfur burned in air is converted into sulfur trioxide, and the concentration of sulfur trioxide in the sulfur house is usually equal to about 10 per cent of that of the sulfur dioxide concentration. The formation of sulfur dioxide by burning sulfur in air may be stated by the following equation:

$$\underset{\text{(Sulfur)}}{S} + \underset{\text{(Oxygen)}}{O_2} \rightarrow \underset{\text{(Sulfur dioxide)}}{SO_2}$$

When sulfur dioxide dissolves in water or fruit juice it forms sulfurous acid *which is a weak acid that should not be confused with sulfuric acid.* The equation for the reaction of sulfur dioxide with water to produce sulfurous acid is:

$$\underset{\text{(Sulfur dioxide)}}{SO_2} + \underset{\text{(Water)}}{H_2O} \rightarrow \underset{\text{(Sulfurous acid)}}{H_2SO_3}$$

Sulfurous acid is used as a preservative in numerous food products. This acid, and its salts (sulfites) are reducing substances (having oxygen-removing power) and it is this property which is probably responsible for its action in preventing discoloration.

The control of sulfuring so that fruit is not undersulfured is of primary importance to the producer of quality dried fruits. The trade demands a light and uniformly colored product that will not deteriorate or darken during storage. For this reason the fruit must contain a sufficient quantity of sulfur dioxide when first dried.

When fruit once darkens during storage, subsequent exposures to sulfur dioxide will not change the appearance of the darkened fruit to that of the originally prepared fruit. Consequently it is often necessary to dispose of darkened fruit on a lower-quality basis and at a lower price. Love (1937) has emphasized the importance of the first sulfur treatment in regard to the retention of color in dried apricots.

To maintain the desired qualities in fruit it has been found necessary to incorporate in it an excess of sulfur dioxide to allow for losses occurring during handling and storage. The exact amount of sulfur dioxide needed to preserve the color and other qualities of dried fruit varies with the nature of the fruit and with storage conditions. For example, dried cut fruits may be relatively low in sulfur dioxide content and still retain the characteristic color of the fruit if properly and thoroughly dried. Cut fruits of high moisture content will darken during storage even though

[7] Unpublished data from sulfuring investigations project of the Research Laboratory of the Dried Fruit Association of California, 1928.

they contain a high initial sulfur dioxide content. The amount of sulfur dioxide which should be incorporated in the fruit at the drying yard to maintain quality is approximately, in parts per million (1,000 p.p.m. equals $1/10$ of 1 per cent by weight), as follows: apricots, 2,000; peaches and nectarines, 2,000; pears, 1,000; golden bleach raisins, 800, sulfur bleach raisins, 1,500; and apples, 800. In certain districts as a result of adverse climatic conditions, inadequate drying-yard practices and poor sulfur absorption and retention by the fruit, it is difficult to obtain the necessary quantity of sulfur dioxide in the fruit.

The technique of sulfuring fruits usually consists of exposing the fruit on trays to sulfur dioxide in a closed chamber for periods of time, varying according to the variety and maturity of the fruit, the locality, and the experience of the operator. The sulfured fruit is then dried in the sun or in a mechanical drier. Nichols (1933) has described in detail the sulfuring procedure commonly used in California. The treatment of fruit with sulfur dioxide appears to be a relatively simple process. There are, however, numerous variations in procedure, the relative merits of which have never been determined. During the last half century or more of the development of the dried-fruit industry, many practices have been adopted and many designs of equipment developed which may not be well founded, or which may be subject to change or modification under current operating conditions. Within a given district it has been observed that growers tend to adopt similar methods, some of which are questionable. Practices may vary markedly between districts with no apparent reason. Many problems and questions have arisen concerning the factors affecting the burning of sulfur, and the absorption and retention of sulfur dioxide by the fruit. They relate to sulfur-house design, orientation, gas concentration, temperature of the compartment, and the climate in general.

PURPOSE OF THE INVESTIGATION

The 1936 apricot drying season in the Hollister district found many of the producers experiencing difficulty in their sulfuring practice. A survey of the conditions existing in other areas revealed that the same difficulties were being encountered in many districts, and that the troubles reported in that year were merely a continuation of a series of annual troubles. The investigation of sulfuring practices and problems reported in this publication was conducted during the years 1937, 1938, and 1939.

The purpose of this investigation has been to obtain information that might enable growers to improve their sulfuring and drying procedures

to secure better-quality products. Information was obtained concerning factors involved in the burning of sulfur, sulfur dioxide gas concentration and distribution, and the temperature within the compartment. Information was also obtained concerning the typical sulfuring technique and results from farm practices used in representative districts, and an effort made to correct conditions responsible for such waste as shown in figure 1. Furthermore, an attempt was made to correlate the

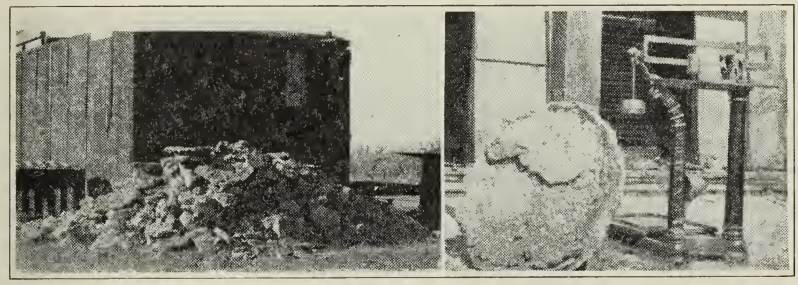

Fig. 1.—Sulfur slag waste resulting from poor burning in earth pits: Left, two- or three-ton accumulation in a large drying yard; right, clinker weighing 69 pounds formed in one season from about thirty burnings.

interrelations of the important structural, chemical, and physical factors common to farm procedure with the absorption and retention of sulfur dioxide by fruit.

REVIEW OF LITERATURE

Certain phases of the sulfuring problem, including methods of sulfuring fruits for drying, have been discussed by a number of authorities. It is of interest to review these publications since they frequently show a divergence of opinion and in certain instances disagree with the results reported in this bulletin.

Nichols (1933) has given a recent summary of the sulfuring procedure used in California.

Beekhuis (1935) made a comparative survey of drying-yard practices and equipment used in the twelve major fruit-producing areas of northern California. He paid particular attention to the construction of sulfur houses, their number, condition and capacity of each unit, elapsed time between cutting and sulfuring, exposure of the fruit to sulfur dioxide and pounds of sulfur used per ton of fresh fruit. He considered the Suisun district the best of the areas surveyed. The general practice in this district is to employ a large number of sulfuring compartments, each holding a single field car. The compartments are joined in a long shed

with overhanging roof which protects the doors. The interior walls are plastered. These compartments were not considered ideal, however, because: (1) their short length requires that the sulfur burner be placed under one end of the car, which interferes with the gas circulation and creates a fire hazard; (2) no provision is made for ventilation; and (3) the doors of many of the compartments are built in a wall parallel with the prevailing winds, a feature he considered conducive to uneven draughts within the compartments. A second burner at the rear of the compartment provided with a vent through the rear wall was recommended to correct this fault. In the Patterson district, Beekhuis observed the use of drying-yard carts for moving stacks of trays rather than the conventional field car and tracks. This favored the installation of moveable, "hood-type" sulfur houses of pressed fiberboard.

Beekhuis used, as a measure of variations in exposure to the sulfur fumes, a "sulfuring factor," defined as the pounds of sulfur used per ton of fresh fruit multiplied by the hours of exposure. Isolated cases were cited of growers successfully sulfuring apricots with a sulfur factor of 10 to 20 (4 to 8 pounds of sulfur per ton and an exposure of 2½ hours). The average factor was about 30–35 with extreme cases extending to 90.

The sulfuring procedures used in Argentina, as described by Croce (1936 and 1937), and in South Africa, as described by Perkins (1925), are very similar to those used in California. The Australian sulfuring practices described by Quinn (1926*a, b*) and Jewell (1927*a, b*) and recommended by Quinn and associates (1929), differ somewhat from those in common use in California.

It is generally agreed that the variety, maturity, and general condition of the fruit are important factors in determining the absorption and retention of sulfur dioxide by the fruit. Jewell (1927*a, b*) stated that peaches and pears do not absorb sulfur dioxide as readily as apricots and for this reason are not as easily oversulfured. According to Culpepper and Moon (1937), peeling or slicing of pears enhances the absorption of sulfur dioxide. Quinn and associates (1929) indicated that fruit, to be sulfured, should be of "eating ripe" maturity. Nichols, Mrak, and Bethel (1939) showed that color and sulfur dioxide retention by dried apricots varied with the locality in which the fruit was produced.

There is no agreement concerning the desirability of sprinkling fruit with water or brine solutions prior to sulfuring. Christie and Barnard (1925) believed that because the reaction $SO_2 + H_2O \rightarrow H_2SO_3$ occurs during sulfuring it was desirable to sprinkle the fruit with water before sulfuring. Anderssen (1929) found that apricots moistened before sulfuring contained more sulfur dioxide than unmoistened apricots, but

the final quality was about the same. According to Jewell (1927*a* and 1927*b*) the amount of moisture on the cut surface of the fruit influences absorption. Chace, Church, and Sorber (1930), on the other hand, could not detect differences in the absorption of SO_2 or in the appearance of fruit sprayed with water before sulfuring. Beekhuis (1936*b*) states that the sprinkling of pears with water has been abandoned in many drying yards as it does not seem to answer any definite purpose. Lyon (1930), Nichols and Christie (1930*a*), and Nichols (1933) state that sprinkling fruit prior to sulfuring has no beneficial effect. Storage of the fruit between cutting and sulfuring was considered undesirable by Beekhuis (1936*a*) because it permitted drying of the fruit surfaces and he recommended that the period between cutting and sulfuring be less than 1½ hours.

Blanching in steam or hot water prior to sulfuring does not alter the sulfur dioxide absorption or retaining capacity of the fruit according to Nichols and Christie (1930*b*) and Chace, Church, and Sorber (1933). Fruit blanched after sulfuring, however, retained 50 per cent more sulfur dioxide than unblanched fruit.

Various types of sulfur burners have been suggested and used. Nichols and Christie (1930*a*), Beekhuis (1936*a* and 1938), and Rennie (1936) described concrete pipe and magnesia burners which have proved satisfactory. Nichols (1933) and Nichols and Christie (1930*a*), stressed the importance of maintaining a dry burner and the latter authors recommended protecting the burner from moisture by the use of oil or tar. Quinn (1926*a* and 1935) suggested the use of a glazed vessel or an old oil drum for a burner. He further recommended that the sulfur be lighted with live coals obtained from a wood fire. On the other hand, Cameron and associates (1929), stated that a minimum of inflammable material should be used to light fires. Nichols, Powers, Gross, and Noel (1925) indicated that it is preferable to burn sulfur in from three to six shallow pans stacked one above the other in zigzag formation in order to obtain a high concentration of sulfur dioxide in a short time. Nichols and Christie (1930*a*) and Nichols (1933) later pointed out the danger of subliming the sulfur when using the stacked pan burner. Residue resulting from the incomplete combustion of sulfur need not be discarded according to Nichols (1933) for it will burn if mixed with other sulfur and given the proper amount of draft. Mixing 1 pound of sodium nitrate (Chile saltpeter) with 20 pounds of sulfur will promote burning under very difficult conditions. Caution should be observed in the preparation and handling of the mixture because of its inflammability.

Sulfur-house construction, design, materials, and location have been

discussed in detail by Christie and Barnard (1925), Cameron and associates (1929), Nichols and Christie (1930*a*), Rennie (1936), Croce (1936) and Beekhuis (1936*a* and 1938). It is agreed that the sulfur house should be tight and constructed of permanent materials if possible. The house should be so located that the prevailing winds will not interfere with burning of sulfur or the distribution of sulfur dioxide gas within the house. California investigators recommend that the sulfur house be constructed of sufficient length to allow for a free space above the burner at the front end of the house. Vents should be used on the front or near both front and rear walls when needed to facilitate burning. Cameron and associates (1929), recommended the use of two controllable vent holes, 1 inch in diameter and about 1 foot apart, located in the roof of the chamber close to the wall farthest from the sulfur burner when only one burner is used. When two burners are used, one at each end of the sulfur house, they recommend that the vents be located in the center of the roof. Jewell (1927*a* and 1927*b*) described two types of houses in common use in Australia: (1) a practically tight, either portable ("malthoid" covering over a wooden frame), or permanent fixture (of brick or fibro-cement sheets); (2) a more or less gas-permeable chamber consisting of a wooden frame covered with hessian cloth or bagging, generally washed with lime.

The amount of sulfur used varies considerably with the kind, variety and condition of the fruit being sulfured. There are, however, several other factors that have an effect on the quantity of sulfur used in a single charge. According to Anderssen (1929) the theoretical maximum of sulfur that can be burned per 100 cubic feet of air is about 1.5 pounds and would yield a concentration of about 20 per cent of sulfur dioxide by volume. Under optimum farm conditions it is doubtful, however, if a concentration exceeding 7 per cent of sulfur dioxide can be obtained by burning sulfur. Bioletti and Cruess (1912) found that in actual practice the possible yield of sulfur dioxide from a given amount of burning sulfur is much less than the theoretical value. This difference was attributed to losses of oxygen resulting from the formation of sulfuric acid, escape of air from the enclosure as it expands with rise in temperature, and the failure of some of the oxygen to combine when the proportion in the air becomes too small to support combustion of sulfur. Pacottet (1911) stated that the low yield of sulfur dioxide obtained when sulfur is burned in wine casks is due to loss of sulfur which is volatilized or melted without burning and to that which forms sulfuric acid. It varies with the amount of sulfur burned in a given space and with the physical condition of the sulfur. Lyon (1930) stated that the

amount of sulfur consumed bears little direct relation to the length of burning period. Other factors that influence it are draught, air temperature, humidity, and area of the ignited surface. Jewell (1927) listed factors influencing absorption and hence the amount of sulfur used as follows: (1) variety of fruit; (2) type of sulfur house; (3) quantity of

TABLE 2

QUANTITY OF SULFUR BURNED AND LENGTH OF SULFURING PERIOD COMMONLY USED IN VARIOUS DRIED-FRUIT-PRODUCING REGIONS

Fruit	Region	Pounds sulfur per ton of fresh fruit	Length of sulfuring period, hours	Bibliography reference
Apricots	California	3–4	2–3	Nichols (1933)
	Argentina	3–4	2–3	Croce (1936)
	Australia	7–8	2–3	Cameron and associates (1929)
	South Africa	2*	4-5	Perkins (1925)
Peaches	California	3–4	3–4	Nichols (1933)
	Argentina	3–4	3–4	Croce (1936)
	Australia	Day, 7; night, 6	Day, 6; night, 12	Jewell (1927*a*)
	South Africa	8	4	Perkins (1925)
Pears (Bartlett)	California	12	24–36	Christie and Barnard (1925)
	Argentina	8	24–36	Croce (1936)
	Australia	10–12	24, maximum	Jewell (1927*a*)
Pears (Kieffer)	Eastern United States	....	12	Culpepper and Moon (1937)
Figs (Adriatic)	California	3	4	Christie and Barnard (1925)
Raisins (sulfur bleach)	California	3	4	Christie and Barnard (1925)
Raisins (golden bleach)	California	2–4	2–3	Nichols and Christie (1930*b*)

* Two pounds per 100 cubic feet of space.

sulfur used per unit weight of fruit or per unit volume of air space; (4) amount of moisture on the cut surface of the fruit; and (5) temperature in the sulfur house.

The quantity of sulfur and the sulfuring period for various fruits as recommended by different authorities are given in table 2.

