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By R. F. Ross

Definition and Nature of Problems

The changes in volume, state and weight that take place in tissues when exposed to various solutions and temperatures, are referred to as the shrinkage. It may be mainly one effect such as the effect of coagulation, or of osmosis, or it may be a combination of both. On the other hand it is affected by autolytic or bacterial chemical effects in the fish tissues. It is therefore evident that the measurements of the shrinkage is the sum of many effects, each of which varies with conditions.

Application: The shrinkage has economic importance in the fishing industry as it affects almost every method of handling or preserving fish. In cooking fish before canning the loss of weight is from 20 to 40 percent. In boiling lobsters there is a loss of 20 percent. or more. In canning extra weight must be put in the cans in order that they may have the required weight after processing. This must be done even if the material has been previously cooked.

In the salting of fish in the dried fish industry there is a loss of weight in the salting and in the drying. Similarly in the salting for the smoked fish business there are changes in weight and texture. This occurs as well when fish are pickled. In cold storage fish may lose as much as 75 percent. of its weight.

So it is evident that the shrinkage effect is a common one in the industry and since its effect is usually a loss in weight it is one of serious economic importance.

Our problem was to (1) Find a method of measuring the shrinkage (2) Discover the nature of the changes taking place in the tissues (3) Measure the effect of various factors and changes in the environment on the shrinkage of fish muscle.

References

References on this subject are scanty. The general subject of coagulation of proteins is discussed in the books by Matthews, Hawk and Bergheim, etc. The previous work of Dr. Forbes and Mr. Weld and other workers at the Fisheries Experimental Station was consulted. References to shrinkage are frequently made in canning magazines as it is a recognised process in the industry, but little of the work is quantitative and most of the information is of a technical nature.

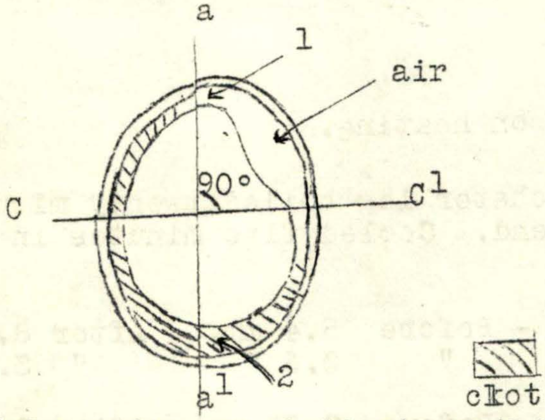
Methods of Attack

1. Direct Linear Measurement. Since Mr. C.B. Weld had obtained some results by measuring the diameter of ice crystals in his work on the structural changes in frozen fish it was thought that direct linear measurements of the shrinkage might be obtained, by using lobster and crab legs. The leg was removed, clamped off and subjected to various treatments and the amount of separation of the muscle from the shell measured by cutting across the leg midway between joints as neatly as possible with a razor blade. Measurement was made under a binocular microscope using a scale marked off in twentieths of a millimetre. In using this method it was assumed that the shell was not affected in size or shape by the boiling. A long series of tests was made but it was found impossible to obtain any accurate results that would check for the following reasons. (1) The impossibility of determining the extent of a three dimensional change by measuring the changes in one or two dimensions. A cross section at one level might not be true for any other level. (2) The variability of the condition of the blood clot which might be present or absent between the meat and the shell. (3) The fact that the meat sometimes adhered to the shell and broke through the middle. (4) The fact that the shell was not a constant basis for comparison - measurements made showing that the diameter through one axis might increase while that through another axis at right angles might decrease. (5) The fact that a pressure was developed inside the shell when heated and that this pressure necessarily varied, hence the conditions of heating varied. Since there was no obvious method of knowing the variation the results would be of absolutely no value;

Experimental Results. Separation of meat from shell.
Experiment I. Lobster leg. Boiled 20 minutes in tap water. Cooled 5 minutes. Clamped before immersion.

Dimension	Outer diameter shell	Inner diameter shell	Interval 1	Interval 2	Diam meat	Shrinkage % of orig. diam.
$a - a^1$	7.4	7.0	0.4	1.0	5.6	26
$b - b^1$	4.4.	4.0	0.4	0.6	3.0	25

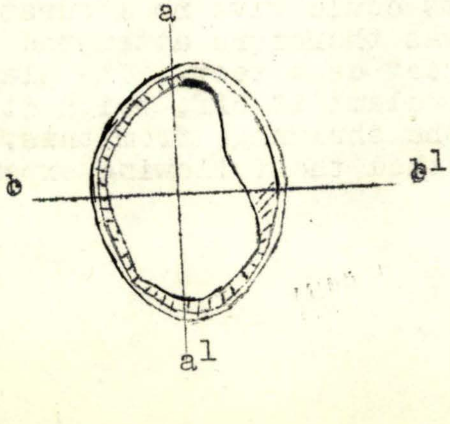
All lengths in millimetres.



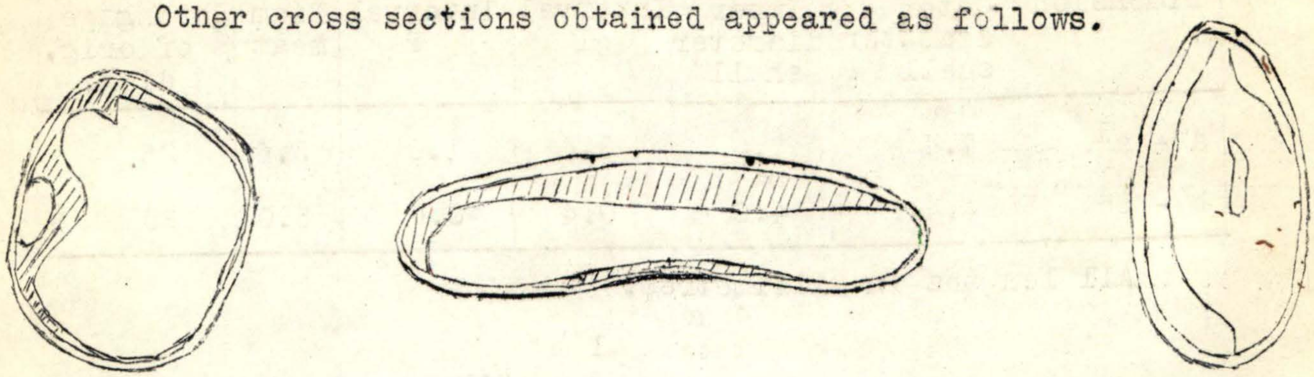
However these shrinkage figures indicate nothing since the air space has been neglected and cannot easily be taken into account.

Experiment 2. Lobster leg boiled twenty minutes in tap water. Cooled five minutes. Clamped before immersion. Treatment exactly as above.

Dimension	Outer diam. shell	Inner diam. shell	Interval 1	Interval 2	Diam. meat	Shrinkage % of orig. diam.
$a - a^1$	7.3	6.9	0	0.4	6.5	5.8
$b - b^1$	4.6	4.2	0	0.8	3.6	19.0



Other cross sections obtained appeared as follows.



Changes in shell on heating.

Experiment 1. Lobster leg boiled twenty minutes in tap water. Clamped at open end. Cooled five minutes in water at room temperature.

1. Long diameter	- Before	8.4 mm.	After	8.3 mm.
Short "	"	3.6 "	"	3.7 "
2. Long diameter	- Before	8.25 mm.	After	8.10 mm.
Short "	"	3.60 "	"	3.80 "

Changes in crab shell on boiling.

Crab legs clamped at open end, boiled fifteen minutes in tap water, and cooled five minutes.

1. Long diameter	- Before boiling	9.50 mm.	After	9.40 mm.
Short "	" "	3.50 "	"	3.50 "
2. Long diameter	- Before boiling	9.35 mm.	After	9.15 mm.
Short "	" "	3.75 "	"	3.95 "

Several other experiments were done with similar results.

Conclusion. These experiments convinced the experimenters that linear measurements could give no accurate measurement of the shrinkage. It was therefore attempted to use the weight of the lobster meat as a test. The plan was to take a claw or leg of lobster, clamp it off, weigh it before and after and attempt to derive the shrinkage from this. With the purpose of testing this method the following experiments were performed.

1. Loss in weight of a lobster claw when boiled.

A claw was removed, clamped off and put into boiling tap water.

Weight of lobster claw less clip	94.3 gms.	
Weight when boiled fifteen minutes	76.3 "	Loss 19.1%

(The above loss was noted to be largely due to a leak past the clamp which allowed a clear watery fluid to come out)

Weight when boiled thirty minutes	63.3 gms.	Loss 32.9%
" " " forty-five "	60.3 "	" 36.0%
" " " sixty "	60.5 "	" 35.9%

2. Changes in the shell in boiling.

In order to render any results reliable it must be proven that the shell does not change weight in boiling or changes by a constant amount. Our experiments showed that this was not the case.

Experiment 1.

Weight of shell	11.7 gms.	Boiled 11 minutes in tap water.
Weight of shell	11.45 gms.	
Percentage loss in weight	2.14%	
Weight in 31 minutes	11.2 gms.	
Percentage loss in 31 minutes	4.27%	

Experiment 2. Tail shell cleaned out and boiled for 20 minutes a 5% solution of salt.

Weight before boiling	24.1 gms.
Weight after boiling and drying	22.3 "
Weight loss	1.7 "
Percentage loss	7%

Experiment 3. Piece of shell cleaned carefully and boiled in tap water for 80 minutes.

