OBSERVATIONS ON THE FAT GLOBULES IN MILK.

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INTRODUCTION.

IT is a well-known fact that creams vary in the process of churning; it is known that some creams take longer than others to "come"; it is known also—and this is of far greater importance—that the butter obtained varies very greatly, both in quantity and quality. But the reasons for these variations are not known. The question arose, some time ago, whether any function of the globules of fat (size, number, etc.) influenced this variation.

This point was taken up by us, at the request of Mr Ernest Mathews, in 1909, and has formed the subject of much work in the laboratory at Watford.

That the globules do have an effect upon the churnability is shown by several writers. For instance, Sturtevant (*Ann. Report, U.S.D.A.*, 1880; Abridged Account in *Journ. Royal Agric. Soc. Eng.*, 1882, xviii, (2), 475—495) showed that "the larger the globule, other things being equal, the quicker the churning." He states that a milk with larger globules gives better butter, and also that "churning is a physical process and acts upon the larger globules only."

It has been stated by Klusemann (*Inaugural Dissertation*, Leipzig, 1893; Abst. in *Chem-Zentralblatt*, 1894, (1), 646; *U.S.D.A. Expt. Stat. Record*, v, 1022) that butter made from milk with large globules has a deep yellow colour, a good taste, and is hard; whereas that made from a milk with small globules has a whitish colour, and is inferior in taste and consistency. He concludes also that the greater the proportion of large globules, the more completely can the cream be churned. But no information is given as to whether this observation is made upon milk

from cows of the same breed; for it is very well known that the breed has a great influence on the colour of the butter.

At the outset, the problem did not appear to be very difficult; but as the work progressed, it was obvious not only that the experimental work was by no means simple, but also that the results were very inconclusive. At first, consideration was given to the globules solely; but it was soon realised that a large number of other factors affected the problem. Moreover, it was quite impossible to give consideration to one variant only, so that it was difficult to determine to what factor any particular result might be due.

Of the variable factors which might affect "churnability¹," the following are the chief:—

- (a) The physical properties of the milk.
- (b) The size, number and distribution of the globules.
- (c) The condition of the serum immediately surrounding the globules—a covering or membrane.
- (d) The effect of food, whether on the globules or on the serum.
- (e) The constitution of the serum.
- (f) The temperature of the cream.
- (g) The ripeness of the cream.
- (h) The percentage of fat in the cream.
- (k) The breed of cow.
- (l) Period of lactation.
- (m) The influence of bacteria.

Before it is possible to determine whether any variation is due to a function of the globules themselves, it is necessary to ascertain the general effect of the other factors.

The size, number and distribution of the globules have been considered in a previous paper (*Journ. Agric. Sci.*, IV, 1911, Pt. 2, 150—176); further results are given below (Tables V—XIII, Figs. 3—6), and a résumé is given of the present knowledge of the much debated problem of the membrane surrounding the globule. The effect of the feed upon the globules forms the main portion of this communication, but its effect on the serum has not been investigated. The constitution of the serum, the effect of the temperature of the cream and the percentage of fat in the cream, upon the churnability, have been considered and will be discussed later. Attention has not yet been given to other factors.

¹ The term "churnability" is used in a general sense to include all the variations which occur in churning.

SUMMARY OF PREVIOUS WORK.

Results of our previous work were published in the *Journ. of Agric. Sci.*, IV, 1911. There, also, a brief summary of the chief papers published on the subject of the fat globules was given, to which it is unnecessary to refer in detail here¹.

When the work was first commenced in 1909, the problem before us was the consideration of the variation in the size of the fat globules, with relation to churning, as regards the *different breeds* of cattle. The breed was considered because it was usually supposed that this was one of the chief factors which influenced churning. The most definite result of our work was that it was shown that consideration must be given to *the character of the milk, irrespective of the breed*. This conclusion is quite contrary to that of other workers, but an examination of their figures shows, undoubtedly, that this is actually the case: the results given by Woll (Digestion Expts., *Seventh Annual Report, Agric. Expt. Stat., Wisconsin*, 1890, 238; also *Agric. Sci.*, 1892, VI, 445) emphasise this point particularly. It is also shown by this year's work, as may be seen from Tables V—XI.

The comparative size of the globules has been worked out very thoroughly by Gutzeit, who measured the mean volume of the globule. Other workers give their results as "relative sizes." In our work we attempted to ascertain the distribution of the fat in the globules, and to this end the number of globules of each size was determined, and curves were drawn. The result of this, however, was negative. At that time we were considering the *breeds of the cows* from which the milks were obtained; had we considered them solely as milks of a certain mean size of globule, much more might have been achieved.

An apparatus was devised to give an absolute figure for the churnability of any cream, but, until the effect of the other factors has been determined, it is impossible to interpret the results. Some experiments to ascertain the optimum temperature were described also.

CONSTITUTION OF THE SERUM.

In addition to the globules themselves, one must consider the causes which prevent them from coalescing. This may be due to

¹ In the English literature, where the subject of globules is dealt with, reference is given chiefly to D'Hont's paper ("Essai sur les dimensions du globule gras en suspension dans le lait. Influence de la race." Courtrai, 1890). This is remarkable since a work has been published by Gutzeit (*Landwirtsch. Jahrbücher*, xxiv. Berlin, 1895, 539—668) which is very exhaustive, and which is based on a very large number of actual measurements.

some quality of the serum in which they are floating. For instance, Babcock (*New York Expt. Stat., Fifth Report*, 1887) investigated the viscosity of various milks, and found that the viscosity of milk is greatest with a large mean-size globule. Of the constituents of milk serum, the albuminoids have by far the greatest influence on the viscosity. He states that "a low coefficient of viscosity for the serum is most favourable to the economical production of butter." On the other hand, coalescence may be prevented by some covering round the globules. This point is considered later.

