



A study of the time-temperature relationships in the cookery of vegetables
by Alda Constance Torgerson

A THESIS Submitted to the Graduate Committee in partial fulfillment of the requirements for the
degree of Master of Science in Home Economics

Montana State University

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IN THE COOKERY OF VEGETABLES

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INTRODUCTION

Vegetables are no longer considered as accessories to a meal, but have come to be regarded as essentials in the daily human food supply. They rank next to cereals in their carbohydrate content and are classed with fruits as an important source of minerals and vitamins B and C. In addition, their pleasing flavors, distinctive colors, and cellular texture make them attractive and stimulate the appetite.

While a number of the vegetables may be used in the raw state, many of them require cooking in order to be edible. However, Bogert (2) says, "Vegetables are more abused in cooking than any other class of foods. It is no wonder that people refuse to eat the unpalatable messes which are usually served up in the name of vegetables, but this is the fault of the cook, not of the vegetables." It is apparent from such a statement that more consideration should be given to the cookery of vegetables, in order that they may be handled in ways that will render them both nutritious and palatable.

Some attention has been given to them in connection with the loss of their nutrients, especially minerals and vitamins, where methods of cookery, addition of salt and amounts of

cooking water were considered.

Changes in the flavor of vegetables have been taken into account from the standpoint of retaining the mild flavors and preventing the development of strong flavors during cooking.

There has also been some evidence to indicate that certain precautions, such as the degree of heat, the length of the cooking period, and the acidity of the water used, should be observed so that the original green, yellow, red or white color of the vegetable might be retained.

Occasionally, various authors have published time-tables for the cooking of vegetables, but upon comparison, their recommendations either do not agree or they suggest a wide range in time. In only a few cases, has there been any mention of the temperature, for which the time was specified.

It is evident, then, that there is a need for more information about the temperature maintained during various methods of cookery and the rate of heat flow into the vegetables subjected to these methods, so that a product may be obtained that is satisfactorily cooked. For this reason, this study has been carried on in connection with the Home Economics Department of the Montana Experiment Station, in an attempt to establish some time-temperature relationships in the cookery of vegetables.

HISTORY

Prior to 1917, very little work had been carried on to determine the nature of vegetable foods and the most satisfactory methods for their preparation. Outside of recipes in cook-books, there was little published material.

Then in 1917, Parloa (14) published a bulletin on the cooking of vegetables, giving some descriptions of the structure and composition of the plants and the principles underlying their preparation for food. However, no exact times were mentioned for their cooking periods and only the suggestion was made that they should be cooked until tender.

In a series of experiments carried on later by Halliday and Noble (8) at the University of Chicago, emphasis was placed on the length of the cooking time in relation to the losses of nutrients, flavor and color in vegetables, when they were cooked by various methods. They definitely recommended certain methods in order to avoid these losses, and advocated a certain range of time for cooking each vegetable with the advice to "cook it only until tender".

While considering cooking methods and the resulting losses, the question arose as to the advisability of using salt during the boiling process. Lanman and Minton (11) investigated this problem and concluded that the color of vegetables was not noticeably changed by the addition of salt to

to the boiling water. While they found that in some cases there was a greater loss of nutrients due to the presence of salt, there appeared to be enough advantage in the texture and flavor of the cooked vegetables to warrant its addition at the beginning of the cooking period. In none of their work, however, did they mention whether the salt had any effect on the temperature of the cooking medium or whether it affected the length of the cooking period. Daniels (4) stated that chemically pure sodium chloride had no hardening effect on the substances of which vegetables are composed, but the calcium contained in most table salt gave results similar to that of cooking in hard water.

Optimum times for cooking as determined by scoring, percentage losses in solids and total ash when the vegetables were cooked to a satisfactory texture, and the H-ion concentration of the water after cooking were included in the results of studies conducted by Field, Server, and Milner (6) on some California fruits and vegetables. The optimum cooking time, they suggested, fell within the ranges given by Halliday and Noble (8) with the exception of cabbage and turnips.

In a study of baking vegetables electrically, Swartz (19) pointed out the time required when the vegetables were baked at various temperatures. When medium potatoes, unpeeled, were placed in an oven at 500° F., they were done in 40 min-

utes, but at 250° F., they were done in 3 - 3½ hours. No method was used for specifically determining when the vegetables were done, as that was based solely on the opinion of the investigator.

Sinoda, Kodera and Oya (16) also seem to recognize a relation between time and temperature in their study of the critical temperature in cooking sweet potatoes. They advise the cooking of the sweet potato at higher temperatures for shorter times due to the fact that a morphological change in the starch granules is observed at temperatures higher than 80° C. Polymerization of the lower sugars begins, and the taste is largely influenced by the content of these unknown polymerization products. (17)

Another factor to be considered in the relation between time and temperature in cooking is altitude. At higher altitudes the temperature of boiling water is lowered and that necessitates an increase in the cooking time. Thiessen (20) in her bulletin published by the Wyoming Experiment Station has presented recommendations for cooking vegetables at an altitude of about 7000 feet above sea level, but her suggestions concerning the times of cooking were not very definite. Also in judging the point at which the vegetables were done, she merely pierced them with a fork to test their tenderness.

A study of the time required for cooking potatoes at an altitude of 5000 feet above sea level was made by Gill (.7),

who concluded that the size of the piece of potato is a factor, which influences the length of time,- a one-inch cube requiring 25 minutes of boiling and a two-inch cube, 30 minutes.

Apparently, then, the length of time required to cook a vegetable at a certain temperature depends upon the rate of heat flow or heat penetration in that vegetable at that particular temperature. Some studies of the rate of heat penetration in cooking have been made by Magoon and Culpepper (12), Bigelow (1), and Thompson (21), but these have been chiefly from the standpoint of the commercial canning of fruits and vegetables. For measuring the rate of heat penetration, they inserted either thermometers or thermocouples into the center of the can, but not necessarily into the center of the pieces of food material. Consequently, their results indicate the heat flow in the liquid or cooking medium as well as in the fruit or vegetable. The same thing might be said of a study at Iowa State College, where Redfield, Nelson and Sunderlin (15) experimented with heat penetration in meats and vegetables, processed in glass containers. They found that the variables used in canning as size of jar, closeness of pack, initial temperature and consistency of the vegetables have a decided influence on the time required for penetration of the heat to the center of the jar.

Some workers have felt that a method of standardization

was needed in order to determine when a vegetable had been desirably cooked. The ordinary way of piercing with a fork was recognized to be uncertain and subject to variance with individual judgment. In attempting to set up a desirable standard for cooked carrots, Landreth (10) used a Vicot apparatus which measured the pressure required to drive a needle into a cube of carrot in five seconds. Lancaster and Sweetman (9) determined the "doneness" of uniform slices of potato by means of a penetrometer. It consisted of a blunt, uniform needle which penetrated the cooked vegetable under a ten gram weight. The amount of penetration into the vegetable was measured. They also studied the speed and evenness of cooking in relation to maturity, size, period in storage and variety of potato. Recently another penetrometer has been devised by the United States Food and Drugs Administration. It also has a blunt, uniform needle which penetrates the cooked vegetable but the weight is supplied by a weighed flask to which mercury is added until a small light indicates that the needle has penetrated to the desired depth. The weight of the flask and the mercury it contains is recorded as the weight required for penetration or an indication of the tenderness of the vegetable.

These studies comprise practically all of the scientific work that has been done along the line of vegetable cookery.

Investigations on the relation of time to temperature or the rate of heat penetration have been carried on chiefly in connection with commercial canning. Recommendations for the time of cooking vegetables by home methods are not very specific with the result that many vegetables are often poorly cooked and therefore unpalatable.

In view of this situation there appears to be a need for further accurate investigation in the field of home cookery of vegetables, particularly in regard to the rate of heat flow at various cooking temperatures.

EXPERIMENTAL PROCEDURE

The vegetables chosen for this study were potatoes, carrots, beets, onions and cabbage, since they are commonly grown in Montana and large quantities of them are usually stored for winter consumption.

These vegetables were obtained from local truck gardens where they were kept in pits and readily available during the winter months. The varieties used throughout the study were:- potatoes, Netted Gem; carrots, Chantenay; beets, Dark Red; onions, True Spanish; and cabbage, Danish Baldhead.

Each vegetable was prepared for cookery according to certain adopted methods. The carrots were thoroughly washed with a vegetable brush, then some were scraped, while others were allowed to retain the skin. A sample weighing approximately 500 grams was used for each cooking test. For the samples, the carrots were cut as accurately as possible into one-inch cubes, two-inch cubes, and one by two-inch pieces, respectively. The one by two-inch pieces were always secured by cutting a two-inch cube lengthwise.

The potatoes were washed and peeled with the exception of those that were to be cooked in the "jackets". The 500-gram samples of potatoes also consisted of one-inch cubes and two-inch cubes, respectively, with the addition of some samples of whole potatoes, approximately two by four inches in size.

The beets were washed well and left whole with the skins on during cooking, for the reason that they "bleed" when cut. A measurement of the diameter and length of each beet was taken.

The onions were washed and the hard outer layers were peeled off before cooking. They were also left whole and measured for diameter and length.

The cabbages were stripped of their coarse outer leaves and were then cut into quarters. Measurements of the length and width of the cut surfaces were recorded as the size of the individual pieces.

In addition to determining the weight of each sample, it seemed desirable to obtain its volume. To do this, the sample was placed in a receptacle of known volume and tap water was added until the lower meniscus of the water was on a level with the graduated mark on the receptacle. The difference between the volume of the receptacle and the volume of the water added gave the volume of the sample of vegetable.

The methods of cookery used for these tests were boiling, steaming, steam pressure cooking, and baking, either directly or in casseroles.

For boiling, two covered aluminum sauce pans, of four-quart capacity and similar in structure, were used as utensils.

Their respective weights including covers were 332 and 335 grams. Two holes were cut in the cover of each pan to permit the insertion of rubber stoppers holding either chemical thermometers or thermocouple wires. In most cases, 750 cc. of tap water, with a pH of 7.8, were poured into each pan to serve as the cooking medium. This water was taken from a large container where the water had been stirred in order to bring it to an approximately uniform temperature. The heat was then supplied by two 800-watt Calrod plates on a Hotpoint electric range with the controls turned to "high". These plates had previously been calibrated to show that they supplied heat at equivalent rates. The pans of water were placed on the hot electric plates at a definite time, and when the thermometers, suspended in the steam over the water, indicated that the boiling point corresponding to the barometric pressure had been reached, the samples of vegetable were added and the controls were turned to "medium".

For steaming the vegetables, a Conservo steamer was used. This consists of a square copper water-pan (11 x 11 x 2 inches) surmounted by a tin-plated cabinet (12 x 12 x 18 inches) having four wire shelves and two doors. After the pan had been filled with tap-water, the steamer was placed on one 800-watt Calrod plate of the Hotpoint electric range with the control turned to "high". When the water was boiling vigorously and

the steamer filled with steam, the vegetable samples, arranged in wire baskets, were placed on the two upper shelves. The thermocouples were introduced through an opening in one corner of the top, where ordinarily a pipe was inserted for the addition of more water.

In steam pressure cooking, three sizes of National Pressure Cookers were used:- the 10 quart size weighing $9\frac{1}{2}$ pounds, with a total volume of 8560 cc.; the 18 quart size weighing $17\frac{1}{2}$ pounds, with a total volume of 18,900 cc.; and the 25 quart size weighing 20 pounds, with a total volume of 24,850 cc. The amounts of tap water added to each pressure cooker for each sample cooked were:- 350 cc. to the 10 quart size; 500 cc. to the 18 quart size; and 750 cc. to the 25 quart size. In each case, the heat was supplied by an 800-watt Calrod plate of the Hotpoint electric range with the control turned to "high". As soon as the water boiled vigorously, producing a liberal amount of steam, the vegetable samples were put into the cooker. The safety-valve in the cover was removed and a rubber stopper carrying the insulated thermocouples was tightly forced into the opening. The cover was then placed on the cooker and the wing-nut screws carefully tightened. The pet-cock was left open and soon a steady flow of steam came from the opening. This stream of steam was allowed to continue for five minutes, so that the air might be complete-

ly removed, then the pet-cock was closed and the pressure was allowed to develop until a temperature of 250° F. was reached. This temperature was maintained within the pressure cooker as long as desired.

The direct baking of the vegetables was carried on in a Hotpoint electric oven (14 x 18 x 18 inches) provided with an automatic heat control. The controls of the upper and lower elements were turned to "high" and the oven was preheated to 375° F. The samples were then placed on a rack held in the eighth groove from the bottom. The thermocouples were brought into the oven through the opening at the back designed for steam escape. The electricity was then turned off the upper element.

Since most of the vegetables were not adapted to direct baking, the plan of baking vegetables in casseroles as developed by Swartz (19) was used. Four covered pyrex casseroles, having uniform volumes of $1\frac{1}{2}$ quarts and similar weights, were secured for this purpose. The vegetable samples were put into the casseroles and just before they were placed in the preheated oven, 250 cc. of hot tap water were added to each. The thermocouples brought in at the back of the oven were introduced into the casseroles through holes bored in the covers.

Thermocouples were used in each cooking test in order to determine the rate of heat flow in the vegetables. Certain

pieces in each sample of vegetable were selected as test pieces and the hot-end junction of a thermocouple was inserted so that its tip just reached the center of a piece. By this means the temperature at the center could be obtained at one-minute intervals. The equipment used for this purpose consisted of four six-foot Hoskins thermocouples, high resistance, No. 22 B & S gauge and asbestos insulated. By means of four Hoskins flexible leads, of high resistance type and standard length, these thermocouples were connected to a four-point selective switch, which in turn was connected to a Hoskins pyrometer, type TA 550° F., high resistance, with automatic cold end compensation.

While cooking the vegetables by boiling, steaming, or baking the temperature at the center of the vegetable gradually approached the boiling point of water and this temperature was maintained until the cooking process was completed. The amount of time that was required at the boiling temperature varied with the vegetable and the method of cooking.

A group of four judges from the Home Economics Department of the Experiment Station scored the cooked vegetables. The vegetables were first allowed to cool so that the heat would not mask the flavor. Judging sheets were supplied with each sample to be scored. Each sheet contained a grading score based on tenderness, texture, flavor and color. Each of these

factors was in turn divided into six gradations, beginning with the most desirable:

In addition to the judging of each sample of cooked vegetables, a penetration test for tenderness was made on at least three pieces from each sample with a penetrometer. This piece of equipment was devised by members of the Food and Drug Administration of the United States Department of Agriculture to use in determining the tenderness of foods under the provisions of the McNary-Mapes amendment to the Federal food and drugs act.

The liquid remaining in the cooking vessel at the completion of each experiment was tested for its pH value by the colorimeter method suggested by Clark (3).

This series of tests has been applied to the vegetables selected for this study and to various-sized pieces of these vegetables, for the purpose of comparing their time-temperature relationships during cookery.

RESULTS

In presenting the results of this investigation, a series of tables will be used, giving the data for the cooking of each vegetable by the various methods, and other results that accompanied these tests. These will be supplemented by a set of graphs showing the heat flow through the vegetables or the time-temperature relationships existing during their cookery.

Table I shows the average results obtained in the cooking of carrots. It will be noted that in the boiling of carrots, some samples were cooked in tap water without salt, while in other cases salt was added to the water at the beginning of the cooking period. In two instances distilled water was used in place of tap water, both with and without salt. In observing the average number of minutes required to cook these various samples under the conditions specified in the table, it will be seen that the size of piece affects the length of the cooking time, the larger the piece, the longer the time. The addition of salt to the tap water appears to have no effect upon the total cooking time. With distilled water, both with and without salt, there are some indications that a slightly longer cooking time is needed. When the 2 x 2 inch pieces of carrot are cooked with the skins on, instead of being scraped, they seem to require a longer cooking period. Although the baking of vegetables in casseroles in the oven has been

TABLE I. COOKING DATA FOR CARROTS.