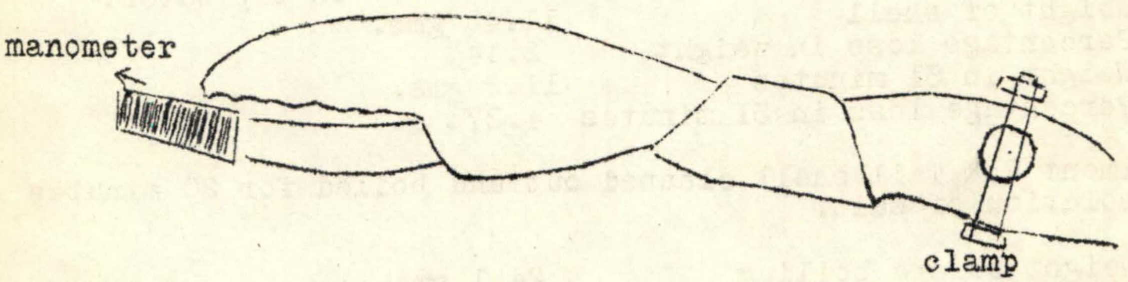
Weight of shell before boiling	10.2 gms.
" " " after "	9.95 gms.
Loss	2.5 gms.
Percentage loss	2.5%

Pressure within the shell in boiling

Previous experiments had indicated that a pressure was developed in a lobster when it is put cold into a hot bath. This is to be expected as the vapour pressure increases rapidly as the temperature is raised and, in a closed system, such as a sealed flask at boiling, may reach 760 mm. of mercury. As the lobster is a somewhat parallel case a pressure develops in the shell due to the vapour pressure of the heated contents and the pressure of expansion on heating. In the lobster, however, the softer tissues of the shell burst outward long before the theoretical maximum is reached, and in the case of a claw with strong tissues and the end clamped off securely, pressures of only 300 mm. have been obtained. Experiments were done to measure this pressure with the results shown later. As the shell bursts a large part of the liquid contents escape into the boiling medium.

Experiment 1.

A lobster claw was taken and clamped off tightly at the open end. A mercufy manometer was arranged next to the pot of boiling water. The tip of the "thumb" of the claw was removed and connected with the manometer by a piece of heavy pressure tubing slipped thightly over the end.



The claw was then dropped quickly into the boiling water and the pressures read. The pressure rose rapidly to 120 mm. mercury when a leak developed near the clamp after which the pressure dropped somewhat and remained in the vicintty of 100 mm. mercury for an hour when the claw was taken out.

Experiment 2.

Another claw was taken and weighed. Weight 51.5 gms. less tip of thumb. It was then connected to the manometer in the same manner as the one in Experiment 1. The pressure rose according to the curve shown (Graph 1, upper curve). On removal the weight was 37.6 gms. making a percentage loss for the whole claw of 26.3%. The weight of the shell when separated from the meat was 18.3 gms. Adding a 4% correction for loss makes the original weight of the shell 19.2 gms. and therefore of the contents 32.3 gms. Final weight of contents was 19.3 gms. Therefore the loss in weight of the contents of the shell is 40.1%.

Experiment 3. Pressure in whole lobster on boiling

A lobster in good condition was taken and weighed (545 gms) The tip of one thumb was cut off and the pressure tube applied as before. The lobster was put into the boiling water as in the other experiments. The pressure rose steadily until about 50mm. mercury. Then a spurt of fluid was seen to issue from a crevice between the carapace and tail shell. After this the curve was much flatter, not going above 65 mm. in an hour.

These results led us to several conclusions.

1. The shell of the lobster is probably permeable under a pressure.

2. Much of the weight of the lobster is lost in the forcible expulsion of liquid by the pressure. None of the meat escapes and the liquid is probably mostly lymph and blood, but it was thought that some soluble proteins might have been escaping that should have been coagulated and left with the meat.

With this idea in mind it was thought that by counteracting the internal pressure of the lobster by an external equal pressure the shrinkage might be decreased. This was done by putting lobsters into cold water in a retort and raising the temperature of the whole system to 100°C. and a pressure inside the retort of 15 lbs. to the square inch.

The results were as follows:

Experiment	Treatment	% Meat	Pressure
1	Retorted 20 min. at 212°F.	27%	15 lbs. Pres/sq.in.
2	" " " " "	21.6%	" "
3	" " " " "	20%	" " "
4	Boiled 20min. at 100°C."	22.8%	0 lbs. " "

Further work should be done on this with a larger quantity of lobsters. The boiled lobster also seemed to give a better product for removal from the shell. An explanation for this is given in the next section.

Histological Study of Shrinkage

C.B. Weld, in his study of the pellicle on smoked fish and also the histology of brine and air frozen fish, measured under the microscope the changes in diameter of cells and cell spaces and in that way obtained important data. It was thought that the study of our problem might be assisted by making a study of this kind. It was thought that the changes in diameters of cells and fibres might gauge the shrinkage. Also a picture of what actually takes place in the tissues during the shrinkage of fish was desirable.

For this study Mr. Weld's technique described in his report of the summer of 1926 was adopted and used. The tissues studied were frozen by CO_2 and sectioned by a microtome. They were then removed from the microtome knife in brackish water. The best sections were then transferred to slides, stained with eosin and dehydrated by running through an alcohol series. They were then mounted in oil of cloves with Canada Balsom around the border ofbthe cover glass.

A series of slides were made of the muscle in the legs of crabs and lobsters. The technique was as follows.
The crabs and lobsters were taken alive and a leg quickly removed and clamped at the open end. The leg was dropped in boiling sea water for a definite time. It was then removed and dropped in water at room temperature for five minutes by which time it was cooled thoroughly. When the sections were made from the raw tissue the whole leg was taken and clamped and then frozen directly by the CO_2. The same difficulty was met with as before in getting accurate results. Any measurements of the sizes of the fibres or cells that were made were not sufficiently uniform or accurate to give definite results that would check the small differences in the amounts of shrinkage. For instance, one minute in boiling water is sufficient to coagulate the tissues completely through the leg, and no appreciable difference is evident for longer times. For longer times longer pieces of tissue are necessary and they are impossible to use on the microtome. Then again the width of each fibre differs from every other one and there is no way of telling how wide a fibre was originally. So as a quantitative method this one is of little use. However some interesting data was obtained as to the changes that take place in the tissues as they coagulate, and also some relative differences in the structures of the tissues of crustacea themselves and between them and the tissues of the fishes. Lobster and crab muscle are seen to contain very little connective tissue between the fibres. The muscle fibres are loose and easily separated and hence difficult to section because the fibres separate so easily. On the other hand fish muscle contains much connective tissue and is much more easily sectioned as the fibres are firmly bound together. Lobster muscle is looser than crab muscle as the fibres of the latter are bound weakly together in groups of four or five. Hence crab is easier to section. The first effect of heat on the tissue is to coagulate the proteins. This greatly weakens the connective tissue. In the crab or lobster coagulation has penetrated 4 mm. in 30 seconds and therefore the first connective tissue to weaken and give way is that which connects the shell to the muscle. If the muscle is still alive, as it usually is in practice, the natural elasticity and tone draws it in and squeezes the juices out into the cavity formed between it and the shell. The effect of the heat on the nerve fibres and reflex centres would be similar, causing a tense contraction of the muscle. This is evidenced by the tense contractions of the muscles that are noted when a live lobster is plunged in boiling

water. If a dead lobster is boiled, owing to the lack of tone in the muscle tissue and the absence of reflexes the meat is not separated into a firm piece but is broken and powdery and sticks to the shell. As the heat is transferred into the tissue coagulation takes place in this contracted condition.

At the Experimental Station here it was noted (Ross - Report on Brine Freezing of Lobsters 1927) that brine frozen lobsters did not shrink away from the shell as well as live lobsters did, when boiled. This is probably the explanation. Instead of the outer connective tissue being weakened while the muscle still was alive - as in boiling live lobsters - the outer tissue was coagulated but the living contraction of the muscle which tears it from the shell was absent, the tissue being killed by the freezing, and hence there was a poor separation of the meat from the shell. A similar effect is noted when lobsters are slowly heated so that they are killed before any part is coagulated.

Slides were prepared and are handed in with this report showing cross sections of crab and lobster legs in which the outer part of the leg had become coagulated while the centre was still alive. These slides show well the changes taking place.

It is noted that the coagulated fibres are more refractive, cloudy in appearance and much more clearly outlined. Small cracks are evident in the fibres. The living tissue is seen to be more transparent with looser spaces between the fibres and with the outlines not so clearly marked. The gross changes noted are a hardening and whitening of the muscle which forms a firm piece, while the fresh muscle is soft, transparent, and almost liquid in consistency.

The experimental work previously done although providing some interesting data had given no accurate information as to the factors influencing the amount of shrinkage. The reasons for this are:

(1) There were too many variable factors.

(2) The impermeability of the shell is doubtful.

(3) There is no simple accurate method of measuring all the changes taking place.

(4) The pressures are not constant or measurable easily without affecting the experiment.

Therefore it was decided to use cubes of cod muscle, to expose these to differing conditions and measure the shrinkage by the change in weight noted.

Shrinkage in Cod Muscle

In these experiments cod muscle was used because it was easiest to obtain fresh, it usually is easier to handle and can be got in more convenient size of pieces than most other fish.

In the experiment to determine the shrinkage, cubes of fish were used. They weighed from 9.5 to 12 gms. usually, and were cut to as nearly cubical shape as possible. The purpose of this was to render the surface area as constant as possible for the weight of fish used.

All solutions used were made up in a 1000 cc. volumetric flask from distilled water and Baker's Analysed NaCl, except where otherwise stated. For a 10% solution 100 gms. NaCl were put in the volumetric flask and distilled water added to make up 1000 cc. of solution.

Weighing was done on a balance and was accurate to 0.1 gm.

Great care was taken that all the fish used should be absolutely fresh. Most of the fish used had not gone into rigor or was still in that stage. Fish beyond this stage was not used unless otherwise stated. This was found to be of very great importance as by far the greatest error seems to be due to varying conditions of the fish.

Percentage error:- The error in weighing the sodium chloride is .1 gm. in 1000 gms. of solution or .01 %. That of the flask is .1%. Errors in weighing the fish = .05 gms. in .10 gms. weighing twice and therefore making an error of 1% in the results. With differences of 1 gm. in the weights before and after this gives a possible error of 10% in any one point. However, since each curve is made through a series of points this error is reduced to from 1 to 2% for the whole curve obtained. It was noted also that as the experimenter became practiced at the technique, the points come to form a very regular curve.