In the work of 1910, published in the *Journ. of Agric. Sci.*, analyses were made to determine whether any correlation existed between the proteids and sugar in the serum, and the fat and the size of globule in the milk. No definite conclusion can, however, be drawn.

Hart (*Journ. Amer. Chem. Soc.*, xxx, No. 2, 1908, 281—285), who investigated this point, showed that:—

- (1) The relation of casein to fat is variable.
- (2) It is due, chiefly, to individuality of the cows.

Brevans (*Hyg. Viande et Lait*, III, 1909, No. 12, 593) also gave tables to show the effect of individuality.

In 1911, therefore, consideration was given to the nitrogen-containing constituents. Analyses were made upon those milks, the creams of which were used for the churnability and for optimum temperature experiments. The total nitrogen was determined by Kjeldahl's method; the total proteids by precipitation with tannic acid; the casein by precipitation with magnesium sulphate; the albumen by difference. The results are given in Table I.

TABLE I.

	Jersey		Guernsey		Kerry		Red Poll	
	Whole milk	Cream	Whole milk	Cream	Whole milk	Cream	Whole milk	Cream
Per cent. fat	Broken in transit	58.21	4.10	57.91	3.92	57.08	3.97	57.91
„ N. $\times 6.38$		1.50	3.34	1.42	3.29	1.53	3.31	1.57
„ non-proteid N.		0.22	0.22	0.01	0.28	0.11	0.18	—
„ total proteids		1.28	3.12	1.41	3.01	1.44	3.13	1.56
„ casein		1.14	2.37	1.17	2.49	1.105	2.62	0.88
„ albuminoids(?)		0.14	0.75	0.24	0.52	0.32	0.51	—
Total proteids	Broken in transit	85.3	93.4	99.4	91.6	93.7	94.4	99.6
Total N. $\times 6.38 \times 100$								
Casein		89.4	76.1	83.1	82.6	76.8	83.9	56.5
Total proteids $\times 100$								

No correlation could be found between these figures and those obtained with the churnability apparatus and the other determinations which were made; this is probably due to the large number of factors involved.

OPTIMUM TEMPERATURE.

It is known that better results are obtained by churning at a low temperature; but, when the literature was examined in order to see upon what experiments this knowledge was based, it was impossible to find any *definite* data.

Some excellent tests were carried out at the various shows of the Royal Agricultural Society, but no precautions were taken to keep the temperature constant. Indeed, on examining some of the results—excellent *practical* results—one finds that the temperature varied, in some cases, between 54° F. and 60° F.; that is to say, practically over the whole range of churning temperature. These were *practical* tests, and it is difficult to see how they could have been carried out differently, without entirely modifying the scale and the method.

In this connection, Robertson (*Canada Expt. Farms Report*, 1892, 71—78; Abst. in *U.S.D.A. Stat. Record*, v, 1894, 641) carried out some experiments on sweet cream at temperatures ranging from 41° F. to 58° F. at the *beginning* of churning. The temperature at the *conclusion* of churning was from 57° F. to 62° F., so that here also no precautions were taken to keep the temperature constant. His results showed that:—

(1) With an initial temperature of 50° F., or under, the quantity of the fat remaining in the butter-milk need not exceed 0.25 %.

(2) For the efficient conversion of the fat, the temperature of the cream should not be above 50° F. *at the commencement*.

(3) That the churn (if a revolving one) should not be more than one quarter full.

Robertson made experiments also on the addition of water to the cream, and showed that there was slightly less percentage-conversion where water had been added to the cream before ripening. He showed, moreover, that the period of lactation had an influence on the conversion, inasmuch as the loss of fat was greatest with the milk of cows which had been more than six-and-a-half months in milk.

In 1909 an attempt was made to determine the optimum temperature definitely, and the apparatus and method were described in detail in the *Journ. Agric. Sci.*, iv, Pt. 2, 1909, 167. It was found that

at higher temperatures the percentage of the fat taken in the cream, which was converted into butter, varied.

The work was repeated in 1911, and in this case not only the temperature but also the percentage of fat in the cream was varied. It seemed to be desirable that the percentage of fat in the cream should be as near as possible to that taken in practical work. Seven samples of cream were taken, as prepared ready for churning by seven different dairy-maids. The fat was found to vary from 36% to 45.5%, the average being 38.5%. A cream containing 38% fat would not churn in our apparatus, however; 30% was the maximum, and even in that case it was necessary to add "breaking" water. Experiments were made, therefore, using fresh cream containing 30% and 25% of fat respectively. 200 grams were taken of each cream, and these were churned at 54° F., 58° F. and 62° F. Where "breaking" water was added towards the end of the churning, the amount was noted. The butter-milk was weighed, and the percentage of fat in it was determined; from this the percentage of fat lost in the butter-milk was calculated.

The results are shown in Tables II and III, and are plotted in curves in Figures 1 and 2.

These results were obtained from one series of experiments only; for at that time the various breeds were being considered, and these could only be obtained at the Royal Show, where it was impossible to make duplicate experiments. Now that it is realised that the milks should be considered in respect to the size of their globules, rather than to the breed, it is possible to repeat the experiments in the laboratory. This it is proposed to do in the near future.

The most definite conclusion which can be drawn from these experiments is that the percentage of fat in the cream has a very marked influence upon the percentage conversion of fat into butter.

It is obvious that the temperature has a considerable influence, but to what extent, these results can only afford an approximation.

The effect of temperature is not marked in the case of Jersey, Guernsey or Kerry milks, provided that the cream is thick. In the other breeds, the effect is more pronounced; but in these cases better results might have been obtained if the cream had contained more fat. In all cases, however, the effect of temperature is very marked if the cream is too thin.

