THE COMPOSITION OF MILK.

WITH SPECIAL OBSERVATIONS ON THE CONSTITUTION OF THE FAT GLOBULES.

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(Read at the Meeting, March 2, 1904.)

OF the 37,589 samples examined in the Aylesbury Dairy Company's laboratory during 1903, 33,063 were analyses of milk. The average composition of 15,313 samples received from the company's farms is given in the following table :

AVERAGE COMPOSITION OF MILK DURING 1903.

MONTH.	MORNING MILK.				EVENING MILK.				AVERAGE.			
	Specific gravity.	Total solids.	Fat.	Solids-not-fat.	Specific gravity.	Total solids.	Fat.	Solids-not-fat.	Specific gravity.	Total solids.	Fat.	Solids-not-fat.
January ..	1·0324	12·68	3·71	8·97	1·0322	13·07	4·07	8·90	1·0323	12·88	3·89	8·99
February ..	1·0324	12·51	3·56	8·95	1·0322	12·85	3·89	8·96	1·0323	12·68	3·72	8·96
March ..	1·0325	12·52	3·55	8·97	1·0323	12·91	3·92	8·99	1·0324	12·67	3·69	8·98
April ..	1·0324	12·47	3·52	8·95	1·0322	12·88	3·91	8·97	1·0323	12·67	3·71	8·96
May ..	1·0325	12·40	3·45	8·95	1·0322	12·92	3·93	8·99	1·0324	12·66	3·69	8·97
June ..	1·0324	12·25	3·34	8·91	1·0322	12·91	3·94	8·97	1·0323	12·58	3·64	8·94
July ..	1·0320	12·29	3·46	8·83	1·0316	12·78	3·94	8·84	1·0318	12·53	3·70	8·83
August ..	1·0320	12·53	3·67	8·86	1·0316	13·05	4·17	8·88	1·0318	12·79	3·92	8·87
September ..	1·0321	12·61	3·69	8·92	1·0318	13·07	4·14	8·93	1·0320	12·84	3·92	8·92
October ..	1·0321	12·82	3·87	8·95	1·0319	13·28	4·31	8·97	1·0320	13·05	4·09	8·96
November ..	1·0324	12·86	3·86	9·00	1·0320	13·23	4·24	8·99	1·0322	13·05	4·05	9·00
December ..	1·0324	12·73	3·75	8·98	1·0320	13·08	4·11	8·97	1·0322	12·90	3·93	8·97
Average ..	1·0323	12·56	3·62	8·94	1·0320	13·00	4·05	8·95	1·0322	12·78	3·83	8·95

The composition of the morning and evening milk is given separately, and the usual difference in fat, averaging 0·43 per cent., is observed. The average fat (3·83) is slightly higher than in 1902 (3·82), and, as almost invariably observed, the poorest milk occurred in June, and the richest in October and November.

The records, of which the above table is a continuation, which were published by Dr. Vieth, in whose footsteps I have endeavoured to follow, are sometimes quoted as representative of the composition of English milk. They are, however, often disputed, and are alleged to seriously overstate the amount of fat; it is therefore advisable to examine the figures to see whether there are any strong grounds for supposing that the samples which passed through Dr. Vieth's and my hands were of exceptional quality.

The first point which I have examined is the influence of the geological formation. I have been able to pick out four formations, on each of which there are a sufficient number of farms to give a fair average—the New Red Sandstone, the Oxford Clay, the Upper Greensand, and the Chalk. It is, of course, doubtful whether the influence of the underlying formation is as great as that of the surface deposits, modified as they are by artificial manuring; but it is practically impossible to obtain any other classification, and any conclusions which can be drawn must be received with caution and merely as indications. With these reservations, I give the average composition for each month during 1902 and 1903 on each of the four formations:

1902.