According to Jewell (1927*a*) the bottom tray of fruit in the sulfur house tends to absorb more sulfur dioxide than fruit on the top trays. This seems to indicate unequal distribution and the concentration of sulfur dioxide fumes at the bottom of the house. Nichols and Christie (1930*a*) stated that the concentration of sulfur dioxide in the chamber

is controlled by the amount of sulfur burned, the rapidity and completeness of burning, the volume of space and quantity of fruit in the chamber and the loss of sulfur dioxide from the chamber through ventilators or leaks; also that the decrease in concentration is further influenced by wind velocity and direction. Nichols (1933) stated that for rapid, uniform sulfuring there must be dense white fumes in the house throughout the sulfuring period.

Chace, Church, and Sorber (1930) found that the concentration of sulfur dioxide fumes in the sulfur chamber influenced the rate of absorption of sulfur dioxide by the fruit. Apricots were satisfactorily sulfured when treated for 3 hours in a chamber having an initial sulfur dioxide concentration of 2 per cent or for 2 hours in a chamber having an initial concentration of 3 per cent. Temperature had less effect on the retention of sulfur dioxide by the fruit than either time of exposure or concentration of the fumes. Temperature above 120° Fahrenheit caused apricots to become red in color. According to Nichols and Christie (1930*a*) temperature affects absorption in several ways. As the temperature rises, the solubility of sulfur dioxide in water decreases. On the other hand, an increase in temperature increases the rate of combination of sulfur dioxide with other substances in the fruit and increases the rate of penetration of it into the fruit tissues. High temperatures presumably soften the fruit and facilitate absorption and penetration. Jewell (1927*b*) found that a longer sulfuring period was required at night than in the daytime because of the lower night temperature. In this connection, Nichols and Christie (1930*a*) indicated that the choice of construction material would depend upon whether a sulfur house is to be used principally during the day or night. Observations showed that while wood and metal houses reach higher temperatures in the day than do concrete or brick houses, at night the temperatures in the concrete and brick houses are higher. Quinn (1926*a*) and Love (1937) also stressed the importance of temperature in sulfuring fruit. According to Love, it is more difficult to sulfur fruit properly in cool weather.

The experiments of R. S. Hiltner[8] have shown that apricots and peaches can be sulfured in 3 hours with relatively small amounts of sulfur by use of his "dense smoke method." The method consists of exposing peaches or apricots for 3 hours in a warm and tight compartment containing dense fumes of sulfur dioxide obtained from burning sulfur in the sulfur house. A dense smoke must be maintained throughout the sulfuring period. The dense smoke method, however, has not come into

[8] Unpublished data from sulfuring investigations project of the Research Laboratory of the Dried Fruit Association of California, 1928.

general use because of periodical and hitherto unexplainable difficulties encountered in obtaining complete combustion of the sulfur.

Beekhuis (1938) and Cruess (1938) suggested testing freshly sulfured fruit by cutting and noting the depth of penetration. Chace, Church, and Sorber (1933) found that this was not a reliable method for determining the extent of sulfur dioxide absorption.

Chace, Church, and Sorber (1933) and Nichols, Mrak, and Bethel (1939) have shown that unfavorable drying weather or drying in the shade favors the loss of sulfur dioxide by the fruit during drying. Anderssen (1929) also found that shade-drying decreased its retention during drying. Beekhuis (1935) cited data to show that apricots dried rapidly retained more of this chemical than those dried slowly. C. F. Love[9] was able to increase the sulfur dioxide content of fruit dried under unfavorable conditions by drying on white painted trays and by stacking the trays at night to avoid excessive losses during the cold, foggy night. Positive but less pronounced increases were noted in fruit spread in the morning to secure the advantage of the morning sun rather than at night.

Roleson and Nichols (1933) stated, in regard to sulfur dioxide retention during drying, that the content of fruit exposed in the drying yard for one day would be nearly the same as that for the ordinary dried product, if no correction for moisture content is made. Hanus and Vorisek (1937) found that the sulfur dioxide content of apricots, dried in ordinary atmosphere and compared on a moist weight basis, remained constant for 35 days. It began to decline only when the apricots ceased to lose water. This apparent constancy was attributed to the comparable loss of water, for where sulfur dioxide was determined on a moisture free basis it decreased during the entire drying period.

Cruess, Christie, and Flossfeder (1920), Cruess and Christie (1921), Cruess (1921*b*), and Caldwell (1923) have shown that fruits to be dried artificially require less sulfuring than fruits to be sun-dried.

Nichols and Christie (1930*a*) described the characteristics of properly sulfured and dried fruits. Roleson and Nichols (1933) stated that for cut fruits other than apples and pears, 2,000–2,500 parts per million of sulfur dioxide in the fruit is considered the optimum.

SCOPE OF INVESTIGATIONS

Experiments to determine the effects of various factors on gas concentration and temperature conditions in the compartment were conducted

[9] Unpublished data from sulfuring investigation project of the California Prune and Apricot Growers Association, 1935.

at Davis in a three-compartment panel-board sulfur house, as designed by Long, Catlin, and Nichols.[10] The structure is shown in figure 15.

Tests involving the relation of certain chemical and physical factors to sulfuring practices were made in the following fruit-growing areas: Aromas, Brentwood, Esparto, Exeter, Fresno, Gridley, Hemet, Hollister, Kerman, King City, Kelseyville, Ojai, Modesto, Suisun, Ventura, and Vacaville. In the field studies data were obtained concerning: (1) number and size of trays to each sulfur house, size of house, and general construction features; (2) weight of sulfur used and completeness of combustion; (3) fruit variety, maturity, and size; (4) gas analyses from at least four points within the compartment at frequent intervals; (5) temperature observations at six points within the compartment at frequent intervals; (6) atmospheric and drying-yard temperature readings during sulfuring and drying; (7) wind velocity and direction; (8) sulfur dioxide analyses of freshly sulfured, of partially dried, and of dried samples; (9) general observations concerning drying-yard practices and climatic condition during drying; (10) results of correcting obvious sulfur-house defects.

Three test houses of different construction materials erected for the work are shown in figure 14.

Fruits used in the various tests were: Royal, Blenheim, Moorpark, Hemskirke, and Tilton apricots; Muir and Lovell freestone and Paloro cling peaches; New Boy nectarines; Bartlett pears; and Thompson seedless grapes.

EXPERIMENTAL PROCEDURE

Burning tests were made with sulfur samples collected from growers located in different drying areas. These samples varied considerably in the time and manner in which they had been stored and in certain physical and chemical characteristics. The burning tests were conducted as follows: Four pounds of sulfur were placed in a round metal pan, 10 inches in diameter and 2½ inches deep. The loaded pan was then placed on the bottom of the burner pit and ignited by touching a lighted match to a depressed area in the sulfur at the center of the pan. The match was subsequently discarded to avoid contaminating the burning sulfur with carbon. The sulfur-house door was then closed and left undisturbed until burning ceased, after which the remaining slag was weighed and observed for surface characteristics.

The effect of sulfuric acid, black-surfaced sulfur slag, and rock sulfur

[10] Long, J. D., H. E. Catlin, and P. F. Nichols. Fruit sulfuring house. California Agr. Ext. Service Farm Building Plan C-173. 1934. (Available from the California Agricultural Extension Service, University of California, Berkeley. Price 25 cents.)

on the burning quality of good sulfur was determined by mixing various quantities of these materials with the sulfur before lighting the sulfur.

For the guidance of chemists certain technical procedures are given in some detail in the following paragraphs.

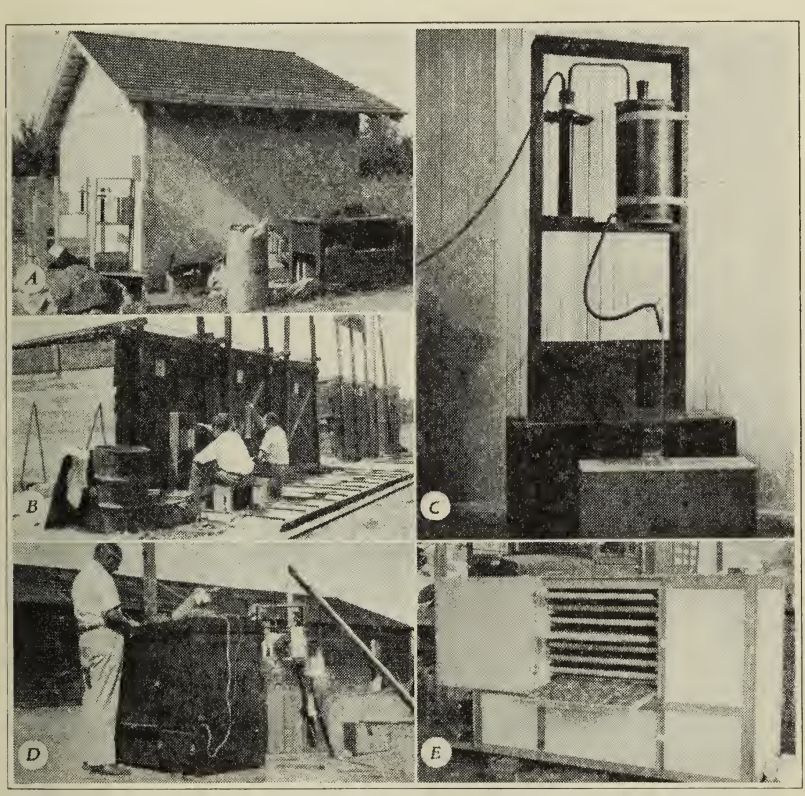

Fig. 2.—Equipment used in the experiments. *A*, Test equipment used with sulfuring at the College of Agriculture, Davis; *B*, test in progress on the house from which the pile of slag shown in figure 1 was taken; *C*, close-up view of analytical equipment for determining sulfur dioxide gas concentration; *D*, small sulfuring compartment used to secure constant concentration of sulfur dioxide gas for making tests; *E*, small electric dehydrater used in studies of sulfur dioxide retention during drying.

Sulfur dioxide concentration attained at various points within the sulfur house during operation were determined with the equipment illustrated in figure 2. Copper-tubing ($^3/_{16}$ inch outside diameter) gas inlets were fastened on tray surfaces at the center and about 1 foot from each end where they were surrounded by fruit. These inlets were located at three elevations, as illustrated in figure 9, for the 1937 experiments. In 1938 and 1939 only four gas inlets were used, located at points *1, 3,*

7, and *9* of the tray stack (fig. 9) because the results of 1937 indicated that these points were sufficient to determine gas distribution. The copper tubes extended out of the sulfur house, through the track openings, and connected with the gas-analysis equipment (fig. 2, *C*) by means of rubber tubing. Gas samples were withdrawn from the house through an absorption vessel, by means of suction resulting from the drainage of water from an air-tight reservoir connected to the absorption vessel. The connections were "swept out" prior to each determination. The volume of water withdrawn from the reservoir constituted a measure of the volume of gas removed from the house. A hydrometer jar, 12 inches in height and 2 inches in diameter, served as the absorption vessel, and gas from the compartment was drawn into the bottom of this jar which contained water, a few drops of starch solution and 1, 2, or 5 cubic centimeters of tenth normal iodine solution. The depth of solution in the vessel was maintained at about 9 inches. The volume of the iodine solution used was adjusted according to the gas concentration within the house so at least 100 cubic centimeters of gas were withdrawn for each test. Gas was slowly drawn through the solution in the hydrometer jar until the blue color resulting from the starch iodine reaction disappeared. At this point all of the iodine had been reduced by sulfur dioxide. The gas concentration was then read on curves prepared for each amount of standard iodine used, plotting cubic centimeters of gas withdrawn from the sulfur house against per cent by volume[11] of sulfur dioxide in the gas sample.

Data for the curves were calculated using Bureau of Standards values for the volume of one pound of sulfur dioxide gas at 80° Fahrenheit and 1 atmosphere pressure which is equal to 5.968 cubic feet. Variations of 20 degrees from this temperature cause changes in this volume of about 4 per cent. The maximum probable error in gas concentration determinations was approximately 5 per cent, caused chiefly by these temperature variations within the gas absorption vessel. This degree of accuracy was considered sufficient for the purposes of these investigations.

Temperature measurements were made with resistance thermometers placed on the trays adjacent to the gas lead inlets. Thermometers were also suspended in the front and rear air spaces inside the house. Atmospheric temperature was determined by suspending thermometers in the shade near the sulfur house. Mercury-bulb thermometers were used to secure the various drying-yard temperatures. Wind velocities were

[11] Per cent by volume of sulfur dioxide at 80° Fahrenheit multiplied by 0.167 = pounds sulfur dioxide per 100 cubic feet.

measured by use of a vane-type anemometer and wind direction was determined by use of a cloth streamer. Readings were made in most instances at 15-minute intervals during the first 3 hours of each test.

Other experiments included absorption studies made by periodically withdrawing fruit samples during sulfuring, through a small opening in the door of the sulfur house or from a specially constructed gas-tight portable sulfur chamber. Samples were withdrawn in such manner that the gas concentration in the chamber was not appreciably affected. Liquid sulfur dioxide was used in the small chamber and distributed by means of a small electric fan located within the chamber. Liquid sulfur dioxide was also used in a limited number of full-scale sulfuring runs to determine any possible advantages over the customary method of burning "flowers of sulfur," and also the comparative costs.

Dehydration studies were made with a specially constructed mechanical drier consisting of a lower air chamber containing electric heaters placed immediately in front of a motor-driven fan and eight 18 × 25 inch trays in an upper chamber. Wet- and dry-bulb thermometers were located in the air-stream at the dry end of the top compartment. A thermostat, the bulb of which was placed adjacent to the thermometers, controlled one of the three 660-watt electric heaters. The other two electric heaters were manually operated. Adjustable ports for control were provided at the fan end of the drier.

Samples of fruit for analyses were collected in glass-topped jars and sealed until sulfur dioxide determinations were made. In the full-scale tests of actual sulfuring practice, at least four samples from the extreme corners of the tray stack, and others from mid-stack points when deemed necessary, were taken and averaged for the final results. The jars were filled with from 10 to 50 pieces of fruit, according to their size and stage of drying. The time between sampling and analysis varied from 1 to 4 days. Trials indicated that sulfur dioxide loss during this interval was insignificant in well-sealed glass jars. Sufficient fruits were always used in the analysis to give a good random sampling.

In the small-scale tests with the tight sulfur box used for the constant gas concentration and similar studies, and in the tests with the dehydrator, the single samples taken for the different stages of the test procedure were representative.

The method of analysis used for sulfur dioxide determination was that described by Nichols and Reed (1932) which involves the distillation of a weighed ground sample of fruit in hydrochloric acid solution into standard iodine solution and titrating the unused iodine with standard sodium thiosulfate solution. Results were reported in parts per million

by weight (1,000 p.p.m. equals 1/10 of 1 per cent by weight). Moisture tests were made on fresh fruit samples by the method of Nichols, Fisher, and Parks (1931) by distillation of a weighed sample of fruit with xylene and the collection of the moisture in a calibrated sedimentation tube under a reflux condenser. Dried samples were tested for moisture with the electric moisture tester developed by Fisher.[12]

EFFECT OF FRUIT CHARACTERISTICS ON ABSORPTION AND RETENTION OF SULFUR DIOXIDE

The physical and chemical factors influencing the absorption and retention of sulfur dioxide by the fruit are as yet incompletely understood. Among the variable factors which are believed to affect the process are

TABLE 3

EFFECT OF SIZE OF TILTON APRICOTS ON THEIR ABSORPTION AND RETENTION OF SULFUR DIOXIDE

Diameter	Absorption, p.p.m.	Retention, p.p.m.	Retention ratio*
Over 2 inches	3,410	510	0.15
1½ to 2 inches	3,510	640	.18
Under 1½ inches	3,730	490	0.13

* The retention ratio is derived by dividing the sulfur dioxide content of the dried fruit by the content of the freshly sulfured fruit; this necessitates no correction for moisture. It is obvious that the higher the ratios the greater the retention. The retention ratios given above are very low, but typical of the drying conditions of the Aromas district.

variety, composition (probably as related both to variety and to locality and other conditions of growth), maturity, and size.