In the tables opposite, the names of the breeds are given, but it must be remembered that the results, as shown, are not necessarily any criterion as to the suitability of any particular breed for dairy work. This point is considered more fully on p. 356.

TABLE II.

Breed	Mean Dia.	Temp. Deg. F.	% Fat	Cream taken gms.	Fat taken gms.	Water added gms.	Weight of Butter obtained gms.	Weight of Butter-milk gms.	% Fat in Butter-milk	Weight of Fat in Butter-milk gms.	% Fat lost
Shorthorn		54	29	200	58	{ 70	68	202	0.75	1.5	2.6
		58				{ —	66.2	133.8	2.3	3.1	5.3
		62				{ —	63.8	136.2	4.4	6.0	10.3
Jersey		54	30	200	60	{ 130	72.5	257.5	0.1	0.25	0.4
		58				{ 100	72.0	228.0	0.2	0.45	0.75
		62				{ 70	78.7	191.3	0.3	0.6	1.0
Guernsey	3.09	54	30	200	60	{ 70	68.8	201.2	0.2	0.4	0.7
		58				{ 70	69.4	200.6	0.2	0.4	0.7
		62				{ —	72.0	128.0	0.45	0.6	1.0
Red Poll	2.84	54	30.5	200	61	{ —	70.0	130.0	2.25	2.9	6.0
		58				{ —	69.0	131.0	3.8	4.9	8.0
		62				{ 70	70.1	199.9	5.58	11.1	18.2
Kerry	2.88	54	30	200	60	{ 70	73.2	196.8	0.1	0.2	0.3
		58				{ 70	68.8	201.2	0.4	0.8	1.3
		62				{ 70	70.2	199.8	0.5	1.0	1.6
Ayrshire		54	30.5	200	61	{ 70	74.2	195.8	0.5	1.0	1.6
		58				{ 70	77.2	192.8	0.75	1.4	2.3
		62				{ —	75.6	124.4	2.6	3.2	5.2

TABLE III

Breed	Mean Dia.	Temp. Deg. F.	% Fat	Cream taken gms.	Fat taken gms.	Water added gms.	Weight of Butter obtained gms.	Weight of Butter-milk gms.	% Fat in Butter-milk	Weight of Fat in Butter-milk gms.	% Fat lost
Shorthorn		54	25	200	50	{ —	61.5	138.5	2.2	3.0	6.0
		58				{ —	41.7	158.3	10.3	16.3	32.6
		62				{ —	49.5	150.5	9.9	14.9	29.8
Jersey		54	25	200	50	{ 50	64.8	185.2	0.4	0.7	1.4
		58				{ —	51.7	148.3	5.4	8.0	16.0
		62				{ —	44.2	155.8	6.9	10.7	21.4
Guernsey		54	26.75	200	53.5	{ —	66.0	134.0	1.2	1.6	3.0
		58				{ —	51.7	148.3	7.7	11.4	21.3
		62				{ —	43.7	156.3	8.1	12.6	23.5
Red Poll		54	26.75	200	53.5	{ —	63.7	136.3	3.9	5.3	10.0
		58				{ —	59.1	140.9	10.1	14.2	26.5
		62				{ —	55.6	144.4	10.8	15.6	29.2
Kerry		54	25	200	50	{ —	61.5	138.5	1.2	1.6	3.2
		58				{ —	52.3	147.5	2.7	4.0	8.0
		62				{ —	48.5	151.5	9.9	15.0	30.0

Fig. 1. Curves showing effects of different temperatures on the percentage conversion of milk fat into butter.

Fig. 2. Curves showing effects of different temperatures on the percentage conversion of milk fat into butter.

For reference, the mean size of the fat globules contained in the milks from which the creams were obtained is given below three of the curves.¹ No correlation could be determined between the percentage conversion and the size of globule.

That the size of globules has an effect on the percentage conversion, however, is shown by Woll (Digestion Expts., *Seventh Ann. Report, Agric. Expt. Stat., Wisconsin*, 1890, 238; also *Agricultural Science*, VI, 1892, 545), who concluded that "large size in the fat globules facilitates both the creaming and the churning of the milk; but the size of the globule is only one of the factors influencing completeness of creaming in churning processes." By mixing milks containing globules of different sizes "the creaming efficiency does not seem to be materially affected."

THE LIMITING-SURFACE OF THE GLOBULES.

In problems connected with churnability, a knowledge as to the presence or absence of a covering to the globules is important.

A very brief account of the different views put forward may be of interest. The various opinions may be classified in three categories. There are those who hold that there is an actual skin, membrane or pellicle round the globule. There are those who consider that there is nothing more than a "sliminess" round the globules; a condition which appears to us to be described best as a *mucilaginous aggregation*. Finally, others deny the existence of any covering whatever.

The membrane theory was first put forward by Raspail (*Schmidt's Jahrbuch*, XXIV) and by Acherson (*Müller's Arch. f. Anat. u. Physiol.*, LIII, 1840), so that the pellicle is often termed Acherson's membrane, though Acherson himself suggested the term *haptogen membrane*. Voltz (*Pflüger's Arch. f. Physiol.*, CII, 1904, 373) carried out a lengthy and detailed research, and concluded that "the fat globules of milk possess pellicles of solid substances, probably actually *solid membranes*."

Of the second view, perhaps the best exposition is that of Storch ("On the structure of the 'Fat Globules' in Cow's Milk," *Analyst*, XXII, 1897, 197—211), who isolated an albuminous substance which he claimed was the actual membrane. He expressly states, however, that "by the term membrane, is not meant a solid film or skin, but merely a layer, a semi-fluid, viscous envelope,"—evidently a "sliminess" round the globules. The use of the terms "membrane," "skin," "envelope," etc.,

¹ The other figures cannot be given.

appears to be unfortunate for the description of such a condition; it causes a misconception, as is evident from some of the criticisms of Storch's work. For this reason, together with one to be mentioned later, we propose the term *mucilaginous aggregation*.

