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THE TREATMENT AND DISPOSAL OF WASTE WATERS FROM DAIRIES AND MILK PRODUCTS FACTORIES

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WATER POLLUTION RESEARCH

TECHNICAL PAPER NO. 8

THE TREATMENT AND DISPOSAL OF WASTE WATERS FROM DAIRIES AND MILK PRODUCTS FACTORIES

LONDON
HIS MAJESTY'S STATIONERY OFFICE
1941

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PREFACE

WITHIN the last ten years the need for the development and application of suitable methods of dealing with the waste waters from dairies and from the manufacture of various products from milk has become particularly urgent with the expansion of the industry and the establishment of large central depots and factories, each receiving the milk from many farms.

Six or seven years ago the Water Pollution Research Board initiated an intensive investigation of the problems involved. In the first place, depots and factories were visited in this country and abroad, and experiments were carried out in the laboratories of the Rothamsted Experimental Station and of the Birmingham Tame and Rea District Drainage Board, with the object of selecting promising methods of solving the problems.

It was soon found that, by simple modifications in the operations in the depots and factories and by greater attention to detail, the quantities of milk and of the products and by-products carried away in the waste waters could in many cases be greatly reduced. Modifications of this kind not only bring about direct savings by increasing the quantity of milk and products available for sale, but they reduce the size and cost of construction and operation of the plant required for treating the waste waters necessarily discharged. It was also concluded from the preliminary work that it would probably be practicable to purify the waste waters by processes similar in general principle to those in use at sewage disposal works, but operated under conditions different from those ordinarily employed in the treatment of domestic sewage.

The next step was to extend the investigation to include experiments on a large scale at a factory, with the objects of testing the methods of purification selected and of obtaining the data necessary to ensure that the plant required could be designed, constructed, and operated at the minimum cost consistent with efficiency. Experimental plants for the work on a large scale were installed at a depot and cheese factory at Ellesmere, Shropshire, where facilities were provided through the kindness of United Dairies Limited. These plants were designed by Mr. H. C. Whitehead, M.Inst.C.E., a member of the Water Pollution Research Board and Engineer to the Birmingham Tame and Rea District Drainage Board. During the construction of the plants and at other times, assistance was also given by Mr. G. A. Hill, Assistant Engineer to the Drainage Board, and other members of Mr. Whitehead's staff.

The experiments made and the results obtained, with the conclusions and recommendations derived from them, are described in this Report. It has been shown that the waste waters necessarily discharged from milk collecting and distributing depots, and from the manufacture of cheese, butter, and other products from milk, can be satisfactorily purified by a new method of treatment in two percolating filters in series with periodic change in the order of the two filters. By this method final effluents of high quality are obtained.

The late Mr. E. H. Richards, B.Sc., F.I.C., who was Head of the Fermentation Department of Rothamsted, was in charge of the chemical section of the investigation at Rothamsted and Ellesmere, assisted by Dr. S. H. Jenkins, M.Sc.Tech., F.I.C., Mr. N. W. Barritt, M.A., and Dr. R. Wilkinson; Dr. Jenkins was in immediate charge of the experiments on a large scale at the factory. The biological section of the work was under the immediate supervision of the late Mr. D. Ward Cutler, M.A., Head of the General Microbiology Department of Rothamsted, assisted by Miss L. M. Crump, M.Sc., Dr. C. B. Taylor, Mr. T. G. Tomlinson, M.Sc., Dr. J. Meiklejohn, and Miss A. Dixon, M.Sc.

The experiments in the laboratories of the Birmingham Tame and Rea District Drainage Board were made by the late Mr. F. R. O'Shaughnessy, F.I.C., Chief Chemist to the Drainage Board, whose experimental work and advice were of great value. Some of the fungi collected during the biological work were identified by Dr. G. R. Bisby of the Imperial Mycological Institute, Kew, and by the Centraalbureau voor Schimmelcultures, Baarn, Holland. Mr. C. H. Roberts, B.A., of the Fisheries Research Staff of the Ministry of Agriculture and Fisheries, assisted in the tests on the effects of the treated effluents on fish.

In addition to the acknowledgments already made, the Department wishes to express appreciation of the assistance provided throughout the investigation by the Directors and Staff of United Dairies Limited, particularly Mr. Ben Davies, Mr. L. Maggs, Mr. E. A. Evans, Mr. R. W. Edwards, Mr. E. B. Anderson, M.Sc., F.I.C., Mr. H. A. Walley, and Mr. G. Stokes. It is also desired to acknowledge the courtesy and assistance of the management and staff of the various depots and factories, both at home and abroad, which were visited.

Representatives of many dairies and factories confronted with difficulties of disposal of waste waters visited the experimental plants and were assisted in other ways in selecting practicable methods of dealing with their particular problems. Plants designed on the basis of the information obtained during the investigation have already been installed and are in satisfactory operation for the treatment of the waste waters from a number of dairies and factories.

Through the Milk Marketing Board and the Scottish Milk Marketing Board, the investigation was undertaken with the co-operation of the milk industry, which made a total contribution of approximately £12,000 towards the cost.

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WATER POLLUTION RESEARCH LABORATORY,
Langley Road,
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September 1941.

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THE TREATMENT AND DISPOSAL OF WASTE WATERS FROM DAIRIES AND MILK PRODUCTS FACTORIES

CHAPTER I. INTRODUCTION

DURING recent years many rivers and streams in this country and abroad have been polluted by discharges of waste waters from dairies and from factories making cheese, butter, condensed milk, and other products from milk. There have also been difficulties at sewage disposal works as the result of discharges of relatively large volumes of the waste waters into the public sewers.

Although the distribution of milk and its use in manufacturing processes are old-established industries, it is only comparatively recently that the problem of disposal of the waste waters has become serious. This is mainly due to changes which have occurred in the methods of distribution and use of milk in manufacturing processes. It is estimated by the Ministry of Agriculture and Fisheries[1]* that, in the year ended 31st May 1928, the volume of milk produced in England and Wales, excluding that fed to stock, was approximately 1,217 million gallons. In 1931-32 the volume was approximately 1,250 million gallons, an increase of about 3 per cent, and in 1936-37 the volume was 1,314 million gallons, an increase of approximately 8 per cent since 1928.

Distribution of milk from large central depots and the manufacture of milk products in large factories are comparatively recent developments in this country. Formerly a large proportion of the milk produced was distributed by the farmer direct to consumers or was sent to distributors, each of whom dealt with a comparatively small volume. A large proportion of the butter and cheese manufactured was made on the farms where the milk was produced. Before 1914 few factories handled more than 5,000 gallons of milk daily. In recent years, however, much larger distributing depots and factories have been erected; some of these now handle as much as 50,000 gallons of milk daily. Many of the depots and factories are situated in rural districts and the waste waters are often discharged into small streams, some of which have in consequence become badly polluted.

The waste waters from the milk industry consist, in general, of water containing milk and whey, buttermilk, and other substances derived from milk. These effluents do not usually contain directly toxic substances. They undergo rapid decomposition, however, as the result of chemical and biochemical changes. When discharged into a river or stream the organic matter they contain is oxidized at the expense of the dissolved oxygen in the water. As the concentration of dissolved oxygen in the water is thus reduced, some oxygen is taken up from the air, but unless the stream is large in comparison with the amount of organic matter, the concentration of dissolved oxygen in the water falls considerably below the saturation value. In a badly polluted stream the concentration of dissolved oxygen may be reduced to a value at which fish and other aquatic organisms characteristic of a healthy river can no longer exist. In addition, the high concentration of organic matter leads

* Numbers refer to the References at end of each chapter.

to the growth of masses of greyish "sewage fungus" which cover the bed and sides of the stream and prevent the growth of the animals and plants which serve as food for fish. Serious nuisance may be caused when the masses of "sewage fungus" die and undergo putrefactive fermentation.

The effect on streams of waste waters from the milk industry is particularly serious because the volume of milk handled and the total quantity of organic matter in the waste waters discharged are much greater in the spring and summer than at other times of the year. Large quantities of organic matter are therefore discharged to streams at times when the volume of water available for dilution may be low and when decomposition of organic matter proceeds rapidly owing to the high temperature of the water.

The fluctuation which occurs in the rate of production of milk throughout the year is due to the fact that a large proportion of the milk produced in this country is from grassland farms where a policy of spring calving is adopted. The rate of production of milk is highest in the spring and summer months when there is a plentiful supply of grass. The demand for liquid milk is fairly constant throughout the year, and in consequence milk products such as cheese, butter, and dried milk are manufactured mainly in the spring and summer when the whole supply of milk cannot be sold in the liquid form. Some dairies and milk products factories close down during the winter months.

Figures supplied by the Milk Marketing Board show that the total volume of milk sold under contract in England and Wales during the 12 months October 1935 to September 1936 was about 900 million gallons, of which 557 million gallons, or 62 per cent, were sold as liquid milk and 343 million gallons, or 38 per cent, were used for the manufacture of milk products.

Several methods of treatment and disposal of dairy waste waters have been used on a large scale both in this country and abroad. The methods tried include irrigation on land, sedimentation in tanks, addition of chemical coagulants, fermentation in septic tanks, treatment in contact beds or in percolating filters, and treatment by the activated sludge process. In general, the effluents produced have not been of very good quality, and in many cases have not been suitable for discharge into rivers and streams in this country.

During the course of the present investigation several milk depots and factories in this country and abroad were visited with the object of studying the methods in use for the treatment of the waste waters.

At one depot and cheese factory the washings from churns and other equipment were stored in a septic tank and the effluent from this tank was passed through a percolating filter, which was operated for 12 hours each day. Though the purification effected was about 90 per cent, the final effluent was unsatisfactory and was not suitable for discharge into a small stream.

At another depot and factory, where condensed milk was manufactured, the waste waters first entered a collecting tank; they were then treated by the activated sludge process. The effluent from this process entered a sedimentation tank and the settled liquid was afterwards passed through percolating filters at a rate of about 150 gallons per day per cubic yard of filtering medium. The plant was being operated for only 17 hours each day, and the liquid and sludge in the activated sludge tank were allowed to remain stagnant at a temperature of about 30° C. for 7 hours each day. The volume of sludge in the aeration tank, as measured by settlement in a glass cylinder for 30 minutes, was only about 1 per cent of the volume of liquid undergoing treatment. It was known that much more efficient purification could be achieved by employing about 10 per cent by volume of activated sludge in the aeration tank, but with this quantity of sludge and with intermittent operation of the plant unpleasant odours were emitted when the liquid and sludge were aerated after each period of stagnation. The degree of purification achieved in the plant as a whole appeared to be about 95 per cent; the final effluent, however, was not of good quality and was unsuitable for admission to a small stream.

At two condensed milk factories in France and Belgium, which were visited in 1935, the waste liquids were treated by the activated sludge process in plants in which aeration was achieved by the action of revolving brushes. According to this method of aeration[2], the mixture of waste liquid and sludge is stirred and aerated by cylindrical brushes revolving at a rate of 65 to 70 revolutions per minute. In the two installations visited, each brush was 10 to 12 ft. in length and about 2 ft. in diameter and the bristles dipped about 0·6 in. into the surface of the liquid. By the action of the brushes a part of the liquid was thrown up as a spray and sludge was maintained in suspension without any additional stirring. Under the conditions of operation of the installations at the time of the visits, treated effluents of excellent quality were being obtained; fish were living in the treated effluents.

As part of the programme of the Water Pollution Research Board, preliminary experiments were begun in 1933 in the laboratories of the Rothamsted Experimental Station. The work included both chemical and biological investigations and was directed mainly to a study of the treatment of milk washings and whey washings by biological filtration and by the activated sludge process. Observations were also made on the changes which occur in the composition of milk effluents during fermentation under anaerobic conditions. In addition, experiments on the treatment of milk effluents in percolating filters were made in the laboratories of the Birmingham Tame and Rea District Drainage Board by Mr. H. C. Whitehead (a member of the Water Pollution Research Board) and the late Mr. F. R. O'Shaughnessy.

In 1935 arrangements were made to extend the investigation to include experiments on a large scale. Through the Milk Marketing Board and the Scottish Milk Marketing Board the industry agreed to co-operate in the work and to contribute towards the cost. Two experimental plants, designed by Mr. H. C. Whitehead, were erected at a milk depot and cheese factory at Ellesmere in Shropshire, where the necessary facilities were provided by United Dairies Ltd. One plant included two percolating filters, each 25 ft. in diameter. Milk washings, whey washings, or mixtures of the two, after settlement, could be passed through the two filters, which could be operated either in parallel or in series with periodic change in the order of the filters. The other plant was designed for the treatment of milk effluents by the activated sludge process with aeration by bubbles of air passed through diffusers. The experiments on a large scale were begun in August 1935 and were continued until September 1938. At the same time, laboratory experiments were continued at Rothamsted. Laboratory experiments were also carried out at Ellesmere.

An account of the whole of the work of the investigation is given in the following chapters.

References

[1] Ministry of Agriculture and Fisheries. Agric. Statist., Lond., 1937, **72,** Part 1, 72. H.M. Stationery Office, London.

[2] Kessener, H., and Rudolfs, W. Activated Sludge for Dairy Waste. *Sewage Wks J.*, 1934, **6,** 318.

CHAPTER II. GENERAL CHARACTER AND QUANTITY OF WASTE WATERS FROM THE MILK INDUSTRY

Milk Collecting and Distributing Depots

AT collecting and distributing depots the milk is usually received in churns of 10 gallons capacity; after cooling it is generally despatched in bulk in railway or road tank wagons. At some depots milk may be pasteurized for local sale. As each churn arrives at the unloading platform at the depot the lid is removed and the milk is poured into a large trough or tank from which it is conveyed to a vat or tank in the depot. The churn and lid are then washed with cold and hot water to which soda and other detergents are usually added. In the larger depots, the churns and lids after draining are transferred to a moving conveyor and passed at a steady rate through a washing plant in which they are cleaned with water and with steam; the washed churns are returned to the farmer.

Before despatch in bulk from the depot the milk is either cooled to prevent deterioration during transport or is first pasteurized and then cooled. In the process of pasteurizing, the milk is maintained at a temperature of not less than 145° F. (62·8° C.) for not less than 30 minutes; it is then rapidly cooled. In the cooling plant the milk is brought into contact with tubes or plates which are cooled by means of brine from a refrigerating unit.

The waste waters from these processes of bulking and treatment of the milk before distribution consist mainly of water mixed with milk and sometimes contain soda and other detergents. Waste waters of this kind are referred to as "milk washings" in this report. The following are the main sources from which these waste waters are discharged:

1. Washings carrying milk spilt on to the floor during the emptying of churns into the collecting trough.
2. Milk drained and washed from churns and lids after removal from the drainage rack covering the milk collecting trough. Any milk adhering to the churns and lids, after their removal from the rack, drains from them while on the conveyor to the washing plant or is washed out with water and steam in the washing plant. In some plants the drainage from the conveyor is collected and may be utilized.
3. Washing water used to clean the churn-tipping and washing plant after use.
4. Washing water from the pasteurizing plant.
5. Washings from the cooling plant.
6. Miscellaneous floor washings.

The de-oxygenating effect of waste waters containing milk, milk products, and by-products on a river or stream may conveniently be assessed by a determination of their biochemical oxygen demand. In this determination the liquid to be tested is diluted with water containing oxygen in solution and the mixture is stored in completely full, stoppered bottles for 5 days at a temperature of 18° C. As the result of chemical and biochemical activity, the constituents of the liquid undergo oxidation, the extent of which is calculated from the weight of dissolved oxygen absorbed in 5 days from the diluting water. The processes of oxidation are similar to those which occur when the liquid is discharged to a stream, and a knowledge of the biochemical oxygen demand therefore enables an estimate to be made of the polluting character of the liquid.

The biochemical oxygen demand of whole milk was found to vary in different samples from 10,000 to 11,600 gm. of oxygen per 100,000 ml. of milk (parts per 100,000), the mean value being 10,950 parts per 100,000. Thus milk washings containing 1 per cent of whole milk would have a biochemical oxygen demand of approximately 110 parts per 100,000. The biochemical oxygen demand of domestic sewage of average strength is about 40 parts per 100,000, so that the effect on a stream of milk washings containing 1 per cent of whole milk would be nearly three times as great as that of an equal volume of crude domestic sewage.

In considering the problem of disposal of an industrial waste water, it is necessary to have full information not only on the average volume and strength of the waste water, but also on the extent to which the volume and strength may vary from time to time. Milk washings from a distributing depot are produced mainly at the time when milk is delivered to the depot, that is during daylight hours. The volume of washings at any time of the day depends mainly on the volume of water used for washing churns and other equipment. The strength and the acidity or alkalinity (*p*H value) of the washings also vary considerably during the day. Some figures for the biochemical oxygen demand and *p*H value of milk washings from one distributing depot on a typical day in July 1935 are shown in Table I.

TABLE I. *Biochemical Oxygen Demand and* pH *Value of Milk Washings from a Distributing Depot on* 17*th July* 1935*

Time (B.S.T.)	Flow	Biochemical oxygen demand (parts per 100,000)	*p*H value
9.45 a.m.	Rapid	60	>8·8
10·45 ,,	Very slight	110	7·3
11·45 ,,	Medium	147	6·9
2·00 p.m.	Rapid	38	6·5
3.00 ,,	Slight	73	6·6
4.00 ,,	Rapid	7·5	>8·8
5.00 ,,	Slight	30	—

The variation in *p*H value is due to the different amounts of soda used for cleaning purposes throughout the day. With so variable a flow during the day and little or no flow during the night, it is evident that a storage tank would be necessary to equalize the flow in any system involving continuous treatment of the liquid.

In most collecting and distributing depots the volume of milk washings on any day tends to be independent of the volume of milk handled, since the churn-washing equipment is often run continuously during the hours when churns are being received and is not stopped during stoppages of only short periods in delivery. Thus the volume of washings is not much less on days when churns are being received at intervals than on days when churns are received continuously. The volume of washings from a particular unit is determined largely by the length of the period between the delivery of the first churns in the morning and the cessation of delivery in the afternoon.

Since the volume of milk washings tends to be independent of the volume of milk handled, whereas the amount of milk lost tends to be roughly proportional to this volume, the concentration of milk in the washings increases with an increase in the volume of milk handled.

The minimum and maximum biochemical oxygen demand of milk washings

* The methods of chemical analysis are described in Appendix I.

from a distributing depot during each month between July 1935 and May 1937 are shown in Table II. In this table are also given the numbers of occasions on which the biochemical oxygen demand on any day was less than 75 per cent or was more than 125 per cent of the mean value for the month. The figures show that considerable variations in biochemical oxygen demand occur from day to day, the maximum daily value during the month frequently being more than three times as large as the minimum value. In designing a plant for continuous treatment of the waste waters, it is important that these varia-

TABLE II. *Biochemical Oxygen Demand of Milk Washings from a Milk Collecting and Distributing Depot*

July 1935 to May 1937

Month	Biochemical oxygen demand (parts per 100,000)		No. of days on which biochemical oxygen demand was determined	No. of days on which biochemical oxygen demand was less than 75 per cent of monthly mean	No. of days on which biochemical oxygen demand was more than 125 per cent of monthly mean
	Minimum	Maximum			
1935					
July ..	59	193	19	5	3
Aug. ..	44	149	19	4	4
Sept. ..	52	162	20	4	4
Oct. ..	50	119	23	3	3
Nov. ..	25	103	18	5	6
Dec. ..	34	130	18	4	4
1936					
Jan. ..	30	146	23	6	4
Feb. ..	66	110	18	2	0
Mar. ..	63	117	20	2	0
Apr. ..	78	186	18	3	5
May ..	70	231	20	4	3
June ..	37	112	20	3	4
July ..	22	87	23	2	6
Aug. ..	37	84	17	1	1
Sept. ..	33	123	16	5	2
Oct. ..	32	85	20	3	3
Nov. ..	14	61	18	8	7
Dec. ..	12	44	20	3	3
1937					
Jan. ..	12	34	21	8	4
Feb. ..	9	34	18	3	1
Mar. ..	35	69	24	8	9
Apr. ..	40	115	24	2	3
May ..	41	88	25	2	5

tions should be minimized as far as possible by careful control of the various operations in the depot or factory.

The average volume of milk carried away with the waste waters from milk distributing depots depends largely on the precautions taken to minimize loss, and differs considerably at different depots. Frequently the waste waters carry away 0·5 to 1·0 per cent of the volume of milk handled. Thus, the waste waters from a depot handling 10,000 gallons of milk per day may contain from 50 to 100 gallons of whole milk daily. When steps are taken to minimize loss, the proportion of milk carried away with the waste waters may be reduced to about 0·2 per cent of the volume handled.

It is not possible to give precise figures for the volume and strength of the waste waters discharged from milk collecting and distributing depots, in relation to the quantity of milk handled, as conditions vary so much from one depot to another. As a general indication, however, it may be taken that the volume of waste water is usually from 0·5 to 1·5 times the volume of milk handled. Assuming that the volume of waste water is the same as the volume of milk and that the waste water contains 0·5 per cent milk, it would have a biochemical oxygen demand of about 55 parts per 100,000.

The composition of cow's milk depends on a number of factors of which the breed of cow is the most important. An indication of the proportion of the more important constituents is given by the figures in Table III; from these figures the approximate concentration of the constituents in fresh milk washings containing a known quantity of milk can be estimated.

TABLE III. *Composition of Cow's Milk*

Constituent	Concentration (per cent)
Water	85–90
Protein	3·0–5·0
Fat	3·0–4·5
Lactose	3·5–5·5
Ash	0·6–0·8

BUTTER MAKING

Butter manufactured at factories is made from whole milk or from cream supplied by the farmer. When whole milk is used, it is separated in centrifugal machines into skimmed milk and cream. The cream, which contains nearly the whole of the fat of the milk, is allowed to " ripen " in vats at a controlled temperature. To assist in the formation of a uniform product, a so-called " starter ", which is a culture of certain selected bacteria, is added to the cream to cause the correct degree of ripening. The cream is then run into a wooden churn where it is agitated until the butter separates, leaving a liquid known as buttermilk. This liquid is run off from the butter, which is then washed with water. Waste waters from butter-making consist mainly of water used for washing the churn after removal of the buttermilk and water used for washing the butter. The chief constituent of these washings is buttermilk. Waste waters containing cream and skimmed milk are also produced from the washing of the centrifugal separators and other apparatus. There are usually, in addition, milk washings from the churns in which the milk is delivered to the factory.

Average values for the composition of buttermilk are given in Table IV. The liquid has a composition similar to that of milk except that the fat content is very much lower.

TABLE IV. *Composition of Buttermilk from Fresh Cream* (*Richmond*[1])

Constituent	Concentration (per cent)
Water	90·98
Protein	3·51
Fat	0·35
Lactose	4·42
Lactic acid	0·01
Ash	0·73

At an average butter factory the volume of waste water is probably 1·0 to 2·0 times the volume of milk used for the separation of cream, and the average biochemical oxygen demand may be from 150 to 300 parts per 100,000, provided that buttermilk is utilized and not run into the waste waters. Buttermilk has a biochemical oxygen demand of between 2,000 and 3,000 parts per 100,000.

Cheese Making

Cheese consists mainly of coagulated casein, fat, and water. It is manufactured from whole milk or from partially skimmed milk or from milk enriched by the addition of cream. The milk is transferred to large cheese vats and is brought to the required temperature. A culture of bacteria (the " starter ") and a quantity of the ferment " rennet " are then added in turn to induce the formation of lactic acid and thus to cause the separation of curd from the liquid whey. When the proper degree of coagulation has been reached, the curd is cut into pieces, the contents of the vat are heated to the required temperature, the curd is allowed to settle, and the whey is run off. The curd is then removed and subjected to further treatment, the nature of which depends on the type of cheese made; with the ordinary types of hard English cheese the curd is ground, salted, pressed, and ripened.

Waste waters from the cheese-making process consist mainly of washings from the vats, after the whey has been run off, and drainings and washings from floors, presses, and other equipment. The washings are usually hot when discharged, and the main impurity they contain is whey. In this report they are referred to as " whey washings ". In addition to whey washings from the cheese-making process, other effluents may be discharged from a cheese factory, depending on the use which is made of the whey produced as a by-product. There are also milk washings from the milk churns and from the unloading and bulking plant.

The biochemical oxygen demand of different samples of whey was found to vary from 3,800 to 4,600 parts per 100,000, the mean value from 13 samples being 4,180 parts per 100,000. Whey washings containing 1 per cent of whey will thus have a biochemical oxygen demand of about 42 parts per 100,000, and will have an effect on a stream similar to that of domestic sewage of average strength; whey washings often contain several per cent of whey. If the volume of the waste water is 1 to 2 times the volume of milk handled, the average value of the biochemical oxygen demand of the waste waters would usually be from 150 to 300 parts per 100,000, provided that the whey is utilized and not discharged with the waste washing waters.

The composition of whey varies considerably and depends on the composition of the original milk, the process of cheese making used, and the skill of the cheese-maker. The composition of whey from the manufacture of Cheddar cheese is given in Table V.

Table V. *Composition of Whey from the Manufacture of Cheddar Cheese* (*Berry*[2])

Constituent	Concentration (per cent)
Water	92·87 to 93·43
Solids	6·57 to 7·13
Protein	0·82 to 0·95
Fat	0·12 to 0·36
Lactose	4·62 to 5·01
Acid as lactic acid	0·144 to 0·236
Ash	0·366 to 0·649

Compared with milk, whey is deficient in nitrogenous constituents. On storage it rapidly becomes acid owing to the decomposition of lactose and the formation of organic acids, including lactic acid.

Manufacture of Other Products

The chief by-product from the production of liquid cream is skimmed milk; from the manufacture of butter the main by-products are skimmed milk and buttermilk; and from the manufacture of cheese the main by-product is whey.

When butter and cheese were made mainly on the farms where the milk was produced, the farmer usually disposed of skimmed milk, buttermilk, and whey by feeding them to livestock. Now that butter and cheese are manufactured in large factories the by-products are often concentrated by evaporation or are dried to a powder before sale as foodstuffs or for other purposes. Some of the skimmed milk, buttermilk, and whey is, however, returned to farmers for use in liquid form as a food for animals. Some factories have their own piggeries which receive whey.

In the manufacture of concentrated or dried milk or milk products, the liquid is first concentrated by evaporation under reduced pressure. Milk is usually condensed in single-effect evaporators and whey in double-effect evaporators. A double-effect evaporator consists of two units, or "effects", in the first of which the liquid is heated by steam. The second effect is heated by vapour from the first effect. A partial vacuum is maintained throughout the apparatus, the pressure decreasing from the first effect to the second. Partly concentrated product flows at intervals or continuously from the first effect to the second. The steam used for heating the first effect condenses and is discharged to waste. In some plants, part of the vapour given off by the liquid heated in the first effect is pumped back and mixed with the steam. The condensed steam may then contain organic matter carried over with the vapour. In the first type of plant the whole of the vapour evaporated from the liquid in the first effect, and in the second type of plant the greater part of this vapour, passes to the second effect, where in heating the partly concentrated liquid it is condensed and discharged to waste. The vapour given off from the second effect is condensed in a condenser in which a partial vacuum is maintained. The condenser is cooled by the circulation of water. In a double-effect evaporator, in addition to water used in washing the plant, waste liquid is discharged from four points:

1. Condensed steam from the first effect; this may be wholly uncontaminated or may be contaminated with vapour from the liquid treated.
2. Vapour evaporated from the liquid in the first effect and condensed in the second.
3. Vapour evaporated from the partially concentrated liquid in the second effect and condensed in the condenser.
4. Condenser cooling water; when indirect cooling is used, this water is uncontaminated.

Of these effluents, the volume of Nos. 2 and 3 together is approximately equal to the volume of water evaporated from the liquid treated. In a plant used for the concentration of whey, the volume of condensate is usually from 70 to 80 per cent of the initial volume of whey.

TABLE VI. *Biochemical Oxygen Demand of Condensed Steam and Vapour after Use for Heating the First Effect of a Double-Effect Evaporator Treating Whey*

Biochemical oxygen demand (parts per 100,000)	No. of samples
0 to 5	10
5 to 10	12
10 to 15	12
15 to 25	11
25 to 40	6
over 40	8

In Table VI are shown the biochemical oxygen demands of a number of samples of condensed steam and vapour after heating the first effect of a double-effect evaporator treating whey. In this plant, in order to economize steam, a vapour decompressor (" booster ") was used to pump back part of the vapour from the whey in the first effect to mix with the steam used to heat this effect. The condensed steam was consequently contaminated with some organic matter. The biochemical oxygen demand of the condensed steam is too high to allow it to be discharged to a stream without some form of treatment.

Condensed vapour evaporated from whey in a double-effect evaporator contains much more organic matter than the condensed steam used to heat the first effect. The biochemical oxygen demands of some samples of mixed condensate from the first and second effects of a double-effect evaporator used for concentration of whey are shown in Table VII.

TABLE VII. *Biochemical Oxygen Demand of Mixed Condensed Vapour from First and Second Effects of a Double-Effect Evaporator Treating Whey*

Date	Biochemical oxygen demand of condensate (parts per 100,000)
Feb. 15, 1938	165
,, 16 ,,	200
,, 17 ,,	250
,, 18 ,,	405
,, 22 ,,	255
,, 24 ,,	520
,, 27 ,,	365
Mar. 7 ,,	185
,, 8 ,,	165
,, 9 ,,	260
,, 10 ,,	340
,, 11 ,,	215
,, 12 ,,	125
,, 14 ,,	160
,, 15 ,,	295

Taking the biochemical oxygen demand of whole whey as 4,200 parts per 100,000, the condensate contained organic matter equivalent to between 3 per cent and 10 per cent of whole whey. Since more than 90 per cent of the water initially present in the whey is evaporated in the plant and is discharged as condensate, the amount of organic matter carried away with the condensate may be very high. Two sources of loss are entrainment of liquid particles with the vapour and removal of volatile organic products, particularly from stale whey. Apart from normal losses, accidental boiling over of whey sometimes occurs, and large quantities of organic matter are then discharged with the waste waters.

Concentrated milk and milk products are sometimes evaporated to dryness either by passing the material over heated rollers or by spraying it into a chamber supplied with heated air. Dried milk, skimmed milk, buttermilk, and whey, prepared in this manner, are used as foodstuffs.

REFERENCES

[1] RICHMOND, H. D. " Dairy Chemistry ". Charles Griffin & Co., 1920; cited by ROGERS, L. A. " Fundamentals of Dairy Science ", 2nd Edition, p. 17. Reinhold Publishing Corporation, New York, 1935.

[2] BERRY, R. A. *J. agric. Sci.*, 1923, **13**, 218; cited as in Ref. 1, p. 42.

CHAPTER III. METHODS OF REDUCING THE QUANTITY OF MILK AND OF MILK PRODUCTS AND BY-PRODUCTS CARRIED AWAY IN WASTE WATERS

IN attempting to solve any problem of treatment and disposal of industrial effluents, the first step should always be to consider the practicability, taking costs into account, of modifying the manufacturing processes so as to reduce the quantity or the polluting character of the waste waters discharged. Only when all practicable measures have been taken to reduce the quantity of polluting matter leaving the factory should methods of purification of the effluents be considered. Frequently polluting industrial effluents contain valuable raw material, saleable products, or material from which valuable by-products can be recovered.

In attempting to reduce the quantity of polluting matter in waste waters from the milk industry, the first essential is that in no circumstances should whole whey and buttermilk be discharged with the waste waters. These by-products have in the past been regarded as waste materials at some factories and have been discharged into streams, where they have caused serious pollution. Whey, for example, has a biochemical oxygen demand of over 4,000 parts per 100,000 and is at least 100 times as strong in polluting character as an equal volume of crude domestic sewage. Thus, if the whole of the whey from a cheese factory handling 10,000 gallons of milk per day were discharged into a stream, its polluting effect would be about the same as that of the crude domestic sewage from a town with a population of 40,000 to 50,000 people.

Whey and buttermilk should be treated as valuable by-products and not as waste materials. They have high food values and can be utilized as food or in the preparation of foods. There is a market for dried whey and buttermilk and there are indications that the market can be further developed.

In the early stages of this investigation it was concluded that the quantities of polluting matter carried away in the waste waters from the various branches of the milk industry could be considerably reduced by simple and relatively inexpensive modifications at the depots and factories to reduce losses of milk and of milk products and by-products.

At most milk distributing depots a considerable proportion of the total loss of milk is due to inadequate drainage of churns after they have been emptied into the collecting trough. In some experiments, full 10-gallon churns were emptied and allowed to drain for different periods, after which the milk which could be removed by further drainage was collected and measured. The results in Table VIII were obtained.

TABLE VIII. *Volume of Milk Remaining in 10-Gallon Churns, after Drainage for Different Periods, and Capable of Removal by Further Drainage*

Period of drainage (sec.)	Volume of milk removed by further drainage (ml.)
3	69
10	40
20	30
30	25
60	15
90	8

In some further experiments, full 10-gallon churns were emptied and were drained for different periods. Each churn was then washed out with 5 litres of water and the weight of oxygen consumed from boiling acid potassium permanganate in 3 minutes by a sample of the water was determined. From this value and from the weight of oxygen consumed by water containing a known concentration of milk, the volume of whole milk remaining in the churns after drainage was calculated (Table IX).

TABLE IX. *Volume of Milk Remaining in 10-Gallon Churns after Drainage for Different Periods, and Removed by Washing with Water*

Period of drainage (sec.)	Volume of milk remaining in churns (ml.)	(as percentage of 10 gal.)
10	91	0·20
20	64	0·14
30	59	0·13
60	41	0·09
90	27	0·06
120	32	0·07
180	27	0·06
300	18	0·04

Soon after the present investigation was begun it was recommended that, at milk collecting and distributing depots where drainage of the churns was inadequate, additional drainage space should be provided, so as to reduce the volume of milk lost with the washings, and other precautions should be taken to ensure that the churns were properly emptied. As an example of the economies which can be achieved by this means, figures are given in Table X showing the percentage of milk in the milk washings from one depot at different times from August 1935 to February 1937. The saving of milk effected during this period was due to the provision of additional drainage space for the churns and to other similar improvements.

TABLE X. *Volume of Milk Handled and Loss of Milk in Washings at a Distributing Depot*

Month	Average volume of milk received daily during month (gal.)	Average biochemical oxygen demand of milk washings (parts per 100,000)	Estimated concentration of whole milk in effluent (per cent)	Estimated average daily loss of milk in washings (gal.)	Milk lost in washings as percentage of milk handled
August 1935	20,000	91	0·8	180	0·9
February 1936	12,000	89	0·8	120	1·0
August 1936	24,000	62	0·6	80	0·3
February 1937	15,000	22	0·2	30	0·2

By installing a drainage rack of correct design with a milk-collecting channel beneath and allowing the churns to remain in an inverted position on the rack for between 1 and 2 minutes, the quantity of milk carried away in the water used for washing the churns can be reduced from more than 0·5 per cent to less than 0·25 per cent of the volume of milk handled. It is, of course, essential that the churns should be of such a design that, in wet weather, dirty water could not run down the outside of the churns into the milk-collecting channel.

The economies which could be effected by arranging for adequate drainage represent a saving of at least 10,000 gallons of milk, or £500 per annum with milk at 1s. per gallon, for a depot receiving an average quantity of 10,000 gallons of milk per day. If adequate drainage trays were installed at all the depots and factories in this country the total saving of milk would be of the order of 3,000,000 gallons per year, or £150,000 per year with milk at an average wholesale price for all purposes of 1s. per gallon.

An investigation has been made by United Dairies Ltd. of the volumes of milk lost in the waste waters from different sources at a milk distributing depot at which the total loss had been reduced to the unusually low figure of less than 0·2 per cent of the volume of milk handled. At the time when the investigation was made, the depot was receiving 2,000 churns daily, containing about 17,000 gallons of milk. The results are shown in Table XI. From these figures it can be seen that of the total daily loss of 28 gallons of milk, 2·5 gallons, or 9 per cent, could be avoided if splashing from the churns during tipping were prevented. The greatest loss from any single source was still from the drainage of the churns after they had been emptied and allowed to stand for an average period of 1 minute on the drainage rack.

TABLE XI. *Losses of Milk from Different Sources at a Milk Distributing Depot Receiving about* 17,000 *Gallons of Milk Daily*

Source	Loss of milk daily (gal.)	Percentage of total loss
1. Spilt during emptying of churns	2·5	9
2. Drained from churns after drainage for usual period (1 min.) on draining rack	10·0	36
3. Remaining in churns after draining for 11 min. but removed during washing	4·5	16
4. Remaining on lids after drainage for 1 min.	3·5	12
5. Washings from tipping and washing plant after use ..	1·5	5
6. Losses from pasteurizing plant	2·0	7
7. Losses from bulking and cooling plant	3·0	11
8. Washings from laboratory, floors, etc.	1·0	4
Total	28·0	100

It has been observed that, under the ordinary conditions of operation at a milk distributing depot, even where a drainage rack is provided, the period allowed for draining differs considerably from one churn to another. This is because no arrangements are usually made to ensure that the churns are placed on the rack and removed from it in the same order. As an example, the figures in Table XII are given to show the observed periods of drainage of 26 churns at one depot.

TABLE XII. *Period of Drainage of Churns at a Milk Distributing Depot*

Period of drainage (sec.)	Number of churns
25–30	7
31–40	4
41–50	6
51–60	5
61–70	1
71–80	0
81–90	2
120	1

These observations were made at a time when the depot was not working at full capacity. At rush periods the difference in the period of drainage allowed for different churns might be expected to be even greater. As a first step in reducing the quantity of milk lost it is clearly of importance that churns should be removed from the drainage rack in the same order as that in which they are placed on it, so as to provide approximately the same period of drainage for each churn.

The figures given in Table XI show that if loss of milk from splashing were entirely avoided, and if the period of drainage of churns were increased to the optimum value, there would remain a loss of about 15·5 gallons of milk per day from the depot investigated, when 17,000 gallons of milk were being received daily. This loss is equivalent to about 0·09 per cent of the milk handled, and probably represents the minimum loss which could be attained under the most efficient conditions of working.

Substantial reductions can usually be made in the volume and polluting character of waste waters discharged from cheese factories. It is important that cheese vats should not be filled too full and should not be stirred so vigorously that liquid is splashed on to the floor. After the removal of whey from the vats, they should first be washed with small quantities of water which should then be added to the whole whey. Subsequent washings with larger quantities of water would then contain much less polluting matter.

Large quantities of whey frequently enter the waste waters when cheese vats are emptied, since the usual type of drain-cock for emptying the vats allows liquid to be splashed over the floor of the cheese room, from which it is subsequently removed with the floor washings. This wastage can be avoided by using a more efficient type of drain-cock, and in some factories removable guards or shields placed round the cocks to prevent splashing have reduced the loss. A considerable amount of whey is often lost from the cheese presses. This loss can be prevented by the installation of collecting tanks at the outlet of the presses.

In butter factories losses of buttermilk can be reduced by first washing out the butter churns with a small quantity of water. These washings can be added to the whole buttermilk, which is evaporated to dryness or used for feeding livestock.

In most milk depots and milk products factories, the total loss of milk and of products and by-products is made up of a number of relatively small losses from the different parts of the plant. These losses can usually be reduced by simple modifications in the design and by constant attention in the operation of the plant. By this means not only can direct savings be made in the depot or factory, but the size and cost of construction and operation of the plant required for the treatment of the waste waters can be greatly reduced.

CHAPTER IV. LABORATORY EXPERIMENTS ON METHODS OF TREATMENT OF WASTE WATERS

Treatment by Fermentation

WASTE waters from dairies and from factories manufacturing milk products are discharged almost entirely during the daytime. In any system of continuous treatment of the waste waters it will therefore usually be necessary to store part of the liquid for a period of at least 12 hours, in order to get greater uniformity in the flow to the treatment plant. During this period of storage some anaerobic fermentation occurs. It is known that at ordinary temperatures the following changes take place in unsterilized whole milk during storage for several days:—

1. Separation of fat as cream.
2. Acid fermentation of lactose.
3. Coagulation of casein.
4. Subsequent proteolysis of casein.

Storage of waste waters containing milk or milk products under anaerobic conditions for periods of several days has been recommended by some authors, either as a complete treatment or as a preliminary process before further treatment of the waste waters by other methods. Anaerobic fermentation is allowed to take place in tanks from which deposited sludge is removed periodically. Various periods of detention from 1 day to 7 days have been advocated. There is no general agreement, however, on the advisability of subjecting waste waters from the milk industry to anaerobic fermentation before treatment by aerobic processes. Some authors have expressed the opinion that anaerobic fermentation renders the liquids more difficult to purify by aerobic processes.

(*i*) *Milk Washings*

In the first experiments which were carried out as part of the investigation described in this report, mixtures of 1·3 per cent of milk with tap water were allowed to ferment in an open glass tank; samples of the liquid, separated from deposited solid matter, were taken daily for analysis during a period of one week. The effects of fermentation on the *p*H value, bacterial count, and biochemical oxygen demand are illustrated by the typical results given in Table XIII. The biochemical oxygen demand of the liquid fell rapidly during the first day of storage owing to the separation of fat and casein. In this experiment the minimum biochemical oxygen demand was obtained after 2 days.

TABLE XIII. *Fermentation, in an Open Tank, of 1·3 per Cent of Milk in Water*

Results of examination of liquid after sedimentation

Period of fermentation (days)	*p*H value	Bacterial count (millions per ml.)	Biochemical oxygen demand (parts per 100,000)
0	7·2	800	140
1	5·6	400	60
2	5·5	280	50
3	5·9	450	65
4	6·2	800	70
5	6·5	950	75
6	6·9	1,200	75

In a further series of experiments fermentation was also allowed to take place in an open glass tank with a capacity of 15 litres. Twelve litres of the mixture were used in each experiment. Samples of liquid, separated from deposited solids, were taken for analysis daily and, at various intervals, 10 litres of the liquid were withdrawn and replaced by fresh mixture. Typical results are shown in Table XIV.

In these experiments the biochemical oxygen demand of the supernatant liquid fell rapidly during the first 1 or 2 days of storage and usually continued to fall more slowly during periods up to 40 days, the longest period tried. The initial large fall in the biochemical oxygen demand was probably due to the separation of fat and casein from the liquid. The iso-electric point of casein corresponds with a *p*H value of about 4·6, at which point fairly rapid precipitation of casein occurs. Thus, when lactic acid was added to a mixture of 1 per cent of milk in distilled water to give a *p*H value of 4·6, the concentration of soluble nitrogen in the liquid fell in 2 hours from 5·9 parts to 2·5 parts per 100,000. When a mixture of 1 per cent of milk in distilled water was allowed to ferment, the *p*H value after 10 days was 4·2 and the concentration of soluble nitrogen had fallen from 5·9 to 2·5 parts per 100,000; under these conditions the casein was precipitated. In a mixture of 1 per cent of milk in Harpenden tap water, however, sufficient buffering substances were present to counteract

TABLE XIV. *Fermentation, in an Open Tank, of a Mixture of Milk with Water*

Results of examination of liquid after sedimentation

No. of additions of fresh mixture	Duration of storage (days)	*p*H value	Bacterial count (millions per ml.)	Biochemical oxygen demand (parts per 100,000)
1	0	7·0	—	120
	1	7·0	160	75
	2	5·9	284	68
	3	5·5	220	38
	4	6·2	350	32
	5	7·0	600	30
	6	7·5	1,060	24
	7	7·5	980	18
3	1	7·1	300	140
	2	5·6	350	56
	3	5·5	260	46
	4	5·7	450	40
	5	6·0	670	30
	6	6·3	810	27
	7	6·3	950	25
	40	7·2	400	6
7	1	7·2	1,020	132
	3	5·7	400	64
	5	5·9	530	54
	6	6·8	980	66
	30	7·1	1,200	30

to some extent the lowering of the *p*H value by the fermentation of lactose to lactic acid; less precipitation of casein therefore occurred. After storage of this mixture for 10 days the *p*H value of the liquid was 5·8 and proteolysis of casein was proceeding; the concentration of soluble nitrogen had fallen from 5·9 parts only to 4·6 parts per 100,000. Strong putrefactive odours were given off during proteolysis of the casein.

(*ii*) *Whey Washings*

The effect of fermentation on the composition of whey washings was determined in experiments in which mixtures of 3 per cent of whey in water were allowed to pass continuously through open 6-litre tanks fitted with scum boards; the average periods of detention in different experiments were 12 hours, 24 hours, and 48 hours. The whey and diluting water were stored in separate vessels and were mixed in the correct proportions immediately before entering the fermentation tanks. Samples of effluent from the tanks were taken for analysis at intervals during a period of experiment of about a month. The effluents were comparatively clear and contained little suspended matter. Average values of the biochemical oxygen demand and of the concentration of lactose and acid in the effluent are given in Table XV; the acid (calculated as acetic acid) was determined by direct titration with alkali. During fermentation a considerable proportion of the lactose of the whey was decomposed; part of the lactose was converted to organic acids. Little change occurred in the biochemical oxygen demand of the whey washings during periods of fermentation up to 48 hours.

TABLE XV. *Fermentation, in an Open Tank, of 3 per Cent of Whey in Water*

	Average composition of liquid			
	Before fermentation	After fermentation for 12 hours	After fermentation for 24 hours	After fermentation for 48 hours
Parts per 100,000				
Biochemical oxygen demand	116	115	114	112
Acid (as acetic acid) ..	9	46	54	58
Lactose	119	77	61	39

TREATMENT BY ADDITION OF CHEMICAL PRECIPITANTS

Many attempts have been made to purify waste waters from dairies and milk products factories by the addition of chemical precipitants such as lime, ferrous sulphate, aluminoferric, and mixtures of these substances. It had been shown, in laboratory experiments, that under favourable conditions the polluting character of certain types of waste liquids, including milk washings, could be reduced by about one-half by the addition of lime and ferrous sulphate. Usually, however, the degree of purification achieved was not very high, especially with liquids in which most of the polluting material was in a soluble form.

During the present investigation, experiments were made to determine the effect of the addition of different concentrations of lime, aluminoferric, and mixtures of these substances to milk washings containing whole milk in concentrations between 0·25 and 2·0 per cent by volume.

In each experiment mixtures of milk were made with tap water with a temporary hardness equivalent to 28 parts calcium carbonate per 100,000. To 1-litre portions of the mixture were added weighed quantities of the freshly ground precipitants in the dry state; the liquid was then shaken 3 times at intervals of 5 minutes and was allowed to stand for a period of 45 minutes. In those experiments in which mixtures of lime and aluminoferric were used, the aluminoferric was added first and the liquid was shaken; the lime was then added and the liquid was again shaken. After standing for a period of 45 minutes, samples for analysis were withdrawn by means of a pipette passed into the clearest layer of liquid. Care was taken to avoid disturbance of any solid material floating on the surface. The biochemical oxygen demand and the *p*H value of the samples were determined. The results obtained are shown in Table XVI.