Shrinkage of Fish Exposed to Brines of Various Concentrations at Room Temperature

Technique

The cod was taken absolutely fresh, filleted and cut as required into cubes of approximately 10 gms. in weight. No fish had been out of water for more than six hours. The solution had been made up beforehand and allowed to stand, and had been thoroughly mixed. Each cube was weighed to 0.1 gm. and then put in a small dish and immersed in the solution. Approximately 100 cc. of solution was placed in each dish. The time of immersion was taken and the time of removal. The dish was swirled around every few minutes to give better mixture of the contents near the fish. On removal the fish was enveloped in cheesecloth and all surplus moisture removed by gently pressing the dry cheese cloth to the fish. A check experiment showed that if this was done in a careful manner and the same way each time the possible error was .05 gm. which is below the smallest differences measured in the weighing. Cheesecloth was found to be best as a dryer because it did not adhere to the fish as did blotting paper and filtor paper. A soft towel was equally as good as cheese cloth. The cube was then immediately weighed to .1 gm. The difference in weight was then taken and expressed as a percentage of the original weight of the cube. The curves obtained for the different concentrations are shown in the accompanying graph. (Number 2) Each of these curbes although a single series in itself has been checked by others as shown in the check diagrams. The fact that none of the points are exactly on one curve is supposed to be due to small variations in the shape and condition of the cubes of fish. As is indicated by the curves, distilled water gives the greatest increase in weight, while saturated salt solution gives the greatest loss. With concentrations less than 17% NaCl there is a gain in weight. The least gain in weight (except around 17% where the curve crosses) is found at 1.5% NaCl, where a cusp is formed in the curve. It is suggested that at this point, since the salt solution is at about the same concentration as in the fish, the tension is so low that there is very little interchange of molecules in either direction. When the shrinkage is plotted against the concentration of brine for a set time an interesting curve is obtained. Such a curve is shown in Graph No. 3, where fish cubes were immersed in different concentrations for two hours. It is thus really a cross section of the curves of fig. 2 at the two hour level. The results are not exactly as one would expect. The dip at the iso-tonic point with a peak gain at 5% concentration and no loss of weight until a concentration of 17% is obtained were surprises. Forbes, working at the Experimental Station on a similar problem, noted that at one third saturation, about 8%, the fish did gain weight but made no measure of the limits of the gain and has no mention of the dip at the iso-tonic point. We have shown that the brine does not reduce the weight of a piece of fish until a strength of two-thirds saturation is obtained, i.e. in a 17% solution of sodium chloride. The explanation of such a curve is in our opinion this. As we have measured the weight change we have measured the sum of the gain or loss of water, plus the gain or loss of salts, plus the gain or loss of soluble proteins. At 0% concentration the gain in weight is due to the absorption of water less the loss of soluble proteins and salts. At 5% the gain is due to the penetration of salt less the loss of water and proteins. It is then evident that the salt that enters plus its water of solution is heavier than the water and proteins lost.

Checks

Curve 4 shows the results of a chack series run through to test the validity of a curve obtained for 1% sodium chloride. The two curves marked (b) and (c) were run through at the same time with the same solutions of 1% Baker's Analysed salt in distilled water and using the same fish. It is evident that the two curves are well within the margins of error allowed as shown by the circles around each point. The curve (d) was made at another time about a month previously with different fish but with a standard solution of Baker's Analysed salt in distilled water just as the one above. The temperature was kept at the same point. For the first hour it is noted that the points run consistently lower although still within the limits of experimental accuracy. There are various explanations for this lowering. The most obvious one is the condition of the fish. No two fish are exactly alike either in age, condition, texture or autolytic state and it is reasonable to believe that this may be the reason. The second reason is that the margins of error are greatest where the differences are least, or in the first part of the curve. At two hours the curves have crossed at one place, and at three hours they practically coincide.

In dotted lines above is plotted a curve (a) for distilled water for purposes of comparison. The curve for 5% NaCl is slightly lower than distilled water and far beyond the limits of the curve for 1% NaCl. So it is maintained that although our limits of accuracy may make it difficult to distinguish between 1%, 1.5% and 2%, there is a definite drop from distilled water to 1% NaCl and a definite rise from 1% NaCl to 5% NaCl which justifies us in making a drop in the curve between distilled water and 5% NaCl.

Some of the curves show an irregular feature. The distilled water curve rises to a maximum in abour 100 minutes for a 10 gm. piece. After that there is a drop in the curve. The explanation advanced for that is that the cells which become distended, finally begin to rupture allowing the escape of the diluted proteins into the media.

It was also observed and may be mentioned in passing that the surface of the cubes varied greatly as they were removed from concentrations of various strengths. The surface below the iso-electric point was rough and very similar to the surface of a cauliflower, hard, swelled, and bulged. From the iso-electric point to 15% the surface was very smooth and slippery with a slimy surface. From 17% to saturation the surface was not so smooth or slippery as below that but not as rough as between 1.5% and 0%.

Effect of Various Impurities and Adulterants in Salts on Shrinkage at Room Temperatures

The curves in Graph 5 record the results of several experiments made with the same fish at the same time but using various salts. The curves indicate that these salts make practically no difference in the shrinkage. The salt used as a standard is Baker's Analysed a specially pure sodium chloride with practically all other salts removed by chemical means. Rice's Table Salt is said to contain 1% Magnesium Carbonate. "Sifto" Table salt with 1% Magnesium phosphate, and sea salt, commonly used in the fishing industry is evaporated sea water or a sea salt. There is nothing in the curves to indicate any effects due to the impurities contained. The probable explanation is that the impurities are present in too small a proportion to be noticed on the curves. No experiments were made in which known salts of other metals were added to the solutions, although it is possible that such salts in higher proportions might materially alter the permeability of the tissues, and alter the shrinkage.

Effect of Age of the Fish on Shrinkage

In obtaining material for experimental purposes care was taken that the fish obtained was perfectly fresh. In many cases fish was used in which the tissue was still alive or was passing through the process of death. Rigor began in from one to four hours if the fish was kept in a room at 25°C. Fish previous to rigor was of a strong, stiff, rubbery texture somewhat like a thick jelly, and rather transparent in color with a pronounced iridescence across a cut surface.

When rigor came on, the piece of fish became shorter, and thicker and harder, but was not as tough and when cut across gave a rough surface while the optical properties were almost lost. The color became slightly whiter and the semi-transparity was lost.

When rigor had passed, the fish assumed the appearance by which it is best known on the market. The stiffness had passed off completely, also the elasticity, and the result was a weak flaccidity. The surface was rough and slimy. The myomeres begin to separate. The fish was white and opaque.

It was thought that such marked physical changes as the above might possibly be neglected in the shrinkage curves, so advantage was taken of the availability of such fish and curves made. Since every piece of fish varies in its condition, no two pieces of fish pass through these changes in the same time. But fresh fish from which a piece was removed for the previous experiments, was kept on ice for twenty-four hours and then treated in the same manner as the fresh fish. This resulted in a series of curves as shown in Graph No. 6. In this graph the shrinkage of fresh fish is compared with that of fish that has been kept on ice for twenty-four hours.

Of the twenty-four hour fish in order to illustrate its variability two different curves have been made. One in which the twenty-four hour fish was in good condition (i.e., traces of rigor still persisting, myomeres still firmly attached and the fish fairly strong) while the other although it had received similar treatment was weak and soft, the myomeres separating and the surface soft and plastic. The curves indicate the results of experiments in which distilled water and saturated salt solutions were used. Other series were made with 1% and 2% but fell in relatively the same place as with fresh fish so are omitted for the sake of simplicity.

Results:-

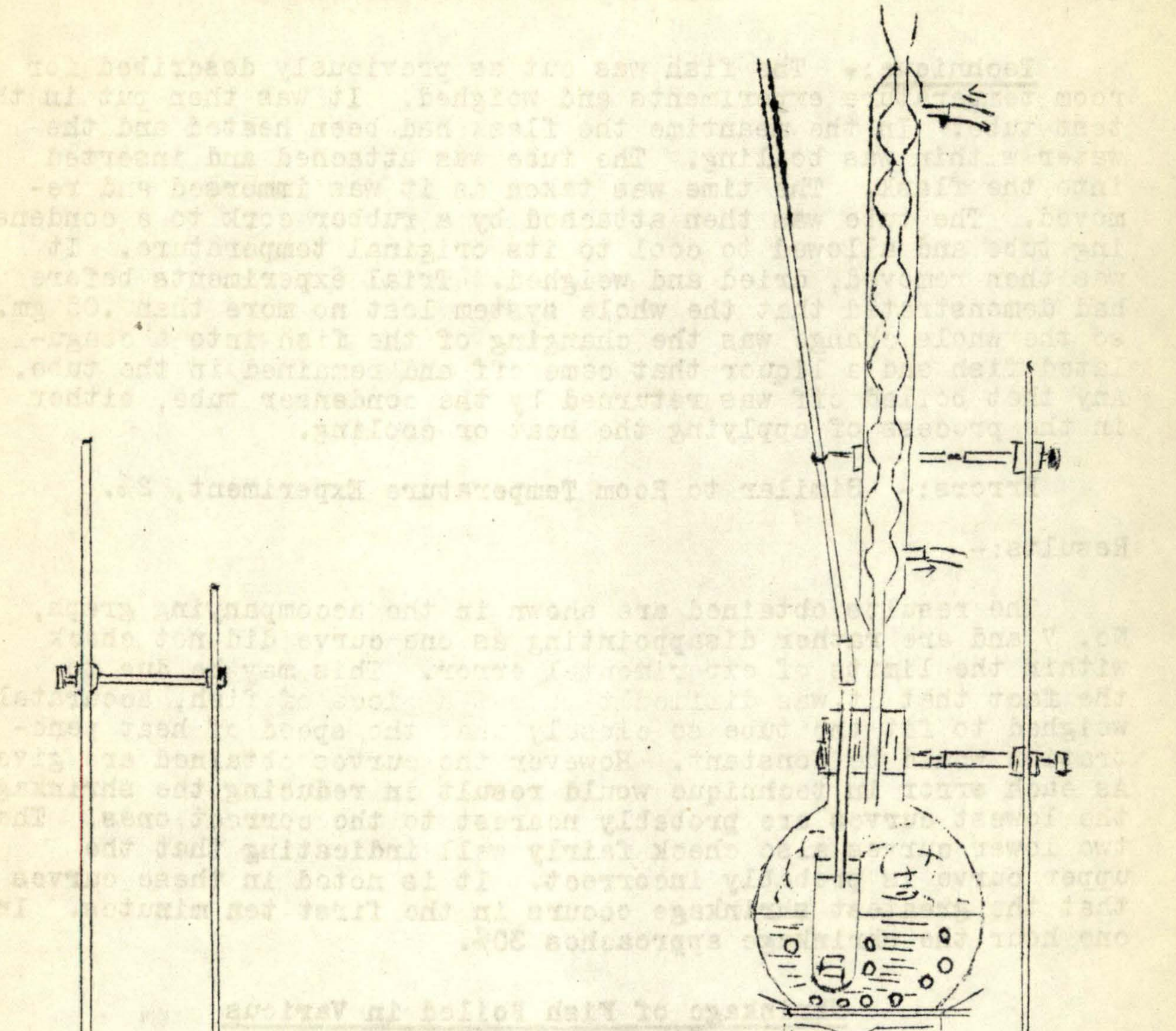
Saturated Salt:- It is noted that the poorest fish, i.e., that furtherest removed from the fresh condition is the one in which the least loss of weight has occurred. In three hours in brine it has lost only half of what fresh fish would have lost. Fish in better condition loses more weight, while fresh fish loses most of all. It was an experiment of this nature made at the beginning of the work that aroused us to the danger of the error due to variability in the condition of the fish, with the result that absolutely fresh fish was used for the work. The results here agree with the observations of fisherman who say that old fish takes up more salt than fresh fish thus causing less shrinkage.