Investigation of the physical and chemical processes of absorption and retention are fundamental to a complete solution of the farm-sulfuring problem. Further work is in progress, particularly with regard to the effect of temperature and added fixative agents. It is known that sulfur dioxide is readily absorbed by the liquid present on the freshly cut surface of the fruit, forming sulfurous acid which gradually penetrates the tissues. Some penetration proceeds simultaneously through the skin-covered surface of the fruit, but at a slower rate.

The size of the fruit is believed to be a factor in the absorption of sulfur dioxide and later loss. Table 3 gives the results of a test in which apricots selected for uniform maturity in three size ranges were exposed simultaneously to sulfur dioxide in a concentration of 2 per cent, for 3

[12] Fisher, C. D. Apparatus for determining moisture content of dried fruits, etc., by electrical conductivity. U. S. Patent No. 1,961,965. 1934.

hours. The data obtained are not very conclusive. In spite of care in selecting the fruits, the maturity may not have been as uniform as indicated by appearance; furthermore in analyzing for sulfur dioxide the limit of accuracy is considered to be about 50 parts per million.

A comparison of maturity differences secured in a field test is shown in table 4. The results indicate that maturity is a critical factor in successful sulfuring practice. From this and other tests by the authors and those by other investigators, notably Quinn (1926*a* and 1926*b*) and Jewell (1927*a* and 1927*b*) it is obvious that ripe fruit frequently absorbs less sulfur dioxide than green, but always has a much higher retention ratio. The term "retention ratio" expresses the relative amount of sulfur dioxide present in the dried fruit as compared with that absorbed by the fresh fruit during sulfuring. This method of comparison obviates the necessity of correcting for moisture differences.

TABLE 4

ABSORPTION AND RETENTION OF SULFUR DIOXIDE AS AFFECTED BY MATURITY IN APRICOTS

Variety	Maturity	Absorption, p.p.m.	Retention, p.p.m.	Retention ratio
Moorpark	Green	3,490	230	0.07
	Ripe	3,490	590	.17
Tilton	Green	3,810	210	.05
	Ripe	3,380	610	0.18

Variation in size and difference in composition are believed to be primarily responsible for the differences in absorption (not retention) expressed in table 5 wherein the gas environment is expressed in terms involving both sulfur dioxide concentration and exposure periods of typical farm-sulfuring practice. Since the exposure period tends to be constant for each kind of fruit this gas-environment factor essentially is based on the average sulfur dioxide gas concentration during sulfuring.

The data in the last column give an indication of the absorption characteristics of the various fruits and varieties. It is interesting to note that pears exhibit the lowest factor, that the large Moorpark and Hemskirke apricot varieties have the highest, and that the Paloro cling peach has a slightly higher value than the two freestone varieties. A similar indication of the effect of varietal differences is given in table 9. Studies under controlled conditions must be made before the exact rôle of possible variations in composition as related to variety can be determined.

A comparison by districts of the absorption factors of Blenheim or Royal apricots, is given in table 6. Using as criteria the results of the tests made in experimental houses at Davis, in 1937, and at Aromas, in 1939, it is obvious that the gas-environment rating secured in ordinary farm sulfuring houses in the coastal areas is appreciably below that which can be readily maintained in good sulfuring practice.

TABLE 5

RELATION OF FRUIT VARIETY TO SULFUR DIOXIDE ABSORPTION

Fruit and variety	Number of tests	Average exposure in minutes	Average absorption factor*
Apricots:			
Tilton	7	210	10.43
Blenheim or Royal	29	220	12.25
Moorpark	2	185	19.00
Hemskirke	3	180	19.50
Nectarines:			
New Boy	2	260	8.40
Peaches:			
Muir	3	245	8.73
Lovell	1	275	10.20
Paloro	2	240	11.20
Pears:			
Bartlett	2	2,180	0.89
Raisins:			
Thompson Seedless	2	160	10.50

* "Absorption factor" is a numerical expression used here to compare the absorption of sulfur dioxide by various fruits in different sulfur houses, operating under farm conditions, throughout the state. The factor number represents absorption by the fruit in parts per million divided by "gas environment" value which in turn is equal to the percentage gas concentration in the sulfur house multiplied by the minutes of exposure of the fruit while sulfuring. The gas environment was conveniently determined in each case by planimeter measurements of the area enclosed by the graphs; a representative graph is shown in figure 6.

The results of previous investigators, particularly of Nichols, Mrak, and Bethel (1939) have indicated considerable variation in the absorption characteristics between fruit grown in the interior valleys and that in the coastal areas. It appears that the variations may be due to differences in composition, as previously explained, and perhaps also in part to the higher relative absorption in the concentrations found in sulfur houses of the coastal areas. In tests with all kinds of fruit it has been noted that fruit exposed to the lower gas concentrations absorbs a higher proportional amount than that exposed to higher concentrations. For example, apricots exposed to a 1 per cent maximum concentration might absorb 1,500 p.p.m. of sulfur dioxide, but would take in appreciably

TABLE 6

RELATION OF LOCALITY TO SULFUR DIOXIDE ABSORPTION BY BLENHEIM OR ROYAL APRICOTS

Locality and year	Number of tests	Average gas environment value*	Average absorption factor
Hemet (1938)	3	272	10.50
Davis (1937)	2	339	11.05
Upper Ojai Valley (1938)	1	175	11.20
Suisun Valley (1938)	8	247	11.70
Aromas (1939)	4	318	11.25
Aromas (1938)	5	184	12.40
Hollister (1937)	7	291	12.94
Ventura (1938)	2	155	13.30
King City (1938)	1	205	15.80

* For meaning of "gas environment value" see footnote to table 5.

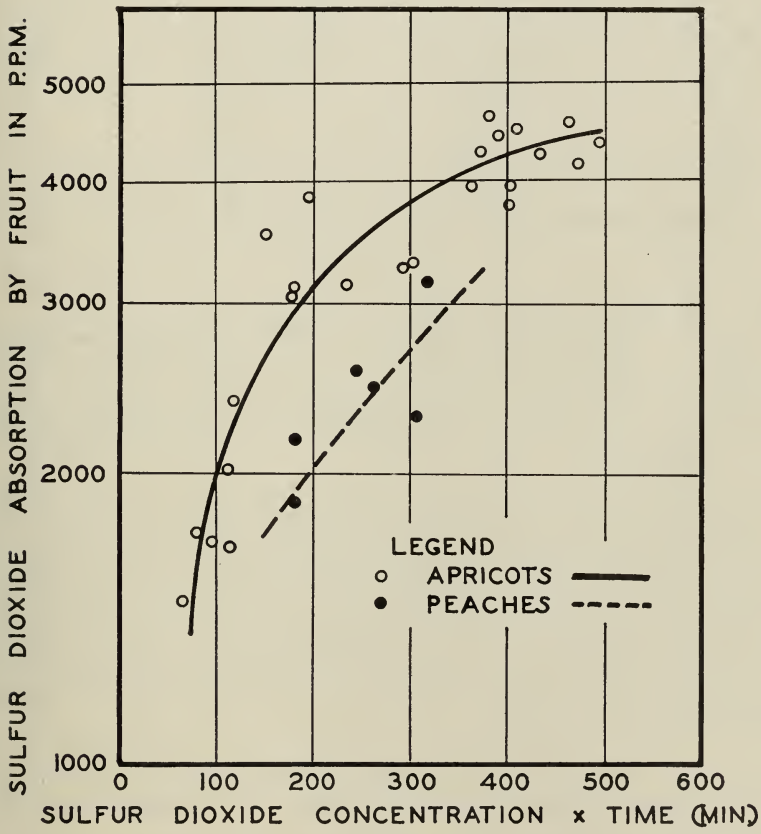

Fig. 3.—Showing the sulfur dioxide absorption by apricots as related to the environmental factor defined as sulfur dioxide concentration in per cent by volume in the sulfuring chamber multiplied by time in minutes. It is evident that under farm conditions an increase in the environmental factor would not greatly increase absorption above the 4,500-p.p.m. level. The few tests that were made with peaches illustrate their relatively slower absorption.

less than 3,000 p.p.m. if subjected to a 2 per cent sulfur dioxide environment for the same period. From table 6 it is apparent that in the Hollister area tests a high concentration was maintained, but that similar

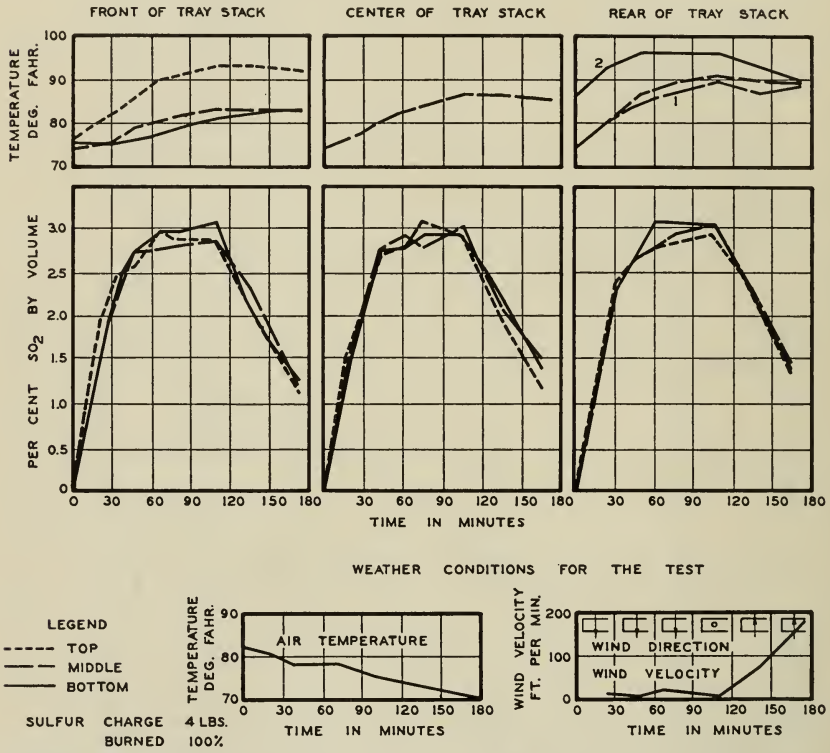

Fig. 4.—Typical curves and analytical results showing the type of data taken during each field test. These data are from test 53, Davis, sulfuring Tilton apricots in the house illustrated in figure 2, *A*. Note the uniformity of the sulfur dioxide concentration curves taken from nine points within the tray stack, and the fact that a concentration above 2.5 per cent was maintained for 90 minutes—two characteristics of a desirable gas environment. Temperature curve *1* was taken just outside the tray stack, and curve *2* at the rear track level. Missing temperature curves in this test were due to broken contacts. The temperature curves at the top front and at the rear track level indicate the direction of the convection currents within the compartment. Corresponding data on the absorption and retention of sulfur dioxide by the fruit used in these tests are given in table 7.

data in the Ventura and Aromas (1938) areas were low. The differences in the absorption ratios for these districts do not correspond with those of the gas-environment values.

Sufficient data were secured in 24 experiments at Davis to plot the sulfur dioxide absorption of apricots (fig. 3) using the planimeter measurement of the sulfur dioxide concentration and the time as described in

table 5 for the independent variable, and plotting the absorption on a logarithmic scale. A limited number of tests with peaches are also given on the curve, and show the slower absorption of this fruit. It is obvious that in typical farm sulfuring practice apricots tend to reach a maximum absorption of 4,500 p.p.m. under a gas environment such as is illustrated in figure 4. In short, further sulfuring, under these conditions would not noteworthily increase absorption. The slopes of the absorption curves in figure 3 give the rate of change of the proportion of sulfur dioxide in the fruit in parts per million with respect to the environmental value (percentage of sulfur dioxide in gas chamber $\times$ time in minutes).

FACTORS AFFECTING THE GAS ENVIRONMENT

As indicated in table 6, and in figure 3, the conditions under which fruit is exposed to the gas influence the absorption of sulfur dioxide in the fruit. Obviously, for uniformity of absorption at all points in the tray

TABLE 7

DATA OF ABSORPTION AND RETENTION OF SULFUR DIOXIDE FOR THE RESPECTIVE GRAPHS SHOWN IN FIGURE 4

Location (top to bottom) of fruit in tray stack	Front of tray stack		Center of tray stack		Rear of tray stack	
	Absorption of SO_2 by fresh fruit	Retention of SO_2 by dried fruit	Absorption of SO_2 by fresh fruit	Retention of SO_2 by dried fruit	Absorption of SO_2 by fresh fruit	Retention of SO_2 by dried fruit
	p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
Top	4,060	1,950	4,000	1,960	3,840	2,230
Middle	3,900	1,970	3,960	2,240	4,000	1,990
Bottom	3,960	2,230	3,920	2,340	3,840	2,710

stack it is necessary to have a uniform distribution of gas within the compartment. The gas concentration, the exposure period, and the temperature of the fruit are all factors in the rate and amount of absorption. Field tests in which these factors were considered were conducted in the major dried-fruit-producing areas of the state. Data from the field tests were plotted for analysis, as shown in figure 4. For the 4 pounds of sulfur burned, the gas-concentration curve shows an ample concentration maintained for a suitable time, as evidenced by the average sulfur dioxide absorption of 3,942 p.p.m. (table 7). The distribution throughout the tray stack, taken at the nine points illustrated in figure 9, is also fairly uniform.

Influence of Tight Construction.—In many of the field tests disturbances were noted attributable to drafts caused by moderate breezes blowing through relatively tight-appearing construction joints, poorly fitted

doors, or poorly designed ventilation openings. In the test of a four-car tandem house made with a moderate breeze blowing, sulfur dioxide concentrations varied uniformly from 0.75 per cent maximum, at the loosely-fitted door end, to 1.5 per cent maximum at the other. A variation from 1 per cent at the bottom of the tray stack to 2 per cent at the top is shown in figure 12; this difference was due to a poorly designed system which caused excessive ventilation.

Convection Distribution.—In single-car houses a tendency for a lower temperature and a lower concentration of sulfur dioxide at the lower front portion of the tray stack just behind the sulfur burner has been noted. This is caused by sluggish convection currents through the lower trays, and sulfur dioxide removal through absorption by the fruit. The rapid rise of gases immediately above the burner appears to retard diffusion from the front. Under such conditions the atmosphere at this point may take half an hour to reach concentrations of sulfur dioxide equivalent to those at other points in the tray stack, and sometimes remains slightly lower throughout the sulfuring period. This variation occurred in all types of sulfur houses tested, but is not sufficiently marked to be considered a serious fault.

The use of a structural design which approximates the convection-channel clearances shown in figure 9 would appear to be a satisfactory solution. This difficulty is the reverse of that noted by Jewell (1927*a*) in the tendency of the fruit on the bottom trays to have the highest absorption. No corroborating evidence was found for this situation, but it may have been caused by a temperature differential between top and bottom of the tray stack.

Tray Construction.—Where free convection currents maintain a uniform gas concentration about the tray stack, and open spaces are left across the ends of the trays, the gas diffuses through the tray length rapidly. In only a few tests was the accumulation of gas at the central tray points noticeably slower than at the ends of the trays.

The three sizes of standard tray design used in California, the 2 × 3 foot open-end raisin tray, and the 3 × 6 foot and 3 × 8 foot closed-end trays used for other fruits, appear to be well designed for their purpose. For sulfuring the largest-sized fruit, it is desirable to increase the depth of the side rail, or the thickness of the bottom cleats, to maintain approximately ½ inch clearance between the fruit and the bottom of the tray above.