TABLE XVI. *Effect of Lime and Aluminoferric on Milk Washings*

Biochemical oxygen demand and *p*H value of settled liquid

Concentration of whole milk in milk washings (per cent)	Concentration of aluminoferric added (gm. per 100 litres)	Biochemical oxygen demand (parts per 100,000) *p*H value—*in italics* Concentration of lime added (gm. CaO per 100 litres)							
		0		10		50		100	
0·25	0	35	*7·0*	31	*8·0*	29	*9·2*	—	
	10	26	*6·7*	30	*7·8*	26	*8·8*	—	
	50	5	*6·2*	4	*6·5*	7	*7·0*	—	
	200	6	*4·2*	4	*4·7*	2	*4·9*	—	
0·5	0	60	*6·9*	59	*8·0*	56	*8·4*	—	
	10	59	*6·8*	57	*7·2*	56	*8·0*	—	
	50	15	*6·0*	17	*6·4*	18	*7·6*	—	
	200	11	*4·2*	11	*4·2*	7	*4·6*	—	
1·0	0	129	—	112	—	113	*8·2*	111	*8·4*
	10	123	—	112	—	101	*8·3*	103	*8·1*
	50	30	—	24	—	28	*7·2*	30	*8·3*
	200	13	—	20	—	20	*4·6*	33	*6·0*
1·5	0	164	*6·8*	150	*6·9*	209	*7·0*	—	
	10	207	*6·6*	156	*6·8*	129	*8·2*	—	
	50	52	*6·3*	50	*6·4*	104	*6·9*	—	
	200	55	*4·7*	76	*4·6*	36	*4·7*	—	
2·0	0	223	*6·8*	233	*6·9*	218	*7·1*	—	
	10	231	*6·4*	220	*6·6*	222	*7·2*	—	
	50	68	*6·1*	113	*6·5*	95	*6·7*	—	
	200	96	*5·0*	78	*4·8*	59	*5·0*	—	

Addition of lime alone had little effect on the biochemical oxygen demand of the milk washings. Aluminoferric, added in a concentration of 10 parts per 100,000, caused little change in the biochemical oxygen demand, but when added in concentrations of 50 or 200 parts per 100,000, the biochemical oxygen demand of the liquid was considerably reduced. With milk washings containing 0·25 per cent milk, the reduction in biochemical oxygen demand effected by the addition of aluminoferric in concentrations of 50 or 200 parts per 100,000 was about 85 per cent. In some experiments a slightly greater reduction in biochemical oxygen demand was caused by the addition of mixtures of lime and aluminoferric than by the same quantity of aluminoferric alone; in other experiments addition of lime decreased the effect of the aluminoferric.

It was observed that when aluminoferric only was added to milk washings, the precipitated solids first rose to the surface of the liquid. Part of the solid material later settled to the bottom of the vesssel. When lime was added alone or in admixture with aluminoferric, the precipitated solids were deposited without having first risen to the surface.

In some further experiments chemical precipitants were added to milk washings, containing 1 per cent milk, which were mixed with 0·1 per cent lactose and to similar milk washings mixed with 0·1 per cent lactic acid. The conditions of experiment were similar to those in the experiments reported in Table XVI, except that the water used to dilute the milk and added substances was a soft water. Typical results are shown in Table XVII.

TABLE XVII. *Effect of Lime and Aluminoferric on Milk Washings containing Added Lactose and Lactic Acid*

Biochemical oxygen demand and *p*H value of settled liquid

Liquid treated	Concentration of aluminoferric added (gm. per 100 litres)	Biochemical oxygen demand (parts per 100,000) *p*H *value—in italics* Concentration of lime added (gm. CaO per 100 litres) 0	10	50	100	200
Water containing 1 per cent milk and 0·1 per cent lactose	0	171 *6·8*	161 *9·8*	159 >*10·2*	165 >*10·0*	160 >*10·0*
	10	164 *5·8*	169 *9·2*	164 >*10·2*	145 >*10·0*	163 >*10·0*
	50	158 <*4·6*	134 —	131 —	140 —	140 *9·7*
	200	58 <*4·6*	119 —	22 —	39 —	40 *9·8*
Water containing 1 per cent milk and 0·1 per cent lactic acid	0	164 *4·6*	165 *4·5*	149 *4·8*	175 *9·8*	180 >*10·0*
	10	171 <*4·4*	169 <*4·4*	149 <*4·4*	160 *9·6*	175 >*10·0*
	50	144 <*4·4*	156 <*4·4*	134 *4·5*	73 *8·4*	170 *9·6*
	200	119 <*4·4*	101 <*4·4*	113 <*4·4*	105 *4·6*	93 *5·8*

In general, the addition of a given quantity of coagulants caused about the same reduction in biochemical oxygen demand in milk washings containing added lactose as in milk washings alone. The effect of coagulants on milk washings containing added lactic acid was, on the whole, less marked than their effect on milk washings containing added lactose.

These experiments confirmed the view that large reductions in biochemical oxygen demand are not usually obtained by the action of chemical precipitants on liquids in which a considerable proportion of the biochemical oxygen demand is due to dissolved substances.

TREATMENT IN PERCOLATING FILTERS

At the time when this investigation was begun, treatment of milk washings and other waste waters from the milk industry by percolation through biological filters appeared to be one of the most successful methods of purification in use. In general, however, final effluents of sufficiently high quality to allow them to be discharged into small streams, without causing serious pollution, had not then been obtained. In most commercial plants the waste liquids, in order to provide a uniform flow, were collected in storage tanks before passing to the percolating filters; in some plants the storage tanks were enlarged so as to allow anaerobic fermentation of the waste liquids to proceed for several days before filtration.

(*i*) *Milk Washings*

In the first laboratory experiments, during the present investigation, on the treatment of milk washings in percolating filters, the liquid treated was water containing 1·3 per cent milk; this mixture had an average biochemical oxygen demand of about 140 parts per 100,000. An experimental percolating filter consisted of a column of six cylindrical stoneware jars, each 12 in. high and

4 in. in diameter. Each jar had a perforated base and was supported by a stoneware dish with a single hole in the centre. The effluent from each jar was caught in the dish on which it was standing and was distributed on to the surface of the medium in the jar beneath it. Samples of effluent from any section of the filter could be taken for analysis. The jars were filled with washed gravel, graded 0·5 to 1·0 in. At the beginning of the experiments there was no biological film on the gravel.

At dairies and factories manufacturing milk products considerable quantities of soda are used in the washing of churns and other equipment and, as a result, the waste waters are often strongly alkaline in reaction. In the laboratory experiments, therefore, soda was added to the mixtures of water and milk in amounts sufficient to give liquids with *p*H values of approximately 7, 8, 9, and 10. Each of four percolating filters was supplied with one of the liquids for a period of 1 month at a rate equivalent to about 100 gallons per day per cubic yard of filtering medium. Samples of effluent from the different sections of each filter were analysed at intervals of a few days. Typical results are given in Table XVIII.

TABLE XVIII. *Treatment of Milk Washings, containing* 1·3 *per Cent Milk, in Percolating Filters*

Interval after beginning of experiment (days)	Section of filter (numbered 1 to 6 from top to bottom)	Reduction in biochemical oxygen demand caused by passage through filters (as percentage of initial value) — Approximate *p*H value of liquid supplied to filters: *p*H 7 (Filter A)	*p*H 8 (Filter B)	*p*H 9 (Filter C)	*p*H 10 (Filter D)
5	6	97	97	88	82
7	6	96	97	96	91
10	1	62	58	52	47
	2	88	72	64	59
	3	93	89	86	70
	4	95	94	90	88
14	1	58	56	56	58
	2	90	92	89	88
	3	96	98	93	96
21	1	35	40	43	37
	2	87	90	92	92
	3	96	98	97	96
28	3	86	87	82	93

After the filters had been in operation for a few days, active biological films had developed on the particles of gravel and the filters were then purifying the liquid to the extent of 80 to over 90 per cent, as measured by the test for biochemical oxygen demand in 5 days. Large quantities of solid matter were, however, deposited on the gravel, especially in the top section, and after 3 weeks the filters showed signs of becoming choked. At the end of the 4th week the film on the filtering medium was examined; it consisted of a dense white mass of fungi in which were embedded globules of fat. On a basis of dry weight, the film contained about 5 per cent total nitrogen and 65 per cent fat.

Formation of film appeared to be slightly delayed in the top sections of filters C and D, which were receiving liquids to which soda had been added to raise the *p*H values to 9 and 10 respectively. Addition of soda, however, had no appreciable effect on the rate of formation of film in the deeper sections of the filters. During passage through the top section of Filter D, the *p*H value of the liquid fell from about 10 to about 8.

It appeared from these experiments that difficulty would be caused in the treatment of milk washings in a percolating filter owing to the deposition of solid organic matter in the filtering medium and the consequent choking of the filter. Experiments were therefore made in which a mixture of 1 per cent milk in water was first allowed to ferment in tanks for 1 or 2 days. After separation from floating and deposited solid matter, the liquid was treated in a sectional percolating filter at a rate equivalent to 100 gallons per day per cubic yard of medium. The medium used in these experiments was gravel graded 0·25 to 0·5 in. Some of the results obtained are given in Table XIX.

TABLE XIX. *Treatment in a Septic Tank and Percolating Filter of* 1 *per Cent of Milk in Water*

Biochemical oxygen demand of crude liquid about 110 parts per 100,000
Rate of application to percolating filter equivalent to 100 gallons per day per cubic yard of filtering medium

Interval after beginning of experiment (weeks)	Biochemical oxygen demand (parts per 100,000)		
	Effluent from septic tank	Effluent from 3rd section of filter	Effluent from 6th section of filter
1	62	52	36
2	60	45	10
3	68	44	10
4	72	28	1·4
5	74	3·0	1·5
16	74	25	1·6
17	84	3·1	1·7

Development of biological film on the filtering medium appeared to occur more slowly than in the previous experiments, in which mixtures of water and milk were applied to percolating filters without previous anaerobic fermentation. After a period of 4 weeks, final effluents with a biochemical oxygen demand of less than 2 parts per 100,000 parts were obtained and this quality of effluent was maintained until the end of the experiment, which occupied 17 weeks. There were no signs of ponding on the surface of the filter.

It had been observed by Mr. H. C. Whitehead, Chief Engineer of the Birmingham Tame and Rea District Drainage Board, and the late Mr. F. R. O'Shaughnessy, Chief Chemist to the Drainage Board, that percolating filters used for the purification of sewage, which had become partially choked by deposition of solid matter, could be cleaned by treatment with well-purified effluent from another filter. Some experiments on the treatment of milk washings by a system of double filtration with periodic change in the order of the filters were made, for the Water Pollution Research Board, by Mr. Whitehead and Mr. O'Shaughnessy in the laboratories of the Birmingham Tame and Rea District Drainage Board.

In one experiment two small filters were used, each 56 in. high and filled with gravel about 0·25 in. in size. The liquid treated was water containing 0·2 per cent milk and in some experiments lime water was added to raise the *p*H value of the mixture. The liquid was treated in the first filter at a rate equivalent to 100 gallons per day per cubic yard of medium; the effluent from this filter was treated at the same rate in the secondary filter. The rate of flow through two filters together was thus equivalent to 50 gallons per day per cubic yard of medium. On the 15th day of the experiment there was a whitish-grey deposit in the top layer of the primary filter; the order of the two filters in series was then changed. After a further 14 days the whitish-grey deposit had disappeared and brown granular masses were observed lower down the filter and in the effluent. During this period a whitish-grey film was deposited in the top layer of the medium in the filter which was being used as a primary filter. When the order of the two filters in series was changed at intervals of about a fortnight, both filters could be kept free from excessive growths of film and ponding did not occur. Typical results of examination of samples of the crude liquid and of the effluent from the primary and secondary filters are shown in Table XX.

TABLE XX. *Treatment of* 0·2 *per Cent of Milk in Water by Double Filtration*

Rate of flow 50 gallons per day per cubic yard of medium in the two filters together

	Crude liquid	Effluent from primary filter	Effluent from secondary filter
*p*H value	10·5	7·1	7·1
Biochemical oxygen demand (parts per 100,000)	25·7	0·05	0·30
Nitrate *plus* nitrite (parts N per 100,000)	0	0·60	1·20

These results showed that well-purified effluents could be obtained by treatment of milk washings, with a biochemical oxygen demand of about 25 parts per 100,000, in two filters in series with periodic change in the order of the filters, when the rate of flow of crude liquid was 50 gallons per day per cubic yard of filtering medium in the two filters together. In other experiments it was shown that equally good results were obtained when liquids containing 0·2 per cent milk and 10 per cent settled sewage were similarly treated.

(*ii*) *Whey Washings and Mixtures of Milk Washings and Whey Washings*

Several laboratory experiments in which diluted whey and mixtures of diluted whey and milk were treated in two percolating filters in series, with periodic change in the order of the filters, were included in the Department's experiments at Ellesmere, Shropshire.

In the first experiments of this series a drain-pipe, 2 ft. long and 6 in. in diameter, was used as the primary filter and another similar drain-pipe as the secondary filter; each pipe had a grid at the bottom to support the filtering medium, which was metallurgical coke graded 0·75 to 1·5 in. The primary filter stood on top of the secondary filter and the primary effluent was supplied to the secondary filter without sedimentation. To change the order of filtration, the filters were interchanged in position.

The crude liquids treated were diluted whey and mixtures of diluted whey and milk; the rate of treatment was 50 gallons per day per cubic yard of medium in the two filters together. The order of the filters was changed periodically to prevent clogging of the medium by deposited film. Some of the results are shown in Table XXI. After the filters had matured, well-purified effluents were obtained.

TABLE XXI. *Treatment of Whey Washings and Mixtures of Whey Washings and Milk Washings by Double Filtration*

Rate of treatment 50 gallons per day per cubic yard of medium in the two filters together

Liquid treated	Interval after beginning of experiments (months)	Biochemical oxygen demand (parts per 100,000)	
		Crude liquid	Effluent from secondary filter
Water containing 0·5 per cent whey	1	33	9·9
	2	40	11·9
	3	48	4·8
	4	26	1·3
Water containing 1·0 per cent whey	5	51	1·3
	6	42	1·0
	7	45	0·5
	8	54	2·6
	9	71	2·5
	10	76	1·7
Water containing 0·5 per cent whey and 0·125 per cent milk	1	62	17·3
	2	53	7·9
	3	57	4·7
	4	41	1·6
Water containing 1·0 per cent whey and 0·125 per cent milk	5	69	1·0
	6	61	0·6
	7	77	1·1
	8	79	1·8
	9	97	1·5
	10	94	2·4
Water containing 0·5 per cent whey and 0·25 per cent milk	1	89	34·0
	2	62	13·1
	3	76	8·4
	4	58	1·5
Water containing 1·0 per cent whey and 0·25 per cent milk	5	85	1·7
	6	75	0·7
	7	83	1·0
	8	92	1·5
	9	100	1·5
	10	89	2·4
Water containing 0·5 per cent whey and 0·5 per cent milk	1	126	37·0
	2	93	14·1
	3	98	12·7
	4	94	2·6
Water containing 1·0 per cent whey and 0·5 per cent milk	5	130	2·2
	6	132	1·4
	7	129	1·1
	8	106	2·0
	9	125	4·2
	10	106	3·3

In a second series of experiments each filter consisted of a drain-pipe 4 ft. in length and 6 in. in diameter; the medium used was again metallurgical coke graded 0·75 to 1·5 in. Effluent from the primary filter was allowed to settle for a period of approximately 24 hours before being applied to the secondary filter. The order of the filters in series was changed at intervals of about a fortnight. The liquids treated were 1 per cent whey in water and 1 per cent whey plus 0·25 per cent milk in water, and the rates of treatment were 50 and 100 gallons per day per cubic yard of medium. At the beginning of the experiments, the filters receiving liquid at a rate equivalent to 50 gallons per day per cubic yard were already matured, but the filters receiving liquid at a rate of 100 gallons per day per cubic yard had not been matured. The biochemical oxygen demands of the untreated liquid and of the final effluent, averaged over successive periods of 1 month, are shown in Table XXII.

TABLE XXII. *Treatment of Whey Washings and Mixtures of Whey Washings and Milk Washings by Double Filtration*

Liquid treated	Period of experiment	Average biochemical oxygen demand (parts per 100,000)			
		Rate of treatment 50 gal. per day per cubic yard of medium		Rate of treatment 100 gal. per day per cubic yard of medium	
		Crude liquid	Effluent from secondary filter	Crude liquid	Effluent from secondary filter
Water containing 1·0 per cent whey	1st month	40	0·5	42	13·7
	2nd ,,	48	1·0	34	3·1
	3rd ,,	42	0·7	45	1·0
	4th ,,	34	0·4	43	1·1
	5th ,,	45	0·6	44	0·9
	6th ,,	43	1·0	40	1·4
	7th ,,	44	0·5	—	—
	8th ,,	40	0·4	—	—
Water containing 1·0 per cent whey and 0·25 per cent milk	1st month	65	0·5	71	17·1
	2nd ,,	77	0·8	70	4·0
	3rd ,,	71	1·8	66	2·2
	4th ,,	70	0·9	70	1·6
	5th ,,	66	0·7	66	1·9
	6th ,,	70	0·6	58	1·6
	7th ,,	66	0·4	—	—
	8th ,,	58	0·4	—	—

At a rate of treatment of 50 gallons per day per cubic yard of medium, final effluents with a biochemical oxygen demand usually not exceeding 1 part per 100,000 parts were obtained. The effluents generally contained nitrate and a high proportion of dissolved oxygen. At a rate of treatment of 100 gallons per day per cubic yard of medium, satisfactory final effluents were obtained after the filters had been in service for a period of 2 months. No trouble was experienced from clogging of the filters, but excessive growth on the primary filter was more rapidly removed, after the order of filtration had been changed, in the filters receiving liquid at a rate of 50 gallons per day per cubic yard than in the filters in which the rate of treatment was 100 gallons per day per cubic yard. The crude liquids supplied to the primary filters were usually acid in reaction, with *p*H values between 4·2 and 5·8; the final effluents were neutral or slightly alkaline.

Experiments were also made to determine the effect of anaerobic fermentation of mixtures of diluted whey and milk on the subsequent treatment of the liquid by passage through two percolating filters in series with periodic change in the order of the filters. The filters used were again drain-pipes, 4 ft. in length and 6 in. in diameter, filled with metallurgical coke graded 0·75 in. to 1·5 in. The crude liquid was water containing 1 per cent whey and 0·25 per cent milk. In different experiments this liquid was applied to the primary filter at rates equivalent to 50 gallons and 100 gallons per day per cubic yard of medium in the two filters together. In some experiments the liquid was applied directly to the primary filter; in other experiments it was first allowed to ferment in an open tank for 24 hours before filtration. Effluents from the primary filters were allowed to settle for an average period of 24 hours before the supernatant liquid was applied to the secondary filters. The experiments were continued for 3 months with periodic changes in the order of the filters. The biochemical oxygen demand of the crude and fermented liquids and of the final effluents, averaged over successive periods of 1 month, is shown in Table XXIII.

TABLE XXIII. *Treatment of Washings containing 1 per Cent Whey and 0·25 per Cent Milk by Fermentation and Double Filtration*

Rate of treatment of liquid (gal. per day per cubic yard of medium in two filters together)	Period of experiment	Average biochemical oxygen demand (parts per 100,000)			
		Treatment by double filtration		Treatment by fermentation followed by double filtration	
		Crude liquid	Final effluent from secondary filter	Crude liquid after fermentation for 24 hours	Final effluent from secondary filter
50	1st month	60	0·2	43	0·3
	2nd ,,	48	0·4	43	0·8
	3rd ,,	67	0·3	52	0·4
100	1st month	60	0·7	43	0·7
	2nd ,,	48	1·2	43	0·5
	3rd ,,	67	1·5	52	1·2

At both rates of treatment the quality of the effluents from the primary and secondary filters was about the same whether or not the crude liquid was subjected to fermentation before filtration. It was observed, however, that the quantity of material deposited in the surface layer of medium in the primary filters was greater in the filters receiving unfermented crude liquid than in the filters receiving liquid which had first been allowed to ferment for 24 hours.

TREATMENT BY THE ACTIVATED SLUDGE PROCESS

(i) *Milk Washings*

In one series of laboratory experiments made during the present investigation, tap water containing 0·25, 0·5, and 1·0 per cent milk was aerated in admixture with activated sludge derived from the treatment of diluted milk. For each concentration of milk four experiments were made. In one pair of experiments lime was added to raise the *p*H value of the liquid to 10; in the other pair no addition of lime was made. In one experiment of each of these pairs air was admitted in the form of comparatively large bubbles from open glass tubes, and in the other experiment of the pair small bubbles of air from diffusers were employed. Comparison of the results of tests for biochemical oxygen demand in 5 days indicated that under the conditions of experiment the smaller bubbles of air were only slightly more effective than the larger bubbles in purifying the mixtures. For this reason, only the averages of the results with the two sizes of bubbles are given.

Each mixture was aerated for 4 to 5 days; it was then allowed to settle for 1½ hours and the supernatant liquid was withdrawn and replaced by a fresh mixture before aeration was resumed. The experiments were continued during a period of 29 days. Average results are given in Table XXIV.

TABLE XXIV. *Treatment of Milk Washings by Aeration in Admixture with Activated Sludge Prepared from Milk Washings*

Proportion of milk in untreated washings (per cent)	Addition of lime to crude liquid: 0=no lime added +=lime added to raise *p*H value to 10	Average biochemical oxygen demand (parts per 100,000)			
		Untreated liquid	Final effluent; period of aeration 1 day	Final effluent; period of aeration 2 days	Final effluent; period of aeration 4 days
0·25	0	32	11·8	8·5	4·1
0·25	+	30	16·3	14·0	7·6
0·5	0	61	10·1	7·5	4·7
0·5	+	58	44·7	35·3	17·0
1·0	0	116	26·2	12·4	7·9
1·0	+	111	92·2	73·5	50·0

Under the conditions of the experiments in which lime was not added to raise the *p*H value, the degree of purification effected, as measured by the test for biochemical oxygen demand, ranged between 63 and 83 per cent in 1 day, 73 and 89 per cent in 2 days, and 87 and 93 per cent in 4 days. The addition of sufficient lime to raise the *p*H value of the untreated liquids to about 10 greatly retarded purification.

The methods of operation in the next series of experiments were similar to those just described, except that no lime was added and that small quantities of sewage sludge from an activated sludge plant at a sewage disposal works were added to the first batches of diluted milk before aeration. No further additions of sewage sludge were made during the experiments. Average results of these experiments are given in Table XXV. With mixtures containing 0·25 and 0·5 per cent milk the results were an improvement on those obtained in the first series, but they were not so good with 1·0 per cent milk. Mixtures containing 0·25 and 0·5 per cent milk were purified to the extent of over 90 per cent by aeration for 2 days.

Some laboratory experiments were made in which mixtures of milk washings with activated sludge were aerated in tanks either by diffused air or by surface aeration. Each tank used for surface aeration was fitted with a cylindrical brush, 2·5 in. in diameter, revolving about a horizontal axis across the width of the tank near one end; the bristles of the brush dipped just into the surface of the liquid. When rotated by an electric motor at a speed of about 200 revolutions per minute, the agitation caused was sufficient to maintain the activated sludge in suspension.

The sludges from the earlier series of experiments were mixed together and 1 litre of mixed sludge was used in starting each experiment. The 1 litre of sludge was added to 7 litres of tap water containing 1·1 per cent milk. After aeration for 46 hours and settlement for 2 hours, 5 litres of supernatant liquid were withdrawn and replaced by the same volume of water containing 1·1 per cent milk. The experiments with 1·1 per cent milk and treatment for 48 hours were continued for about 5 weeks. Mixtures containing 0·5 per cent milk were afterwards employed and the period of treatment was again 48 hours; these experiments were continued for 2 weeks. During the next 2 weeks, mixtures containing 0·5 per cent milk were treated for 24 hours. Some experiments with treatment for 48 hours and 24 hours were also made with 0·5 per cent milk in tap water to which 10 per cent domestic sewage had been

TABLE XXV. *Treatment of Milk Washings by Aeration in Admixture with Activated Sludge Prepared from Domestic Sewage*

Proportion of milk in untreated washings (per cent)	Biochemical oxygen demand (parts per 100,000)			
	Untreated liquid	Final effluent; period of aeration 1 day	Final effluent; period of aeration 2 days	Final effluent; period of aeration 4 days
0·25	33	4·0	2·7	2·0
0·5	61	8·6	4·9	2·0
1·0	118	55·3	31·7	11·3

added. The average results of these various experiments are given in Table XXVI.

Both methods of aeration gave similar amounts of purification. On the basis of the figures for the biochemical oxygen demands of the treated liquids after settlement, the purification achieved with revolving brushes ranged from 88 to 94 per cent and the purification with bubbles of air ranged from 92 to 96 per cent. After removal of suspended matter by filtration through filter paper the biochemical oxygen demands of the treated effluents were all equivalent to a purification of 94 to 98 per cent. Optimum conditions for aeration by the two methods may not have been attained and no significance can be attributed to the small differences in the purification achieved by the two methods under the conditions of these experiments.

Some experiments were made in which mixtures of 1 per cent milk with water were first allowed to ferment under partially or wholly anaerobic conditions and the liquid, separated from deposited solids, was then aerated in admixture with activated sludge. Fermentation was carried out under four sets of conditions: (1) in an open vessel at room temperature, (2) in an open vessel at a temperature of 30° C., (3) in a closed vessel to which air was occasionally admitted at room temperature, and (4) under strictly anaerobic conditions at room temperature in a closed vessel in which the space above the liquid was filled with nitrogen. Each morning and evening part of the liquid, separated from sludge, was removed from the tank and replaced by an equal volume of a mixture of 1 per cent milk in water. The liquids obtained by fermentation overnight were filtered through cotton wool and aerated for periods of 1 to 3 days in admixture with activated sludge derived from diluted milk. The best results were obtained when the liquids were fermented in open vessels at room temperature. With these mixtures the biochemical oxygen demand of the liquid after fermentation was reduced by aeration with activated sludge from a value of about 90 parts per 100,000 to a value of about 3·5 parts per 100,000, corresponding with a purification of 96 per cent. Rather less purification was achieved in the liquids fermented at a temperature of 30° C. in an open vessel and at laboratory temperature in a closed bottle. The average biochemical oxygen demand of liquid after fermentation under strictly

TABLE XXVI. *Treatment of Milk Washings by Aeration in Admixture with Activated Sludge*

Proportion of milk in untreated mixture (per cent)	Method of aeration	Period of aeration (hours)	Biochemical oxygen demand (parts per 100,000)			Dissolved oxygen in treated liquid (parts per 100,000)
			Untreated liquid	Treated liquid after settlement	Treated liquid after filtration through filter paper	
1·1	Diffused air	48	137	8·2	2·6	0·04
1·1	Brush	48	137	8·7	3·5	0·56
0·5	Diffused air	48	56	3·5	1·4	0·43
0·5	Brush	48	56	6·5	1·9	0·84
0·5	Diffused air	24	56	2·1	1·1	0·35
0·5	Brush	24	56	4·2	2·2	0·66
*0·5	Diffused air	48	66	2·5	1·5	0·51
*0·5	Brush	48	66	4·4	1·8	0·66
*0·5	Diffused air	24	80	6·7	5·0	—
*0·5	Brush	24	80	3·0	1·3	—

anaerobic conditions followed by aeration with activated sludge was 10 to 11 parts per 100,000; in this case the purification achieved by aeration with activated sludge was about 88 per cent.

After these experiments had been in progress for 52 days, "bulking" of the activated sludge occurred and the quality of the final effluents deteriorated considerably. The condition of the sludge was improved by aerating it for 2 days without any further addition of fermented liquid.

In the experiments just described, treatment of diluted milk by fermentation followed by treatment of the separated liquid by the activated sludge process was carried out by the "fill and draw" or "batch" method. In later experiments a mixture of water with 1 per cent milk flowed continuously at a controlled rate into one end of a tank fitted with baffles to minimize short circuiting of the liquid. The rate of flow was adjusted to give an average

* These mixtures were made with tap water to which 10 per cent of domestic sewage liquor had been added.

period of detention of about 24 hours. Effluent from the fermentation tank flowed continuously into a settling tank to remove suspended matter, and then into a tank where it was aerated in admixture with activated sludge. During the latter part of the experiments the settling tank was omitted and effluent from the fermentation tank flowed direct to the aeration tank. The aeration tank was V-shaped in vertical cross-section and contained 3 baffles; liquid passed underneath the first and third baffles and over the second. Air was passed into the liquid through diffusers fitted at the bottom of each compartment. After the liquid had been treated in the aeration tank for an average period of 24 hours, the mixture of liquid and activated sludge flowed to a settling tank where the sludge was separated for return to the aeration tank. Treatment of the mixture of 1 per cent milk in water was continued for a period of about 8 weeks; the average results obtained are given in Table XXVII. The maximum and minimum daily values for the biochemical oxygen demand of the final effluent were 4·1 parts and 0·2 part per 100,000, and the average value was 2·5 parts per 100,000. These effluents were obtained from mixtures of milk and water with an average biochemical oxygen demand of 110 parts per 100,000.

TABLE XXVII. *Treatment of 1 per Cent of Milk in Water by Fermentation and the Activated Sludge Process*

Average results

	Crude liquid	Supernatant liquid after fermentation	Final effluent after treatment by activated sludge process
Parts per 100,000:			
Biochemical oxygen demand ..	110	68	2·5
Ammonia (as N)	—	2·5	0·35
Nitrite (as N)	—	—	0·33
Nitrate (as N)	—	—	1·5
Dissolved oxygen	—	—	0·9

(*ii*) *Milk Washings containing Added Lactose and Lactic Acid*

Waste waters from factories manufacturing butter and cheese contain a higher proportion of lactose than do waste waters from milk collecting and distributing depots, and they may also contain lactic acid in amounts depending on the period during which the waste waters have been stored before treatment. Laboratory experiments were therefore made to determine the rate of purification of 0·5 per cent milk in water to which various amounts of lactose and lactic acid had been added. The liquids were aerated in admixture with activated sludge derived originally from diluted milk or from domestic sewage; the sludges were those remaining after the laboratory experiments already described had been completed. Liquid was withdrawn from the aeration tanks at intervals of 3 days and was replaced by fresh liquid; activated sludge was allowed to settle from the liquid and was returned to the tanks. The experiments were continued during a total period of 53 days. The results of the experiments are given in Table XXVIII.

Additions of lactose or lactic acid in concentrations not exceeding 0·1 per cent did not greatly affect the quality of the final effluent after aeration for 3 days, though they reduced the amount of purification obtained after 1 day. When lactic acid was added to the untreated liquid in a concentration of 0·1

TABLE XXVIII. *Treatment of Milk Washings containing Added Lactose and Lactic Acid by Aeration in Admixture with Activated Sludge*

Origin of initial activated sludge	Proportion of milk in untreated mixture (per cent)	Lactose added (per cent)	Lactic acid added (per cent)	Biochemical oxygen demand (parts per 100,000)			*p*H value		
				Untreated liquid	Treated liquid after aeration for 1 day	Treated liquid after aeration for 3 days	Untreated liquid	Treated liquid after aeration for 1 day	Treated liquid after aeration for 3 days
Diluted milk	0·5	0	0	56	12	7·6	7·1	7·7	8·2
	0·5	0·025	0	81	15	4·2	7·1	7·9	8·1
	0·5	0·05	0	96	14	5·7	7·1	7·8	8·1
	0·5	0·10	0	116	18	8·9	7·1	7·8	8·0
	0·5	0	0·025	78	10	3·9	6·3	7·9	8·0
	0·5	0	0·05	84	16	3·7	6·1	7·8	8·1
	0·5	0	0·10	109	33	4·9	4·6	7·8	8·1
Sewage	0·5	0	0	56	4	2·0	7·1	8·1	8·1
	0·5	0·05	0	96	12	4·4	7·1	8·1	8·1
	0·5	0	0·05	84	8	5·7	6·1	8·0	8·0

per cent, the *p*H value was reduced to 4·6; after aeration for 1 day the value had risen to 7·8, and after 3 days to 8·1.

(*iii*) *Whey Washings and Mixtures of Milk Washings and Whey Washings*

In the first experiments, liquids containing 0·25 and 0·5 per cent whey, with or without the addition of 0·1 per cent milk, were aerated by diffused air in admixture with activated sludge for a period of 22 hours each day; the sludge was then allowed to settle during a period of 2 hours. After settlement, 5 litres of supernatant liquid were drawn off from the total volume of 7 litres of mixed liquid and sludge used in each experiment and were replaced by 5 litres of untreated liquid. The average results obtained during each month of the experiment, which was continued for a total period of 5 months, are given in Table XXIX. After the second month, final effluents of good quality were obtained, with a biochemical oxygen demand usually less than 2 parts per 100,000.

Experiments were then made in which liquids containing higher concentrations of whey and milk were aerated, in admixture with activated sludge, for a period of 22 hours daily. These experiments were continued for a period of 2 months; the average results over this period are given in Table XXX. The purification achieved was better than in any other experiments carried out in the laboratory by the activated sludge process, probably because the sludges had by this time become fully activated. With a period of aeration of 22 hours, the biochemical oxygen demand of the untreated liquid was reduced from between 30 and 50 parts per 100,000 to less than 1 part per 100,000 for the settled final effluent. The final effluent usually contained only traces of nitrite and nitrate, but it contained dissolved oxgyen in amounts corresponding to more than 60 per cent of the saturation value.

(*iv*) *Effect of Temperature*

Experiments were made to determine the effect of temperature on the treatment of milk washings by the activated sludge process; the temperature range studied was 2° C. to 45° C. In each experiment, a mixture of milk washings and activated sludge prepared from milk washings was aerated in a small

TABLE XXIX. *Treatment of Whey Washings and Mixtures of Whey Washings and Milk Washings by Aeration in Admixture with Activated Sludge*

Period of experiment	Proportion of whey in untreated liquid (per cent)	Proportion of milk in untreated liquid (per cent)	Average biochemical oxygen demand (parts per 100,000)	
			Untreated liquid	Final effluent after settlement
1st month ..	0·25	0	9	1·8
2nd ,, ..	0·25	0	12	1·3
3rd ,, ..	0·25	0	11	1·3
4th ,, ..	0·25	0	15	1·1
5th ,, ..	0·25	0	12	1·4
1st month ..	0·25	0·1	21	3·8
2nd ,, ..	0·25	0·1	28	2·3
3rd ,, ..	0·25	0·1	25	2·2
4th ,, ..	0·25	0·1	27	1·3
5th ,, ..	0·25	0·1	28	1·4
1st month ..	0·5	0	17	3·7
2nd ,, ..	0·5	0	20	1·5
3rd ,, ..	0·5	0	21	1·1
4th ,, ..	0·5	0	23	0·8
5th ,, ..	0·5	0	23	1·4
1st month ..	0·5	0·1	30	4·1
2nd ,, ..	0·5	0·1	39	2·2
3rd ,, ..	0·5	0·1	36	1·7
4th ,, ..	0·5	0·1	38	0·9
5th ,, ..	0·5	0·1	36	1·4

tank fitted with an electrical immersion heater or a cooling unit; the temperature was thermostatically controlled. The liquid was aerated by means of a revolving brush, the arrangement of which was similar to that used in some

TABLE XXX. *Treatment of Whey Washings and Mixtures of Whey Washings and Milk Washings by Aeration in Admixture with Activated Sludge*

Proportion of whey in untreated liquid (per cent)	Proportion of milk in untreated liquid (per cent)	Average biochemical oxygen demand (parts per 100,000)	
		Untreated liquid	Final effluent after settlement
0·5	0·25	40	0·7
1·0	0	32	0·4
1·0	0·125	39	0·4
1·0	0·20	47	0·8

of the earlier experiments. For a short period each day aeration was stopped, the sludge was allowed to settle in the aeration tank, and a measured volume of supernatant liquid was drawn off and replaced by an equal volume of water containing 0·75 per cent milk. If necessary some sludge was also removed so as to maintain approximately the same proportion of sludge in the liquid in the aeration tank. The results obtained are given in Table XXXI.

TABLE XXXI. *Effect of Temperature on the Treatment of Milk Washings, containing 0·75 per Cent Milk, by the Activated Sludge Process for 24 Hours*

Biochemical oxygen demand of crude liquid about 80 parts per 100,000

Temperature (° C)	Duration of experiment (days)	Average 5-day biochemical oxygen demand (parts per 100,000)		Fat in activated sludge (per cent of dry weight)	Kjeldahl nitrogen in activated sludge (per cent of dry weight)
		Treated liquid after sedimentation	Treated liquid after filtration through filter paper		
2	21	20·1	2·0	16·5	7·9
5	28	14·5	2·4	15·7	7·7
10	20	3·5	1·4	14·2	8·3
15	20	2·1	1·0	11·8	8·2
20	40	0·9	0·6	9·1	8·3
30	30	0·4	0·3	1·4	8·1
35	28	1·1	0·9	1·2	8·2
40	26	6·8	5·2	3·8	8·1
45	30	17·2	13·6	4·5	7·7

The optimum temperature for purification of milk washings by the activated sludge process appeared to be about 30° C. At this temperature the sludge settled readily when aeration was stopped, and the biochemical oxygen demand of the final effluent, both after settlement and after filtration through filter paper, was low. At 2° C., the lowest temperature tried, the sludge settled much less rapidly and the average biochemical oxygen demand of the settled effluent was more than 20 parts per 100,000; the biochemical oxygen demand of the effluent after filtration through paper was, however, only 2·0 parts per 100,000, indicating that most of the oxygen-absorbing material in the effluent consisted of matter in suspension. At a temperature of 45° C. the milk washings, after aeration with activated sludge, had a high biochemical oxygen demand both after settlement and after filtration through paper; thus a considerable part of the oxygen-absorbing material consisted of substances in solution. The proportion of fat in the activated sludge was least when the mixture of milk washings and activated sludge was aerated at 30° C.; the highest proportion was found when the mixture was aerated at 2° C. The proportion of total nitrogen in the activated sludge was about the same over the range of temperature 2° C. to 45° C.

The effect of aerating milk washings with activated sludge for different periods and at different temperatures is shown in Table XXXII. At 30° C. the period of aeration was reduced from 24 hours to 8 hours without seriously affecting the quality of the final effluent; at 20° C., however, the biochemical oxygen demand of the effluent was considerably increased when the period of aeration was decreased from 24 hours to 12 hours.

TABLE XXXII. *Effect of Temperature and Period of Aeration on the Purification of Milk Washings, containing 0·75 per Cent Milk, by the Activated Sludge Process*

Biochemical oxygen demand of crude liquid about 80 parts per 100,000

Temperature (° C.)	Period of treatment (hours)	Duration of experiment (days)	Average biochemical oxygen demand (parts per 100,000)	
			Final settled effluent	Final effluent after filtration through filter paper
30	8	16	0·7	0·5
	24	30	0·4	0·3
20	12	20	4·8	1·6
	24	37	1·0	0·6

SUMMARY OF LABORATORY EXPERIMENTS

When milk washings are allowed to ferment, solid matter separates and the biochemical oxygen demand of the liquid is usually reduced. During fermentation the liquid becomes more acid in reaction owing to the conversion of lactose to lactic acid. When the quantity of acid produced is sufficient to lower the *p*H value of the liquid to about 4·6, casein is precipitated with other solid matter, and the biochemical oxygen demand of the supernatant liquid is considerably reduced. When alkalis or buffering substances are present in the crude liquid in concentrations sufficiently high to prevent the *p*H value from falling below about 5·8, proteolysis of casein occurs, no very great reduction in the biochemical oxygen demand of the supernatant liquid takes place, and unpleasant putrefactive odours are given off. Very little reduction occurred in the biochemical oxygen demand of whey washings, containing 3 per cent whey, during fermentation for periods of 48 hours. It is probable that, under the conditions at many dairies and milk products factories, fermentation of waste waters would give rise to nuisance from odour.

Addition to milk washings of aluminoferric, in a concentration of 10 parts per 100,000, in admixture with lime, in concentrations between 0 and 100 parts per 100,000, caused little or no reduction in the biochemical oxygen demand. Considerable reduction in biochemical oxygen demand was caused by the addition of aluminoferric in concentrations of 50 and 200 parts per 100,000.

Treatment of milk washings by filtration through a single percolating filter caused a reduction of as much as 98 per cent in the biochemical oxygen demand of the liquid. After a time, however, the surface of the filtering medium became choked by a growth of film which consisted largely of fungi in which were embedded globules of fat. When milk washings were first allowed to ferment for 1 or 2 days and were then treated in a percolating filter at a rate equivalent to 100 gallons per day per cubic yard of medium, the filter did not become choked and final effluents with biochemical oxygen demands of less than 2 parts per 100,000 were obtained.

Experiments were made in which milk washings containing 0·2 per cent milk were passed at a rate of 100 gallons per day per cubic yard of medium through a percolating filter; the effluent from this filter was then applied at the same rate of flow to a similar secondary filter. Solid matter which had been deposited in the surface layer of medium in the primary filter was removed when the order of filtration was changed. When the order of the filters in series was reversed at intervals of about a fortnight, both filters remained free from excessive deposition of solid matter and well-purified final effluents were obtained.

Satisfactory effluents were also obtained when mixtures containing up to 1·0 per cent whey and 0·5 per cent milk were treated by double filtration, with periodic change in the order of the filters, at a rate equivalent to 50 gallons per day per cubic yard of medium in the two filters together. Using the same procedure but with settlement of the primary effluent before application to the secondary filter, well-purified effluents were obtained when a mixture containing 1·0 per cent whey and 0·25 per cent milk was treated at a rate equivalent to 100 gallons per day per cubic yard of medium in the two filters together. The quality of the final effluent in these experiments was not improved when the crude liquid was allowed to ferment for 24 hours before application to the primary filter.

It was shown that the biochemical oxygen demand of milk washings containing up to 0·5 per cent milk could be reduced considerably by aeration for 2 days in admixture with activated sludge prepared originally from milk washings or from domestic sewage. In these experiments the activated sludge was not fully matured and the quality of the final effluent was not high. When the activated sludge had become mature the biochemical oxygen demand of mixtures containing up to 0·5 per cent whey and 0·9 per cent milk was reduced from 30 to 40 parts per 100,000 to less than 2 parts per 100,000 by aeration in admixture with the sludge for a period of 22 hours. By aeration of liquids containing 1·0 per cent whey and 0·25 per cent milk for 22 hours in admixture with matured activated sludge, the biochemical oxygen demand was reduced from nearly 50 parts per 100,000 to less than 1 part per 100,000.

Experiments were made in which liquids containing 0·5 per cent milk were treated by means of activated sludge for periods of 24 hours at controlled temperatures from 2° C. to 45° C. The optimum temperature was about 30° C.; at this temperature the settled final effluent had a biochemical oxygen demand of not more than 0·5 part per 100,000.

From these laboratory experiments it was concluded that treatment on a large scale of waste waters from dairies and milk products factories by fermentation under anaerobic conditions or by addition of chemical coagulants would probably not be satisfactory.

It seemed likely that fermentation under anaerobic conditions would give rise to nuisance from odour and would leave considerable quantities of unpleasant sludge for disposal. To effect any great reduction in the polluting character of the waste water by the addition of aluminoferric required large quantities of the coagulant and would leave a considerable quantity of sludge for disposal. In any case further treatment after fermentation or after addition of aluminoferric would be necessary to produce a final effluent suitable for discharge into many rivers and streams.

The most promising methods of treatment tried in the laboratory were: (1) filtration through two percolating filters in series, with periodic change in the order of the filters, and (2) aeration in admixture with activated sludge. It was therefore decided to carry out tests of these two methods of treatment on a large scale.

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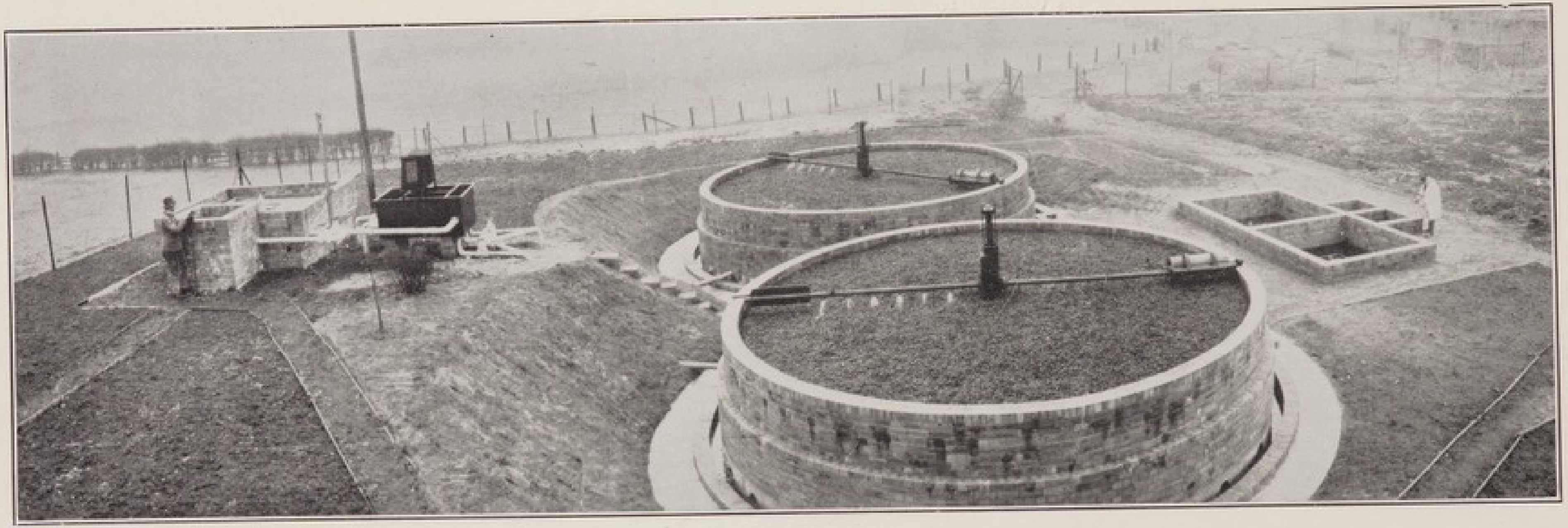


Plate 1. Panoramic View of Double-Filtration Plant, Ellesmere.