MONTH.	NEW RED SANDSTONE.		OXFORD CLAY.		UPPER GREENSAND.		CHALK.	
	Fat.	Solids-not-fat.	Fat.	Solids-not-fat.	Fat.	Solids-not-fat.	Fat.	Solids-not-fat.
January	3·94	8·96	3·77	8·91	3·93	9·00	3·88	8·92
February	3·75	8·98	3·76	8·91	3·88	9·01	3·92	8·94
March	3·61	8·91	3·68	8·90	3·88	9·02	3·85	8·95
April	3·55	8·89	3·75	8·94	3·85	9·02	3·82	8·90
May	3·58	8·88	3·62	8·96	3·68	9·01	3·67	8·93
June	3·46	8·90	3·56	8·87	3·63	8·92	3·55	8·84
July	3·57	8·85	3·62	8·79	3·77	8·80	3·67	8·79
August	3·63	8·80	3·82	8·76	3·88	8·74	3·82	8·75
September	3·83	8·87	3·89	8·89	3·93	8·86	3·88	8·87
October	4·11	8·94	3·96	9·01	3·99	8·98	4·01	8·94
November	4·14	8·92	4·02	8·99	3·94	8·95	3·94	8·93
December	4·14	8·92	4·03	9·02	3·99	9·00	4·05	8·99
Average	3·78	8·90	3·79	8·91	3·86	8·94	3·84	8·90

1903.

			NEW RED SANDSTONE.		OXFORD CLAY.		UPPER GREENSAND.		CHALK.	
			Fat.	Solids-not-fat.	Fat.	Solids-not-fat.	Fat.	Solids-not-fat.	Fat.	Solids-not-fat.
January	...	...	3·84	8·96	3·90	9·00	3·89	9·01	3·97	9·03
February	...	...	3·60	8·91	3·80	8·99	3·78	8·97	3·81	8·99
March	...	...	3·59	8·93	3·77	9·00	3·84	9·00	3·83	9·00
April	...	...	3·57	8·92	3·73	8·97	3·89	9·01	3·80	8·99
May	...	...	3·63	8·95	3·66	8·96	3·72	8·98	3·67	8·97
June	...	...	3·49	8·93	3·55	8·92	3·71	8·93	3·66	8·93
July	...	...	3·60	8·83	3·67	8·81	3·78	8·83	3·74	8·84
August	...	...	3·84	8·84	3·86	8·86	3·93	8·86	3·92	8·87
September	...	...	3·91	8·92	3·82	8·90	3·92	8·93	3·93	8·91
October	...	...	4·07	8·96	4·05	8·94	4·08	8·93	4·12	8·98
November	...	...	3·97	8·97	4·04	9·02	3·95	8·96	4·08	9·00
December	...	...	3·90	8·91	3·91	9·01	3·82	8·96	3·97	8·97
Average	...	...	3·75	8·92	3·81	8·94	3·86	8·95	3·88	8·96

The only conclusion that I venture to draw, seeing the possible influence of other conditions, is that the milk raised on the two cretaceous formations tends to be better in quality than the others; but the difference is not so marked as to permit of any sweeping assertion.

The second point is the influence of the times of milking. It is quite well known that the more equal the intervals between milkings are made, the more even is the quality of the milk. As near as I can ascertain, the average intervals of milking of the cows from which the samples I examined were drawn are 10·8 hours between the morning and evening milkings, and 13·2 hours between the evening and morning. If these intervals tend to become less equal, the morning milk will tend to be poorer and the evening richer, though the average is only slightly affected. It is hardly necessary to give any examples of this, but I mention it as it is a possible cause of instances of milk being very low in fat.

A third point lies in the consideration of the incidence of the samples on varying percentages of their constituents. An average tells us nothing of the variations; thus 50 represents the average of 0 and 100, as well as the average of 49·9 and 50·1, but it is evident that the average is a very much better representation of the latter pair of figures than of the former. It would be impossible to give the whole of the figures obtained, but the practical effect can be obtained by the use of the theory of probabilities. The range of incidence of the samples can be expressed by the "probable error." It is necessary, in the first instance, to make sure that the deviation of milk samples from the mean follows the law of errors which is expressed by the formula

$$y = ke^{-h^2x^2}$$

As a convenient and sufficient series, I have taken the aggregate of six years' analyses published in the Report of the Milk Standards Committee, 1901, Appendix xxv., p. 394, and have tried whether this series agrees with the law of errors. Taken as a whole, such wide divergences are found that the law cannot apply to these samples; it only appears to apply to quite low percentages of fat. I find, however, that by splitting the series into two a sufficiently good agreement is found. By means of the formula

