Perkins.
Apparatus and method for determining
the hardness of butter fat.


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A THESIS

AN APPARATUS AND METHOD FOR DETERMINING THE HARDNESS OF BUTTER FAT

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AN APPARATUS AND METHOD FOR DETERMINING THE HARDNESS OF BUTTER FAT.

One of the important properties to be taken into account in judging the quality of butter is the so called Body, by which is meant the hardness, consistency or firmness of the butter. Body is described by the butter judge in such terms as perfect, firm, hard or tallowy, weak and sticky and is estimated by pressing a piece of the butter between the thumb and finger or between the tongue and the roof of the mouth. This property is, doubtless, very closely related to the hardness of the butter fat; although it is not definitely known just to what extent the body of the butter can be influenced by the manner of handling the milk and cream, churning, washing and working the butter, etc. Probably some of these factors do exert a certain influence in this respect, although they are more directly concerned in establishing another property of the butter known as texture. It has heretofore been impossibel to secure definite data on this point on account of the lack of a suitable method for measuring the hardness of butter.

Several investigators have attempted to measure the hardness of butter produced under experimental conditions by more accurate methods than those used by the butter judge.

Wood & Parsons[1] report results obtained by the use of a method which consists essentially of dropping a weighted glass rod through a glass tube 1 meter long, held vertically above the surface of the butter to be tested; and noting the depth of penetration on a scale attached to the glass tubing. J. B. Lindsay and his associates[2] report results secured by a method similar to that described above, except, that the large glass tube was dispensed with and the depth of penetration was measured directly on the plunger. The results in both cases were expressed in mm. of penetration. Wood and Parson's determinations were performed at 15.5 degrees C. after the butter had stood in a cool room for several days. Those reported by Lindsay, et al., were performed on butter which was removed from cold storage and allowed to stand at room temperature, for some time.

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1 Bulletin 13 N. Hampshire Agr. Exp. Station

2 Report Hatch Experiment Station, Mass. Agricultural College, Page 28. 13th Annual Report Hatch Experiment Station Mass. Agricultural College- Page 167.
14th Annual Report Hatch Experiment Station, Mass. Agricultural College.
16th Annual Report Hatch Experiment Station, Mass. Agricultural College, Pages 59-60
21st Annual Report Hatch Experiment Station, Mass Agricultural College, Pages 99-102.

Bartlett[3] reports unsatisfactory results by the use of a method similar to those already described.

C. F. Doane[4] laments the lack of a suitable Mechanical method for measuring the hardness of butter.

In the light of his own experience, the writer fails to see how concordant results can be obtained in extended series of experiments, by <u>any</u> system of measuring the hardness of butter fat, without a much closer control of the temperature than that described by the other investigators referred to; some of whom seem to have been content with allowing the samples to stand for a certain length of time at room temperature.

The method of measuring penetration on the plunger itself proved, in the writer's hands, very unsatisfactory, on account of the splash of fat which often rose around the plunger, making an accurate reading of the depth of penetration impossible. To our mind the method of stating results in mm. of penetration of some arbitrary plunger is also an unsatisfactory basis of comparison, for the hardness of butter fat.

In some of our experimental work, here, it became essential to measure the hardness of the butter fat produced, with a reasonable degree of accuracy; and in such a way that results obtained throughout experiments extending over long periods of time, would be entirely comparable. Since none of the methods already described seemed suitable to our purpose, the writer set about devising the apparatus and method now to be described.