CHAPTER V. EXPERIMENTS ON A LARGE SCALE

TREATMENT IN TWO PERCOLATING FILTERS IN SERIES WITH PERIODIC CHANGE IN THE ORDER OF THE FILTERS

Description of Plant

THE two experimental plants for the treatment of milk and whey washings were erected side by side at the factory of United Dairies Ltd. at Ellesmere, Shropshire. The volume of milk received at the factory, during the period of the investigation, ranged from about 10,000 gallons per day in the winter to more than 30,000 gallons per day in the spring. A large proportion of the milk is despatched from the factory in bulk for distribution as liquid milk; the remainder is used for the manufacture of cheese. Whey from cheese making, together with whey from a number of factories in the neighbourhood, is concentrated under reduced pressure and the product is sold for use in the preparation of foods.

Milk washings from churns, road tanks, and other equipment, and from the washing of floors in that part of the factory handling milk for distribution, are discharged into one drain. Whey washings from those parts of the factory in which cheese is made and whey is concentrated are discharged into a second drain.

A plan and vertical section of the experimental double-filtration plant are shown in Figures 1 and 2 and a panoramic view of the plant is shown in Plate 1.

The rate of production of waste waters at the factory and the concentration of polluting matter they contain vary considerably during the day, and no wastes are produced for several hours during the night. In order to equalize the flow and composition of the crude liquid, and to allow of continuous operation of the two experimental plants, waste waters required for the experiments were made to flow by gravity from the factory to one or both of two collecting tanks below ground level. Milk washings, whey washings, or a mixture of the two could be discharged by branch pipes and valves from the drains of the factory into these tanks as required. The collecting tanks were rectangular in plan.

Liquid for the two experimental plants was pumped through a pipe 2 in. in diameter from the collecting tanks; a perforated metal screen prevented large particles of solid matter from entering the pipe. The rate of delivery of liquid to the filtration plant and the activated sludge plant could be regulated by means of valves.

Crude liquid from the collecting tanks was pumped to a brickwork chamber fitted with a V-notch gauge; it then flowed by gravity to a sedimentation tank. This tank was of the Dortmund type and had a total capacity to the overflow weir of 1,600 gallons. For a depth of 3 ft., the tank was 7 ft. 6 in. square in horizontal cross-section; the lower portion was 6 ft. in depth and was in the form of an inverted pyramid. Liquid entered in an upward direction near the top of a central inlet box, from which it flowed downwards and then upwards to the overflow weir. A wooden frame, partly submerged, was fitted at a distance of 2 in. from the weirs to prevent scum from being discharged with the settled liquid. Any sludge which collected at the bottom of the tank was periodically withdrawn and conveyed by pipe-line to a sludge-drying bed on adjoining land. Sufficient head of liquid was available to allow the sludge to be removed without pumping.

The collecting tanks and the sedimentation tank served only to equalize the rate of flow of the waste waters and to remove coarse suspended matter. They were not intended to allow time for the crude wastes to ferment, though fermentation did occur in these tanks, particularly during periods of warm weather.

Settled liquid from the sedimentation tank flowed by gravity to a small steel tank provided with two V-notch flow gauges with floats and indicators. In this chamber the liquid could be mixed with a measured proportion of river water, or of final effluent from the plant. During most of the period in which the plant was in operation the settled crude liquid was diluted with final effluent from the plant.

From the mixing and gauging tank the settled and diluted liquid flowed by gravity to one or other of two circular percolating filters, A and B, over which it was distributed by means of a rotating distributor. Each filter was 25 ft. in diameter and was filled to a depth of about 4 ft. 3 in. with 77 cubic yards of hard metallurgical coke, graded 0·75 in. to 1·5 in.; the coke rested partly on the concrete floor of the filter and partly on drainage tiles, semi-circular in section, radiating from the centre to the outside wall of the filter. Effluent from the filter flowed to a channel surrounding the filter and thence to a sump.

Primary effluent from the first filter, which might be Filter A or Filter B, entered a sedimentation or humus tank of the same shape and size as the sedimentation tank for crude waste water. After settlement it was pumped to the second filter and the effluent from this filter entered a humus tank of the same shape and size as the humus tank for the liquid from the primary filter. After settlement, part of the effluent from the final humus tank was pumped back to the gauging tank to be used for diluting the settled crude liquid; the remainder was discharged to a small stream. Sludge from the humus tank receiving the effluent from the primary filter and sludge from the final humus tank could be removed to the sludge-drying bed, either by gravity flow or by pumping.

There were two sludge-drying beds, each 26 ft. long and 20 ft. wide, excavated to a depth of about 2 ft. All surplus sludge from the two experimental plants was discharged to the first of these beds; the material included sludge from the balancing and storage tanks and from the primary sedimentation tank of each plant, humus from the two humus tanks of the double-filtration plant, and surplus activated sludge from the final sedimentation tank of the activated sludge plant. Supernatant liquor from the first drying bed was returned to the storage tanks and treated in admixture with the waste waters. At intervals of two or three months, the wet sludge was pumped from the first drying bed to the second, which was at a slightly higher level. About twice a year a layer of partly dried sludge, about 2 in. thick, was removed from the second bed.

During most of the period of operation of the plant, the order of the two filters in series was changed at intervals usually of about 3 weeks.

Treatment of Milk Washings

Operation of the experimental double-filtration plant was begun in August 1935. For a few weeks settled and diluted milk washings were supplied to the filters at a rate equivalent to 100 gallons per day per cubic yard of medium in each filter or 50 gallons per day per cubic yard of medium in the two filters together. It was found, however, that at this rate of flow the distributors did not move uniformly and distribution of the liquid on to the filters was in consequence unsatisfactory. To obtain uniform distribution it was necessary to supply not less than 12,600 gallons of diluted liquid daily, equivalent to about 81 gallons per day per cubic yard of medium in the two filters together. This rate of flow was maintained during most of the period between 7th August 1935 and 5th April 1936. For two months, however, between the middle of December 1935 and the middle of February 1936, milk washings were not

FIG. 1.

PLAN OF DOUBLE-FILTRATION PLANT, ELLESMERE

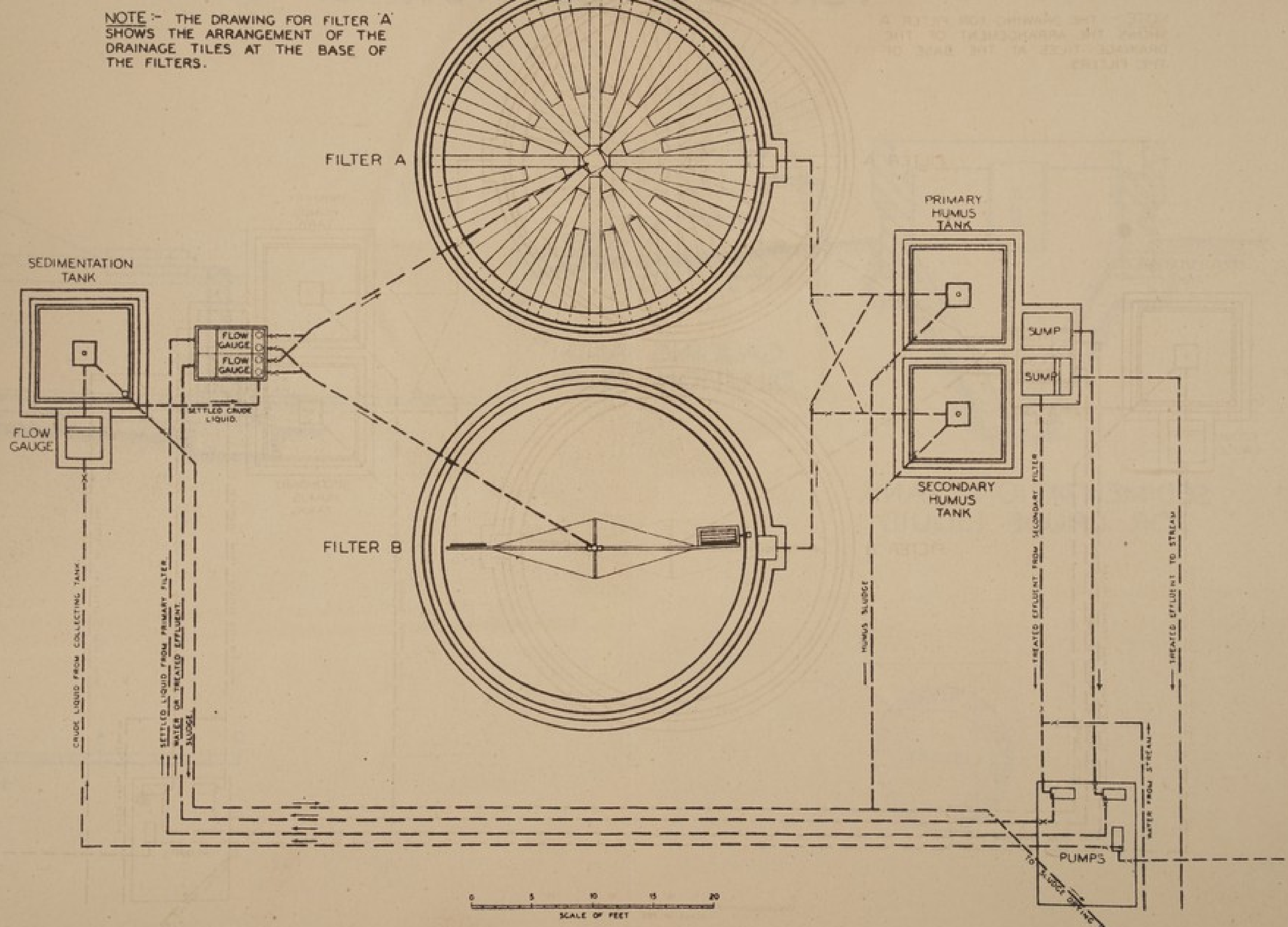
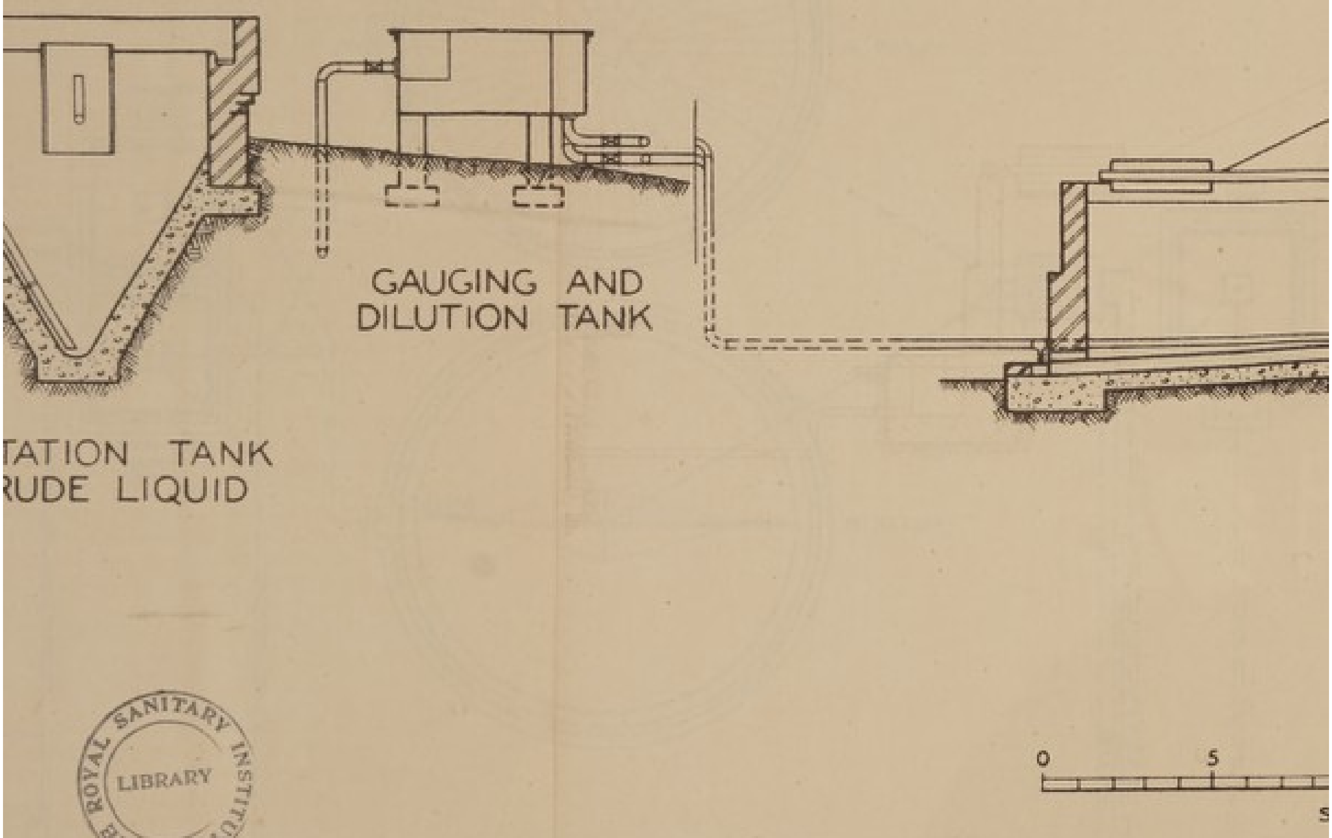


FIG. 2

VERTICAL SECTION OF DOUBLE-F



always available in sufficient quantity and during the night purified effluent was applied to the primary filter.

From 7th August to 2nd September 1935, the mixture supplied to the filters contained one volume of settled crude liquid with six volumes of purified effluent; from 2nd September 1935 to 5th April 1936 the liquid treated was usually a mixture of one volume of settled crude milk washings with four volumes of purified effluent. Occasionally large variations in the strength of the crude milk washings occurred and the proportions of crude liquid and purified effluent were then altered.

At first little growth of film occurred on the surface of the medium in the primary filter and the order of the filters in series was not changed until 9th September, nearly 5 weeks after the beginning of the experiments. Changes in the order of the filters in series were afterwards made at intervals of about 3 weeks.

The average results of analysis of samples of liquid from different parts of the plant, during the period 7th August 1935 to 5th April 1936, are given in Table XXXIII. These results show that the crude milk washings in the

TABLE XXXIII. *Treatment of Milk Washings in Two Percolating Filters in Series with Periodic Change in the Order of the Filters*
Average Results, 7th August 1935 *to* 5*th April* 1936

Rate of treatment of diluted milk washings 81 gallons per day per cubic yard of medium in the two filters together

	Crude milk washings	Crude milk washings after sedimentation	Settled and diluted crude liquid supplied to primary filter	Settled effluent from primary filter	Settled effluent from secondary filter
Temperature (° C.)	19	14	9	9	7·5
*p*H value	7·1	6·7	7·2	7·9	8·2
Parts per 100,000					
Biochemical oxygen demand ..	82	70	21	> 2·4	0·8
Oxygen absorbed from acid permanganate in 4 hours ..	15·0	11·1	3·8	1·04	0·64
Dissolved oxygen	—	—	—	0·81	1·03
Total nitrogen (as N)	2·77	2·91	1·13	0·59	0·75
Ammonia (as N)	0·87	1·39	0·35	0·03	0·03
Nitrite (as N)	—	—	—	0·006	0·002
Nitrate (as N)	—	—	—	0·31	0·61
Soluble solids	86·4	91·4	75·1	70·6	69·7
Suspended solids	27·1	22·7	9·2	0·6	0
Incubation Test					
No. of samples tested ..	—	—	—	33	33
No. of samples passed	—	—	—	27	33
No. of samples failed	—	—	—	6	0

collecting tank had a biochemical oxygen demand of about 80 parts per 100,000 parts; the final effluent after sedimentation had an average biochemical oxygen demand of only 0·8 part per 100,000 parts. The purification achieved in the plant, calculated from the reduction in biochemical oxygen demand, was thus about 99 per cent. The final effluent contained a trace of nitrite and an appreciable quantity of nitrate. It did not contain any fat, though fat was present in the crude milk washings in a concentration of about 20 parts per 100,000.

Between the middle of January and the middle of February the temperature of the air was low. At night the temperature of the air near the surface of the filtering medium was often below 0° C. and on one occasion some of the liquid froze on the surface of the filters. The quality of the final effluent usually deteriorated slightly during particularly cold weather. Thus on 11th February, when the temperature of the final effluent was never higher than 0·5° C., the biochemical oxygen demand of the settled and diluted milk washings was 27 parts per 100,000, that of the primary effluent after sedimentation was 9·6 parts per 100,000, and that of the final effluent after sedimentation was 2·7 parts per 100,000. The average biochemical oxygen demands during the whole of February were: settled and diluted milk washings, 24·1 parts per 100,000; primary effluent after sedimentation, 2·6 parts per 100,000; and settled final effluent, 0·9 part per 100,000.

On 10th September 1935, an accident occurred in the factory and very strong milk washings, with a biochemical oxygen demand of nearly 3,770 parts per 100,000, were admitted to the collecting tank of the filtration plant. The liquid distributed on the primary filter on 10th September, even after sedimentation and dilution with purified effluent, had a biochemical oxygen demand of more than 47 parts per 100,000; the exact figure for the biochemical oxygen demand is not known, since all the dissolved oxygen was used up during incubation of the samples under test, but there is no doubt that the figure was greatly in excess of 47 parts per 100,000. As a result, a layer of fat was deposited on both the primary and secondary filters, and the upper layer of the primary filter, to a depth of about 1 ft. from the surface, became partially choked. By 2nd October the abnormal deposits of solid matter and growths of biological film had disappeared. On 11th September, one day after the flush of strong milk washings had been applied to the primary filter, the biochemical oxygen demand of the settled effluent from the primary filter was 9·4 parts per 100,000, and that of settled effluent from the secondary filter was 3·1 parts per 100,000. By the following day, however, the biochemical oxygen demand of the settled effluent from the secondary filter had fallen to 0·7 part per 100,000.

On 6th April 1936 the rate of flow of settled and diluted milk washings was increased to 19,200 gallons per day; this corresponds with a rate of treatment of 124 gallons per day per cubic yard of medium in the two filters together. Treatment at this rate was continued until 19th June, a period of about 6 weeks. No excessive growth of biological film or deposition of solid matter in the filtering medium occurred and effluents of good quality were obtained (Table XXXIV).

Between 20th June and 18th November 1936, that is for a period of nearly 22 weeks, settled and diluted milk washings were passed through the plant at a rate of approximately 25,200 gallons per day; this corresponds with a rate of treatment of 164 gallons per day per cubic yard of medium in the two filters. During this period the milk washings leaving the factory became more dilute and the proportion of settled milk washings in the mixture of milk washings and final effluent applied to the primary filter was increased from 20 per cent to 40 per cent of the total volume of liquid. The results obtained during this period are given in Table XXXV. These results show that milk washings, which after sedimentation and dilution had an average biochemical oxygen demand of 21 parts per 100,000 parts, could be treated at a rate equivalent to 164 gallons per day per cubic yard of medium to yield an effluent which, after sedimentation, had an average biochemical oxygen demand of only 0·3 part per 100,000 parts. The effluent was well oxygenated and contained a high proportion of nitrate.

On 12th July slight ponding occurred on the surface of the medium in Filter A after it had been in use as the primary filter for 3 weeks. The order of the filters in series was then changed. Three days later slight ponding was still evident on the surface of Filter A, but the ponding entirely disappeared during the next 4 days. With this exception, no ponding of the filters occurred during the whole of the period of 22 weeks. During part of the period the amount of biological film on the medium at the surface of both the primary and the secondary filters was very small; this appeared to be due to biological activity within the filters, resulting in the discharge of large quantities of humus. A marked increase in the amount of solid matter discharged from

TABLE XXXIV. *Treatment of Milk Washings in Two Percolating Filters in Series with Periodic Change in the Order of the Filters*

Average Results, 6th April to 19th June 1936

Rate of treatment of diluted milk washings 124 gallons per day per cubic yard of medium in the two filters together

	Crude milk washings	Crude milk washings after sedimentation	Settled and diluted crude liquid supplied to primary filter	Settled effluent from primary filter	Settled effluent from secondary filter
Temperature (° C.)	29	26	20	14	13
*p*H value	5·8	5·7	6·9	8·0	8·1
Parts per 100,000					
Biochemical oxygen demand ..	128	103	23	1·4	0·8
Oxygen absorbed from acid permanganate in 4 hours ..	20·4	13·0	3·6	0·86	0·75
Dissolved oxygen	—	—	—	0·85	0·99
Total nitrogen (as N)	5·37	4·60	1·86	1·04	1·40
Ammonia (as N)	0·66	1·11	0·24	0	0
Nitrite (as N)	—	—	—	0	0
Nitrate (as N)	—	—	0·49	0·56	0·99
Soluble solids	107·8	97·7	71·9	66·1	63·8
Suspended solids	45·0	33·6	10·7	0·3	0·4
Incubation Test					
No. of samples tested ..	—	—	—	11	11
No. of samples passed ..	—	—	—	11	11
No. of samples failed	—	—	—	0	0

Filter B was first noticed on 24th October, when Filter B was being used as the primary filter; the discharge continued after the order of the filters in series had been changed on 26th October. A marked increase in the amount of solid matter discharged from Filter A was first noticed on 31st October. On 4th November the effluent from the primary filter contained, before sedimentation, 3·4 parts of suspended solids per 100,000 parts; the effluent from the secondary filter contained 5·8 parts per 100,000. The humus discharged from both filters settled rapidly in the humus tanks. The sludge obtained from the settling tank for primary effluent on 24th October contained 4·3 per cent of dry matter and the sludge on 31st October contained 3·3 per cent. On 31st October sludge from the settling tank for secondary effluent contained

4·0 per cent of dry matter. The loss on ignition of the humus was 40 to 60 per cent of the dry weight.

By November 1936 the installation of a new churn-washing machine and modifications in the operations in the factory had so reduced the quantity of milk carried away in the washing water that the experimental plant could no longer be operated at the desired load. The volume of medium in each filter was therefore reduced from about 80 cubic yards to approximately 42 cubic yards by reducing the diameter from 25 ft. to 18 ft. The change was made by removing the filtering medium and inserting a cylindrical sheath of galvanized iron sheeting parallel with the permanent brick wall of each filter. The medium was not washed or re-graded before replacement in the filters. Jet-

TABLE XXXV. *Treatment of Milk Washings in Two Percolating Filters in Series with Periodic Change in the Order of the Filters*
Average Results, 20th June to 18th November 1936

Rate of treatment of diluted milk washings 164 gallons per day per cubic yard of medium in the two filters together

	Crude milk washings	Crude milk washings after sedimentation	Settled and diluted crude liquid supplied to primary filter	Settled effluent from primary filter	Settled effluent from secondary filter
Temperature (° C.)	46	40	29	17	15
*p*H value	6·1	6·3	6·9	7·9	8·1
Parts per 100,000					
Biochemical oxygen demand	60	53	21	0·7	0·3
Oxygen absorbed from acid permanganate in 4 hours	6·9	5·4	2·5	0·65	0·59
Dissolved oxygen	—	—	—	0·83	0·93
Total nitrogen (as N)	2·58	2·58	1·42	0·63	0·68
Ammonia (as N)	0·69	1·09	0·50	0	0
Nitrite (as N)	—	—	—	0	0
Nitrate (as N)	—	—	0·26	0·42	0·64
Soluble solids	47·2	50·4	44·1	40·6	40·8
Suspended solids	29·7	23·6	10·9	0·5	0·6
Incubation Test					
No. of samples tested	—	—	—	16	16
No. of samples passed	—	—	—	16	16
No. of samples failed	—	—	—	0	0

impelled distributors were substituted for the water wheel type of distributors originally installed.

The opportunity was also taken of altering the pipe connections between the filters and the humus tanks. Originally the pipe connections were arranged so that each tank could be supplied with effluent from either Filter A or Filter B. One tank was used always for the sedimentation of effluent from the primary filter and the other for effluent from the secondary filter. It was found that, owing to the small head available between the effluent channels of the filters and the humus tanks, solid matter was frequently deposited in the cross-connections between the tanks and filters, and caused flooding in the effluent channels. The connections were therefore shortened by connecting each filter permanently to one humus tank, so that a tank which had been used for sedimentation of effluent from the primary filter would be used for sedimentation of effluent from the secondary filter when the order of the filters in series was changed. Operation of the plant was suspended between 19th November and 8th December 1936, while these alterations were being made.

When operation of the plant was resumed, settled and diluted milk washings were treated at a rate equivalent to 160 gallons per day per cubic yard of medium in the two filters together. The average results of analysis of the liquid at different points in the plant during the period of about 6 weeks from 9th December 1936 to 22nd January 1937 are given in Table XXXVI.

TABLE XXXVI. *Treatment of Milk Washings in Two Percolating Filters in Series with Periodic Change in the Order of the Filters*
Average Results, 9th December 1936 *to* 22*nd January* 1937

Rate of treatment of diluted milk washings 160 gallons per day per cubic yard of medium in the two filters together

	Crude milk washings	Crude milk washings after sedimentation	Settled and diluted crude liquid supplied to primary filter	Settled effluent from primary filter	Settled effluent from secondary filter
Temperature (° C.)	35	19	12·5	10·5	10
*p*H value	6·9	6·9	7·2	7·7	7·9
Parts per 100,000					
Biochemical oxygen demand..	21	23	11	1·1	0·8
Oxygen absorbed from acid permanganate in 4 hours ..	3·4	3·2	1·6	0·7	0·6
Dissolved oxygen	—	—	—	1·12	1·08
Total nitrogen (as N)	1·17	1·17	0·69	0·50	0·44
Ammonia (as N)	0·25	0·37	0·25	0	0
Nitrite (as N)	—	—	—	0	0
Nitrate (as N)	—	—	0·19	0·30	0·39
Soluble solids	33·9	37·1	37·6	34·5	35·7
Suspended solids	11·1	11·8	6·1	2·0	2·6
Incubation Test					
No. of samples tested ..	—	—	—	5	5
No. of samples passed ..	—	—	—	5	5
No. of samples failed	—	—	—	0	0

After operation for 24 days solid matter had accumulated on the surface of the medium in Filter A, the primary filter, and had caused some ponding, especially in that part of the medium immediately below the track of each jet of the distributor. The order of the filters in series was then changed and after 5 days no ponding was visible on Filter A. A considerable amount of solid matter, however, had been deposited in the surface layer of the medium in Filter B. It was found by quantitative determinations that the amount of film associated with a measured volume of medium from the primary filter on 30th December 1936 and 16th January 1937 was considerably greater than had been found previously during the investigation.

The average biochemical oxygen demand of the liquid applied to the primary filter was 11·1 parts per 100,000 and the average biochemical oxygen demand of the final effluent after sedimentation was 0·8 part per 100,000 parts. The degree of purification achieved was less than during the period 20th June to 18th November 1936, when the average biochemical oxygen demand of settled and diluted milk washings was reduced from 21 parts to 0·3 part per 100,000 parts by treatment at a rate of 160 gallons per day per cubic yard of medium.

Although the filters had been reduced to about one half thei- original capacity, a supply of crude liquid at a rate of 160 gallons per day per cubic yard of filtering medium could not be maintained during the winter of 1936-37 owing to the seasonal decrease in the quantity of milk handled by the factory and to further reductions in the volume of milk lost in the milk washings. From 23rd January to 17th March 1937 the plant was operated for an average time of only 16·5 hours daily. During this period the filters were supplied at a rate of 6·8 gallons per hour per cubic yard of medium in the two filters, equivalent to 164 gallons per 24 hours per cubic yard of medium. The settled and diluted milk washings applied to the primary filter had an average biochemical oxygen demand of about 17 parts per 100,000, and the final effluent after sedimentation had an average biochemical oxygen demand of less than 1 part per 100,000 (Table XXXVII).

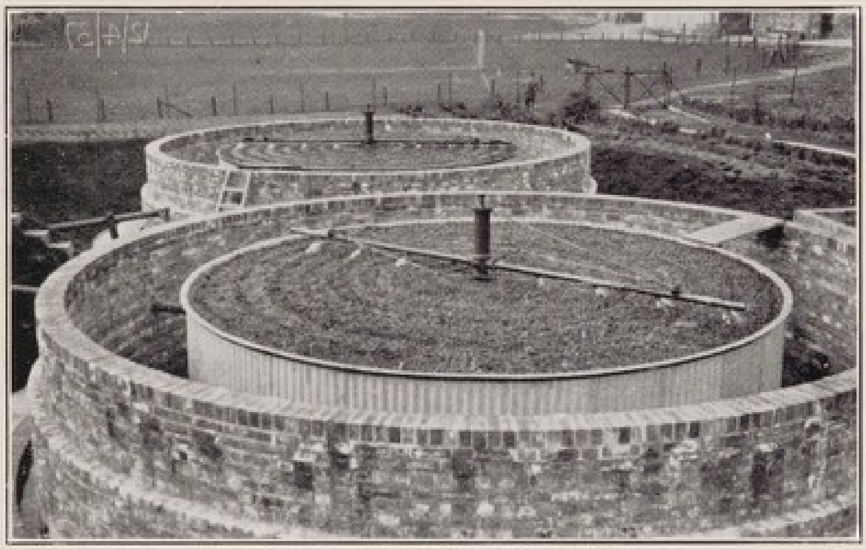
TABLE XXXVII. *Treatment of Milk Washings in Two Percolating Filters in Series with Periodic Change in the Order of the Filters*
Average Results, 23rd January to 17th March 1937

Plant operated for only 16·5 hours daily
Rate of treatment of diluted milk washings equivalent to 164 gallons per day (6·8 gallons per hour) per cubic yard of medium in the two filters together

	Crude milk washings	Crude milk washings after sedimentation	Settled and diluted crude liquid supplied to primary filter	Settled effluent from primary filter	Settled effluent from secondary filter
Temperature (° C.)	26	18·5	15·5	8·5	7
*p*H value	6·8	6·8	6·9	7·6	7·8
Parts per 100,000					
Biochemical oxygen demand..	23	21	17	1·5	0·8
Oxygen absorbed from acid permanganate in 4 hours ..	3·6	2·8	2·5	0·72	0·56
Dissolved oxygen	—	—	—	1·00	1·10
Total nitrogen (as N)	1·29	1·21	1·26	0·81	0·89
Ammonia (as N)	0·47	0·49	0·44	0	0
Nitrite (as N)	—	—	—	Trace	0
Nitrate (as N)	—	—	0·13	0·44	0·61
Soluble solids	39·3	39·6	39·3	33·4	34·2
Suspended solids	12·8	9·9	8·9	3·0	1·9
Incubation Test					
No. of samples tested ..	—	—	—	7	7
No. of samples passed ..	—	—	—	7	7
No. of samples failed	—	—	—	0	0

To obtain information on the behaviour of the plant at high rates of flow, it was decided to add milk to the milk washings so as to provide sufficient liquid of the desired strength. The primary filter was then supplied with settled

(*a*)



(*b*)

PLATE 2. Photographs of the Filters of the Double-Filtration Plant, April 1937.

Showing different stages in the removal of biological film and deposited solid matter from the surface of one filter and the accumulation of similar material on the surface of the other filter.

(*a*) 9th April. Filter A, in foreground, the primary filter.

(*b*) 12th April. Order of filters in series changed on 10th April. Filter A, in foreground, had been the secondary filter for two days.

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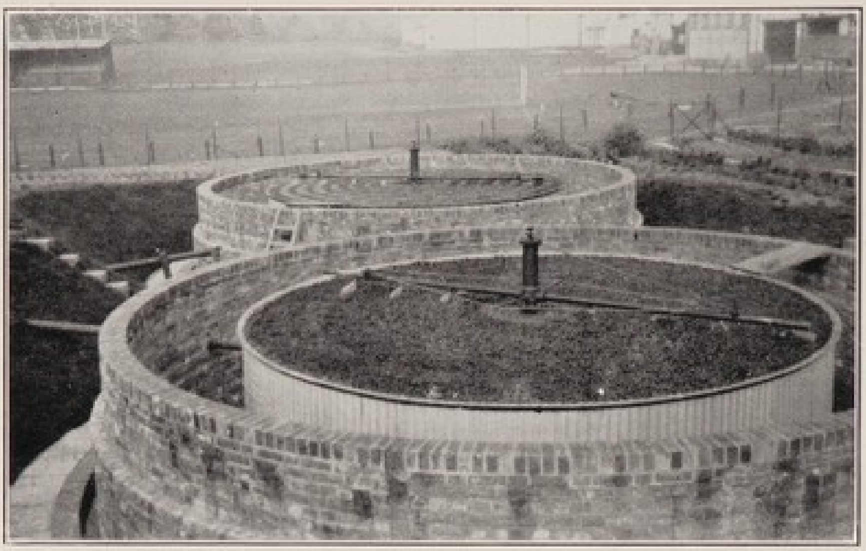
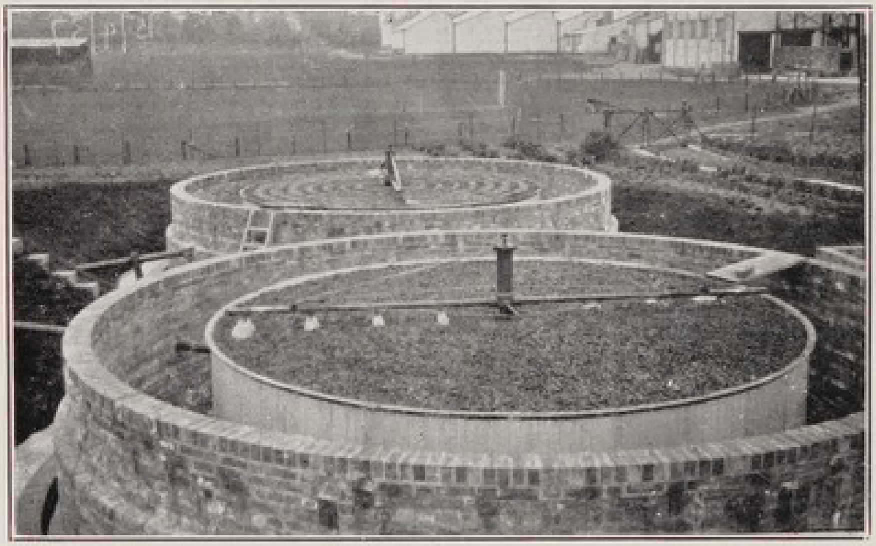


(*c*)



(*d*)

PLATE 2 (*contd.*). Photographs of the Filters of the Double-Filtration Plant April 1937.

Showing different stages in the removal of biological film and deposited solid matter from the surface of one filter and the accumulation of similar material on the surface of the other filter.

(*c*) 13th April. Filter A had been the secondary filter for three days.

(*d*) 15th April. Filter A had been the secondary filter for five days.

and diluted liquid with a biochemical oxygen demand of about 30 parts per 100,000; the plant was run continuously throughout the 24 hours and the rate of flow was 160 gallons per day per cubic yard of medium in the two filters. After operating for 3 days under these conditions the rate of flow was increased to 200 gallons per day per cubic yard of medium, and this rate was maintained for a further 9 days.

On 31st March 1937 the rate of supply of settled and diluted milk washings was increased to the equivalent of 240 gallons per day per cubic yard of filtering medium; this rate of treatment was continued until 4th June, that is for about 9 weeks. The average results are given in Table XXXVIII.

TABLE XXXVIII. *Treatment of Milk Washings in Two Percolating Filters in Series with Periodic Change in the Order of the Filters*
Average Results, 31*st March to* 4*th June* 1937

Rate of treatment of diluted milk washings 240 gallons per day per cubic yard of medium in the two filters together

	Crude milk washings	Crude milk washings after sedimentation	Settled and diluted crude liquid supplied to primary filter	Settled effluent from primary filter	Settled effluent from secondary filter
Temperature (° C.)	35	31	23·5	19	17·5
*p*H value	6·0	6·0	6·5	7·6	7·8
Parts per 100,000					
Biochemical oxygen demand	60	55	30	1·4	1·0
Oxygen absorbed from acid permanganate in 4 hours	8·6	5·9	3·5	0·76	0·70
Dissolved oxygen	—	—	—	0·63	0·81
Total nitrogen (as N)	2·50	2·52	1·67	0·76	0·92
Ammonia (as N)	0·78	1·07	0·61	0	0
Nitrite (as N)	—	—	—	0·01	0
Nitrate (as N)	—	—	0·08	0·39	0·59
Soluble solids	44·1	46·5	41·5	32·8	34·4
Suspended solids	22·2	16·6	11·2	2·3	2·1
Incubation Test					
No. of samples tested	—	—	—	9	9
No. of samples passed	—	—	—	9	9
No. of samples failed	—	—	—	0	0

The liquid supplied to the primary filter had the high average biochemical oxygen demand of approximately 30 parts per 100,000, and the average biochemical oxygen demand of the final effluent, after sedimentation, was 1 part per 100,000. During the period the amount of film and deposited solid matter in the surface layer of medium increased, and it was necessary to change the order of the filters in series at least once a fortnight in order to prevent ponding. The material which had accumulated on the surface of the primary filter was rapidly dispersed, however, when the order of the filters in series was changed; the concentric rings of growth in the tracks of the jets of the distributor had usually disappeared by the second or third day after changing the order of the filters. This is well illustrated in Plate 2, in which are shown four photographs of the two filters taken between 9th May and 15th May 1937.

Treatment of Mixtures of Whey Washings and Milk Washings

On 9th June 1937 experiments were begun on the treatment of washings containing both milk and whey. The first mixture contained one volume of whey washings with three volumes of milk washings; approximately half of the total polluting matter was contributed by each constituent. Owing to the schedule of operation in the factory and the arrangement of the waste water drains from the factory it was necessary to store whey washings for about 24 hours before making up the mixture of whey washings and milk washings in the collecting tank; the milk washings entered the collecting tank immediately after discharge from the factory. The mixed washings, after sedimentation, were diluted with treated effluent so as to provide a liquid with a biochemical oxygen demand of 25 to 30 parts per 100,000 parts for application to the primary filter at a rate equivalent to 160 gallons per day per cubic yard of medium in the two filters.

The average results obtained between 9th June and 2nd July 1937 are given in Table XXXIX. A well-purified final effluent with an average

Table XXXIX. *Treatment of Mixtures containing Three Volumes of Milk Washings and One Volume of Whey Washings in Two Percolating Filters in Series with Periodic Change in the Order of the Filters.*
Average Results, 9th June to 2nd July 1937

Rate of treatment of diluted washings 160 gallons per day per cubic yard of medium in the two filters together

	Crude liquid	Crude liquid after sedimentation	Settled and diluted crude liquid supplied to primary filter	Settled effluent from primary filter	Settled effluent from secondary filter
Temperature (° C.)	32	29	22	20	18·5
*p*H value	5·4	5·4	6·4	7·7	8·0
Parts per 100,000					
Biochemical oxygen demand	77	68	27	0·8	0·5
Oxygen absorbed from acid permanganate in 4 hours	11·9	7·3	3·9	1·35	1·03
Dissolved oxygen	—	—	—	0·62	0·81
Total nitrogen (as N)	2·20	2·30	1·30	0·49	0·51
Ammonia (as N)	0·38	0·88	0·24	0	0
Nitrite (as N)	—	—	—	0	0
Nitrate (as N)	—	—	0·09	0·25	0·41
Soluble solids	47·5	54·4	53·5	43·5	39·9
Suspended solids	12·0	12·6	5·4	1·4	1·0
Incubation Test					
No. of samples tested	—	—	—	3	3
No. of samples passed	—	—	—	3	3
No. of samples failed	—	—	—	0	0

biochemical oxygen demand of only 0·5 part per 100,000 parts was obtained; the effluent was well oxygenated and contained nitrate but neither nitrite nor ammonia.

For a period of about 4 weeks, 3rd July to 30th July, a mixture of equal volumes of whey washings and milk washings was treated. Approximately three-quarters of the total polluting matter was due to the whey washings. The rate of treatment was equivalent to 160 gallons per day per cubic yard of medium in the two filters. Average results of analysis of liquids from different points in the plant are shown in Table XL. The average biochemical oxygen demand

TABLE XL. *Treatment of Mixtures containing Equal Volumes of Milk Washings and Whey Washings in Two Percolating Filters in Series with Periodic Change in the Order of the Filters*

Average Results, 3rd July to 30th July 1937

Rate of treatment of diluted washings 160 gallons per day per cubic yard of medium in the two filters together

	Crude liquid	Crude liquid after sedimentation	Settled and diluted crude liquid supplied to primary filter	Settled effluent from primary filter	Settled effluent from secondary filter
Temperature (°C.)	31	29	22	20	19
*p*H value	5·2	5·5	6·4	7·7	7·8
Parts per 100,000					
Biochemical oxygen demand	101	74	26	0·9	0·3
Oxygen absorbed from acid permanganate in 4 hours	17·8	8·7	4·2	1·20	0·91
Dissolved oxygen	—	—	—	0·53	0·79
Total nitrogen (as N)	2·75	2·44	1·11	0·59	0·63
Ammonia (as N)	0·78	1·22	0·36	0·18	0·03
Nitrite (as N)	—	—	—	0	0
Nitrate (as N)	—	—	0·06	0·20	0·40
Soluble solids	54·0	51·0	38·9	29·1	33·6
Suspended solids	19·8	16·4	13·1	1·6	1·3
Incubation Test					
No. of samples tested	—	—	—	4	4
No. of samples passed	—	—	—	4	4
No. of samples failed	—	—	—	0	0

of the settled and diluted washings was 26 parts per 100,000, and well-purified effluents were obtained by filtration of this liquid at a rate of 160 gallons per day per cubic yard of medium.

It was observed that when mixtures containing 50 per cent whey washings were treated, the type of growth on the surface of the medium differed from that which developed when milk washings only were treated. With milk washings only, a film of soft material, usually brown in colour, developed on the surface of the medium in the primary filter; with liquids containing 50 per cent whey washings the film was not so soft and was usually lighter in colour. Material deposited on the surface of the primary filter during the treatment of liquids containing whey was less easily removed, when the order of the filters in series was changed, than was material deposited during the treatment of milk washings only.

In order to obtain information on the maximum rate at which a mixture of equal volumes of whey washings and milk washings could be treated in the filtration plant, the rate of flow of settled and diluted liquid was raised at the end of July 1937 to 240 gallons per day per cubic yard of medium. Treatment at this rate was continued until 24th September, that is for a period of about 8 weeks. The average results are given in Table XLI. Throughout the period,

TABLE XLI. *Treatment of Mixtures containing Equal Volumes of Milk Washings and Whey Washings in Two Percolating Filters in Series with Periodic Change in the Order of the Filters*

Average Results, 31st July to 24th September 1937

Rate of treatment of diluted washings 240 gallons per day per cubic yard of medium in the two filters together

	Crude liquid	Crude liquid after sedimentation	Settled and diluted crude liquid supplied to primary filter	Settled effluent from primary filter	Settled effluent from secondary filter
Temperature (° C.)	33	30·5	25	22·5	21
*p*H value	5·4	5·3	6·3	7·4	7·7
Parts per 100,000					
Biochemical oxygen demand	65	57	26	>1·7	0·4
Oxygen absorbed from acid permanganate in 4 hours	13·4	9·5	4·9	1·25	0·77
Dissolved oxygen	—	—	—	0·37	0·79
Total nitrogen (as N)	1·91	1·71	0·90	0·46	0·55
Ammonia (as N)	0·39	0·53	0·23	0·06	0·04
Nitrite (as N)	—	—	—	0	0
Nitrate (as N)	—	—	0·04	0·09	0·35
Soluble solids	35·1	39·9	45·0	30·6	29·9
Suspended solids	15·9	15·8	8·0	2·3	1·3
Incubation Test					
No. of samples tested	—	—	—	8	8
No. of samples passed	—	—	—	7	8
No. of samples failed	—	—	—	1	0

final effluents with a low biochemical oxygen demand were obtained; the average value was 0·4 part per 100,000 parts and the highest value on any day was 1·4 parts per 100,000 parts. Towards the end of September, however, the filters showed signs of ponding. This condition appeared to be caused by the formation of a relatively impervious layer of film on the surface of the medium; when the film was pierced, any pools of liquid on the surface of the medium rapidly disappeared and did not re-appear until the medium was again covered by a further growth of film. On 24th September the supply of crude liquid was stopped and the filters were cleaned by circulating purified effluent for a period of 8 days.

When operation of the plant was resumed on 5th October 1937, the filters were supplied with a settled and diluted mixture containing three volumes of whey washings with one volume of milk washings; the rate of treatment of the diluted crude liquid was reduced from 240 gallons to 160 gallons per day per cubic yard of filtering medium. The average results obtained during the period 5th October to 21st November 1937 are given in Table XLII. Between 5th and 31st October the average figures for biochemical oxygen demand of the diluted crude liquid and of the effluent from the primary and secondary filters were: diluted crude liquid, 28 parts per 100,000; effluent from primary filter, 1·5 parts per 100,000; effluent from secondary filter, 0·5 part per 100,000. During October there was no excessive growth of film on the filters. During November difficulty was experienced in making up a mixture of whey washings and milk washings with a biochemical oxygen demand of 25 to 30 parts per 100,000; thus, between 1st and 20th November the average biochemical oxygen demand of the diluted crude liquid was 41 parts per 100,000. The quality of the primary and secondary effluents gradually deteriorated and excessive growths accumulated on the surface of the filters, which, however, were never badly ponded. The surface of the medium was turned over with a fork and canal water was circulated through the two filters from 22nd November to 6th December, a period of 15 days. Most of the surface growth disappeared and a large amount of solid matter was washed out of the filters.