Method of Cooking	Condition of Carrot	No. of Trials	Av. Size Piece in.	Av. Wt. Sample gms.	Av. Vol. Sample c.c.	Kind of Water	Vol. of Water c.c.	Wt. of Salt gms.	Cooking Temp. °F.	Av. No. Minutes Cooked
Boiling	scraped	4	1 x 1	503.0	600	tap	750	--	203.2	30
"	"	2	1 x 2	531.0	660	"	750	--	202.8	35
"	"	8	2 x 2	547.6	585	"	750	--	203.4	40
"	"	4	1 x 1	501.5	575	"	750	5	203.2	30
"	"	2	1 x 2	528.0	640	"	750	5	202.8	35
"	"	8	2 x 2	512.7	608	"	750	5	202.4	38
"	"	10	2 x 2	524.4	610	distilled	750	--	202.9	42
"	"	6	2 x 2	518.0	617	"	750	5	203.1	42
"	with skins	2	1 x 2	543.0	620	tap	750	--	202.1	35
"	" "	2	2 x 2	563.0	750	"	750	--	202.1	44
"	" "	2	1 x 2	553.0	640	"	750	5	202.1	35
"	" "	2	2 x 2	563.0	750	"	750	5	202.1	44
Steaming	scraped	4	1 x 1	490.0	625	"	1000	--	202.9	35
"	"	8	2 x 2	511.4	648	"	1000	--	203.1	44
"	with skins	4	1 x 2	527.5	635	"	1000	--	203.3	40
"	" "	4	2 x 2	517.5	655	"	1000	5	203.3	46
Baking*	scraped	5	1 x 1	501.6	636	"	250	--	202.4	82
"	"	3	2 x 2	514.7	637	"	250	--	202.4	90
P.C.** 10 qt.	"	1	1 x 1	463.5	610	"	350	--	250.0	3
" 18 "	"	1	1 x 1	506.0	600	"	500	--	250.0	3
" 25 "	"	1	1 x 1	498.0	660	"	750	--	250.0	3
" 10 "	"	1	1 x 2	535.0	660	"	350	--	250.0	5
" 18 "	"	1	1 x 2	533.4	640	"	500	--	250.0	4
" 25 "	"	1	1 x 2	518.5	---	"	750	--	250.0	4
" 10 "	"	1	2 x 2	537.4	660	"	350	--	250.0	6
" 18 "	"	1	2 x 2	531.3	640	"	500	--	250.0	5
" 25 "	"	1	2 x 2	537.5	670	"	750	--	250.0	5
" 10 "	with skins	1	2 x 2	550.5	520	"	350	--	250.0	12
" 18 "	" "	1	2 x 2	579.0	590	"	500	--	250.0	11
" 25 "	" "	1	2 x 2	550.0	660	"	750	--	250.0	10

* Baking in covered casserole

** Steam pressure cooking

recommended by some workers, the time needed to cook carrots by this method is twice as long as for boiling. The time for steam pressure cooking is noticeably short, in fact, about one-half as long as the time usually suggested for carrots at 250° F. in the time-tables.

Figures 1, 2, 3, 4, 5, 6 and 7 show a graphical representation of the average heat flow in cooking carrots by these various methods. These graphs are plotted from the thermocouple readings taken at intervals of one or two minutes. In figure 1 a comparison of the heat flow in pieces of scraped carrot of different sizes shows a sharp curve in the case of the smaller piece and a more gradual curve in the larger pieces. When salt is added to the cooking water the total cooking time is the same as for unsalted water and the heat curves are very similar. It will be noted in figure 2 that the rate of heat flow in carrots is the same when the cooking medium is either tap water or distilled water without salt, but the addition of salt appears to cause a sharper rise with tap water than with distilled water. In figure 3, curves are shown when the skins were left on the carrots during the boiling process. Since the 1 x 2 inch pieces were prepared by cutting a 2 x 2 inch pieces lengthwise, the skin was left on only one side and the time for boiling was the same as for boiling the scraped 1 x 2 inch pieces (see figure 1). The 2 x 2 inch

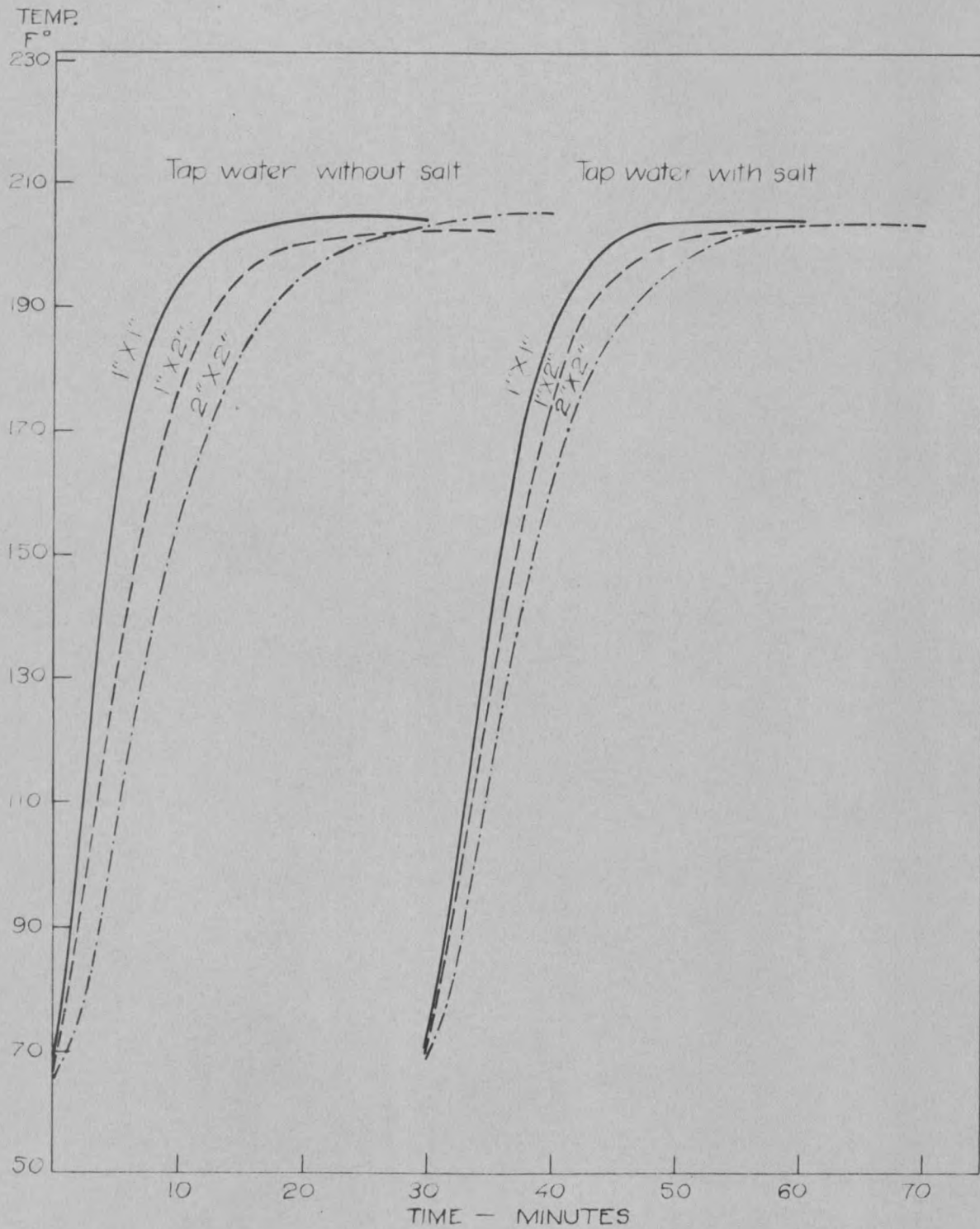


Fig. 1. Curves showing the time-temperature relationships during the boiling of scraped carrots, cut into pieces of various sizes, in tap water, without and with salt.

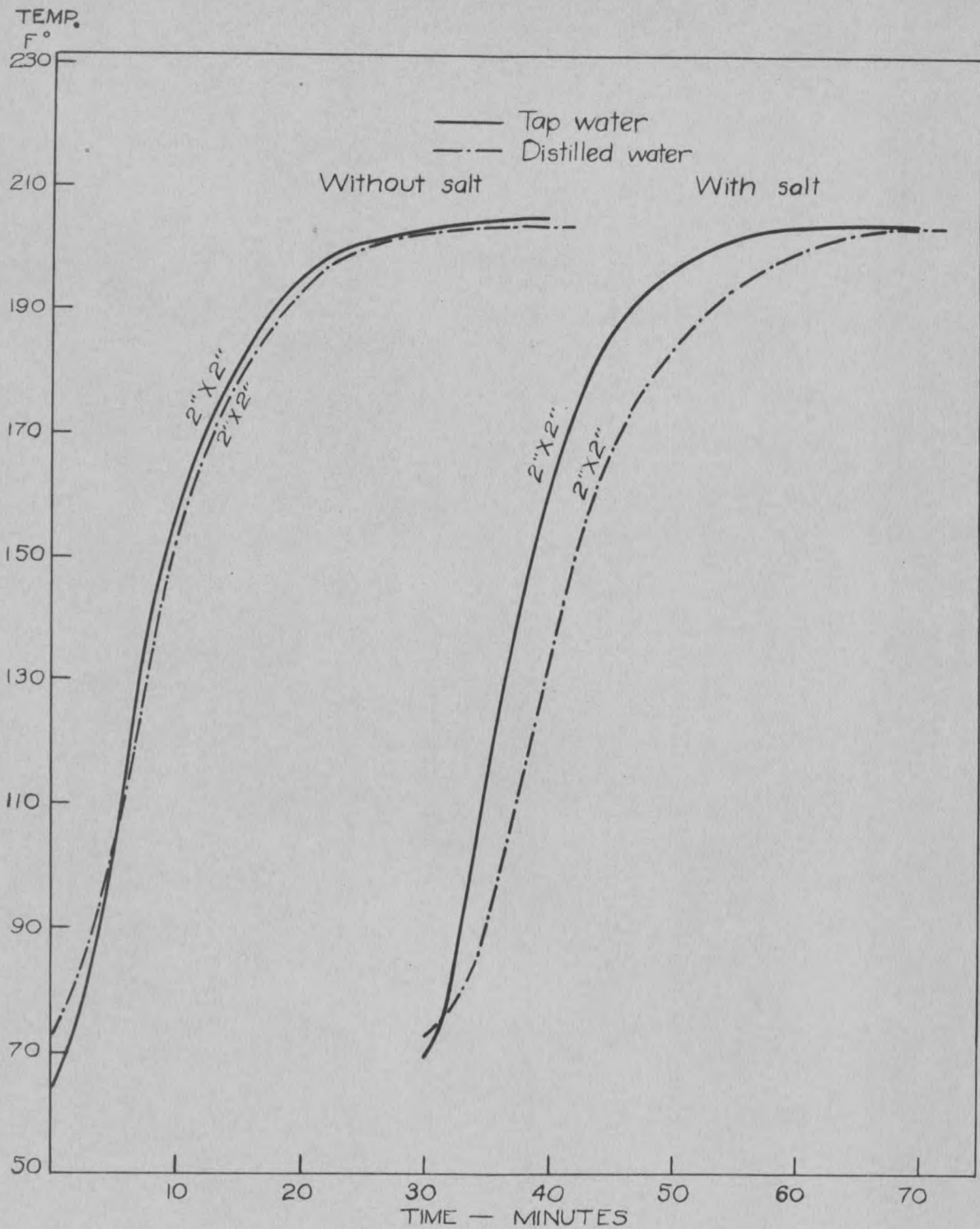


Fig. 2. Curves showing the time-temperature relationships during the boiling of scraped carrots in tap water and distilled water without and with salt.

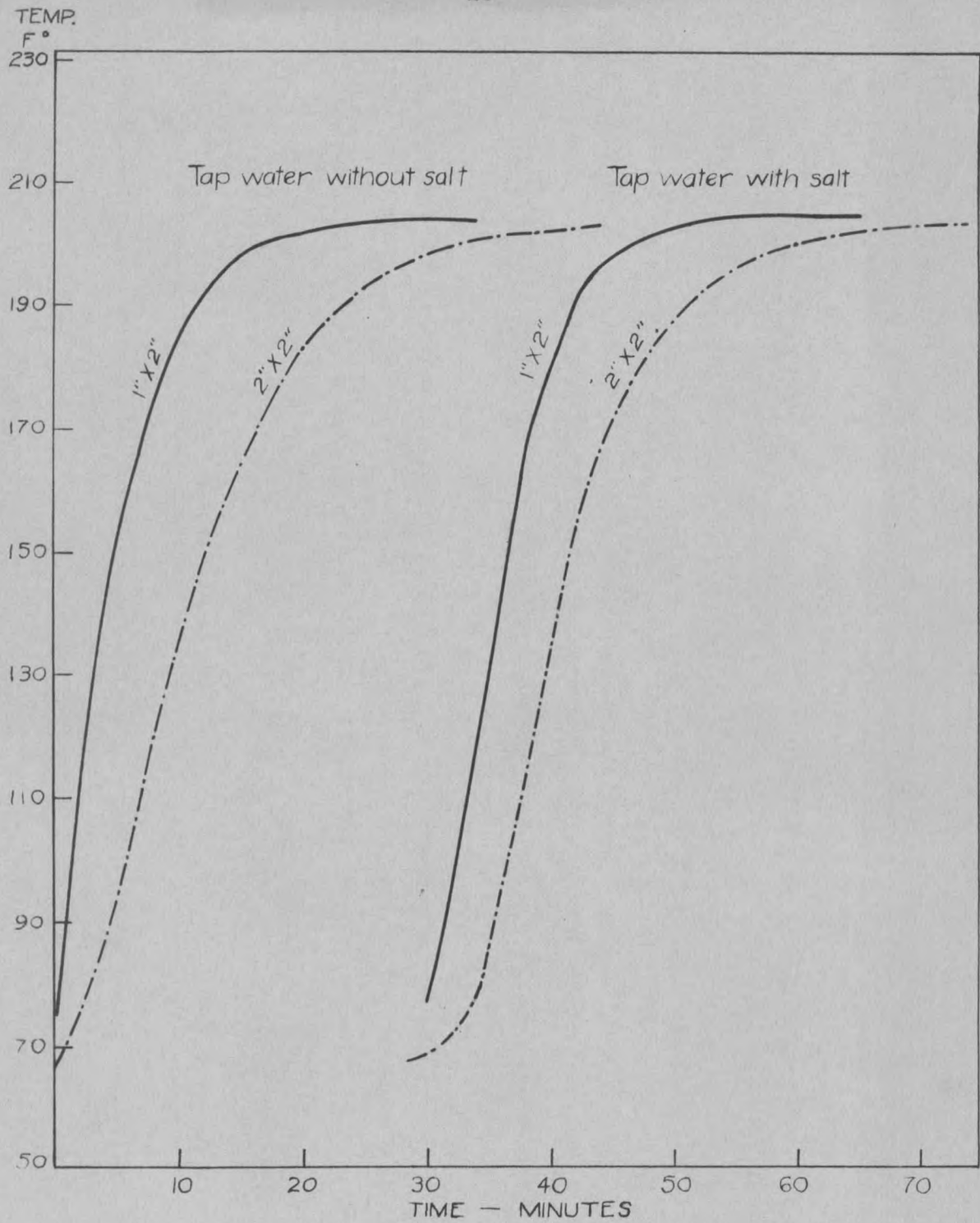


Fig. 3. Curves showing the time-temperature relationships during the boiling of carrots, with skin on, in tap water without and with salt.

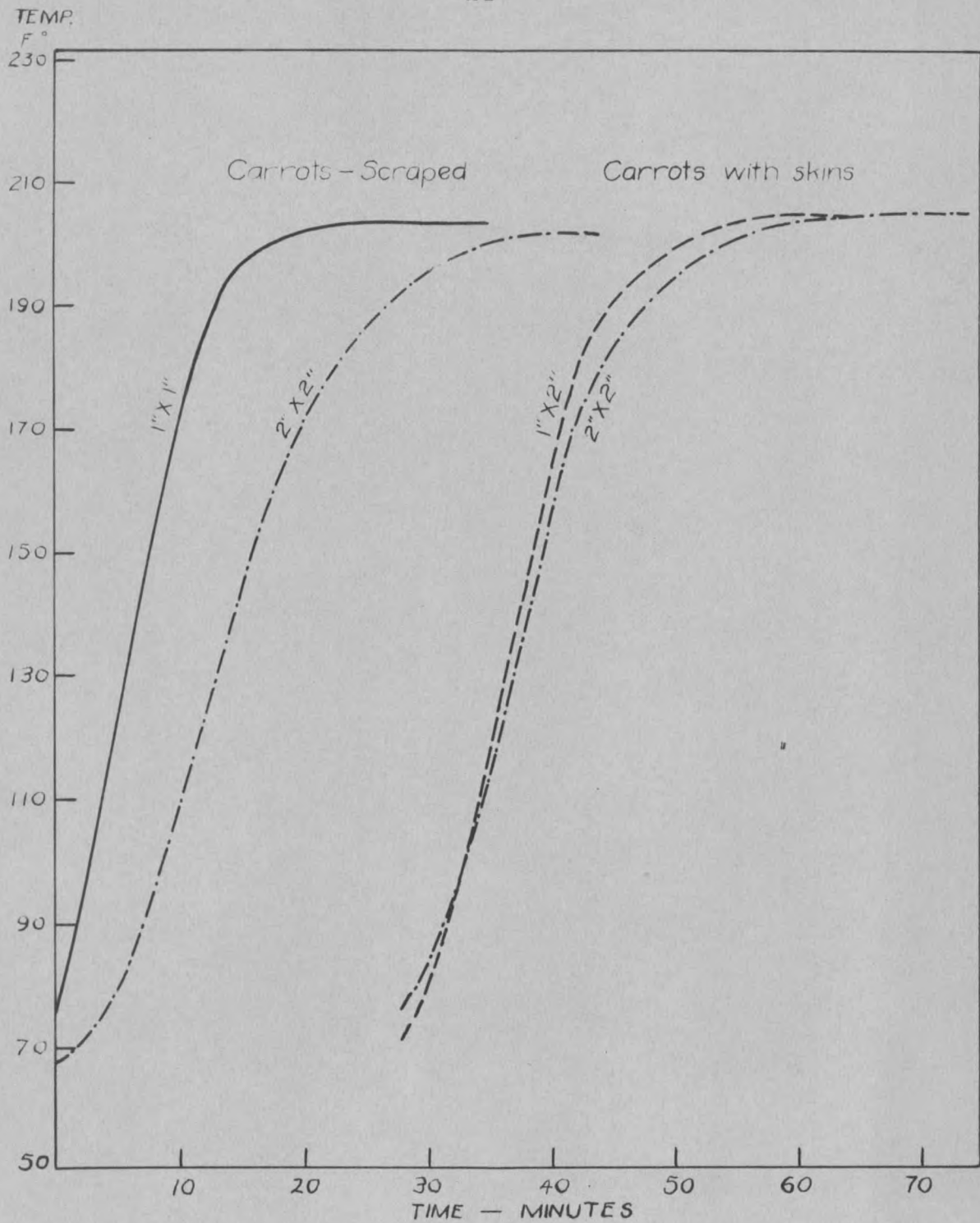


Fig. 4. Curves showing the time-temperature relationships during the steaming of carrots, scraped and with skins.