Distilled Water:- With these results little is shown except the variability of the twenty-four hour fish. The curves of 24 hour fish in good condition run higher than those of fresh fish

Shrinkage at 100°C. Unexposed to Medium

Purpose:- In these experiments it was intended to find the effect of 100°C. on the fish without exposure to any liquid medium, thus driving the effect of the temperature alone.

Apparatus:- A test tube one inch in diameter and about three inches long was used for the fish. This was sealed with a rubber cork through which a long tube passed. This tube served as a condenser for the vapours coming off the fish. The test tube was passed through the top of a litre flask and arranged so that it would be bathed in the water in the flask. The long tube from the test tube passed up through a hole in the cork of the flask. The level and concentration of the boiling medium in the flask was maintained by a large reflux condenser attached to it.



Cooling Apparatus   Heating Apparatus

Apparatus for Shrinkage Tests at 100°C.

Technique:- The fish was cut as previously described for room temperature experiments and weighed. It was then put in the test tube. In the meantime the flask had been heated and the water within was boiling. The tube was attached and inserted into the flask. The time was taken as it was immersed and removed. The tube was then attached by a rubber cork to a condensing tube and allowed to cool to its original temperature. It was then removed, dried and weighed. Trial experiments before had demonstrated that the whole system lost no more than .05 gm. so the whole change was the changing of the fish into a coagulated fish and a liquor that came off and remained in the tube. Any that boiled off was returned by the condenser tube, either in the process of applying the heat or cooling.

Errors:- Similar to Room Temperature Experiment, 2%.

Results:-

The results obtained are shown in the accompanying graph, No. 7 and are rather disappointing as one curve did not check within the limits of experimental error. This may be due to the fact that it was difficult to get a piece of fish, accurately weighed to fit the tube so closely that the speed of heat penetration would be constant. However the curves obtained are given. As each error in technique would result in reducing the shrinkage the lowest curves are probably nearest to the correct ones. The two lower curves also check fairly well indicating that the upper curve is probably incorrect. It is noted in these curves that the greatest shrinkage occurs in the first ten minutes. In one hour the shrinkage approaches 30%.

Shrinkage of Fish Boiled in Various Strengths of Brine

The purpose of the following series of experiments was to determine the loss of weight of fish when subjected to a brine at its boiling point for various times. In these experiments there is the effect of the temperature combined with the extractive power of the brine, if any.

The apparatus used was that described in the previous section without the small test tube and its condensing tube. The boiling medium was placed in the large flask, heated, and kept at its original concentration by the reflux condenser.

Technique:- The fish is weighed and dropped into the boiling medium for a certain definite time. The solutions were made up from distilled water and Baker's Analysed Sodium Chloride as before. On removal the piece of fish was allowed to cool to room temperature, dried, if necessary, and weighed in the same manner as before. The percentage error in this case is similar to that originally calculated 2%, plus an added factor, depending on the temperature at which the final weighing is made. When fish is boiled in distilled water, removed and weighed at once, there has been practically no loss of weight. However, the steam which evaporates from it as it cools may reduce its weight 30% before reaching room temperature. This is the most variable factor. In order to reduce it as much as possible all pieces of fish were left standing for the same time after removal and were hence cooled to approximately the same extent before being weighed. However, this factor should be remembered in interpreting the curves.

Results:-

The results are shown in Graph No. 8, for fresh fish and in Graph No. 9, for 24 hour fish - i.e. iced for 24 hours.

Fresh Fish:- The curves done indicate that there is not much variation in the shrinkage around the lower concentrations of brine and that the loss of weight is approximately 26%, and the greatest loss in weight occurs in the first five minutes. Boiling for long periods, however, can increase the loss to 40% of the original weight. Boiling in saturated salt solution very quickly causes a loss of 40% of the original weight.

24 Hours Fish:- In these curves it is seen that the losses are greater with the exception of the curve for saturated salt solution in which it is slightly less. The curve for distilled water and 1% salt solution are the lowest both running along and approaching 40% loss. The peculiar position of the 0% and 1% curves might be explained by their power of dissolving out constituents made more available by the changes of autolytic and bacterial nature. The saturated salt solution shrinkage might be explained as water extraction. The position of the other two curves could be explained by lowered dissolving power and little extractive power.

Shrinkage of Steamed Fish

In these experiments it was proposed to find the effect of exposure to steam from boiling water on the shrinkage of fish.

Apparatus:- The steam was generated in a large flask, and conducted by a glass tube to a 250 cc. glass jar. On the bottom of the jar was a small frame of wire netting to support the fish and keep it out of any water that condensed on the bottom of the jar. A large amount of steam passed in. The outlet of the steam tube was near the bottom of the jar and the steam rose up over the piece of fish and escaped through a small opening at the top which was loosely corked. The temperature in the jar during cooking was 98°C. ± 1°C.

Technique:- The apparatus was heated up first of all by passing steam through vigorously for five minutes. The fish was weighed as before and dropped into the steaming jar for a definite time. On removal it is cooled to room temperature, in a similar manner to that described in the last section, and then weighed. The percentage error is therefore similar to that of boiling fish and can be taken as about 4%.

Results:-

The results are shown on Graph No. 10. The broken curves show the shrinkage in fresh fish while the continuous one shows it for 24 hour fish. As usual most of the loss of weight occurs in the first five minutes and the maximum loss of weight seems to approach 30% as a limit while for short periods, with some of the samples, twenty minutes steaming resulted in a loss of only 20%. Fresh fish and fish iced for 24 hours seem to shrink about the same amount. A comparison curve is given at the bottom showing the effect of boiling in distilled water compared with steaming. The explanation suggested is that the soluble constituents of the fish muscle are not so liable to be removed when treated with steam. The temperature is also slightly lower with steam (2°C). The experiments indicate that steaming is the best method of cooking for the conservation of weight.

This concludes the report, and in summing up, the following things might be mentioned.

(1) A study was made of certain crustacea-lobster and crabs-relating to the changes that take place in boiling. Weight changes, pressures etc., have been measured and an explanation offered for the fact that the lobster sometimes separates imperfectly from its shell when cooked, especially brine frozen lobsters and dead lobsters.

(2) A histological study of the changes taking place in lobster and crab muscle was made and slides made showing the different changes.

(3) Various methods of measuring the shrinkage of fish muscle when cooked or exposed to brines were tried and either discarded or adopted.

(4) The effect of various methods of applying heat on the weight change has been investigated.

(4) A study was made of the effects of different brines at room temperature for different times on the weight of fish muscle. Curves were obtained to show these changes.