$$y = \frac{1}{2\sqrt{\pi}} \left(\int_0^{\frac{3.59-f}{0.19}} e^{-\left(\frac{x}{0.19}\right)^2} d\left(\frac{x}{0.19}\right) + \int_0^{\frac{4.0-f}{0.25}} e^{-\left(\frac{x}{0.25}\right)^2} d\left(\frac{x}{0.25}\right) \right)$$

the probability (y) of samples occurring with a percentage of fat (f) can be calculated to agree very closely with the facts. The formula was calculated empirically, but 3.59 and 4.0 agree with the averages of morning and evening milks, and 0.19 and 0.25 are in very close agreement with their respective deviations from the mean, and the numbers of samples of morning and evening milks are practically equal. The following table shows the probability of a sample falling at the percentage of fat named:

Percentage of Fat.	Calculated.	Actual.	Percentage of Fat.	Calculated.	Actual.
Above 5.0	0.001	0.003	3.9	0.090	0.091
5.0	0.001	0.002	3.8	0.100	0.098
4.9	0.003	0.003	3.7	0.104	0.100
4.8	0.005	0.006	3.6	0.101	0.100
4.7	0.009	0.008	3.5	0.089	0.089
4.6	0.015	0.013	3.4	0.071	0.072
4.5	0.022	0.020	3.3	0.051	0.055
4.4	0.031	0.029	3.2	0.033	0.034
4.3	0.042	0.042	3.1	0.018	0.018
4.2	0.053	0.052	3.0	0.010	0.010
4.1	0.066	0.067	Below 3.0	0.007	0.007
4.0	0.078	0.081			

The above figures relate to analyses of single churns of milk which contain the mixed milk of several cows. The milk of single cows will vary much more, and, though the averages may be the same, the "probable error" will be greater.

Other series of analyses may give less favourable results:

- Because, owing to some cause connected with the breed or individuality of cows, the soil, etc., the average is lower.
- Because, owing to less regular intervals of milking, the morning milk is poorer and the evening richer; or,
- Because, owing to the milk of a smaller number of cows than will fill a churn being mixed, or from greater individual differences, the "probable error" is greater.

In a recent paper (*Journ. Soc. Chem. Ind.*, 1904, p. 3) S. H. Collins has stated that his figures suggest that there is some truth in the opinion that milk in the North of England is not as rich as that in the South; unfortunately, he does not give his figures, but only the proportion of samples from single cows which fall below the Board of Agriculture standard. As he takes my figures as representing the South, I should have liked to have been able to compare the two. I would point out that, so far from considering the cow the analyses of whose milk I published last year (*ANALYST*, xxviii., 290) a remarkably bad one, as he assumes, it is really a rather good cow, and above the average, and therefore my figures showing that 5.5 per cent. of the samples were below 3 per cent. of fat are not so greatly different to his 6.7 per cent. of the samples below 3 per cent. of fat; the difference is still less when the fact that the somewhat unusual practice of milking three times a day with very unequal intervals was followed at one of the two farms from which his samples were drawn, and, were this undoubted cause of low fats eliminated, his figures would probably be more favourable than mine.

His method of preserving the samples (by the addition of a mixture of ether and chloroform with or without formaldehyde) is one which will conduce to inaccurate results. I assume that the preservative mixture was added soon after milking, when the fat would be largely in the liquid condition, and the fat would then dissolve a considerable amount of ether and chloroform, which would tend to prevent solidification and the consequent rise of density; as his solids-not-fat were calculated from the fat and density, this would tend to give low results, and doubtless some of his low figures are due to this cause. On the other hand, his fat, which was estimated by the Gerber method, would be rather too high, owing to the presence of chloroform in the fat.

That these errors are actually caused is shown by the following figures; a milk in which the fat was liquid, and which was a little frothy, was used.

The fat by Gerber was 3.85 and 3.90, and after the addition of ether-chloroform it was 4.02, 4.05, and 4.05. The specific gravity was 1.0319, and remained the same after the addition of ether-chloroform; next day the specific gravity of the original milk had risen to 1.0327, while that of the preserved sample was 1.0323. After eighteen hours 1 c.c. of ether-chloroform was added to 100 c.c. of the milk, and its specific gravity was 1.0327; the specific gravity of neither milk changed during two days longer. This shows that the fat when solid does not appreciably dissolve ether and chloroform, while it does so when liquid. This was confirmed by the fact that after three days the sample to which the ether-chloroform was added at once had an acidity of 25°, and after five days of 55°, while the sample which had stood eighteen hours before the mixture was added had acidities of 20° and 31° at the same times; this difference can only be due to the withdrawal of the preservative by the liquid fat. The results of Collins do not, therefore, afford any conclusive evidence that milk in the North of England is poorer than that in the South, and do not bear out the contention that the standard should be lowered.