With regard to the substance isolated by Storch, Voltz (*Pflüger's Arch. f. Physiol.*, CII, 1904, 373) more recently has obtained a substance which surrounded the globules even after they had been very thoroughly washed, but he found that there were extraordinary variations in the composition, according to the conditions of the experiment. Both these workers were able to stain the substance round the globule, but each drew different conclusions.

In our opinion, the divergent results obtained and the views held by the different workers are all to be reconciled on the theory that *constituents of the milk serum are adsorbed to the surface of the globule*.

On this theory, milk would not differ essentially from many artificial emulsions. It is generally accepted that milk differs from an ordinary emulsion in that the fat is not extractable with ether. If sufficient ether is used, however, the fat can be removed completely. Further, a number of artificial emulsions—*cyllin* in water, for example—behave exactly like milk in this respect, the oil being removed by ether only with great difficulty. In both cases the fat is comparatively easily extracted if the emulsifying agent is broken down. Moreover, it is possible to detect and to isolate the aggregated adsorbed emulsifying agent surrounding the globules in an artificial emulsion, so that it is only reasonable to conclude that similar conditions prevail in milk. In short, the difference between milk and an artificial emulsion appears to be one of degree only, and that difference is to be explained by the phenomenon of adsorption.

In this connection, the paper of Marshall (*Pharm. Journ. and Pharmacist*, Feb. 27th, 1909) and that of Ramsden ("Observations on Surface Membranes, Bubbles, Emulsions, and Mechanical Coagulation," *Chem. News*, LXXXVIII, 1903, 49—51; also *Proc. Royal Soc.*, LXXII, 1904, 458) are of considerable interest.

An actual solid membrane is not incompatible with the theory, as is clearly shown by Ramsden (1903) when discussing this theory:—"An intense *special interface viscosity*...has been found with every pair of liquids capable of forming persistent emulsions, hitherto examined." And "...the presence of a pellicle at the interfaces between caseinogen solutions and pure butter fat...." Also "the existence of a proteid

'Haptogen-membrane' round the cream globules of milk cannot be any longer doubted."

Storch's conclusions are based upon the result of one experiment. Voltz made repeated experiments, and obtained substances which varied greatly in composition according to the conditions. An examination of his figures shows that it is what one would expect, according to the adsorption theory, but they have not been submitted to mathematical analysis, since the data are insufficient.

FEEDING EXPERIMENTS—1912.

Several observers have noted that the food has an effect upon the globules, but, unfortunately, their results are contradictory.

Sturtevant, (*Ann. Report U.S.D.A.*, 1880; Abridged Account in *Journ. Royal Agric. Soc. Eng.*, XVIII, (2), 1882, 475—495) concluded that *brans* and *shorts* diminished the size of the globule, whereas corn-meal "influenced uniformity." Woll (*Sixth Ann. Report, Agric. Expt. Stat., Wisconsin*, 1889, 122; also *Seventh ditto*, 1890, 246) stated that dry food decreased the number and increased the size of the globules. Corn gave the same result as dry food. Gutzeit (*Landwirtsch. Jahrbücher*, Berlin, XXIV, 1895, 539—668), who carried out an extremely large number of observations, came to the conclusion that it was *not* true that one food would increase the diameter and another diminish it; but that, with a sudden change of fodder, there was a temporary change in the size.

It should be observed that the differences found by Woll were small, and, according to our experience, are within the limits of experimental error. Moreover, they are expressed in "relative sizes," and not in mean diameters, as we have done; nor in mean volumes, as Gutzeit has done; so that the figures appear, at first sight, to be more conclusive than one might otherwise suppose.

As the matter is of great importance in the present work, it was considered advisable to carry out further experiments, not with any idea of ascertaining the influence upon the quantity and quality of milk, but solely with respect to the globules.

It was decided to take three sets of cows; to one, to give an ordinary food such as would be given normally, having a proteid-carbohydrate ratio of about 1:6; to another set of cows to give food having an abnormally high, and to the third set a food having an abnormally low, ratio. The object of these abnormal foods was to

accentuate any difference, and it was considered advisable to accentuate them as much as possible, because there is a considerable difference of opinion as to whether the size of the globules is actually altered. Not only that, but there is a natural diminution in size as the period of lactation advances, so that, in any case, a diminution in size must be expected with those cows fed on the normal food; an effect which it was desirable to exclude as far as possible.

The experiments were carried out in a dairy very near to the laboratory, where some forty cows are milked. The breed is not pure, but is chiefly Shorthorn. They were being stall-fed, so that one could know exactly the quantity of food they received. Six cows were taken and were divided into three lots of two each, one lot for each ration.

In addition, Mrs Dudley Cory-Wright, of Dorking, very kindly allowed us to carry out similar experiments with three of her cows, two Guernseys and one Jersey. These received the same dry rations, but they were turned out, and therefore had an unknown quantity of grass, so that it is impossible to give ratios.

Photographs of the milk and other data were taken before the experiments commenced; then rations were given according to Table IV. Samples of the morning and evening milk were taken every third day. After 22 days¹, a measurement of the globules showed no alteration, and it was decided to modify the rations, so as to accentuate the ratios to an even greater extent.

Determinations were made every third day, as before, for 26 days, and then the food of the cows was changed over; so that those cows which had been having the food with a high ratio were given the food with the low ratio, and vice versa. The cows receiving the food with the normal ratio continued as before.

FOOD.

A decision as to the most suitable rations was very difficult, since discrepant figures are given for the composition of each material. As the chief authority, the figures of Crowther were taken. The rations given were based chiefly upon suggestions of Dr Hedworth Foulkes, and are tabulated below.