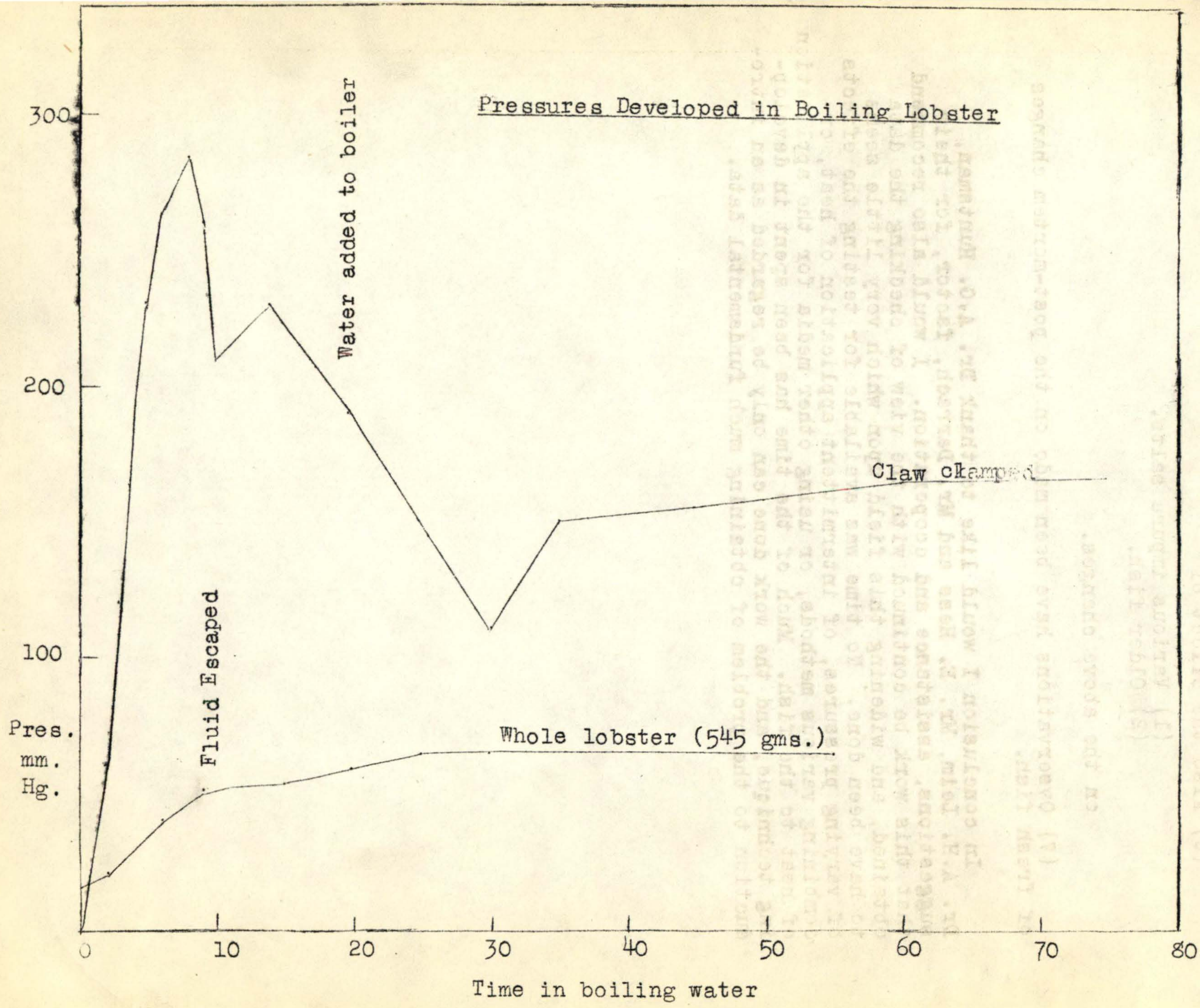
(6) Also the effect of

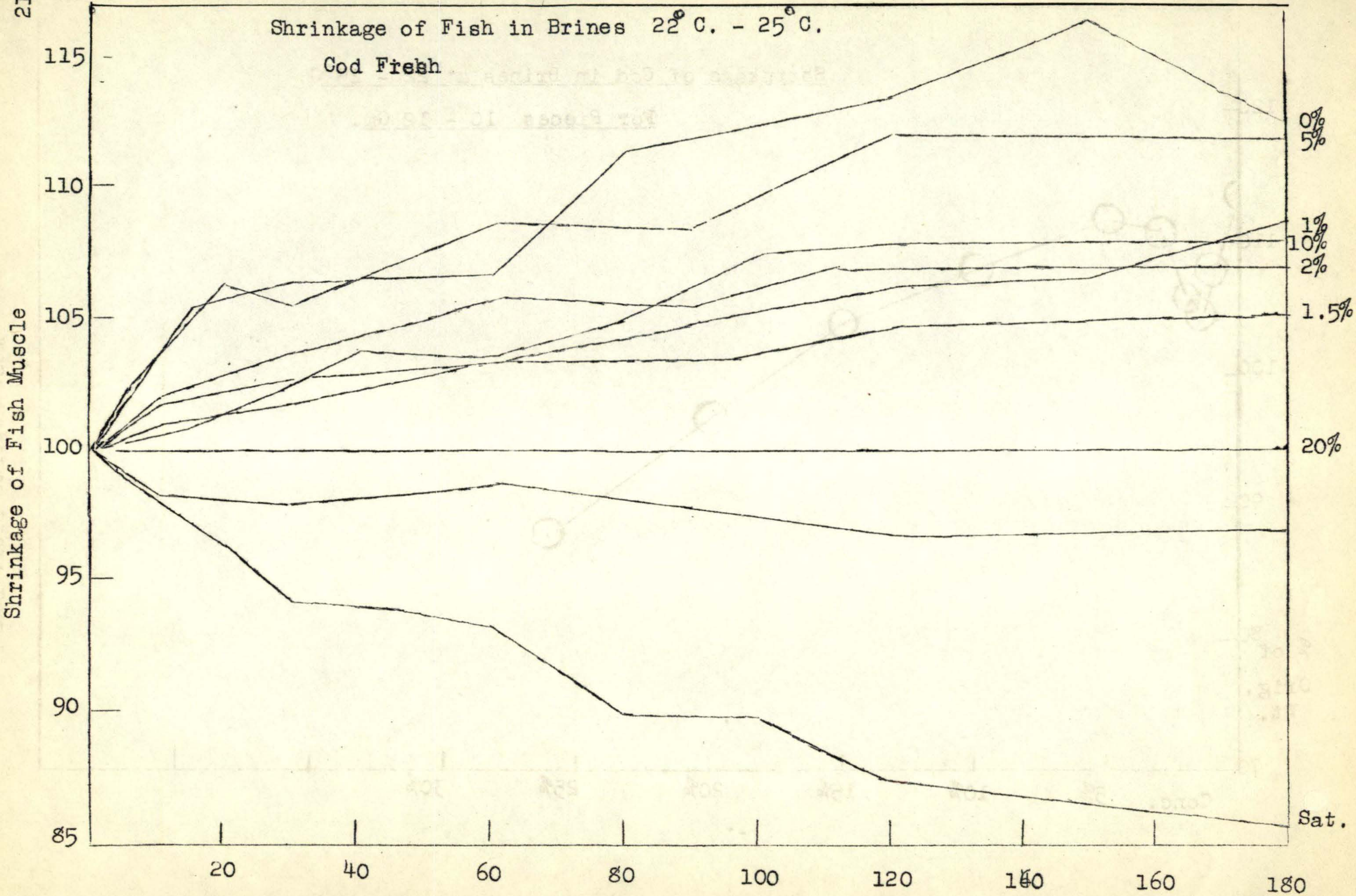
(1) Various impure salts.
(2) Older fish.

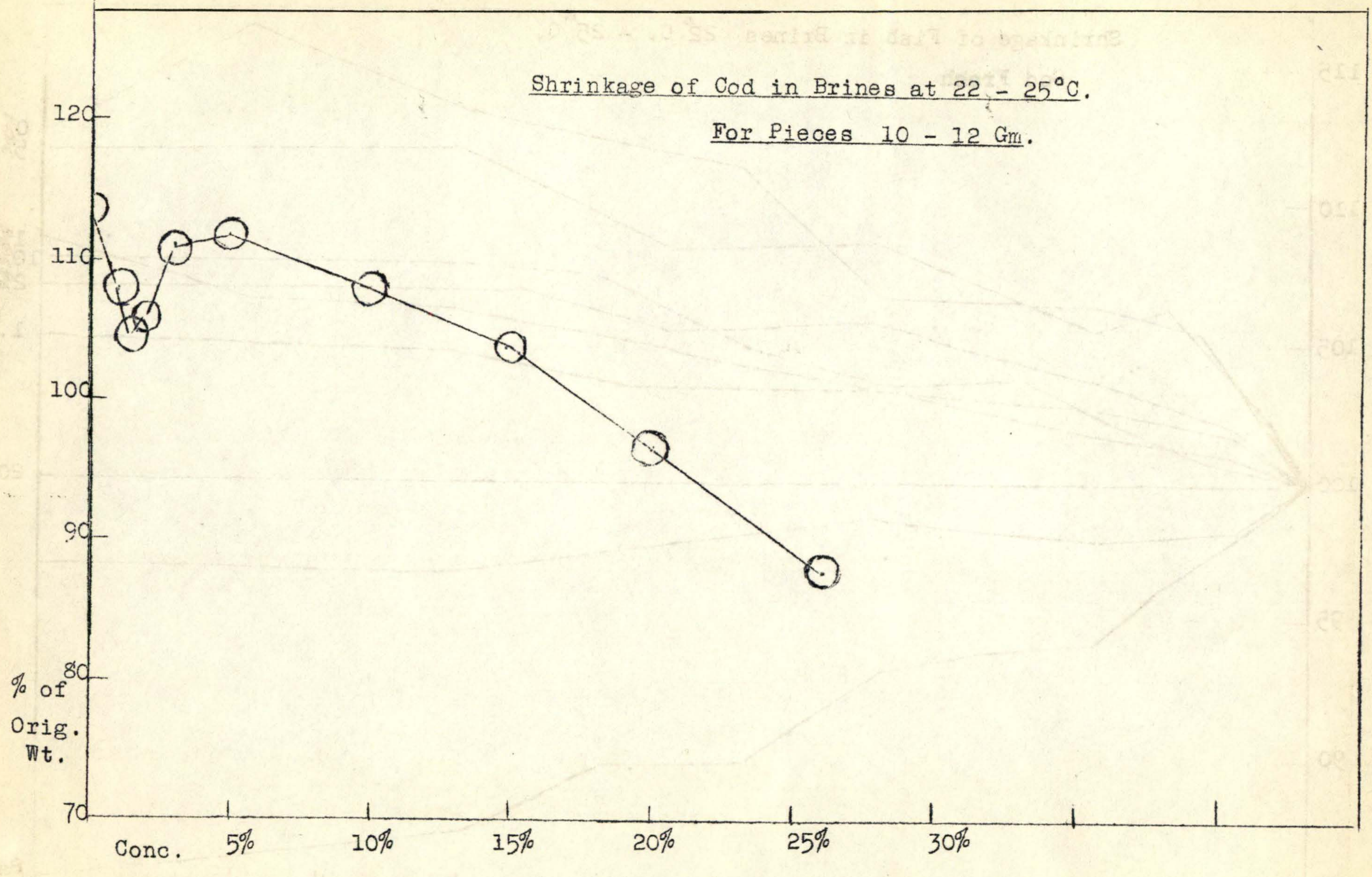
on the above changes.