TABLE XLII. *Treatment of Mixtures containing Three Volumes of Whey Washings and One Volume of Milk Washings in Two Percolating Filters in Series with Periodic Change in the Order of the Filters.*
Average Results, 5th October to 21st November 1937

Rate of treatment of diluted washings 160 gallons per day per cubic yard of medium in the two filters together

	Crude liquid	Crude liquid after sedimentation	Settled and diluted crude liquid supplied to primary filter	Settled effluent from primary filter	Settled effluent from secondary filter
Temperature (° C.)	—	19·5	16	14·5	12·5
*p*H value	4·8	4·9	5·8	7·3	7·5
Parts per 100,000					
Biochemical oxygen demand	78	73	34	>2·5	0·7
Oxygen absorbed from acid permanganate in 4 hours	15·4	12·5	6·3	1·1	0·7
Dissolved oxygen	—	—	—	—	0·91
Total nitrogen (as N)	2·67	2·81	1·64	0·51	0·60
Ammonia (as N)	0·68	0·81	0·45	0·09	0·06
Nitrite (as N)	—	—	—	0·004	0·009
Nitrate (as N)	—	—	0·14	0·07	0·40
Soluble solids	63·2	74·0	55·8	40·1	35·0
Suspended solids	12·0	10·7	6·7	2·2	1·2

From 7th December 1937 to 11th February 1938, a period of nearly 10 weeks, no whey washings were produced at the factory at Ellesmere and the liquid treated consisted of milk washings mixed with cold water from the canal and with a measured volume of whole whey. The quantity of whey added was such that the final mixture was equivalent to a liquid containing three volumes of whey washings and one volume of milk washings. The average biochemical oxygen demand of the settled and diluted liquid supplied to the primary filter was 19 parts per 100,000; this liquid was supplied at a rate equivalent to 160 gallons per day per cubic yard of filtering medium in the two filters. During this period the plant was operated under adverse conditions, since the temperature of the mixture of milk washings, canal water, and whole whey, which was treated during the coldest months of the year, was much lower than that of a mixture of milk washings and whey washings as discharged from the factory. The average biochemical oxygen demand of the final effluent throughout the period was 0·9 part per 100,000 (Table XLIII),

TABLE XLIII. *Treatment of Mixtures containing Three Volumes of Whey Washings and One Volume of Milk Washings in Two Percolating Filters in Series with Periodic Change in the Order of the Filters*

Average Results, 7th December 1937 *to* 11*th February* 1938

Rate of treatment of diluted washings 160 gallons per day per cubic yard of medium in the two filters together

	Crude liquid	Crude liquid after sedimentation	Settled and diluted crude liquid supplied to primary filter	Settled effluent from primary filter	Settled effluent from secondary filter
Temperature (° C.)	—	10	9	8	10·5
*p*H value	5·6	5·2	6·3	7·1	7·3
Parts per 100,000					
Biochemical oxygen demand	45	40	19	>1·6	0·9
Oxygen absorbed from acid permanganate in 4 hours	15·7	12·8	6·1	1·5	0·7
Dissolved oxygen	—	—	—	0·75	1·06
Total nitrogen (as N)	1·73	1·50	0·84	0·39	0·50
Ammonia (as N)	0·07	0·18	0·05	0·01	0·02
Nitrite (as N)	—	—	—	0·01	0·04
Nitrate (as N)	—	—	0·04	0·08	0·21
Soluble solids	74·4	48·4	36·9	28·4	2·50
Suspended solids	12·6	10·6	5·1	1·8	0·9

and except on one occasion, when a liquid containing an abnormally high concentration of whey was supplied to the primary filter, the biochemical oxygen demand of the final effluent was never appreciably higher than 1 part per 100,000. After the filters had been operated under these conditions for about 10 weeks, however, a tough resistant growth accumulated on the surface of the filtering medium and some ponding occurred. The filters were therefore again cleaned by circulating treated effluent through them for a period of 23 days.

From 7th March to 11th August 1938 diluted whey washings only were treated in the filtration plant. After these experiments had been completed the filters were again supplied with a liquid containing the equivalent of three volumes of whey washings with one volume of milk washings, diluted with final effluent before application to the primary filter. The mixture of whey washings and milk washings was made by diluting the required amounts of whole whey and milk with water. Approximately nine-tenths of the total polluting matter, as determined by the test for biochemical oxygen demand, was due to the whey washings and one-tenth was due to the milk washings.

Throughout the period well-oxygenated effluents of good quality were obtained and the condition of the filtering medium remained entirely satisfactory. The temperature was considerably higher than it had been during the period between October 1937 and March 1938, when the earlier experiments on the treatment of mixtures of three volumes of whey washings with one volume of milk washings were made. It is probable that the higher temperature was of importance in maintaining the good condition of the filtering medium in the later experiments.

Between 13th August and 15th September 1938 the average biochemical oxygen demand of the settled and diluted liquid supplied to the primary filter was 29 parts per 100,000 and the average biochemical oxygen demand of the final effluent was 0·7 part per 100,000; the effluent contained a high proportion of nitrate and the concentration of dissolved oxygen was never much less than that required for saturation (Table XLIV). It was noticed that a greater amount of fatty scum formed on the surface of the crude liquid in the storage tank than in the earlier experiments in which the temperature was lower.

TABLE XLIV. *Treatment of Mixtures containing Three Volumes of Whey Washings and One Volume of Milk Washings in Two Percolating Filters in Series with Periodic Change in the Order of the Filters*

Average Results, 13th August to 15th September 1938

Rate of treatment of diluted washings 160 gallons per day per cubic yard of medium in the two filters together

	Crude liquid	Crude liquid after sedimentation	Settled and diluted crude liquid supplied to primary filter	Settled effluent from primary filter	Settled effluent from secondary filter
Temperature (° C.)	20	24	19	18·5	18
*p*H value	4·5	4·7	5·1	7·2	7·5
Parts per 100,000					
Biochemical oxygen demand	95	73	29	0·8	0·7
Oxygen absorbed from acid permanganate in 4 hours	21·8	11·1	4·5	0·6	0·4
Dissolved oxygen	—	—	—	0·78	1·12
Total nitrogen (as N)	3·00	2·43	0·95	0·27	0·58
Ammonia (as N)	0·37	0·41	0·13	0	0
Nitrite (as N)	—	—	—	0	0·002
Nitrate (as N)	—	—	0·15	0·12	0·53
Soluble solids	68·2	26·1	26·6	19·4	17·4
Suspended solids	21·0	18·6	8·0	2·3	1·8
Incubation Test					
No. of samples tested	—	—	—	5	5
No. of samples passed	—	—	—	2	5
No. of samples failed	—	—	—	3	0

TREATMENT OF WHEY WASHINGS

From 7th March to 11th May 1938 the liquid treated in the filters consisted of whey washings only. For the first 3 weeks whey washings from the factory were available, but for the remainder of the period it was necessary to use whole whey diluted with canal water. The temperature of the crude liquid was thus much lower than that of whey washings discharged from a cheese factory. The diluted crude liquid, which had an average biochemical oxygen demand of 27 parts per 100,000, was supplied to the filters at a rate of 106 gallons per day per cubic yard of medium. It was found that the rotary distributors would not revolve satisfactorily with this rate of flow, and siphons were installed so that the liquid was applied to the filters intermittently; later the rotation of the distributors was assisted by sails which were rigged at the extremities of the distributor arms. No difficulty was experienced during this period in the operation of the plant; the filters remained in good condition, and a final effluent with an average biochemical oxygen demand of only 0·6 part per 100,000 parts was obtained; the effluent contained an appreciable amount of nitrate and was well oxygenated (Table XLV).

TABLE XLV. *Treatment of Whey Washings in Two Percolating Filters in Series with Periodic Change in the Order of the Filters*

Average Results, 7th March to 11th May 1938

Rate of treatment of diluted whey washings 106 gallons per day per cubic yard of medium in the two filters together

	Crude whey washings	Crude whey washings after sedimentation	Settled and diluted crude liquid supplied to primary filter	Settled effluent from primary filter	Settled effluent from secondary filter
Temperature (° C.)	14	14	12	11	11
*p*H value	5·1	5·1	5·6	6·9	7·2
Parts per 100,000					
Biochemical oxygen demand..	63	54	27	2·9	0·6
Oxygen absorbed from acid permanganate in 4 hours ..	17·5	16·0	6·9	1·0	0·4
Dissolved oxygen	—	—	—	0·70	1·04
Total nitrogen (as N)	1·41	1·05	0·73	0·46	0·53
Ammonia (as N)	0·05	0·04	0·11	0	0
Nitrite (as N)	—	—	—	0·01	0
Nitrate (as N)	—	—	0·15	0·16	0·47
Soluble solids	58·9	37·2	25·3	16·0	16·3
Suspended solids	8·7	7·0	4·3	1·3	0·7
Incubation Test					
No. of samples tested ..	—	—	—	9	9
No. of samples passed ..	—	—	—	0	8
No. of samples failed	—	—	—	9	1

On 12th May the rate of flow of the settled and diluted whey washings was increased from 106 gallons to 132 gallons per day per cubic yard of filtering medium. From 12th May to 24th June 1938, a period of about 6 weeks, the average biochemical oxygen demand of the settled and diluted whey washings applied to the primary filter was 21 parts per 100,000, and the average biochemical oxygen demand of the final effluent after sedimentation was 0·6 part per 100,000 (Table XLVI). No difficulty was experienced in the operation of the plant and there was no excessive growth on the surface of the filtering medium. In early June large quantities of sludge were discharged with the effluents from both filters.

From 25th June to 12th August 1938, a period of 7 weeks, settled and diluted whey washings, with an average biochemical oxygen demand of 27 parts per 100,000, were treated in the filters at a rate of 160 gallons per day per

TABLE XLVI. *Treatment of Whey Washings in Two Percolating Filters in Series with Periodic Change in the Order of the Filters*
Average Results, 12th May to 24th June 1938

Rate of treatment of diluted washings 132 gallons per day per cubic yard of medium in the two filters together

	Crude whey washings	Crude whey washings after sedimentation	Settled and diluted crude liquid supplied to primary filter	Settled effluent from primary filter	Settled effluent from secondary filter
Temperature (° C.)	14	14	12	11	11
*p*H value	4·7	4·8	5·3	6·9	7·2
Parts per 100,000					
Biochemical oxygen demand..	56	44	21	1·3	0·6
Oxygen absorbed from acid permanganate in 4 hours ..	14·1	8·8	4·4	0·5	0·3
Dissolved oxygen	—	—	—	0·68	0·92
Total nitrogen (as N)	1·33	1·13	0·71	0·33	0·59
Ammonia (as N)	1·23	1·05	0·55	0·19	0·13
Nitrite (as N)	—	—	—	0	0
Nitrate (as N)	—	—	0·10	0·11	0·43
Soluble solids	39·9	25·6	22·7	14·8	15·9
Suspended solids	9·3	6·7	4·3	0·9	2·1
Incubation Test					
No. of samples tested ..	—	—	—	6	6
No. of samples passed ..	—	—	—	2	6
No. of samples failed	—	—	—	4	0

cubic yard of filtering medium (Table XLVII). At the beginning of the period the filters were in good condition. Some difficulty was experienced during June, when it was necessary to dismantle the pump used for returning effluent from the primary filter to the secondary filter. It was also necessary to overhaul the rotary distributors, which, for some days, did not rotate freely. As a result of these difficulties there was some deterioration in the quality of the effluent from the primary filter, and the film which had accumulated on the medium in this filter was not easily removed when the order of the filters was changed. On 18th June the film was broken up by lightly forking the surface of the medium. In July and August, when the pumps and distributors were operating satisfactorily, the condition of the medium rapidly improved and the effluents from both the primary and secondary filters were of excellent quality. The average biochemical oxygen demand of the final effluent for the whole of the period from 25th June to 12th August was only 0·7 part per 100,000.

AMOUNT AND COMPOSITION OF FILM AND DEPOSITED SOLID MATTER ON FILTERING MEDIUM

From time to time during the investigation samples were taken from the surface layer of medium in the two filters and the amount and composition of the film and deposited solid matter associated with a measured volume of medium were determined. The film and deposited solid matter were removed

TABLE XLVII. *Treatment of Whey Washings in Two Percolating Filters in Series with Periodic Change in the Order of the Filters*

Average Results, 25th June to 12th August 1938

Rate of treatment of diluted washings 160 gallons per day per cubic yard of filtering medium

	Crude whey washings	Crude whey washings after sedimentation	Settled and diluted crude liquid supplied to primary filter	Settled effluent from primary filter	Settled effluent from secondary filter
Temperature (° C.)	19	22	20	19	19
*p*H value	4·6	4·6	5·0	6·9	7·5
Parts per 100,000					
Biochemical oxygen demand	83	68	27	2·8	0·7
Oxygen absorbed from acid permanganate in 4 hours	20·4	11·6	5·1	0·9	0·6
Dissolved oxygen	—	—	—	0·43	0·89
Total nitrogen (as N)	2·23	1·86	0·92	0·29	0·57
Ammonia (as N)	0·18	0·15	0·08	0·03	0·03
Nitrite (as N)	—	—	—	0·001	0·004
Nitrate (as N)	—	—	0·12	0·10	0·43
Soluble solids	42·7	33·6	26·9	19·1	18·0
Suspended solids	17·5	12·1	7·2	1·2	0·9
Incubation Test					
No. of samples tested	—	—	—	6	6
No. of samples passed	—	—	—	2	6
No. of samples failed	—	—	—	4	0

by washing the samples of medium with water. In general, it was found that the amount of material associated with the surface layer of medium in a filter increased during the period in which the filter was being used as the primary filter and decreased when the order of the filters in series was reversed. This is illustrated by the upper part of Figure 3, in which the weights of film and deposited solid matter associated with 5·5 litres of the medium from the surface of both filters at different times during the period 1st April to 11th June 1936 have been plotted. Settled and diluted milk washings only were treated during this period. From 1st April to 5th April the rate of treatment of the diluted washings was equivalent to 81 gallons per day per cubic yard of medium in the two filters together, and from 6th April to 11th June the rate was equivalent to 124 gallons per day per cubic yard of medium. The lower part of Figure 3 shows the variations which occurred in the proportion of fat in the film and deposited solid matter associated with the surface layer of medium in the two filters. In general the proportion of fat in the medium in a filter increased when the filter was supplied with settled and diluted milk washings and decreased when the filter was supplied with settled primary effluent.

In Table XLVIII are shown the average amounts of film and the proportion of fat and total nitrogen in the film associated with the medium in the surface layer of the primary and secondary filters during the period 20th January 1936 to 23rd April 1937. Throughout this period settled and diluted milk washings only were supplied to the primary filter. The rate of treatment was increased by stages from 80 gallons to 240 gallons per day per cubic yard of medium. In calculating the average amount and composition of the film, only those samples have been included which were taken at least ten days after the order of the filters in series had been changed. In general the amount of film and deposited solid matter associated with unit volume of medium was greater in the primary filter than in the secondary filter; the greatest amount of film and solid matter

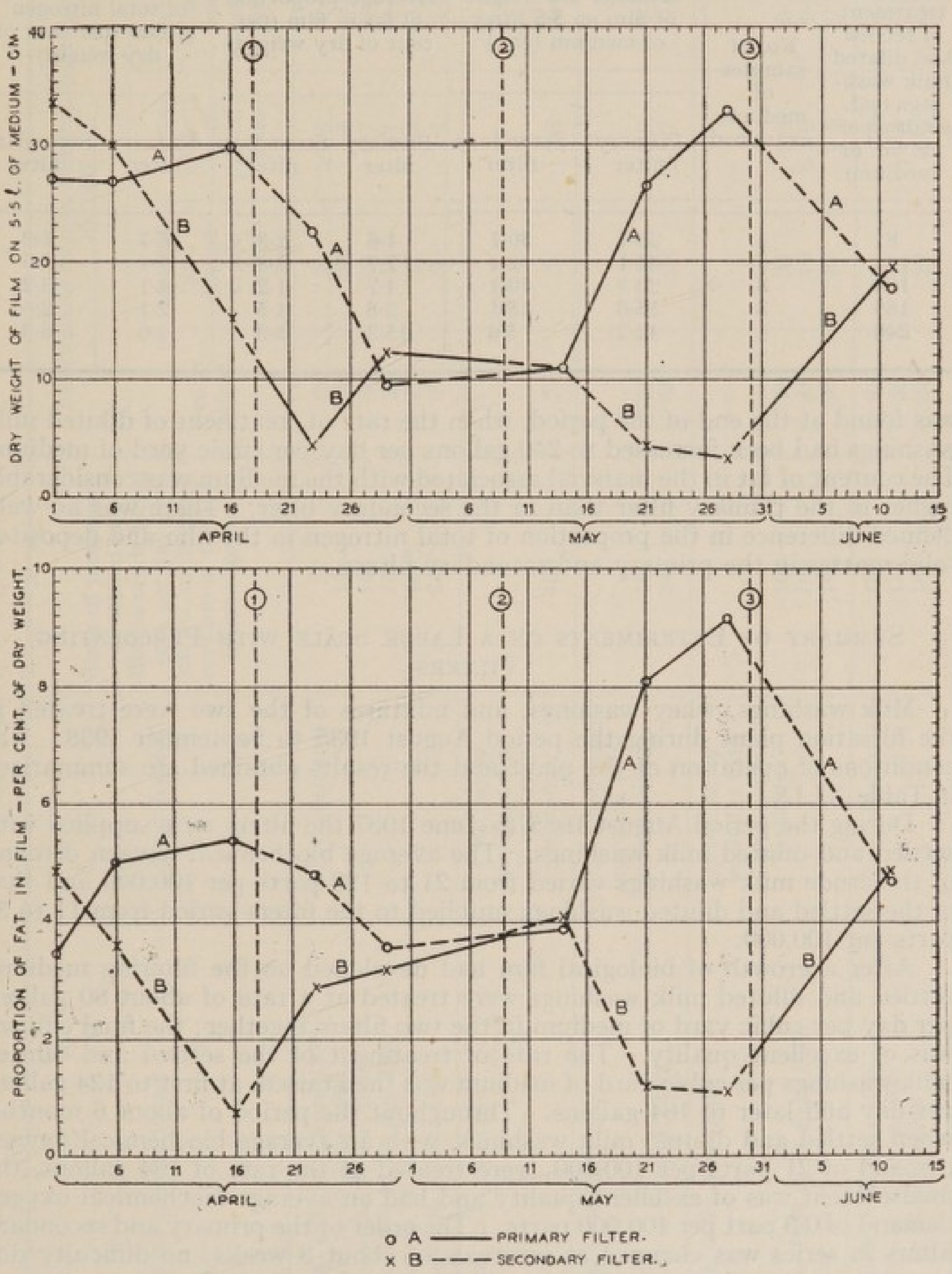


FIG. 3. Amount of Film, and Fat in Film, on Surface of Filtering Medium in Primary and Secondary filters, 1st April to 11th June 1936.

The vertical dotted lines 1, 2, and 3 show the dates on which the order of the filters in series was changed.

TABLE XLVIII. *Average Amount of Film and Proportion of Fat and Total Nitrogen in Film on Medium Near the Surface of the Primary and Secondary Filters during Treatment of Milk Washings* *20th January* 1936 *to* *23rd April* 1937

Rate of treatment of settled and diluted milk washings (gal. per day per cu. yd. of medium)	No. of samples of medium examined	Average dry weight of film on 5·5 litres of medium (gm.)		Average proportion of fat in film (per cent of dry weight)		Average proportion of total nitrogen in film (per cent of dry weight)	
		Primary filter	Secondary filter	Primary filter	Secondary filter	Primary filter	Secondary filter
81	4	23·4	30·1	4·6	2·8	5·7	4·9
124	5	30·1	12·4	7·7	2·8	7·1	5·5
164	3	20·3	10·1	4·7	1·2	4·1	3·2
180	3	35·6	15·1	3·8	1·5	2·1	2·0
240	1	42·2	5·6	15·3	5·3	4·0	6·3

was found at the end of the period, when the rate of treatment of diluted milk washings had been increased to 240 gallons per day per cubic yard of medium. The content of fat in the material associated with the medium was considerably higher in the primary filter than in the secondary filter. There was no well-defined difference in the proportion of total nitrogen in the film and deposited solid matter in the primary and secondary filters.

SUMMARY OF EXPERIMENTS ON A LARGE SCALE WITH PERCOLATING FILTERS

Milk washings, whey washings, and mixtures of the two were treated in the filtration plant during the period August 1935 to September 1938. The conditions of operation of the plant and the results obtained are summarized in Table XLIX.

During the period August 1935 to June 1937 the filters were supplied with settled and diluted milk washings. The average biochemical oxygen demand of the crude milk washings varied from 21 to 128 parts per 100,000 and that of the settled and diluted washings supplied to the filters varied from 11 to 30 parts per 100,000.

After a growth of biological film had developed on the filtering medium, settled and diluted milk washings were treated at a rate of about 80 gallons per day per cubic yard of medium in the two filters together; the final effluent was of excellent quality. The rate of treatment of the settled and diluted milk washings per cubic yard of medium was then raised, at first to 124 gallons per day and later to 164 gallons. Throughout the period of about 6 months, when settled and diluted milk washings, with an average biochemical oxygen demand of 21 parts per 100,000, were treated at the rate of 164 gallons, the final effluent was of excellent quality and had an average biochemical oxygen demand of 0·3 part per 100,000 parts. The order of the primary and secondary filters in series was changed at intervals of about 3 weeks; no difficulty due to excessive growths on the filtering medium was experienced.

To obtain information on the behaviour of the filtration plant at high rates of treatment, settled and diluted milk washings with an average biochemical oxygen demand of 30 parts per 100,000 were supplied to the filters for a period of about 2 months at a rate of 240 gallons per day per cubic yard

TABLE XLIX. *Summary of Conditions of Operation of Double-Filtration Plant August 1935 to September 1938*

Period of experiment	Liquid treated	Rate of treatment of settled and diluted crude liquid (gal. per day per cu. yd. of filtering medium in the two filters together)	Biochemical oxygen demand (parts per 100,000)				Average temperature of settled effluent from secondary filter
			Crude liquid	Settled and diluted crude liquid	Settled effluent from primary filter	Settled effluent from secondary filter	
7 Aug. 1935 to 5 April 1936	Milk washings	81	82	21	>2·4	0·8	7·5
6 April to 19 June 1936	,, ,,	124	128	23	1·4	0·8	13
20 June to 18 Nov. 1936	,, ,,	164	60	21	0·7	0·3	15
9 Dec. 1936 to 22 Jan. 1937	,, ,,	160	21	11	1·1	0·8	10
23 Jan. to 17 March 1937	,, ,,	164*	23	17	1·5	0·8	7
31 March to 4 June 1937	,, ,,	240	60	30	1·4	1·0	17·5
9 June to 2 July 1937	1 vol. whey washings with 3 vol. milk washings	160	77	27	0·8	0·5	18·5
3 July to 30 July 1937	1 vol. whey washings with 1 vol. milk washings	160	101	26	0·9	0·3	19
31 July to 24 Sept. 1937	,, ,,	240	65	26	>1·7	0·4	21
5 Oct. to 21 Nov. 1937	3 vol. whey washings with 1 vol. milk washings	160	78	34	>2·5	0·7	12·5
7 Dec. 1937 to 11 Feb. 1938	,, ,,	160	45	19	>1·6	0·9	10·5
13 Aug. to 15 Sept. 1938	,, ,,	160	95	29	0·8	0·7	18
7 March to 11 May 1938	Whey washings	106	63	27	2·9	0·6	11
12 May to 24 June 1938	,, ,,	132	56	21	1·3	0·6	11
June to 12 Aug. 1938	,, ,,	160	83	27	2·8	0·7	19

* Plant operated for only 16.5 hours daily.

of medium. The final effluent had an average biochemical oxygen demand of about 1 part per 100,000, but it was necessary to change the order of the filters every week or 10 days instead of at intervals of 3 weeks, to ensure adequate removal of solid matter from the top layer of the primary filter.

For a short period a mixture of one volume of whey washings with three volumes of milk washings, diluted with treated effluent to give a liquid with an average biochemical oxygen demand of 25 to 30 parts per 100,000, was treated at a rate of 160 gallons per day per cubic yard of medium. No difficulty was experienced in the operation of the plant and final effluents of good quality were obtained.

In July 1937 a mixture of equal volumes of whey washings and milk washings was treated at the same rate of flow, again with no difficulty in the operation of the plant; the effluent had the low average biochemical oxygen demand of 0·3 part per 100,000. In order to obtain information on the maximum rate at which this mixture of whey washings and milk washings could be treated by double filtration, the rate of flow of settled and diluted crude liquid was raised to 240 gallons per day per cubic yard of medium and was maintained at this value for nearly 2 months. Throughout the period final effluents with a low biochemical oxygen demand were obtained, the average value being 0·4 part per 100,000. Towards the end of the period, however, the filters showed signs of ponding and it was decided to clean them by stopping the supply of crude liquid and circulating purified effluent through the filters.

Mixtures containing three volumes of whey washings with one volume of milk washings were treated at a rate of 160 gallons per day per cubic yard of medium during two periods, one of approximately 4 months, from October 1937 to February 1938, and one of approximately 1 month, from the middle of August to the middle of September 1938. At the beginning of the first period difficulty was experienced in making up a settled and diluted crude liquid with a biochemical oxygen demand of 25 to 30 parts per 100,000, and on many occasions the strength of the liquid supplied to the filters was much higher. Final effluents of good quality were obtained, but excessive quantities of solid matter and growth collected in the surface layer of medium in the filters, and after 7 weeks it became necessary to clean the filters by circulating treated effluent through them. Treatment of the mixture of whey washings and milk washings was then resumed at the same rate of flow, and for a period of nearly 10 weeks effluents with an average biochemical oxygen demand of less than 1 part per 100,000 were obtained. At the end of this period, however, it was again necessary to remove surface growths from the filtering medium by circulating treated effluent through the filters. The unsatisfactory behaviour of the plant during this period was probably due in part to the low temperature of the crude liquid, which was made up from milk washings, whole whey, and canal water, since hot whey washings from the cheese factory were not then available. In August and September 1938, when the temperature was higher, excellent results were obtained from the treatment of mixtures of three volumes of whey washings and one volume of milk washings, after settlement and dilution with final effluent, at a rate of 160 gallons per day per cubic yard of medium.

Whey washings only were treated in the filtration plant during a period of about 5 months, from March to August 1938. The rate of treatment of the settled and diluted crude liquid per day per cubic yard of filtering medium was at first 106 gallons; later it was raised to 132 gallons and finally to 160 gallons. No difficulty was experienced in the operation of the plant and the quality of the final effluent was good throughout the experiments.

The results obtained during the investigation have shown that, under ordinary conditions of operation at a dairy or milk products factory, milk washings, whey washings, and mixtures of the two can be satisfactorily purified when the settled crude liquid, diluted when necessary to give a liquid with a biochemical oxygen demand of 20 to 30 parts per 100,000, is passed through two percolating filters in series at a rate of 160 gallons per day per cubic yard of medium. Milk washings of the same strength can be satisfactorily treated at a rate of 240 gallons per day per cubic yard of medium, provided that the operation of the plant is carefully controlled, but a rate of 160 gallons per day per cubic yard seems to be the maximum advisable under conditions at dairies and milk products factories. This rate is considerably higher than is usual in sewage disposal works in the treatment of domestic sewage by single filtration, allowance being made for the difference in strength of the crude liquids.

Milk washings are more easily purified than whey washings of similar strength, since the film formed on the surface of the primary filter when whey washings are treated is tougher than that formed with milk washings and is not so easily removed when the order of the filters in series is changed.

Purification in percolating filters proceeds more rapidly at relatively high temperatures (20° C. to 30° C.) than at lower temperatures. The only serious difficulty encountered during the present work was in the winter of 1937-38, when crude liquid was made up from whole whey and a relatively small volume of milk washings, diluted with cold canal water. In a commercial plant not only would whey washings be discharged at a relatively high temperature, but the greatest load on the plant would be in spring and summer when the air temperature is also relatively high.

An important feature in the treatment of milk washings and whey washings by the process of double filtration is that application to the filters of liquid of abnormally high strength during a short period, which might occur as the result of an accident in a factory, causes only a temporary deterioration in the quality of the final effluent, and any excessive deposition of solid matter in the surface layer of the filtering medium is rapidly removed.

At no time during the operation of the double-filtration plant was any fat found in the settled final effluent. The highest average concentration of fat in the crude liquid occurred during April and June 1936, when the milk washings treated contained 22·8 parts per 100,000 parts; no fat was present in the effluent from either the primary or the secondary filter.

The *p*H value of the crude milk washings ranged from 5·8 to 7·1; the *p*H value of final effluent from the treatment of milk washings was from 7·8 to 8·2. Crude whey washings were often strongly acidic in reaction, especially if they had been stored for some time; the usual *p*H value of the crude whey washings was from 4·6 to 5·1. Final effluent from the treatment of whey washings was always neutral or slightly alkaline in reaction.

The effluents from both the primary and secondary filters usually contained a high proportion of dissolved oxygen; average concentrations over the whole period of operation of the plant were 0·72 part per 100,000 in effluent from the primary filter and 0·95 part per 100,000 in effluent from the secondary filter. Fresh water at a temperature of 15° C. contains, when saturated with dissolved oxygen, approximately 1 part per 100,000 parts, so that effluent from the secondary filter was almost saturated with dissolved oxygen. It was found that trout were unharmed when living in a tank through which final effluent from the double-filtration plant was passed continuously.

Nitrite was absent or was present in only small quantities in the final effluent. Nitrate was usually present in the effluent from both the primary and secondary filters; the average concentration of nitrate for the whole period of operation of the plant was equivalent to 0·24 part of nitrogen per 100,000 parts in the primary effluent and 0·50 part of nitrogen per 100,000 in the secondary effluent. Since the final effluent was used for diluting the settled crude liquid, nitrate was also present in the liquid supplied to the primary filter.

CHAPTER VI. EXPERIMENTS ON A LARGE SCALE TREATMENT BY THE ACTIVATED SLUDGE PROCESS

Description of Plant

A PANORAMIC view of the experimental activated sludge plant is shown in Plate 3 and a plan and vertical section of the plant are shown in Figures 4 and 5. The plant included a primary sedimentation tank, two aeration tanks, a final sedimentation tank, pumps, air compressor, flow gauges, and other equipment.

Crude liquid was pumped from the main collecting tank through a brick-work chamber, containing a **V**-notch flow gauge, to the primary sedimentation tank. This tank, which had a total capacity of about 1,600 gallons, was of the same size and shape as the primary sedimentation tank of the filtration plant. Settled crude liquid entered a small steel tank containing two **V**-notch flow gauges with floats and indicators. In this tank the liquid could be diluted with measured quantities of water or of purified effluent.

From the gauging and mixing tank, liquid flowed by gravity to enter the two aeration tanks. These tanks could be operated either in series or in parallel, but throughout the investigation they were operated in parallel. There were two inlet pipes, controlled by separate valves, to each tank. Each tank was rectangular in horizontal section, with bevelled angles at the bottom; each was 16 ft. long, 8 ft. wide, and about 6 ft. deep, and held approximately 4,375 gallons. Porous plates were set in groups of 6 in channels at the base of the tank near the long walls. Through these plates air was blown by a compressor by way of pipes controlled by valves. The circulatory motion given to the liquid by the bubbles of air was assisted by a prismatic block of concrete along part of the floor of the tank. Liquid and sludge flowed continuously into the tanks and out over the outlet weirs into the final sedimentation tank, which was of the same design and size as the primary sedimentation tank for the crude waste waters.

Settled effluent from the final sedimentation tank flowed into a sump whence part was returned for diluting settled crude liquid from the primary sedimentation tank; the remainder was discharged to a small stream. Part of the sludge from the final sedimentation tank was returned continuously, without any further aeration, through a **V**-notch flow gauge to the inlet end of the aeration tanks. Surplus sludge was discharged periodically to a sludge-drying bed. This bed was 26 ft. long, 21 ft. wide, and 2 ft. deep.

Treatment of Milk Washings

When operation of the activated sludge plant was begun, early in August 1935, the aeration tanks were first filled with water from a small stream, the Tetchill Brook, and the supply of air was turned on. The water was then gradually displaced by a mixture of one volume of settled milk washings with six volumes of water. Later, treated effluent from the plant was used in place of water from the brook and the proportion of diluent was reduced.

After the plant had been in operation for about 3 weeks the quantity of activated sludge which had been collected and could be returned to the aeration tanks gave a mixture containing about 5 per cent of sludge by volume as measured after settlement for 1 hour in a glass cylinder. At the beginning of September 1935 the volume of sludge in liquid withdrawn from the aeration tanks had increased to about 15 per cent by volume after settlement for 3 hours; the supernatant liquid, however, was not clear. During the first month of operation the biochemical oxygen demand of the final effluent, after settlement, was usually more than 6 parts per 100,000 parts; the effluent contained no nitrite

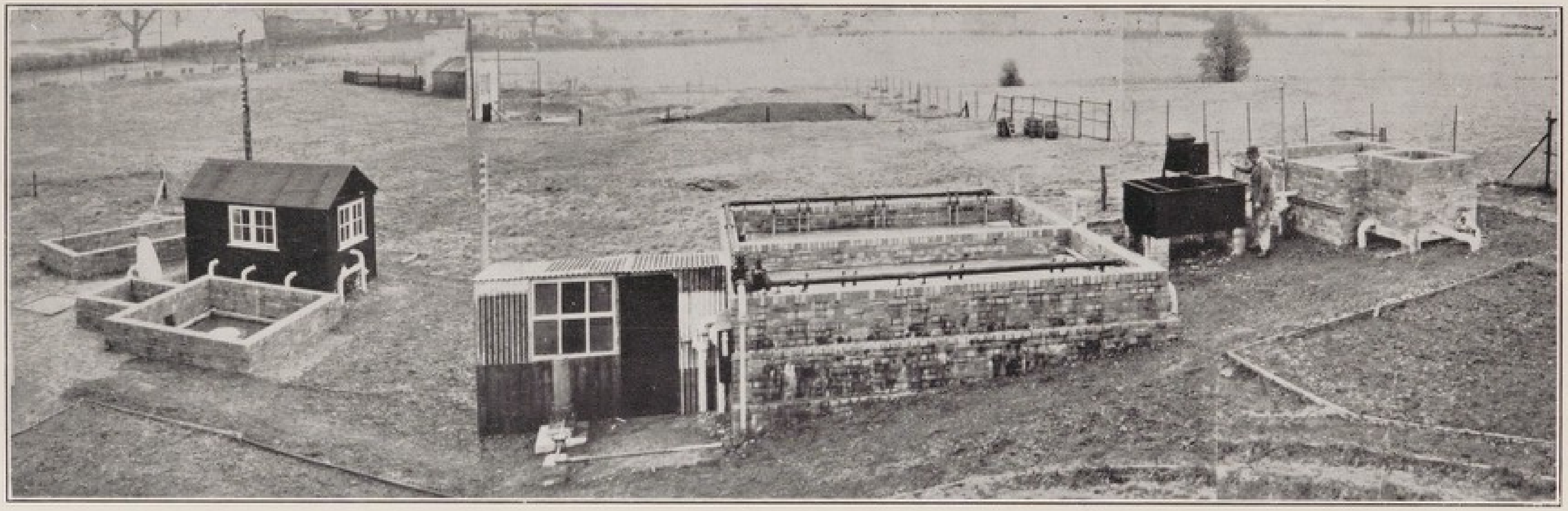


PLATE 3. Panoramic View of Activated Sludge Plant, Ellesmere.

and only very small amounts of nitrate and dissolved oxygen. On 10th September an accident occurred in the factory and resulted in the admission of abnormally strong settled crude liquid to the aeration tanks; the quality of the final effluent at once deteriorated and did not recover for some time. During the period 10th to 18th September the biochemical oxygen demand of the final effluent after settlement ranged from 7 parts to more than 19 parts per 100,000.

Until 15th September the volume of settled and diluted crude liquid treated in the activated sludge plant was about 12,600 gallons per day. On 16th September the volume was reduced to 7,200 gallons per day and the volume of air supplied to the aeration tanks was increased from 14 to 20 cu. ft. per minute. These conditions were maintained until 9th October, that is until 9 weeks after operation of the plant was first begun. Between 16th September and 9th October the average biochemical oxygen demand of the settled and diluted crude liquid supplied to the aeration tanks was 31 parts per 100,000 and the average biochemical oxygen demand of the final effluent after settlement was 3·7 parts per 100,000.

On 10th November 1935 the rate of treatment of settled and diluted milk washings was increased to 9,600 gallons per day. The total volume of sludge returned from the final sedimentation tank and mixed with the settled crude liquid entering the aeration tanks was approximately 2,400 gallons per day. With these rates of flow the average period during which the settled crude liquid was aerated with activated sludge was approximately 17·5 hours. These conditions were maintained until 27th November, that is for a period of about 7 weeks; the average results during this period are given in Table L.

TABLE L. *Treatment of Milk Washings by the Activated Sludge Process*
Average Results
10th October to 27th November 1935

Volume of diluted milk washings treated—9,600 gal. per day
Volume of sludge returned to aeration tanks—2,400 gal. per day
Average period of aeration—17·5 hours

	Crude milk washings	Crude milk washings after sedimentation	Settled and diluted crude liquid supplied to aeration tanks	Settled final effluent
Temperature (° C.)	18·5	13	12	9
*p*H value	7·0	6·6	7·0	7·5
Parts per 100,000				
Biochemical oxygen demand	69	61	19	3·3
Oxygen absorbed from acid permanganate in 4 hrs.	13·8	10·5	4·0	1·7
Dissolved oxygen	—	—	—	0·72
Total nitrogen (as N)	2·38	2·90	1·39	0·59
Ammonia (as N)	0·36	0·83	0·23	0·03
Nitrite (as N)	—	—	—	0·02
Nitrate (as N)	—	—	—	0·08
Soluble solids	78·0	95·2	71·0	58·0
Suspended solids	24·4	22·2	9·1	2·7
Incubation Test				
No. of samples tested	—	—	—	7
No. of samples passed	—	—	—	4
No. of samples failed	—	—	—	3

The average biochemical oxygen demand of the settled and diluted milk washings supplied to the aeration tanks was 19 parts per 100,000 and the average biochemical oxygen demand of the settled final effluent was 3·3 parts per 100,000 parts. The effluent had a *p*H value of about 7·5; it contained nitrate and a considerable quantity of dissolved oxygen. There was no fat in the final effluent, although the diluted milk washings supplied to the aeration tanks contained nearly 4 parts of fat per 100,000 parts. The volume of sludge which settled in a given time from liquid removed from the aeration tanks fluctuated within wide limits from day to day. Thus, on 7th November the amount of sludge in liquid withdrawn from the aeration tanks, after settlement in a glass cylinder for 30 minutes, was 55 per cent by volume; after settlement for 24 hours the amount of sludge was 10 per cent by volume. On 8th November the corresponding proportions of sludge were 63 per cent and 10 per cent respectively. On the following day, 9th November, however, the amount of sludge after settlement for 30 minutes was only 17 per cent by volume and after settlement for 24 hours the proportion of sludge was 6 per cent. Some sludge was discharged to the drying bed on 8th November, but the sudden changes in the volume as measured by settlement for a given time were probably caused by changes in the character of the sludge.

During the period of about 13 weeks from 28th November 1935 to 1st March 1936, settled and diluted milk washings were treated at a rate of 6,350 gallons per day. The total volume of activated sludge returned daily to the aeration tanks was maintained at 2,400 gallons and the average period of aeration was 24 hours. The average results are given in Table LI. During this period the

TABLE LI. *Treatment of Milk Washings by the Activated Sludge Process*
Average Results
28th November 1935 *to* 1*st March* 1936

Volume of diluted milk washings treated—6,350 gallons per day
Volume of sludge returned to aeration tanks—2,400 gallons per day
Average period of aeration—24 hours

	Crude milk washings	Crude milk washings after sedimentation	Settled and diluted crude liquid supplied to aeration tanks	Settled final effluent
Temperature (° C.)	17·5	8·5	6	4
*p*H value	7·7	6·5	7·0	7·5
Parts per 100,000				
Biochemical oxygen demand . .	78	64	20	2·6
Oxygen absorbed from acid permanganate in 4 hrs.	15·3	10·3	3·9	1·2
Dissolved oxygen	—	—	—	0·89
Total nitrogen (as N)	2·65	2·67	1·03	0·43
Ammonia (as N)	0·16	0·33	0·11	0·03
Nitrite (as N)	—	—	—	0
Nitrate (as N)	—	—	—	0·02
Soluble solids	90·5	85·3	58·7	50·9
Suspended solids	25·7	20·5	7·6	1·3
Incubation Test				
No. of samples tested	—	—	—	13
No. of samples passed	—	—	—	7
No. of samples failed	—	—	—	6

FIG. 4.

PLAN OF ACTIVATED SLUDGE PLANT, ELLESMERE

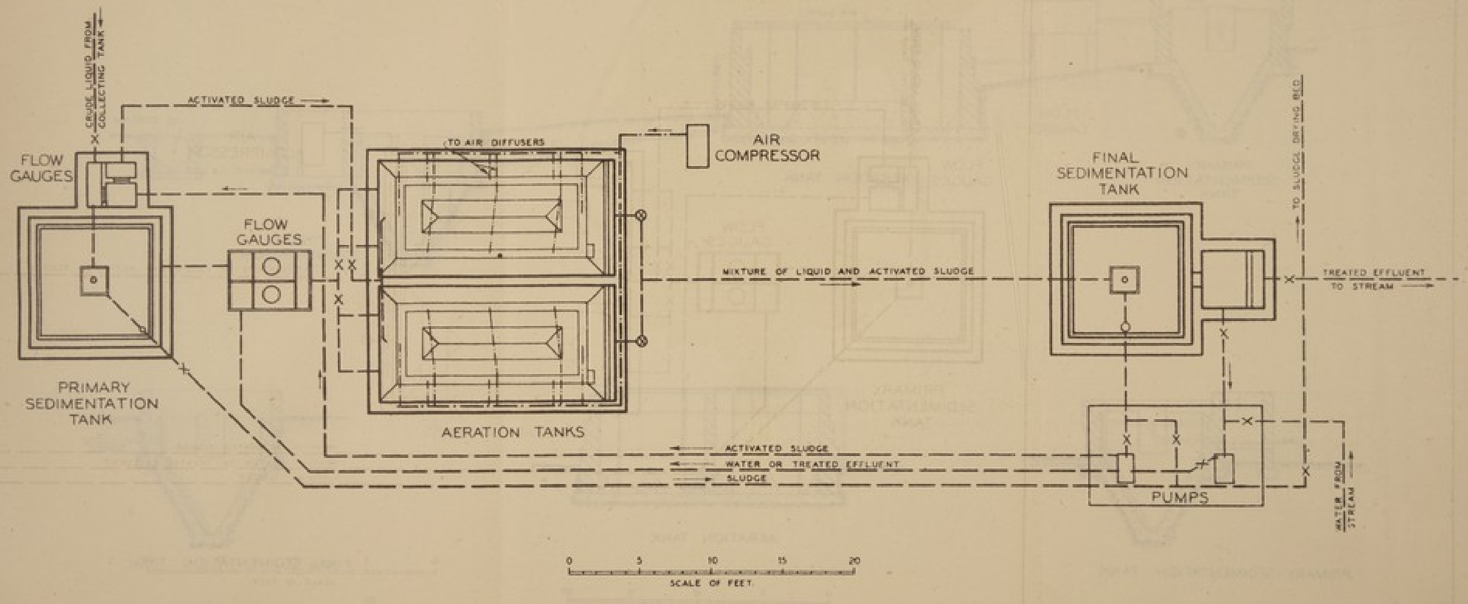
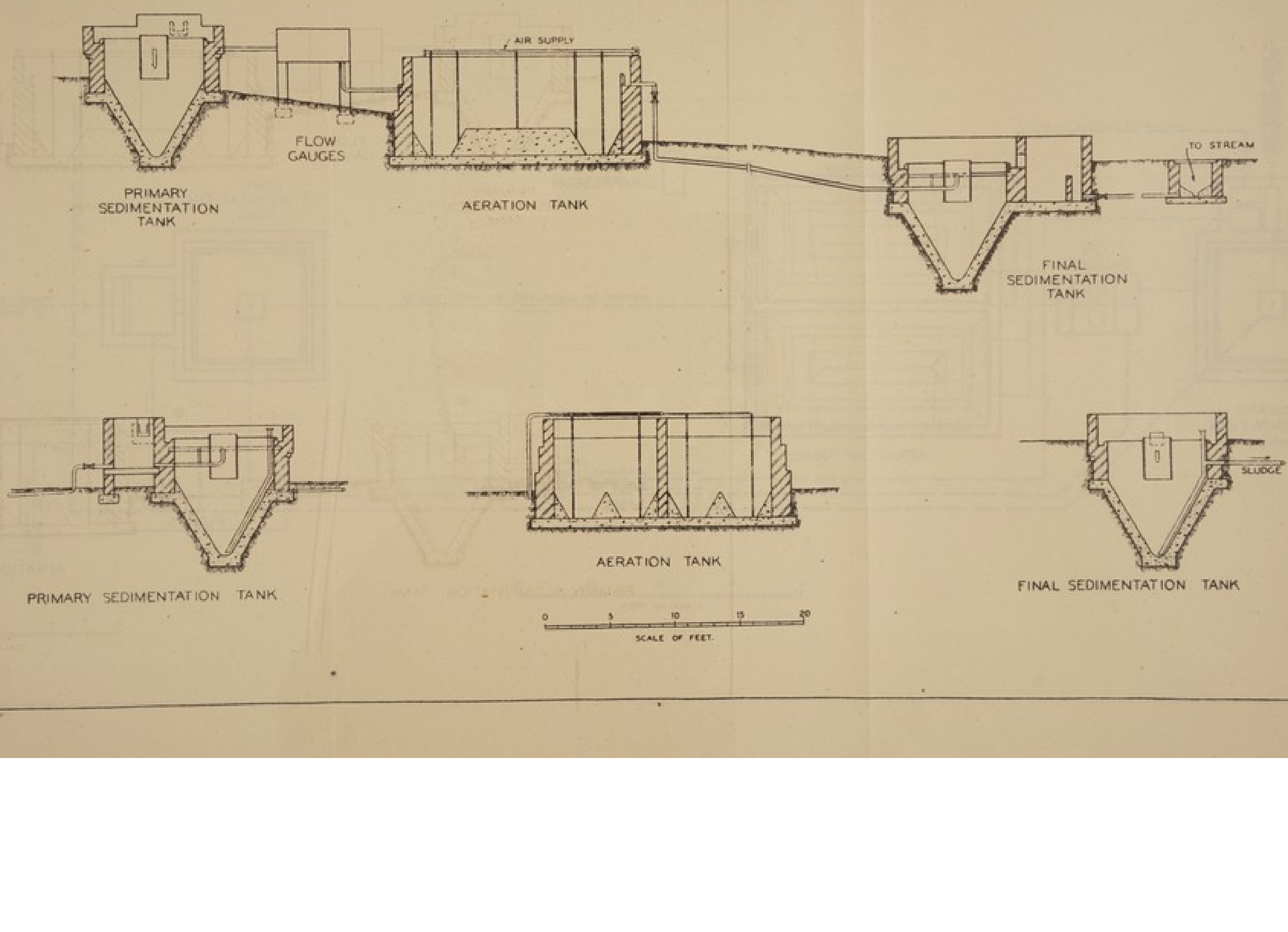


FIG. 5.