Sulfur Dioxide Gas Concentration Obtainable.—Theoretically, sulfur burning within a closed compartment and utilizing all of the oxygen in the air develops a 21 per cent sulfur dioxide concentration. Several fac-

tors contribute to materially reduce this percentage in practice. The maximum gas concentration reached in an empty compartment was 7 per cent. In actual sulfuring practice the rapid absorption of the gas by the fruit still further reduces the concentration, a maximum of 3.5 per cent being reached in this series of tests. With conditions similar to those of figure 7, the empty compartment maximum was about 6 per cent and the buffer effect of the fruit reduced the maximum sulfur dioxide concentration to about 3.0 per cent. Large sulfur-burning area, adequate air supply, and freedom from sulfur impurities increase the rate of burning and develop higher gas concentrations. Leaky houses permit a ready escape of the gas with low concentrations as a result.

Temperature.—Sulfur-house temperatures depend on the following factors: rate and duration of burning of the sulfur; convection and circulation characteristics of the house; outside air temperature; house construction material, or design features that absorb and transmit solar radiation to the compartment; the temperature of the fruit entering the compartment; and the cooling effect of the evaporation from the moist fruit surfaces.

Burning sulfur within the sulfur house generates heat. As shown in figure 4, the heat generated by free-burning sulfur in a 10-inch-diameter pan is sufficient to raise the air temperature within the tray stack about 15° Fahrenheit. Opposing this temperature rise is the evaporative cooling effect of moisture leaving the freshly cut fruit surfaces, as well as the heat capacity of the fruit mass. Burners with large surface areas increase the temperature rapidly, and to relatively high maximum points. Burner baffles decrease the rate of burning, so the temperatures rise slowly and somewhat more uniformly throughout the house. The tests on mechanical forced-draft burning showed little temperature difference over normal natural-draft burning. Air temperatures surrounding the fruit consistently ranged between 80° and 100°, with a maximum record of 134° for the interior valleys, and a minimum of 70° for the coastal areas. A temperature differential of 12° to 18° exists between top and bottom trays in houses located in coastal areas; those in the interior valleys usually have a much lower variation.

Outside the tray stack in the free air of the compartment the temperature commonly ranges up to 15° Fahrenheit higher; temperatures taken 6 feet above the sulfur burner may be 30° above the average air temperatures within the tray stack. The hot gases tend to travel back under the ceiling, down the rear wall and forward under the tray stack to the burner again, as indicated in figure 9. A temperature differential of 20° between ceiling and floor is not uncommon, and as much as 50° has been

recorded. These differences tend to equalize when burning has ceased. Such temperature variations induce convection currents which facilitate uniform gas distribution within the compartment. Locating burners at each end of the compartment or midway of the floor area under the tray stacks tends to cause conflicting convection currents and uneven distribution of sulfur dioxide.

Atmospheric temperatures during the sulfuring period and the solar heat absorption by the structure have some effect on interior temperatures. As previously mentioned, the thermal insulation and heat absorption characteristics of certain construction materials may play a part in reducing the effects of the solar radiation. Nichols and Christie (1930*a*) observed differences in the temperatures occurring in concrete or brick houses as compared with those in wood structures. A horizontal ceiling helps to insulate the structure. Although house construction material or design may influence the interior temperatures, these differences are not usually large enough to greatly affect the temperature of the fruit. Tests on houses of different construction have failed to indicate any marked variations in sulfur dioxide fixation due to their interior temperature differences. Small-scale, controlled experiments with liquid sulfur dioxide, however, indicated that fruit temperature does exert a marked effect on absorption and retention. High temperatures result in lower absorption, but in higher retention. Royal apricots sulfured at a constant sulfur dioxide concentration of 2 per cent for 3 hours at an average temperature of 62° Fahrenheit had an absorption of 3,870 p.p.m. while at a temperature of 117° the absorption was 2,970 p.p.m. Placed on the same drying yard they produced dried specimens of 300 and 860 p.p.m., respectively. Further work is being done on this phase of the study.

The Favorable Gas Environment.—From a total of 75 field tests, results comparable to those illustrated in figure 4 indicate that farm practice should be directed to securing the sulfur dioxide environment obtained by burning the quantities of sulfur and exposing the fruit for the periods given in table 8. The favorable absorption data indicated in the table, for freshly sulfured fruit, were secured in field trials under reasonably good farm practice; they would appear capable of material improvement. An individual grower attempting to improve his sulfuring practice should have an analysis made of his freshly sulfured fruit and from these results modify the pan area, amount of sulfur, or exposure period to secure the desired absorption. The analysis of freshly sulfured fruit is used here to avoid the variable of sulfur dioxide loss in the drying yard.

Laboratory tests using liquid sulfur dioxide at various concentrations

indicated that the higher concentrations may result in a more rapid absorption by the fruit. However, "fixation"[13] of sulfur dioxide by the fruit tissues also requires time; and a minimum exposure time—as yet undetermined but believed to be dependent on such factors as variety, maturity, and composition—is essential to avoid excessive sulfur dioxide losses in the drying yard.

Somewhat higher concentrations than those indicated in figure 4 can be secured in burning sulfur by using burner pans of larger diameters. Longer effective sulfuring periods are obtained by using larger quanti-

TABLE 8

CONDITIONS OF GOOD FARM SULFURING PRACTICE
(Using 10-inch-diameter pan burner and tight house)

Fruit	Pounds sulfur burned per 1,000 pounds cut fruit	Sulfuring period, hours	Maximum SO_2 concentration in house, per cent	Probable SO_2 content of fresh fruit after sulfuring, p.p.m.
Apricots	4	3	2.5	4,000
Nectarines	5	4	2.5	3,200
Peaches	5	4	2.5	3,200
Pears	13	30	1.0	2,000
Raisins (sulfur bleach)	2	2	2.5	1,500

ties of sulfur, in a burner pan of any given size. The sulfur dioxide concentration in the gaseous atmosphere drops to an ineffective low point within about 1 hour after the sulfur has burned to completion and there is little advantage in holding the fruit in the compartment longer if drying-yard conditions are favorable.

In the majority of the farm structures tested the gas environment values were materially less than the optimum for good practice indicated in table 8. The major causes for this were the use of earthen burning pits, ineffective or baffled burners, poor-burning sulfur, improper ventilation, and leaky houses.

TYPES OF SULFUR AND FACTORS AFFECTING THEIR USE

The most commonly used source of sulfur dioxide gas is sublimed sulfur, burned within the sulfur compartment, although rock and granu-

[13] By "fixation" is meant the result of those changes either physical or chemical, or both, which in effect cause a bonding between the fruit substance and sulfur dioxide. When "fixation" takes place, sulfur dioxide is more firmly held by the fruit in contrast to the "free" sulfur dioxide that readily escapes from the fruit immediately after sulfuring.

lated sulfurs are occasionally used. In a few cases gas obtained from the evaporation of liquid sulfur dioxide has also been tried.

Variability in Sulfur Burning.—During the harvest of 1936 unusual difficulty was reported from several districts in getting the sulfur to burn satisfactorily. Early the next spring about two dozen samples of sulfurs remaining from the previous season, and stored over winter in typical farm storage sheds, were collected. When these were burned in clean metal pans in an empty sulfur compartment one group burned to

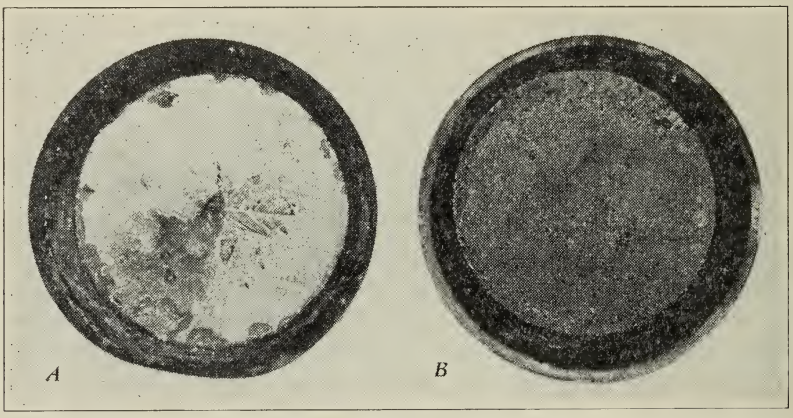

Fig. 5.—Illustrations of slag resulting from incomplete burning: *A*, Light-colored slag indicates that the fire was smothered through insufficient ventilation; *B*, dark-surfaced slag indicates that the fire was smothered by carbon or carbonaceous matter or other impurities which floated to the surface of the molten sulfur.

completion, or between 90–100 per cent; the remainder, comprising about two-thirds of the samples collected, burned to only 10–40 per cent. Invariably, the sulfur slag from the latter group was covered with a black film or scum as shown in figure 5,*B*. Unsuccessful attempts were made to correlate this incomplete combustion with the use of metal sulfur burners, insufficient ventilation, moisture absorbed from the air, and texture and acidity of the sulfur. An admixture of the slag from a poor-burning sample, however, was found to materially reduce the burning percentage of a sulfur which previously burned to completion.

Investigations pertaining to the composition of the black film and factors contributing to its formation and influence on the completeness of combustion of sulfur were conducted in the laboratory of the Chemistry Division by H. W. Allinger and C. S. Bisson. The information resulting from their studies is summarized in the remaining paragraphs of this section.

Chemical tests on the slag obtained from some poor-burning sulfurs showed that the black surface film consisted largely of carbon or carbonaceous matter with small amounts of iron compounds and silicious material. Further experiments indicated that the film probably originated from the interaction of the hot molten sulfur (or hot sulfur vapors) with traces of certain organic impurities present in the sulfur or the burner. Extraction of samples of poor-burning sulfurs with solvents to remove oily contaminants increased the amount of sulfur that would burn.

Laboratory tests were therefore directed toward determining the type of impurities which contributed to this black film formation. The addition of very small amounts of different organic substances to samples of a high-quality sulfur was found to decrease the percentage of sulfur burned and to produce a film or scum similar in appearance and effect on burning to that observed when contaminated sulfurs are burned. Of the many organic substances added, the petroleum oils were found to favor the formation of the black film or scum, and to decrease the percentage of sulfur burned. Small amounts of iron oxide and ignited dust showed little or no effect on the percentage of sulfur burned. Samples of a high-grade sulfur when stored for several days in an atmosphere of vapors arising from fuel oil at room temperature were found to absorb sufficient amounts of volatile carbon compounds to cause black film formation, and to decrease the amount of sulfur burned. This would probably have an important bearing on defining proper conditions for the storage of sulfur.

By raising the temperature of samples of poor-grade commercial sulfurs, which increases their volatility, such sulfurs can be made to burn almost completely.

Later, in the field trials it was observed that farm practices were sometimes the source of sulfur contamination with resultant difficulties in burning. Attempting to burn sulfur in oily pots or storing sulfur on oily floors gave ample opportunity for contamination. In one instance sulfur stored over winter in a farm garage burned poorly, owing presumably to the automobile exhaust gases which had been absorbed.

Liquid Sulfur Dioxide.—In a comparison trial with liquid sulfur dioxide, 10 pounds of the liquid was used in a relatively tight house to sulfur 1,000 pounds of Tilton and Royal apricots. A maximum gas concentration of 5.75 per cent sulfur dioxide was attained, and a concentration of 2 per cent or more maintained over an exposure period of 3 hours. Chemically, 10 pounds of the liquid sulfur dioxide is the equivalent of 5 pounds of burning sulfur. Theoretically, the gas formed from

either would result in approximately a 33 per cent concentration if it were all contained in the available gas space of about 180 cubic feet in the one-car compartment under the standard temperature and pressure conditions stated in the section on experimental procedure. In practice, however, leakage and absorption reduce the theoretical values materially.

To compensate for the convection currents normally induced by the burning of the sulfur, three 6-inch electric fans were used in the liquid sulfur dioxide trial, but the distribution so secured was very poor. Temperature on the trays ranged between 70° and 75° Fahrenheit. Analyses of the fruit so sulfured averaged 4,600 p.p.m. in the freshly sulfured samples and 450 p.p.m. in the dried product. The parallel check run in which 4 pounds of sublimed sulfur was burned, and the exposure maintained at 3 hours, resulted in analyses of 4,050 p.p.m. and of 500 p.p.m. At current market prices the sublimed sulfur is the more economical source of sulfur dioxide gas.

Fruit treated with fumes from liquid sulfur dioxide showed little "juicing" when removed from the sulfur house, but juiced as much as the check lot after standing in the drying yard for a short period of time. No other differences were noted in the two lots of fruit.

SULFUR BURNERS

In the majority of farm sulfur houses the sulfur is burned in an earthen pit excavated just inside the door and between the car track rails. Numerous trials with various burners demonstrated the desirability of limiting the burning area of the molten sulfur so as to secure gas concentrations similar to those indicated in figure 4. This avoids dissipation of the heat of burning, and also protects the burning sulfur from contamination. Moreover, restricting the burning area also permits designing a ventilation system which will provide an adequate supply of air to maintain combustion without excessive loss of gas through venting.

Metal Pan Burners.—A tin pan, of 10-inch diameter and 3-inch depth, makes a very satisfactory, easily cleaned sulfur burner. Setting this on the floor in the open space between the front of the tray stack and compartment doors brings it close to the air inlets and gives it sufficient space to avoid a fire hazard. The sulfur should be leveled in the pan, and ignited with a match which is subsequently discarded to avoid carbonaceous contamination of the sulfur. The pan confines the molten sulfur during the initial stages of burning and aids in maintaining the temperature necessary for combustion. There appears to be little practical value in insulating the pan burner to prevent the loss of heat, except in

the case of poor-burning sulfur. By raising the temperature of such sulfur through insulation, or by the use of regenerative burners, or of superimposed pans, it may be possible to secure complete combustion in spite of contamination. Such measures, however, are not recommended with good-burning sulfur because of the danger of sublimation of the sulfur and subsequent deposition on the fruit. If the floor of the house consists of damp soil, a layer of gravel beneath the pan burner will minimize chilling. The pan may be placed in a shallow pit, if desired, for fire safety.

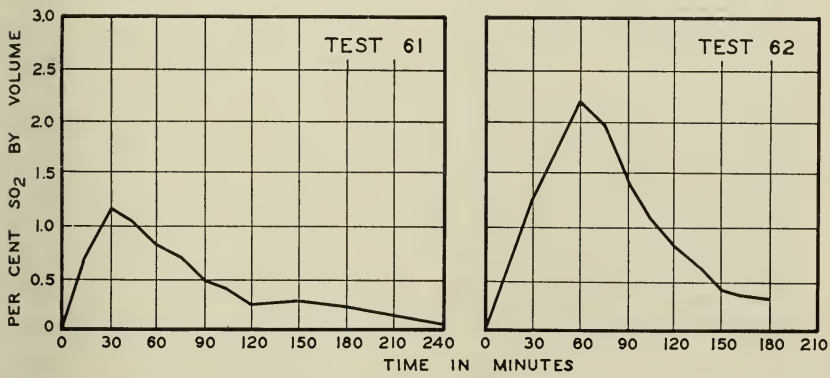

Fig. 6.—Average results of two successive tests of a two-car parallel compartment made on the same day. In test 61, 6½ pounds of sulfur were divided and burned in two earth pits 21 inches deep. In test 62, the only change was to burn the same amount of sulfur in two pans set in the pits. Under the higher gas concentration of the second test the apricots absorbed 2,670 parts per million of sulfur dioxide, as compared to 2,010 for the first.