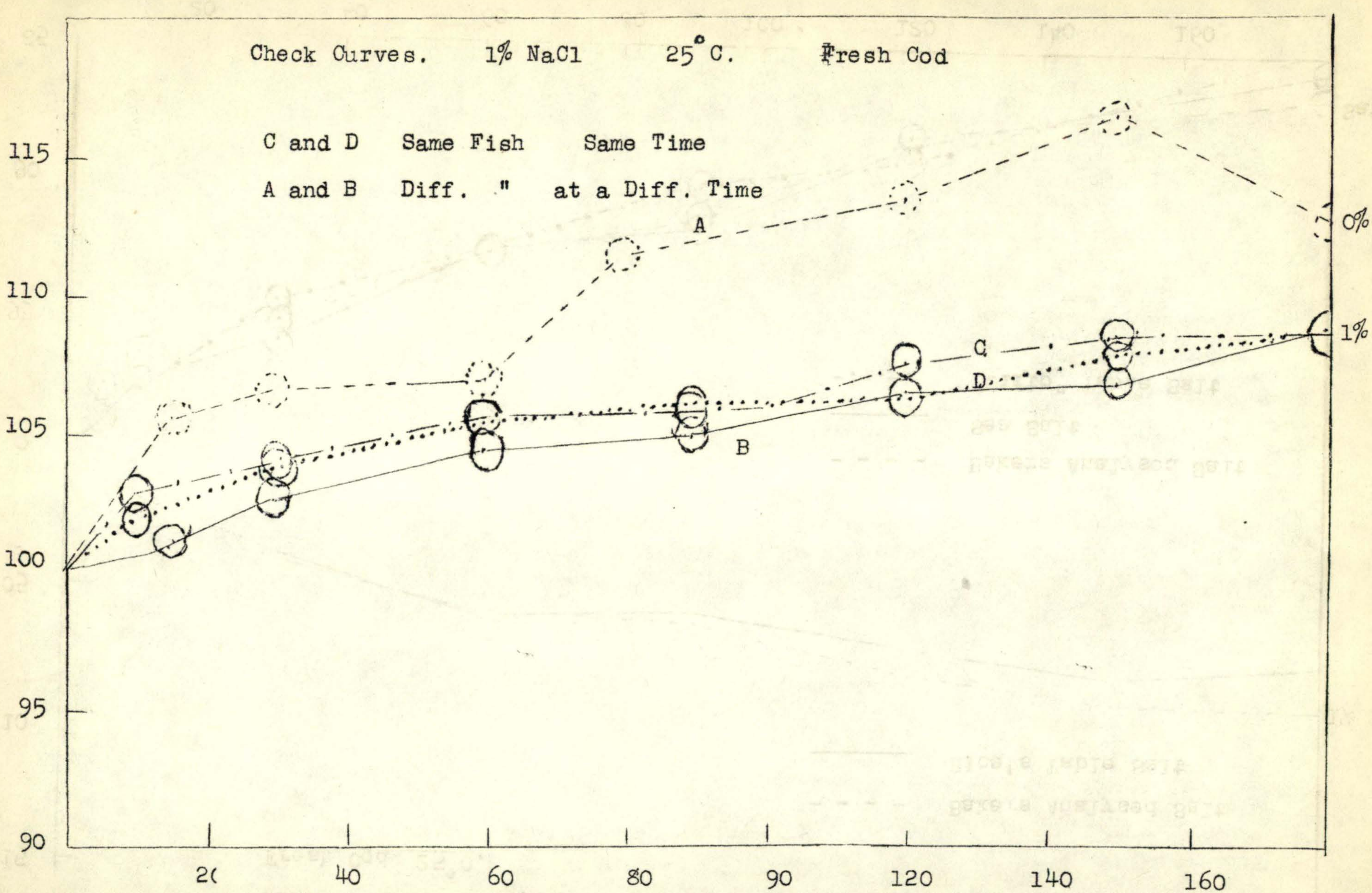
(7) Observations have been made on the post-mortem changes of fresh fish.

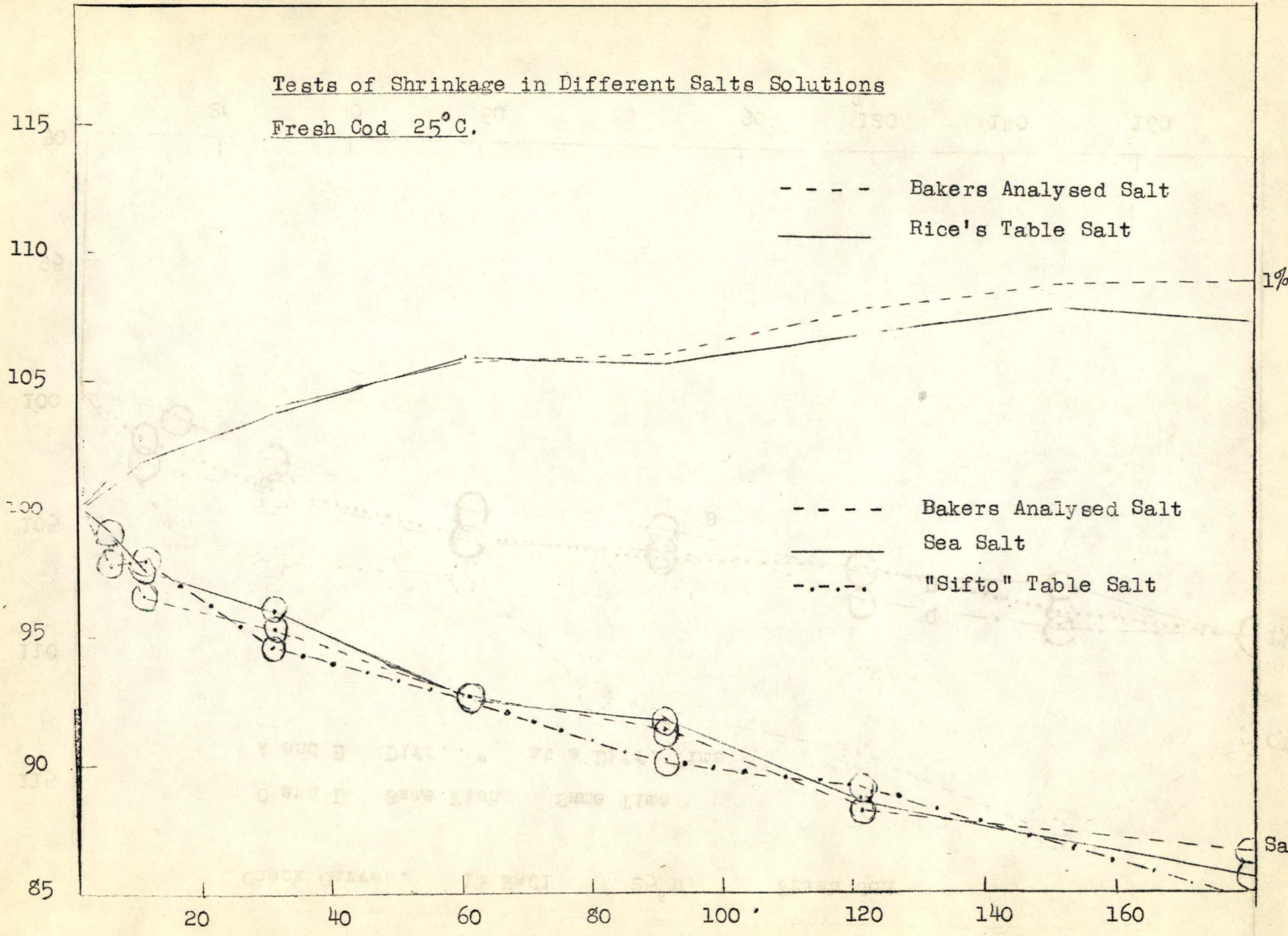
In conclusion I would like to thank Dr. A.G. Huntsman, Dr. A.H. Leim, Mr. E. Hess and Mr. Darrach, factor, for their suggestions, assistance and cooperation. I would also recommend that this work be continued with the view of checking the data obtained, and widening this field upon which very little seems to have been done. No time was available for testing the effects of varying pressures, of intermittent application of heat, or combining various methods, or using other media for the application of heat to the fish. Much of the time has been spent in developing technique, and the work done can only be regarded as an introduction to the problem of obtaining much fundamental data.


Pressures Developed in Boiling Lobster
Water added to boiler
Claw clamped
Fluid Escaped
Whole lobster (545 gms.)
Pres.
mm.
Hg.
300
200
100
0
10
20
30
40
50
60
70
80
Time in boiling water


Shrinkage of Fish in Brines 22° C. - 25° C.
Cod Fresh
Shrinkage of Fish Muscle
115
110
105
100
95
90
85
20
40
60
80
100
120
140
160
180
0%
5%
1%
10%
2%
1.5%
20%
Sat.