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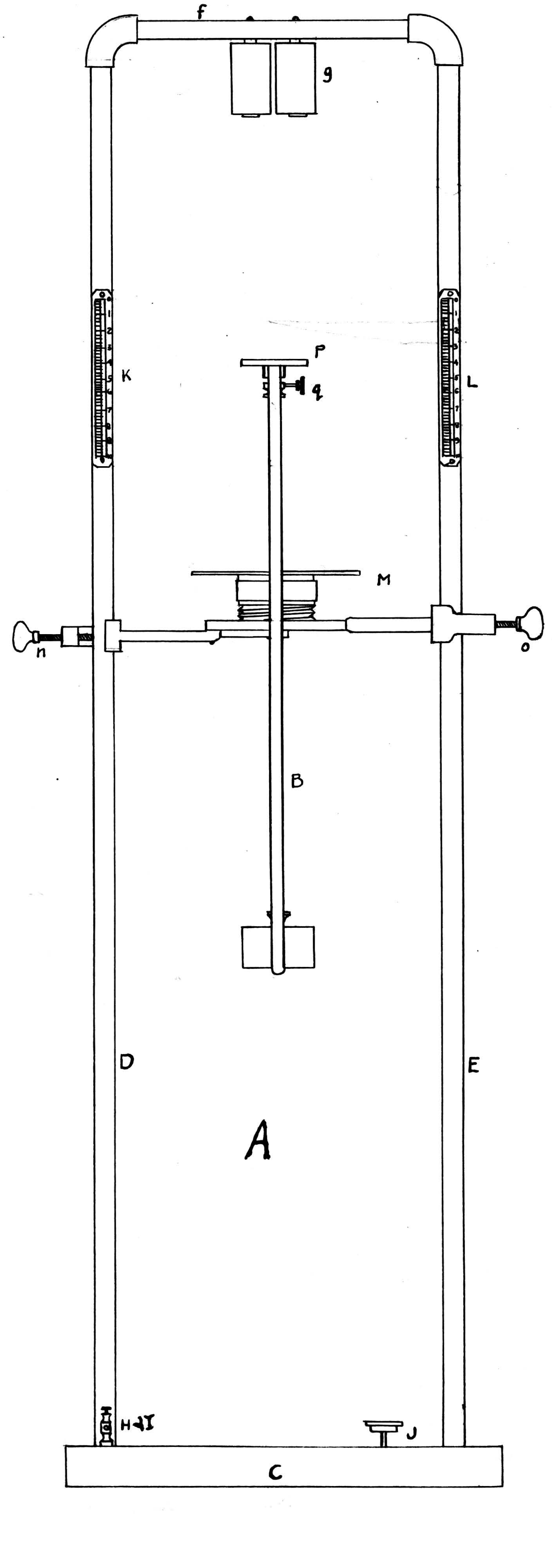
(3) 14th Annual (1899) Report Maine Agricultural Exp. Station, Page 109.

(4) Maryland Agricultural Exp. Station Bulletin 64 Page 53.



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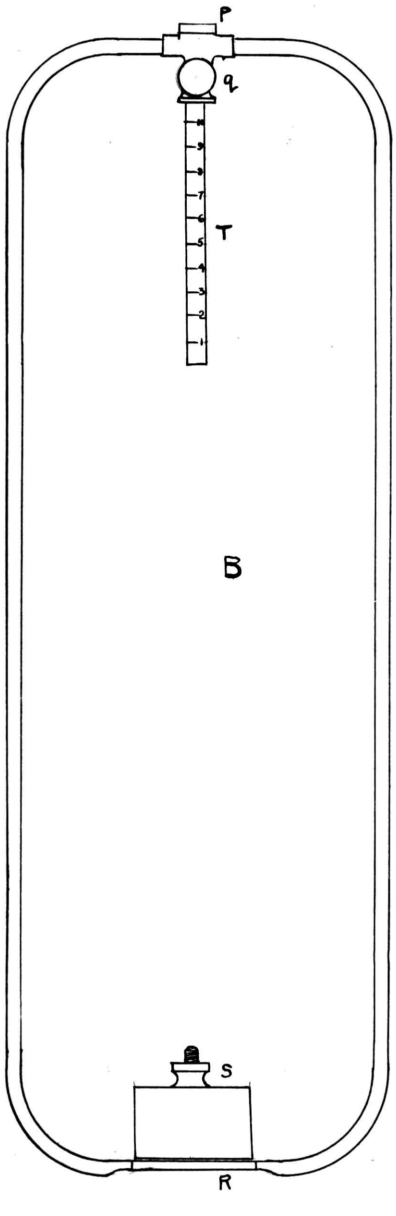