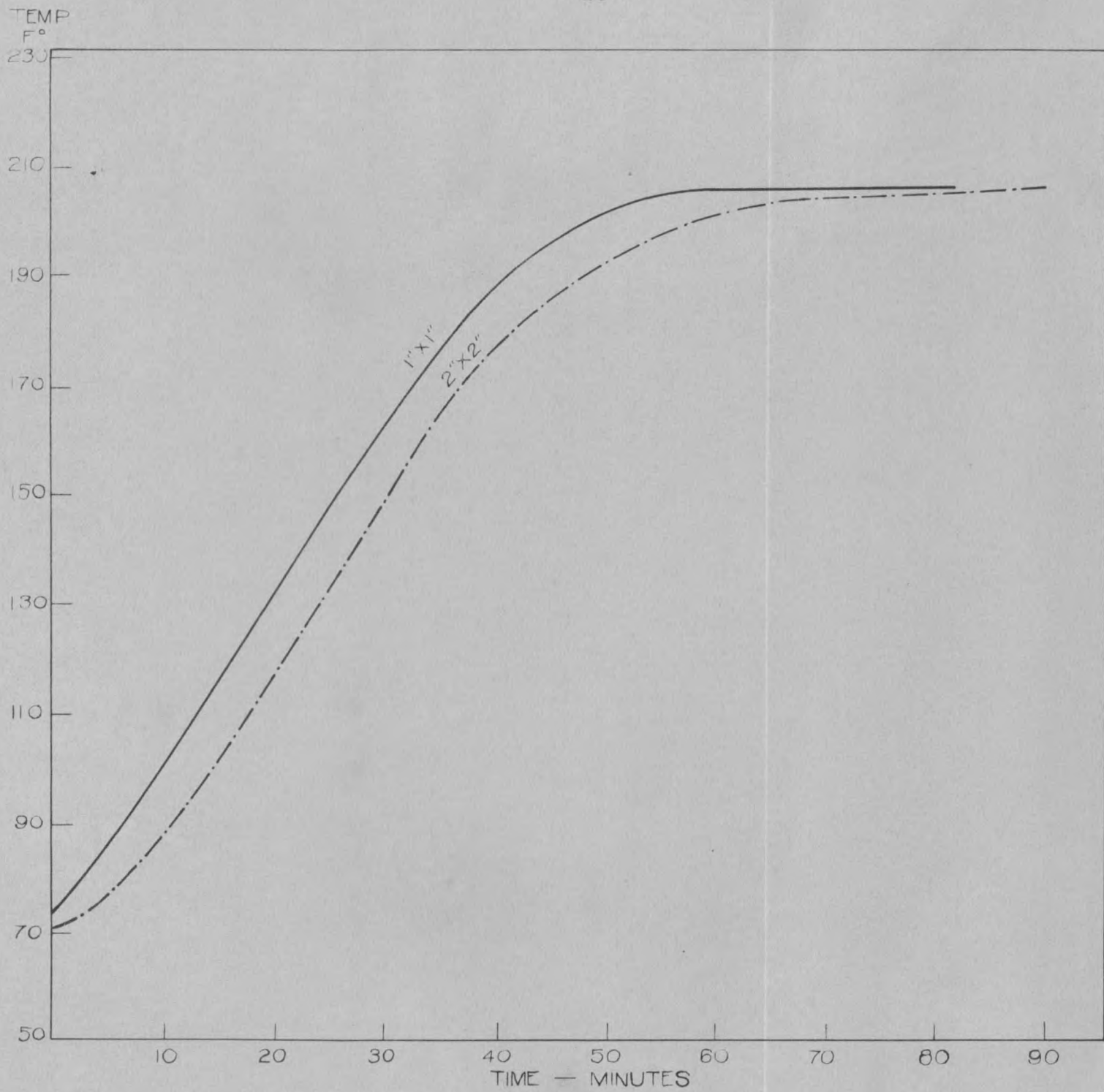


Fig. 5. Curves showing the time-temperature relationships during the baking of scraped carrots in casseroles.

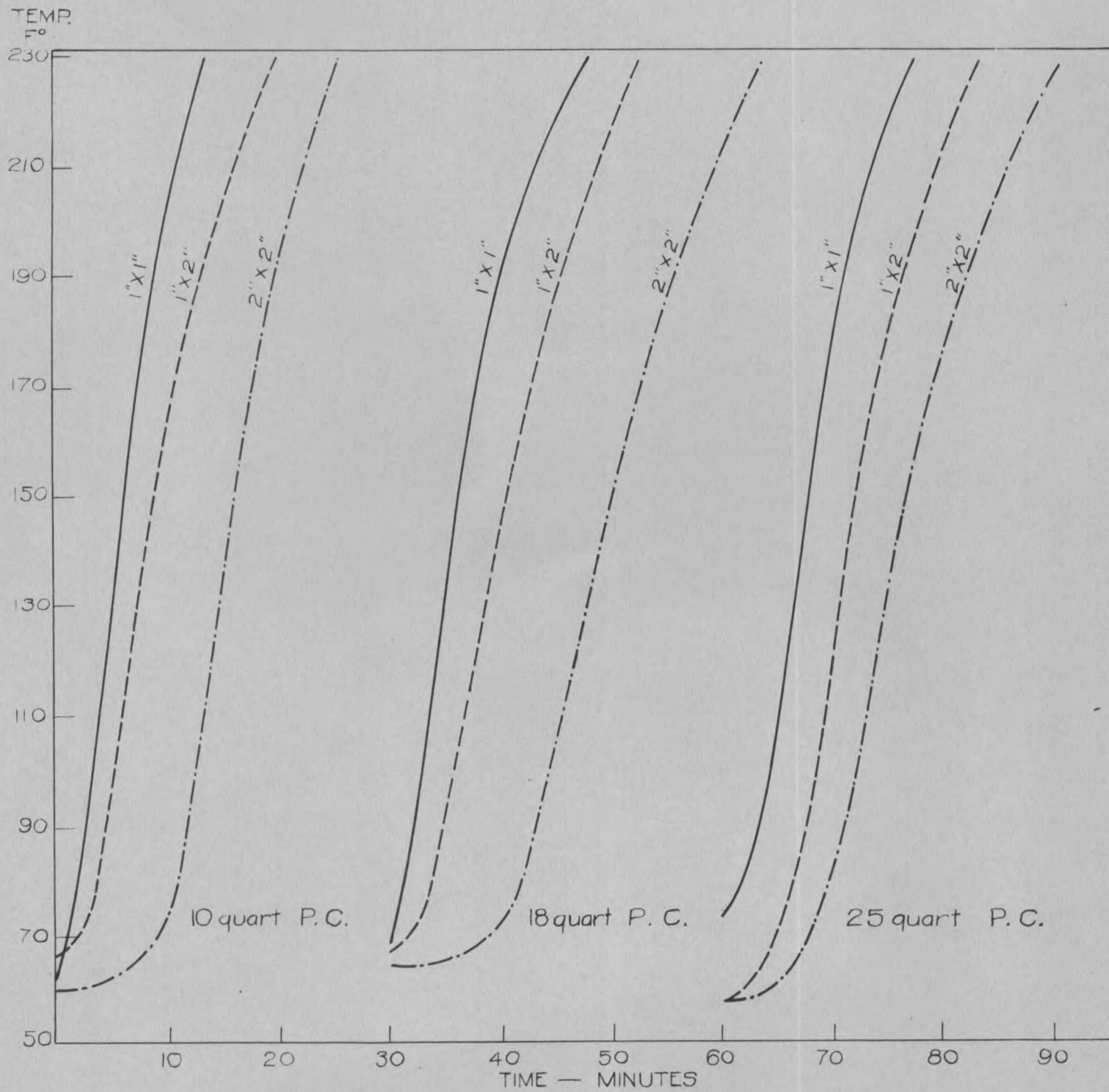


Fig. 6. Curves showing the time-temperature relationships during the cooking of scraped carrots in pressure cookers of three sizes.

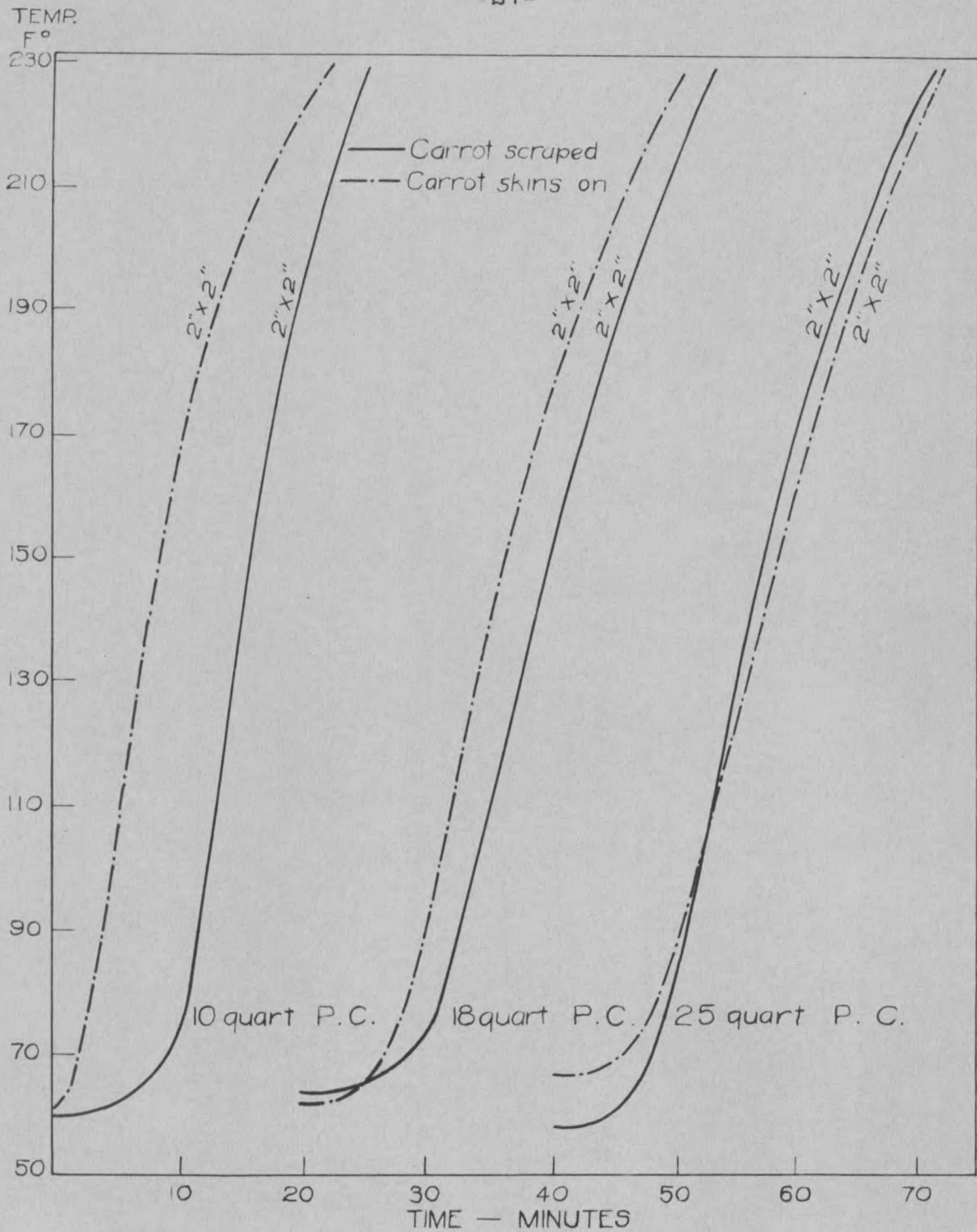


Fig. 7. Curves showing the time-temperature relationships during the cooking of carrots, scraped and with skins on, in pressure cookers of three sizes.

piece completely encircled by skin appears to have a slower rate of heat flow, both with and without salt in the cooking liquid, and this resulted in a longer cooking period.

It will be seen in figure 4 that steaming appears to cause a lag in the heat flow in scraped carrots when compared to that of boiling and the total time is longer. When the skins are left on, however, the rate of heat penetration more nearly approaches that during boiling.

There is a noticeable lag in the heat flow when carrots are baked in casseroles as indicated in figure 5. Again, the size of piece makes some difference and the total time is double that of boiling.

Figure 6 represents a comparison of the time for cooking various-sized pieces of carrots in three sizes of pressure cookers. In each case the smallest piece required the shortest time. All of the graphs are much steeper than in any other method of cooking. A comparison of the pressure cooking of 2 x 2 inch pieces of carrots with and without skins is shown in figure 7. The heat flow in the pieces with skins appears to be much more rapid when cooked in the 10 quart and 18 quart pressure cookers, but about the same as the scraped carrot in the 25 quart pressure cooker.

Table II gives the average results that were found in the cooking of potatoes. Again it will be noted that in boil-

TABLE II. COOKING DATA FOR POTATOES.

Method of Cooking	Condition of Potato	No. of Trials	Av. Size Piece in.	Av. Wt. Sample gms.	Av. Vol. Sample c.c.	Kind of Water	Vol. of Water c.c.	Wt. of Salt gms.	Cooking Temp. °F.	Av. No. Minutes Cooked
Boiling	peeled	4	1 x 1	501.5	590	tap	750	--	202.6	20
"	"	4	2 x 2	493.0	565	"	750	--	202.6	42
"	"	4	1 x 1	502.5	558	"	750	5	202.6	20
"	"	4	2 x 2	525.0	570	"	750	5	202.6	42
"	"	4	3 $\frac{1}{2}$ x 1 $\frac{1}{2}$	505.5	535	"	1000	--	202.8	42
"	with skins	4	3 $\frac{1}{2}$ x 1 $\frac{1}{2}$	514.5	550	"	1000	--	202.4	40
"	peeled	4	3 $\frac{1}{2}$ x 1 $\frac{1}{2}$	486.5	553	"	1000	5	202.8	42
"	with skins	4	3 $\frac{1}{2}$ x 1 $\frac{1}{2}$	530.0	588	"	1000	5	202.4	40
Steaming	peeled	4	1 x 1	499.0	568	"	1000	--	202.8	32
"	"	4	2 x 2	497.5	540	"	1000	--	202.8	44
Baking*	"	4	1 x 1	505.0	553	"	250	--	203.4	52
"	"	4	2 x 2	497.0	545	"	250	--	203.4	52
"	with skins	4	3 $\frac{1}{2}$ x 2	560.0	465	"	---	--	250.0	56
P.C.** 10 qt.	peeled	1	1 x 1	510.0	550	"	350	--	250.0	3
" 18 "	"	1	1 x 1	506.0	545	"	500	--	250.0	3
" 25 "	"	1	1 x 1	505.0	560	"	750	--	250.0	3
" 10 "	"	1	2 x 2	550.0	590	"	350	--	250.0	12
" 18 "	"	1	2 x 2	510.0	550	"	500	--	250.0	11
" 25 "	"	1	2 x 2	490.0	560	"	750	--	250.0	10

* Baking in covered casserole
 ** Steam pressure cooking

ing the 1 x 1 inch piece requires a much shorter cooking time than the 2 x 2 inch piece, in this case less than one-half the time is needed. The addition of salt to the cooking liquid appears to have no effect on the time. The peeled whole potatoes apparently require a little more time than the whole potatoes that are cooked with the skins on. The steaming of the 1 x 1 inch piece demands a distinctly longer time than for boiling but the 2 x 2 inch piece appears to need very little more time. Baking again requires the longest time of all the methods studied. The size of the piece appears to make no difference in the time required for baking potatoes in the casseroles. The cooking period for the potatoes baked with the skins on in direct oven heat at 350° F. conforms to recommendations by others who have made similar studies. The pressure cooking periods are very much shorter than those suggested in time-tables. The 2 x 2 inch pieces of potato required from three to four times as many minutes as the 1 x 1 inch pieces.