VERTICAL SECTIONS OF ACTIVATED SLUDGE PLANT, ELLESMERE



temperature of the liquid undergoing treatment in the aeration tanks was low. The average biochemical oxygen demand of the settled crude liquid entering the aeration tanks was about 20 parts per 100,000, and the average biochemical oxygen demand of the settled final effluent was 2·6 parts per 100,000. The effluent contained a small amount of nitrate and was well oxygenated.

From the end of November 1935 until 20th January 1936 only small quantities of sludge were discharged to the drying bed from the final sedimentation tank. During this period the amount of sludge, which settled from liquid taken from the aeration tanks and allowed to stand in a glass cylinder, ranged from 8 to 24 per cent by volume after 30 minutes, 5 to 15 per cent after 1 hour, and 3 to 9 per cent after 24 hours. Between 25th February and 6th March 1936, " bulking " of the sludge occurred. In samples of liquid from the aeration tanks during this period, the volume of sludge, after allowing the liquid to stand in a glass cylinder for 30 minutes, was from 77 to 93 per cent by volume; in this condition the sludge occupied a relatively large volume and was not easily separated from the liquid by sedimentation.

Between 17th December 1935 and 14th February 1936 the volume of milk washings discharged from the factory was sometimes insufficient to supply the activated sludge plant at the desired rate of flow and the supply of milk washings to the aeration tanks was then stopped between the hours of 5 p.m. and 8 a.m.

Until the beginning of March 1936 the liquid supplied to the aeration tanks was made up by mixing approximately one volume of settled milk washings with three volumes of settled final effluent. From 2nd March to 17th April 1936, a period of nearly 7 weeks, a mixture of one volume of settled milk washings with two volumes of settled final effluent was used; this mixture had an average biochemical oxygen demand of nearly 30 parts per 100,000, whereas the diluted milk washings previously treated had an average biochemical oxygen demand of about 20 parts per 100,000. From 2nd March to 17th April the volume of diluted washings treated daily was approximately 3,430 gallons and the total volume of sludge returned daily to the aeration tanks was maintained at 2,400 gallons; the average period of aeration was approximately 36 hours. For the first time since the beginning of the experiments the average biochemical oxygen demand of the final effluent was below 2 parts per 100,000 (Table LII).

It was necessary to discharge some sludge each day between 13th and 31st March. In general the volume of sludge discharged was adjusted so that when a sample of liquid from the aeration tanks was allowed to stand in a glass cylinder the volume of sludge which settled during 30 minutes was 35 to 50 per cent by volume.

From the middle of April 1936 to the first week in June, 6,350 gallons of settled and diluted milk washings (biochemical oxygen demand 30 to 40 parts per 100,000) with 2,400 gallons of sludge were passed each day through the aeration tanks; the average period of aeration was 24 hours. Under these conditions a final effluent with an average biochemical oxygen demand of 2·1 parts per 100,000 was obtained (Table LIII). Towards the end of May some difficulty was caused by " rising " of sludge. When this occurs, particles of sludge are buoyed up by bubbles of gas, rise to the surface in the final sedimentation tank, and cannot easily be separated from the effluent.

During the period 2nd June to 17th July 1936 the liquid treated consisted of equal volumes of settled milk washings and purified effluent; this mixture was aerated with activated sludge for an average period of 35 hours. The results obtained are given in Table LIV. The average biochemical oxygen demand of the settled final effluent was 2·4 parts per 100,000. On a number of occasions " rising " of sludge occurred and this no doubt adversely affected the quality of the final effluent. Thus, between 13th and 17th July the

TABLE LII. *Treatment of Milk Washings by the Activated Sludge Process*
Average Results
2nd March to 17th April 1936

Volume of diluted milk washings treated—3,430 gallons per day
Volume of sludge returned to aeration tanks—2,400 gallons per day
Average period of aeration—36 hours

	Crude milk washings	Crude milk washings after sedimentation	Settled and diluted crude liquid supplied to aeration tanks	Settled final effluent
Temperature (° C.)	21	13	10·5	9
*p*H value	6·7	6·4	7·0	7·6
Parts per 100,000				
Biochemical oxygen demand	101	79	29	1·7
Oxygen absorbed from acid permanganate in 4 hrs.	17·7	11·3	4·6	0·9
Dissolved oxygen	—	—	—	0·68
Total nitrogen (as N)	4·43	3·23	1·38	0·37
Ammonia (as N)	0·38	0·68	0·32	0·04
Nitrite (as N)	—	—	—	0
Nitrate (as N)	—	—	—	0
Soluble solids	105·2	91·8	76·7	63·6
Suspended solids	37·1	23·1	9·5	0
Incubation Test				
No. of samples tested	—	—	—	7
No. of samples passed	—	—	—	3
No. of samples failed	—	—	—	4

Proportion of sludge settled from liquid taken from aeration tanks, after standing in a glass cylinder (per cent by volume):

After 0·5 hr.	.. ..	58 per cent
,, 1 ,,	.. ..	43 ,, ,,
,, 2 hrs.	.. ..	30 ,, ,,
,, 4 ,,	.. ..	22 ,, ,,
,, 24 ,,	.. ..	13 ,, ,,

biochemical oxygen demands, in parts per 100,000, of the settled final effluent and of the effluent after filtration through filter paper were:

13/7/1936, settled effluent 3·9; filtered effluent 0·6
14/7/1936, ,, ,, 3·7; ,, ,, 0·7
15/7/1936, ,, ,, 2·6; ,, ,, 0·6
16/7/1936, ,, ,, 5·4; ,, ,, 0·8
17/7/1936, ,, ,, 4·3; ,, ,, 0·6

The average biochemical oxygen demand of the final effluent after filtration through filter paper was 0·8 part per 100,000 as compared with 2·4 parts per 100,000 for the final effluent after sedimentation. A considerable part of the impurity in the effluent was thus due to material in suspension, including particles of sludge buoyed up by bubbles of gas. It was found that when a sample of liquid from the aeration tanks was allowed to stand in a glass cylinder the sludge settled rapidly, but after about 4 hours it rose to the surface. Bubbles

TABLE LIII. *Treatment of Milk Washings by the Activated Sludge Process*
Average Results
18*th April to* 1*st June* 1936

Volume of diluted milk washings treated—6,350 gallons per day
Volume of sludge returned to aeration tanks—2,400 gallons per day
Average period of aeration—24 hours

	Crude milk washings	Crude milk washings after sedimentation	Settled and diluted crude liquid supplied to aeration tanks	Settled final effluent
Temperature (° C.)	25	18·5	15	13·5
*p*H value	5·9	5·8	6·7	7·6
Parts per 100,000				
Biochemical oxygen demand ..	145	101	38	2·1
Oxygen absorbed from acid permanganate in 4 hrs.	23·3	13·1	5·6	1·5
Dissolved oxygen	—	—	—	0·55
Total nitrogen (as N)	5·32	4·03	2·43	1·43
Ammonia (as N)	0·63	1·19	0·61	0·43
Nitrite (as N)	—	—	—	0·07
Nitrate (as N)	—	—	—	0·37
Soluble solids	114·2	113·2	96·9	76·9
Suspended solids	50·6	24·3	9·7	0·6
Incubation Test				
No. of samples tested	—	—	—	7
No. of samples passed	—	—	—	5
No. of samples failed	—	—	—	2

Proportion of sludge settled from liquid taken from aeration tanks, after standing in a glass cylinder (per cent by volume):

After 0·5 hr.	.. ..	52 per cent
,, 1 ,,	.. ..	37 ,, ,,
,, 2 hrs.	.. ..	27 ,, ,,
,, 4 ,,	.. ..	18 ,, ,,
,, 24 ,,	.. ..	12 ,, ,,

of gas could be seen adhering to the particles of sludge; when the sludge was stirred gently, foaming occurred as the bubbles escaped and the sludge then settled to the bottom of the cylinder.

" Rising " of sludge in the final sedimentation tank of an activated sludge plant is often accompanied by high concentrations of nitrate in the final effluent; this was the case during the period 4th June to 17th July (Table LIV), when the average concentration of nitrate in the final effluent was equivalent to 0·44 part of nitrogen per 100,000 parts. It is often stated that " rising " of sludge is due to the escape of small bubbles of gaseous nitrogen produced during the decomposition of compounds of nitrogen.

On 18th July 1936 the volume of settled and diluted milk washings passed through the aeration tanks daily was increased from 3,430 gallons to 6,350 gallons; the volume of activated sludge returned daily to the aeration tanks was 2,400 gallons and the average period of aeration was 24 hours. It was expected that with this increase in the volume of milk washings treated daily

TABLE LIV. *Treatment of Milk Washings by the Activated Sludge Process*
Average Results
2nd June to 17th July 1936

Volume of diluted milk washings treated—3,600 gallons per day
Volume of sludge returned to aeration tanks—2,400 gallons per day
Average period of aeration—35 hours

	Crude milk washings	Crude milk washings after sedimentation	Settled and diluted crude liquid supplied to aeration tanks	Settled final effluent
Temperature (° C.)	35	36·5	20·5	17·5
*p*H value	5·5	5·8	6·3	7·3
Parts per 100,000				
Biochemical oxygen demand	76	54	32	2·4
Oxygen absorbed from acid permanganate in 4 hrs.	10·3	5·2	3·8	1·4
Dissolved oxygen	—	—	—	0·29
Total nitrogen (as N)	3·67	3·10	2·18	1·86
Ammonia (as N)	0·77	1·27	0·82	0·03
Nitrite (as N)	—	—	—	0·03
Nitrate (as N)	—	—	—	0·44
Soluble solids	47·6	47·5	45·4	41·8
Suspended solids	31·6	15·3	10·1	1·1
Incubation Test				
No. of samples tested	—	—	—	7
No. of samples passed	—	—	—	5
No. of samples failed	—	—	—	2

Proportion of sludge settled from liquid taken from aeration tanks, after standing in a glass cylinder (per cent by volume):

After	0·5 hr.	30 per cent
,,	1 ,,	22 ,, ,,
,,	2 hrs.	16 ,, ,,
,,	4 ,,	13 ,, ,,
,,	24 ,,	8 ,, ,,

the concentration of nitrate in the final effluent would decrease and that less difficulty would be encountered from rising of sludge. The average results obtained between 18th July and 6th September 1936, a period of about 7 weeks, are given in Table LV.

Well-purified final effluents, with an average biochemical oxygen demand of only 1·2 parts per 100,000, were obtained from the treatment of diluted milk washings with an average biochemical oxygen demand of 25 parts per 100,000. All samples of final effluent tested remained odourless and colourless after incubation for 5 days at a temperature of 26·7° C. Throughout the period high concentrations of nitrate were found in the final effluent; the average concentration was equivalent to 0·8 part of nitrogen per 100,000 parts. Little difficulty was experienced from rising of sludge and in general the sludge obtained was well flocculated and settled rapidly in the final sedimentation tank. It was observed, however, that in many of the samples of liquid from the aeration tanks sludge rose to the surface when the samples were allowed to stand in glass cylinders for periods of 5 to 6 hours.

TABLE LV. *Treatment of Milk Washings by the Activated Sludge Process*
Average Results
18*th July to* 6*th September* 1936

Volume of diluted milk washings treated—6,350 gallons per day
Volume of sludge returned to aeration tanks—2,400 gallons per day
Average period of aeration—24 hours

	Crude milk washings	Crude milk washings after sedimentation	Settled and diluted crude liquid supplied to aeration tanks	Settled final effluent
Temperature (° C.)	40	31	24·5	21
*p*H value	6·0	6·3	6·5	7·3
Parts per 100,000				
Biochemical oxygen demand	63	51	25	1·2
Oxygen absorbed from acid permanganate in 4 hrs.	7·0	5·1	3·1	0·9
Dissolved oxygen	—	—	—	0·29
Total nitrogen (as N)	2·76	2·53	1·47	0·83
Ammonia (as N)	0·71	1·25	0·78	0·02
Nitrite (as N)	—	—	—	0·02
Nitrate (as N)	—	—	—	0·79
Soluble solids	36·8	48·7	42·5	38·7
Suspended solids	35·6	17·1	9·7	0
Incubation Test				
No. of samples tested	—	—	—	7
No. of samples passed	—	—	—	7
No. of samples failed	—	—	—	0

Proportion of sludge settled from liquid taken from aeration tanks, after standing in a glass cylinder (per cent by volume):

After 0·5 hr.	18 per cent
„ 1 „	14 „ „
„ 2 hrs.	12 „ „
„ 4 „	10 „ „
„ 24 „	7 „ „

During the period of 7 weeks from 7th September to 25th October, 3,120 gallons of settled milk washings, without the addition of purified effluent, were treated daily in admixture with 2,400 gallons of activated sludge; the average period of aeration was 38 hours. The average biochemical oxygen demand of the undiluted milk washings entering the aeration tanks was 50 parts per 100,000; well-purified effluents with an average biochemical oxygen demand of only 1·2 parts per 100,000 were obtained (Table LVI). The activated sludge usually settled rapidly and except on a few occasions light particles of sludge were not carried over with the effluent from the final sedimentation tanks.

From 26th October 1936 to 17th March 1937, a period of about 20 weeks, the liquid supplied daily to the aeration tanks contained approximately 6,350 gallons of undiluted settled milk washings with 2,400 gallons of returned activated sludge; the average period of aeration was 24 hours.

Between 1st and 4th January 1937 operation of the plant was interrupted and 3 transverse baffles were fitted in each aeration tank to minimize short-circuiting of the liquid from the inlet to the outlet ends of the tank. Crude

TABLE LVI. *Treatment of Milk Washings by the Activated Sludge Process*
Average Results
7th September to 25th October 1936

Volume of milk washings treated—3,120 gallons per day
Volume of sludge returned to aeration tanks—2,400 gallons per day
Average period of aeration—38 hours

	Crude milk washings	Crude milk washings after sedimentation, supplied to aeration tanks without dilution	Settled final effluent
Temperature (° C.)	41·5	26·5	16·5
*p*H value	6·2	6·3	7·5
Parts per 100,000			
Biochemical oxygen demand	64	50	1·2
Oxygen absorbed from acid permanganate in 4 hrs.	7·3	5·1	0·7
Dissolved oxygen	—	—	0·42
Total nitrogen (as N)	2·77	2·29	0·38
Ammonia (as N)	0·59	1·20	0
Nitrite (as N)	—	—	0
Nitrate (as N)	—	—	0·18
Soluble solids	59·7	57·8	42·6
Suspended solids	33·0	22·8	0·1
Incubation Test			
No. of samples tested	—	—	7
No. of samples passed	—	—	7
No. of samples failed	—	—	0

Proportion of sludge settled from liquid taken from aeration tanks, after standing in a glass cylinder (per cent by volume):

After	0·5 hr.	40 per cent
,,	1 ,,	33 ,, ,,
,,	2 hrs.	28 ,, ,,
,,	4 ,,	22 ,, ,,
,,	24 ,,	16 ,, ,,

liquid entering the tank passed under the first baffle, over the second baffle, and under the third baffle to the outlet chamber. The activated sludge was aerated continuously while these alterations were made.

Between 26th October and 31st December 1936, before baffles had been fitted in the aeration tanks, the average biochemical oxygen demand of the settled milk washings was about 32 parts per 100,000 and the average biochemical oxygen demand of the final effluent after sedimentation was 0·6 part per 100,000 parts. From 5th to 22nd January 1937, after baffles had been fitted, the average biochemical oxygen demand of the settled milk washings supplied to the aeration tanks was 17 parts per 100,000 and the average biochemical oxygen demand of the settled final effluent was 0·6 part per 100,000 parts.

By the end of January modifications in the operations in the factory had so reduced the quantity of milk carried away by the washing water that the activated sludge plant could no longer be operated continuously. From

23rd January to 17th March 1937 the plant was supplied with 6,350 gallons of settled milk washings per day, that is about 265 gallons per hour, on every second day. On the other days milk washings were supplied at a rate of 265 gallons per hour between 8 a.m. and 5 p.m.; during the night the contents of the aeration tanks were aerated continuously but the supply of liquid to the tanks was shut off. The average biochemical oxygen demand of the settled milk washings between 23rd January and 17th March 1937 was 21 parts per 100,000 and the average biochemical oxygen demand of the settled final effluent was 0·8 part per 100,000 parts. The average results for the whole of the period from 26th October 1936 to 17th March 1937 are given in Table LVII.

TABLE LVII. *Treatment of Milk Washings by the Activated Sludge Process*
Average Results
26th October 1936 *to* 17*th March* 1937

Volume of milk washings treated—6,350 gallons per day
Volume of sludge returned to aeration tanks—2,400 gallons per day
Average period of aeration—24 hours

	Crude milk washings	Crude milk washings after sedimentation, supplied to aeration tanks without dilution	Settled final effluent
Temperature (° C.)	29	19	11
*p*H value	6·7	6·8	7·4
Parts per 100,000			
Biochemical oxygen demand	28	26	0·7
Oxygen absorbed from acid permanganate in 4 hrs.	3·7	3·2	0·6
Dissolved oxygen	—	—	0·90
Total nitrogen (as N)	1·50	1·42	0·42
Ammonia (as N)	0·47	0·52	0
Nitrite (as N)	—	—	0
Nitrate (as N)	—	—	0·32
Soluble solids	37·8	41·6	36·5
Suspended solids	14·6	12·0	1·3
Incubation Test			
No. of samples tested	—	—	17
No. of samples passed	—	—	17
No. of samples failed	—	—	0

Proportion of sludge settled from liquid taken from aeration tanks, after standing in a glass cylinder (per cent by volume):

After 0·5 hr.	29 per cent
,, 1 ,,	24 ,, ,,
,, 2 hrs.	18 ,, ,,
,, 4 ,,	14 ,, ,,
,, 24 ,,	11 ,, ,,

Well-purified final effluents containing nitrate and large amounts of dissolved oxygen were obtained. The effluent had no harmful effect on trout immersed in it for periods of 18 hours.

It has previously been mentioned that the volume of sludge settled in a given time from liquid withdrawn from the aeration tanks varied widely from day to day. It was observed on 6th November that the amount of sludge in liquid taken from the aeration tanks, after settlement in a glass cylinder for 1 hour, was 11 per cent by volume. Immediately after this sample had been taken, the inside walls and floors of the aeration tanks were brushed and a second sample of liquid was withdrawn. After settlement in a cylinder for 1 hour the amount of sludge was 31 per cent by volume.

After 17th March whole milk was added to the milk washings in the storage tank so that the activated sludge plant could be supplied continuously with crude liquid of the desired strength. During the period 18th March to 28th April 1937, 6,350 gallons per day of undiluted settled milk washings, with an average biochemical oxygen demand of about 50 parts per 100,000, were aerated in admixture with activated sludge, returned from the final sedimentation tank at a rate of 2,400 gallons per day; the average period of aeration was 24 hours. The settled final effluent was well oxygenated and contained a large amount of nitrate; the average biochemical oxygen demand of the effluent was 1·0 part per 100,000 (Table LVIII). On three occasions during

TABLE LVIII. *Treatment of Milk Washings by the Activated Sludge Process*

Average Results

18*th March to* 28*th April* 1937

Volume of milk washings treated—6,350 gallons per day
Volume of sludge returned to aeration tanks—2,400 gallons per day
Average period of aeration—24 hours

	Crude milk washings	Crude milk washings after sedimentation, supplied to aeration tanks without dilution	Settled final effluent
Temperature (° C.)	42	25	16
*p*H value	5·9	6·1	7·1
Parts per 100,000			
Biochemical oxygen demand	60	52	1·0
Oxygen absorbed from acid permanganate in 4 hrs.	8·8	6·1	0·8
Dissolved oxygen	—	—	0·66
Total nitrogen (as N)	2·57	2·58	1·24
Ammonia (as N)	0·64	0·95	0
Nitrite (as N)	—	—	0·02
Nitrate (as N)	—	—	0·77
Soluble solids	49·0	49·1	31·3
Suspended solids	24·3	18·4	2·9
Incubation Test			
No. of samples tested	—	—	4
No. of samples passed	—	—	4
No. of samples failed	—	—	0

Proportion of sludge settled from liquid taken from aeration tanks, after standing in a glass cylinder (per cent by volume):

After 0·5 hr.	29 per cent
,, 1 ,,	24 ,, ,,
,, 2 hrs.	19 ,, ,,
,, 4 ,,	16 ,, ,,
,, 24 ,,	14 ,, ,,

this period " rising " of sludge occurred in the final sedimentation tank. On 24th March, when the amount of activated sludge in liquid from the aeration tanks was more than 50 per cent by volume after sedimentation in a cylinder for 30 minutes, some sludge was discharged to the drying bed.

Up to the end of April 1937 the maximum volume of milk washings successfully treated in the plant was 6,350 gallons per day of settled crude liquid with an average biochemical oxygen demand of 52 parts per 100,000. The average period of aeration was approximately 24 hours. The quality of the final effluent was better in the later experiments than in the earlier, though the quantity of water used to dilute the crude milk washings was less in the later experiments. This may have been due in part to a gradual increase in the activity of the activated sludge. In addition the temperature of milk washings discharged from the factory was higher than that of the water or final effluent with which they were diluted, and dilution therefore tended to reduce the rate of biological activity in the aeration tanks. During the period when the aeration tanks were supplied with 6,350 gallons per day of a settled crude liquid with an average biochemical oxygen demand of 52 parts per 100,000, a well-purified effluent was obtained even on occasions when the biochemical oxygen demand of the settled crude liquid was as high as 76 parts per 100,000.

In order to obtain information on the maximum capacity of the activated sludge plant, the volume of settled milk washings, with an average biochemical oxygen demand of about 50 parts per 100,000, supplied daily to the aeration tanks was increased on 29th April 1937 from 6,350 gallons to 9,270 gallons; the volume of activated sludge returned to the aeration tanks daily was maintained at 2,400 gallons and the average period of aeration was about 18 hours. These conditions were maintained until 30th May, that is for a period of approximately 1 month. The temperature during this period was usually high; the observed temperature of the liquid in the aeration tanks was never lower than 20° C., and for several successive days it was as high as 27° C. Well-purified effluents with an average biochemical oxygen demand of less than 1 part per 100,000 were obtained; the effluents contained nitrate and appreciable quantities of dissolved oxygen (Table LIX). " Rising " of sludge, which had sometimes occurred when the period of aeration of the settled milk washings was 24 hours, ceased when the period of aeration was reduced to 18 hours. After operation of the plant for some weeks under these conditions, however, the sludge changed in character and could not be satisfactorily settled in the sedimentation tank.

On 31st May the period of aeration was increased to 24 hours and satisfactory conditions were again established. Treatment of settled milk washings, with an average biochemical oxygen demand of 54 parts per 100,000, by aeration for 24 hours was continued from 31st May to 8th June 1937; the average biochemical oxygen demand of the settled final effluent was 0·5 part per 100,000 parts.

In Chapter IV laboratory experiments were described in which milk washings were aerated at different controlled temperatures in admixture with activated sludge. As the temperature was increased from 2° to 30° C. the proportion of fat in the activated sludge decreased from 16·5 to 1·4 per cent of the dry weight; the content of total nitrogen in the sludge, however, was fairly constant over this range of temperature (Table XXXI, p. 32). During the period September 1935 to April 1937, in which settled and diluted milk washings were treated in the activated sludge plant, determinations were made of the fat in the settled crude liquid supplied to the aeration tanks and of fat, total nitrogen, and ash in samples of activated sludge. The results are given in Table LX, together with the approximate temperature of the liquid in the aeration tanks and the biochemical oxygen demand of the final effluent.

Fat was present in the settled crude milk washings in concentrations varying between 0·5 part and 9·5 parts per 100,000. In general the content of fat in

TABLE LIX. *Treatment of Milk Washings by the Activated Sludge Process*
Average Results
29th April to 30th May 1937

Volume of milk washings treated—9,270 gallons per day
Volume of sludge returned to aeration tanks—2,400 gallons per day
Average period of aeration—18 hours

	Crude milk washings	Crude milk washings after sedimentation, supplied to aeration tanks without dilution	Settled final effluent
Temperature (° C.)	51	32	22
*p*H value	6·1	6·1	7·2
Parts per 100,000			
Biochemical oxygen demand	59	50	0·8
Oxygen absorbed from acid permanganate in 4 hrs.	8·5	4·9	0·5
Dissolved oxygen	—	—	0·53
Total nitrogen (as N)	2·36	2·42	0·27
Ammonia (as N)	0·69	0·77	0·05
Nitrite (as N)	—	—	0
Nitrate (as N)	—	—	0·17
Soluble solids	36·1	44·4	29·9
Suspended solids	21·7	17·0	1·5
Incubation Test			
No. of samples tested	—	—	4
No. of samples passed	—	—	4
No. of samples failed	—	—	0

Proportion of sludge settled from liquid taken from aeration tanks, after standing in a glass cylinder (per cent by volume):

After 0·5 hr.	.. ..	51 per cent
,, 1 ,,	.. ..	45 ,, ,,
,, 2 hrs.	.. ..	40 ,, ,,
,, 4 ,,	.. ..	32 ,, ,,
,, 24 ,,	.. ..	22 ,, ,,

the activated sludge was higher when the process was operated at low temperatures than at higher temperatures; the highest concentrations of fat in the sludge occurred on 8th and 27th December 1935, when the temperature was 4·5° C. and 3° C. In a large proportion of the samples of activated sludge the total nitrogen was between 6 and 8 per cent of the dry weight; occasionally, however, the percentage of nitrogen was lower. In the laboratory experiments the total nitrogen in the activated sludge was between 7·7 and 8·3 per cent of the dry weight.

Some experiments were made to determine the effect of temperature on "rising" of sludge. Samples of liquid containing activated sludge were withdrawn from the outlet end of the aeration tanks and were incubated for 16 hours in open vessels at different controlled temperatures. Analyses of the liquids after incubation, and observations on the condition of the activated sludge are given in Table LXI. In general, in the liquids incubated at a high temperature, the final concentration of ammonia was higher, and the final

TABLE LX. *Composition of Settled and Diluted Milk Washings, of Settled Final Effluent, and of Activated Sludge, during Operation of Activated Sludge Plant*

September 1935 *to April* 1937

Date	Approximate temperature of liquid in aeration tanks (° C.)	Biochemical oxygen demand of settled final effluent (parts per 100,000)	Average content of fat in liquid supplied to aeration tanks (parts per 100,000)	Composition of activated sludge (per cent dry weight)		
				Fat	Nitrogen	Ash
1935						
11 Sept. ..	15	9·4	4·0	2·9	6·3	17
22 Nov. ..	7	3·9	2·3	12·2	6·0	19
8 Dec. ..	4	2·2	2·7	20·2	7·5	24
27 ,, ..	3	2·7	2·8	20·5	5·8	18
1936						
20 Jan. ..	2	4·0	—	6·9	6·8	28
28 ,, ..	5	1·8	2·6	4·7	6·6	22
5 Feb. ..	2	2·1	2·5	6·2	6·5	28
11 ,, ..	1	3·4	4·1	4·3	6·4	22
24 Mar. ..	11	0·4	4·4	1·0	8·6	24
1 April ..	12	1·2	4·6	3·5	8·5	21
7 ,, ..	10	2·0	7·2	4·9	8·2	22
16 ,, ..	7	1·8	1·1	1·7	7·9	31
23 ,, ..	8	0·9	2·2	1·2	8·3	21
29 ,, ..	11	1·2	6·5	4·9	7·9	21
14 May ..	16	2·6	4·6	1·2	9·0	23
21 ,, ..	16	6·2	3·6	1·7	7·3	26
28 ,, ..	15	1·2	9·5	2·7	8·1	22
11 June ..	11	1·5	3·4	1·3	8·9	21
19 ,, ..	16	1·6	2·7	8·1	4·5	25
2 Oct. ..	18	0·8	3·4	1·8	3·6	27
23 ,, ..	16	0·4	3·0	1·3	7·2	26
14 Nov. ..	12	0·2	3·2	2·6	7·3	30
10 Dec. ..	—	0·6	3·0	1·9	6·4	22
30 ,, ..	15	1·1	3·5	4·3	6·8	27
1937						
13 Jan. ..	12	0·5	2·1	1·8	7·0	30
3 Mar. ..	9	0·6	2·5	1·2	3·5	28
19 ,, ..	13	0·9	0·5	1·3	2·0	9
13 April ..	18	1·4	5·9	2·3	7·3	23
23 ,, ..	20	1·2	3·6	3·0	7·3	22

concentrations of nitrate and dissolved oxygen were lower, than in liquids incubated at a low temperature. At temperatures of 0° C. to 2° C., and at 20° C., sludge did not rise to the surface during incubation; at temperatures of 27° C. to 30° C. the sludge contained entrained bubbles of gas and rose to the surface during incubation.

TREATMENT OF MIXTURES OF WHEY WASHINGS AND MILK WASHINGS

The first mixture of whey washings and milk washings contained one volume of whey washings with three volumes of milk washings; about half of the total polluting matter was contributed by each constituent. Approximately 6,350 gallons per day of the mixture, after sedimentation and dilution with purified effluent, were aerated for an average period of 24 hours in admixture with activated sludge, which was returned from the final sedimentation tank at a rate

TABLE LXI. *Composition of Liquid Withdrawn from Aeration Tanks and Condition of Activated Sludge after Incubation in Open Vessels for 16 Hours at Different Temperatures*

	Temperature of incubation (° C.)			
	0 to 2	20	27	28 to 30
Condition of sludge	Not risen to surface	Not risen to surface	Some sludge risen to surface	Some sludge risen to surface
Parts per 100,000				
Ammonia (as N)	0·017	0·033	0·049	0·066
Nitrite (as N)	0·015	0·018	0·012	0·021
Nitrate (as N)	0·49	0·31	0·34	0·18
Dissolved oxygen	0·93	0·44	0·24	0·27

of 2,400 gallons per day. Although the mixture of whey washings and milk washings, after sedimentation, was acid in reaction, with a *p*H value of 5·6, the final effluent was slightly alkaline in reaction, with a *p*H value of 7·4 (Table LXII). Well-purified effluents with an average biochemical oxygen demand of 0·5 part per 100,000 were obtained.

After operation for about 3 weeks under these conditions, a mixture of equal volumes of whey washings and milk washings, in which approximately three-quarters of the polluting matter was contributed by the whey washings, was supplied to the activated sludge plant; the average period of aeration was 24 hours. Satisfactory final effluents with an average biochemical oxygen demand of 0·5 part per 100,000 were obtained (Table LXIII), but on some days "bulking" of the sludge occurred. Nitrate was usually present in the final effluent.

From 26th July to 20th September 1937, a period of 8 weeks, a mixture of equal volumes of settled and diluted whey washings and milk washings, with an average biochemical oxygen demand of 52 parts per 100,000, was treated by aeration with activated sludge for an average period of 18 hours. Well-oxygenated final effluents of good quality were obtained (Table LXIV). The condition of the activated sludge throughout the period, however, led to some difficulty in the operation of the plant. On several days "rising" of sludge occurred in the final sedimentation tank, although the concentrations of nitrite and nitrate in the final effluent were small. The sludge in the aeration tanks, which hitherto had usually been reddish-brown in colour, sometimes became greyish-brown, and when this was so the final effluent was usually cloudy. On one day each week the supply of crude liquid to the aeration tanks was stopped during 15 hours. Aeration for 15 hours without the addition of crude liquid usually restored the reddish-brown colour of the sludge and improved the quality of the final effluent.

In general the sludge was more voluminous than it had been hitherto. "Bulking" of sludge sometimes occurred and it was necessary to discharge comparatively large volumes of surplus sludge to the drying bed on several occasions. Usually sludge was discharged only when the volume of sludge in liquid from the aeration tanks exceeded 50 per cent by volume after sedimentation in a cylinder for 30 minutes. When the sludge appeared to be very dense, however, part of it was discharged even if the amount settling during 30 minutes was less than 50 per cent by volume. If too large a volume of dense sludge had been allowed to accumulate in the aeration tanks, any sudden reduction in its density would have resulted in the carrying over of light

TABLE LXII. *Treatment of Mixtures containing One Volume of Whey Washings and Three Volumes of Milk Washings by the Activated Sludge Process*

Average Results
9th June to 2nd July 1937

Volume of diluted crude liquid treated—6,350 gallons per day.
Volume of sludge returned to aeration tanks—2,400 gallons per day
Average period of aeration—24 hours

	Crude liquid	Crude liquid after sedimentation	Settled and diluted crude liquid supplied to aeration tanks	Settled final effluent
Temperature (° C.)	45	27·5	24	20
*p*H value	5·4	5·6	6·1	7·4
Parts per 100,000				
Biochemical oxygen demand ..	77	61	37	0·5
Oxygen absorbed from acid permanganate in 4 hrs.	11·1	8·1	5·8	0·8
Dissolved oxygen	—	—	—	0·64
Total nitrogen (as N)	2·20	2·50	1·52	0·31
Ammonia (as N)	0·45	0·58	0·42	0
Nitrite (as N)	—	—	—	0
Nitrate (as N)	—	—	—	0·11
Soluble solids	47·6	72·3	60·7	33·0
Suspended solids	12·0	9·4	4·2	1·2
Incubation Test				
No. of samples tested	—	—	—	3
No. of samples passed	—	—	—	3
No. of samples failed	—	—	—	0

Proportion of sludge settled from liquid taken from aeration tanks, after standing in a glass cylinder (per cent by volume):

After 0·5 hr.	.. ..	41 per cent
,, 1 ,,	.. ..	31 ,, ,,
,, 2 hrs.	.. ..	25 ,, ,,
,, 4 ,,	.. ..	21 ,, ,,
,, 24 ,,	.. ..	17 ,, ,,

particles of sludge with the final effluent. The effluents obtained when the sludge was " bulking " did not always contain suspended particles, but were frequently clear and well purified. The most satisfactory method of reducing the effects of " bulking " appeared to be to reduce the load on the plant without completely stopping the supply of crude liquid to the aeration tanks and to discharge surplus sludge after allowing it to become compacted during settlement in the final sedimentation tank. It was observed that, when sludge was discharged to the drying bed at a high rate during a short period, cloudy effluents of poor quality were obtained; when surplus sludge was discharged at a low rate over a longer period, effluents of good quality were maintained.

From 21st September to 4th October 1937 the mixture of equal volumes of whey washings and milk washings supplied to the aeration tanks had an average biochemical oxygen demand of 38 parts per 100,000; the period of aeration was increased to 24 hours. Final effluents with an average biochemical

TABLE LXIII. *Treatment of Mixtures containing Equal Volumes of Whey Washings and Milk Washings by the Activated Sludge Process*

Average Results
3rd July to 25th July 1937

Volume of diluted crude liquid treated—6,350 gallons per day
Volume of sludge returned to aeration tanks—2,400 gallons per day
Average period of aeration—24 hours

	Crude liquid	Crude liquid after sedimentation	Settled and diluted crude liquid supplied to aeration tanks	Settled final effluent
Temperature (0° C.)	42	27	24	21
*p*H value	5·3	5·5	6·3	7·3
Parts per 100,000				
Biochemical oxygen demand ..	96	68	35	0·5
Oxygen absorbed from acid permanganate in 4 hrs.	15·9	8·8	5·4	1·0
Dissolved oxygen	—	—	—	0·65
Total nitrogen (as N)	2·56	2·32	1·32	0·40
Ammonia (as N)	0·77	1·13	0·44	0·05
Nitrite (as N)	—	—	—	0·03
Nitrate (as N)	—	—	—	0·23
Soluble solids	52·0	51·1	48·8	31·2
Suspended solids	15·5	12·5	10·8	0·9
Incubation Test				
No. of samples tested	—	—	—	3
No. of samples passed	—	—	—	3
No. of samples failed	—	—	—	0

Proportion of sludge settled from liquid taken from aeration tanks, after standing in a glass cylinder (per cent by volume):

After	0·5 hr.	57 per cent
,,	1 ,, ...	45 ,, ,,
,,	2 hrs.	35 ,, ,,
,,	4 ,, ...	28 ,, ,,
,,	24 ,, ...	20 ,, ,,

oxygen demand of only 0·5 part per 100,000 were obtained and the difficulty in separating the activated sludge in the final sedimentation tank was much reduced.

From 5th October to 25th October the crude liquid supplied to the plant contained three volumes of whey washings with one volume of milk washings; this liquid was treated without previous dilution with water or purified effluent. Approximately 6,350 gallons of crude liquid and 2,400 gallons of activated sludge entered the aeration tanks daily and the average period of aeration was 24 hours. The quantity of whey washings discharged during the manufacture of cheese at the factory was insufficient to supply the activated sludge plant at the desired rate. Effluent from the whey concentration plant was therefore used when possible to make up the deficiency. Since the whey concentration plant was not operated every day, as large a volume of whey washings as possible was collected when the plant was working; the whey washings were stored in a tank, sometimes for several days, and were used to supply the

TABLE LXIV. *Treatment of Mixtures containing Equal Volumes of Whey Washings and Milk Washings by the Activated Sludge Process*

Average Results

26th July to 20th September 1937

Volume of diluted crude liquid treated—9,270 gallons per day
Volume of sludge returned to aeration tanks—2,400 gallons per day
Average period of aeration—18 hours

	Crude liquid	Crude liquid after sedimentation	Settled and diluted crude liquid supplied to aeration tanks	Settled final effluent
Temperature (° C.)	45	30	28	23·5
*p*H value	5·4	5·4	5·9	7·3
Parts per 100,000				
Biochemical oxygen demand	72	57	52	0·6
Oxygen absorbed from acid permanganate in 4 hrs.	14·8	9·3	5·4	1·0
Dissolved oxygen	—	—	—	0·61
Total nitrogen (as N)	1·77	1·83	1·29	0·24
Ammonia (as N)	0·44	0·63	0·52	0·02
Nitrite (as N)	—	—	—	0
Nitrate (as N)	—	—	—	0
Soluble solids	38·0	42·8	56·1	29·8
Suspended solids	18·1	13·7	11·4	2·4
Incubation Test				
No. of samples tested	—	—	—	9
No. of samples passed	—	—	—	9
No. of samples failed	—	—	—	0

Proportion of sludge settled from liquid taken from aeration tanks, after standing in a glass cylinder (per cent by volume):

After 0·5 hr.	51 per cent
„ 1 „	42 „ „
„ 2 hrs.	32 „ „
„ 4 „	25 „ „
„ 24 „	14 „ „

activated sludge plant at the desired rate. Towards the end of October the desired volume and strength of the whey washings were maintained by the addition of whole whey and later the whey washings used consisted entirely of whole whey diluted with water in the storage tank. Milk washings from the factory were always available.

The *p*H value of the crude liquid entering the aeration tanks was low; the maximum value during the period was 5·4 and the usual value was about 5·0. The final effluent, however, was always neutral or slightly alkaline in reaction (Table LXV). The average biochemical oxygen demand of the crude liquid was 53 parts per 100,000 and that of the final effluent was 1·9 parts per 100,000. Some difficulty was experienced owing to " bulking " of sludge, particles of which were carried over with the final effluent. Thus on 18th October, when " bulking " occurred, the biochemical oxygen demand of the final effluent was 8·6 parts per 100,000 after sedimentation and 2·4 parts per 100,000 after filtration through filter paper. Throughout the period the effluent contained

TABLE LXV. *Treatment of Mixtures containing Three Volumes of Whey Washings with One Volume of Milk Washings by the Activated Sludge Process*

Average Results, 5th October to 25th October 1937

Volume of crude liquid treated—6,350 gallons per day
Volume of sludge returned to aeration tanks—2,400 gallons per day
Average period of aeration—24 hours

	Crude liquid	Crude liquid after sedimentation, supplied to aeration tanks without dilution	Settled final effluent
Temperature (° C.)	25	24	17·5
*p*H value	4·9	5·0	7·2
Parts per 100,000			
Biochemical oxygen demand	66	53	1·9
Oxygen absorbed from acid permanganate in 4 hrs.	12·1	8·0	1·1
Dissolved oxygen	—	—	0·60
Total nitrogen (as N)	2·02	2·54	0·66
Ammonia (as N)	0·74	0·74	0
Nitrite (as N)	—	—	0
Nitrate (as N)	—	—	0·07
Soluble solids	35·4	57·2	36·0
Suspended solids	11·2	10·6	5·7
Incubation Test			
No. of samples tested	—	—	2
No. of samples passed	—	—	0
No. of samples failed	—	—	2

Proportion of sludge settled from liquid taken from aeration tanks, after standing in a glass cylinder (per cent by volume):

After	0·5 hr.	31 per cent
,,	1 ,, ...	26 ,, ,,
,,	2 hrs.	22 ,, ,,
,,	4 ,, ...	18 ,, ,,
,,	24 ,, ...	15 ,, ,,

only small quantities of nitrate but it was usually well oxygenated. During the last week of the period the quality of the effluent deteriorated.

On 26th October the volume of crude liquid treated daily was reduced from 6,350 to 3,430 gallons; the average period of aeration was thus increased from 24 hours to 36 hours. After the fifth day of operation under these conditions the quality of the effluent improved. Difficulty was experienced, however, in making up crude liquids of the desired strength and the average biochemical oxygen demand of the settled liquid supplied to the aeration tanks was 73 parts per 100,000 (Table LXVI). The final effluent had an average biochemical oxygen demand of 2·0 parts per 100,000; it contained no nitrate but was well oxygenated.

On 19th November the compressor supplying air to the aeration tanks broke down and was out of operation until 24th November; during this time the activated sludge remained in the tanks without aeration. The sludge was aerated without the addition of crude liquid from 25th to 27th November,

TABLE LXVI. *Treatment of Mixtures Containing Three Volumes of Whey Washings and One Volume of Milk Washings by the Activated Sludge Process*

Average Results, 26th October to 18th November 1937

Volume of crude liquid treated—3,430 gallons per day
Volume of sludge returned to aeration tanks—2,400 gallons per day
Average period of aeration—36 hours

	Crude liquid	Crude liquid after sedimentation, supplied to aeration tanks without dilution	Settled final effluent
Temperature (° C.)	—	16	11
*p*H value	4·7	4·8	7·2
Parts per 100,000			
Biochemical oxygen demand	88	73	2·0
Oxygen absorbed from acid permanganate in 4 hrs.	18·5	12·2	1·0
Dissolved oxygen	—	—	0·78
Total nitrogen (as N)	2·96	2·86	0·34
Ammonia (as N)	0·65	0·68	0
Nitrite (as N)	—	—	0
Nitrate (as N)	—	—	0
Soluble solids	81·8	81·4	33·0
Suspended solids	12·5	8·9	4·1

Proportion of sludge settled from liquid taken from aeration tanks, after standing in a glass cylinder (per cent by volume):

After 0·5 hr.	.. ..	46 per cent
,, 1 ,,	.. ..	36 ,, ,,
,, 2 hrs.	.. ..	27 ,, ,,
,, 4 ,,	.. ..	22 ,, ,,
,, 24 ,,	.. ..	18 ,, ,,

and between 28th November and 6th December it was aerated with the addition of a small volume of milk washings.

On 7th December the supply of a mixture of three volumes of whey washings and one volume of milk washings was resumed at a rate of 3,430 gallons per day; the average period of aeration was 36 hours. By this time whey washings from the factory were no longer available and the liquid treated was a mixture of milk washings, whole whey, and water from a canal. From 7th December 1937 to 4th February 1938, when crude liquid with an average biochemical oxygen demand of 38 parts per 100,000 was supplied to the aeration tanks, fairly satisfactory effluents with an average biochemical oxygen demand of 1·4 parts per 100,000 were obtained (Table LXVII). It was never necessary to increase the period of aeration above 36 hours.

Between 5th February and 12th August 1938 diluted whey washings only were treated in the activated sludge plant. After these experiments, however, the aeration tanks were again supplied with a mixture containing three volumes of whey washings and one volume of milk washings. From 13th to 31st August, when the period of aeration was 36 hours, nitrate was present in the final effluent in comparatively high concentrations, and particles of activated sludge often rose to the surface of the final sedimentation tank. On 1st

TABLE LXVII. *Treatment of Mixtures containing Three Volumes of Whey Washings and One Volume of Milk Washings by the Activated Sludge Process*

Average Results, 7th December 1937 *to* 4*th February* 1938

Volume of crude liquid treated—3,430 gallons per day
Volume of sludge returned to aeration tanks—2,400 gallons per day
Average period of aeration—36 hours

	Crude liquid	Crude liquid after sedimentation, supplied to aeration tanks without dilution	Settled final effluent
Temperature (° C.)	37·5	10·5	7·5
Parts per 100,000			
Biochemical oxygen demand	46	38	1·4
Oxygen absorbed from acid permanganate in 4 hrs.	16·6	12·3	0·8
Dissolved oxygen	—	—	1·01
Total nitrogen (as N)	1·79	1·45	0·43
Ammonia (as N)	0·07	0·09	0·04
Nitrite (as N)	—	—	0
Nitrate (as N)	—	—	0·01
Soluble solids	80·3	47·9	21·8
Suspended solids	12·2	9·7	2·5

Proportion of sludge settled from liquid taken from aeration tanks, after standing in a glass cylinder (per cent by volume):

After	0·5 hr.	21 per cent
,,	1 ,, ...	19 ,, ,,
,,	2 hrs.	16 ,, ,,
,,	4 ,, ...	15 ,, ,,
,,	24 ,, ...	12 ,, ,,

September, therefore, the average period of aeration was reduced from 36 hours to 24 hours. From this date until 15th September, when the experiments were concluded, only small quantities of nitrate were found in the effluent and " rising " of sludge was greatly reduced. The temperature of the liquid in the aeration tanks was considerably higher than in the earlier experiments, in which mixtures containing three volumes of whey washings and one volume of milk washings were treated, and, possibly for this reason, the degree of purification achieved was much higher than in the earlier experiments. Between 13th August and 15th September the settled crude liquid supplied to the aeration tanks had the high average biochemical oxygen demand of 71 parts per 100,000; the average biochemical oxygen demand of the final effluent was only 0·6 part per 100,000 parts (Table LXVIII).