P
q
T
B
S
R

The apparatus used, as shown in the accompanying cut, comprises a firm support (A), and a separate light frame (B) carrying the penetrating needles and the weights. The support consists of a heavy iron base (C) into which are inserted two upright rods (D & E) about 1 meter long, one of which is hollow and contains wires connecting g,h, and i. These uprights are about 25 cm apart and are joined together at the top by a piece of hollow iron rod (f), to the center of which is suspended an electro-magnet (g). h & i are binding posts for attaching the batteries to operate the magnet. A key (J), attached to the base, serves for making and breaking the current through the magnet. K & L are millimeter scales reading downward. Attached to the upright rods is an adjustable platform (M) for carrying the sample whose hardness is to be tested. The coarser adjustment of the height of the platform is secured by means of the clamps n and o. This adjustment does not need to be regulated except at rare intervals. A finer adjustment is secured by simply turning (M) which is supported from N -O by a 1¾ " nut and screw. The frame (B) is of hollow brass tubing to get it as light as possible, while still retaining the necessary degree of strength. It is about 40 cm, long and 15 cm. wide. P is a piece of soft Swedish iron to be acted on by the electro magnet. Directly beneath this inside the frame, is a socket and set-screw (q) to hold the needle T in place.

At the opposite end of the frame is a small Platform (E) for carrying the weights, which are made with a hole drilled through the centre so that they can be placed over the screw projecting above the platform, and held firmly in place by the nut S. The frame (B), when carrying any one of the set of needles, weighs 200 grammes. Additional weights are provided, making possible any combination of exact multiples of 100 gr. up to 1200. A set of needles is provided having cross sectional areas of 5, 10, 15, 25, 50, and 100 sq. mm. They are cylindrical in shape and slightly more than 10 cm. long, being marked at a distance of 10 cm. from the end. The largest sizes are of hollow tubing plugged at the ends, and the smallest made with heavy shanks to secure the uniformity of weight. The scales (K & L) attached to the upright rods which were previously referred to are so placed that when the frame with needle and weights is held in place by the electro-magnet, preparatory to making the test, the point of the needle is at zero on the scales. The height of the adjustable platform (M) is then so regulated that the surface of the sample to be tested is at 100 mm. on the scale. A small plumb bob (W) is made use of in this connection. The distance of fall before reaching the surface of the butter is, then, always 10 cm.

In making the determination, the frame (B) with a suitable needle and weights is suspended from the electro magnet; and the beacker of fat placed in position beneath the needle; the height being regulated as described above. The frame is then released by means of the key. The depth of penetration is ascertained by stretching a very fine wire in line with the mark on the needle, and noting its position on either scale. The average of two readings is taken as the depth of penetration. Since the cross sectional area of the penetrating needle is known, and the depth of penetration has been ascertained; their product indicates the volume of butter fat displaced. The amount of weight acting on the needle is known, and the distance through which it falls is constant; if, then, the amount of weight employed, expressed in grammes, is divided by the volume of fat displaced, expressed as cu.mm. the quotient will represent the weight in grammes required to displace 1 cu. mm. of the fat, or the number of kilos required to displace 1 cu. cm. at the stated temperature. This is the basis employed to express the proportionate hardness of the fat. A sample of fat is said to have a hardness of 1 at stated temperature when 1 kilo will displace 1 c.c. of fat; or of 1.2 or .85, when 1200 or 850 grammes respectively are required to displace 1 c.c. of fat.

The amount of weight employed and the size of the needle used depend, of course, on the character of the fat; and the temperature at which the hardness is determined. With a proper combination of needles and weights, the needle will remain practically stationary in the fat after the initial plunge. If, however, too much weight or too small a needle be employed, the needle continues to sink slowly making an accurate reading of the depth of penetration impossible. In the reverse case, with too large a needle or too little weight, the penetration is of course much less; and the percentage experimental error proportionately greater.