Earthen Pits and Other Burners.—Several comparative trials showed unmistakably the advantage of pan burners over the earthen pits commonly used. The results of one such trial are shown in figure 6. In the earthen pits the molten sulfur is dissipated and cooled among the clods, almost invariably leaving some slag. In one instance 69 pounds of waste slag were removed from a burner pit after one season's operation, estimated at thirty burnings (fig. 1). Hearths or shallow pits of concrete give excellent results as sulfur burners, provided they are kept clean. Pits lined with concrete pipe are difficult to clean. It is important that the burner be so shaped as to concentrate the molten sulfur to a burning surface area comparable to that of a 10-inch-diameter pan if comparable gas concentration characteristics are desired. Stove burners outside the compartment appear to offer little advantage other than a saving of interior space.

Burner Baffles.—It is important in the natural-draft system that the

surface of the burner not be constricted if free burning is desired. Placing a shield close above the burner, as is commonly done when the burner is beneath the tray stack, materially reduces the rate of burning and con-

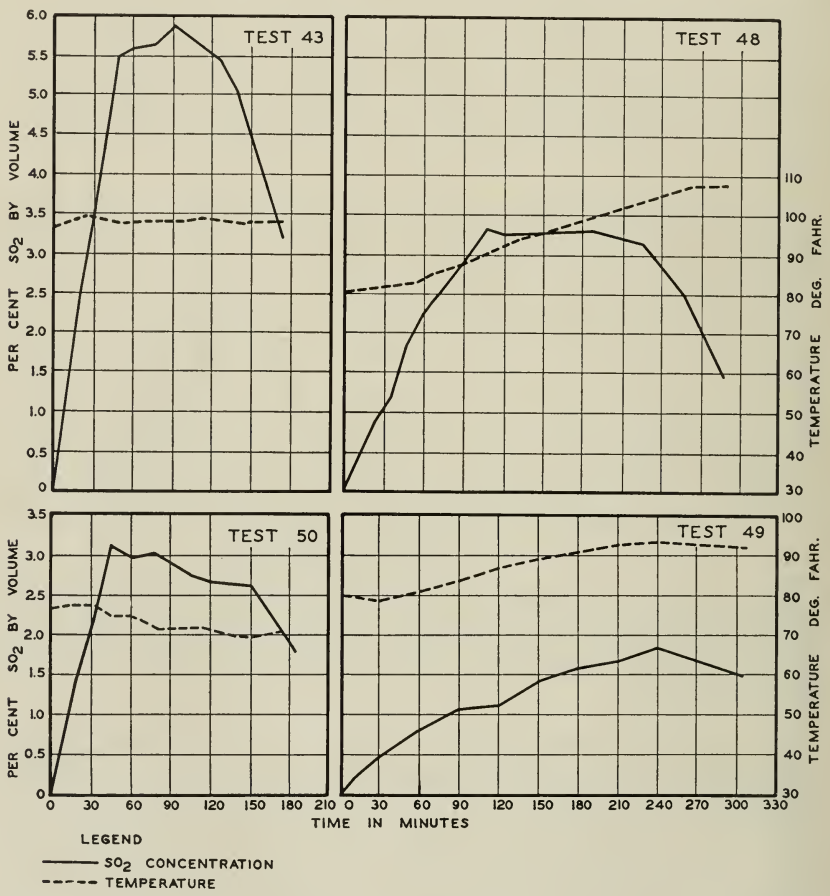

Fig. 7.—Tests showing the effect of burner baffles and fruit on the gas concentration and temperature in the sulfuring compartment. Baffles retard the rate of burning, and the fruit by absorption, buffers the sulfur dioxide to a lower concentration in the compartment. The compartment vents consisted of two track inlet openings and a 1-inch vertical outlet flue at mid-height of the rear wall. Test 43 shows the concentrations in an empty compartment; test 48 was made in a similar empty compartment but which had a sheet-metal burner baffle raised only 2 inches at the rear edge of the burner. Test 50 corresponds to test 43 and test 49 to test 48 except that in these two the compartments were filled with fruit. Wind directions were similiar for the four tests; wind velocities ranged from 300 to 600 feet per minute for tests 43 and 48, and 0 to 125 feet per minute for tests 49 and 50. The apricots used in the two latter tests absorbed 4,420 and 4,570 parts per million, respectively, more in 180 minutes under the higher gas concentration than in 300 minutes under a gas concentration half as high.

sequently the gas concentration in the house (fig. 7). A preferable correction in such instances is to fasten a sheet-metal shield permanently against the underside of the car, leaving the burner as unobstructed as possible (fig. 10).

DESIGN OF THE SULFUR HOUSE

The ideal sulfur house is a compartment of suitable size and economical construction made relatively tight against air infiltration. It may hold one or more tray stacks, but must provide space for the sulfur burner and channels for convection circulation about each stack and adjacent to the open ends of the trays. For tight construction a ventilation system will be required. A clean sulfur burner is essential.

In most drying yards the tray stack is piled on a flatcar with flanged wheels, and run into the house on steel rails. The conventional farm sulfur house holds one stack of fruit trays piled as high as two men can conveniently reach, usually numbering about 25 trays. Some operators prefer a lift car which can be removed, leaving the tray stack supported within the compartment on horses or on ledges built along the side walls. Judged by the effectiveness of sulfuring there appears to be no choice between the two arrangements. Several types of houses used in commercial practice are shown in figure 8.

House Capacity.—Smaller operators generally prefer the one-car house as the more convenient; larger operators find some economy of construction in multiple-car houses. The latter types follow different arrangements. Two-car tandem and parallel, four-car tandem, four-car tandem-parallel, and seven-car tandem (the latter with a crosswise placement of the tray stack rather than the conventional lengthwise arrangement) are some of the designs which have been studied in this investigation.

Type of House.—Small operators and those with young orchards sometimes use a movable "lift-over" or "hood-type" house which can be placed over tray stacks on the cars or wooden horses. Those built of paper or panel board on a light wood frame as described by Beekhuis (1935) are relatively short-lived and inconvenient to operate, but may be economically warranted for very small-scale production.

A unique tunnel type, continuous-operation sulfur house was the subject of one field test. Cars of freshly cut fruit entered at one end and were discharged some hours later from the opposite end. Sulfur burners were placed at both ends and at mid-length. The large fruit capacity and mode of operation did not appear conducive to economical practice or to accurate control, particularly when starting or ending the day's run.

The discomfort of the sulfur dioxide gas to the operators, moreover, was deemed a serious fault.

Convection Channels.—The general fundamentals of all such structures are that, for economy of sulfur to be burned and satisfactory operation, the compartment shall be tight, and no larger than necessary to cover the tray stacks and provide for the convection currents which dis-

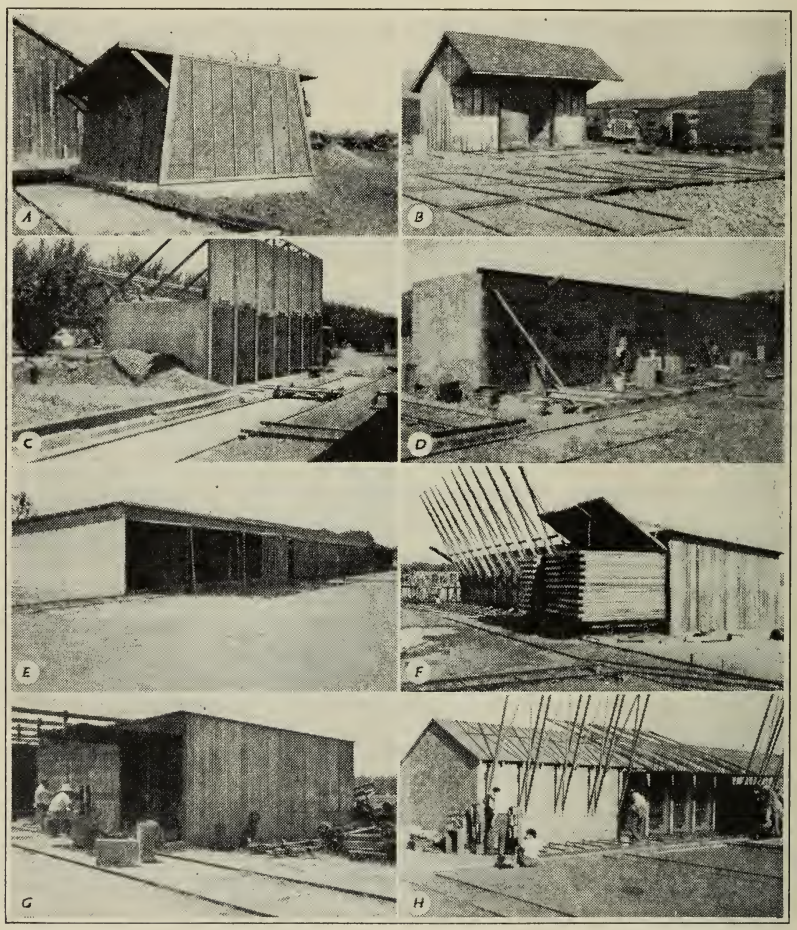

Fig. 8.—Typical farm sulfur houses of the better types: *A*, Well-built wood frame house with sloping front and rear walls, asphalt paper neatly applied over wood sheathing, and top-hinged doors, counterbalanced; *B*, wood frame house with overhanging roof and plastered interior; *C*, concrete house with vertical sliding doors; *D*, concrete house with side-hinged doors in a removable wood frame; *E*, large-capacity wood frame houses with top-hinged doors, such as used in pear drying; *F*, cumbersome overhead counter-balances for top-hinged doors on shed-roofed houses; *G*, four-car house in tandem-parallel arrangement; *H*, stucco and plaster houses of tight construction except for excessive ventilation.

tribute the sulfur dioxide gas from the sulfur burner. With tight compartments, proper size and placement of sulfur burner, and adequate venting, it appears possible to secure adequate gas concentration and uniform distribution in any design or size of compartment. Since most of the sulfur houses in use are of single-car design, and most farmers and investigators favor the small house, this discussion will feature the permanent structure of that type.

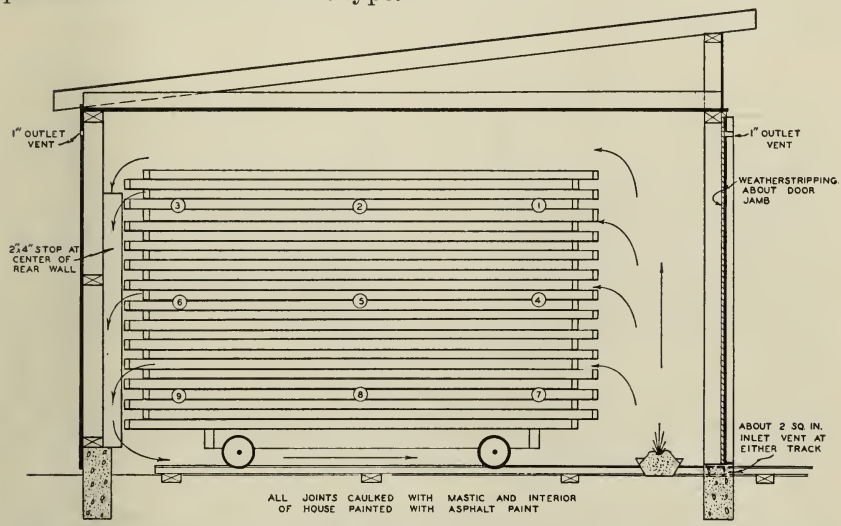

Fig. 9.—Longitudinal section of typical, well-designed sulfur house showing pan burner, convection channels and ventilation openings. The numerals on the tray stack indicate the relative positions of the gas-sampling outlets. With a tight ceiling the roof shape is unimportant. Arrows indicate direction of the gas flow. The numbers indicate points at which experimental gas samples and temperatures were taken.

The depth of the sulfuring compartment must allow for the length of the tray stack, which is frequently staggered 3 inches to provide hand holds on the trays, and a space above the sulfur burner at the front and one at the rear wall to provide for convection currents, as indicated in figure 9. If the compartment provides for cars in tandem, a spacer should be used to insure a 3-inch clearance between tray stacks for the same reason.

If the compartment is constructed too short to permit a free air space above the burner, a pit 18 inches deep may be excavated under the front end of the car for the burner and a fire-protective sheet-metal plate fastened beneath the car as shown in figure 10. The convection currents from this arrangement, however, are less positive in direction and the gas distribution slower than with the free-standing burner, and the trays immediately above are subject to heating. A second corrective arrangement is

a small addition for the burner built against the rear wall of the compartment.

It is essential that the convection channel about the tray stack not be restricted; an opening of about 3 inches across the top, down the back wall, and under the tray stack is necessary for air circulation from the burner and return. The rear-wall convection channel may be maintained by placing a 2 × 4 inch stud vertically at the center of the rear wall as shown in figure 9.

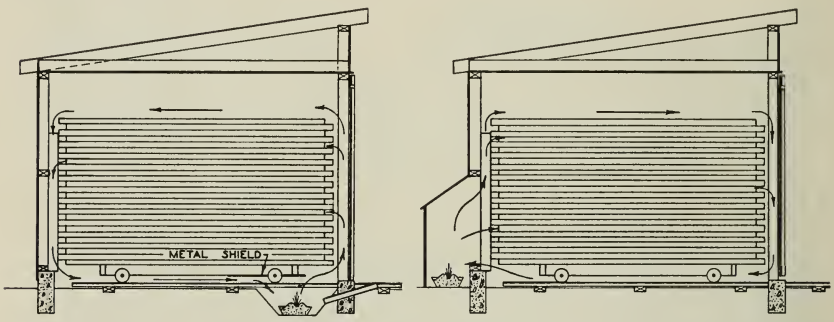

Fig. 10.—Location of the burner: if the compartment is too short to permit a free-standing burner, it may be placed in a pit under the car which is protected with a metal shield. A second method of correction is to construct a tight addition at the rear for the sulfur burner, such as shown in the illustration at the right.

A horizontal ceiling is recommended, in preference to leaving the house open to the roof, as this reduces the gas volume and facilitates convection about the tray stack. The shape of the roof itself is unimportant except that some protection may well be given to the doors. The wide overhang shown in figure 8, *B*, however, is probably more than is economically justified.

The width of the compartment also should be reduced to a minimum; a clearance of 2 to 3 inches on either side of the tray stack should be adequate to permit ready placement or removal of the cars.

Tight Construction.—A fundamental requirement of the compartment is that it must be tight against air leakage which would cause drafts and disturb the sulfur dioxide gas distribution about the tray stack; such construction is shown in figure 9. This requires tight sheathing and that all construction joints of the structure be sealed, the larger ones with mastic. Painting the interior surfaces of the structure with asphalt or other acid-resistant paint seals small cracks. The light, wood-frame structures covered with sacking as described by Jewell (1927*a* and 1927*b*) are much too porous to hold a desirable gas concentration. Lining the compartment with asphalt building paper or plywood with sealed

joints is also practiced, and is one of the most satisfactory methods of correcting badly deteriorated wood frame houses. The structure should be so tight that no light sources other than the vents are visible to a person within the closed compartment, and that fumes can be seen escaping from only the vents of a house in operation. Since the door is difficult to keep tight in its frame, it is necessary to use a replaceable weather strip-

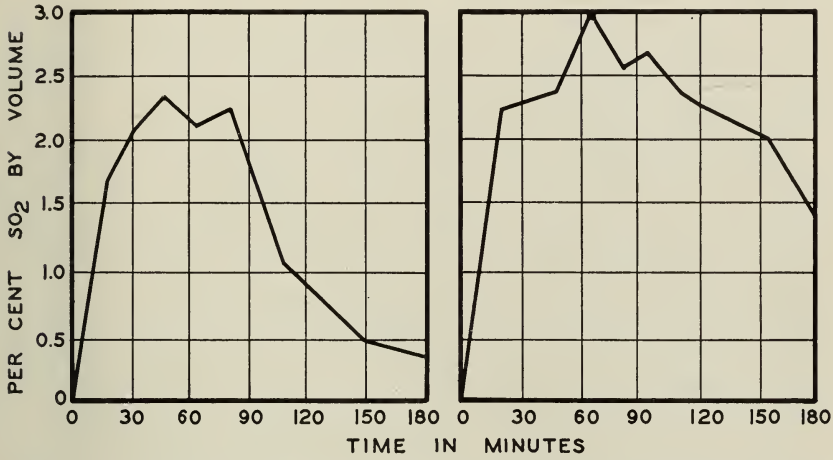

Fig. 11.—The tightness of the door can be a critical factor in an otherwise tight house, as shown in the results of simultaneous tests on two compartments of the house shown in figure 8, *C*. The superior gas concentration secured in the compartment as illustrated by the graph at the right was achieved by plugging the 1½-inch-diameter outlet vent at the top center of the rear wall and the ¼-inch crack behind the top of the vertical sliding door. The door crack alone had opened about 10 square inches of leakage area. The large amount of sulfur burned (8½ pounds) accounts for the concentration curves being much higher than would normally be expected from the earth burner-pits used. The sulfur dioxide absorption by the apricots in the untightened compartment was 3,140 parts per million, and by those in the tightened compartment, 3,780.

ping or some similar pliant material along the door jamb to form a tight joint when the door is closed. The results obtained by tightening the doors of the house illustrated in figure 8, *C* are shown in figure 11.