Shrinkage of Cod in Brines at 22 - 25°C.
For Pieces 10 - 12 Gm.
120
110
100
90
80
70
% of Orig. Wt.
Conc.
5%
10%
15%
20%
25%
30%


Check Curves. 1% NaCl 25°C. Fresh Cod
C and D Same Fish Same Time
A and B Diff. " at a Diff. Time
A
B
C
D
0%
1%
115
110
105
100
95
90
20
40
60
80
90
120
140
160
Shrinkage of Fish Muscle



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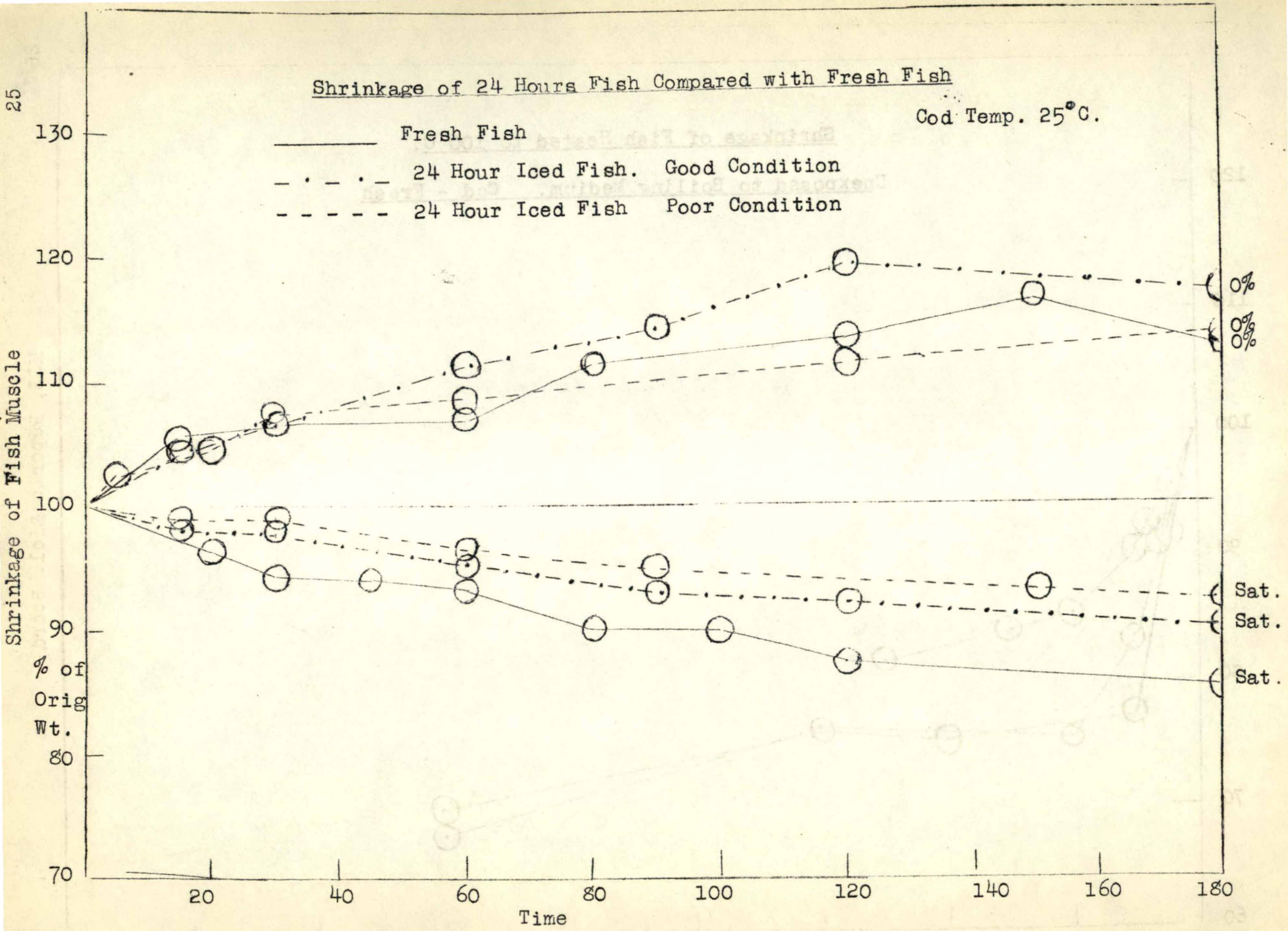
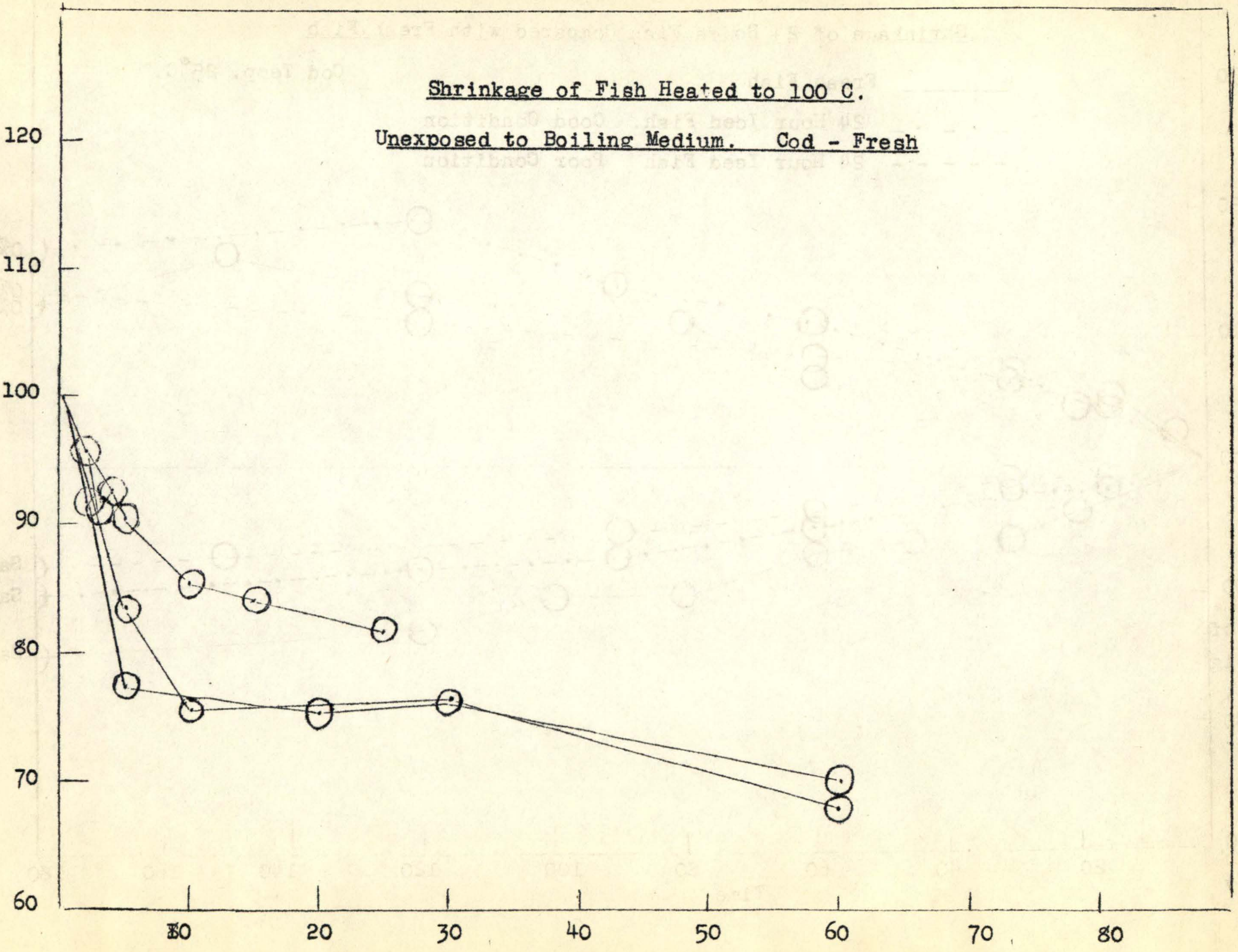
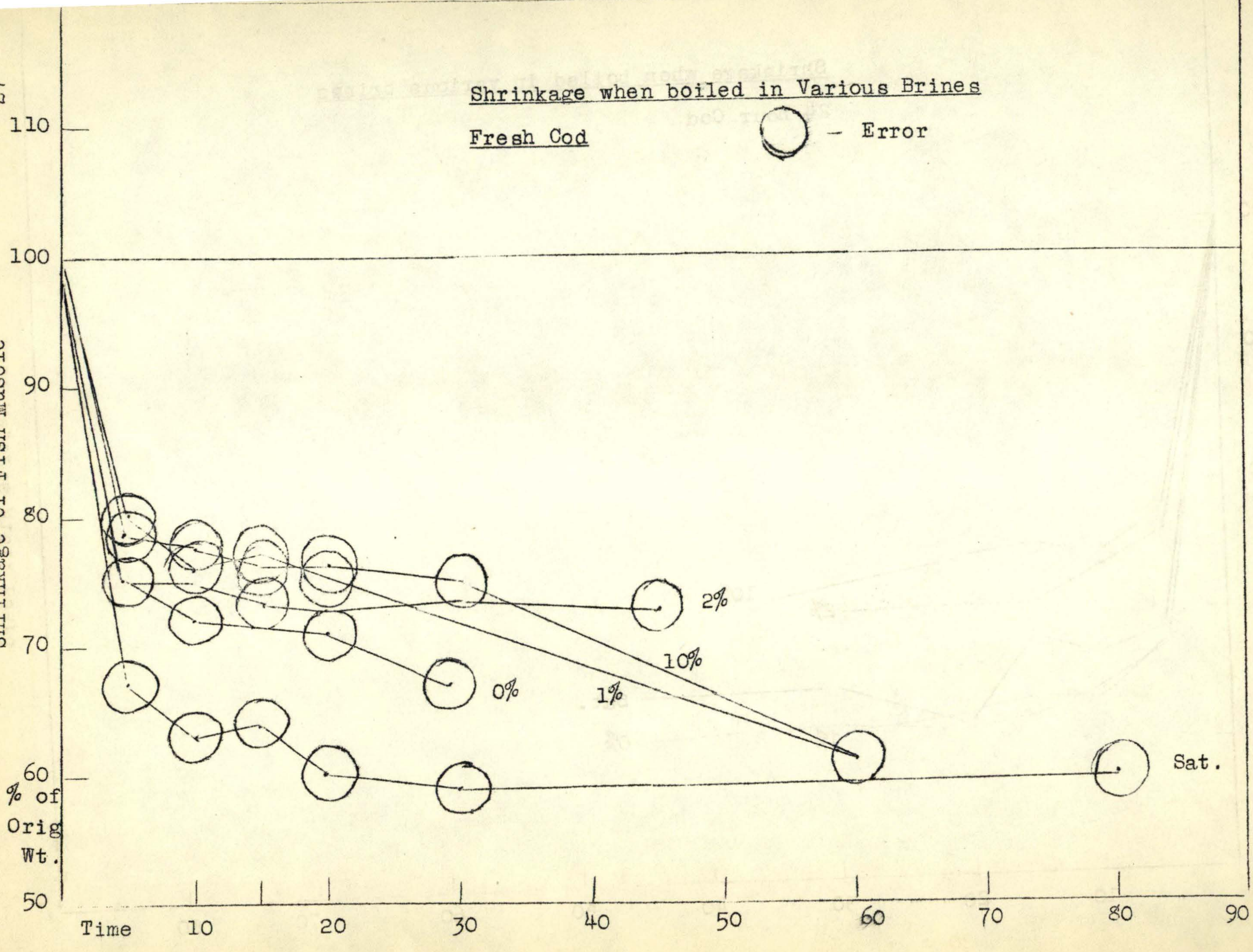
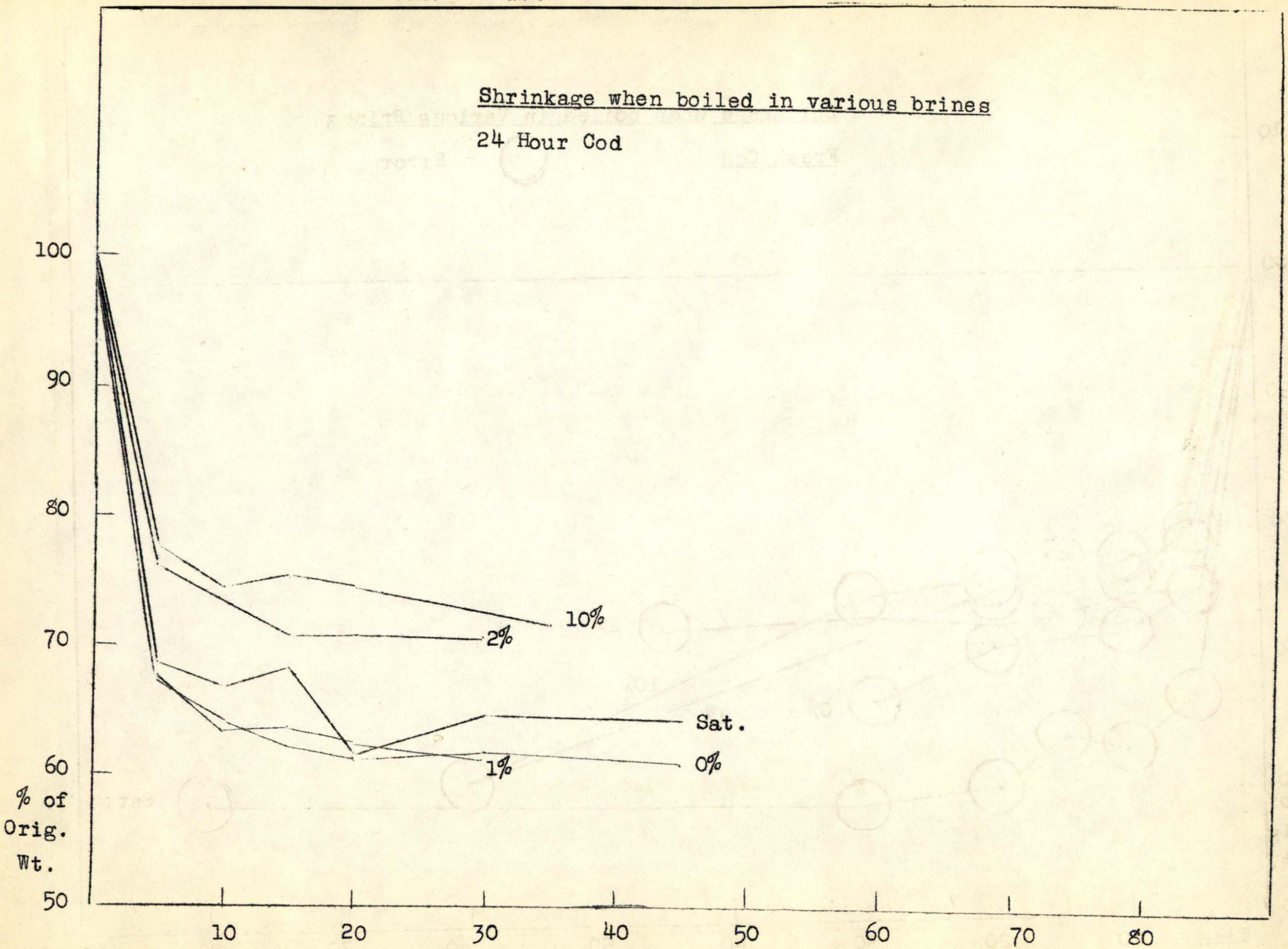