As to the materials, the grass was ordinary meadow grass, containing no clover. The hay was similar. The maize meal was ordinary material

¹ Woll (*Sixth Ann. Report, Agric. Expt. Stat., Wisconsin*, 1889, 71) also fed his cows 3 or 4 weeks, before changing the fodder.

purchased in Watford. The soya cake and cotton cake were obtained from Messrs Bibby, who very kindly made a reduction in price for the experiments, and who have been very obliging in many details. All the cake supplied was prepared specially in one batch, so that there should be no variation.

The rations shown in column A in Table IV were given for 22 days; after that the rations were given as shown in column B, having the corresponding ratios. The final examination was made on the 38th day. The cows were milked at 4.0 a.m. and at 1.0 p.m.

TABLE IV.

RATIONS (per cow per day)	High Albuminoid Ratio		Medium Albuminoid Ratio		Low Albuminoid Ratio	
	A.	B.	A.	B.	A.	B.
	For 22 days	After 22 days	For 22 days	After 22 days	For 22 days	After 22 days
Meadow grass (no clover)	42 lbs.	42 lbs.	56 lbs.	56 lbs.	42 lbs.	42 lbs.
Hay	—	—	—	—	14 lbs.	14 lbs.
Soya cake	4 lbs.	6 lbs.	—	—	—	—
Cotton cake (undec.)	—	—	3 lbs.	5 lbs.	—	—
Maize meal	—	—	—	—	4 lbs.	6 lbs.
DIGESTIBLE FOOD RATIO *	1 : 2.75 : 0.24	1 : 2.2 : 0.22	1 : 5.2 : 0.33	1 : 4.4 : 0.33	1 : 8.9 : 0.36	1 : 8.9 : 0.38
Total solids	12 lbs.	13.75 lbs.	14 lbs.	15.5 lbs.	24 lbs.	25.75 lbs.
QUANTITIES OF CONSTITUENTS PER RATION						
Total albuminoids	3.0 lbs.	3.8 lbs.	2.3 lbs.	2.9 lbs.	3.1 lbs.	3.3 lbs.
„ carbohydrates	5.3 „	5.8 „	6.6 „	7.3 „	13.0 „	14.3 „
„ fat	0.6 „	7.4 „	0.6 „	0.7 „	0.8 „	1.0 „
Digestible albuminoids ..	2.0 „	2.7 „	1.3 „	1.6 „	1.5 „	1.6 „
„ carbohydrates ..	5.5 „	5.9 „	6.8 „	7.2 „	13.1 „	14.4 „
„ fat	0.5 „	0.6 „	0.4 „	0.5 „	0.5 „	0.6 „

* These ratios are arranged :—albuminoid, carbohydrate, fat.

The method of mensuration of the globules has been given in a former paper (*Journ. Agric. Sci.*, IV, Pt. 2, 1911, 155—166) but a detailed description, together with an account of Babcock's method, appears in a subsequent portion of this issue¹, p. 357.

¹ It would be well to emphasise, once more, the futility of attempting to judge either of the average size of the globules or of the fat content in a milk, by visual examination. It must not be supposed that a field full of small globules contains more fat than one with a small number of large globules; or vice versa; determination alone can decide this.

It should be pointed out that, in Babcock's method, it is not possible to check the results. In our method, however, this can be done as pointed out below; any discrepancy may be due to erroneous counting, to bad sampling, or to selection of a bad field for the photograph, and the count can be neglected as being erroneous.

The two methods of computation of the mean diameter are¹:—

A. The globules can be counted and the size of each measured, so that the distribution of the fat in the different sizes of globules can be determined. From the numbers so obtained curves can be drawn which show graphically the distribution of the fat.

B. Where the mean diameter alone is required, the number of globules in a known area is counted; the depth of the cell is known, so that the volume of milk in the area measured is known also; the percentage of fat, determined by analysis², is reduced to give the volume of fat in the volume measured; this fat is distributed in the known number of globules, so that the mean diameter of the globules can be calculated. This is the method by which the mean diameters have been calculated for Tables VI—XIII and Figs. 3—6.

For some of the milks the mean diameters have been calculated also by method A, and the figures thus obtained are bracketed in Tables VI—X. The agreement or disagreement of these two figures is a measure of correctness of the determination, and an asterisk is placed against those in which there is an appreciable discrepancy.

An excellent instance of the value of this dual method of calculation is afforded by the following. The milk of Cow 10 on August 18, p.m., gave an analytical figure of 7.32 for the percentage of fat. This abnormally high figure appeared to be due to an error in analysis; but, using this percentage, the mean diameter was 3.41; whereas by the first method, not using the analytical figure, the mean diameter was 3.32. Such good agreement shows that the analytical figure was substantially correct.

¹ In our work published in 1911, p. 163, the centres of gravity of the curves A were given as representing the *mean* diameters. These are to be calculated from the number of globules in the area counted, and the percentage of fat. This will be rectified in due course. The use of the word "mean" was incorrect, and should have read "average." The distinction between these two terms, and their significance, is considered in detail in the account of the mensuration of the globules, p. 372.

² An important, and a very disconcerting source of error was experienced. The fat was determined in a centrifugal apparatus, using the amyl alcohol and sulphuric acid method. The milks, at first, showed great discrepancies. The tubes were then standardised, using a milk checked by the Adams method, and the following correction factors were found necessary:—1.03, 1.23, 1.18, 1.06, 1.10, 1.04.

It might be pointed out that the second method is, practically speaking, a modification of Babcock's original method, but the volume measured is much larger—about 10 times.

The results obtained from these feeding experiments have been tabulated, and, in order that they may be seen at a glance, curves have been drawn, as given below, pp. 350, 351.