Type of Door.—The type of door is often a matter of controversy. The ordinary door hinged at the side is sometimes criticized as being in the way of car movements, but the field experiments failed to substantiate this claim, particularly if the house was set back far enough from the cross track to permit free operation of the door. Advantages are simplicity of construction and operation, and the ease with which it may be weather-stripped. A door hinged at the top to swing up is in a convenient position when opened, but counterweighting and the horizontal position subject the door to racking and early deterioration. Overhead

door supports as illustrated in figure 8, *G* add to the life of top-hinged doors; a counterweight and cable balance as shown in figure 8, *A* causes less racking of the structure than the overhead balances shown in figures 8, *F* and *H*. The vertical sliding door tends to rack the entire structure, and is more difficult to weather-strip, particularly at the crack between door and ceiling. Regardless of type, the door must be well braced to hold its shape, and should have roof or flashing protection to prevent roof water draining directly on the door. Eccentric or wedge fasteners, such as refrigerator door fasteners, should be used to force the door to a tight fit against the jamb weather-stripping. Door hardware should be painted with bituminous paint to protect it against acid attack.

Natural Ventilation.—Since the amount of air within a closed compartment is not sufficient to burn the sulfur necessary to accumulate and maintain the desired sulfur dioxide concentration, it is obvious that some ventilation must be supplied. If it has been possible to tighten the compartment against leakage beyond the critical ventilation point and no ventilation is supplied, the burning sulfur will smother. The color of the sulfur slag formed under such conditions will be a bright sulfur yellow, in contrast to the continuous black coating over the slag resulting from sulfur smothered by impurities as illustrated in figure 5.

Tests were made of several types of natural-draft ventilation for tight houses, including outlet and inlet holes of various areas and locations, and vertical outlet flues. Ceiling outlets similar to those described by Cameron and associates (1929) gave satisfactory results. It was concluded, however, that the simplest adequate system for the one-car house using a 10-inch-diameter burner pan consists of inlets of not more than 2-square-inch area each at both track openings under the door, and two outlets of 1-inch-diameter holes placed, respectively, at the top center of the door and of the rear wall. When the burner pan is set in a pit, a 2-inch pipe sloping down from in front of the door to the pan level may be used as an air inlet instead of the track vents. These systems are relatively free of backdrafting or any gas disturbance within the compartment, regardless of the direction or velocity of the wind. If a strong wind is blowing directly against either the front or rear wall, closing the outlet on the windward side is desirable to reduce drafts on the interior. If the wind is blowing against the front of the house, it is also advisable to partially close the inlets. With a tight house and ventilation system of this type the orientation of the house with respect to the wind has little effect on the conditions within the compartment. The results to be expected from such a house under practical operating conditions will be comparable with those illustrated in figure 4.

If it should be found desirable to increase the sulfur dioxide concentration by more rapid burning from a larger-area sulfur burner, it will be necessary to increase the size of the ventilation system in proportion. An incomplete series of controlled tests on this phase of the problem indicate that the total outlet area should be about $\frac{1}{50}$ of that of the free-burning surface area of the sulfur. It is easily possible to get the

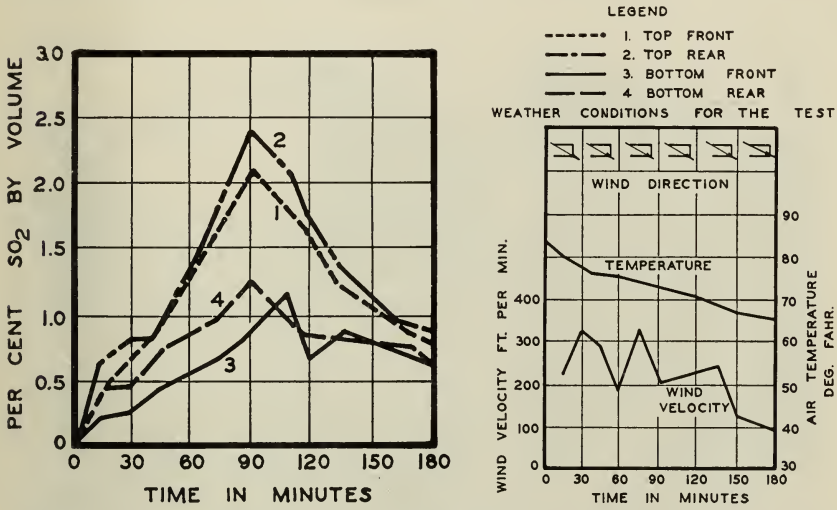

Fig. 12.—Excessive venting may cause drafts. The results shown above were secured in the new, plastered house, shown in figure 8, *H*. Inlet vents of a 4-inch tile under the door and four 1-inch diameter holes at the bottom of the door, and an outlet vent consisting of a 1½-inch pipe through the rear wall at mid-height, were used. In addition there was appreciable leakage between the door and jamb. The draft sweeping through the lower part of the house resulted in a definite gas stratification.

ventilation system too large; keep the area just adequate to completely burn the sulfur. The results of excessive and improperly designed ventilation in the house illustrated in figure 8, *H* are shown in figure 12.

Forced Ventilation.—A limited number of observations and tests were made of forced-draft ventilation in which air was supplied under a slight pressure to the sulfur burner by a mechanical system, with no provision for outlets other than leakage. In no instance were the results superior to those of an adequate and well-designed natural-draft system, when a good-burning sulfur was used. Forced draft, however, permits the use of rock sulfur and of the poorer grades of sublimed sulfur which do not burn readily under natural-draft conditions. The economic advantage of a fan to burn these cheaper grades of sulfur is questionable. Typical forced-draft equipment is shown in figure 13.

Some tests were also made of a forced convection system in which small

electric fans placed within the compartment augmented the natural convection. The advantages secured with this system over those of natural convection in a properly built house are so slight that they do not justify the added expense.

Construction Material.—The material used in the construction of a house must permit construction which will remain tight under the hazards of use and weather. The use of large sheet materials with few

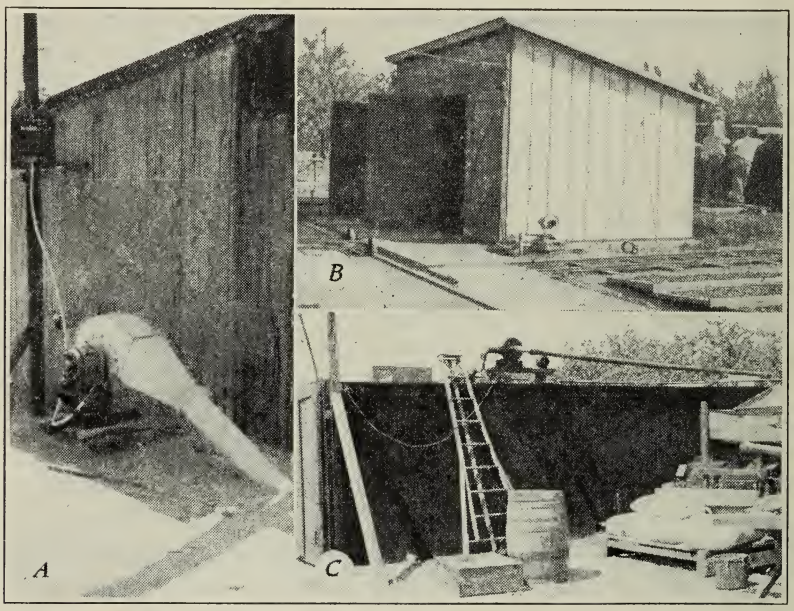

Fig. 13.—Fan installations for mechanical ventilation to the sulfur burner. *A*, Large installation for multiple houses. *B*, Small-scale installation mounted on the ground near the front of the house. *C*, installation for a single large house, mounted on the roof. The installations tested did not give results superior to properly designed natural draft; such equipment may, however, permit the burning of the cruder forms of sulfur.

construction joints appears more favorable than that of those with numerous joints. Concrete, brick, plywood, sheet steel, and matched lumber sheathing covered with asphalt building paper on a wood frame have been used successfully.

Many observations and tests made on sulfur houses constructed of different materials, including the experimental houses shown in figure 14, failed to show an outstanding operating advantage for any one, provided the construction was tight. Masonry structures have some effect in maintaining a more uniform interior temperature, generally tending to lower temperatures during the warmer part of the day and

higher at night. The plywood and steel structures permitted more ready conduction of solar radiation, and their interior temperatures tended to follow the diurnal atmospheric temperature. Under the test conditions, however, these effects were not of sufficient magnitude to have any appreciable effect on the temperature of the fruit; heat from the burning sulfur was a factor of greater importance in this respect.

Masonry and steel structures have the advantage of being fire-resistant. Plastered structures as a class were among the tightest of the farm

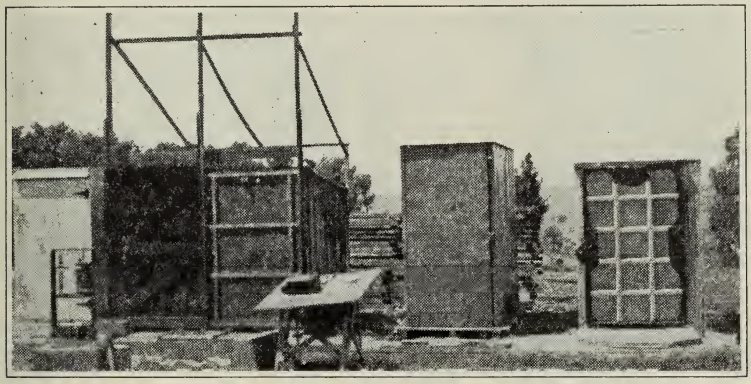

Fig. 14.—Experimental sulfur houses of different materials erected near Aromas. From left to right they are: a plywood house of shop-fabricated panels; an old farm duplex with one compartment remodeled with plywood; a shop-fabricated steel house; and a concrete house made of precast panels.

structures tested; heavy annual maintenance is required, however, owing to the destructive action of acid on the plaster.

Painting.—It is recommended that structures, regardless of the material, be given two bituminous or other acid-resisting paint coats on the interior to protect them against the severe acid conditions incident to their use, and to decrease leakages. Steel and concrete surfaces, including plaster and mortar joints in brick construction, are susceptible to early attack by the acid and should be painted two coats with a good grade of gilsonite asphalt or other acid-resistant paint. Houses with wood siding should be painted on the exterior to prevent weathering and the formation of shrinkage cracks. A good grade of exterior lead-and-oil paint should be used; plumbago paint has been used in some instances as being more resistant to the sulfur dioxide gas.

Moisture Condensation.—When fruit sulfured in the evening was permitted to remain in the experimental steel and plywood houses all night, condensation formed on the walls and ceiling; no moisture was apparent at any time in the concrete house. Such condensation may be

a factor augmenting the destructive action of the sulfur dioxide gas on the construction materials.

Remodeling Old Houses.—The house should be built on a concrete foundation in preference to mud sills to gain greater rigidity and freedom from cracks. It is essential that the joint between foundation and

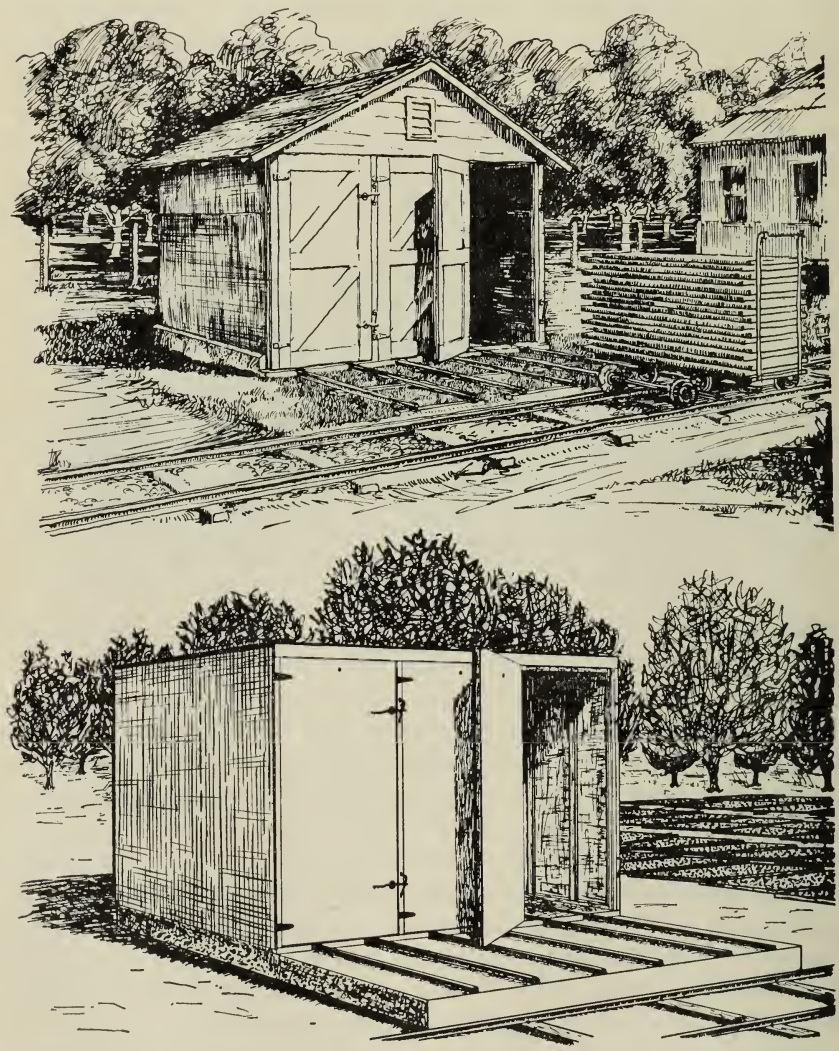

Fig. 15.—Sulfuring houses embodying the principles of good design. Plans and specifications for these are available for a nominal fee from the Agricultural Extension Service, University of California, Berkeley, California. The upper picture shows a gable-roofed three-compartment house, listed as plan C-173; the lower is a three-compartment, flat-roofed plywood structure, plan C-194.

sill be sealed with asphalt mastic to prevent air infiltration. A concrete floor is an aid in maintaining sanitary conditions.

Steel rails used for car tracks are durable and more satisfactory than wood rails lined with strap steel.

Old sulfur houses which are structurally sound can be reconditioned by sealing the interior, tightening the door, and reroofing. For the interior treatment, plastering, or lining with asphalted paper, plywood or light-gauge sheet steel followed by proper painting will prove satisfactory.