Shrinkage of 24 Hours Fish Compared with Fresh Fish
Cod Temp. 25°C.
Fresh Fish
24 Hour Iced Fish. Good Condition
24 Hour Iced Fish Poor Condition
0%
0%
0%
Sat.
Sat.
Sat.
Shrinkage of Fish Muscle
% of Orig Wt.
130
120
110
100
90
80
70
20
40
60
80
100
120
140
160
180
Time

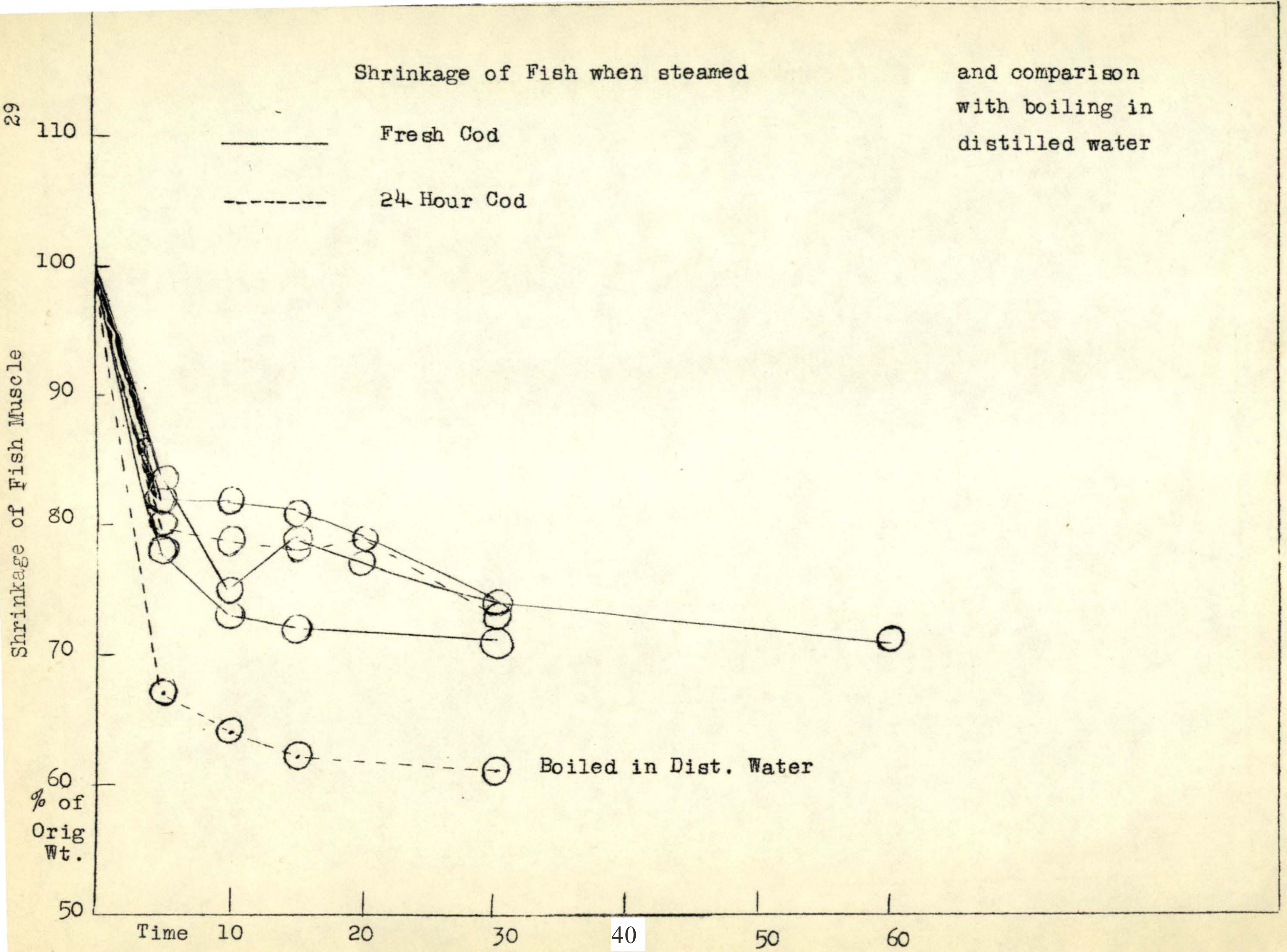
Shrinkage of Fish Heated to 100 C.

Unexposed to Boiling Medium. Cod - Fresh




Shrinkage when boiled in Various Brines
Fresh Cod
- Error
110
100
90
80
70
60
50
Shrinkage of Fish Muscle
% of Orig Wt.
2%
10%
1%
0%
Sat.
Time
10
20
30
40
50
60
70
80
90


Shrinkage when boiled in various brines
24 Hour Cod
100
90
80
70
60
50
% of
Orig.
Wt.
10%
2%
Sat.
1%
0%
10
20
30
40
50
60
70
80


Shrinkage of Fish when steamed
and comparison with boiling in distilled water
Fresh Cod
24 Hour Cod
Boiled in Dist. Water
Shrinkage of Fish Muscle
% of Orig Wt.
110
100
90
80
70
60
50
Time
10
20
30
40
50
60