Figures 8, 9, 10, 11, 12 and 13 give a graphical representation of the average heat flow in cooking potatoes by the four methods studied. The thermocouple readings upon which the graphs are based were taken every minute during the pressure cooking and every two minutes during the boiling, steaming and baking of the potatoes. Figure 8 shows the heat flow

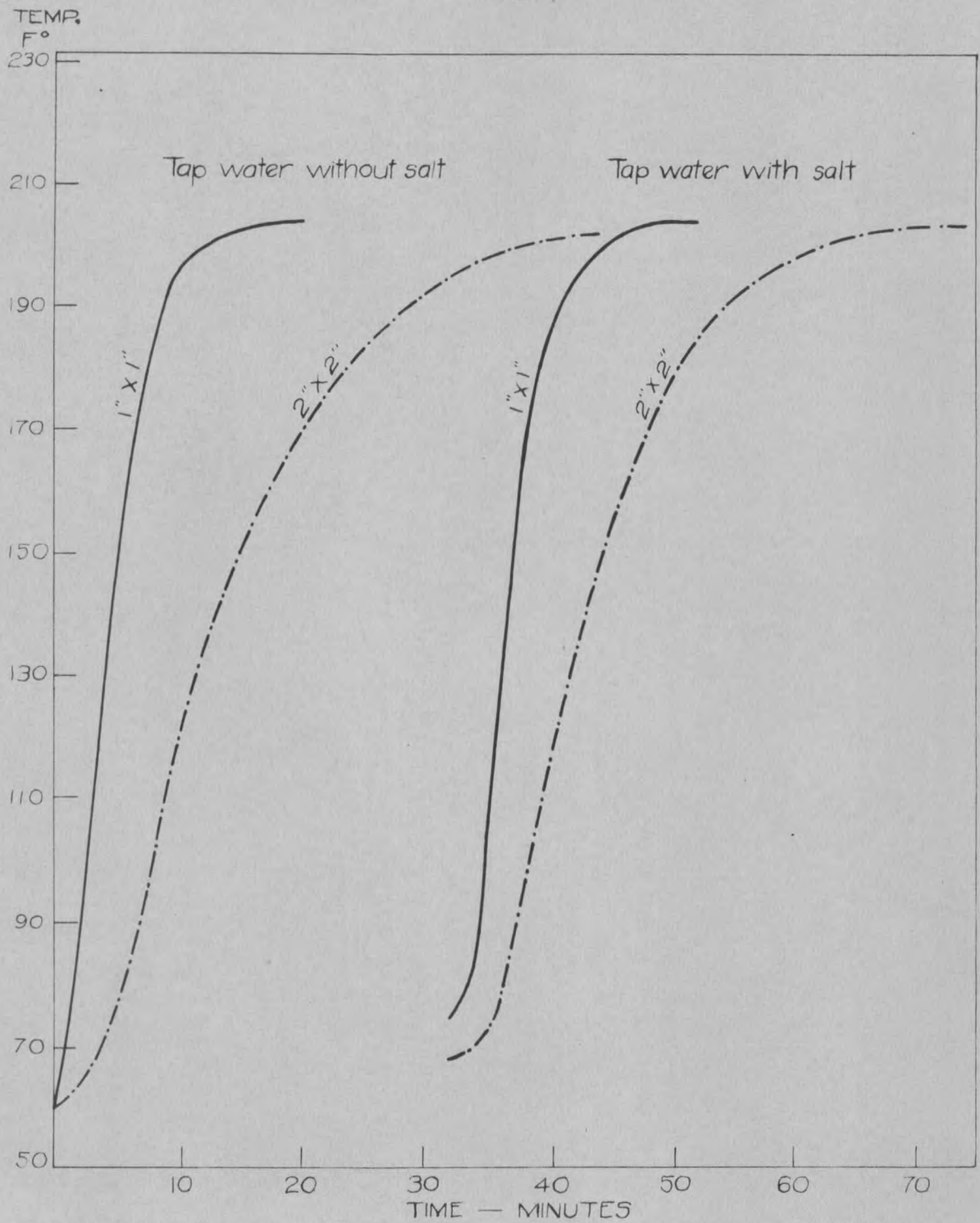


Fig. 8. Curves showing the time-temperature relationships during the boiling of peeled potatoes, cut into pieces of various sizes, in tap water without and with salt.

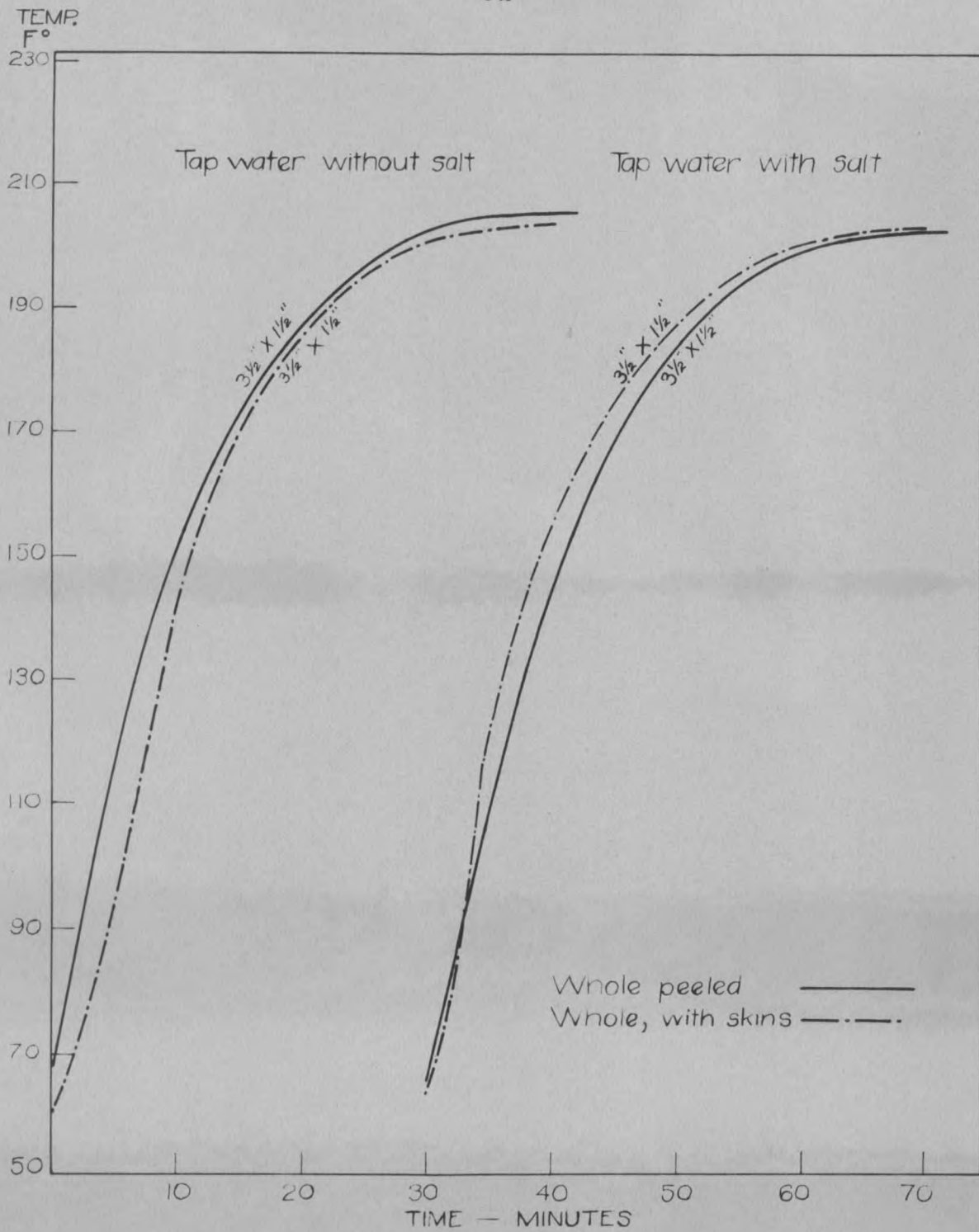


Fig. 9. Curves showing the time-temperature relationships during the boiling of whole potatoes, peeled and with skins, in tap water, without and with salt.

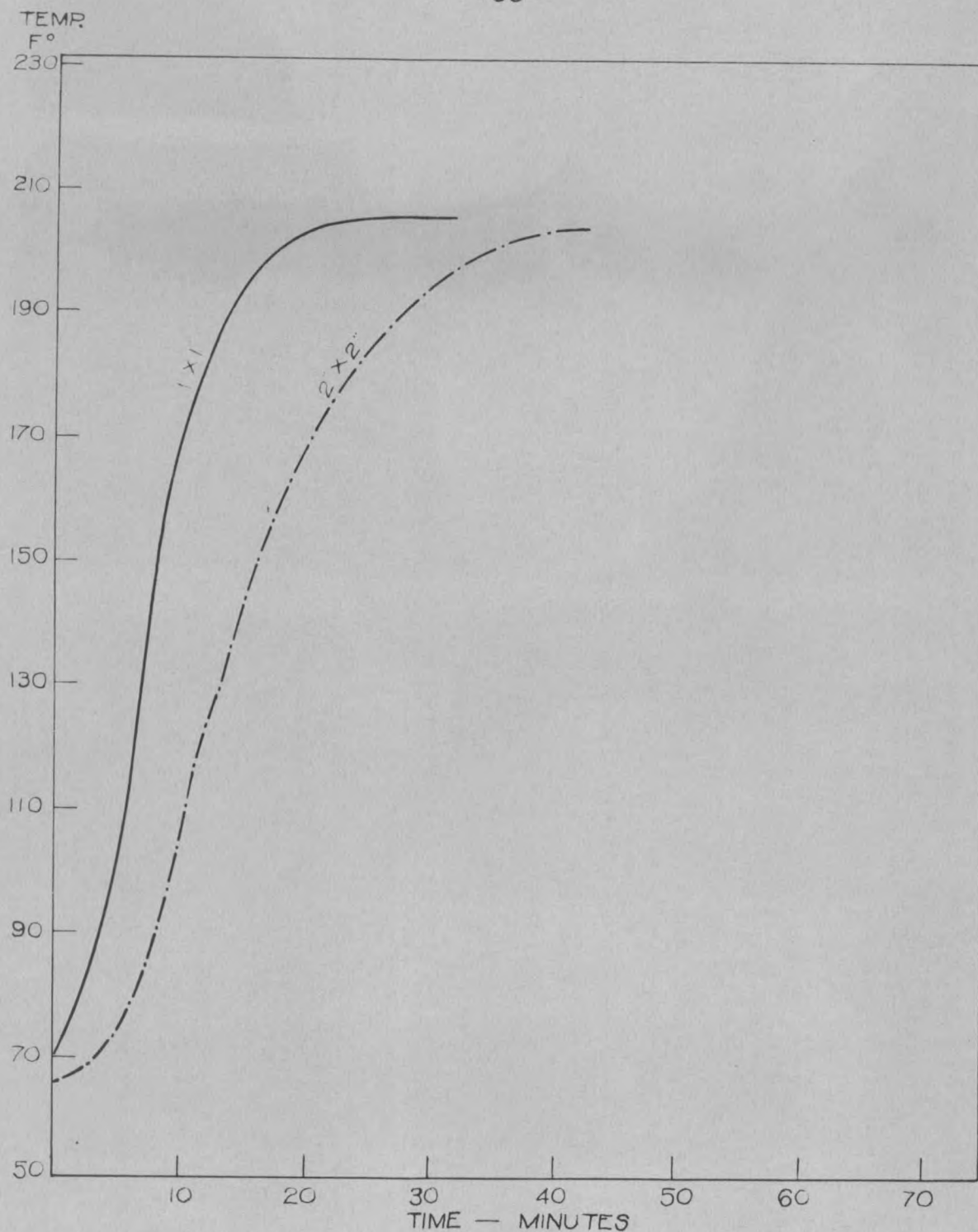


Fig. 10. Curves showing the time-temperature relationships during the steaming of peeled potatoes, in pieces of different size.

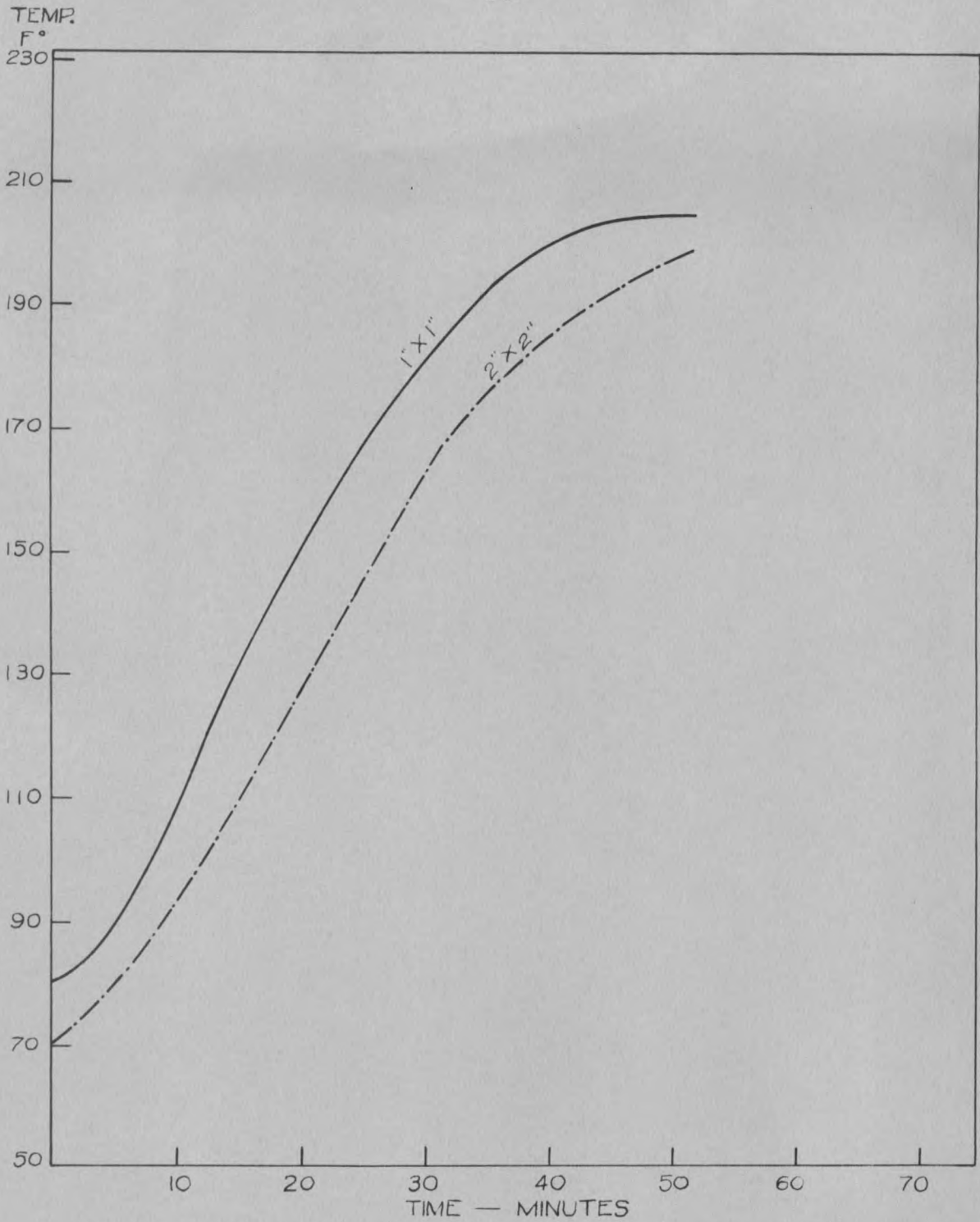


Fig. 11. Curves showing the time-temperature relationships during the baking of peeled potatoes in casseroles.