TREATMENT OF WHEY WASHINGS

During the period of about 8 weeks from 5th February to 31st March 1938, diluted whey washings only were treated in the activated sludge plant; the average period of aeration was 36 hours. The strength of the undiluted whey washings fluctuated widely from day to day and the biochemical oxygen demand varied between about 100 parts and 500 parts per 100,000. Determinations

TABLE LXVIII. *Treatment of Mixtures containing Three Volumes of Whey Washings and one Volume of Milk Washings by the Activated Sludge Process*

Average Results, 13th August to 15th September 1938

Volume of crude liquid treated from 13th to 31st August—3,430 gallons per day
Volume of crude liquid treated from 1st to 15th September—6,350 gallons per day
Volume of sludge returned to aeration tanks—2,400 gallons per day
Average period of aeration from 13th to 31st August—36 hours
Average period of aeration from 1st to 15th September—24 hours

	Crude liquid	Crude liquid after sedimentation, supplied to aeration tanks without dilution	Settled final effluent
Temperature (° C.)	20	22	19·5
*p*H value	4·5	4·7	7·4
Parts per 100,000			
Biochemical oxygen demand	95	71	0·6
Oxygen absorbed from acid permanganate in 4 hrs.	21·8	10·3	0·6
Dissolved oxygen	—	—	0·98
Total nitrogen (as N)	3·00	2·37	0·56
Ammonia (as N)	0·37	0·39	0
Nitrite (as N)	—	—	0·006
Nitrate (as N)	—	—	0·30
Soluble solids	58·2	34·1	18·7
Suspended solids	21·0	8·8	1·8
Incubation Test			
No. of samples tested	—	—	5
No. of samples passed	—	—	5
No. of samples failed	—	—	0

Proportion of sludge settled from liquid taken from aeration tanks, after standing in a glass cylinder (per cent by volume):

After 0·5 hr.	36 per cent
,, 1 ,,	30 ,, ,,
,, 2 hrs.	25 ,, ,,
,, 4 ,,	22 ,, ,,
,, 24 ,,	19 ,, ,,

of the oxygen demand from permanganate were made daily in order to estimate approximately the proportion of diluting water to be added to the whey washings to give a liquid with a biochemical oxygen demand of 35 to 50 parts per 100,000. This method was not very successful and on some days the biochemical oxygen demand of the liquid supplied to the aeration tanks was found to be more than 100 parts per 100,000. The average biochemical oxygen demand of the settled crude liquid was 65 parts per 100,000. The final effluent from the plant throughout the period was unsatisfactory and had a biochemical oxygen demand exceeding 4·4 parts per 100,000 (Table LXIX). By the middle of February the activated sludge contained a considerable proportion of filaments of the "sewage fungus" *Sphærotilus* and by the beginning of March "bulking" of sludge was occurring. Finally it became necessary to improve the condition of the sludge by additional aeration, and from 18th to 22nd March the supply of crude liquid to the aeration tanks was stopped during each night while

TABLE LXIX. *Treatment of Whey Washings by the Activated Sludge Process*
Average Results
5th February to 31st March 1938

Volume of whey washings treated—3,430 gallons per day
Volume of sludge returned to aeration tanks—2,400 gallons per day
Average period of aeration—36 hours

	Crude whey washings	Crude whey washings after sedimentation, supplied to aeration tanks without dilution	Settled final effluent
Temperature (0° C.)	16·5	12	9·5
*p*H value	5·7	5·3	7·1
Parts per 100,000			
Biochemical oxygen demand	—	65	>4·4
Oxygen absorbed from acid permanganate in 4 hrs	15·8	17·1	2·1
Dissolved oxygen	—	—	0·69
Total nitrogen (as N)	1·40	1·15	0·23
Ammonia (as N)	0·32	0·81	0
Nitrite (as N)	—	—	0
Nitrate (as N)	—	—	0
Soluble solids	55·8	40·8	26·7
Suspended solids	8·8	8·8	2·2
Incubation Test			
No. of samples tested	—	—	7
No. of samples passed	—	—	1
No. of samples failed	—	—	6

Proportion of sludge settled from liquid taken from aeration tanks, after standing in a glass cylinder (per cent by volume):

After	0·5 hr.	74 per cent
,,	1 ,,	65 ,, ,,
,,	2 hrs.	51 ,, ,,
,,	4 ,,	38 ,, ,,
,,	24 ,,	18 ,, ,,

aeration was continued. From 23rd to 25th March the sludge was aerated without the addition of any crude liquid. This led to an improvement in the condition of the activated sludge and in the quality of the final effluent. The temperature was low throughout the period and this no doubt adversely affected the results obtained.

At the beginning of April whey washings from the cheese factory were no longer available. From 1st April to 11th May 1938, a period of about 6 weeks, the liquid supplied to the aeration tanks was obtained by diluting whole whey with water from the canal; part of the whole whey and canal water was replaced by condensate from the whey concentration plant when this was available. A volume of 3,430 gallons of diluted whey was treated daily in admixture with 2,400 gallons of returned activated sludge; the average period of aeration was 36 hours. The average biochemical oxygen demand of the settled crude liquid was 44 parts per 100,000, and of the final effluent 3·4 parts per 100,000 (Table LXX). The condition of the activated sludge was again unsatisfactory and on 12 days the supply of crude liquid to the aeration tanks was discontinued

TABLE LXX. *Treatment of Whey Washings by the Activated Sludge Process*
Average Results
1st April to 11th May 1938

Volume of whey washings treated—3,430 gallons per day
Volume of sludge returned to aeration tanks—2,400 gallons per day
Average period of aeration—36 hours

	Crude whey washings	Crude whey washings after sedimentation, supplied to aeration tanks without dilution	Settled final effluent
Temperature (° C.)	13	12	11
*p*H value	4·9	4·9	7·0
Parts per 100,000			
Biochemical oxygen demand	55	44	3·4
Oxygen absorbed from acid permanganate in 4 hrs.	17·9	14·5	1·0
Dissolved oxygen	—	—	0·85
Total nitrogen (as N)	1·46	0·88	0·28
Ammonia (as N)	0·03	0·02	0
Nitrite (as N)	—	—	0
Nitrate (as N)	—	—	0
Soluble solids	35·4	57·2	36·0
Suspended solids	11·2	10·6	5·7
Incubation Test			
No. of samples tested	—	—	5
No. of samples passed	—	—	0
No. of samples failed	—	—	5

Proportion of sludge settled from liquid taken from aeration tanks, after standing in a glass cylinder (per cent by volume):

After 0·5 hr.	49 per cent
,, 1 ,,	37 ,, ,,
,, 2 hrs.	29 ,, ,,
,, 4 ,,	23 ,, ,,
,, 24 ,,	16 ,, ,,

for 15 hours daily, though aeration was continued throughout the 24 hours. The temperature was again low throughout the period; the average temperature of the final effluent was 11° C.

It was evident that, at the low temperatures prevailing at the beginning of May, the activated sludge plant was unable to treat whey washings satisfactorily when the period of aeration was 36 hours. On 12th May, therefore, the volume of whey washings treated daily was reduced from 3,430 to 1,970 gallons; the volume of activated sludge returned daily to the aeration tanks was unchanged at 2,400 gallons and the period of aeration was thus increased from 36 hours to 48 hours. Between 12th May and 24th June 1938, when the plant was operated under these conditions, the temperature of the liquid in the aeration tanks gradually increased from about 10·5° to 17·5° C.

With the lower rate of flow of the crude liquid a considerable reduction in the concentration of polluting matter occurred in the primary sedimentation tank, the average biochemical oxygen demand of the whey washings being reduced from 56 to 33 parts per 100,000 parts. By 14th May the quality of the final effluent had improved noticeably, and after 21st May the biochemical oxygen demand of the effluent was always less than 1 part per 100,000. The average biochemical oxygen demand of the effluent during the period was 1·3 parts per 100,000; the effluent contained nitrate and was well oxygenated (Table LXXI).

TABLE LXXI. *Treatment of Whey Washings by the Activated Sludge Process*
Average Results
12th May to 24th June 1938

Volume of whey washings treated—1,970 gallons per day
Volume of sludge returned to aeration tanks—2,400 gallons per day
Average period of aeration—48 hours

	Crude whey washings	Crude whey washings after sedimentation, supplied to aeration tanks without dilution	Settled final effluent
Temperature (° C.)	18	20	17
*p*H value	4·7	4·7	7·1
Parts per 100,000			
Biochemical oxygen demand	56	33	1·3
Oxygen absorbed from acid permanganate in 4 hrs.	14·1	8·46	0·59
Dissolved oxygen	—	—	0·91
Total nitrogen (as N)	1·33	1·07	0·40
Ammonia (as N)	0·10	0·15	0·15
Nitrite (as N)	—	—	0·02
Nitrate (as N)	—	—	0·20
Soluble solids	39·9	25·9	15·9
Suspended solids	9·3	7·3	1·2
Incubation Test			
No. of samples tested	—	—	6
No. of samples passed	—	—	3
No. of samples failed	—	—	3

Proportion of sludge settled from liquid taken from aeration tanks, after standing in a glass cylinder (per cent by volume):

After 0·5 hr.	47 per cent
,, 1 ,,	32 ,, ,,
,, 2 hrs.	28 ,, ,,
,, 4 ,,	23 ,, ,,
,, 24 ,,	17 ,, ,,

By 25th June 1938 the quality of the effluent had so improved that the period of aeration of the whey washings was reduced from 48 hours to 36 hours; the plant was operated under these conditions until 12th August, a period of 7 weeks. The settled whey washings supplied to the aeration tanks had the high average biochemical oxygen demand of 66 parts per 100,000. The quality of the final effluent, however, was consistently good throughout the period and its average biochemical oxygen demand was only 0·6 part per 100,000 (Table LXXII). Nitrate and nitrite were not present in the effluent until 23rd July, but between 23rd July and 11th August nitrate was present in an average concentration equivalent to 0·4 part N per 100,000 parts and nitrite in an average

TABLE LXXII. *Treatment of Whey Washings by the Activated Sludge Process*
Average Results
25th June to 12th August 1938

Volume of whey washings treated—3,430 gallons per day
Volume of sludge returned to aeration tanks—2,400 gallons per day
Average period of aeration—36 hours

	Crude whey washings	Crude whey washings after sedimentation, supplied to aeration tanks without dilution	Settled final effluent
Temperature (° C.)	19	21·5	19
*p*H value	4·6	4·7	7·1
Parts per 100,000			
Biochemical oxygen demand	83	66	0·6
Oxygen absorbed from acid permanganate in 4 hrs.	20·4	8·9	0·6
Dissolved oxygen	—	—	0·80
Total nitrogen (as N)	2·23	1·87	0·45
Ammonia (as N)	0·18	0·17	0·02
Nitrite (as N)	—	—	0·039
Nitrate (as N)	—	—	0·17
Soluble solids	42·7	28·1	17·9
Suspended solids	17·5	11·9	1·5
Incubation Test			
No. of samples tested	—	—	6
No. of samples passed	—	—	6
No. of samples failed	—	—	0

Proportion of sludge settled from liquid taken from aeration tanks, after standing in a glass cylinder (per cent by volume):

After 0·5 hr.	38 per cent
,, 1 ,,	30 ,, ,,
,, 2 hrs.	25 ,, ,,
,, 4 ,,	23 ,, ,,
,, 24 ,,	18 ,, ,,

concentration equivalent to 0·11 part N per 100,000 parts. "Rising" of activated sludge occurred on some occasions, especially towards the end of the period.

REVIEW OF EXPERIMENTS ON A LARGE SCALE WITH THE ACTIVATED SLUDGE PROCESS

Operation of the activated sludge plant was begun in August 1935. During the first two months a supply of activated sludge was prepared by aerating mixtures of milk washings with river water or with treated effluent. The conditions of operation of the plant and the results obtained during the period October 1935 to September 1938 are summarized in Table LXXIII. Throughout the period a volume of 2,400 gallons of activated sludge was returned daily from the final settling tank to the aeration tanks for aeration in admixture with settled crude liquid, diluted when necessary with treated effluent.

Between October 1935 and May 1937, a period of about 19 months, milk washings only were treated in the plant. At first the volume of settled and

TABLE LXXIII. *Summary of Conditions of Operation of Activated Sludge Plant*

10th October 1935 *to* 15*th September* 1938

Period of experiment	Liquid treated	Volume of diluted crude liquid treated daily (gal.)	Average period of aeration (hours)	Biochemical oxygen demand (parts per 100,000)			Average temperature of settled final effluent (° C.)
				Crude liquid	Settled liquid entering aeration tanks	Settled final effluent	
1935							
10 Oct.–27 Nov.	Milk washings	9,600	17·5	69	19	3·3	9
28 Nov. 1935–1 March 1936	,,	6,350	24	78	20	2·6	4
1936							
2 March–17 April	,,	3,430	36	101	29	1·7	9
18 April–1 June	,,	6,350	24	145	38	2·1	13·5
2 June–17 July	,,	3,600	35	76	32	2·4	17·5
18 July–6 Sept.	,,	6,350	24	63	25	1·2	21
7 Sept.–25 Oct.	,,	3,120	38	64	50	1·2	16·5
26 Oct. 1936–17 March 1937	,,	6,350	24	28	26	0·7	11
1937							
18March–28April	,,	6,350	24	60	52	1·0	16
29 April–30 May	,,	9,270	18	59	50	0·8	22
1937							
9 June–2 July	1 vol. whey washings with 3 vol. milk washings	6,350	24	77	37	0·5	20
1937							
3 July–25 July	1 vol. whey washings with 1 vol. milk washings	6,350	24	96	35	0·5	21
26 July–20 Sept.	,,	9,270	18	72	52	0·6	23·5
1937							
5 Oct.–25 Oct.	3 vol. whey washings with 1 vol. milk washings	6,350	24	66	53	1·9	17·5
26 Oct.–18 Nov.	,,	3,430	36	88	73	2·0	11
7 Dec. 1937–4 Feb. 1938	,,	3,430	36	46	38	1·4	7·5
1938							
12 Aug.–31 Aug.	,,	3,430	36 }	95	71	0·6	19·5
1 Sept.–15 Sept.	,,	6,350	24 }				
1938							
5 Feb.–31 March	Whey washings	3,430	36	—	65	>4·4	9·5
1 April–11 May	,,	3,430	36	55	44	3·4	11
12 May–24 June	,,	1,970	48	56	33	1·3	17
25 June–12 Aug.	,,	3,430	36	83	66	0·6	19

diluted crude liquid treated daily was 9,600 gallons, and the average period of aeration was about 17·5 hours. Final effluents of poor quality were obtained under these conditions. The volume of crude liquid supplied daily to the aeration tanks was then reduced so as to increase the period of aeration, at first to 24 hours and later to 36 hours. With a period of aeration of 36 hours the final effluents obtained were of fair quality, with an average biochemical oxygen demand of 1·7 parts per 100,000. The quality of the effluent deteriorated when the period of aeration was reduced, in April 1936, from 36 hours to 24 hours, and the quantity of liquid treated daily was again reduced to give a period of aeration of 35 hours. These conditions were maintained from 4th June to 17th July 1936. The final effluent was not of good quality; this was partly due to " rising " of sludge, when particles of sludge, buoyed up by bubbles of gas, rose to the surface of the liquid in the final sedimentation tank and were carried away with the final effluent. Evidence of other investigators has indicated that " rising " of sludge is due to the formation of bubbles of gaseous nitrogen, produced during decomposition of soluble nitrogenous substances. Nitrate was present in the final effluent in high concentrations when " rising " of sludge was occurring, and in July 1936 the period of aeration was reduced from 35 hours to 24 hours, with the object of reducing the quantity of nitrite and nitrate in the final effluent.

From July to September 1936 the average biochemical oxygen demand of the settled and diluted milk washings supplied to the aeration tanks was 25 parts per 100,000, and by aeration of this liquid in admixture with activated sludge for periods of 24 hours, well-purified effluents with an average biochemical oxygen demand of 1·2 parts per 100,000 were obtained. No difficulty was encountered in the settlement of the activated sludge in the final sedimentation tank. Effluents of equally good quality were also obtained during a period of 7 weeks in September and October 1936, when the strength of the liquid supplied to the aeration tanks was increased to give an average biochemical oxygen demand of 50 parts per 100,000, and the period of aeration was increased to 38 hours.

Between 26th October 1936 and 28th April 1937 the period of aeration of the mixture of settled milk washings and activated sludge was 24 hours; up to 17th March 1937 the average biochemical oxygen demand of the settled crude liquid was 26 parts per 100,000, and from 18th March to 28th April 1937 it was 52 parts per 100,000. Well-purified effluents, with an average biochemical oxygen demand not exceeding 1 part per 100,000, were obtained throughout the period and no serious difficulty in the operation of the plant was encountered.

During May 1937, in order to obtain information on the maximum capacity of the activated sludge plant, the period of aeration was reduced to 18 hours; the liquid treated had an average biochemical oxygen demand of 50 parts per 100,000. It was found that the plant could not be operated satisfactorily with this load; the character of the sludge changed, " bulking " of sludge occurred and interfered with the separation of the sludge in the final sedimentation tank, and it finally became necessary to increase the period of aeration to 24 hours.

Mixtures containing one volume of whey washings with three volumes of milk washings were satisfactorily treated by aeration for 24 hours; the average biochemical oxygen demand of the settled and diluted crude liquid was 37 parts per 100,000. Effluents of good quality were also obtained by aeration for 24 hours of activated sludge in admixture with settled and diluted crude liquid containing equal volumes of whey washings and milk washings and having an average biochemical oxygen demand of 35 parts per 100,000. When the strength of the settled and diluted crude liquid was increased to give an average biochemical oxygen demand of 52 parts per 100,000 and the period of aeration was reduced to 18 hours, the quality of the final effluent did not change appreciably, but the condition of the activated sludge deteriorated and additional aeration became necessary.

From 5th October 1937 to 4th February 1938 and from 12th August to 15th September 1938, the crude liquid treated was a mixture of three volumes of whey washings with one volume of milk washings. At first the average biochemical oxygen demand of the liquid supplied to the aeration tanks was 53 parts per 100,000 and the period of aeration was 24 hours; under these conditions the quality of the final effluent was sometimes unsatisfactory, largely owing to the low settling rate of the activated sludge, particles of which were carried over with the effluent from the final sedimentation tank. The period of aeration was then increased to 36 hours, but the crude liquid supplied to the aeration tanks had the high average biochemical oxygen demand of 73 parts per 100,000 and unsatisfactory effluents were again occasionally obtained. Somewhat better results were obtained when the strength of the crude liquid supplied to the aeration tanks was reduced to give an average biochemical oxygen demand of 38 parts per 100,000; the temperature was low during this period and this probably reduced the efficiency of the plant. In August and September 1938, when the temperature was much higher, effluents of excellent quality were obtained by treatment of mixtures of three volumes of whey washings with one volume of milk washings, with an average biochemical oxygen demand of over 70 parts per 100,000. At first the period of aeration was 36 hours, but this was later reduced to 24 hours without causing deterioration in the quality of the final effluent.

Whey washings only were treated during the period 5th February to 12th August 1938. Up to the middle of May the period of aeration was 36 hours and the average biochemical oxygen demand of the crude liquid supplied to the aeration tanks was at first 65 parts per 100,000 and was later 44 parts per 100,000. The temperature was low during this period. Effluents of poor quality were obtained, and in May 1938 the strength of the crude liquid was reduced and the period of aeration was increased to 48 hours; the quality of the final effluent then improved considerably. This improvement may have been due in part to the rise in temperature which occurred in May and June. During the period 25th June to 12th August 1938, when the temperature was high, effluents of excellent quality were obtained from the treatment of settled whey washings, with the high average biochemical oxygen demand of 66 parts per 100,000, by aeration for a period of 36 hours.

The results indicate that the efficiency of treatment of milk washings and whey washings by the activated sludge process is influenced considerably by temperature; this is in agreement with the laboratory experiments described in Chapter IV. In warm weather satisfactory effluents were obtained by treatment of crude liquid, with a biochemical oxygen demand of 35 to 50 parts per 100,000, by aeration with activated sludge for a period of 24 hours. In cold weather the capacity of the plant was considerably smaller. There was some indication that whey washings were rather more difficult to treat than milk washings, but in the summer months effluents of excellent quality were obtained by aeration for 36 hours of activated sludge in admixture with whey washings with an average biochemical oxygen demand of 66 parts per 100,000. Equally good effluents resulted from aeration for 36 hours or for 24 hours of mixtures with an average biochemical oxygen demand of 71 parts per 100,000, containing three volumes of whey washings and one volume of milk washings. In cold weather it would be necessary either to reduce the strength of the crude liquid supplied to the aeration tanks or to increase the period of aeration.

Throughout the investigation the effluents from the activated sludge plant were well oxygenated. The average concentration during the whole period of operation was 0·69 part of dissolved oxygen per 100,000 parts; this represents about 70 per cent of the concentration of dissolved oxygen required to saturate water at a temperature of 15° C. The concentration of dissolved oxygen in the effluent was, however, less than in the final effluent from the double-filtration plant, in which the average concentration during the whole period of operation was 0·95 part per 100,000.

Final effluent from the activated sludge plant never contained fat, though fat was always present in the crude liquids treated. The effluent was always neutral or slightly alkaline in reaction even when the crude liquid had a *p*H value as low as 4·6.

On the whole, the effluents obtained by treatment of milk washings and whey washings by the activated sludge process were not of such good quality as the effluents obtained by the treatment of similar liquids by the process of double filtration. Aeration of crude liquid, with an average biochemical oxygen demand of 50 parts per 100,000, with activated sludge for 24 hours represents a rather lower rate of treatment than is usual at many sewage disposal works in the treatment of domestic sewage by the activated sludge process, allowance being made for the difference in the strength of the crude liquids. On the other hand, the rate at which milk washings and whey washings were treated in the double-filtration plant to give effluents of good quality was considerably higher than is usual in the treatment of domestic sewage by the process of single filtration.

Considerable care is needed in the treatment of milk washings and whey washings by the activated sludge process in order to maintain the sludge in good condition. Difficulties may be caused both by "rising" and by "bulking" of sludge. "Rising" of sludge, which is usually associated with the occurrence of high concentrations of nitrates and nitrites in the final effluent, may be prevented by increasing the strength of the crude liquid or by reducing the period of aeration. When, however, the crude liquid is too strong or the period of aeration is too short, the activated sludge "bulks", that is to say, it becomes voluminous and difficult to separate from the final effluent by sedimentation. "Bulking" may be controlled to some extent by careful control of the volume of sludge discharged from the final sedimentation tank to the drying bed, but ultimately it usually becomes necessary to increase the period of aeration or to decrease the strength of the crude liquid. In general, treatment of milk washings and whey washings by the activated sludge process is more difficult to control and is more easily upset by flushes of liquid of abnormally high strength than is treatment by biological filtration in two filters in series with periodic change in the order of the filters.

CHAPTER VII. BIOLOGICAL INVESTIGATIONS

TREATMENT OF WASTE WATERS BY THE PROCESS OF DOUBLE FILTRATION

THE main objects of the biological work were to determine the nature and relative abundance of the organisms present during the treatment of waste waters from dairies and milk products factories, to study the factors causing changes in the relative abundance of the different types, and if possible to obtain information on the part played by each type of organism in the processes of purification. The work included laboratory experiments at the Rothamsted Experimental Station and at Ellesmere, and observations of the various types of organisms in samples of liquid, of sludge, and of film on filtering medium from the two experimental plants at Ellesmere.

Organisms on the Surface of the Filters

As a result of the method of operation of the double-filtration plant, periodic changes occurred in the amount and nature of the film on the surface of the medium in the two filters. Immediately after the order of the filters in series had been changed, the amount of biological film and other solid matter on the surface of the primary filter was usually small; settled crude liquid with an average biochemical oxygen demand of about 25 to 50 parts per 100,000 parts was then distributed on this filter for a period of 2 or 3 weeks, and during this time the amount of film and deposited solid matter gradually increased. The liquid distributed on the secondary filter had an average biochemical oxygen demand usually not exceeding 3 parts per 100,000, and the amount of material which had accumulated on the medium at the surface of this filter decreased during the period of 2 to 3 weeks before the order of the filters in series was again reversed. An essential feature of this method of double filtration is thus the alternate building up and removal of surface film.

When operation of the filtration plant was begun in August 1935, an opportunity was provided for studying the development of biological film on the clean metallurgical coke used as filtering medium. Settled and diluted milk washings were at first supplied to the primary filter at a rate of 50 gallons per day per cubic yard of medium in the two filters together, but this rate was soon increased to 80 gallons per day per cubic yard of medium; treatment at this rate was continued from 7th August 1935 to the end of March 1936. By the end of the first week of operation a white film, consisting of different types of bacterial zooglœæ with numerous protozoa, had grown on the surface of the medium in the primary filter.

Another opportunity was provided for studying the development of biological film in December 1936, when the filters were re-started after having been out of operation while being reduced in size. The medium was replaced in the filters without having been washed or re-graded. After the filters had been supplied with milk washings for a week, a white film had developed on the medium of the primary filter and the purification effected by the two filters in series had reached a high standard. The organisms present in the film on the primary filter were mainly bacterial zooglœæ; there were few protozoa. Diatoms and other green algæ did not appear until the filters had been in operation for some time.

During the period in which milk washings were treated in the double-filtration plant, the biological film on the surface of the medium consisted largely of gelatinous masses of bacterial zooglœæ, though filaments of the "sewage fungus", *Sphærotilus*, were usually present in film in the top layer of the primary filter. In March 1937 the rate at which settled and diluted milk washings were supplied to the filters was increased from 164 gallons to 240 gallons per day per cubic yard of filtering medium. This led to an increase in the amount of film and also to some change in its composition. For the first time a fungus, *Saprolegnia* sp., became subdominant and the film as a result became tougher and less easily washed away.

Until June 1937 milk washings only were treated in the double-filtration plant. In June 1937 a mixture of whey washings and milk washings was supplied to the filters and thereafter the proportion of whey in the crude liquid was increased at intervals until, from March to August 1938, liquids containing whey washings only were treated. The addition of whey washings to the crude liquid encouraged the growth of fungi in the top layer of the filtering medium in the primary filter. The most abundant organism was a species of *Saprolegnia*; this fungus grew slowly but persisted for a long time and was difficult to remove by changing the order of the filters. Other fungi in the top layer included species of *Fusarium*, *Sporotrychum*, *Oospora* (Plates 4*a*

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(a)

(b)

PLATE 4. *Oospora* on Filtering Medium on the Primary Filter.

(a) *Oospora lactis* (×94).

(b) *Oospora fragrans* (×94).

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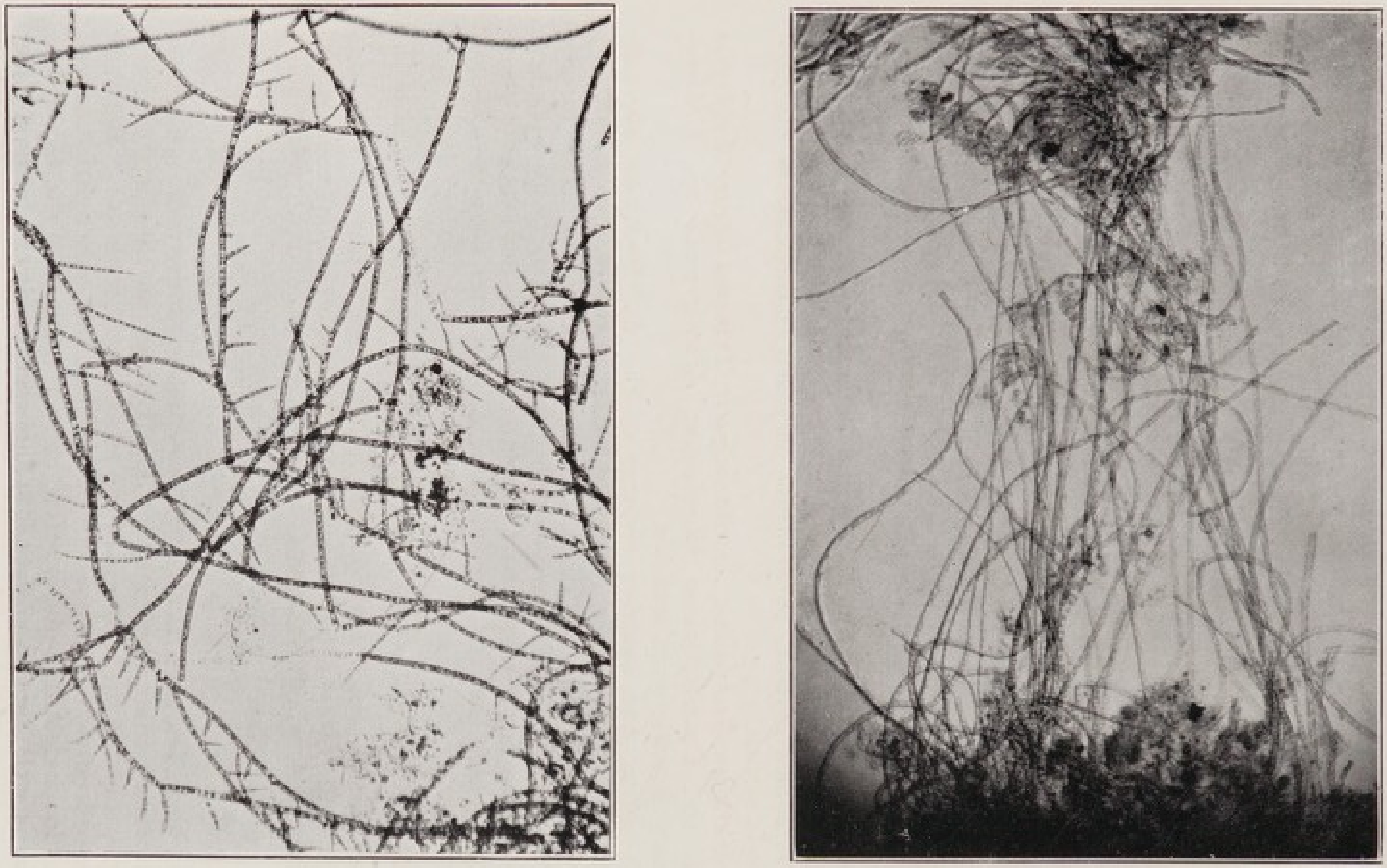


(a) (b)

Plate 5. *Stigeoclonium* and *Ulothrix* on Filtering Medium.

(a) *Stigeoclonium tenue* (×94).
(b) *Ulothrix subtilis* (×94).

and 4*b*) and *Rhodotorula*; these fungi disappeared much more rapidly than *Saprolegnia* when the order of the filters was changed. Signs of ponding on the filters, which occurred several times during this period, seemed to be due chiefly to the growth of a tough film of *Saprolegnia* sp. Protozoa were abundant in the top layers during the treatment of liquids containing whey, as were also nematodes, rotifers, *Psychoda* larvæ, and other metazoa. Throughout the investigation yeasts were never abundant in the film on the surface of the filtering medium.

Algæ occurred on the medium at the surface of the filters throughout the investigation; they were found mainly on the filter being used as the secondary filter. The most abundant forms were the following: *Protococcus* sp., *Stigeoclonium tenue* (Plate 5*a*), *Ulothrix subtilis* (Plate 5*b*), and two species of *Phormidium* of the order Oscillatoriaceæ, which formed shiny black patches on the surface of the filter medium; diatoms of the *Navicula* type also occurred. Other algæ were *Scenedesmus* sp., *Chlamydomonas* sp., *Oscillatoria* sp.; *Cladophora* sp. and *Œdogonium* sp. were each found on one occasion.

The protozoa found in the biological film during the investigation were:

Flagellata: *Cercomonas crassicauda, Heteromita globosa, Oikomonas termo, Tetramitus spiralis, Bodo saltans, Sainouron microteron, Peranema* sp., *Astasia* sp.

Ciliata: *Paramœcium putrinum, Colpidium colpoda, Glaucoma scintillans, Euplotes charon, Lionotus fasciola, Chilodon cucullulus, Vorticella putrinum, Epistylis* sp., *Aspidisca costata, Pleuronema chrysalis, Cinetochilum margaritaceum, Gastrostyla steinii.*

Rhizopoda: *Hartmanella hyalina, Arcella vulgaris, Trinema lineare, Euglypha* sp., *Centropyxis* sp., *Cochliopodium bilimbosum, Microgromia* sp., *Chlamydophrys stercoreum, Acanthocystis aculeata.*

During each spring and summer swarms of the fly *Psychoda alternata* inhabited the filters. Most of the flies were found in the comparatively dry interspaces between the concentric rings of thicker surface film which formed in the track of each jet of the rotary distributors. Here the eggs were laid below the surface; the larvæ which hatched out tended to migrate into those parts of the filters where the film and deposited solid matter were most dense.

Distribution of Organisms in Different Parts of the Filters

The observations on which this account of the distribution of organisms in different parts of the filters is based were made during periods when mixtures of milk washings and whey washings, or whey washings only, were being treated.

(*i*) *Primary Filter*

After a filter had been used as the primary filter for some time, concentric rings of comparatively thick film could usually be seen on the surface of the filter; each ring was in the track of one of the jets of the distributor. Between these rings were concentric zones in which the medium was only lightly covered with biological film and other solid matter; the appearance of the top of the filtering medium is well shown in Plate 2. The medium of the primary filter provided four main types of habitat for organisms: (*a*) the medium at the surface of the filter immediately in the track of the jets of the distributor, (*b*) the medium at the surface of the filter between the jets of the distributor, (*c*) medium below the surface of the filter, varying in depth but not usually extending below 1 ft., and (*d*) medium below a depth of 1 ft.

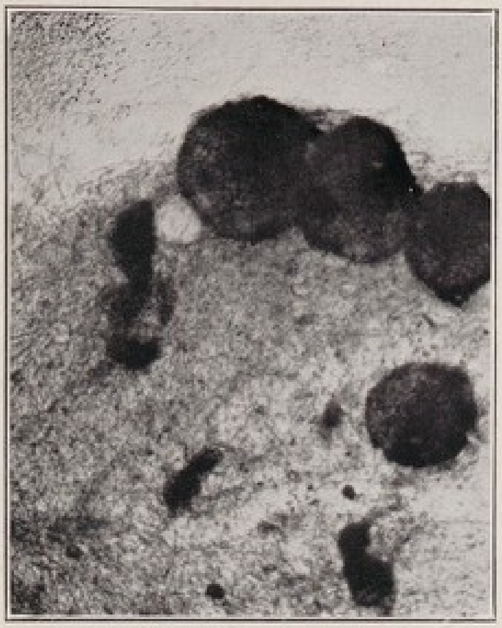
The biological film on the surface of the medium in the top layer, in the track of the jets of the distributor, was usually from 2 to 3 mm. in thickness and was characterized by the orange colour of the fungus *Fusarium* which occurred at the surface of the film. Below the layer of this fungus was a thin layer of the fungus *Phoma*, which could be distinguished by its dark brown pycnidia (Plates 6*a* and 6*b*). Below the layer of *Phoma* and resting directly on the coke was a layer of algæ which were unable to develop to any extent when covered with the layers of fungi. *Phoma* was sometimes found on the surface of the film, co-dominant with *Fusarium*, but in this case it usually occurred at the edges of the concentric rings of growth and imparted a dark brown colour to the film. The pycnidia could be seen with the naked eye as dark brown specks. Protozoa were rarely found in the surface film, possibly owing to the relatively high velocity of the liquid impinging on the film from the jets of the distributor.

The surface of the medium in the spaces between the tracks of the distributor jets was relatively dry and was only lightly covered with biological film. Large numbers of *Psychoda* laid their eggs on the under surfaces of the pieces of coke medium. The larvæ migrated to positions in the filter where larger quantities of organic matter were available and where the adult flies could not have survived.

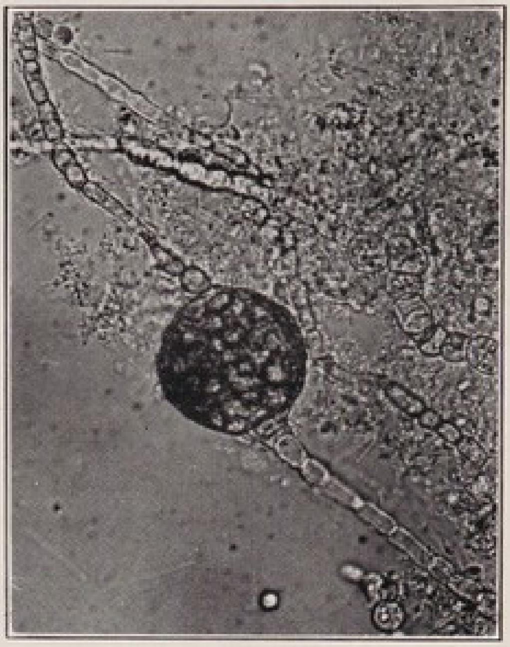
Immediately below the surface of the filtering medium occurred the fungi *Fusarium*, *Oospora*, and *Leptomitus*. *Oospora* did not usually extend very far downwards, though it was the most abundant organism at a greater depth on one occasion, when the biochemical oxygen demand of the crude liquid supplied to the primary filter was higher than usual. The characteristic texture of the underlying film was due mainly to hyphæ of the fungus *Saprolegnia*, which sometimes bound the pieces of coke together. *Leptomitus lacteus*, a fungus closely allied to *Saprolegnia*, occurred during one period in close association with *Saprolegnia* but subsequently disappeared. Ponding of the primary filter, which occurred on a few occasions when the strength or volume of liquid distributed on the filter was too high, was due chiefly to the fungi in the biological film in this zone of the primary filter, though the film also contained a large amount of bacterial matter, both in the form of zooglœæ and as free bacteria. Packets of bacteria resembling *Sarcina*, which occurred in this part of the biological film, were similar in appearance to those found in activated sludge; the organisms were similar in appearance to nitrifying bacteria found by Winogradsky[1] in sewage but did not cause oxidation of ammonium sulphate. Shapeless gelatinous masses formed by the growth of a species of purple bacterium were found in the sub-surface layer of medium. The characteristics of this bacterium are described in Appendix II.

Immediately below the top surface of the medium both fungi and bacteria were usually in active growth. At greater depths in the zone of medium from the surface of the filter to a depth of about 1 ft. the film resembled black mud; it contained ferrous sulphide and the filamentous sulphur bacterium, *Beggiatoa alba*. The protozoan population of this zone was very variable and appeared to be influenced by the amount of oxygen and organic matter available. The ciliates *Colpidium colpoda* and *Paramœcium putrinum* were found in situations where aeration was good and where plentiful supplies of organic matter were available for food. At times Vorticellids were found in large numbers, and in the underlying blacker parts of the film there were large numbers of flagellates and small amœbæ. *Tetramitus spiralis* and species of *Mastigamœba*, *Peranema*, *Colpoda*, and *Colponema*, nematodes, small oligochætes, and larvæ of *Psychoda* were always present in this part of the film.

At depths in the filter greater than about 1 ft. there appeared to be little growth of new film, and the medium was covered with a black or brown mass containing black mud, mats of *Saprolegnia*, and numerous hyphæ of *Beggiatoa alba*. The hyphæ of *Saprolegnia* had lost most of their protoplasm and were evidently undergoing decomposition. The number of flagellates appeared to increase at increasing depths from the surface. *Colpidium colpoda*, *Parmœcium*



(*a*)



(*b*)

(*c*)

PLATE 6. *Phoma* and *Fusarium* on Filtering Medium.

(*a*) Pycnidia of *Phoma* on surface of filtering medium in primary filter (×94).

(*b*) A young pycnidium of *Phoma mori* (×420).

(*c*) A filament of *Fusarium* from film on the secondary filter. Terminal cells full of protoplasm and remainder of filament empty. Stained with eosin (×420).

putrinum, *Chilodon cucullulus*, and a long spatulate ciliate were usually present, and *Bodo saltans* was often found. The testaceous rhizopods *Centropyxis* sp. and *Arcella vulgaris* were fairly common.

(*ii*) *Secondary Filter*

When the order of the two filters in series was changed, the layer of fungi which had covered the algæ adhering to the surface of the medium in the primary filter was gradually removed and the concentric rings of film and deposited solid matter under the tracks of the jets of the distributor disappeared. Provided that the plant was not being overloaded, the layer of fungi on the primary filter could usually be dispersed by about the 5th day after changing the order of the filters. The medium on the secondary filter then provided three types of habitat for the growth of organisms: (*a*) the upper surface of the filtering medium, (*b*) from the surface to a depth of about 1 ft., and (*c*) below 1 ft.

When the growth of fungi had been removed from the secondary filter the underlying algæ began to grow. The most abundant alga was usually *Stigeoclonium tenue*, which grew in bright green, spongy masses on the surface of the filter, but at the beginning of 1938 the dominant alga was *Ulothrix subtilis*. Two species of *Phormidium* were sometimes locally dominant on the surface of the filter. One species was found from December 1936 to September 1938, and a second species first appeared at the beginning of 1938. The unicellular alga *Chlamydomonas* sp. was present in the motile and encysted conditions and occurred also in gelatinous palmelloid masses. *Protococcus* sp., *Scenedesmus* sp., and Naviculoid diatoms also occurred. *Stigeoclonium tenue* was found on several occasions, actively liberating zoospores from its cells.

Below the surface of the secondary filter morphological changes occurred in the fungi and bacterial zooglœæ which ultimately led to their dispersal. A prominent feature in this zone was the large number of *Psychoda* larvæ, nematodes, and a small red oligochæte. At depths greater than 1 ft., part of the biological material was brown and matted and consisted largely of an indefinite mass of bacterial debris, held together by empty and collapsed fungal hyphæ. There was also a large amount of black mud, associated with the sulphur bacterium *Beggiatoa*; this organism sometimes formed a surface coat on the medium; this coat had a white metallic sheen. *Colpidium colpoda*, *Paramæcium putrinum*, and other ciliates were present in relative abundance, and sometimes *Vorticella* sp. and *Carchesium* sp. were found in large numbers. *Æolosoma*, *Chætonotus* (Gastrotricha), and Tardigrada were also found. At lower levels in the filter, testaceous rhizopods were present, together with *Aspidisca costata*, *Lionotus fasciola*, *Cyclidium* sp., rotifers, and occasionally the fungus *Dactylella* sp. A more detailed description of the fungi found in the filters is given in Appendix III.

Biological Processes Involved in the Dispersal of the Film from the Primary Filter after Changing the Order of the Filters in Series

The changes which occurred, after the order of the filters in series had been reversed, in the condition of the biological film and deposited solid matter which had previously accumulated in the primary filter were observed with the aid of the microscope.

In the primary filter, under optimum conditions of nutrition, the septate filaments of the fungus *Fusarium* were full of protoplasm. When the order of the filters in series was changed many of the cells lost their protoplasm; some cells, however, were filled with protoplasm, part of which appeared to have come from the emptied cells (Plate 6*c*). At this stage the filaments readily broke across the empty cells. The cells filled with protoplasm no doubt gave rise to further growth of the organism when the filter again occupied the primary position. Specialized resting bodies or chlamydospores were produced terminally or intercalarily in a normal filament, and appeared as short, wide, thick-walled cells. These were found after most of the film of *Fusarium* had disappeared and the algal film had begun to develop.

When the order of the filters in series was reversed, the first reaction of the fungus *Saprolegnia*, which had grown in the sub-surface layer of the primary filter, was the development of reproductive organs; usually zoosporangia were produced (Plates 7*a* and 7*b*), but occasionally oosporangia were observed (Plate 7*c*). The zoosporangia usually appeared during the first few days after the order of the filters had been changed. In *Saprolegnia* a process also occurred which was in some respects similar to that which occurred in *Fusarium*; cells were cut off from the aseptate hyphæ, and in these cells protoplasm accumulated at the expense of the rest of the hypha. The full cells or gemmæ were probably released by fragmentation of the hyphæ (Plate 7*d*). These observations on the behaviour of *Saprolegnia* agree with those of Klebs[2], who found that zoosporangia were formed from mycelium, which had previously been well nourished, when it was placed in fresh water. He also found that when the fungus was grown in a weak nutrient solution, sporangia and oogonia were formed, and later, when the food supply was exhausted, the mycelium was transformed into gemmæ.

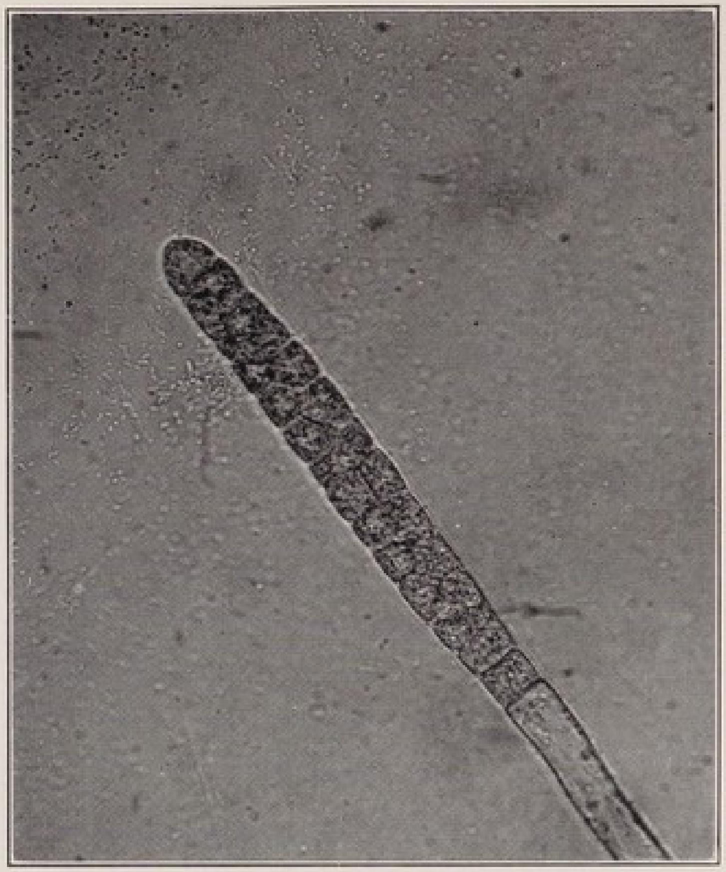
The zooglœal masses formed on the primary filter largely disappeared when the filter occupied the secondary position. Observations were made on zooglœæ aerated in nutrient solutions, in effluents from the double-filtration plant, and in distilled water, and the zooglœæ were also observed in drops of these liquids in moist chambers. It was found that in the presence of food materials a zooglœal mass tended to increase in volume and that there was an increase in the amount of gelatinous matter forming the matrix of the zooglœa. In the absence of food the zooglœæ lost this gelatinous consistency, shrank in volume, and became brown and papery in texture. The edge of a well-nourished zooglœal mass is well defined and the bacteria are confined within the gelatinous matrix; the edge of a starved zooglœal mass is difficult to distinguish and appears to be breaking down. Butterfield[3] found that, when a zooglœa which had developed from a pure culture was washed in frequent changes of distilled water, some of the bacteria in the mass became motile and dispersed into the surrounding water. It seems likely that the gelatinous matter which holds together the bacteria in zooglœæ may act as a source of food under conditions of starvation and would therefore decrease in amount. On the secondary filter the zooglœæ would tend to break away and be washed down into the lower layers owing to the decrease in the gelatinous matter which binds the zooglœæ to the medium.

In the secondary filter the filamentous bacteria *Sphærotilus* and *Beggiatoa* tended to break up into short lengths and subsequently disintegrated and were washed away with the effluent.