Before discussing these tables, it should be pointed out that the number of cows was very small. But, although the calculations have been considerably simplified, owing to the adoption of the photographic method, yet the work is very laborious and all our available time was occupied. Moreover, the cost of the work was considerable, and would have been excessive had more cows been taken.

TABLE V.

Cow 7. Calved "lately" (? April).

Date	Morning				Afternoon			
	Average daily yield of milk	Fat	No. of globules	Mean diameter	Average daily yield of milk	Fat	No. of globules	Mean diameter
22. 7. 12	lbs. 22.5	% 3.33	1677	μ 2.94* (3.94)	lbs. 13.0	% 4.22	1397	μ 3.38* (3.76)
25. 7. 12	23.25	3.0	—	—	16.25	3.77	—	—
28. 7. 12	22.4	2.83	—	—	15.4	3.44	—	—
31. 7. 12	20.5	3.22	1296	3.16 (3.12)	14.3	4.22	1740	3.16
3. 8. 12	22.3	3.39	1710	2.93	15.2	3.51	1609	3.03
6. 8. 12	22.3	3.07	927	3.48	14.7	3.84	1140	3.50
9. 8. 12	22.7	—	—	—	15.5	—	—	—
12. 8. 12	23.5	2.76	1019	3.25	14.7	3.90	1417	3.27
Food modified mid-day Aug. 13								
15. 8. 12	23.4	2.67	1230	3.01	16.3	3.84	1335	3.32
18. 8. 12	24.25	2.94	1527	2.91 (2.93)	16.75	3.72	1709	3.03 (3.24)
Food changed Aug. 18								
30. 8. 12	22.1	3.12	1573	2.94	14.7	3.48	1627	3.01

TABLE VI.

Cow 8. Calved "some time ago" (? March).

Date	Morning				Afternoon			
	Average daily yield of milk	Fat	No. of globules	Mean diameter	Average daily yield of milk	Fat	No. of globules	Mean diameter
22. 7. 12	lbs. 16.5	% 2.41	403	μ 4.58* (5.48)	lbs. 9.5	% 3.99	430	μ 4.91* (5.58)
25. 7. 12	17.7	2.52	—	—	10.1	5.29	—	—
28. 7. 12	17.2	2.50	—	—	8.8	4.83	—	—
31. 7. 12	16.7	2.44	258	4.92 (5.11)	9.1	5.16	509	5.05
3. 8. 12	17.7	2.78	363	4.60	9.3	4.52	578	4.63
6. 8. 12	16.7	2.71	297	4.87	9.25	4.44	328	5.57 (5.72)
9. 8. 12	16.3	—	—	—	9.1	—	—	—
12. 8. 12	16.8	2.94	523	4.15	8.25	3.84	494	4.62
Food modified mid-day Aug. 13								
15. 8. 12	16.8	2.46	288	4.77	9.3	4.14	399	5.09
18. 8. 12	17.75	1.98	314	4.32* (4.91)	10.3	5.16	721	4.50 (4.20)
Food changed Aug. 18								
30. 8. 12	16.6	2.52	341	4.55	9.4	4.56	677	4.41

TABLE VII.

Cow 9. Calved "considerable time ago" (? Nov. or Dec.).

Date	Morning				Afternoon			
	Average daily yield of milk	Fat	No. of globules	Mean diameter	Average daily yield of milk	Fat	No. of globules	Mean diameter
22. 7. 12	lbs. 12.0	% 2.61	1481	μ 2.82 (3.08)	lbs. 7.0	% 3.66	1729	μ 3.00 (3.19)
25. 7. 12	13.5	2.89	—	—	6.5	3.92	—	—
28. 7. 12	12.25	2.83	—	—	6.0	4.77	—	—
31. 7. 12	11.0	3.11	1940	2.74 (2.98)	5.8	4.61	2133	3.02
3. 8. 12	13.1	2.94	1488	2.93	6.6	4.26	1727	3.15
6. 8. 12	12.3	3.00	1162	3.20	5.5	4.03	1353	3.36
9. 8. 12	11.7	—	—	—	6.2	—	—	—
12. 8. 12	10.8	3.36	2029	2.76	5.5	5.04	1384	3.59
Food modified mid-day Aug. 13								
15. 8. 12	10.5	2.94	1730	2.78	5.4	4.32	1790	3.13
18. 8. 12	11.9	2.82	1578	2.83 (2.90)	6.0	4.38	2273	2.91 (3.17)
Food changed Aug. 31								
30. 8. 12	11.7	4.08	1343	3.38	6.1	4.68	1461	3.44

Fat Globules in Milk

TABLE VIII.

Cow 10. Calved "considerable time ago" (? March).

Date	Morning				Afternoon			
	Average daily yield of milk	Fat	No. of globules	Mean diameter	Average daily yield of milk	Fat	No. of globules	Mean diameter
22. 7. 12	lbs. 12.5	% 4.02	1616	μ 3.16* (1.49)	lbs. 7.25	% 5.50	1943	μ 3.30 (3.10)
25. 7. 12	13.9	3.66	1993	—	6.75	5.00	—	—
28. 7. 12	13.2	4.16	—	—	5.9	5.11	—	—
31. 7. 12	11.8	3.55	2061	2.38 (2.68)	5.9	4.44	2312	2.90
3. 8. 12	12.8	4.38	2504	2.81	5.8	5.21	2489	2.98
6. 8. 12	11.1	4.20	2086	2.95	5.3	4.56	2221	3.30
9. 8. 12	12.2	—	—	—	5.5	—	—	—
12. 8. 12	10.9	3.96	2220	2.83	5.3	5.64	1812	3.41
Food modified mid-day Aug. 13								
15. 8. 12	10.8	4.44	1612	3.27	5.1	6.24	1592	3.68
18. 8. 12	8.6	5.22	2411	3.02 (2.79)	4.3	7.32	2346	3.41 (3.32)
Food changed Aug. 18								
30. 8. 12	9.4	4.32	2538	2.79	4.9	5.52	2845	2.91

TABLE IX.