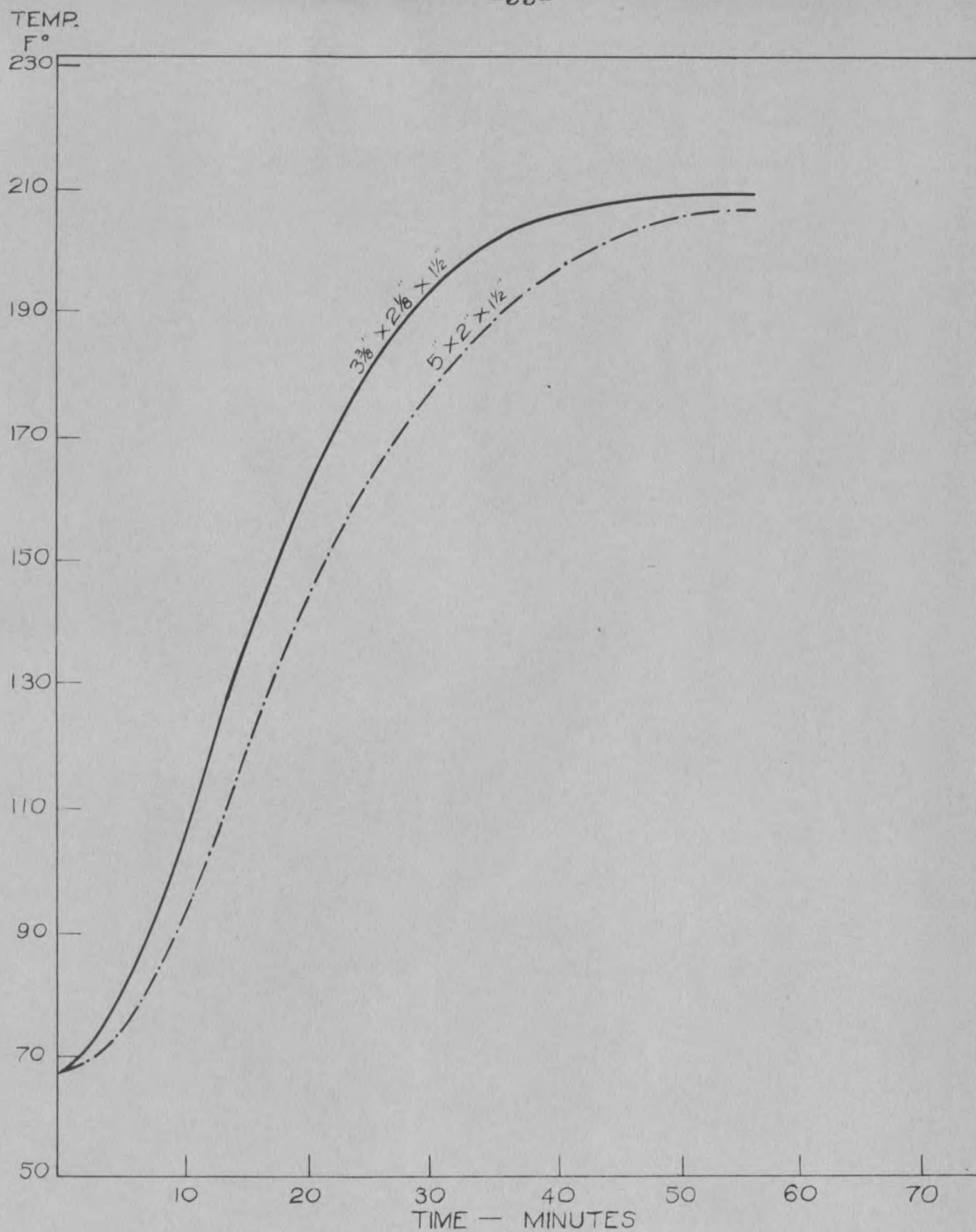


Fig. 12. Curves showing the time-temperature relationships during the baking of whole potatoes with skins on.

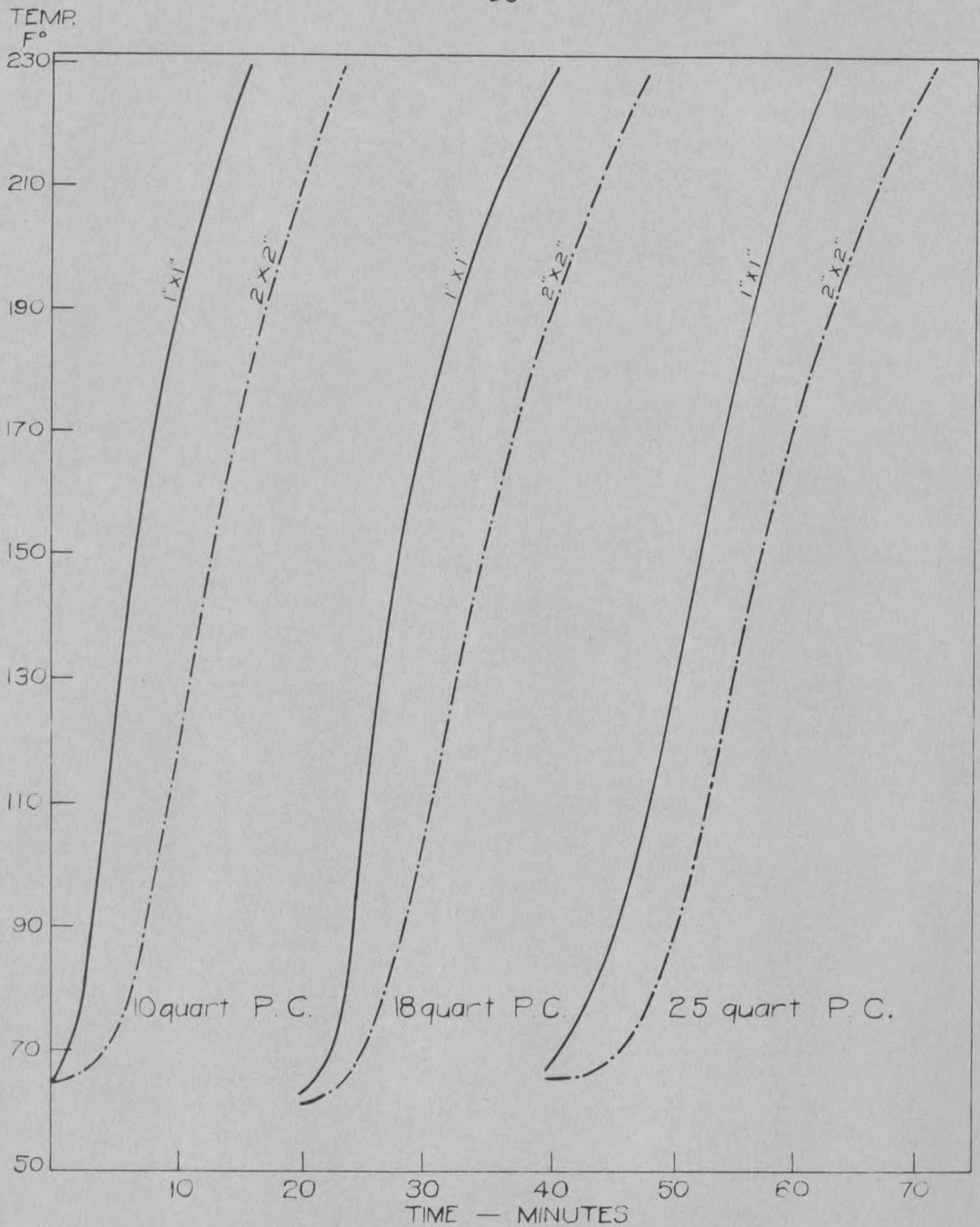


Fig. 13. Curves showing the time-temperature relationships during the cooking of peeled potatoes in pressure cookers of three sizes.

during the boiling of peeled potatoes of different sizes. The curve for the 1 x 1 inch piece is much more abrupt than the curve for the 2 x 2 inch piece and the total time is much shorter. Again the addition of salt to the cooking water seemed to cause no great difference in the curves. It is evident from figure 9 that the heat flow in the potatoes boiled with skins is very similar to that of the peeled potatoes. There is a greater lag in the heat flow in the 1 x 1 inch pieces of steamed potatoes than in boiled potatoes as shown by figure 10. Figure 11 shows the curves for the baking of potatoes in casseroles. They are fairly similar for the two sizes of piece but the more flattened curve indicates the longer time required. The heat flow in potatoes baked in their skins is given in figure 12. The curve is somewhat similar to that of baking in casseroles but is slightly steeper. Figure 13 shows the curves for the pressure cooking of potatoes. The smaller piece, 1 x 1 inch, has the sharper curve but the curves for the three sizes of pressure cooker are rather similar.

The average results obtained in the cooking of beets are given in table III. It will be noticed that a longer cooking time is required for beets than for any of the other vegetables studied. There is relatively very little difference in the amount of time required for boiling when salt is added to the cooking water or when no salt is used. Steaming

TABLE III. COOKING DATA FOR BEETS.

Method of Cooking	Condition of Vegetable	No. of Trials	Av. Size Piece in.	Av. Wt. Sample gms.	Av. Vol. Sample c.c.	Kind of Water	Vol. of Water c.c.	Wt. of Salt gms.	Cooking Temp. °F.	Av. No. Minutes Cooked
Boiling	with skins	4	3 x 2	554.5	495	tap	1500	--	202.8	138
"	" "	4	3 x 2	626.5	750	"	1500	5	202.9	130
Steaming	" "	4	3 x 2 $\frac{1}{2}$	590.0	740	"	1000	--	202.4	140
Baking*	" "	4	3 x 2	546.2	627	"	250	--	202.4	150
P.C.** 10 qt.	" "	1	3 $\frac{1}{2}$ x 3 $\frac{1}{4}$	500.0	520	"	350	--	250.0	57
" 18 "	" "	1	3 $\frac{1}{2}$ x 2 $\frac{1}{2}$	406.0	380	"	500	--	250.0	52
" 25 "	" "	1	3 $\frac{1}{2}$ x 3 $\frac{1}{4}$	491.0	---	"	750	--	250.0	52

TABLE IV. COOKING DATA FOR ONIONS.

Boiling	peeled	4	2 x 2	484.5	573	tap	750	--	203.2	48
"	"	4	2 x 2	511.5	610	"	750	5	202.8	48
Steaming	"	4	2 x 1 $\frac{1}{2}$	517.5	675	"	1000	--	203.2	58
Baking*	"	4	2 x 2	496.2	643	"	250	--	202.9	90
P.C.** 10 qt.	"	1	2 $\frac{1}{4}$ x 2	476.0	560	"	350	--	250.0	8
" 18 "	"	1	2 $\frac{1}{4}$ x 2	504.0	540	"	500	--	250.0	8
" 25 "	"	1	2 $\frac{1}{4}$ x 2	506.0	560	"	750	--	250.0	8

TABLE V. COOKING DATA FOR CABBAGE.

Boiling	quartered	4	3 x 2 $\frac{1}{2}$	516.0	740	tap	750	--	202.8	24
"	"	2	3 x 2 $\frac{1}{2}$	494.0	675	"	750	5	202.8	20
Steaming	"	4	3 x 2 $\frac{1}{2}$	507.0	690	"	1000	--	203.2	36
Baking	"	4	3 x 2 $\frac{1}{2}$	495.0	645	"	250	--	203.3	50
P.C.** 10 qt.	"	1	3 $\frac{1}{2}$ x 2 $\frac{1}{4}$	505.0	670	"	350	--	238.0	***
" 18 "	"	1	3 $\frac{1}{2}$ x 2 $\frac{1}{4}$	472.0	650	"	500	--	230.0	"
" 25 "	"	1	3 x 2	506.0	710	"	750	--	230.0	"

* Baking in covered casserole
 ** Steam pressure cooking

*** Finished cooking before reaching 250° F.
 See table

appears to require about the same amount of time as boiling and the time for baking is slightly greater. Apparently, beets can be cooked in the pressure cooker in about one-third to one-half the time required for boiling.

Figures 14, 15, 16 and 17 include the graphical representations of the heat flow during the cooking of beets. Figure 14 shows the effect of the presence or absence of salt in the cooking water. From the thermocouple readings taken every two minutes during the boiling of the beets, there appears to be very little difference under the two conditions. The heat flow during the steaming of beets is shown in figure 15 in comparison with onions and cabbage. The cabbage has an abrupt curve with a short steaming time; the onions show some lag and the time is increased; while the beets have a decided lag in heat flow and the total time is much greater than for the other vegetables. Figure 16 presents a comparison of the heat flow in cabbage, onions and beets during the baking in casseroles. All of the curves are more flattened than in any other method of cooking and the total times are all increased over those of steaming and boiling. The pressure cooking of beets is graphically represented in figure 17. The steeper curves and the higher temperatures reached account for the shorter period of cooking time.

Table IV shows the average results obtained during the

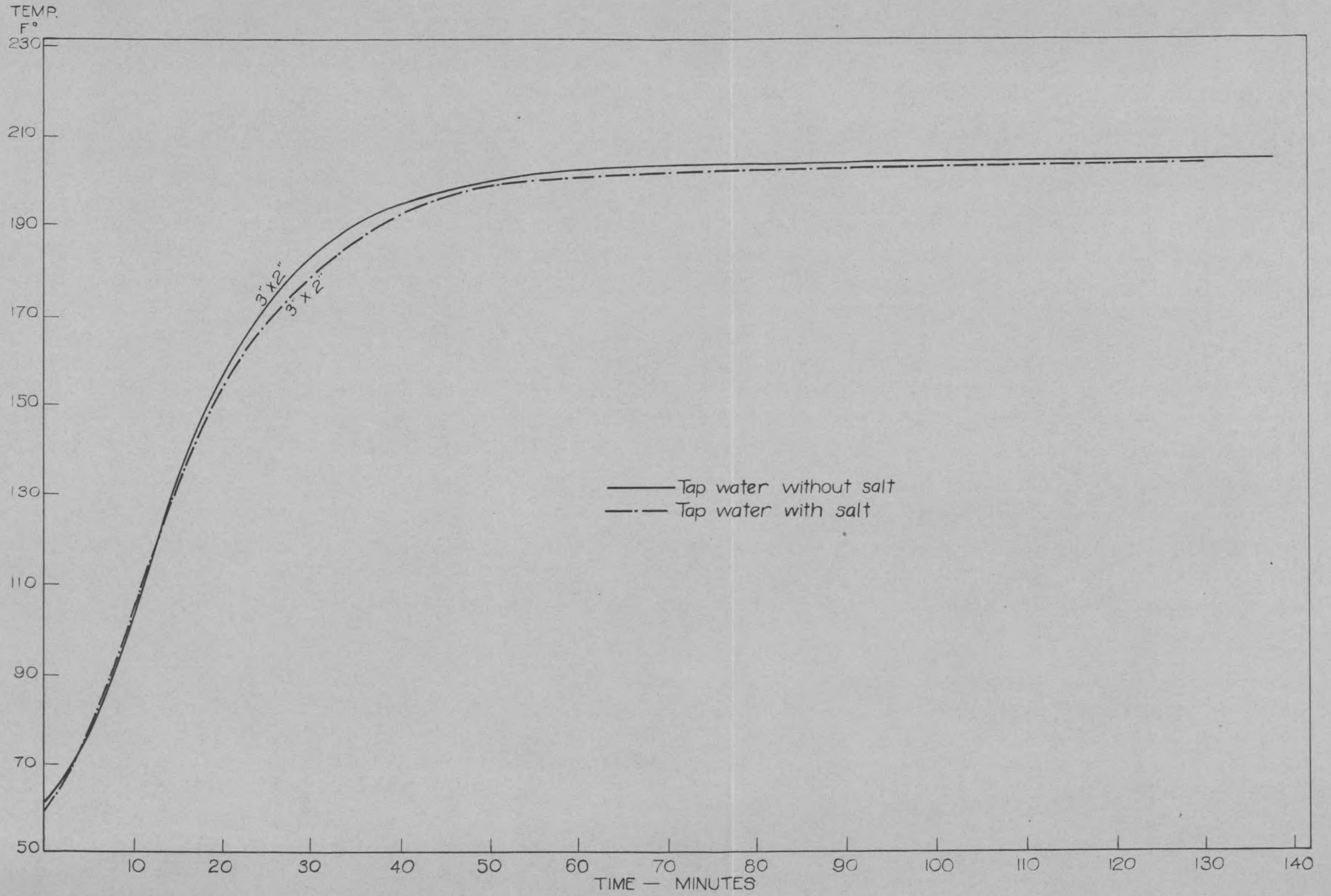


Fig. 14. Curves showing the time-temperature relationships during the boiling of whole beets in tap water without and with salt.

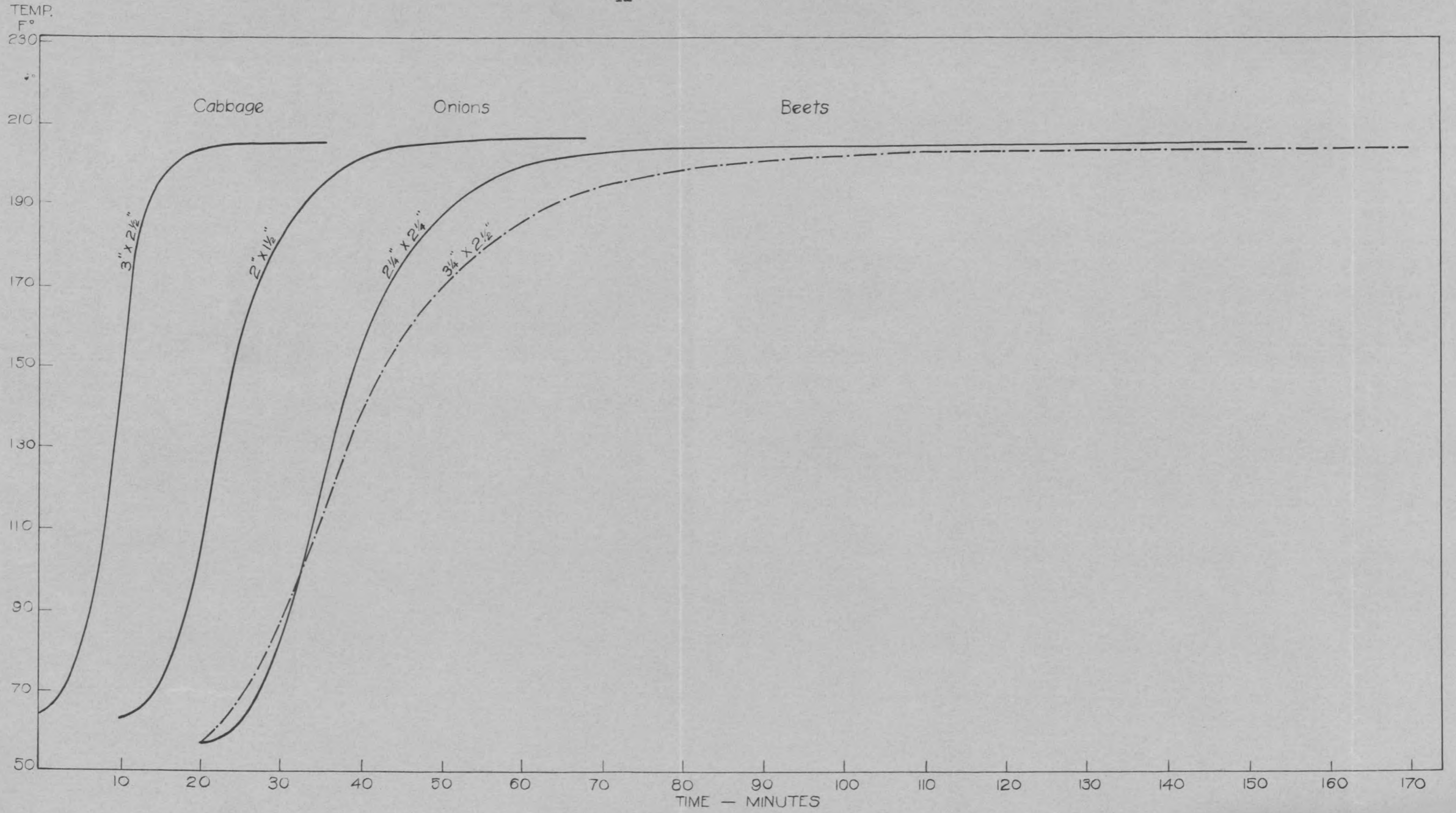


Fig. 15. Curves showing the time-temperature relationships during the steaming of cabbage, onions and beets.