New Construction.—Plans for two designs of sulfur houses are available, as shown in figure 15.[14] Structures erected from these plans have been built and tested under farm operating conditions, and found to meet the standards outlined in this publication.

RETENTION OF SULFUR DIOXIDE BY THE FRUIT DURING DRYING

Of the sulfur dioxide held by the fruit when it leaves the sulfur house only a fractional part remains at the end of the drying period. The greatest loss occurs during the first 24 hours of drying-yard exposure. The graphs shown in figures 16 and 17 indicate the change in the proportion of sulfur dioxide in the fruit at different periods during drying. The sulfur dioxide retention has been plotted on a logarithmic scale so that the relative slopes of the curves may better illustrate the rate of change in this proportion for the different stages of drying. It has been determined that the losses are minimized by rapid dehydration, and by favorable drying-yard conditions. It is desirable to secure as rapid drying as possible, especially during the first half day. The fundamental conditions favoring rapid drying are heat and dry air passing over the trays.

Relation of Loss of Moisture and of Sulfur Dioxide.—The observation stated above is in keeping with the observations of Roleson and Nichols (1933) and Hanus and Vorisek (1937) that the sulfur dioxide content of fruit after it has been exposed in the drying yard for one day will approximate the retention when dried. During the first 24 hours the loosely held sulfur dioxide tends to leave the fruit rapidly. Heating of the fruit by solar radiation and the drying of the fruit surface apparently increase the fixation of sulfur dioxide and make its escape from the fruit more difficult. After this initial period the rate of loss of sulfur dioxide decreases, the rate being greater from the moist fruit and slow-

[14] Plans available from Agricultural Extension Service, University of California, Berkeley, California. (Price 25 cents per plan.)

ing as the drying approaches completion. The rate of moisture loss tends to follow a similar trend.

The sulfur dioxide content of fruit is expressed in parts per million as related to the weight of the drying or dried fruit at a given time. In

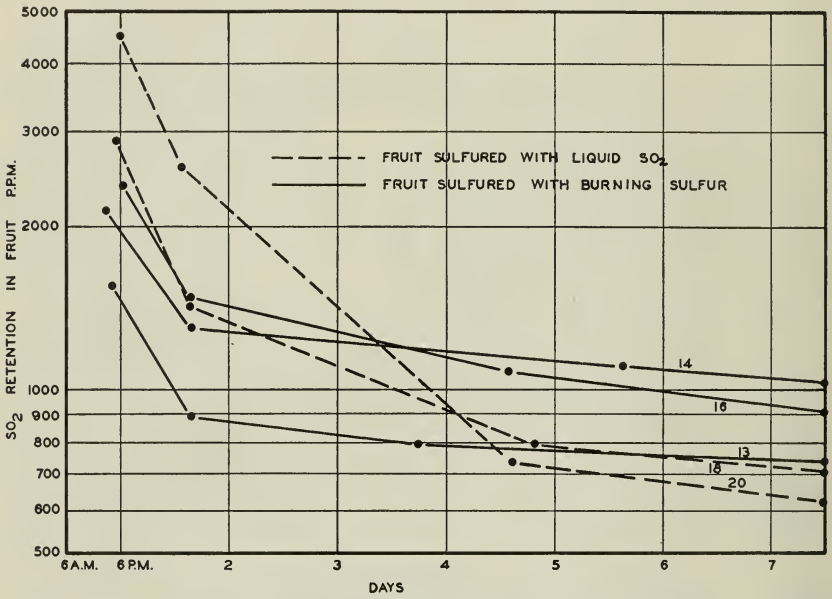

Fig. 16.—Five tests showing the loss of sulfur dioxide from drying apricots under natural drying-yard conditions. Fruit sulfured with liquid sulfur dioxide for a short time evidently had low fixation.

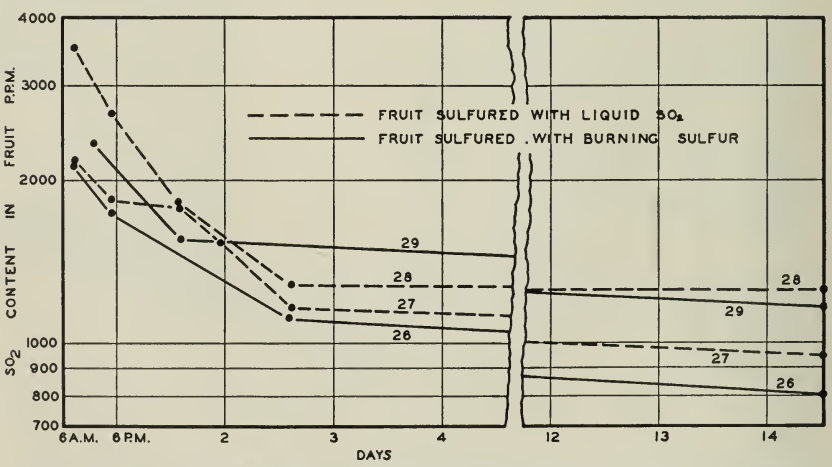

Fig. 17.—Four tests showing loss of sulfur dioxide from drying pears under typical drying-yard conditions. Fruit sulfured with liquid sulfur dioxide evidently had low fixation.

most of the fruit-drying areas the loss of weight in water is sufficient after the first 24 hours to tend to keep the ratio for sulfur dioxide content almost constant. In the Aromas apricots and in the Lake County pears this ratio was not maintained constant but declined at a much

TABLE 9

SULFUR DIOXIDE RETENTION IN DRIED FRUIT AS AFFECTED BY VARIETY AND LOCALITY

Fruit and variety	District	Year	Number of tests	Sulfur dioxide in freshly sulfured fruit, p.p.m.	Sulfur dioxide in dried fruit, p.p.m.	Retention ratio
Apricots:						
Blenheim	Vacaville	1937	2	4,005	1,978	0.49
Blenheim	Davis	1937	1	4,250	1,970	0.46
Blenheim	Aromas	1938	4	2,230	715	0.32
Blenheim	Hollister	1937	5	3,475	1,085	0.31
Hemskirke	Hollister	1937	4	2,400	1,254	0.52
Moorpark	Hollister	1937	1	1,970	1,035	0.52
Royal	Hemet	1938	3	2,730	2,800	1.02
Royal	Upper Ojai Valley	1938	1	1,970	1,225	0.62
Royal	Ventura	1938	2	4,160	1,790	0.43
Royal	Suisun Valley	1938	8	2,720	1,052	0.39
Royal	King City	1938	1	3,253	1,104	0.34
Royal	Aromas	1938	3	2,130	600	0.29
Royal	Aromas	1939	4	2,781	420	0.15
Tilton	Davis	1937	6	4,340	2,350	0.54
Tilton	Hollister	1937	1	2,670	1,090	0.41
Tilton	Aromas	1938	5	2,480	565	0.23
Tilton	Aromas	1939	3	2,056	309	0.15
Nectarines:						
New Boy	Gridley	1937	2	2,030	1,150	0.57
Peaches (clingstone):						
Paloro	Escalon	1937	2	2,510	1,630	0.65
Peaches (freestone):						
Lovell	Brentwood	1937	1	1,860	1,040	0.56
Muir	Esparto	1937	2	2,800	1,530	0.55
Pears:						
Bartlett	Kelseyville	1938	5	2,760	1,106	0.41
Raisins (sulfur bleach):						
Thompson Seedless	Kerman	1938	13	2,365	1,020	0.42

slower rate after the first day; this is shown in figures 16 and 17. In the Hemet district the moisture loss is sufficiently more rapid than the sulfur dioxide loss to cause an apparent gain in the sulfur dioxide content, as shown in the analysis and retention ratio of table 9.

Expressing the analyses as actual contents on a moisture-free basis rather than as ratios would have shown a continual sulfur dioxide loss

from the time the fruit left the sulfur house for both Aromas and Hemet, the difference being a much smaller and slower loss for the latter. The ratio expression is preferred for this investigation as it is commonly used in the dried fruit industry. A more accurate picture of the various phenomena concerned would be secured if the analyses were expressed on a moisture-free basis.

Effect of Climatic Differences.—The climatic differences of the various districts particularly with respect to temperature and relative humid-

TABLE 10

COMPARISON OF SULFUR DIOXIDE LOSSES FROM FRESHLY SULFURED APRICOTS HELD IN TRAY STACKS OVERNIGHT WITH THOSE SPREAD IN THE EVENING; AROMAS, 1939

Fruit and test conditions	Absorption, p.p.m.	SO_2 content of freshly sulfured fruit next morning, p.p.m.	Per cent SO_2 lost overnight	SO_2 content of dried fruit, p.p.m.	Retention ratio, dried fruit
Royal apricots; kept in house overnight; door left open from 8:00 p.m; night fog.	2,325	1,510	35	530	0.23
Tilton apricots; kept in house overnight with door ajar from 8:30 p.m; night fog.	3,185	1,830	43	475	.15
Tilton and Blenheim apricots; held on car on track overnight from 7:00 p.m; night fog	2,635	1,256	53	415	.16
Royal apricots; spread on drying yard at 6:00 p.m. as fog rolled in	2,330	1,100	53	355	.15
Royal apricots (same lot as preceding) spread at 9:30 a.m. after remaining in opened sulfur house overnight	2,330	1,260	46	330	0.14

ity materially affect the retention ratios, as shown in table 9. A comparison of these ratios serves as a relative rating of the drying effectiveness, or drying-yard efficiency, in the different districts. The drying conditions in Aromas in 1939 were not so favorable as during 1938, and this is reflected in the retention ratios for the two years. Considerable difference in retention ratio may be secured in any given district or between districts of similar climate because of the variations in the initial sulfur dioxide absorption by the fruit. The higher the initial absorption analysis for any given drying condition, the lower the retention ratio. Hence, it is obvious that the fixation of sulfur dioxide by the fruit is not directly proportional to the absorption. Furthermore, it will be observed that quickly sulfured fruit of high initial sulfur dioxide content loses this

at the greatest rate; this is, presumably, attributable to the fixation-time factor previously mentioned.

Placing of Fruit on the Drying Yard in the Evening.—Growers frequently hold sulfured fruit overnight in the sulfur house rather than

TABLE 11

EFFECT OF LOCATION OF DRYING YARD WITHIN A DISTRICT ON RETENTION OF SULFUR DIOXIDE; AROMAS, 1938

Test no.	Location	SO_2 absorption, p.p.m.	Absorption factor	SO_2 in dried fruit, p.p.m.	Retention ratio
13a	Hillside location	1,550	31.0	670	0.43
14a	Hillside location	2,120	10.9	940	.44
15a	Notch between two hills, subject to strong air currents	1,060	10.1	830	.78
16a	Protected hollow on river bank, in alfalfa field	2,380	13.2	650	0.27

TABLE 12

EFFECT OF GROUND COVER IN THE DRYING YARD ON SULFUR DIOXIDE RETENTION BY APRICOTS

Drying-yard condition		SO_2 content of freshly sulfured fruit, p.p.m.	SO_2 retention, p.p.m.	Retention ratio
Green grass, 8 to 10 inches high	Trays laid on grass	2,910	490	0.17
	Trays supported 2 feet above the ground	2,260	510	.23
Dry grass	Trays laid on 2-inch rails, flat on the ground	3,200	640	.20
	Trays supported 2 feet above the ground	3,340	850	0.25

spread it on the drying yard in the late afternoon or evening. While considerable sulfur dioxide loss takes place from fruit so held in the house it is not so great as that from fruit spread during a cool, humid evening. In developing the individual test data for table 9 it was noticed that invariably those samples spread after midafternoon had retention ratios below the average for that district.

If the fruit is held in the tightly closed house overnight, it frequently

juices enough to run out on the tray. This causes a loss in weight of the dried product, impairs the quality grade, and increases the labor of tray cleaning. Most operators follow the practice of opening the door slightly, or of partially removing the car from the house, as they believe that this reduces juicing, presumably because of the cooling of the fruit.

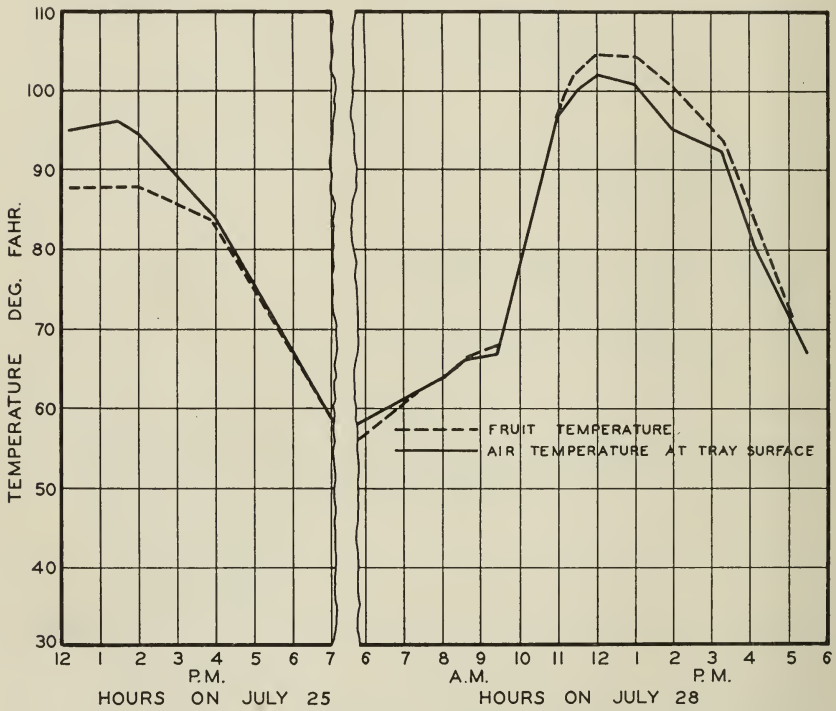

Fig. 18.—Typical Aromas drying-yard conditions for two days, showing the relative internal temperatures of the fruit at different stages of drying with relation to adjacent air temperatures. The freshly sulfured fruit was placed in the drying yard at noon. Evaporative cooling at the cut surface of freshly sulfured fruit holds the internal temperature below the air temperature until the surface has dried. The divergence between temperature of air and partially dried fruit on the 28th was minimized by clouds.

Comparative tests indicating the losses to be expected from this procedure and from evening spreading in the drying-yard, are summarized in table 10. Although these results were from only one test for each condition, it would appear desirable under such conditions to delay sulfuring until about midnight and to open the house as early next morning as possible to prevent excessive juicing.

Securing High Retention Ratio.—Drying-yard factors favorable to high retention ratios include: (1) spreading the fruit in the drying-yard

immediately after sulfuring to secure full sun exposure and (2) a moderate, arid breeze to evaporate any juice from the cups and the surface moisture in 3 hours or so. Shade, fog, or location near bodies of water or green vegetation all retard drying and reduce sulfur dioxide retention.

Table 11 gives comparison data of one test sample each from four privately operated drying yards in the Aromas district, located within a 1-mile radius. Those for tests 13*a* and 14*a* were hillside locations; the retention ratios of these two were almost identical. Test 15*a* was on a drying yard in a "notch" between two peaks and subjected to strong air currents. The high retention ratio, however, is believed to be partially

TABLE 13

EFFECT OF TRAY COLOR ON SULFUR DIOXIDE RETENTION BY TILTON APRICOTS

Color	SO_2 content of freshly sulfured fruit, p.p.m.	SO_2 retention, p.p.m.	Retention ratio
Black	3,165	400	0.13
White	3,165	270	.08
Weathered brown	3,165	420	0.13

due to the fact that the test fruit was held overnight in the sulfuring compartment and subjected to leakage from an adjacent compartment, with a higher fixation resulting. Test 16*a* is from a lowland drying yard, near a river. The humidity from the heavy vegetation along the river and from the alfalfa covering the drying yard undoubtedly delayed drying and so reduced the retention ratio. Similar undesirable results from green vegetative ground cover in the drying yard were also noted in one instance in the Hemet district. The high absorption ratio for test 13*a* is believed to be due to the exceptionally low gas enviroment maintained during sulfuring.