Sludge Discharged from the Filters

Sludge from a secondary filter from which most of the surface deposits had disappeared was usually black in colour; it consisted mainly of the black muddy material found in the lower layers of the filter. It contained many diatoms as well as *Protococcus*, *Scenedesmus*, *Chlamydomonas*, and fragments of *Stigeoclonium*. There were large numbers of empty tests of testaceous rhizopods, but little or no fresh bacterial or fungal matter. There were many more flagellates than ciliates and a spirally twisted flagellate *Tetramitus spiralis* was common. Sludge from the primary filter was usually grey in colour and

(a)



(b)

PLATE 7. *Saprolegnia* on Filtering Medium in Secondary Filter.

(a) *Saprolegnia* from film on secondary filter, two days after change in order of filters; production of zoosporangia from hyphæ. Stained with eosin (×94).

(b) Zoosporangium of *Saprolegnia* (×420).

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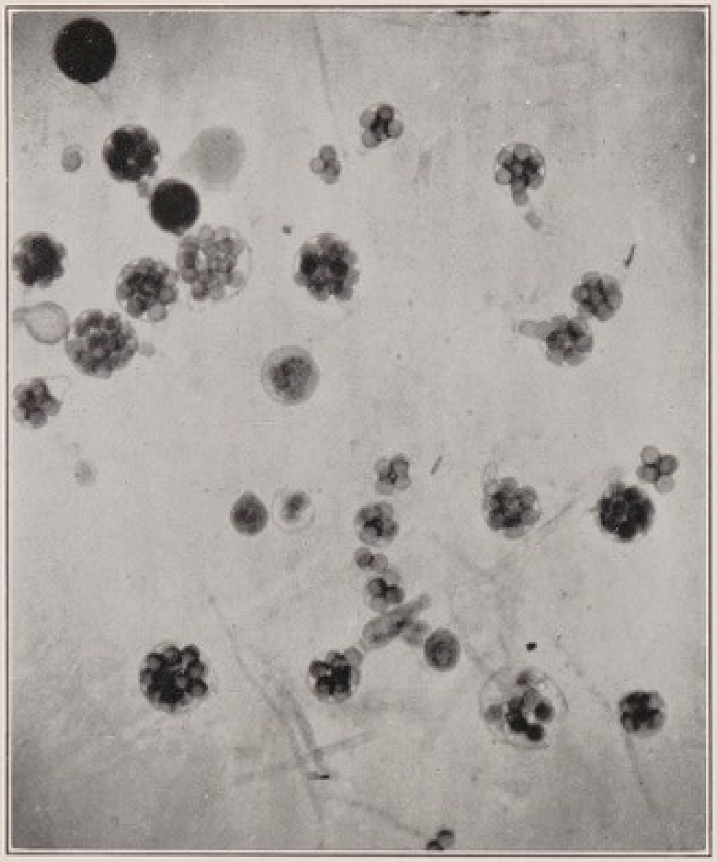

(c)

(d)

PLATE 7 (*contd.*). *Saprolegnia* on Filtering Medium in Secondary Filter.

(*c*) Oogonia of *Saprolegnia* (×94).

(*d*) Formation of gemma in a hypha of *Saprolegnia* from film on the secondary filter. Stained with carbol-erythrosin (×420).

contained fragments of fungi and bacterial zooglœæ. Usually there was a great number of free bacteria and of ciliates and flagellates. *Colpidium colpoda*, *Paramœcium putrinum* and a large spatulate ciliate were common. Towards the end of the period, before the order of the filters in series was changed, a large amount of sludge was discharged from the secondary filter, whereas the amount of sludge discharged from the primary filter was much less; this indicates that the processes of disintegration were more active in the secondary filter than in the primary filter.

It was noticed that much larger amounts of humus were discharged from the secondary filter during spring, summer, and autumn than during winter. The onset of this flushing out of humus from the secondary filter in the spring coincided with a marked increase in the number of *Psychoda* flies and larvæ, and it is possible that the sudden increase in insect activity was an important factor in the process of removal of solid matter from the filters.

Laboratory Experiments on the Effect of *p*H Value on the Composition of Biological Film in Small Filters Treating Whey Washings

In the large-scale double-filtration plant it was found that, when milk washings only were treated, the biological film on the filtering medium consisted largely of bacterial zooglœæ; when mixtures of milk washings and whey washings or whey washings only were treated, the proportion of fungi in the film considerably increased. The change in the relative abundance of organisms in the biological film, however, cannot immediately be attributed to the different composition of the two crude liquids. Other factors may have been of importance; for example, wide fluctuations occurred in the temperature of the settled crude liquid supplied to the primary filter. Also the *p*H value of the settled and diluted crude liquid was in general lower with whey washings than with milk washings. With milk washings the *p*H value of the liquid distributed on the primary filter was usually between 6·5 and 7·2; with mixtures containing equal volumes of milk washings and whey washings the *p*H value was about 6·3, and with whey washings only the usual values were from 5·0 to 5·6. Some laboratory experiments were made in an attempt to assess the effect of the *p*H value of whey washings on the type of biological film developed on percolating filters.

Two sets of primary and secondary filters were used; each filter was 6 in. in diameter and 6·5 ft. in depth. In one experiment whey washings, containing 1 per cent of whey and with a *p*H value of 4·8, were passed through a primary filter and a secondary filter in series. In the other experiment whey washings of the same strength, but with the addition of sodium carbonate to raise the *p*H value to 7·0, were passed through two filters in series at the same rate of flow. In both experiments the order of the filters in series was changed periodically. After 10 days a tough film containing a large proportion of the fungus *Saprolegnia* had developed on the primary filter receiving whey washings with a *p*H value of 4·8; the film on the primary filter receiving whey washings with a *p*H value of 7·0 was much softer and contained a considerable proportion of bacterial matter, besides *Saprolegnia*, *Sporotrichum*, and *Oospora*. The ciliate *Colpidium* was scarcer on the filter receiving whey washings only than on the filter receiving whey washings containing added sodium carbonate. When the order of the filters in series was reversed, the film on the filter which had received whey washings with a *p*H value of 7·0 was dispersed more easily than the film on the other primary filter. From these experiments it appears that *p*H value may be of importance in determining the relative abundance of different types of organisms in the biological film on filters treating dairy waste waters.

Isolation and Identification of Bacteria

In order to identify bacteria it is necessary to obtain them in pure culture. The method used also enables a rough estimation of their numbers to be made. A known volume of the liquid containing the bacteria is mixed with sterile liquefied gelatin or agar, and the infected medium is spread out in an even layer in a Petri dish and allowed to solidify. These plates are incubated at a suitable temperature. Each micro-organism develops into a colony visible to the eye, provided that the conditions of the experiment allow of its growth. Such colonies can be counted and can be sub-cultured so that their characteristics can be studied. Various dilutions of the liquid containing the bacteria can be made so that series of plates showing different amounts of growth are obtained and those plates which are overcrowded can be discarded. It is known, however, that only a rough estimate of the total number of living bacteria originally present can be obtained in this way, since no culture medium is suitable for the growth of all types of bacteria; in addition, it is difficult to break up masses of bacteria in the sample of liquid so effectively that each colony which develops is produced from only a single organism. It is known that some of the bacteria which occur as zooglœæ in the biological film on filtering medium and in activated sludge do not grow readily on solid culture media; these may not have occurred, therefore, among the colonies isolated by this method.

During the first year of the investigation several culture media were used; it was found later, however, that more than 90 per cent of the total number of species isolated could be grown on nutrient agar and, after September 1936, this medium only was employed. The numbers of species of bacteria isolated from liquids from different parts of the two large-scale plants at Ellesmere, with the different culture media tried, are shown in Table LXXIV. The species which were incapable of growth on nutrient agar occurred only occasionally and in small numbers.

Table LXXIV. *Numbers of Species of Bacteria Isolated from Different Culture Media Incubated after Inoculation with Liquids from the Experimental Plants*

Culture medium*	No. of species of bacteria isolated from each medium	No. of species of bacteria isolated from each medium as a percentage of total no. of species from all media during the same period	No. of species isolated only from each medium
Nutrient agar	71	77	9
Czapek agar	13	54	1
MacConkey agar	71	52	3
Urine agar	25	52	0
Mannitol agar	42	45	0
Casein agar	37	38	1
Milk agar	57	37	1
Lactate agar	68	37	1
Propionate agar	65	34	1
Wort agar	68	32	2
Milk washings agar	23	29	0

The abundance of bacteria differed considerably in samples of liquid taken from different points in the two large-scale plants and in samples from the same

* Composition of culture media given in Appendix V.

point on different occasions. Satisfactory isolations of species could not be made from plates containing more than about 60 colonies; plates were therefore made from a large number of dilutions. Reliable counts could only be made of the more numerous forms.

In general, bacteria can only be identified after a long series of physiological tests in pure culture. The classification of bacteria is at present very unsatisfactory, since there is no general agreement on the characteristics which constitute true specific, or even generic, differences. For example, the genus *Aerobacter* Beijerinck, which includes forms allied to *Bacterium lactis aerogenes* Escherich, is recognized by Bergey and co-workers[4], but is not admitted by Lehmann and Neumann[5]. For convenience the generic name *Aerobacter* has been used in this investigation to include a number of organisms, all of which produce acid and gas from certain carbohydrates, including sucrose and lactose, and all of which grow on fumarate medium with the production of acetyl-methyl-carbinol, but which differ one from another in such characteristics as motility, formation of indole, appearance on agar slopes after incubation, and behaviour when incubated with media containing dulcitol and sorbitol.

Most of the species of bacteria isolated during this investigation are referred to by numbers only and no attempt has been made to identify them with species already described in the literature, nor to give names to any that appear to be new species.

Up to June 1938, 156 species of bacteria were isolated from the experimental plants at Ellesmere, but, of these, 123 species were often absent. The chief characteristics and physiological reactions of the remaining 33 species are described in Appendix VI.

Species of Bacteria from the Double-Filtration Plant

At regular intervals throughout the investigation samples were taken for bacteriological examination of crude liquid from the primary sedimentation tank, of settled and diluted crude liquid supplied to the primary filter, and of effluents from each of the two filters. A brief account of those species of bacteria which were found in relative abundance in different parts of the plant is given in the following paragraphs.

(*i*) *Primary Sedimentation Tank*

In both the double-filtration plant and the activated sludge plant crude liquid from the storage tank was first allowed to settle in a primary sedimentation tank; the sedimentation tank was of the same size and shape in each plant and the crude liquid supplied to the two tanks was of the same composition. In general, the same species of bacteria were found in liquid in the two sedimentation tanks, but some species were more abundant in one tank than in the other. For example, species Nos. 5 and 27* were more common in the primary sedimentation tank of the double-filtration plant, and species 4 and 17 were more common in the primary sedimentation tank of the activated sludge plant. The dominant organisms in the primary sedimentation tanks were not always dominant in other parts of the plants; this was especially true of the activated sludge plant, where the conditions in the aeration tanks favoured the development of other species.

(*ii*) *Settled Crude Liquid and Effluents from Primary and Secondary Filters*

From August 1935, soon after operation of the plant was begun, until October 1935, the most abundant bacteria in samples of settled and diluted crude liquid and in effluent from the primary and secondary filters were two

* Numbers refer to Table LXXVII, Appendix VI.

species of *Aerobacter*, Nos. 2 and 3. On different occasions one or other of these two species was dominant and sometimes both species were present together in large numbers; species Nos. 5, 7, and 13 were also found in varying abundance. During the winter of 1935-36, the two species of *Aerobacter*, Nos. 2 and 3, were present in only small numbers; the dominant species were Nos. 4 and 13. In February 1936 the abundance of species 2 and 3 greatly increased, but in June they were much less abundant; the dominant species were then 18, 21, and 23. In their physiological reactions, species 21 and 23 resemble species of the genus *Aerobacter*; the chief difference is that species 21 and 23 do not ferment sucrose. In the early summer of 1937, at the end of the period when milk washings only had been treated in the double-filtration plant, the dominant species was again No. 2; species 5 and 23 were also abundant.

From 9th June 1937 the crude liquid contained both milk washings and whey washings. At the end of June the most abundant bacteria were species Nos. 5, 13, 25, and 26. Of these, species 25 and 26 had not previously been found in large numbers. No. 25 is a species of *Aerobacter* and closely resembles No. 2 in general characteristics and physiological reactions. In July 1937 species Nos. 13 and 26 were dominant, but in November 1937 neither of these species was found and the dominant bacterium was No. 18. The species of *Aerobacter*, No. 25, occurred abundantly in January 1938, but by March it had been superseded by another species of *Aerobacter*, No. 27, and by species No. 7. In May 1938 the most abundant bacteria were Nos. 31 and 32; species 31 had not previously been found. Effluent from the primary filter contained large numbers of No. 7. At this time none of the bacteria which occurred abundantly belonged to the genus *Aerobacter*. In June 1938 the dominant species were Nos. 25 and 33. Species No. 33, which appeared to be a form of *Bact. coli*, had not previously been found in samples from the double-filtration plant. It was very abundant in June 1938 throughout the double-filtration plant and the activated sludge plant, but was never found at any other period. In September 1938 the dominant species in the double-filtration plant were Nos. 5, 7, 13, and 18.

Of the bacteria which were dominant on different occasions, most species were present at other times, though in relatively small numbers. There were in addition some species which, throughout the investigation, were usually present in relatively small numbers but which never became dominant. Two species which were present on nearly every occasion when a bacteriological examination was made were No. 6, which occurred at all positions in the double-filtration plant, and No. 8, which occurred most abundantly in effluent from the primary and secondary filters. Species No. 8 may be primarily concerned with the decomposition of substances left over by other organisms.

Effect of Environment on Bacterial Population

Among the most important factors which might be expected to influence the distribution of bacteria in the two large-scale plants were (1) the chemical composition of the crude liquid, (2) the concentration of organic matter in the liquid in different parts of the plants, (3) temperature, and (4) hydrogen-ion concentration. It has been mentioned that changes occurred in the bacterial population of the double-filtration plant immediately after the crude liquid had been changed from milk washings to a mixture of milk washings and whey washings. Even when the same type of crude liquid was treated during long periods, however, frequent changes occurred in the composition of the bacterial population, so that the effect of the addition of whey washings to the crude liquid cannot easily be assessed.

In the two plants, concentration of organic matter (as measured by the test for biochemical oxygen demand), temperature, and hydrogen-ion concentration were so interrelated that the effect of any one of these factors in influencing the bacterial population cannot be determined with certainty from the data available. For example, in crude liquid in which the biochemical oxygen demand was high, the *p*H value was usually comparatively low, and the average temperature was 20° to 25° C.; in partially or completely treated effluents in which the biochemical oxygen demand was low, the *p*H value was usually comparatively high and the average temperature was 10° to 15° C. In Table LXXV data are given showing the frequency of occurrence of seven of the

TABLE LXXV. *Frequency of Occurrence of Seven Species of Bacteria in Milk Factory Waste Waters with a Biochemical Oxygen Demand of more than* 38 *Parts per* 100,000

Number of occasions on which each species was present in liquids of the *p*H value and temperature stated, expressed as a percentage of the number of samples examined

Species of bacterium	Temperature of crude liquid (° C.)			*p*H value of crude liquid			
	11–15	16–20	21–25	4·5–5·0	5·1–5·5	5·6–6·0	6·1–6·5
No. 2	56	50	100	0	70	100	64
,, 3	44	64	100	0	70	100	64
,, 4	44	64	71	0	20	85	64
,, 5	62	64	59	86	60	77	27
,, 7	69	71	65	71	70	77	55
,, 8	50	36	23	57	30	31	27
,, 13	38	43	23	14	60	31	45

most abundant species of bacteria in crude liquids (milk washings, whey washings, and mixtures of the two), with a biochemical oxygen demand of more than 38 parts per 100,000, for different ranges of temperature and *p*H value. The number of occasions on which each species was present for each range of temperature or *p*H value has been expressed as a percentage of the number of samples examined within that range of temperature or *p*H value. In Table LXXVI similar information is given showing the relative frequency of occurrence of the same species of bacteria in effluents from the primary and secondary filters of the double-filtration plant, and in final effluent from the activated sludge plant. Relatively large numbers of bacteria were present in the crude liquids examined, and when a species of bacterium is recorded as " present " in Table LXXV, 1 ml. of liquid contained at least one million individuals of the species. Treated effluents contained much smaller numbers of bacteria and a species would be recorded as " present " in Table LXXVI if there were two or three thousand individuals per ml.

In general, the species of bacteria examined were able to tolerate the fairly wide differences in concentration of organic matter, temperature, and *p*H value which occurred in the plants. The results in Tables LXXV and LXXVI suggest that certain species were adversely affected at certain temperatures and *p*H values, but considerably more data would be required in order to assess the relative importance of the various factors.

TABLE LXXVI. *Frequency of Occurrence of Seven Species of Bacteria in Effluents, with a Biochemical Oxygen Demand of less than 6 Parts per 100,000, from the Double-Filtration Plant and Activated Sludge Plant at Ellesmere*

Number of occasions on which each species was present in liquids of the *p*H value and temperature stated, expressed as a percentage of the number of samples examined

Species of bacterium	Temperature of effluent (° C.)				*p*H value of effluent		
	0–5	6–10	11–15	16–20	7·1–7·5	7·6–8·0	8·1–8·5
No. 2	63	61	89	48	33	78	100
,, 3	12	69	83	87	72	62	83
,, 4	87	100	78	30	61	62	89
,, 5	25	31	61	74	67	42	56
,, 7	25	92	89	87	56	54	100
,, 8	75	85	72	52	83	54	89
,, 13	63	85	83	74	56	73	100

SOURCE OF ORGANISMS IN THE DOUBLE-FILTRATION PLANT

When operation of the double-filtration plant was begun, the liquid treated was a mixture of milk washings with water from a small brook; at no time was the filtering medium inoculated with sewage or with any other source of living organisms. The storage and settling tanks, filtering medium, and other parts of the plant were exposed to infection by organisms from a number of sources, including the air, crude liquids from the factory, washings from soil, and diluting water from the brook.

Large numbers of spore-forming bacteria are found in air, water, and soil. Very few of these forms, however, were isolated from the double-filtration plant during the investigation, and no species of spore-forming bacterium ever became established. Of the species listed in Appendix VI, none has hitherto been found to be a regular inhabitant of any type of soil.

It thus seems that most of the common bacteria isolated from the plant were derived from the crude liquids treated. This suggestion is supported by the fact that fourteen of the species which occurred most frequently in effluents from the plant were found in the crude waste waters discharged from the factory; species Nos. 1, 25, and 26 were found in one sample of the whey washings and species Nos. 1, 2, 3, 4, 5, 6, 7, 8, 13, 15, 18, and 24 were found in one sample of the milk washings.

The sources from which the fungi, algæ, protozoa, and other organisms in the biological film on the filters were derived is not known with certainty. The fungi *Oospora*, *Phoma*, and *Rhodotorula*, however, are commonly found in waste waters from dairies and may have been derived from the crude liquids treated.

TREATMENT OF MIXTURES OF MILK WASHINGS AND WHEY WASHINGS IN THE LABORATORY IN FILTERS INOCULATED WITH PURE CULTURES OF FUNGI AND BACTERIA

Some laboratory experiments were made to determine the amount of purification achieved when mixtures of milk washings and whey washings were treated by single filtration in small percolating filters inoculated with pure cultures of some of the fungi and bacteria which were most abundant in the large-scale plants. The crude liquid, which contained 1 per cent of whey and 0·25 per cent of milk, was allowed to stand for 6 hours at laboratory temperature and was then sterilized before being applied to the filters. The filtering medium was also sterilized and was then inoculated with a pure culture of a fungus or bacterium; it was found, from periodical examinations, that the filter medium had not become contaminated with any foreign organisms during the experiments. Some reduction in the biochemical oxygen demand of the liquid was effected by treatment in filters inoculated with the fungi *Fusarium* sp., *Saprolegnia* sp., and *Oospora lactis*, and with the bacteria Nos. 2 and 4. Of these organisms, bacterium 4 appeared to be the most efficient under the conditions of the experiments. A considerably greater degree of purification of the crude liquid was effected by treatment in sterilized filters inoculated with a small quantity of crude liquid from the primary settling tanks of the large-scale plants or with biological film from the filters of the double-filtration plant.

These experiments showed that fungi can utilize directly the nutrient material in milk washings and whey washings. It is unlikely, however, that the relative importance as purifying agents of different organisms in a mixed culture can be determined from a study of their relative efficiencies when grown in pure cultures, since a mixed population may contain many organisms whose activities are of importance for the activity of the population as a whole.

Summary of Biological Investigations on the Treatment of Waste Waters by the Process of Double Filtration

When milk washings were treated in the double-filtration plant, the most abundant organisms in the biological film on the filtering medium were bacterial zoogl œæ. With the highest rate of treatment tried—240 gallons per day per cubic yard of medium—the fungus *Saprolegnia* occurred in considerable amount. With mixtures of milk washings and whey washings or with whey washings only, several species of fungi occurred in large amounts, especially in the surface layer of medium in the primary filter. The biological film with whey washings was tougher than with milk washings and was less easily dispersed by changing the order of the filters. On some occasions, when the strength or rate of treatment of crude liquid was very high, the flow of liquid through the filters was impeded; this was due mainly to the growth of fungi in the top layer of medium. In the lower parts of the filter little active growth of film occurred and the medium was covered with a black or brown mass containing black mud, sulphur bacteria, and decomposing fungal hyphæ. Large numbers of living protozoa occurred, more particularly in the deeper parts of the filter.

When the order of the filters in series was reversed, changes occurred which led to the dispersal of much of the biological film which had accumulated on the surface of the primary filter. In the fungi, which formed the most resistant part of the film, protoplasm was withdrawn into certain cells and at the same time other cells lost their protoplasm; specialized resting bodies and reproductive bodies were also formed. As a result of these changes the fungal hyphæ broke up into fragments and much of the material was washed down into the lower layers of the filter. Somewhat similar changes occurred in bacterial zoogl œæ. These changes in fungi and zoogl œæ occur when the organisms are in contact with liquids deficient in food materials. The success of the method of double filtration thus depends to a large extent on maintaining the concentration of food materials in the primary effluent at a level sufficiently low to cause the desired changes and so to allow accumulated film to be removed rapidly from the secondary filter.

Usually not more than two or three species of bacteria were present in abundance at any one time in effluents from the filters of the double-filtration plant. Large and frequent fluctuations occurred in the relative abundance of the different species.

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CHAPTER VIII. BIOLOGICAL INVESTIGATIONS

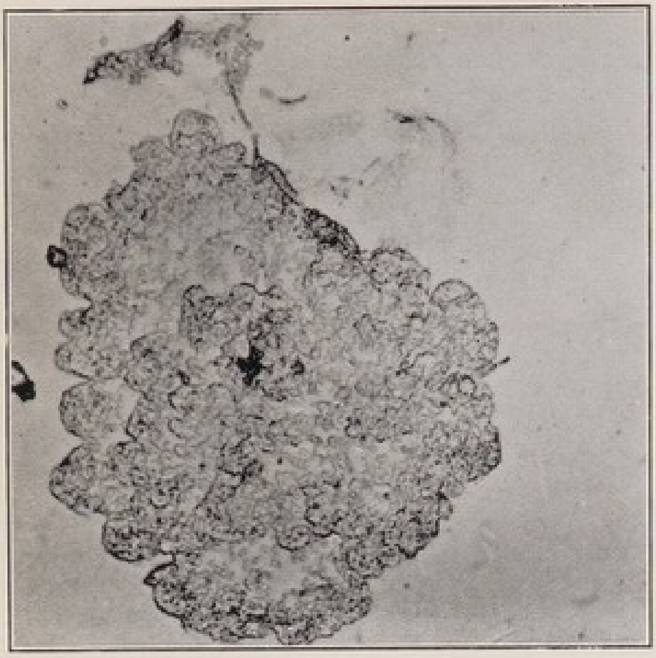
TREATMENT OF WASTE WATERS BY THE ACTIVATED SLUDGE PROCESS

Organisms in Activated Sludge

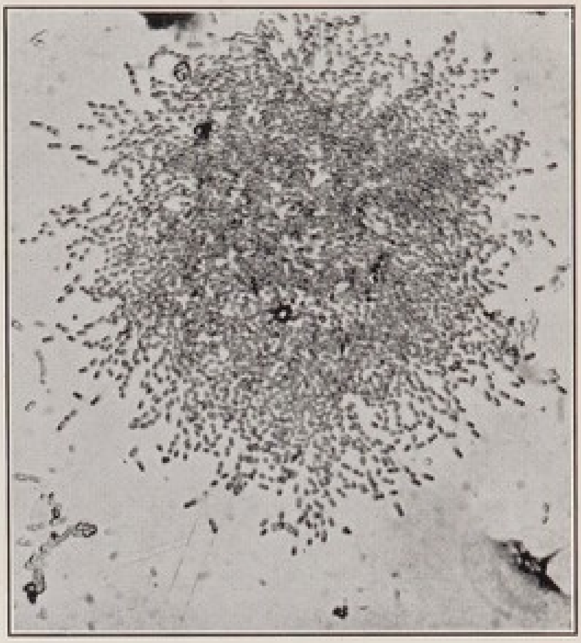
ACTIVATED sludge from the aeration tanks of the large-scale plant at Ellesmere was composed of non-living material, associated with bacteria and protozoa and sometimes with filaments of fungi and algæ. When operation of the plant was begun in 1935, the first flocs of activated sludge formed in the aeration tanks appeared to originate from gelatinous bacterial zooglœæ; each zooglœa was probably formed by the repeated division of a single bacterium of the type *Zooglœa ramigera* (Butterfield). Zooglœal colonies were found on glass slides which were suspended in the aeration tanks, and they were also found floating freely in the liquid when the strength and volume of crude milk washings or whey washings supplied to the aeration tanks were sufficiently high. Later, other organisms became attached to the zooglœæ; for example, a single strand of *Sphærotilus* might adhere and grow into a colony of numerous filaments. Sessile protozoa such as *Vorticella* and *Epistylis* might also become attached and proliferate. The zooglœæ first formed probably had characteristic shapes depending on the species of bacterium from which they were derived. In the mature floc, however, the characteristic shape was lost, probably owing to the action of Protozoa, Rotifera, Nematoda, and Tardigrada and to the disruptive action of bubbles of air from the diffusers of the aeration tanks.

During 1937 and 1938 activated sludge from the aeration tanks was examined each week and a rough estimate was made of the relative abundance of the different types of organism. From August 1937 to September 1938 masses of organisms resembling *Sarcina* were always present and were often abundant. During the months of July, August, and September, both in 1937 and in 1938, the protozoan population consisted almost entirely of the following genera:

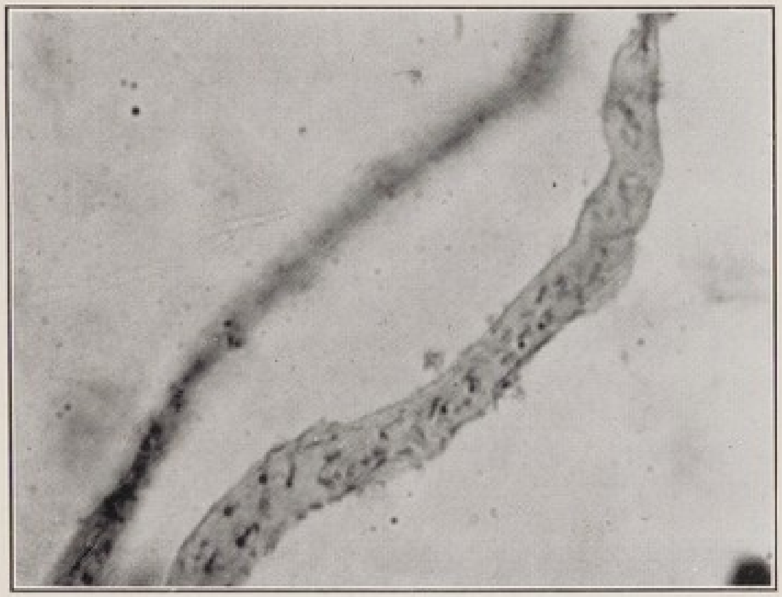
Ciliates: *Aspidisca, Euplotes, Lionotus.*
Flagellates: *Peranema.*
Testaceous Rhizopods: *Trinema, Euglypha, Centropyxis, Arcella.*



(a)



(b)



(c)

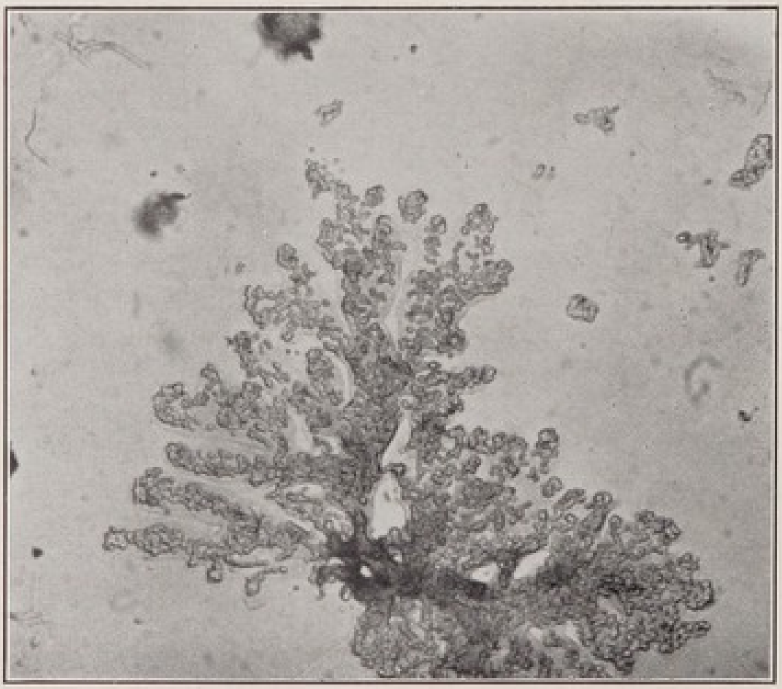
PLATE 8. Bacterial Zooglœæ on Glass Slides after Immersion in Aeration Tanks of the Activated Sludge Plant.

(a) Lobed circular zooglœa (×420). Slide immersed for ten days and removed 20th February 1937.

(b) Bacterial colony (×420). Slide immersed for ten days and removed 20th February 1937.

(c) "Finger" type of zooglœa (×420). Slide immersed for ten days and removed 20th February, 1937.

(*d*)



(*e*)

PLATE 8 (*contd.*). Bacterial Zoogloeæ on Glass Slides after Immersion in Aeration Tanks of the Activated Sludge Plant.

(*d*) "Finger" type of zoogloea (×94). December 1936.

(*e*) Filamentous zooglœa (×840). February 1937.

This association of protozoa occurred during periods when the plant was in satisfactory operation and good effluents were being produced. From March to April 1937 and from January to May 1938 the "sewage fungus" *Sphærotilus* occurred abundantly and the results of operation of the plant were not so satisfactory. During these periods the same species of protozoa were still present, but there was a decrease in the numbers of testaceous rhizopods and a noticeable increase in the numbers of smaller flagellates. Other types of protozoa occasionally present in the aeration tanks included *Stentor*, *Coleps hirtus*, *Vorticella*, *Carchesium*, *Epistylis*, and *Podophrya*. Three species of flagellates which were common in the aeration tanks could not be identified with known species (Appendix IV).

Other organisms which were frequently present in the aeration tanks included nematodes, rotifers, and Chironomid larvæ (bloodworms). *Æolosoma hemprichii* (Oligochæta) and *Chætonotus* (Gastrotricha) were found in June 1937. Tardigrades were first noticed in July 1937 and for a short period were very abundant; later, individuals were often found in the aeration tanks.

Growth of Organisms on Glass Slides Immersed in the Aeration Tanks

In an investigation of the bacteria in soil, Cholodny[1] developed a method in which glass slides were buried for different periods; the organisms which had developed on the slides were then stained and were examined microscopically. A similar method was used for studying the growth of organisms in the aeration tanks at Ellesmere. Glass slides were immersed in the liquid near the inlet to the tanks, in the central compartment, and near the outlet. The slides were removed when a sufficient growth of organisms had occurred and after they had been washed the organisms were fixed in Bouin's picro-formol solution and stained with hæmatin, using ferric alum as a mordant.

From the results of the investigation, which extended over a year and during which more than 600 slides were examined, it was found that the majority of the growths on the glass slides were bacterial colonies which had developed *in situ*; the type of growth on the slides changed when the composition of the settled crude liquid supplied to the aeration tanks was changed. The rate of growth of bacteria on the slides and the rate of growth of activated sludge increased when the strength of the settled crude liquid supplied to the aeration tanks was increased.

The development of bacterial growths on slides immersed at different positions in the aeration tanks appeared to depend on the concentration of nutrient material available at the different positions. On slides near the inlet to the tanks vigorous growth usually occurred; on slides in the middle of the tanks vigorous growth only developed when settled crude liquid with a high biochemical oxygen demand was being treated. Colonies of bacteria were never found on slides near the outlet of the tanks, though numerous isolated bacteria were present. The rate of growth of bacteria on slides near the inlet of the tanks was not due to the presence of substances such as fat, which might have assisted bacteria to adhere to the slides, since no increased growth occurred when slides smeared with milk, gelatin, or egg albumen were used.

Various types of bacterial zooglœæ were found during 1936 and 1937 on the slides immersed in the aeration tanks. From December 1936 to February 1937, when the biochemical oxygen demand of the settled crude liquid supplied to the tanks was comparatively low, the total amount of growth on the slides was small; the zooglœæ were usually circular with a lobed edge (Plate 8*a*), though other types were common (Plates 8*b*, *c*, and *d*). From 29th April to 30th May 1937 the average period of aeration was 18 hours and the average biochemical oxygen demand of the settled crude liquid was about 50 parts per 100,000 parts. During May a thread-like zooglœa grew on slides immersed in the aeration tanks (Plate 8*e*). From 9th June to 2nd July the crude liquid treated was a mixture of one volume of whey washings with three volumes of milk washings. Soon after whey washings had been added to the crude liquid a new type of circular zooglœa appeared and became the most abundant type; this consisted of a colony of short, thick, rod-like bacteria with a tendency to the formation of chains (Plate 8*f*). From September to November 1937 the most abundant organisms on the slides were zooglœæ containing long, rod-shaped bacteria; these bacteria also occurred abundantly as isolated individuals (Plate 8*g*). Between November 1937 and February 1938 very little growth occurred on slides immersed in the aeration tanks during periods of 14 days.

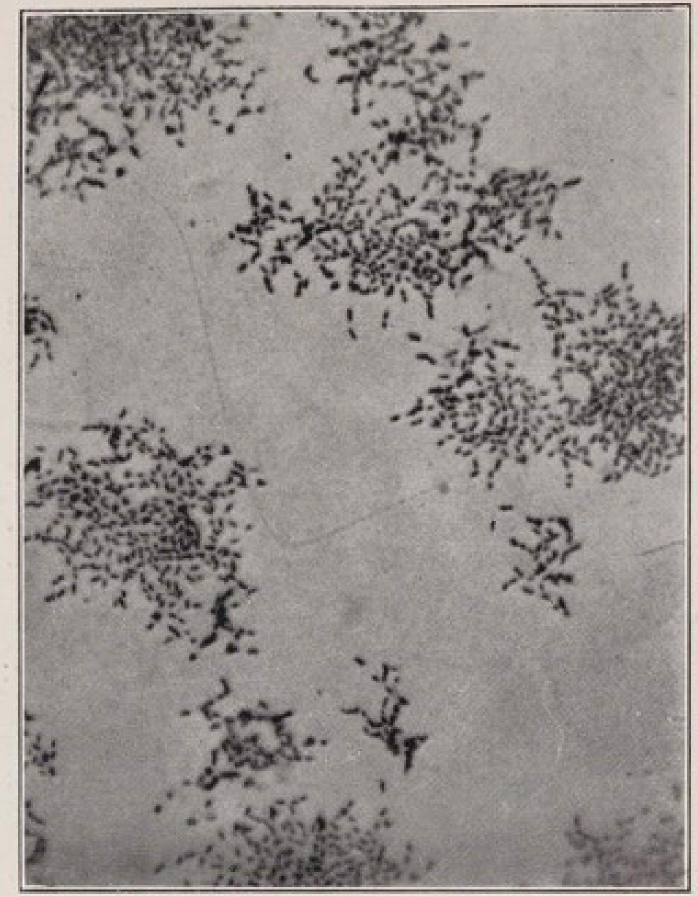
The results obtained by the examination of slides immersed in the aeration tanks indicated that at any time only one or two types of bacteria were dominant. After a comparatively short period the dominant types usually disappeared and were replaced by other types.

"Bulking" of Sludge and Occurrence of *Sphærotilus*

Occasionally during 1937, and again between January and May 1938, "bulking" of activated sludge occurred; the rate of settlement of the sludge in the final sedimentation tank was then so low that particles of solid matter were carried away with the final effluent. On these occasions "bulking" was accompanied by the presence in the sludge of an unusually large amount of *Sphærotilus* which impeded the settlement of the flocs (Plate 9*a*). The type of *Sphærotilus* which occurred in 1937 agreed best with the description of *Sphærotilus natans* var. *cladothrix* given by Butcher[2]. On glass slides immersed in the aeration tanks this organism grew from a single filament attached by a basal disc, and by repeated false branching it assumed a brush-like appearance (Plate 9*b*). The cells of the filaments were enclosed in a sheath and were about 4·7 μ long and 1·7 μ wide. Each branch was formed by one of the cells of a filament breaking through the sheath and continuing to divide in another plane. The filaments of this form were not held together by mucilage as are the filaments of other species of *Sphærotilus*.

Between January and May 1938 another type of *Sphærotilus* was dominant; this took the form of filaments radiating from the centre of the sludge flocs. The filaments were non-branching and were 1·0 μ to 1·5 μ in diameter; the separate cells within the sheath could be distinguished only with difficulty. Since the strands were often found radiating from aggregates of short, thick rods, it seems likely that the organism is pleomorphic. In Plate 9*c* the two types of *Sphærotilus* are shown growing together on a glass slide; the cells in the sheath of the filaments of *Sphærotilus natans* var. *cladothrix* can be seen distinctly, but the radiating filaments of the other type appear to be homogeneous. Butcher[2] observed threads of *Sphærotilus natans* growing from gelatinous masses of *Zooglœa ramigera* and suggested that the latter might be an extreme form of *Sphærotilus natans*.

Sphærotilus was abundant in activated sludge during the colder months of the year. It disappeared when the sludge was aerated without the addition of crude liquid. In a laboratory experiment, activated sludge, which was "bulking" badly when taken from the large-scale plant, was aerated in two small tanks at controlled temperatures of 11° and 23° C.; whey washings were added continuously at the same rate to each tank. After 3 weeks the amount of *Sphærotilus* associated with the activated sludge aerated at 11° C. had not changed appreciably, whereas most of the *Sphærotilus* had disappeared from the sludge aerated at 23° C. At the conclusion of the experiment the sludge aerated at 23° C. settled more rapidly than the sludge aerated at 11° C.



(*f*)

(*g*)

PLATE 8 (*contd.*). Bacterial Zoogloeæ on Glass Slides after Immersion in Aeration Tanks of Activated Sludge Plant.

(*f*) Rod-shaped bacteria (×420). 19th June 1937.

(*g*) Free rod-shaped bacteria and zooglœa composed of short, thick, rod-shaped bacteria (× 420). Slide immersed for two days and removed 27th October 1937.

to face p. 102]

[to face p. 103

(a)

(b)

(c)

PLATE 9. *Sphærotilus* in Aeration Tanks of Activated Sludge Plant.

(a) Activated sludge containing *Sphærotilus* (×420). February 1938.

(b) Colony of *Sphærotilus* (×94) on a glass slide after immersion in aeration tank. December 1936.

(c) Growth on a glass slide (×840) after immersion in aeration tank, May 1938. *Sphærotilus natans* var. *Cladothrix* and radiating strands of the type of *Sphærotilus* predominant at this period. Stained with hæmatin.

Species of Bacteria in the Aeration Tanks of the Activated Sludge Plant

During the first few months of operation of the two large-scale plants at Ellesmere the same species of bacteria were dominant in the aeration tanks of the activated sludge plant as in the effluent from the two filters of the double-filtration plant. At the beginning of 1936, however, the dominant species in the two plants were different. At this stage Species Nos. 9, 13, and 18* were the most abundant bacteria in the aeration tanks; the most abundant species in the double-filtration plant were Nos. 4 and 13. During the remainder of the investigation the same species were sometimes dominant at the same time in the two plants, but sometimes the dominant species in the two plants were different. In April 1936 the most abundant bacterium in the aeration tanks was Species No. 3, and later in the year the most abundant species was 17.

In 1937, at the end of the period when milk washings only were treated, about 80 per cent of the bacteria isolated from the aeration tanks belonged to Species No. 22; fairly large numbers of Species No. 5 were also present. From 9th June to 2nd July 1937 the crude liquid treated was a mixture of one volume of whey washings with three volumes of milk washings, and from 3rd July to 20th September 1937 the crude liquid contained equal volumes of whey washings and milk washings. Species No. 22 remained dominant in the aeration tanks until the end of July 1937. During November Species No. 1 was dominant, though Species No. 18, which was the most abundant bacterium in the double-filtration plant at this time, occurred in large numbers in the aeration tanks. In the spring of 1938 Species Nos. 5 and 32 predominated in the aeration tanks. From that time until the conclusion of the experiments, in September 1938, the dominant species at any time were the same in both plants. Throughout the investigation the most abundant species of bacteria in the aeration tanks were proteolytic.

As in the double-filtration plant, the majority of the species of bacteria found in abundance in the activated sludge plant were also found in crude milk washings or in whey washings.

Summary of Biological Investigations on the Treatment of Waste Waters by the Activated Sludge Process

When operation of the large-scale plant was begun, the first flocs of activated sludge formed in the aeration tanks appeared to originate from gelatinous bacterial zooglœæ; later, protozoa, *Sphærotilus*, and other organisms became attached to the flocs and the zooglœæ lost their characteristic shapes.

Glass slides were immersed in the aeration tanks and the organisms growing on them were examined. Most of the organisms found on the slides were bacterial zooglœæ. Growth was most vigorous on slides near the inlet of the tanks, where the concentration of nutrient material in the liquid was highest. Usually there were one or two dominant types of bacteria, though the particular dominants varied from time to time.

Occasionally " bulking " of the activated sludge occurred, especially in cold weather; this was accompanied by the growth of excessive amounts of the " sewage fungus " *Sphærotilus*, of which two types were recognized.

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[2] Butcher, R. W. Contribution to our Knowledge of the Ecology of Sewage Fungus. *Trans. Brit. mycol. Soc.*, 1932, **27**, 112.

* Numbers refer to Table LXXVII, Appendix VI.

GENERAL SUMMARY AND CONCLUSIONS

Introductory

During recent years the problems of treatment and disposal of the waste waters from the milk industry have increased in importance with the development of the industry and the establishment of depots and factories each receiving the milk from many farms. Serious pollution of rivers and streams, and difficulties at sewage disposal works in many parts of the country, have been caused by discharges of waste waters from dairies and from factories manufacturing butter, cheese, condensed milk, and other products from milk.

Character and Quantity of Waste Waters

At milk collecting and distributing depots, where milk is received and is distributed after cooling and after pasteurizing, the waste waters consist mainly of washings from floors and from delivery churns, coolers, pasteurizing plant, tank wagons, and other equipment. The volume of waste waters varies considerably at different collecting and distributing depots, but is usually from 0·5 to 1·5 times the volume of milk handled. The quantity of milk carried away with the waste waters depends largely on the precautions taken to minimize loss and differs considerably at different depots. Frequently the waste waters carry away from 0·5 to 1·0 per cent of the volume of milk handled. Thus, if the volume of washing water is about the same as the volume of milk handled, a milk collecting and receiving depot handling 10,000 gallons of milk per day may discharge each day 10,000 gallons of waste waters containing from 50 to 100 gallons of milk. The waste waters would have a biochemical oxygen demand of from 55 to 110 parts per 100,000 parts. Average domestic sewage has a biochemical oxygen demand of about 40 parts per 100,000 parts and the average volume of domestic sewage per head of the population per day is about 25 gallons. A volume of 10,000 gallons per day of milk washings containing 1 per cent of milk is thus equivalent in its deoxygenating effect on a stream to the domestic sewage from a population of 1,200 people.

From factories making butter, cheese, and other products, in addition to washings from delivery churns there are washings from butter churns, cheese vats, and other equipment. At a butter factory the average volume of waste waters is probably 1·0 to 2·0 times the volume of milk used for the separation of cream. The average biochemical oxygen demand of the waste waters may be from 150 to 300 parts per 100,000; that is, the amount of polluting matter in the waste waters may be very nearly four to over seven times the amount in the same volume of domestic sewage of average strength. Waste waters from cheese factories contain whey from the washing of cheese vats and other equipment, besides milk washed from milk churns and from the unloading and bulking plants. The volume of waste waters may be from 1·0 to 2·0 times the volume of milk handled and the biochemical oxygen demand of the waste waters would usually be from 150 to 300 parts per 100,000 parts. Waste waters from the manufacture of condensed milk, concentrated whey, and similar products, which are made by concentrating the liquid under reduced pressure in steam-heated evaporators, may contain considerable amounts of the raw material, which is carried over as vapour or as a spray during evaporation of the liquid.

In the past, some factories have considered whey and buttermilk to be waste materials of no value and have discharged them into streams, with disastrous polluting effects. Whey has a biochemical oxygen demand of 4,000 to 5,000 parts per 100,000 and is at least 100 times as strong in polluting character as an equal volume of crude domestic sewage. Whey and buttermilk should be treated as valuable by-products and not as waste materials. They have high food values and can be utilized as food and in the preparation of foods.

Reduction of Quantity of Polluting Matter in Waste Waters

In the early stages of the present investigation it was concluded that the quantities of polluting matter carried away in the waste waters from the milk industry can be considerably reduced by simple and inexpensive modifications in the operations within the factories and by more careful control of the processes of draining and washing. At many depots and factories the delivery churns are rapidly emptied and insufficient time is allowed to drain the churns adequately before they are transferred to the washers. By installing a simple drainage rack with a milk-collecting channel, and by allowing the churns to drain on the rack for between 1 and 2 minutes, the quantity of milk carried away in the water used for washing the churns can be reduced from more than 0·5 per cent to less than 0·25 per cent of the milk handled. This represents a saving of at least 10,000 gallons of milk per annum for a depot receiving an average quantity of 10,000 to 12,000 gallons per day. Substantial improvements can usually be made in the methods of draining and washing cheese vats, butter churns, and other equipment, to bring about considerable reductions in the quantities of whey, buttermilk, and other products in the waste waters. Cheese vats and butter churns, for example, after the removal of whey and buttermilk, should first be washed with small quantities of water which should be added to the whey and buttermilk. Subsequent washings with larger quantities of water would then contain much less polluting matter.