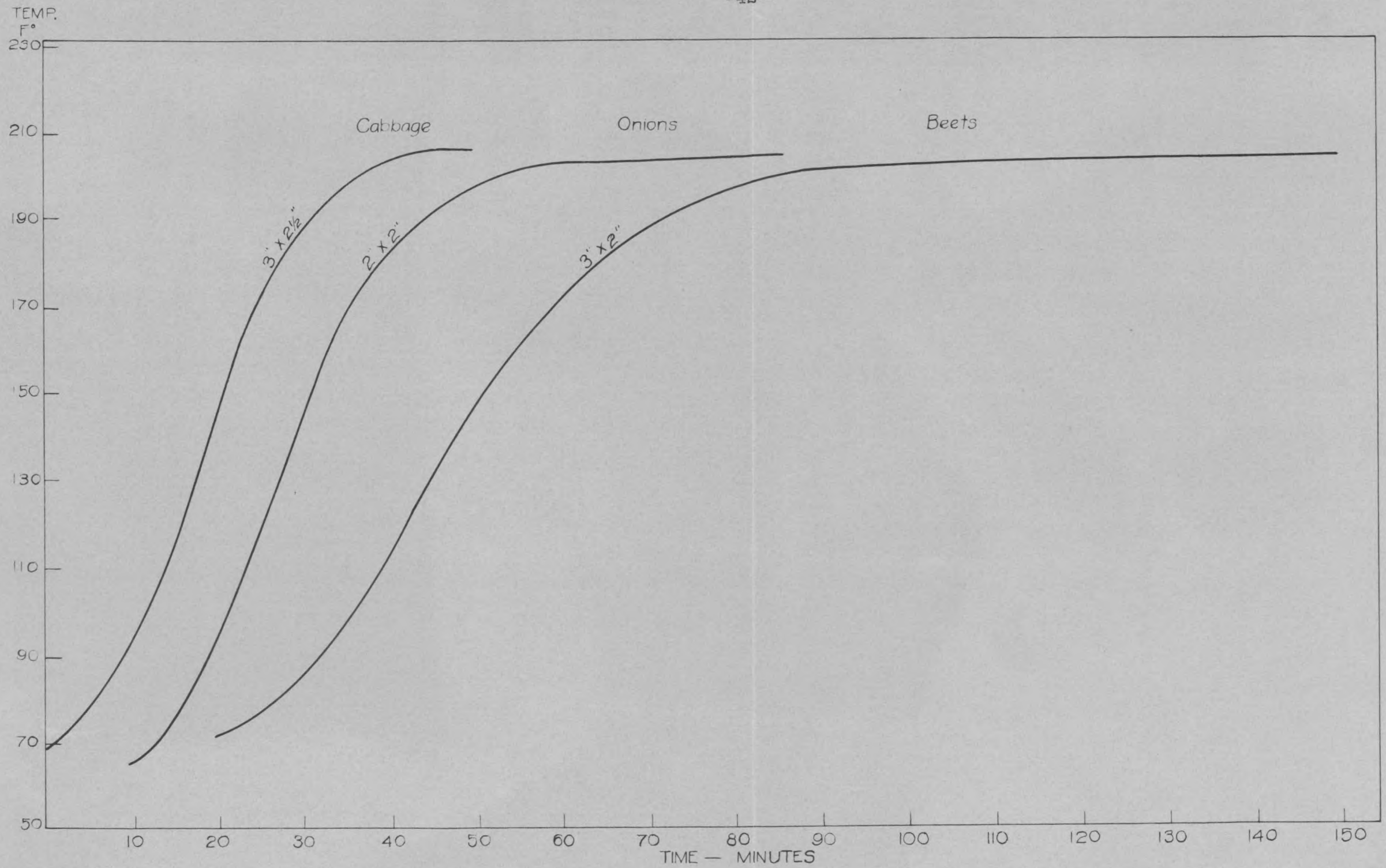


Fig. 16. Curves showing the time-temperature relationships during the baking of cabbage, onions, and beets in casseroles.

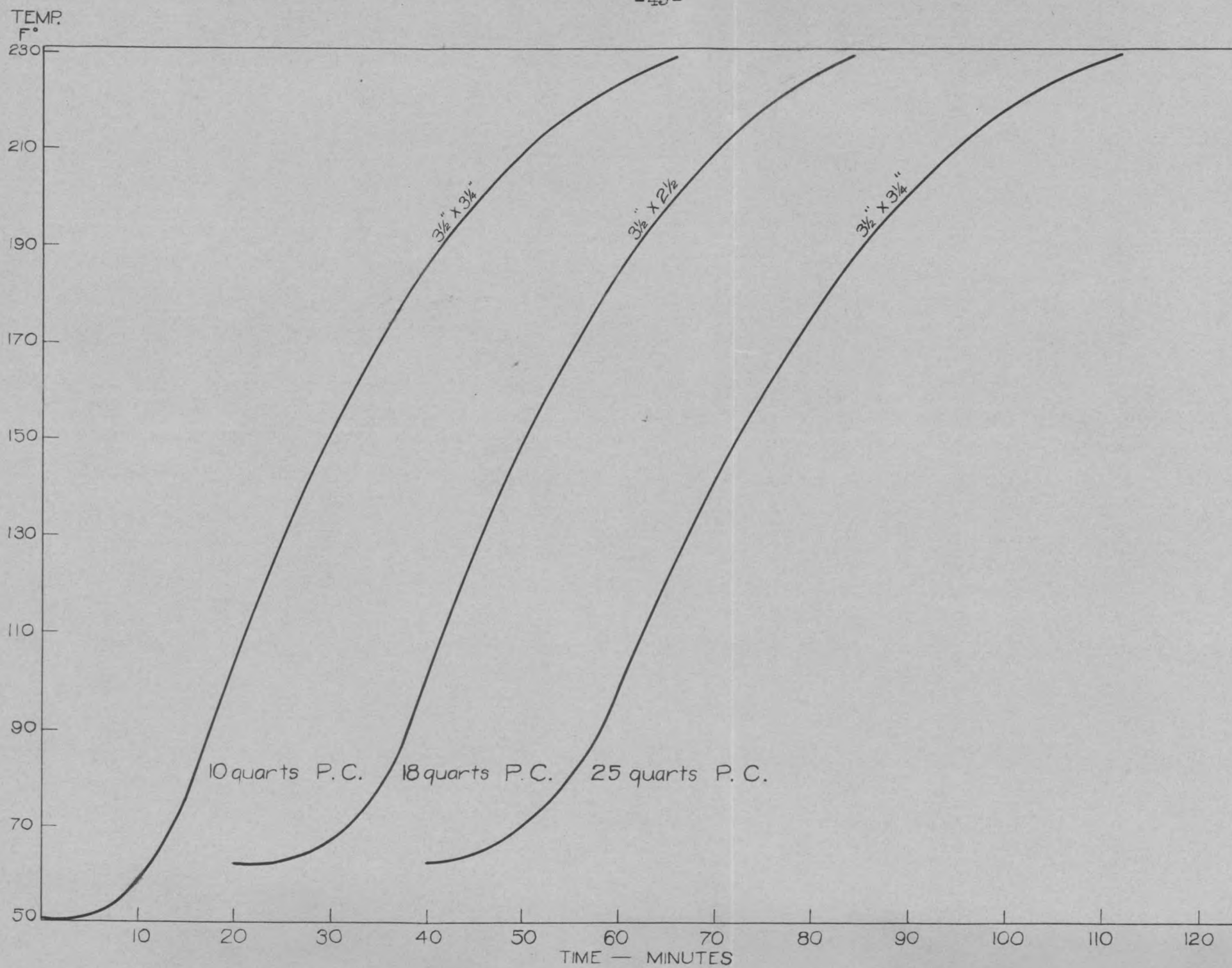


Fig. 17. Curves showing the time-temperature relationships during the cooking of beets in pressure cookers of three sizes.

cooking of onions. As compared with boiling in tap water alone, the addition of salt to the cooking water appears to make no difference in the total time required. Steaming seems to increase the time somewhat and baking almost doubles the time required. The size of the pressure cooker apparently makes no difference in the time that is necessary for cooking onions at 250° F.

Figures 15, 16, 18 and 19 present the graphs showing the rate of heat flow in onions. The curves in figures 15 and 16 have already been discussed in comparison with the cooking of beets. Figure 18 shows the similarity in the curves when salt is added to the boiling water or when it is omitted. In both cases the total time remains about the same. The curves that are presented in figure 19 showing the time and temperature in cooking onions in the three sizes of pressure cookers are very similar, as would be indicated by the times that were given in table IV.

Table V gives the average results in the cooking of cabbage. There is some evidence that the addition of salt to the cooking water decreases the time required for boiling. Steaming appears to require one and one-half as much time as boiling, and baking requires twice as much time as boiling. Cooking cabbage in the pressure cooker resulted in a satisfactory product when the internal temperature of the cooker

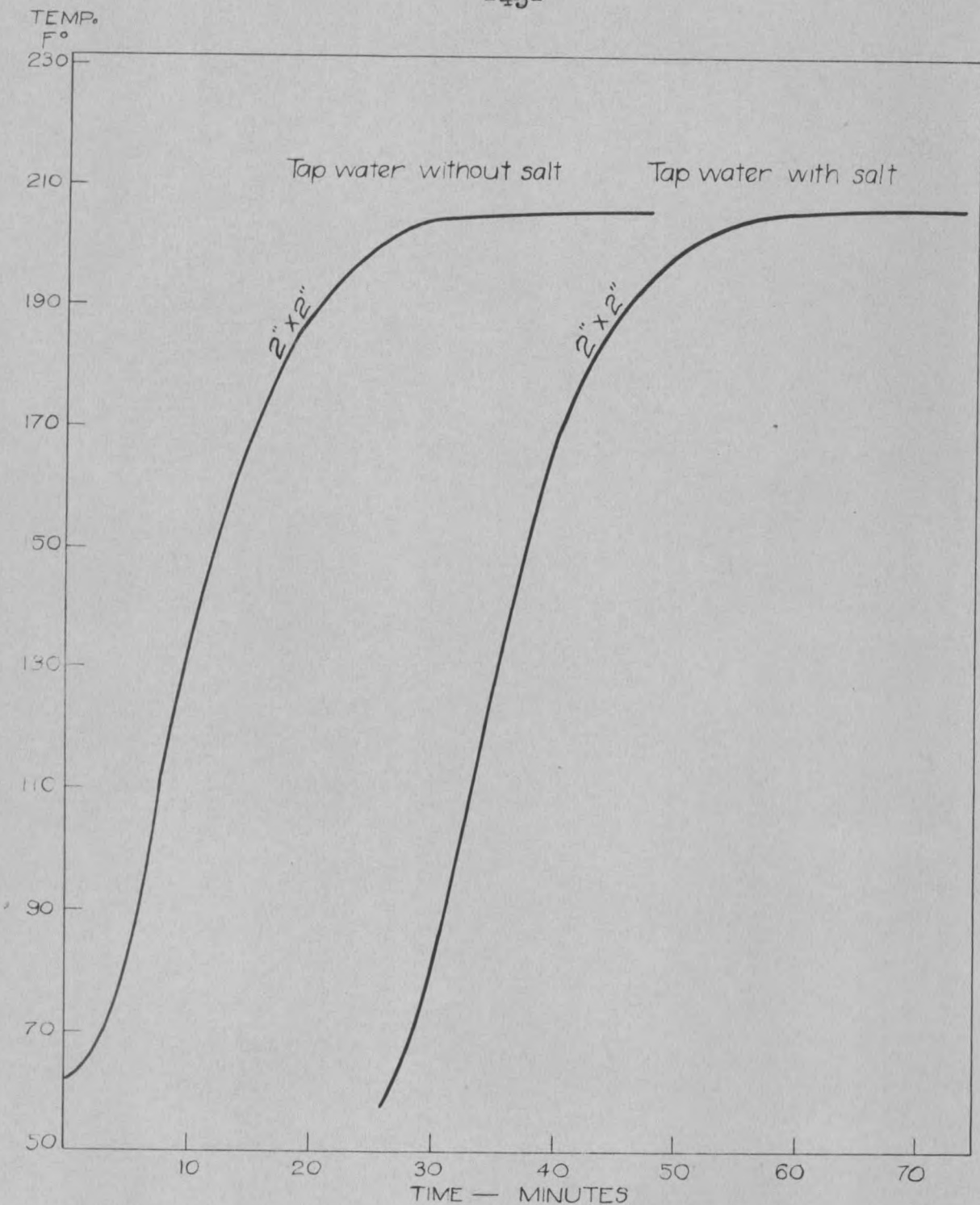


Fig. 18. Curves showing the time-temperature relationships during the boiling of whole onions, in tap water without and with salt.

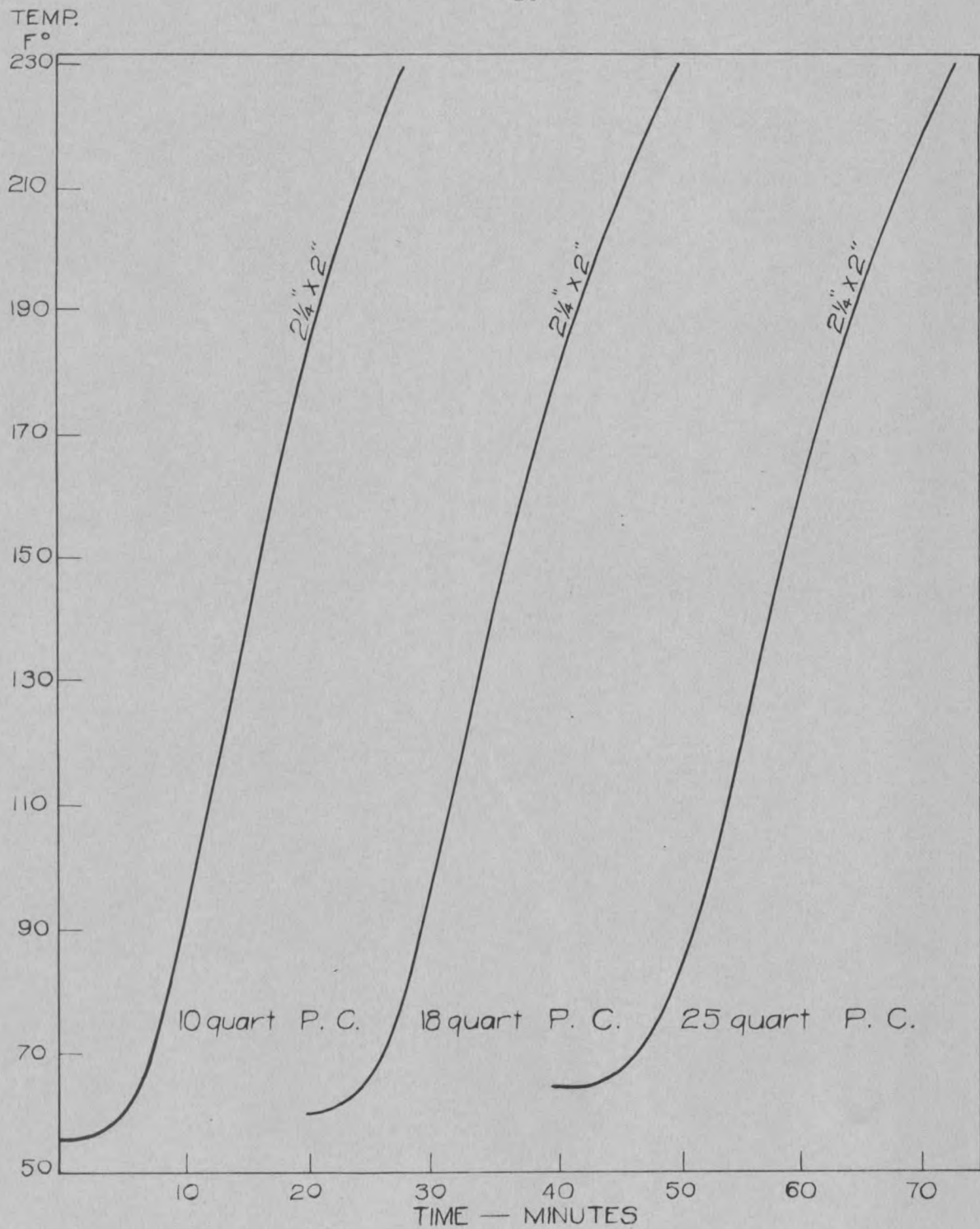


Fig. 19. Curves showing the time-temperature relationships during the cooking of whole onions in pressure cookers of three sizes.

reached approximately 230° F. The cabbage was very much overcooked when the temperature within the cooker was allowed to reach 250° F., as recommended in some of the time tables.