The suspension of the weights far below the needle brings the centre of gravity of the falling portion of the apparatus below the point of the needle, causing the latter to invariably assume a vertical position, making it much easier to ascertain the true depth of penetration than would be the case if the point of the needle were at or below the centre of gravity. After its release by the electro-magnet, the apparatus meets with no resistance whatever in its fall, except, that offered by the air, until the point of the needle reaches the surface of the butter.

It might be argued that gravity was acting through a greater distance in the case of a sample which was penetrated 30 mm., than in the case of one which was penetrated, say, only 15 mm.; or again it might be argued that the amount of friction on the sides of a small needle would be proportionately greater than that on a larger needle, on account of the greater surface area in proportion to its volume. These objections, if they are at all patent, would tend to counteract each other; and at any rate their influence is not perceptible in the results; for duplicate determinations carried out with varying sizes of needles and weights, where the depth of penetration is necessarily greater in some cases than in others, show no greater variations than occur when the same sizes of needles and weights are used throughout; provided, that combinations which render accurate readings difficult to make be avoided.

In practice we endeavor to secure a combination of needles and weights which will give a penetration of about 25 or 30 mm. and with our wide range of weights, 200 to 1200 grammes; have ordinarily found it necessary to make use, only, of the needles having cross sectional areas of 25 and 50 sq.mm.

While the agreement of duplicate readings is not as close as is ordinarily expected in quantitative chemical work, it is, considering the nature of the determination, reasonably satisfactory. The extreme variations rarely exceed 2 millimeters with a penetration of 25 to 30, and in the majority of cases, the readings have a closer agreement than that mentioned above. #

In carrying out the determinations many difficulties were encountered, some of which had been mentioned or hinted

As explained on Page 15 much of the data presented in this paper was secured before the apparatus had assumed its completed form, which accounts for the apparent discrepancy between this statement and the results as given in the tables.

at by the other investigators named above. Since we were primarily interested in the properties of the fat itself, rather than in those of the manufactured butter, the determinations were made on the rendered fat. It was noticed, among other things, that the fat in cooling tended to separate into layers of different hardness; the harder portions crystalizing first at the outside of the container, leaving the softer portions at the centre.

The observed penetration would thus vary, depending on which portion of the fat, in the receptacle, was penetrated. To overcome this difficulty, the samples were placed in a pan of cold water and stirred with a glass rod until the rod could be removed without leaving an impression in the fat; the cooling being then allowed to proceed in the natural way. By this method, samples were obtained uniform in composition throughout, and satisfactory duplicate readings of the depth of penetration were secured, regardless of which portion of the fat in the container was penetrated.
Tables 1 and 2 show data illustrating this point.

TABLE 1.

All the samples shown in Table 1 were taken from the same large dish of melted butter fat, which had been thoroughly mixed, and were identical in composition. After being poured into the small jars in which the hardness was measured the samples received the same treatment in every respect, except that the samples so designated were stirred with a glass rod, as described elsewhere in this paper, while they were being cooled in a pan of running water. The samples designated as unstirred were not disturbed until they were solid. The samples were all removed at the same time to the constant temperature bath and kept at almost exactly 15 degrees C for 18 hours.

Stirred while Cooling.

Sample No.	Penetration.
1	21. mm.
2	22. "
3	22.5 "
4	22 .5 "
5	22.
6	23
7	22
Average	22.1

Not Stirred-

Sample No.	Penetration.
8	28
9	24
10	29
11	25
12	25
13	27
14	24
15	25
Average	25.8

TABLE 2.

The data presented in Table 2 is of the same nature as that shown in Table 1, the samples having received practically identical treatment to that given the samples in Table 1. The butter fat tested, however, was from a different source.

Stirred While cooling.