It will be remembered that in 1897 Professor Storch published an important paper on the "Structure of the Fat Globules of Milk" (*ANALYST*, xxii., 197), and in the discussion I took exception to his view that the fat globules in milk were sur-

rounded by a semi-solid membrane of mucoid substance. In a recent paper (*Revue Générale du Lait*, II., No. 15, *et seq.*, 1903) M. Beau has given a recapitulation of the various theories of the physical constitution of the fat globules, including that of Storch, with which he agrees, and has given details of many experiments not included in Storch's paper in the ANALYST; he has further criticised my views, and in doing so has used arguments which appear to me fallacious.

To briefly recapitulate, Storch bases his theory on the facts that he has separated a new proteid from milk; that it is impossible to free cream entirely from proteid by washing with a cane-sugar solution or with water in a centrifuge; that the composition of the mucoid membrane is established by a series of differences of analyses of cream and butter, and butter and buttermilk, as

Proteid	...	...	...	...	...	6.42
Ash	...	...	...	...	...	1.03
Water	...	...	...	...	...	92.55

or thereabouts; that on staining cream with picro-carmin, and washing it, a coloured layer is left; and on the behaviour of milk with ether. I disputed his conclusions on the ground that if a layer of the composition given existed round the globules, cream should contain proportionately less milk-sugar and somewhat less solids-not-fat, and rather more proteids than milk, which I did not find to be the case, and have since confirmed this. I also showed that the behaviour of milk with ether could be explained by the assumption that the fat globules in milk after some time become solid, which, in conjunction with my brother, I have proved to be the case (*Dairy Chemistry*, Appendix A., p. 338, and ANALYST, xxvi., 117), and that Storch's photographs of the coloured layer round the globules did not agree with the view put forward, but was in accordance with the assumption that a liquid layer was condensed round the globule by surface energy. Beau criticises the latter assumption by saying that Storch does not think that there is a regular membrane, but merely a gelatinous one, and that this would be analogous to a condensed liquid layer. I must dispute this, as, if the gelatinous layer has the composition assigned by Storch, it must differ in composition from the surrounding serum, and there must therefore be a sharp dividing-line between them, which does not exist in Storch's photographs. Many of the diatoms and algæ are surrounded by gelatinous layers, and these can be sharply stained, though gelatinous; while Storch's photographs show a gradual merging of the coloured layer into the colourless surroundings, and this is exactly what would be expected in a condensed liquid layer from which the colour could only slowly diffuse.

Beau answers my point about the deficiency of milk-sugar, which should follow if Storch's view were correct, by saying that this supposes that the absorption of water by the mucoid layer is of a chemical nature, and not a physical phenomenon affecting all the soluble constituents of milk. I would point out that the supposition is Storch's, not mine, and if it is abandoned, the composition—nay, even the very existence—of the mucoid membrane must be abandoned too.

Before describing some further observations I have made on the question of a membrane round the fat globules, I propose to show that Storch's observations are

much less conclusive than he has assumed. He relies largely on the fact that proteids cannot be washed entirely out of cream. The question which must first be asked is, Cannot solids in a fine state of division in suspension in a liquid be entirely separated from each other? I would answer this in the negative; thus, Portland cement and Kentish ragstone suspended in a liquid of density intermediate between the two undergo but a very partial separation on centrifuging. Blood (density 1.06) is carried up with the fat globules (density 0.93) when suspended in milk serum (density 1.036), unless the temperature is raised; the lighter particles carry up the heavy ones entangled. Storch gives the density of the mucoid membrane as 1.0228. He has used for washing his cream a cane-sugar solution of 33 per cent. (density about 1.1), or of 9 per cent. (density about 1.035). The proteid under these circumstances could not possibly all be separated from the fat. As the fat separation was imperfect, the proteid separation would be imperfect too, but the same ratio of fat to proteid would be expected in each case were Storch's view correct; while if, as I contend, the proteid is simply in suspension and unconnected with the fat globules, the separation of the proteid should be less perfect the lower the density of the medium used for washing. Storch's own figures show this to be the case, as only about half the proteid per 100 grammes of fat was found with a 9 per cent. sugar solution as with a 33 per cent. solution, and less still when water was used. His experiments, therefore, where they are not inconclusive, tend to negative the conclusions he draws from them. Storch also mentions that the use of a separator tends to remove the mucoid membrane from the globules. Seeing that both fat and mucoid membrane have a lower density than milk serum, it is difficult to see why this should be so, especially as the effect of centrifugal force (*i.e.*, force multiplied by time) is not so inordinately greater than the effect of gravitation. It is, however, quite easy to see that a partial separation should take place if the fat globules and mucoid substance are both free in the milk.