Figures 15, 16, 20 and 21 are graphs representing the heat flow in cabbage when cooked by various methods. Thermocouple readings taken at one and two minute intervals were used in plotting the curves. Figures 15 and 16, showing the curves for steaming and baking cabbage have already been discussed in connection with the cooking of beets and onions. In figure 20 it appears that the addition of salt to the boiling water made a more abrupt curve of heat flow and resulted in a shorter cooking period than when no salt was used. Figure 21 shows the heat flow in cabbage during pressure cooking. The very abrupt rise in temperature explains why the cabbage was cooked by the time the internal temperature of the cooker had reached 230° F.

Directions for the use of the pressure cooker state that "the processing or cooking period begins when the indicator on the dial registers the required pressure". Observations made here during the continued rise of pressure cookers of different sizes have led to the conclusion that too little attention is given to the period of time preceding the cooking period and the effect that it might have upon the length of the cooking period. For instance, the directions again state

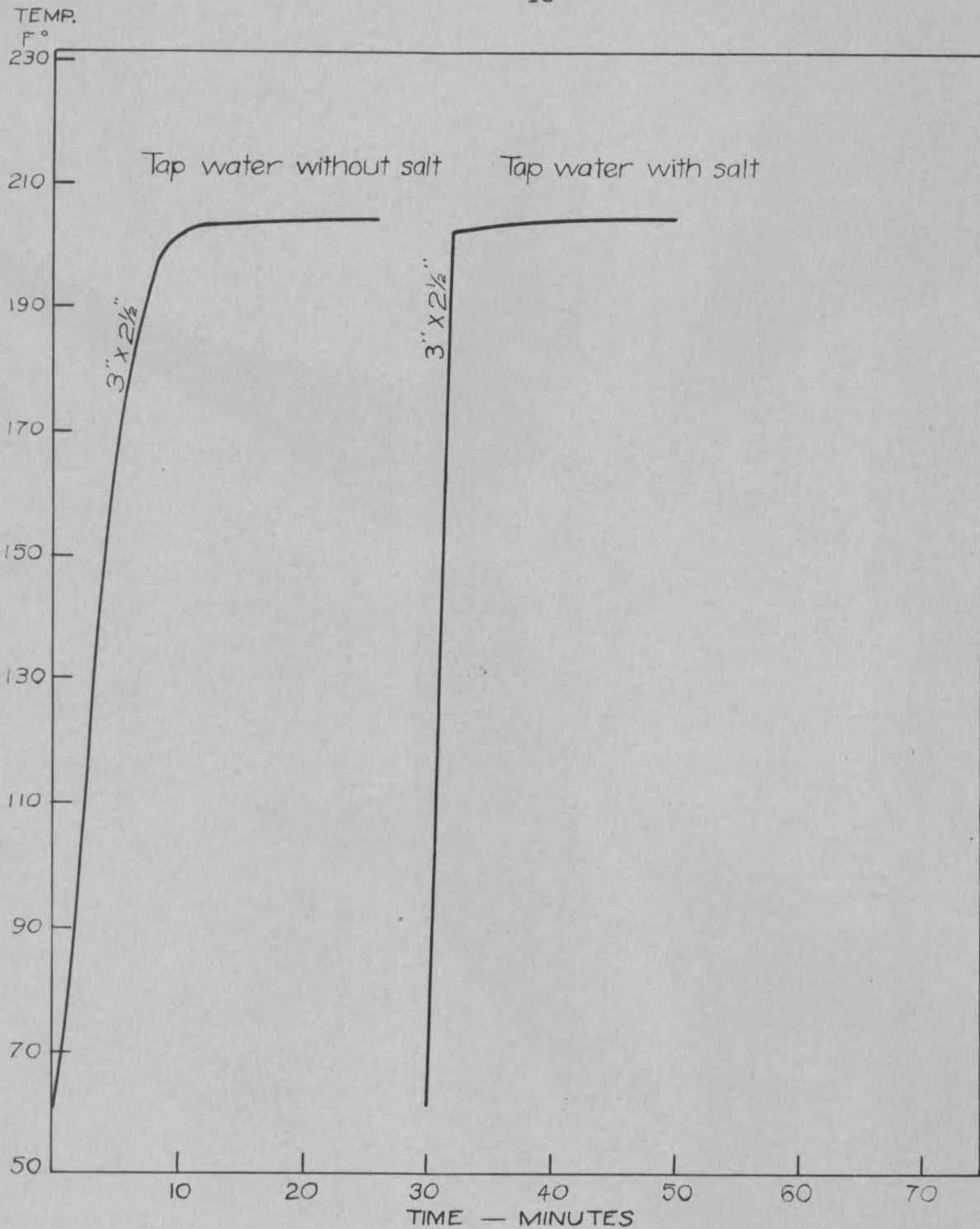


Fig. 20. Curves showing the time-temperature relationships during the boiling of cabbage in tap water without and with salt.

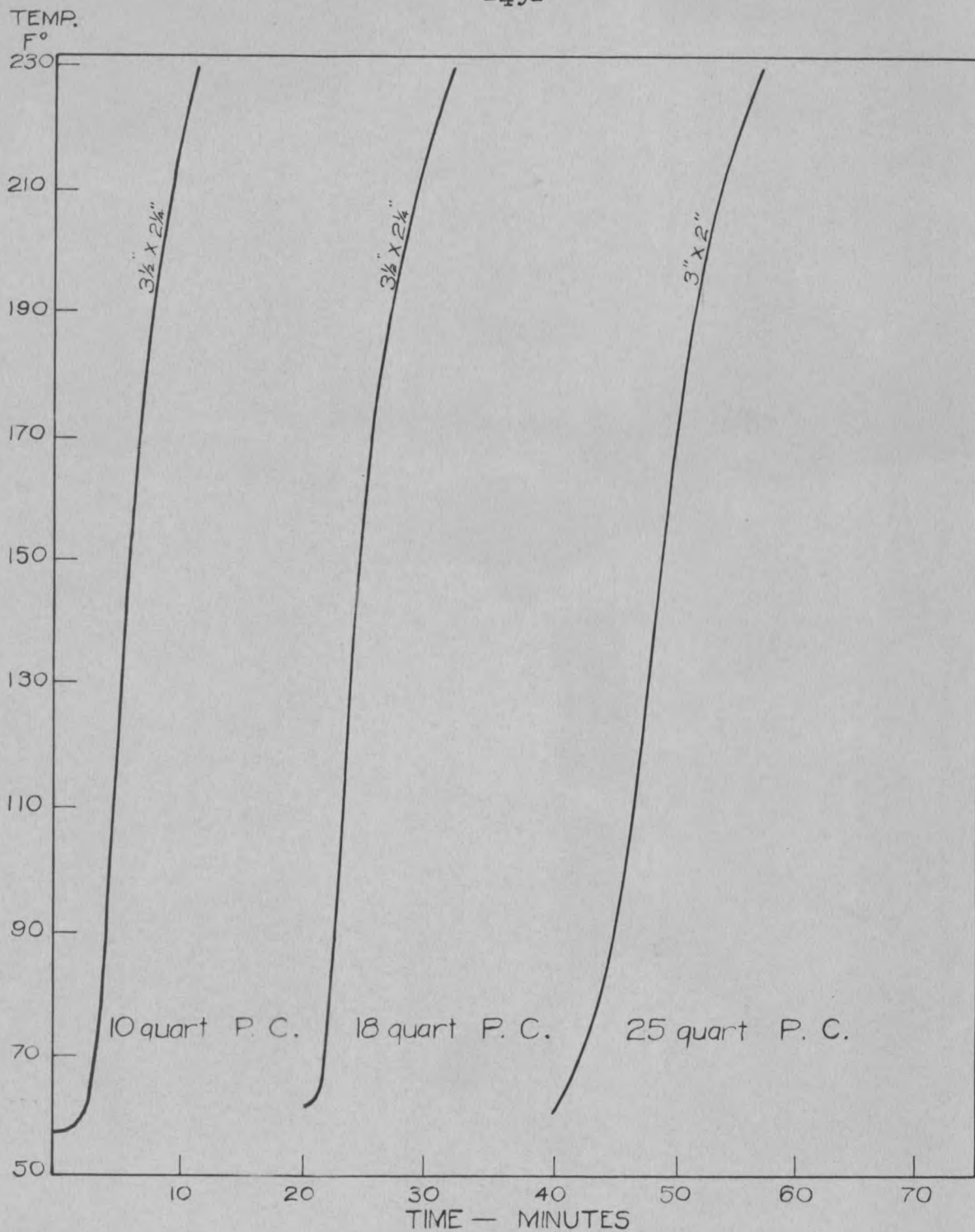


Fig. 21. Curves showing the time-temperature relationships during the cooking of cabbage in pressure cookers of three sizes.

that "the petcock is to be closed as soon as steam begins to issue from it, indicating that cold air has been driven out". A study carried on at Iowa State College (13) advises that steam should be allowed to escape from the petcock in a steady stream for 7 minutes in order to drive out the air and make it possible to attain the desired temperature. In connection with this present study, made at an altitude of 5000 feet above sea level, it was found that a period of 5 minutes of streaming steam was sufficient to remove the air.

In order to assemble all of the data relative to the experiments on pressure cooking, including not only the cooking periods but also all of the preliminary periods, table VI was compiled. In the number of minutes that elapsed from the time until the steam appeared and again from the closing of the petcock until the pressure was reached, there appears to be considerable variation. This seems to accompany the difference in size of pressure cooker as well as the difference in size of piece. It is interesting to note that the carrots, potatoes, beets and cabbage were judged as done when cooked to an internal temperature of 230° F., with the exception of onions that were done at 215° F.

Tables VII, VIII, IX, X and XI give the average scores that were assigned to the color, texture, tenderness and flavor of the cooked vegetables by the group of judges. The results

TABLE VI. COMPLETE DATA FOR STEAM PRESSURE COOKING OF THE VEGETABLES STUDIED, SHOWING THE MINUTES REQUIRED FOR DIFFERENT STAGES IN THE PROCESS AND THE INTERNAL TEMPERATURES REACHED IN THE VEGETABLES.

Size of Piece	Size Pressure Cooker	Initial Temp. Vegetable	Min. until Steam Appears	Min. of Steam Escape	Min. from Closing Petcock to Pressure	Min. at Pressure
Carrots - scraped						
1 x 1	10 qt.	62° F.	3 --95° F.	5 --180° F.	3 --210° F.	3 --231° F.
1 x 1	18 "	68	3 --99	5 --175	6 --213	3 --230
1 x 1	25 "	74	4 --90	5 --160	6 --214	3 --230
1 x 2	10 qt.	66° F.	4½ --92° F.	5 --156° F.	6½ --209° F.	5 --231° F.
1 x 2	18 "	67	6 --100	5 --155	7 --207	4 --231
1 x 2	25 "	57	8 --94	5 --155	7 --214	4 --230
2 x 2	10 qt.	60° F.	10 --72° F.	5 --135° F.	5 --189° F.	6 --230° F.
2 x 2	18 "	64	14 --100	5 --145	9 --198	5 --230
2 x 2	25 "	58	12 --100	5 --150	9 --209	5 --230
Carrots - with skins						
2 x 2	10 qt.	61° F.	3 --75° F.	5 --141° F.	3 --174° F.	12 --230° F.
2 x 2	18 "	62	7 --72	5 --110	8 --174	11 --230
2 x 2	25 "	66	8 --75	5 --110	9 --172	10 --230
Potatoes - peeled						
1 x 1	10 qt.	67° F.	4 --108° F.	5 --176° F.	4 --213° F.	3 --230° F.
1 x 1	18 "	64	6 --120	5 --180	6 --215	3 --230
1 x 1	25 "	67	10 --120	5 --173	6 --217	3 --230
2 x 2	10 qt.	65° F.	4 --65° F.	5 --108° F.	3 --160° F.	12 --230° F.
2 x 2	18 "	61	6 --74	5 --113	6 --160	11 --230
2 x 2	25 "	66	8 --75	5 --109	9 --181	10 --230
Beets - whole						
3½ x 3¼	10 qt.	49° F.	2 --49° F.	5 --51° F.	3 --60° F.	57 --230° F.
3½ x 2½	18 "	62	3 --62	5 --64	5 --74	52 --230
3½ x 3¼	25 "	62	7 --65	5 --74	8 --100	52 --230
Onions - whole						
2½ x 2	10 qt.	56° F.	7 --68° F.	5 --113° F.	5 --160° F.	8 --215° F.
2½ x 2	18 "	60	7 --73	5 --116	6 --162	8 --215
2½ x 2	25 "	65	10 --80	5 --115	6 --162	8 --215

TABLE VI. (continued)

Size of Piece	Size Pressure Cooker	Initial Temp. Vegetable	Min. until Steam Appears	Min. of Steam Escape	Min. from Closing Petcock to Pressure
Cabbage - quartered					
$3\frac{1}{2}$ x $2\frac{1}{4}$	10 qt.	57° F.	4 --75° F.	5 --197° F.	3 --230° F.
$3\frac{1}{2}$ x $2\frac{1}{4}$	18 "	62	2 --75	5 --206	5 --230
3 x 2	25 "	60	3 --75	5 --136	8 --230

TABLE VII. AVERAGE JUDGING SCORES AND RESULTS OF TESTS ON COOKED CARROTS.

Method of Cooking	Condition of Carrot	Size of Piece	Salt in gms.	Av. Judging Scores*				Av. Penetration gms.	Av. pH Value Cooking Liquid
				Color	Texture	Tenderness	Flavor		
Boiling	scraped	1 x 1	--	4.7	2.6	3.6	2.9	391	7.0
"	"	1 x 2	--	4.1	2.6	3.2	2.7	433	7.0
"	"	2 x 2	--	4.5	3.7	3.6	4.0	288	7.0
"	"	1 x 1	5	4.3	3.2	4.4	3.2	285	7.0
"	"	1 x 2	5	4.3	2.5	2.9	2.8	354	7.0
"	"	2 x 2	5	4.5	3.0	1.0	2.8	236	7.0
"**	"	2 x 2	--	4.3	2.6	2.6	3.2	366	5.8
"	"	2 x 2	5	4.6	2.5	3.6	3.2	303	5.8
"	with skins	1 x 2	--	4.3	2.5	2.8	1.9	369	7.0
"	" "	2 x 2	--	4.2	2.5	3.1	2.5	279	7.0
"	" "	1 x 2	5	4.4	1.8	2.6	2.2	321	6.8
"	" "	2 x 2	5	4.1	2.3	2.7	2.4	288	7.0
Steaming	scraped	1 x 1	--	4.6	2.6	3.4	2.5	319	7.8
"	"	2 x 2	--	4.4	2.4	2.9	2.6	390	7.8
"	with skins	1 x 2	--	4.7	2.3	2.9	2.7	438	7.8
"	" "	2 x 2	--	4.7	2.9	4.1	3.1	247	7.8
Baking***	scraped	1 x 1	--	4.3	2.9	2.8	2.5	313	5.8
"	"	2 x 2	--	4.7	2.6	2.1	3.1	374	5.9
P.C.****10 qt.	"	1 x 1	--	3.7	2.5	2.8	1.7	205	---
" 18 "	"	1 x 1	--	4.3	3.1	4.3	3.1	141	7.0
" 25 "	"	1 x 1	--	3.7	3.2	4.6	2.2	132	7.0
" 10 "	"	1 x 2	--	4.5	2.3	3.2	2.6	157	6.3
" 18 "	"	1 x 2	--	4.5	3.6	3.3	2.9	138	6.1
" 25 "	"	1 x 2	--	3.5	3.5	3.6	2.2	192	---
" 10 "	"	2 x 2	--	4.4	2.8	1.9	2.1	123	6.4
" 18 "	"	2 x 2	--	3.7	2.1	1.3	1.3	87	6.1
" 25 "	"	2 x 2	--	4.4	2.7	2.6	2.7	121	---
" 10 "	with skins	2 x 2	--	3.8	2.8	3.3	2.4	168	6.8
" 18 "	" "	2 x 2	--	4.5	3.8	3.2	2.7	109	6.1
" 25 "	" "	2 x 2	--	4.1	3.6	1.6	2.2	119	6.8

* System used in scoring vegetables:-

0 = very poor
 1 = poor
 2 = fair
 3 = medium
 4 = good
 5 = excellent

** Distilled water
 *** Baking in covered casserole
 **** Steam pressure cooking

TABLE VIII. AVERAGE JUDGING SCORES AND RESULTS OF TESTS ON COOKED POTATOES.