Sample No.	Penetration.
1	12.5 mm.
2	12.5 "
3	12.5
4	12.0
5	12.5
6	13.5
7	13.5
8	12.5
Average	12.7

Not Stirred.

Sample No.	Penetration.
9	18.5
10	16.0
11	16.0
12	18.0
13	19.5
14	18.5
15	17.5
Average	17.7

These trials were made with a large number of beakers of mixed fat, and the samples were all under identical conditions, except that part were stirred, as described, while cooling, and the others were not. In all cases the samples were held, at, or near, the testing temperature long enough to insure thorough cooling. It will be noticed that the penetration in the case of the unstirred samples was greater on every occasion, than with the stirred samples, due doubtless to the fact, that in the small vessels employed to contain the fat, the penetration invariably took place near the centre, where the softer portions of the fat were collected. Trials were also made with the fat in large containers, where different portions of the fat in the same vessel were penetrated. The results are shown in Tables 3 & 4.

TABLE 3-

Fat in large containers (600 CC Griffin beakers)

Samples were all stirred while cooling. No effort was made to have samples 1, 2, 3, & 4 of the same composition. Samples were held at about 15 degrees C in the constant temperature bath for 18 hours.

	Penetration in mm at centre. 1 determination only	Penetration in mm near edge Average of 4 determinations
Sample 1	20.5	18.6
2	27.	25.5
3	30.5	30.7
4	30.5	29.7

TABLE 4.

The same conditions obtained here as described for the samples in Table 3, except that none of the samples were stirred during the cooling process.

	Penetration in mm at centre 1 determination	Penetration in mm near edge Average of 4 determinations
Sample 1	30.5	22.1
2	30.5	22
3	29.5	21.8
4	29.0	20.8

It will be noticed from the tables just referred to, that when the samples were stirred during the process of cooling, the penetration was practically the same, regardless of which portion of the fat was penetrated; or at least, the difference, if there was any, came far within the limits of experimental error under the best conditions; but, that in the case of the unstirred samples, the penetration was much greater when measured at the centre, than when it was measured near the edges of the receptacle. The penetration when measured midway between the centre and edge was just about the average of that obtained at the centre and that obtained at the edge.

Another very serious difficulty encountered was that of maintaining the temperature, at which it was desired to perform the tests, with a close enough approximation to constancy. It was soon found, that in order to secure results of any value, we must maintain for several hours a temperature constant to within 0.1 degree, or at most 0.2 degree, C. Numerous attempts were made to accomplish this by the use of thermal regulators in conjunction with water baths, and water jacketed ovens, by allowing the samples to stand in running water, etc. Failure was, doubtless, due to the fact, that the temperature which it was necessary to maintain was very close to that of the room and often below it. In the method which we finally adopted, a large flat bottomed water bath with cover was tightly packed with non-conducting material, in this case, excelsior, inside a double walled box.

With this arrangement it was found entirely feasible to control the temperature, within the rather close limits prescribed above, when the temperature of the room was not more than 2 or 3 degrees C. from that to be maintained. The necessity of such a close control of the temperature will be better understood after glancing at Table 5. in which is given the results secured as the comparative hardness of a sample of fat at temperatures varying from 10 degrees to 19 degrees C.

Table 5.