Cow 11. Calved "some time ago" (? Nov. or Dec.).

Date	Morning				Afternoon			
	Average daily yield of milk	Fat	No. of globules	Mean diameter	Average daily yield of milk	Fat	No. of globules	Mean diameter
22. 7. 12	lbs. 8.75	% 3.32	1427	μ 3.06 (3.23)	lbs. 5.25	% 3.55	1538	μ 3.09 (3.22)
25. 7. 12	10.9	3.00	—	—	5.6	3.66	—	—
28. 7. 12	10.5	3.93	—	—	5.2	3.89	—	—
31. 7. 12	9.75	3.61	1552	3.10* (3.61)	4.75	4.50	1665	(3.25)
3. 8. 12	10.9	3.11	1704	2.85	5.25	3.51	1852	2.89
6. 8. 12	10.75	2.88	1192	3.13	5.2	4.08	1799	2.44
9. 8. 12	10.1	—	—	—	5.4	—	—	—
12. 8. 12	10.6	2.94	1736	2.78	5.25	3.78	1516	3.16
Food modified mid-day Aug. 13								
15. 8. 12	10.75	2.88	1668	2.80	5.7	3.60	1644	3.03
18. 8. 12	11.3	2.40	1396	2.59 (2.53)	5.6	4.04	2261	2.83 (2.91)
Food changed Aug. 18								
30. 8. 12	9.6	3.69	1793	3.04	5.0	3.96	2019	2.92

TABLE X.

Cow 12. Calved "lately" (? April).

Date	Morning				Afternoon			
	Average daily yield of milk	Fat	No. of globules	Mean diameter	Average daily yield of milk	Fat	No. of globules	Mean diameter
22. 7. 12	lbs. 12·0	% 3·44	300	μ 5·27 (5·24)	lbs. 8·0	% 4·88	544	μ 4·85* (5·88)
25. 7. 12	13·5	3·89	—	—	8·25	4·72	—	—
28. 7. 12	14·0	3·11	—	—	8·0	4·99	—	—
31. 7. 12	11·2	3·16	300	4·36* (5·41)	8·25	4·77	608	4·64
3. 8. 12	15·1	3·62	339	5·14	8·4	5·49	688	4·66
6. 8. 12	14·7	3·00	237	5·44	7·0	5·52	530	5·09
9. 8. 12	13·5	—	—	—	7·5	—	—	—
12. 8. 12	13·7	2·88	229	5·43	7·6	5·16	494	5·10
Food modified mid-day Aug. 13								
15. 8. 12	13·3	2·70	196	5·59	8·2	4·56	516	4·82
18. 8. 12	13·25	3·66	527	4·46 (4·92)	7·1	4·80	—	—
Food changed Aug. 18								
30. 8. 12	12·25	3·60	416	4·80	6·5	6·36	605	5·12

The tables include determinations made upon the morning and the evening milk; for the curves, however, an average of these two daily measurements was taken. The "average yield of milk" represents the daily average for the three-day period. The fat was estimated on the centrifuge. The number of globules was determined, as already mentioned. The mean diameters were worked out from the number of globules and the percentage of fat—method B. Those figures for the mean diameter given in brackets were calculated from the actual measurements of the globules—method A. On August 13 (mid-day) the food was slightly modified; the rations were changed over on August 18, as shown.

One of the most noticeable features of the tables is that the numbers for each cow are very irregular, whether considering the fat, the number of globules, or the diameter. This is probably due to the examination of too small a volume of milk.

With regard to the curves, which have been plotted from these figures, in order to reduce any individual peculiarity of the cows, an average given by the two cows of each set has been plotted in the upper of the three curves (*a*). This curve, of course, does not give any absolute value, but it does show the variations during the period of the experiments.

Fig. 3. Curves showing variation in mean size of fat globules during feeding experiments. The perpendicular dotted line indicates the point at which the High Ratio Food was changed to Low Ratio Food. Mean size of globules plotted as ordinates; dates as abscissae.

One would expect that the globules would diminish in size in any case, owing to the advancement of the period of lactation; but the curve is so irregular that one cannot observe a diminution in size, even due to this factor. Equally irregular variations have been experienced by others, as will be seen by an examination of Gutzeit's figures.

The only conclusion which can be drawn from these experiments is that the food has little or no influence on the size of the globules, if the "ratio" is taken as the criterion.

Fig. 4. Curves showing variation in mean size of fat globules during feeding experiments (control). Mean size of globules plotted as ordinates; dates as abscissae.

It is to be noted, however, that Woll (Digestion Expts., *Seventh Ann. Report, Agric. Expt. Stat., Wisconsin*, 1890, 238; also *Agricultural Science*, vi, 1892, 545) stated that it was *dry* food which gave the larger globules, but no information is given as to the *food ratio*. In our case, all the cows received grass, but the proportions were greater for those which had the food with low ratio; moreover, these cows had no cake, but maize meal and hay in place of it.

A plain food of grass only in the one case, and of dry foods only in the other, was not given in this series of experiments, because it was asserted by the herdsman that the cows would "go off their milk," owing to the character of their previous feed.

Fig. 5. Curves showing variation in mean size of fat globules during feeding experiments. The perpendicular dotted line indicates the point at which the Low Ratio Food was changed to High Ratio Food. Mean size of globules plotted as ordinates; dates as abscissae.

It is proposed to repeat the experiments, giving some cows a "dry" food and others grass only. In these experiments, it is suggested that observations should be made on the effect of the foods

upon the character of the serum and upon the churnability; for, in connection with previous experiments, it has been noted that there seems to be some relationship between the time of churning, the colour and quality of the butter, and the size of the globules. It is proposed also to make more determinations on each sample, taking them at longer intervals. Referring to the Tables V—X once more, it is to be noticed that there is a considerable difference in the mean diameter of the globules of the morning and evening milk on the same day; generally, those of the afternoon are the larger.