Further evidence of the influence of drying-yard environment on the retention of sulfur dioxide by the fruit is given in table 12. These data are from one test series of Aromas (1939), hence the influence of humidity close to the ground and above dried grass is more pronounced because of the night fogs than would be the case in interior-valley yards. For such climatic conditions, or on drying yards covered with green grass, setting the trays on wooden horses 2 feet above the ground will prove beneficial.

Fruit Temperatures During Drying.—When fruit is first exposed to the sun the ready evaporation of moisture maintains the internal temperature of the fruit below that of the air at the tray surface. Later the slower evaporation and darker color of the fruit (and consequently

TABLE 14

COMPARISON OF THE EFFECT OF SUN-DRYING AND DEHYDRATION ON RETENTION OF SULFUR DIOXIDE BY APRICOTS; AROMAS

Treatment	SO_2 retention, p.p.m.	Per cent increase in SO_2 retention of dehydrated over sun-dried	Retention ratio
Sulfured with liquid SO_2 for 95 minutes at 4 per cent concentration			
Freshly sulfured fruit	2,870	...	....
Sun-dried; spread 5:00 p.m.	520	...	0.18
Dehydrated	790	52	.27
Sun-dried; spread next a.m.	600	...	.21
Dehydrated	790	32	0.27
Sulfured under typical farm conditions			
Freshly sulfured fruit	1,418	...	....
Sun-dried	370	...	0.26
Dehydrated	778	110	.55
Freshly sulfured fruit	1,820	...	....
Completely sun-dried	690	...	.38
Sun-dried 24 hours	900	...	....
Dehydrated, after sun-drying 24 hours	1,190	72	.65
Freshly sulfured fruit	2,394	...	....
Sun-dried	472	...	.19
Sun-dried, after dehydrating 1 hour	520	10	.22
Freshly sulfured fruit	2,600	...	....
Sun-dried	375	...	.15
Dehydrated, after sun-drying 3 hours	1,810	375	.68
Dehydrated	1,780	375	.68
Freshly sulfured fruit	1,770	...	....
Sun-dried	420	...	.24
Dehydrated, after sun-drying 3 hours	920	119	.52
Dehydrated	1,050	150	0.60

greater absorption of solar radiation) result in internal temperatures rising above the air temperature during the hours of solar radiation, as shown in figure 18.

Effect of Tray Color.—The color and surface texture of the tray is a factor in the heating of the fruit, the darker colors being more effective in absorbing solar radiation and transmitting it to the fruit. This is

TABLE 15

Effect of Dehydration on Time of Drying and on Sulfur Dioxide Retention; Aromas

Dehydration studies										Sun-drying control				
Preheating period vents closed			Drying period vents open		Moisture content in dried fruit, per cent	Total drying time, hours	SO_2 absorption in freshly sulfured fruit, p.p.m.	SO_2 retention in dehydrated fruit, p.p.m.	Retention ratio	Moisture content in dried fruit, per cent	Total drying time, days	SO_2 absorption in freshly sulfured fruit, p.p.m.	SO_2 retention in sun-dried fruit, p.p.m.	Retention ratio
Time hours	Temp. °F	Relative humidity per cent	Temp. °F	Relative humidity, per cent										
2	150–160	48	140–145	11–30	11.7	20.5	3270	1280	0.39	17.4	12–15	3140	430	0.137
2	165–175	40	160–165	11–25	18.3	15.5	3247	1880	.58	22.3	12–15	3247	412	.127
3	140–150	35	145–150	16–25	18.0	15.0	2600	1780	.68	22.9	12–15	2525	375	.148
3	160–165	30	145–150	15–20	13.2	18.0	1770	1050	0.60	20.5	12–15	1770	420	0.240

shown in the one test itemized in table 13. During the progress of this experiment it was observed that air temperatures on the tray surfaces were 12° to 18° Fahrenheit higher at midday on the black-painted surfaces than on the white. Those on the naturally weathered brown tray surfaces were within 6° of the black-surface temperatures. Fruit temperatures exhibited the same general differences, but tended to range 5° to 12° below their respective tray temperatures for the first 5 days of drying because of evaporative cooling.

Dehydration.—The apparent effect of rapid drying in reducing the sulfur dioxide loss, at least during the initial stages, led to a limited number of dehydrater trials, all with favorable results. The data shown in table 14 give the scope of one trial series designed to show the relative effect of complete dehydration, and of partial dehydration taken either as the initial drying period or delayed until after an initial sun exposure intended to fix a more attractive color. The retention ratios of the dehydrated products in every case show an appreciable advantage, although all initial sulfur dioxide contents were low. The moisture loss in the dehydrater was sufficiently rapid to give an apparent gain in sulfur dioxide content, but obviously lower total retention, compared to that in the fruit put in from initial drying-yard exposures. This is similar to the situation existing in the arid Hemet drying yards, previously described.

Table 15 lists the dehydrater data for a series of runs in which the drying was expedited by preheating for 2 to 4 hours in the dehydrater with the vents closed. This brought the fruit up to the dehydrating temperature more rapidly and so reduced the time requirement for drying.

Apricots immediately after dehydration appeared somewhat lighter in color and with slightly less luster than the drying-yard product. In the 1939 tests dehydrated fruit after three months' storage had attained a very attractive color, markedly superior to the darkening drying-yard fruit produced in the check tests.

SUMMARY

The results secured in this investigation on the sulfuring of fruits for drying indicate that there are three phases of the problem: (1) The absorption of sufficient sulfur dioxide by the freshly cut fruit to allow for normal drying and storage losses and still maintain a high-quality fruit; (2) the maintenance of favorable drying conditions with low loss of sulfur dioxide; (3) storage at cool temperatures and moderately low humidities to retain the sulfur dioxide during storage. Only the

first two of these are within the scope of the present investigations, since they are of immediate concern to the grower. The conclusions and observations based on the survey and experiments are summarized in the following paragraphs.

The sulfur house should be economical and durable and designed to promote rapid, uniform sulfuring. In a house of sufficiently tight construction to prevent drafts, vents will be required to provide air for burning the sulfur. For the type of vents recommended, a fixed ratio must be maintained between the vent area and the surface area of the sulfur burner. Doors hinged at the side and secured with refrigerator-type latches are preferable to vertical sliding doors or those hinged at the top, when the door opening does not exceed 4 feet. For wider openings a door hinged at the top and secured against the jambs with refrigerator-type latches is preferable. The interior surfaces of sulfuring compartments should be painted with acid-resistant paints, regardless of the construction material, for durability and to tighten the structure against air leakage.

An old, leaky sulfuring compartment giving unsatisfactory results should be remodeled or replaced. Plans for new sulfur houses are available through the Agricultural Extension Service, University of California.

Sulfur should be burned in a clean metal pan of 10-inch diameter. Clean concrete hearths of equivalent area are satisfactory burners. Unlined earthen pits are unsatisfactory. Insulated, regenerative or forced-draft burners may be desirable for burning the poorer grades of sulfur, or those carrying contaminants.

Laboratory experiments have demonstrated that the black film or scum from some low-quality sulfurs consists chiefly of carbon or carbonaceous matter. Of the various kinds of organic materials added to test samples of a high-quality sulfur, petroleum oils were found to cause the formation of a black surface film most rapidly, and thus decreases the percentage of sulfur burned. By increasing the temperature of poor-burning sulfurs to cause more rapid volatilization, it was shown that poor-quality sulfur could be burned completely.

A good grade of refined sulfur is recommended as being more economical and less troublesome than cheaper grades. The sulfur should burn completely, leaving not more than 1 or 2 ounces of residue from the standard 4- or 5-pound charge. If an appreciable amount of slag remains, the reason may be surmised from its color. Proper handling and storage of the sulfur supply is essential; it must not be permitted to come into contact with oily surfaces or vapors.

The temperatures at various points in the sulfur house differ considerably during sulfuring, commonly showing a difference of 20° Fahrenheit between ceiling and floor. Sulfuring fruit at the relatively high temperatures of 100°–120° tends to decrease absorption but increases retention of sulfur dioxide. Fruits sulfured at high temperatures, however, bleed more readily than when sulfured at lower temperatures.

The freshly sulfured fruit should be dried as rapidly as possible. Every possible advantage should be taken in the location of the drying yard, and in placing the fruit on the drying field, to maintain conditions favorable to rapid moisture evaporation.

Dehydration offers definite advantages in coastal areas where climatic conditions during the drying season are unfavorable to the production of a high-quality product.

Size, variety, and maturity as well as the districts in which the fruit is produced and dried are important factors in determining the absorption of sulfur dioxide during sulfuring and its retention during drying.

ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance received from the Pomology and Chemistry divisions of the College of Agriculture; Dr. Ioan Radu, Institute for Agricultural Research of Rumania, Bucharest; Messrs. H. A. Beekhuis, H. Bedford, B. L. Hatherell, and Farrell Stone of the California Dried Fruit Association; farm advisors R. D. McCallum, V. W. De Tar, M. M. Winslow, V. F. Blanchard, and T. W. Thwaits; F. E. Twining and Max Bartholomew; Dr. Maynard Joslyn; the Douglas Fir Plywood Association; the Portland Cement Association; the Soule Steel Company; and numerous growers and drying-yard operators.

LITERATURE CITED

Anderssen, F. G.
1929. Sulfur dioxide in dried fruit. Union So. Africa Dept. Agr. Bul. 84:3–14.

Beekhuis, H. A.
1935. Sulfuring cut fruits as a dry-yard practice. Rept. Dried Fruit Assoc. Calif. 15 p. (Mimeo.) February 15. Dried Fruit Association of California, San Francisco, Calif.
1936*a*. Producing California quality cut dried fruit. Bul. Dried Fruit Assoc. of Calif. 16 p. Dried Fruit Association of California, San Francisco, Calif.
1936*b*. Producing dried pears. Rept. Dried Fruit Assoc. Calif. 6 p. (Mimeo.) April 17. Dried Fruit Association of California, San Francisco, Calif.
1938. Sulfuring cut fruits in the dry-yard. Rept. Dried Fruit Assoc. Calif. 5 p. (Mimeo.) Dried Fruit Association of California, San Francisco, Calif.

Bioletti, Frederick T., and William V. Cruess.
1912. Enological investigations. Calif. Agr. Exp. Sta. Bul. 230:1–118.

Bioletti, Frederick T., and A. E. Way.
1919. Saving raisins by sulfuring. Calif. Agr. Exp. Sta. Cir. 211:1–4.

Caldwell, Joseph S.
1923. Evaporation of fruits. U. S. Dept. Agr. Dept. Bul. 1141:1–64.

Cameron, S. S., G. Quinn, C. G. Savage, W. R. Jewell, and A. V. Lyon.
1929. The sulfuring of dried fruits. Austral. Council Sci. & Indus. Res. Jour. 2:151–55.

Chace, E. M., C. G. Church, and D. G. Sorber.
1930. Large-scale experiments in sulfuring apricots. Indus. and Engin. Chem. Indus. Ed. 22:1317–20.
1933. Large scale experiments in sulfuring apricots. II. Effect of dehydrating, shade drying, and blanching. Indus. and Engin. Chem. Indus. Ed. 25: 1366–70.

Christie, A. W., and L. C. Barnard.
1925. The principles and practice of sun-drying fruit. California Agr. Exp. Sta. Bul. 388:1–60.

Croce, Francisco M.
1936. Desecacion natural de fruta. Ministero de Industrias y Obras Publicas, Mendoza, Argentina. Boletin 5:3–90.
1937. Desecacion natural y artificial de frutas y hortalizas. Ministero de Industrias y Obras Publicas, Mendoza, Argentina. Boletin 24:1–344.

Cruess, W. V.
1921*a*. Salvaging rain damaged prunes. California Agr. Exp. Sta. Cir. 212:1–11.
1921*b*. Evaporation of fruits and vegetables. Amer. Jour. Pub. Health 11:6–12.
1938. Commercial fruit and vegetable products. 2nd ed. p. 453–54. McGraw Hill Book Company, New York, N. Y.

Cruess, W. V., and A. W. Christie.
1921. Dehydration of fruits. California Agr. Exp. Sta. Bul. 330:49–77.

Cruess, W. V., A. W. Christie, and F. C. H. Flossfeder.
1920. The evaporation of grapes. California Agr. Exp. Sta. Bul. 322:421–71.

Culpepper, C. W., and H. H. Moon.
1937. Drying Kieffer pears and the use of the dried product. U. S. Dept. Agr. Dept. Cir. 450:1–24.

HANUS, JOSEPH, and JAN VORISEK.
1937. The determination of sulfur dioxide as a preserving agent in dried fruit. Chem. Listy 31:408–13. Abstracted in: Chem. Abs. 32:3501.[9]

JEWELL, W. R.
1927*a*. Sulfuring dried fruit. Victoria Dept. Agr. Jour. 25:457–62.
1927*b*. Sulfuring dried fruit. Victoria Dept. Agr. Jour. 25:565–67.

LOVE, C. F.
1937. Sulfuring cut fruits. Sunsweet Standard 21:8.

LYON, A. V.
1930. The sulfuring of apricots. Austral. Council Sci. & Indus. Res. Jour. 3:161–66.

NICHOLS, P. F.
1933. Methods of sun-drying fruits. California Agr. Ext. Cir. 75:1–37.

NICHOLS, P. F., and A. W. CHRISTIE.
1930*a*. Drying cut fruits. California Agr. Exp. Sta. Bul. 485:1–46.
1930*b*. Dehydration of grapes. Calif. Agr. Exp. Sta. Bul. 500:1–31.

NICHOLS, P. F., C. D. FISHER, and W. PARKS.
1931. Finding moisture content. West. Canner and Packer 23:11–13.

NICHOLS, P. F., E. M. MRAK, and R. BETHEL.
1939. Effect of drying and storage conditions on color and SO_2 retention of dried apricots. Food Res. 4:67–74.

NICHOLS, P. F., RAY POWERS, C. R. GROSS, and W. A. NOEL.
1925. Commercial dehydration of fruits and vegetables. U. S. Dept. Agr. Dept. Bul. 1335:1–40.

NICHOLS, P. F., and H. M. REED.
1932. Distillation methods for determination of sulfur dioxide. Indus. and Engin. Chem., Analyt. Ed., 4:79–84.

PACOTTET, P.
1911. Vinificacion en los vinedos meridionales. J. B. Balliere e Hijos. Paris. p. 224–28.

PERKINS, L.
1925. Fruit drying in South Africa. Union So. Africa Dept. Agr. Reprint 46: 1–25.

QUINN, GEO.
1926*a*. Notes on sulfuring fruits prior to drying. Jour. Dept. Agr. South Australia 30:500–10.
1926*b*. Fruit drying for amateurs and beginners. Jour. Dept. Agr. South Australia 30:514–27.
1935. Fruit drying for amateurs and beginners. Dept. Agr. South Australia Bul. 198:1–16.

QUINN, GEO., C. G. SAVAGE, A. V. LYON, and W. R. JEWELL.
1929. Sulphuring apricots. Victoria Dept. Agr. Jour. 27:607–08.

RENNIE, A. R.
1936. Producing high quality apricots. Rept. Dried Fruit Assoc. Calif. 8 p. (Mimeo.) April 17. Dried Fruit Association of California, San Francisco, Calif.

ROLESON, E. P., and P. F. NICHOLS.
1933. Pointers for sulfur dioxide. West. Canner and Packer 25:7.

SHEAR, S. W.
1939. Deciduous fruit statistics. Giannini Found. Agr. Econ. Contrib. 66:1–73. (Mimeo).

15*m*-11,'40(6645)