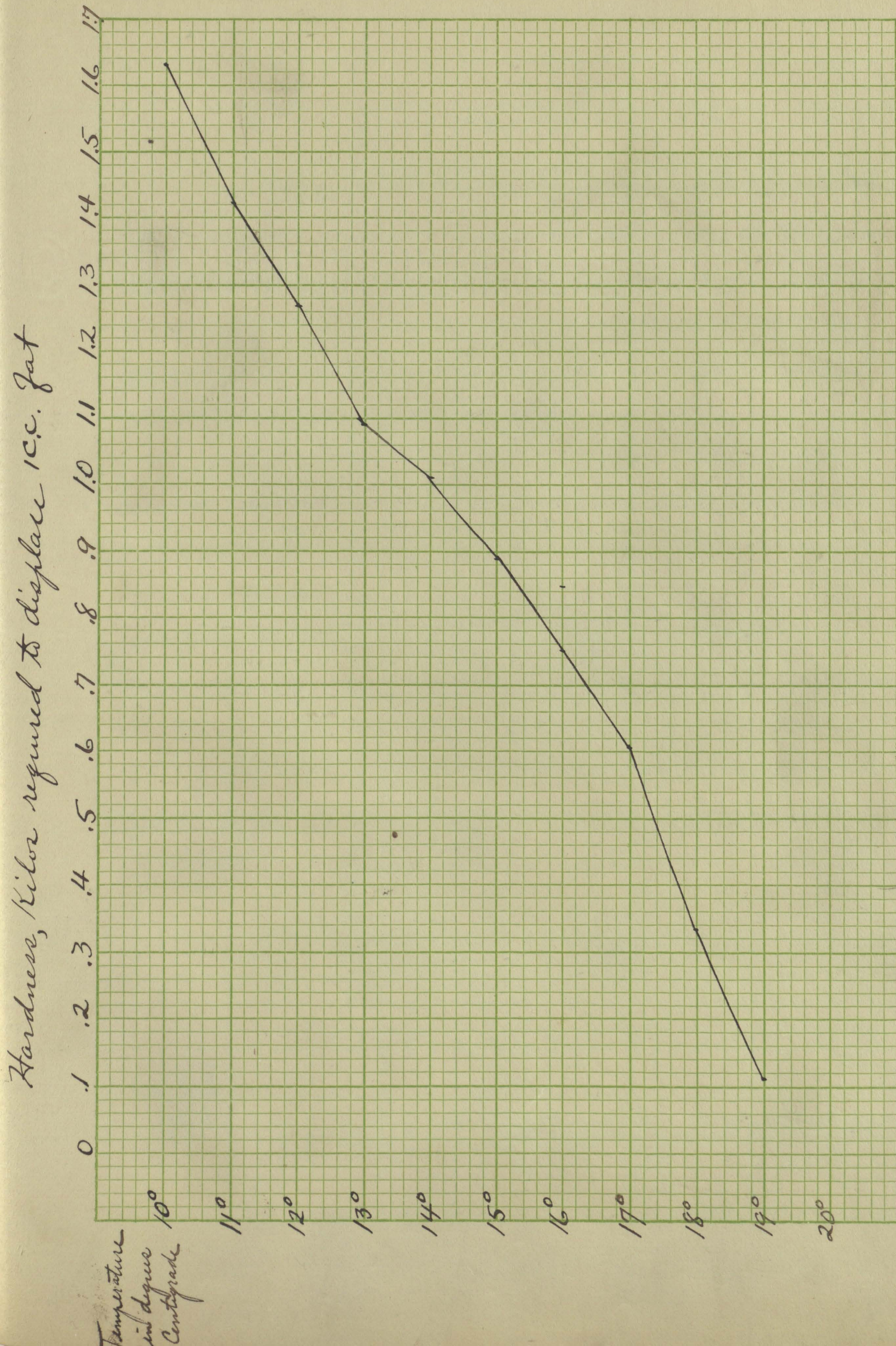
Showing the hardness of the same samples of butterfat at temperature ranging from 10° to 19° Centigrade.

Each value as stated was calculated from the average of several determinations, carried out according to our regular method of procedure as given elsewhere.

Hardness in terms of Kilos required to displace 1 cc of fat at stated temperature.

Temperature	
10°	1.630
11°	1.420
12°	1.270
13°	1.092
14°	1.012
15°	0.890
16°	0.750
17°	0.603
18°	0.337
19°	0.113

Figure 3


Hardness, Kilos required to displace 1 c.c. fat
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
Temperature in degree Centigrade
10°
11°
12°
13°
14°
15°
16°
17°
18°
19°
20°

The hardness of this sample, which was a typical one, was almost 15 times as great at 10 degrees as at 19 degrees, the increase in hardness being quite regular, as is better shown by a curve (Fig 3) in which the temperature in centigrade degrees is plotted as ordinates, and the figures expressing the relative hardness as abcissae.