It may be observed, also, that in a number of the samples the percentage of fat is below the Government standard, and that in some it is abnormally high—a fact which can scarcely be due to sampling, as this was done within a short time of milking.

The number of globules in the milk of the same cow, at different periods, varies very considerably; in one case, a variation from 328 to 721 globules per unit volume in twelve days.

The results obtained from the cows at Dorking have been tabulated and curves drawn from them (Tables XI—XIII and Fig. 6). Here, again, it would appear that the feeding has had no effect on the globules. In this case, one may fairly presume that the cows had a very much larger quantity of *wet* food, yet no diminution in size of the globules is to be observed. With these cows, there is a much greater regularity in the size of the globules.

TABLE XI.

Cow 1. Jersey.

Date	Morning				Afternoon			
	Average daily yield of milk	Fat	No. of globules	Mean diameter	Average daily yield of milk	Fat	No. of globules	Mean diameter
	lbs.	%		μ	lbs.	%		μ
Aug. 3	18.3	3.30	2167	2.68	12.0	4.98	3130	2.72
„ 6	17.7	—	—	—	12.4	4.68	3467	2.58
„ 9	17.75	—	—	—	11.5	4.62	—	—
„ 12	18.0	3.72	2633	2.62	11.5	4.74	3085	2.69
„ 15	17.1	3.96	1859	3.00	10.5	5.10	2672	2.89
„ 18	16.8	3.96	2397	2.76	11.1	4.92	2793	2.82

Fat Globules in Milk

TABLE XII.

Cow 2. Guernsey.

Date	Morning				Afternoon			
	Average daily yield of milk	Fat	No. of globules	Mean diameter	Average daily yield of milk	Fat	No. of globules	Mean diameter
Aug. 3	lbs. 15.9	% 3.90	1526	μ 3.19	lbs. 9.75	% 5.04	1540	μ 3.46
„ 6	15.9	4.38	1853	3.11	10.1	4.14	2117	2.92
„ 9	16.1	—	—	—	9.9	5.22	—	—
„ 12	16.0	3.96	1632	3.14	9.7	4.50	1685	3.24
„ 15	15.75	—	—	—	8.9	4.74	1420	3.49
„ 18	15.4	4.32	1487	3.28	9.5	4.92	1841	3.24

TABLE XIII.

Cow 3. Guernsey.

Date	Morning				Afternoon			
	Average daily yield of milk	Fat	No. of globules	Mean diameter	Average daily yield of milk	Fat	No. of globules	Mean diameter
Aug. 3	lbs. 16.75	% 4.80	1099	μ 3.81	lbs. 10.9	% 5.76	1347	μ 3.79
„ 6	16.8	3.96	1085	3.59	11.25	—	—	—
„ 9	16.6	4.62	—	—	9.9	5.10	—	—
„ 12	15.0	5.40	1415	3.65	10.5	7.08	1557	3.87
„ 15	15.2	4.68	1237	3.64	9.5	6.00	1345	3.84
„ 18	14.8	4.80	862	4.14	9.7	6.06	1097	4.13

There is one point which appears to be of considerable economic interest. It is generally considered that Jerseys and Guernseys give milks with large globules, which cream well, whereas Shorthorns occupy a medium position. In the work of this year, the mean sizes of the globules are remarkable; the Jerseys and Guernseys are in agreement with the usual values, whereas those of the impure

Shorthorn are not only considerably larger than those of the Jerseys, but also they are larger than any mean sizes which have been seen by us, or recorded by Gutzeit, for any breed. Woll (*Eleventh Ann. Report, Agric. Expt. Stat., Wisconsin, 1894, 230*), however, records a Shorthorn milk having a mean size globule of 7.5μ , and gives other measurements of the same order as ours.

Fig. 6. Curves showing variation in mean size of fat globules during feeding experiments at Dorking. Mean size of globules plotted as ordinates; dates as abscissae.

These high values can scarcely be due to errors in counting, as they occur frequently. Neither can it be due to sampling, which might be the case if the milk had been standing some time before sampling,

when the upper layer would contain a greater number of larger globules, and also if the sample had been taken from this upper layer. The fact that an abnormally high percentage of fat was not found, precludes this possibility; on the contrary, the largest mean size occurs in the morning milk of cow 12, when the percentage of fat is the lowest recorded for that milk (2.70%).

Not only is it our experience that Shorthorn milks sometimes have a mean globule considerably larger than those of an average Jersey milk, but Woll (*Eleventh Ann. Report, Agric. Expt. Stat., Wisconsin, 1894, 230*), making determinations upon milks from a whole herd (99 cows), obtained similar figures.

If the size of globule is an important factor in dairying—as many consider—the question arises as to whether the *strain* of the cow may not be of more importance than the actual *breed*. That is to say, though, generally speaking, Jerseys are superior to Shorthorns for dairy work, yet certain *strains* of Jerseys may be inferior to certain *strains* of Shorthorns, and so with other breeds.

The only other suggestion bearing on this point, which we can find, is that contained in a paper of Cederholm (*U.S.D.A. Expt. Stat. Record, XII, 1901, 482*). He estimated the fat in the several cows' milks, and then that in the milks of their daughters by different bulls. His results show that each bull almost always causes an increase or a decrease in the percentage of fat. He concludes therefore "that the bull exerts a decided influence for better or worse on the milk product of his progeny."

This raises the question—important in its practical aspect—as to whether more attention should not be given to this point in attempting to improve our dairy herds. It is considered in actual practice, but scarcely sufficiently in interpreting experimental results.