I have made some observations which are not in accord with Storch's view. It is evident that a substance of the composition of his mucoid membrane should not have the same refractive index as milk serum, and a layer of a thickness of one-tenth of the radius of a globule should therefore be visible. I have examined milk under various conditions of staining, and with powers up to 3,000 diameters, and have failed to see any layer. In milk, cream, and the serum from butter I have seen, however, many solid particles quite separate from the fat which stain differentially.

If Storch's view is correct, that the mucoid membrane loses water when heated, the mean density of the fat globules should increase on heating. I have found a mean percentage of fat in milk separated at 30° of 0.22, and in milk separated at 70° of 0.08, while Storch's theory would rather indicate the reverse. Further, milk heated to 70°, cooled immediately to 30°, and separated at once gives identically the same percentage of fat as that separated at 30°, and this is not in accord with Storch's theory. More "separator slime" should be removed at 70° than at 30°, and it should contain less water at the higher temperature. It actually contains rather more.

The fat globules of milk can be broken up by suitable means, and the mean diameter reduced below that of the smallest natural globule. In doing this the mucoid layer would be removed from at least the greater number, and, according to

Storch's theory, this milk (or cream) should churn very easily ; it is, however, nearly impossible to churn it.

According to my view, the amount of serum as condensed liquid layer should be very greatly increased in cream in which the fat globules are broken up, and owing to the greatly increased surface energy of the very small globules diffusion of the milk-sugar should be quite slow. If this view is true, estimations of milk-sugar made by adding the minimum amount of precipitant for the proteids should be higher than those made by diluting and precipitating the proteids. A cream containing 20·65 per cent. fat gave 3·69 per cent. of milk-sugar, with 1·3 c.c. acid mercuric nitrate added to 50 c.c., and only 3·45 per cent. when diluted with an equal bulk of water and precipitated with the same volume of acid mercuric nitrate. By thus exaggerating the effect of the condensed liquid layer definite evidence of its presence is obtained.

As all Storch's observations can be explained without the assumption of a mucoid membrane, as his experiments are not themselves wholly in accord with his view, and as other experiments are against it, the theory of the mucoid membrane round the fat globules must be considered as disproved.

DISCUSSION.

The PRESIDENT (Mr. Fairley) said that, as far as his own experience went in the West Riding of Yorkshire, he had found no such difference in the quality of the milk as Mr. Collins had suggested in his recent paper before the Society of Chemical Industry. At about the same time, Mr. Herbert Ingle, who was then a member of the staff of the Yorkshire College at Leeds, had also obtained at the Garforth Experimental Farm some results of a similar character, which, however, he (the President) could not help thinking were rather exceptional. The question of the interval between the morning and evening milkings was a somewhat complicated one. The cow was often treated as though it were merely a milk-making machine, but the primary purpose of the milk was to feed the young animals, and when the intervals at which the milk was drawn off were lengthened as compared with the natural intervals, it seemed obvious that irregularities in the quality of the milk must result. Conditions of temperature and exposure, as was shown in the course of the evidence before the Butter Regulations Committee, had a great deal to do with the quality of the butter and milk produced, and this would also be influenced by the time and mode of feeding, time of lactation, and possibly other factors that were not yet known. In connection with the question of the influence of geological conditions, he would like to ask whether the ash of these milks had been investigated, and whether there was any perceptible difference as regards ash in the milk produced on different formations.