A statement made by Wood & Parsons in the paper already referred to, would lead one to infer that it was necessary, or at least highly desirable, that the butter be kept for several days in the cold before making the penetration test. In order to determine whether or not this procedure was necessary, and to settle other similar questions which came to our mind regarding the treatment of the fat before making the tests, a series of trials was run, the results of which are given in Tables 6-7.

Table 6.

To show the effect of previous cooling on the observed hardness of butter fat. The entire series of samples was taken from a large jar of, thoroughly mixed, melted fat. All were stirred until they were nearly solidified. The samples designated as cooled were kept in a cold storage room at 7 degrees C for about 15 hours. The others were kept in the laboratory at very nearly the same temperature at which they solidified, between 19 and 20° C. All were removed to the constant temperature bath at the same time and kept at 15° C for about 5 hours.

Cooled

Sample No.	Penetration
1	15.5 mm.
2	15.5 "
3	15.0 "
4	14.5 "
5	15.0 "
6	16.0 "
7	14.5 "
Average	15.1 "

Uncooled-

Sample No.	Penetration
8	15
9	15
10	15
11	18
12	17
13	17.5
Average	16.2

Table 7.

The conditions applying to the data presented in Table 7 were nearly the same as those given for the data in Table 6 The cooled samples were kept in a room at all times below 10° C for 2 days. The others were kept very nearly at their freezing point during that time. All were placed in the constant temperature bath at the same time and kept at 15° C for 24 hours.

Cooled.

Sample No.	Penetration
1	25. mm
2	21.5 "
3	25 "
4	26.5 "
5	26 "
6	21 "
Average	24.1 "

Uncooled.

Sample No.	Penetration.
7	23.5 mm
8	24
9	20.5 "
10	24 "
11	21.5 "
Average	22.7 "

Our conclusions regarding these matters as derived from these trials, and observations on large numbers of samples may be summarized as follows:-

It seems to make little or no difference at what temperature a sample of butterfat has previously been kept provided it is held at the testing temperature long enough to become thoroughly warmed or cooled to that temperature, as the case may be. In our experience 4 to 5 hours was usually sufficient for this; when, as in our case, the samples were kept in a covered, well insulated, water bath. In practice, however, we allowed the samples to stand over night at as near the desired temperature as possible; usually within 1 degree C. In the morning, the bath was warmed or cooled as the occasion might demand to the proper temperature; and kept at that temperature for about 5 or 6 hours before the tests were made. When the samples were cooled at once to the testing temperature, without being allowed to stand for any considerable length of time at that temperature; duplicate tests were inclined to vary within much wider limits, than when the samples were allowed to stand as described above. The average results, while not markedly different, were inclined to show a softer condition of the fat than when the tests were carried out as recommended. Cooling the fat to temperatures of 10 degrees C. or lower caused the formation of fissures due to the contraction of the fat on cooling. These interfered considerably with the determination of the hardness by offering a path of less resistance for the penetrating needle. This, in the writer's belief, is the cause for the slightly lower value obtained for the hardness of the fat with the "cooled" samples in Table [redacted] 7.

This tendency became more pronounced as the degree of cooling increased. For this reason no attempt was made to secure data regarding the effect of cooling to extremely low temperatures on the subsequent hardness of the fat. Since Manufactured butter does not exhibit this tendency two 1 lb. prints from the same churning were taken to furnish data on this point, one was placed in a glass jar and packed in a freezing mixture of Ice and salt. The temperature of the bath after one hour was -20° C and at the end of 48 hours was -15°C. The other print was also put into a sealed glass jar surrounded by running water at 19.5° C. At the end of 48 hours both were placed in the constant temperature bath at 15 degrees C. At the end of 72 hours the temperature of the bath had fallen to 8.5 degrees C. The hardness was then measured; the results being given in Table 8.