Method of Cooking	Condition of Potato	Size of Piece	Salt in gms.	Av. Judging Scores*				Av. Penetration gms.	Av. pH Value Cooking Liquid
				Color	Texture	Tenderness	Flavor		
Boiling	peeled	1 x 1	--	3.5	4.0	4.0	2.8	139	6.5
"	"	2 x 2	--	3.5	4.3	3.8	2.6	104	6.4
"	"	1 x 1	5	3.0	4.5	3.6	3.8	149	6.2
"	"	2 x 2	5	3.3	4.5	4.3	2.5	154	6.5
"	"	3 1/2 x 1 1/2	--	3.3	4.2	4.2	4.0	108	7.0
"	with skins	3 1/2 x 1 1/2	--	3.2	4.2	3.5	3.8	147	6.9
"	peeled	3 1/2 x 1 1/2	5	3.4	4.5	4.6	4.3	103	7.0
"	with skins	3 1/2 x 1 1/2	5	3.1	4.5	4.8	4.3	146	7.0
Steaming	peeled	1 x 1	--	4.0	2.8	3.1	3.3	136	7.0
"	"	2 x 2	--	4.0	4.0	3.9	3.5	101	6.6
Baking**	"	1 x 1	--	3.7	4.0	3.5	3.4	211	6.0
"	"	2 x 2	--	3.4	4.4	3.9	3.6	166	6.0
"	with skins	3 1/2 x 2	--	2.9	4.6	3.5	3.0	95	---
P.C.***	10 qt. peeled	1 x 1	--	4.0	4.5	4.0	4.0	89	6.7
"	18 " "	1 x 1	--	4.0	4.6	3.3	2.6	129	6.8
"	25 " "	1 x 1	--	4.0	4.6	2.6	2.3	106	6.8
"	10 " "	2 x 2	--	3.0	4.5	2.0	1.0	126	6.8
"	18 " "	2 x 2	--	3.0	4.5	2.0	1.0	141	7.0
"	25 " "	2 x 2	--	3.0	4.5	3.5	1.0	129	6.9

* System used in scoring vegetables:-

- 0 = very poor
- 1 = poor
- 2 = fair
- 3 = medium
- 4 = good
- 5 = excellent

** Baking in covered casserole
 *** Steam pressure cooking

TABLE IX. AVERAGE JUDGING SCORES AND RESULTS OF TESTS ON COOKED BEETS.

Method of Cooking	Condition of Vegetable	Size of Piece	Salt in gms.	Av. Judging Scores*				Av. Penetration gms.	Av. pH Value Cooking Liquid
				Color	Texture	Tenderness	Flavor		
Boiling	with skins	3 x 2	--	4.3	3.3	4.1	4.2	386	---
"	" "	3 x 2	5	4.5	3.5	4.2	4.2	404	---
Steaming	" "	3 x 2 $\frac{1}{2}$	--	4.5	2.7	3.8	3.5	410	---
Baking**	" "	3 x 2	--	4.4	3.4	3.4	3.5	391	---
P.C.*** 10 qt.	" "	3 $\frac{1}{2}$ x 3 $\frac{1}{2}$	--	4.0	3.3	4.0	4.3	258	---
" 18 "	" "	3 $\frac{1}{2}$ x 2 $\frac{1}{2}$	--	5.0	3.8	3.8	3.8	415	---
" 25 "	" "	3 $\frac{1}{2}$ x 3 $\frac{1}{2}$	--	3.0	3.0	4.0	4.0	221	---

TABLE X. AVERAGE JUDGING SCORES AND RESULTS OF TESTS ON COOKED ONIONS.

Boiling	peeled	2 x 2	--	4.3	3.9	4.4	4.8	---	6.0
"	"	2 x 2	5	3.8	3.9	4.3	4.5	---	5.8
Steaming	"	2 x 1 $\frac{1}{2}$	--	4.0	2.0	4.0	4.0	---	6.8
Baking**	"	2 x 2	--	3.7	2.7	1.9	2.8	---	5.3
P.C.*** 10 qt.	"	2 $\frac{1}{2}$ x 2	--	1.0	3.0	1.0	0.0	---	5.4
" 18 "	"	2 $\frac{1}{2}$ x 2	--	1.0	3.0	1.0	0.0	---	5.8
" 25 "	"	2 $\frac{1}{2}$ x 2	--	4.0	3.0	5.0	0.0	---	6.0

TABLE XI. AVERAGE JUDGING SCORES AND RESULTS OF TESTS ON COOKED CABBAGE.

Boiling	quartered	3 x 2 $\frac{1}{2}$	--	3.0	3.8	4.8	4.2	---	6.4
"	"	3 x 2 $\frac{1}{2}$	5	3.0	4.0	4.6	5.0	---	6.3
Steaming	"	3 x 2 $\frac{1}{2}$	--	3.0	3.0	4.3	2.0	---	7.0
Baking**	"	3 x 2 $\frac{1}{2}$	--	4.0	3.2	3.6	3.3	---	---
P.C.*** 10 qt.	"	3 $\frac{1}{2}$ x 2 $\frac{1}{2}$	--	3.0	3.0	3.5	3.5	---	7.0
" 18 "	"	3 $\frac{1}{2}$ x 2 $\frac{1}{2}$	--	4.0	3.0	4.0	3.0	---	7.0
" 25 "	"	3 x 2	--	3.0	3.0	4.0	3.0	---	7.0

* System used in scoring vegetables:-

- 0 = very poor
- 1 = poor
- 2 = fair
- 3 = medium
- 4 = good
- 5 = excellent

** Baking in covered casserole
 *** Steam pressure cooking

of the penetration tests for tenderness are also found in these tables in order that they might be compared with the judges' opinions of tenderness. No penetration tests were made on onions or cabbage because of their structure. The average hydrogen ion concentration of the cooking liquids as expressed in pH value is listed here for all cases where it was possible to make the tests colorimetrically.

It will be seen in table VII that the pH value of the cooking liquid when carrots were boiled in tap water was usually 7.0 but when they were baked in tap water this value fell to 5.8 which was similar to that of the distilled water in which carrots were boiled. The pH value of the liquid after the pressure cooking of carrots seems to indicate greater acidity than after boiling or steaming. All of the pH values for the liquid used in cooking onions were noticeably lower than the pH of the tap water itself. In the cooking of cabbage the pH values were lower for the liquid from boiling than from steaming and pressure cooking.

DISCUSSION

From the data presented in the preceding tables and graphs, it is apparent that certain factors are involved in the relationship between the time required for cooking vegetables and the temperature at which they are cooked.

Perhaps one of the most outstanding factors in this relationship is the size of the piece of vegetable to be cooked. It has been consistently observed in this study that when large and small pieces of the same vegetable were cooked at the same temperature, the larger piece always required a longer cooking period. This is probably due to the greater distance through which the heat must flow in order to reach the center of the larger piece. However, it is interesting to note that the different times required for heat penetration into different-sized pieces of the same vegetable are not always in direct proportion to these sizes, that is, it does not usually take exactly twice as much time for heat to reach the center of a 2 x 2 inch piece as a 1 x 1 inch piece. This appears to vary with the texture and structure of the vegetables.

While canning of vegetables is a process somewhat different from their direct cooking, it should be noted that, in canning, the size of the can is a factor that has been considered in determining the time of the processing period.

Bigelow (1), of the National Cannery Association, states

"the time necessary for heat to penetrate to the center of cans of different size is approximately proportional to the square of the radii of the cans. It should be understood that this refers only to the time necessary to bring the center of the cans to specified temperatures." Magoon and Culpepper (12) conclude that the differences in the diameter of the containers are of much less importance in those materials in which there is a free liquid than in materials of heavy consistency, so there is little difference in the processing period of No. 2 and No. 3 tin cans of string beans, but there is considerable difference in the processing period of No. 2 and No. 3 tin cans of sweet corn. Redfield, Nelson and Sunderlin (15) at Iowa State College recommend additional times for processing quart jars over the times required for pint jars.

The only worker who has used definite sizes of vegetable pieces in determining their cooking time at a certain temperature is Gill (7) and her work was limited to potatoes. However, her results coincide with the results found in this study. A lack of recognition of the effect of size of piece upon the length of the cooking period for vegetables probably accounts for the wide range of time given in time-tables which have been presented by a number of the workers.

Another factor that seems to have received little attention is the internal temperature of the vegetable that should

be reached when it is cooked. Denton (5) in 1922 stated that "with the exception of meat, eggs and custards, most foods cooked under ordinary household conditions reach a temperature of approximately 100° (boiling point) throughout their mass by the time they are "done", whether cooked in boiling water, in an oven, or in hot fat at 200° C., more or less. However, it may readily be shown that the temperature attained within a given time period is altogether dependent upon the size of the food mass. Boiled potatoes weighing 200 grams or less, are done at 97° - 99° C., those weighing 300 grams or more, are done at 90° - 95° C." In this study, conducted at an altitude of 5000 feet, where the boiling point of water varies from 94.5° to 95.5° C., or 202° to 204° F., the vegetables cooked by boiling, steaming and baking always reached an internal temperature comparable to the boiling point of water, regardless of their size. In addition, it was always necessary to hold them at this internal temperature for a certain period of time before they were done. This will be seen in the last portion of each curve in the graphs. A recent study reported in 1933 by Stout and Drosten (18) on the heat flow through bakery products, shows a similar condition that exists during the baking of bread. They state that when oven temperatures varied from 200° to 250° C. the inside temperature of a loaf of bread did not exceed 100° to 101° C. during baking. This

temperature had to be maintained for at least a period of 9 minutes to produce a done loaf of bread.

During the pressure cooking of vegetables at 250° F. or 15 pounds pressure (corrected for this altitude), they always seemed to be "done" when the internal temperature of the vegetable reached 230° F. This apparently was the correct internal temperature for all vegetables tested, regardless of size.

Another question that enters into this problem of vegetable cookery is whether the addition of salt to the water makes any difference in the total time required for boiling vegetables. Preliminary to this study a test was made by adding 5 grams of salt to 750 cc. of tap water, allowing it to boil and comparing its boiling temperature with that of an equivalent amount of water having no salt. There was no increase in temperature, according to a mercury thermometer, when salt was present. An examination of the data and graphs will also show that there was practically no difference in the time or temperature for cooking vegetables, whether salt was present or absent. This seems to be consistent with the findings of others. Magoon and Culpepper (12) state that "sodium chloride has very little direct effect upon the rate of change of temperature in the can, during canning."

Still another matter to be considered in the cookery of

vegetables is whether the presence or absence of their skins, during the cooking process, has any effect on their rate of cooking. Potatoes and carrots were used for these tests and the results indicate that the presence of skins on the carrots may retard the rate of heat flow, but the skins on the potatoes seemed to cause a slight increase in the rate of heat flow as compared with peeled potatoes. This difference might be attributed to the fact that the pieces of carrot were cut at both ends in order to obtain a 2 x 2 inch piece while the potatoes were cooked whole and had no cut surfaces. Whether it is a difference between cut skin or intact skin, or in texture of skin, has not been determined.

In making a comparison of the four methods of cooking that were used in this study it was noticed that there seemed to be a difference in the rate at which each kind of heat, depending upon its source, penetrated the vegetables. Steam pressure cooking always required the least amount of time to cook the vegetables. Boiling came next in time required; steaming next; and baking was the slowest process. This is particularly interesting when their respective temperatures are noted:- steam pressure cooking, 250° F.; boiling 202° F.; steaming, 202° to 204° F.; and baking, 350° F. It would seem that there must be some difference in the quality or quantity of energy derived from each of these four media that

bring the heat to the vegetable, particularly the latter.

In considering the different vegetables it was found that they varied in the rate at which they cooked. This, doubtless, is caused by unlike structures found in the types of vegetables used:- potatoes are tubers or underground stems; carrots and beets are roots; onions are bulbs; and cabbage is a compact head formed of leaves. It is also recognized that the maturity of vegetables may have some effect on their cooking rate. In this study the vegetables were practically uniform in their degree of maturity as they had been stored in pits for three to four months.

In studying the graphs that represent the time-temperature relationships during the boiling, steaming and baking of vegetables it will be seen that they may be divided into three distinct periods. The first period consists of a rapid rise of temperature within the vegetable, indicated on the graph by the first, steep portion. The second period is one of progressive decrease in the rate of temperature rise, which results in the curved part of the graph. The third or final period is one of constant temperature where the center of the vegetable has attained the temperature of boiling water. The length of the third period varies with different vegetables and with different methods of cooking. In the graphs representing pressure cooking these periods are not apparent.

In addition to the factors which have just been discussed there are some observations which are interesting to note. From the tests for tenderness that were made with the penetrometer, it was evident that different weights were necessary to penetrate different kinds of vegetables, even though they were all scored as "done" by the judges. This indicates that our ideas about the qualities that mark the "doneness" of vegetables vary with each vegetable.

Another observation that seems to be related to the time and temperature required for cooking vegetables is the hydrogen-ion concentration of the water in which they were cooked. This study appears to show a greater acidity of the liquid after pressure cooking and baking in casseroles than in the other methods, when expressed in pH values. It may be possible that the high temperature in pressure cooking and the long period in baking have tendencies to cause a chemical change in the vegetable with a resulting increase in acidity.

SUMMARY

1. In this study of the time-temperature relationships in the cookery of vegetables, the following vegetables were used:- carrots, potatoes, beets, onions and cabbage.
2. These vegetables were cooked by boiling, steaming, direct baking, baking in casseroles and by steam pressure cooking.
3. The cooking tests, that furnished the data for this study, were carried on at an altitude of about 5000 feet above sea level, where the temperature of boiling water varies from 202° to 204° F.
4. Thermocouples, with their hot-end junctions inserted into the exact center of each piece of vegetable tested, indicated the temperature within the vegetable at definite time intervals.
5. From the data presented, it is apparent that certain factors are involved in the relationship between the time required for cooking vegetables and the temperature at which they are cooked.
6. One of the most important factors is the size of the piece of vegetable. A large piece requires a longer cooking period than a small piece, even though the time is not in direct proportion to the size.
7. In boiling, steaming and baking vegetables, it is necessary

for the center of the piece to reach the boiling point of water and maintain that temperature for a certain period of time, depending on the kind of vegetable and method of cooking.

8. During the pressure cooking of these vegetables at 250° F. or 15 pounds pressure (corrected for an altitude of 5000 feet) they were done when the internal temperature of the vegetable reached 230° F. In the case of cabbage this temperature was reached before the temperature in the pressure cooker was 250° F.
9. The addition of salt to the water when boiling vegetables did not appear to make any difference in the boiling temperature of the cooking liquid, nor in the total time required for cooking.
10. When pieces of carrot were prepared for cooking by cutting off the ends but leaving the skins encircling the carrot, the heat flow into the piece of vegetable was retarded. When potatoes were cooked with the skins left on intact there seemed to be a slight increase in the rate of heat flow as compared with peeled potatoes.
11. In making a comparison of the four methods of cooking it was noted that there seemed to be a difference in the rate at which the heat in each method penetrated the vegetables. Steam pressure cooking always required the least

amount of time to cook the vegetables; boiling came next; steaming next; and baking was the slowest process.

12. These vegetables differed in the rate at which they cooked, doubtless due to a difference in their structure.
13. Graphs representing the time-temperature relationships during the boiling, steaming and baking of vegetables may be divided into three distinct periods. The first is steep, indicating a rapid rise in temperature; the second is curved, showing a decreasing rate of rise; the third is horizontal, showing maintenance of constant temperature.
14. Penometer tests of cooked vegetables show that the term "doneness" does not mean that they all have the same degree of penetration.
15. The higher acidity of the liquid from pressure cooked and casserole-baked vegetables suggests that some chemical change has occurred during these cooking processes.

CONCLUSIONS

1. The time required to cook a vegetable depends on the rate at which heat penetrates to its center and produces a desirable degree of tenderness, known as "doneness".
2. In comparing the four methods of cooking used in this study, steam pressure, with its higher temperature, caused a more rapid rate of heat penetration and thus required the least amount of time for cooking the vegetables. Boiling came next in time required; steaming, next; and baking was the slowest process.
3. With the exception of steam pressure cooking the rate of heat penetration into the vegetables falls into three periods. In the first, there is a rapid rise in temperature; in the second, a slower rate of increase in temperature; and in the third, maintenance of a constant temperature.
4. The size of the piece of vegetable to be cooked affects the time required for the penetration of heat. The larger the piece the longer the time that is required for cooking.
5. In boiling, the addition of salt to the cooking liquid does not appreciably raise its boiling temperature nor does it appear to affect the time required for cooking vegetables.

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