Dr. VOELCKER said that it was satisfactory to those who, whether on the Milk Standards Committee or otherwise, had advocated the maintenance of a high standard with regard to milk, to find that their views were so fully borne out by these results of Mr. Richmond's. It would, however, be of particular interest to know what had been the effect of such an exceptional season as that of 1903 on the composition of milk. The season had been one in which grass had been very plentiful, but more or less watery in nature, and roots also had been exceptional in their

composition. Nevertheless, the average figures of Mr. Richmond were practically the same as in the preceding year. One would also like to know whether the figures that Mr. Richmond obtained in the different periods of the year showed any marked differences as compared with the corresponding periods of previous years. He was afraid he could not quite follow Mr. Richmond in the conclusions he drew with regard to the influence of geological surroundings. As a matter of fact, the greensand was quite different in character from the chalk, for, as he knew from his own farm, the greensand contained very little lime indeed. At all events, if he were a dairy farmer, he would much rather have a farm on the new red sandstone than one on the upper greensand or on the chalk. The real point was the nature of the herbage grown, and it was well known that neither the greensand nor the chalk gave good pasture land, or land very suitable for dairy farming generally. Although it might be granted that individual samples, or even a series of samples, might give actually a higher percentage of fat, yet such small differences as were here shown sank into insignificance beside the difference in the general yield of milk that would be produced on farms situated on one or other of these formations. He had read Mr. Collins's paper, but was not altogether inclined to agree even with its general conclusions, for in the milk of individual cows such wide variations occurred that it was really not safe to draw any general conclusions therefrom.

Mr. L. MYDDELTON NASH inquired what was meant by the expression *degrees of acidity*.

The PRESIDENT asked whether Mr. Richmond had noticed any constant difference in the milk obtained from different parts of the country.

Mr. RICHMOND, in reply, said that, with reference to the President's last question, these figures seemed to show that there was a difference. A large portion of the milk came from the district comprising the middle of Berkshire and a large portion of Wiltshire, which was mainly on the chalk and upper greensand, and these two formations practically represented one district. Further north the new red sandstone extended over a large portion of the North-West of England, including Cheshire, whence some portion of the milk was drawn. Speaking of Wiltshire reminded him, however, of the famous Stratton herd, the influence of which would probably be felt over a considerable part of that district, and would have something to do with the milk from there being of better quality. It was quite true that the cow was often regarded merely as a milk-making machine. Artificial selection had much influence on milk production, and probably as time went on its effect would be actually to convert the cow into a milk-producing machine of a more and more perfect kind. An interesting point in connection with the effect of temperature was that a sudden cold day after a series of warm ones was almost invariably accompanied by a decrease in the quantity of milk yielded; but, at the same time, the milk contained a higher proportion of fat than usual. The converse also was to some extent true. That seemed to show that the total quantity of fat produced was more constant than the total quantity of milk. He had not, he was sorry to say, the proportions of ash in the samples, as this determination was not made in the majority of cases; and when it was made, the samples were often mixtures of various milks. With regard to the effect of season, he did not think he had ever noticed two years in which the results

corresponded more closely than in 1902 and 1903. Almost in every month the composition of the milk had been the same each year, until December was reached, when in 1903 there was a distinct falling off in the percentage of fat as compared with 1902, and his impression was that this falling off was likely to continue, because in January of the present year there was also a decrease amounting to nearly 0.1 per cent. By "degrees of acidity" was meant the quantity of acid in 1 litre of milk neutralized by 1 c.c. of normal alkali, or, if decinormal alkali was used, the quantity in 100 c.c. of milk.

A "BEER-BEATER" FOR USE IN ORIGINAL GRAVITY DETERMINATIONS.

By JOHN S. FORD, F.R.S.E.

IN the determination of the specific, or original, gravity of beer, it is necessary to expel the dissolved carbonic acid gas; this is usually done by shaking violently, or

ONE-FIFTH NATURAL SIZE.

by pouring the liquid from one vessel to another. Where many samples have to be examined, such procedure is somewhat tedious and inefficient. The writer has for some time used the form of electrically-driven beater shown in the accompanying

figure. It is hardly necessary to give any description of the construction, as the illustration sufficiently explains itself. The blades of the propeller have no twist, and thus simply tend to swirl the beer round; this motion is opposed by the flat framework, the result being that the beer is thoroughly beaten, or churned, with liberation of the excess of the dissolved gas.