Table 8.

Butter from same churning. Adjacent prints in tub.

Print No. 1	Print No. 2.
Kept surrounded by running water at 19.5 degrees C for 48 hours.	Kept surrounded by a freezing mixture at a temperature between-15 and -20 degrees C for 48 hours.

Both then kept in same water bath at between 15 degrees and 8.5 degrees C for 72 hours.

Print No. 1. Reading No.	Penetration in mm. with needle having cross sectional area of 50 sq.mm. and a weight of 700 gr.	Print No.2. Reading No.	Penetration in mm.with needle of 50 sq.mm. cross sectional area & 700 gr. weight.
1	21.5	1	18
2	23.0	2	18
3	22.5	3	18
4	22.5	4	18
5	23.0	5	18
Average	22.5	Average	18

It would seem at first sight that the butter which had been cooled to such a low temperature had undergone an increase in hardness in the process. The temperature of the butter composing the two prints in question was taken in several places in the print by means of a delicate thermometer graduated in tenths of a degree centigrade. Print No.1 was found to have a temperature of 9.2° C throughout. No. 2. likewise had a temperature uniform in all parts at 8.7° C. or 0.5° C. lower than that of Print No.1. By referring to Table 5 and comparing it with the data just given the reader will see that the apparent increase in hardness is just about the amount that could naturally be expected on account of the observed variation in the temperature.

It is not our purpose in this paper to present complete data concerning the hardness of any considerable number of the samples of butter fat that have been examined. This data will appear later along with the other analytical data regarding these same samples; a description of the apparatus used and the method adopted being the sole purpose of the present paper. It was decided that, for the purpose for which it was intended, the data would convey more significance if presented as millemeters of penetration with the same needle and weights, than it would if presented as the relative hardness of the fat. Most of the data given in this paper was obtained before the screw arrangement for regulating the height of the platform M (Fig. 1) which carries the sample, had been provided. By using the clamps N, O, alone for this purpose, errors of as much as 1 m.m. in regulating the height of the sample under test were doubtless frequently made. Any such errors directly effected the observed reading. It was not deemed essential, however, for the purpose of the present paper to repeat this work using the improved apparatus.

There is no inherent reason why this method can not be used as well in measuring the hardness of butter as in measuring that of fat. While for the ordinary commercial judging of butter, the degree of accuracy required may not demand the extreme accuracy obtainable with this apparatus, the method would serve a useful purpose in enabling the butter judge to confirm his judgment from time to time, and in helping him to decide doubtful cases. It should also be of decided advantage in "prize butter" contests and for other similar purposes. For the purposes just enumerated above it would not be necessary to regulate temperature as carefully as in the case of our experimental samples. If all the samples to be compared had been kept at the same temperature for 24 hours the data obtained would be entirely comparable. When once the temperature was satisfactorily regulated the author has been able to do from 40-50 determinations per hour. This is doubtless as rapidly as the butter judge could decide on the body of butter by the feeling or tasting methods.

This method and apparatus could be used to advantage in determining the hardness of other fats, Lubricants, waxes, etc. With some few slight modifications it should also be useful in obtaining the setting point of cement measuring the hardness, or penetrability of asphalt, or for any other similar purpose.

The apparatus herein described was constructed by Mr. Emil Klinkerfuss, Mechanician at the University of Missouri, at a total cost for material and labor, including a remodeling after the original form of apparatus had been tested, of approximately $23.00.

Due acknowledgement is hereby made of certain experience gained by the writer in attempting to use an unpublished piece of apparatus designed for the same purpose by Mr. R. H. Shaw, formerly Chemist in charge of this Laboratory.

The writer's deepest thanks are due to Professor C. H. Eckles at whose suggestion the work was undertaken, and whose encouragement and advice have been a constant source of aid.

Many thanks are also due to Dr. Matthew Steel, who gave valuable suggestions regarding the manner of presentation, and to many other of my friends and co-workers who have contributed helpful suggestions at various stages of this work.

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