Laboratory Experiments on Treatment of Waste Waters

When all practicable steps have been taken at the depot or factory to reduce to the minimum the losses of milk and of the products and by-products, the waste washing waters still require treatment to make them suitable for discharge into a river or stream. The present investigation has, therefore, included a study of different methods of treating the wastes.

In the first place numerous laboratory experiments were carried out on methods of treatment of milk washings, whey washings, and mixtures of these liquids. The methods of treatment investigated included anaerobic fermentation, addition of chemical coagulants, treatment by the activated sludge process, and biological filtration.

When milk washings were allowed to ferment in an open tank in the laboratory, the washings became more acid, some solid matter separated, and the biochemical oxygen demand of the liquid was usually reduced. When sufficient free acid was formed during the fermentation, casein and other solid matter was precipitated and there was a considerable reduction in the biochemical oxygen demand of the liquid. Usually, however, alkali was present in the milk washings. The *p*H value did not then fall to the same extent, proteolysis of casein occurred, there was little reduction in the biochemical oxygen demand of the liquid, and strong putrefactive odours were evolved.

Addition of aluminoferric in a concentration of 10 parts per 100,000 parts, either alone or with lime, caused little or no reduction in the biochemical oxygen demand of milk washings, though there was a considerable reduction in the biochemical oxygen demand when aluminoferric was added in a concentration of 50 to 200 parts per 100,000 parts.

Good results were obtained when milk washings or mixtures of milk washings and whey washings were aerated in the laboratory in admixture with activated sludge, prepared originally from milk washings or from domestic sewage. For example, the biochemical oxygen demand of washings containing 1·0 per cent of whey and 0·25 per cent of milk was reduced from about 50 parts per 100,000 to less than 1 part per 100,000 when the washings were aerated in admixture with activated sludge for a period of 22 hours in a warm laboratory.

Effluents of good quality were obtained by treatment of milk washings in a single percolating filter in the laboratory. After a time, however, solid fatty matter was deposited on the surface of the filtering medium, which in consequence became choked. It was found that this difficulty could be avoided by allowing the milk washings to ferment in an open tank for 1 or 2 days before the liquid was treated in the percolating filter. The objections to preliminary fermentation in a large-scale treatment plant are that the quantity of sludge for disposal would be increased and that the process might give rise to odour nuisance. Independent experiments by Mr. H. C. Whitehead (a member of the Water Pollution Research Board) and Mr. F. R. O'Shaughnessy, in the laboratories of the Birmingham Tame and Rea District Drainage Board, showed that preliminary fermentation was unnecessary if the waste waters, after sedimentation, were treated in two percolating filters in series with a change in the order of the filters at intervals of 2 or 3 weeks. With this method the slimy solid matter deposited in the top layer of the primary filter is largely removed when the filter occupies the secondary position and receives effluent from the other filter. Final effluents of good quality were obtained when washings containing mixtures of 1·0 per cent of whey and 0·25 per cent of milk were treated in the laboratory by this method at a rate of 100 gallons per day per cubic yard of filtering medium in the two filters together.

As a result of the laboratory experiments, it was concluded that the most promising methods of treatment of waste waters from the milk industry were (1) filtration through two percolating filters in series with periodic change in the order of the filters, and (2) aeration in admixture with activated sludge.

Large-Scale Experiments

With the financial co-operation of the industry the investigation was extended to include experiments on a large scale at a milk collecting and distributing depot and cheese factory at Ellesmere, Shropshire. Two large-scale experimental plants were erected at the factory during the summer of 1935; the plants were operated until September 1938, a period of about 3 years. In one plant the waste waters were treated by biological filtration and in the other plant they were treated by the activated sludge process.

(*i*) *Percolating Filters*

In the biological filtration plant the crude waste waters, after passing through a balancing tank, and through a primary sedimentation tank to remove coarse suspended matter, were mixed with a measured proportion of water or of treated final effluent from the plant. The mixed liquid then flowed to one or other of two percolating filters, A and B, each filled to a depth of about 4·5 ft. with hard metallurgical coke, graded 0·75 in. to 1·5 in.* Effluent from the primary filter, which might be Filter A or Filter B, was passed through a sedimentation or humus tank, and was then pumped to the secondary filter. Effluent from the secondary filter

* In several double-filtration plants which have recently been constructed and operated at dairies and milk products factories, larger filtering medium graded 1½-2½ in. has been used with satisfactory results. It may sometimes be of advantage to use a larger medium, especially when the waste waters contain a high proportion of fat, as may be the case, for example, at butter factories. Although metallurgical coke was used in the present investigation, satisfactory results are obtained by the use of any filtering medium of a suitable size, provided that it is well graded, does not contain dust, and does not disintegrate as the result of pressure, chemical action, or changes in temperature.

was allowed to settle in another humus tank. Part of the settled final effluent was pumped back and mixed with the crude liquid before distribution on the primary filter; the remainder of the settled final effluent was discharged to a small stream. When settled and diluted crude liquid was distributed on the primary filter, the amount of biological film and other solid matter on the filtering medium gradually increased, especially on the medium near the surface of the filter. At intervals of about 2 weeks the order of the two filters in series was reversed; any excessive amount of biological film which had accumulated on the primary filter was dispersed and washed away when the filter was supplied with settled primary effluent.

In operating the double-filtration plant, milk washings, whey washings, or mixtures of these liquids were allowed to settle in the primary sedimentation tank and were then diluted, usually with final effluent, to give a mixture with a biochemical oxygen demand of 20 to 30 parts per 100,000. Effluents of excellent quality, with a biochemical oxygen demand of less than 1 part per 100,000, were obtained when this settled and diluted crude liquid was treated in the percolating filters at a rate of 320 gallons per day per cubic yard of medium in each filter, or 160 gallons per day per cubic yard of medium in the two filters together. The effluent obtained under these conditions was well oxygenated and contained nitrate in considerable amount. On many occasions the crude waste waters had a *p*H value as low as 4·6; the final effluent was always alkaline in reaction with a *p*H value usually from 7·8 to 8·2. The effluent never contained fat, though fat was usually present in the crude liquid, sometimes in a concentration exceeding 20 parts per 100,000 parts. The final effluent was in every respect suitable for discharge into a river or stream; even without dilution the effluent was harmless to trout.

For short periods, milk washings with an average biochemical oxygen demand of about 30 parts per 100,000 were treated in the filtration plant at a rate of 240 gallons per day per cubic yard of medium in the two filters together. The final effluent was of good quality, with an average biochemical oxygen demand of only 1 part per 100,000, but additional care was necessary in operating the plant and the order of the two filters in series was reversed at intervals of about 10 days. Under the conditions of operation at a factory, a rate of treatment of 160 gallons per day per cubic yard of medium appears to be the maximum advisable for a liquid with a biochemical oxygen demand of 20 to 30 parts per 100,000. This rate is considerably higher than is usual at a sewage disposal works in the treatment of domestic sewage by single filtration, allowance being made for the difference in strength of the crude liquids.

In general, milk washings were more easily purified in the filtration plant than were whey washings of similar strength. The biological film formed on the surface of the primary filter when milk washings were treated consisted largely of gelatinous masses of bacterial zooglœæ; when whey washings were treated, the biological film contained a higher proportion of fungi and was tougher and less easily dispersed when the order of the two filters in series was reversed.

Both milk washings and whey washings are more easily purified, by treatment in percolating filters, at relatively high temperatures (20° C. to 30° C., 68° F. to 86° F.) than at lower temperatures. During the present investigation some difficulty was experienced during the winter of 1937, when whey washings from the factory were not available and the crude liquid treated in the percolating filters was made up from whole whey and a relatively small volume of milk washings, diluted with cold water. In a commercial plant both milk washings and whey washings would be at a relatively high temperature when discharged from the factory, and the greatest load on the plant would be in the spring and summer when the air temperature is relatively high. In designing a large-scale plant care should be taken to ensure that the waste waters are cooled as little as possible before reaching the filters. Consideration should be given to the possibility of using any available waste steam or other waste heat to maintain the temperature of the liquid. If uncontaminated warm condensing water is available, this might be used instead of final effluent to dilute the crude waste waters before treatment in the filters.

One important advantage in the treatment of dairy waste waters by double filtration is that application to the filters of liquid of abnormally high strength during a short period, which might occur as the result of an accident in a factory, causes only a temporary deterioration in the quality of the final effluent; any excessive deposition of solid matter in the surface layer of filtering medium caused by the flush of strong liquid is rapidly removed.

(*ii*) *Activated Sludge Process*

In the activated sludge plant, crude liquid from the collecting and storage tanks was first allowed to settle in a primary sedimentation tank and then entered a small steel tank in which it could be diluted with measured proportions of water or of treated effluent. The mixture then flowed by gravity into two aeration tanks, operated in parallel. Each tank was rectangular in horizontal section and was 16 ft. long, 8 ft. wide, and about 6 ft. deep. At the base of the tank there were channels with porous plates through which air was blown continuously from a compressor. Liquid and activated sludge flowed continuously into the tanks, under and over baffles, and out over weirs into the final sedimentation tank. Settled effluent from the final sedimentation tank was discharged into a small stream, or part could be returned to dilute settled crude liquid from the primary sedimentation tank. Most of the sludge from the final sedimentation tank was returned as a continuous stream, through a flow gauge, to mix with the crude liquid entering the aeration tanks. Surplus activated sludge and sludge from the primary sedimentation tank was discharged to a sludge-drying bed. The activated sludge was produced in the first place by the aeration of milk washings.

Treatment of milk washings and whey washings by the activated sludge process was influenced considerably by temperature; this was in agreement with laboratory experiments in which it was found that the optimum temperature was about 30° C. In warm weather, treatment of milk washings, whey washings, or mixtures of these liquids, with an average biochemical oxygen demand of 35 to 50 parts per 100,000, by aeration in admixture with activated sludge for a period of 24 hours gave a final effluent of excellent quality with a biochemical oxygen demand of less than 1 part per 100,000. In cold weather the capacity of the plant was considerably smaller.

Whey washings appeared to be more difficult to treat than milk washings, though in the summer months final effluents with a biochemical oxygen demand of less than 1 part per 100,000 were obtained by aeration for 36 hours of activated sludge in admixture with whey washings with an average biochemical oxygen demand of 66 parts per 100,000. Equally satisfactory effluents were obtained by treatment of liquids containing three volumes of whey washings and one volume of milk washings, and with an average biochemical oxygen demand of 71 parts per 100,000, by aeration with activated sludge for 36 hours or 24 hours. In cold weather it would be necessary either to reduce the strength of the crude liquid supplied to the aeration tanks or to increase the period of aeration.

Final effluents from the activated sludge plant were usually well oxygenated; they were always neutral or slightly alkaline in reaction, even when crude liquids with a *p*H value as low as 4·6 were treated, and they never contained fat.

Difficulty was caused on some occasions by " rising " and by " bulking " of activated sludge. "Rising" of sludge often occurred when the final effluent contained high concentrations of nitrate; it is caused by the liberation of bubbles of gaseous nitrogen from the decomposition of nitrogenous compounds. Particles of sludge are buoyed up by the bubbles of gas, rise to the surface in the final tank, and are carried over with the effluent. "Rising" usually ceased when the strength of the crude liquid was increased or the period of aeration was decreased. When the strength of the crude liquid was too high, or the period of aeration was too short, however, the activated sludge "bulked"; that is to say, it became voluminous and difficult to separate from the final effluent by sedimentation. In general, treatment of milk washings and whey washings by the activated sludge process was more difficult to control and was more easily upset by flushes of liquid of abnormally high strength than was treatment in percolating filters.

Conclusions

The investigation as a whole has shown that the waste waters from milk collecting and distributing depots and from cheese factories can be satisfactorily treated in percolating filters and by the activated sludge process. Of these two processes, treatment in two percolating filters, with periodic change in the order of the filters, is the more economical and convenient. Under the most favourable conditions, the rate at which milk washings and whey washings were treated in the activated sludge plant, to yield a final effluent of good quality, was rather less than that usual at many sewage disposal works, allowance being made for the difference in strength of the crude liquids. On the other hand, the rate at which milk washings and whey washings were treated in the double-filtration plant to give effluents of good quality was considerably higher than is usual in the treatment of domestic sewage by the process of single filtration.

Recommendations

From the results of the investigation the following recommendations are made for the treatment and disposal of waste waters from the milk industry.

(i) By-products, such as skimmed milk, buttermilk, and whey, should not in any circumstances be discharged with the waste waters from a factory. These liquids should be used for feeding stock, or for the manufacture of food materials or other substances.

(ii) Every effort should be made to reduce the quantity of milk, whey, and other products and by-products carried away with the waste waters. Considerable reductions in the volume and strength of the waste waters can be made at many factories by simple modifications in factory processes and by careful supervision.

(iii) When these precautions have been taken, the waste waters remaining for disposal can be efficiently purified by the process of double filtration. The plant should include a storage and balancing tank of sufficient size to allow the filters to be supplied at a constant rate throughout the 24 hours of the day. The period during which the waste waters are retained in the storage and balancing tank should be no longer than is necessary to ensure even flow, since if the liquid is retained for long periods it undergoes extensive fermentation with the production of further quantities of sludge, and there may be nuisance from odour. Crude waste water, after sedimentation and if necessary after dilution with water or with final effluent to give a mixture with a biochemical oxygen demand not greater than 30 parts per 100,000 parts, should be supplied to the primary filter at a rate not exceeding 320 gallons per day per cubic yard of medium in the primary filter. After sedimentation in a humus tank, the liquid should then be supplied to the secondary filter at the same rate. Effluent from the secondary filter should be allowed to settle in a humus tank before being discharged to a stream. The rate at which the settled and diluted crude liquid is treated in the plant should thus not exceed 160 gallons per day per cubic yard of medium in the two filters together. At intervals of about 2 weeks the order of the two filters in series should be reversed.

APPENDIX I

NOTES ON METHODS OF ANALYSIS OF CRUDE WASTE WATERS AND TREATED EFFLUENTS

1. *Dissolved Oxygen*

The method of Winkler[1], with the Rideal-Stewart modification when nitrite was present, was used with the following modifications: (*a*) the alkaline solution of potassium iodide contained 50 per cent of potassium hydroxide and 10 per cent of potassium iodide; (*b*) the sample was acidified, before titration, with 2 ml. of concentrated sulphuric acid; (*c*) 250 ml. of the acidified sample were withdrawn from each bottle and titrated in a flask with N/32 sodium thiosulphate.

2. *Biochemical Oxygen Demand*

Diluted samples were incubated for 5 days at 20° C. Otherwise the procedure was as described in Ministry of Health methods[1].

3. *Oxygen Absorbed from Permanganate*

50 ml. of sample, or diluted sample, were incubated for 4 hours at 26·7° C. with 10 ml. of 25 per cent sulphuric acid and 10 ml. of N/8 potassium permanganate. After addition of potassium iodide the liberated iodine was titrated with N/16 sodium thiosulphate.

4. *Incubation Test for Effluents*

A glass-stoppered bottle with a capacity of about 100 ml. was completely filled with effluent and incubated for 5 days at 26·7° C. The smell of the sample was then noted; all samples with a putrid smell were described as unsatisfactory.

5. *Free and Saline Ammonia*

In clear effluents, free and saline ammonia was determined by direct Nesslerization. For turbid or coloured samples, a mixture of 250 ml. of sample with 250 ml. of distilled water was distilled after the addition of magnesium oxide; the first 250 ml. of distillate were collected and Nesslerized. In all cases the colour of the Nesslerized solution was compared with that of standard coloured discs in a Hellige comparator.

6. *Total Nitrogen*

Kjeldahl nitrogen was determined by digesting the sample with concentrated sulphuric acid with the addition of sodium sulphate and a small quantity of copper sulphate. The digest was diluted, made alkaline with sodium hydroxide, and distilled into N/14 sulphuric acid; excess acid was titrated with N/14 sodium hydroxide, using methyl red as indicator. Total nitrogen was taken as the sum of the Kjeldahl nitrogen and the nitrogen in nitrites and nitrates.

7. *Nitrite*

10 ml. of effluent or diluted effluent were treated with sodium naphthionate and β-naphthol and one drop of hydrochloric acid, and were then made alkaline with excess ammonia. The resulting colour was compared with that of standard coloured discs in a Hellige comparator.

8. *Nitrate*

5 ml. of effluent or diluted effluent were treated with brucine and sulphuric acid and the resulting colour was compared with that of standard coloured discs in a Hellige comparator.

9. *Total Solids*

100 ml. of sample were evaporated and dried at approximately 100° C.

10. *Suspended Solids*

For crude liquid a volume of 25 to 50 ml., or for treated effluent a volume of 50 to 100 ml., was filtered through asbestos fibre in a 10 ml. Gooch crucible and weighed. The prepared crucible was previously washed with distilled water, dried, ignited, and weighed. Loss on ignition of suspended solids was determined by heating the dried and weighed residue for about 15 minutes in a muffle furnace.

11. *Soluble Solids*

Soluble solids were calculated as the difference between total solids and suspended solids.

12. *Fat*

A mixture of 300 ml. of sample with 25 ml. of ethyl ether and 25 ml. of petroleum ether was heated in a 500 ml. separating funnel by immersing the funnel in hot water until the ether began to boil; the funnel was then shaken vigorously while cooling in a stream of cold water. After separation from the ether extract, the aqueous portion of the liquid was again extracted twice with a mixture of 15 ml. of ethyl ether and 15 ml. of petroleum ether. If the ether emulsified, the emulsion was destroyed by running off the aqueous layer and adding a few drops of ethyl alcohol. All the ether extracts were then combined and evaporated in a dish; the residue was dried for 3 hours at 70° to 80° C. and weighed. The residue was then treated with ether to remove fatty material and was again dried and weighed; the difference in weight represented material soluble in the mixed ethers.

13. *Volatile Fatty Acids*

Volatile fatty acids were separated by steam distillation (Dyer[2]) and were determined by titration with sodium hydroxide (Virtanen and Pulkki[3]).

14. p*H Value*

*p*H value was determined colorimetrically, using a Hellige comparator. The following indicators were used for the different ranges of *p*H value:

Brom phenol blue	*p*H 3·0 to 4·6
Methyl red	*p*H 4·4 to 6·0
Brom thymol blue	*p*H 6·0 to 7·4
Cresol red	*p*H 7·4 to 8·8

References

[1] MINISTRY OF HEALTH. Methods of Chemical Analysis as Applied to Sewage and Sewage Effluents. H.M. Stationery Office, London, 1929.

[2] DYER, D. C. A New Method of Steam Distillation for the Determination of the Volatile Fatty Acids, Including a Series of Colorimetric Qualitative Reactions for their Identification. *J. biol. Chem.*, 1916-17, **28**, 445.

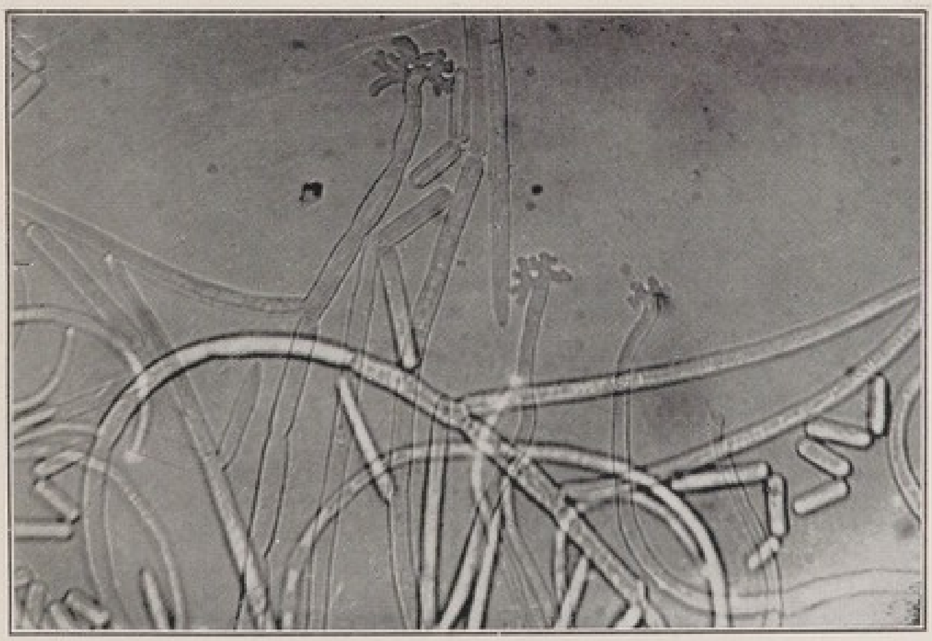
[3] VIRTANEN, A. I., and PULKKI, L. The Volatility with Steam of Water-Soluble Organic Substances. *J. Amer. chem. Soc.*, 1928, **50**, 3138.

APPENDIX II

NOTES ON A PURPLE BACTERIUM FOUND IN THE EXPERIMENTAL PLANTS

A noticeable purple growth occurred on the sides of the primary settling tanks, on the filtering medium near the surface of the primary filter, and in other parts of the treatment plants at Ellesmere. The growth consisted of gelatinous masses of no distinctive shape and unlike typical zooglœæ; the gelatinous masses contained a purple bacterium, shaped like a short, thick, straight or slightly curved rod, measuring about 1·0 μ by 2·9 μ. The bacterium was sometimes found in stellate clusters within the gelatinous masses (Plate 10*a*). Repeated attempts were made to obtain a pure culture by the usual methods, and purple pin-point colonies were obtained on a medium containing thiosulphate after incubation for three weeks, but the bacterium did not survive in subcultures. This species has no action on sugars and does not produce indole or acetyl-methyl-carbinol; it does not reduce nitrates but has a slight peptonizing action on milk. It grows well during aeration of a mixture of 1 per cent of milk in water; addition of small amounts of sodium thiosulphate appears slightly to increase its growth. The purple colour disappears when the organism is kept in a drop of distilled water in a moist chamber.

(a)



(b)

PLATE 10.

(a) Stellate Clusters of Bacteria forming Purple Zooglœæ (×840).

(b) *Oospora fragrans* with Digitate Outgrowths at the Ends of the Hyphæ (×420).

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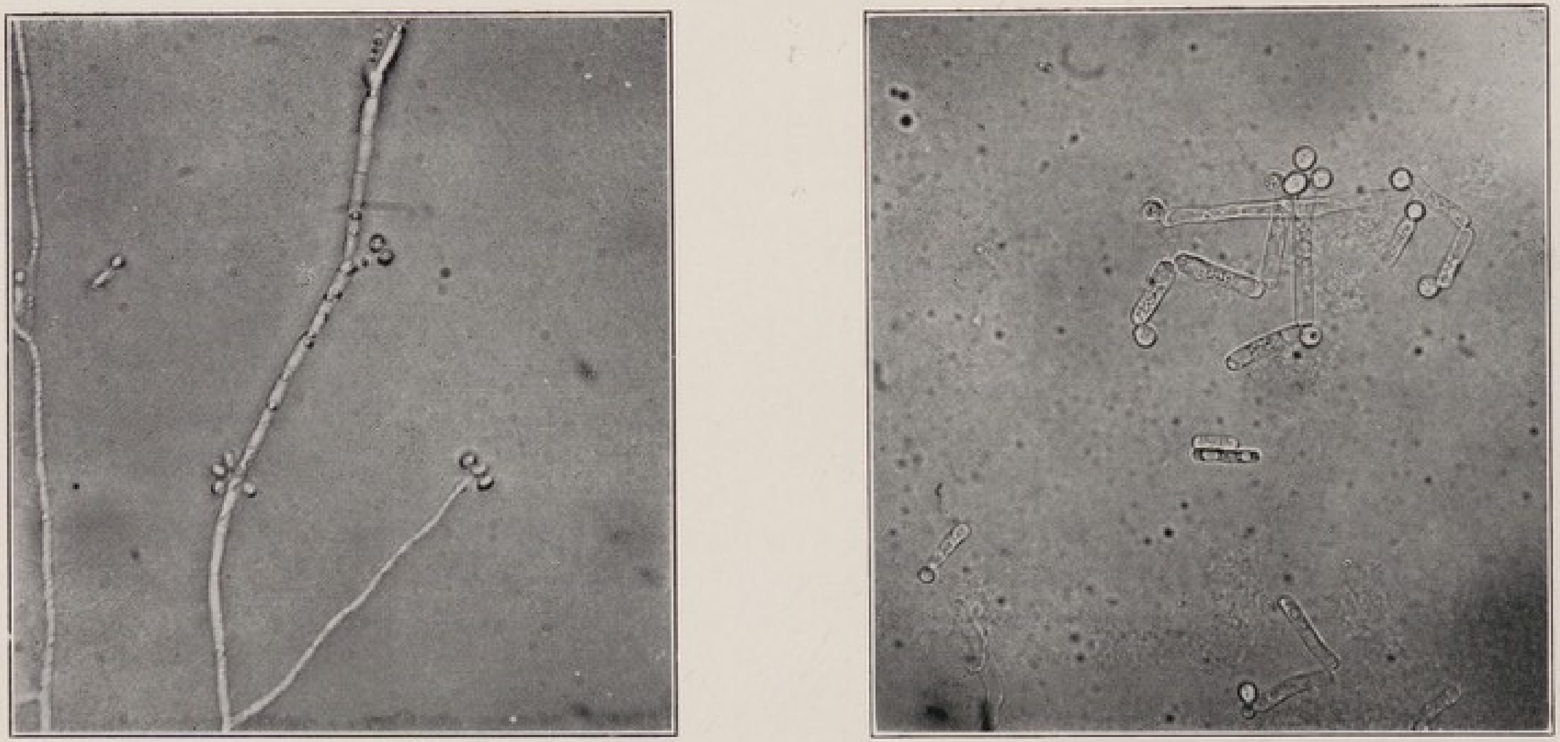


(a) (b)

PLATE 11.

(a) Hyphæ of *Sporotrichum* with Blastospores (×420).

(b) Short Filaments of *Sporotrichum* giving off Blastospores (×420).

APPENDIX III

NOTES ON FUNGI AND YEASTS ISOLATED DURING THE INVESTIGATION

Fungi belonging to the genera *Saprolegnia*, *Fusarium*, *Phoma*, and *Oospora* occurred abundantly and species of several other fungi occurred more rarely on the filtering medium of the double-filtration plant. Activated sludge from the aeration tanks of the large-scale plant contained only a few isolated filaments of fungi. This is attributed to the comparatively low concentration of nutrient material in the aeration tanks, since in laboratory experiments considerable growths of fungi occurred in aeration tanks containing higher concentrations of nutrient substances.

All the fungi found, with the exception of *Saprolegnia*, belonged to the Fungi Imperfecti. *Fusarium merismoides* Corda was identified by Dr. W. L. Gordon of the Dominion Rust Research Laboratory, Winnipeg, Canada, and *Dactylella* sp. by Dr. G. R. Bisby of the Imperial Mycological Institute, Kew Green, Richmond. The remaining fungi were identified at the Centraalbureau voor Schimmelcultures, Baarn, Holland.

Saprolegnia sp. This fungus was found growing abundantly on the filters at Ellesmere. It produces a mycelium of non-septate, branched hyphæ of variable diameter; the cell wall is composed of cellulose, as is indicated by the intense blue coloration produced by treatment with Schulze's solution. Sporangia are produced by the formation of a transverse cell wall separating part of the end of a hypha in which protoplasm has accumulated. The protoplasm of the young sporangium divides into numerous biciliate zoospores which are released from an opening at the apex of the sporangium; the zoospores are able to swim away from the mouth of the sporangium, but soon come to rest. On suitable media, such as yolk of egg or 3 per cent of whey in tap water, oogonia are formed. These are formed intercalarily or at the end of a hypha. The walls of the oogonia contain large simple pits $4{\cdot}5\ \mu$ to $5{\cdot}5\ \mu$ in diameter. There may be from one to twenty eggs in each oogonium. Antheridia are rarely found, but are formed under certain conditions, for example, in the presence of 1 per cent of potassium dihydrogen phosphate. When a culture has used most of its food supply, gemmæ may be formed which have dense protoplasmic contents and consist of sections of a hypha cut off by transverse walls. The species described seem best to agree with Coker's description of *Saprolegnia ferax* (Graith.) Thuret.

Fusarium spp. This group of fungi occurred in abundance on the surface of the primary filters, producing a reddish-orange mat of growth; the fungi have also been found in activated sludge both in the large-scale plant and in laboratory experiments. Three species have been isolated:

(1) *Fusarium merismoides* (Corda). This species, on beer-wort agar, produces long coremia 5 to 10 mm. in length. The sickle-shaped spores are from $30\ \mu$ to $50\ \mu$ long.

(2) *Nectria episphæria* (Tode) Fr., with conidial stage [*Fusarium aquæductum* (Radlk. et Rabh. pr. p.) Lagh. var. *medium* Wr.].

(3) *Fusarium lactis* Pir. et Rib. This species was obtained from activated sludge; it has also been isolated from milk products. It produces a pinkish-white, woolly, aerial growth. The conidia are 1 to $2{\cdot}5\ \mu$ broad and $4{\cdot}5$ to $7\ \mu$ long.

Phoma mori (Mont.). This fungus was found associated with *Fusarium* in biological film on the surface of the medium in the large filters. It developed during laboratory experiments in which activated sludge was aerated with daily additions of whey washings or of solutions of lactose. In these experiments the mycelium consisted of chains of ovoid cells, dark brown in colour. By division of the cells of a filament in three planes a sclerotium may be formed which develops into a pycnidium. The pycnidium opens by an ostiole and discharges small, ovoid, transparent spores, $4\ \mu$ to $8\ \mu$ long by $2\ \mu$ to $5\ \mu$ wide. On potato agar this fungus produces a thin white growth over the surface and, later, pycnidia are produced. These pycnidia appear as brown spots, 0·1 to 0·5 mm. in diameter. *Phoma mori* produces a small amount of acid on glucose, sucrose, and lactose. It turns litmus milk slightly acid or peptonizes the milk to some extent. Gelatin is liquefied slowly.

Phoma pigmentivora Massee was isolated from activated sludge.

Mucor hiemalis Wehmer was isolated from activated sludge; it also occurs in soil.

Mortierella pusilla (Oud.) var. *atrogrisea* (v. Beyma) Zycha was isolated from activated sludge; it occurs in soil and on decaying wood.

Oospora spp. The members of this genus were often found on and just below the surface of the filters in the large-scale plant. They grow very readily on solutions of whey and can tolerate an acid medium. They were frequently isolated from activated sludge in the large-scale plant. Two species were identified:

(1) *Oospora lactis* (Fresen.) Sacc. This species grows on beer-wort agar into a white colony, which may have a white dusty surface owing to the production of oidia. The oidia are very variable in size, but are smaller than those of *Oospora fragrans*. *O. lactis* does not produce acid from glucose, fructose, sucrose, and lactose, but acid is produced in litmus milk.

(2) *Oospora fragrans* (Berkhout) (Plate 10*b*). This species is readily distinguished from *O. lactis* by its dull white appearance and by the production of simple coremia on beer-wort agar. It has a characteristic fruity smell. The oidia are larger than those of *O. lactis*. Acid is produced from glucose and fructose but not from sucrose or lactose; there is no action on litmus milk.

Sporotrichum sp. (Plates 11*a* and 11*b*). This fungus was isolated on many occasions in laboratory experiments in which milk effluents were treated by the activated sludge process; it also developed on aeration of activated sludge to which lactic acid had been added; it did not occur on the large-scale filters. On beer-wort agar a dull white pasty growth is formed. The mycelium consists of branched septate hyphæ about 6 μ in diameter. Spherical conidia, 4 μ to 7 μ in diameter, are given off either laterally, near a transverse wall, or terminally, in which case from one to six may be produced at the end of a single hypha. The conidia arise directly from the hyphæ or from very short sterigmata. At the end of a hypha the conidia may be given off from two or more places and, by dividing while still attached, a small bunch of conidia is produced. *Sporotrichum* also produces isolated cells which bud off one or more conidia. Its appearance in this form is very similar to " *Chalara mycoderma* " as figured by Jörgensen[1].

Two species of *Sporotrichum* have been found:

(1) Closely related to *Sporotrichum Carougeaui* Langeron. It turns litmus milk acid and produces acid from glucose, fructose, and lactose, but not from sucrose.

(2) This species is distinguished from the first by its inability to produce acid from any of the four sugars, and it has no action on litmus milk. The species has not yet been determined.

Pullularia pullulans (De Bary et Löw) Berkh. This fungus produces a jet-black growth on beer-wort agar. It has never been found on the large filters, but was isolated from the activated sludge tanks. In laboratory experiments in which activated sludge was aerated with daily additions of lactose, ammonium carbonate, and potassium dihydrogen phosphate, a sludge gradually developed which was composed almost entirely of *Pullularia pullulans*. Reproduction is by budding of conidia from the sides of the hyphæ. The hyphæ may break up into rather irregular thick-walled cells. These resting cells may, under suitable conditions, produce numerous hyaline buds. Three strains of *Pullularia pullulans* have been isolated:

(1) This strain produces a shiny, black, mucilaginous skin on beer-wort agar. Acid is produced from glucose, fructose, and sucrose, but not from lactose. There is little or no action on litmus milk, and gelatin is slowly liquefied.

(2) This strain forms small, black, raised, warty colonies. No acid is formed from the sugars; litmus milk may be turned slightly acid, and gelatin is slowly liquefied.

(3) A strain of *Hormodendrum viride* (Fresen.) Lindau has also been isolated which is similar in many respects to *Pullularia pullulans*, but which produces a dark olive, aerial growth. Acid is produced from dextrose and fructose, but not from sucrose and lactose.

Leptomitus lacteus Agardh. This fungus belongs to the Saprolegniales, and, like *Saprolegnia*, has a mycelium of branched, aseptate hyphæ. It can readily be distinguished by the constrictions which occur at intervals along the hyphæ, particularly above the place where a branch arises. In the pore formed by the constriction there is a highly refractive cellulin granule (Plate 12*a*). This fungus was associated with *Saprolegnia* in film on the medium of the primary filter; it also occurred in the stream receiving the treated effluent from the factory.

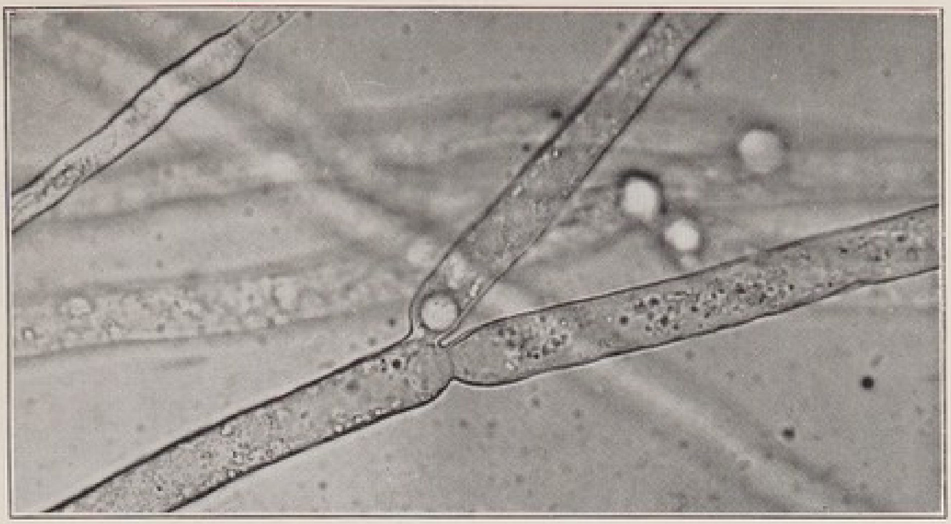
Dactylella sp. (Plates 12*b* and *c*). This remarkable fungus occurred frequently in the aeration tanks of the activated sludge plant; it was also found in the biological film of the primary and secondary filters. It belongs to a group of Hyphomycetes which prey on nematodes. It produces septate hyphæ, 2·5 μ to 5 μ wide, from which are formed short branches which curve round to fuse with the base at regular intervals. These loops act as snares in which nematodes are squeezed to death by the swelling of the three cells forming the loop. Haustoria are then produced which penetrate the body of the nematode. The conidial stage has only once been found. The conidia are top-shaped bodies, consisting of three cells formed at the end of a branch. In the aeration tanks of the activated sludge plant the fungus was found chiefly in the form of branched filaments, giving off very short branches which only occasionally developed into loops.

Rhodotorula mucilaginosa (Jörg.) Lodder. This non-sporing yeast produces a coral-red, liquid growth on beer-wort agar. It was the commonest yeast in various parts of the purification plants, but it never occurred in very great numbers. It is often found associated with milk and milk products.

Several other yeasts were isolated, but they never occurred in large numbers; no one species predominated. The following species have been identified:

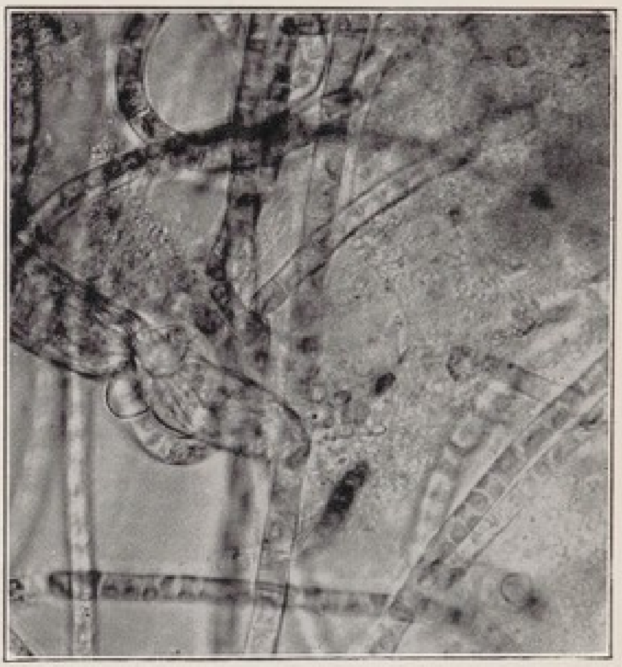
Saccharomyces fragilis Jörgensen.

Saccharomyces lactis Dombrowsky.



(*a*)

(*b*)



(*c*)

PLATE 12.

(*a*) *Leptomitus lacteus,* showing Cellulin Granule (×420).

(*b*) *Dactylella,* showing Pear-shaped Conidum and Loops (×420). The cells of two of the loops have swollen.

(*c*) *Dactylella* with Ensnared Nematode (×420). Two swollen cells of the ensnaring loop can be seen.

Torulopsis uvæ (Pollacci et Nannizzi) Lodder.

Torulopsis globosa Olsen et Hammer.

Torulopsis sp. This species could not be identified with any known yeast. It has no fermentative power. Of the sugars tested it can assimilate only glucose, fructose, and mannose. Nitrogen can be assimilated from peptone, asparagine, urea, and ammonium sulphate, but not from potassium nitrate or potassium nitrite. In malt extract no pellide is formed. The cells are small (2 to 3 μ by 3 to 4·5 μ). It has nearly the same characteristics as *Torulopsis uvæ* (Poll. et Nann.) Lodder, but the cells are smaller. It may be considered to be a new variety of *Torulopsis uvæ*.

Strain of *Torulopsis pulcherrima* (Lindner) Sacc. This yeast has the same fermentative power and the same ability to assimilate compounds of nitrogen as *T. pulcherrima*. The shape and size of the cells are also the same. There is, however, no production of red pigment on media containing iron, and the yeast appears to be a strain of *Torulopsis pulcherrima* (Lindner) Sacc. which has lost the ability to produce pigment.

Candida pseudotropicalis (A. Cast.) Basgal. This fungus is the imperfect stage of *Saccharomyces fragilis* Jörgensen, which is often isolated from buttermilk.

Candida sp. This is probably a new species. It does not ferment sugars, but assimilates glucose, fructose, mannose, galactose, sucrose, maltose, and lactose. It assimilates peptone, asparagine, urea, and ammonium sulphate, but not potassium nitrate or potassium nitrite.

Candida sp. Probably a new species. It assimilates glucose, fructose, and mannose, but not galactose, sucrose, maltose or lactose; it does not ferment any of these sugars. It assimilates peptone, asparagine, urea, and ammonium sulphate, but not potassium nitrate or potassium nitrite.

Phialophora Lignicola (Nannf.) Goid. This fungus was isolated on several occasions from activated sludge.

Reference

[1] JÖRGENSEN, A. Micro-organisms and Fermentation. Griffin and Co., Ltd., London, 1925.

APPENDIX IV

NOTES ON PROTOZOA

The following protozoa occurred frequently in the aeration tanks of the activated sludge plant, but could not be identified with any known species:

Aspidisca sp. Oval, dorsiventrally flattened with no furrows on the back; about 20 μ long. It has a posterior seta or spine, which may be held behind or folded under the body. Movements quick; a characteristic movement is backwards and forwards along a filament of *Sphærotilus* with the seta trailing behind. Occurring with *Aspidisca costata*.

Aspidisca sp. A hypotrichous ciliate similar in habit to *A. costata* but distinguished by its larger size (about 40 μ long) and a prominent spine projecting backwards.

D. A sessile flagellate having a conical lorica containing an individual with one flagellum as long as itself. It may grow in a colony. The stalks may be branched or the stalk of one individual may arise from the inside of the lorica of another. Stalk not contractile.

APPENDIX V

CULTURE MEDIA AND TESTS FOR BACTERIA

Nutrient Agar

Agar agar	15 gm.
Lemco	3 ,,
Peptone	10 ,,
NaCl	5 ,,
Distilled water	1,000 ml.

*p*H value adjusted to 7·0.

Nutrient Gelatin

Gelatin	120 gm.
Lemco	5 ,,
Peptone	10 ,,
NaCl	5 ,,
Distilled water	1,000 ml.

pH value adjusted to 7·0.

Bile Salt Agar (MacConkey)

Agar agar	15 gm.
Peptone	20 ,,
Sodium taurocholate	5 ,,
Lactose	10 ,,
Neutral red	5 ml. of a 1 per cent aqueous solution
Tap water	1,000 ml.

pH value adjusted to 7·0.

Czapek's Medium

Agar agar	15·0 gm.
$NaNO_3$	2·0 ,,
KH_2PO_4	1·0 ,,
KCl	0·5 ,,
$MgSO_4.7H_2O$	0·5 ,,
$FeSO_4.7H_2O$	0·01 ,,
Sucrose	30·0 ,,
Distilled water	1,000 ml.

pH value not adjusted.

Milk Agar

Agar agar	15 gm.
Kubel-Tiemann's litmus	20 ml.
Separated fresh milk neutral to litmus	1,000 ,,

Wort Agar

Agar agar	20 gm.
Beer wort (unhopped)	500 ml.
Distilled water	500 ,,

pH value not adjusted.

Urine Agar

Agar agar	15 gm.
Urine	1,000 ml.

pH value not adjusted.

Milk Washings Agar

Agar agar	15 gm.
Milk washings (1 per cent of milk in water; steamed 30 minutes and filtered)	1,000 ml.

pH value not adjusted.

Mannitol, Propionate, and Lactate Agars

Agar agar	15·0 gm.
K_2HPO_4	1·0 ,,
$MgSO_4.7H_2O$	0·2 ,,
$CaCl_2$	0·1 ,,
NaCl	0·1 ,,
$FeCl_3.6H_2O$	trace
KNO_3	0·5 gm.
Mannitol, sodium propionate, or sodium lactate	1·0 ,,
Distilled water	1,000 ml.

pH value adjusted to 7·2.

Casein Agar

Agar agar	15·0 gm.
Casein	0·2 ,,
Dextrose	2·0 ,,
K_2HPO_4	0·5 ,,
$MgSO_4.7H_2O$	0·2 ,,
Distilled water	1,000 ml.

pH value not adjusted.

Carbohydrate Media

NaCl	0·6 gm.
KCl	0·01 ,,
$CaCl_2$	0·02 ,,
$MgSO_4.7H_2O$	0·01 ,,
$(NH_4)_2HPO_4$	0·24 ,,
Carbohydrate	1·0 ,,
Distilled water	1,000 ml.

*p*H value adjusted to 7·0.

Nitrate Medium

KH_2PO_4	0·5 gm.
K_2HPO_4	0·5 ,,
$CaCl_2$	0·1 ,,
NaCl	0·1 ,,
$MgSO_4.7H_2O$	0·3 ,,
$FeCl_3.6H_2O$	trace
KNO_3	1·0 gm.
Lactic acid	3·5 ,,
Distilled water	1,000 ml.

*p*H value adjusted to 7·0.

Alanine Medium

NaCl	0·6 gm.
KCl	0·01 ,,
$CaCl_2$	0·02 ,,
$MgSO_4.7H_2O$	0·01 ,,
KH_2PO_4	0·6 ,,
K_2HPO_4	0·6 ,,
Alanine	2·0 ,,
Distilled water	1,000 ml.

*p*H value adjusted to 7·0.

Litmus Milk

Separated fresh milk, neutral to litmus	1,000 ml.
Kubel-Tiemann's litmus	20·0 ml.

Indole Test

The organism to be tested is grown in the following solution:

Peptone	10·0 gm.
NaCl	5·0 ,,
Distilled water	1,000 ml.

*p*H value adjusted to 7·0.

When sufficient growth has occurred, 1 ml. of the culture is mixed with 1 ml. of para-dimethylamido-benzaldehyde solution (Ehrlich's reagent) and the mixture is gently warmed. A red colour indicates the presence of indole.

Acetyl-methyl-carbinol Test

The organism to be tested is grown in the following culture solution:

NaCl	5·0 gm.
$MgSO_4.7H_2O$	0·2 ,,
$NH_4H_2PO_4$	1·0 ,,
K_2HPO_4	1·0 ,,
Sodium citrate	2·8 ,,
Glucose	5·0 ,,
Sodium fumarate	10·0 ,,
Distilled water	1,000 ml.

When a good growth has occurred, 5 mg. of solid creatine and 1 ml. of a 40 per cent solution of NaOH are added to 1 ml. of the culture. The tube is shaken vigorously; a red colour indicates the presence of acetyl-methyl-carbinol.

APPENDIX VI

Table LXXVII. *Description of 33 Species of Bacteria Isolated During the Experiments on a Large Scale**

Where the + sign is used to denote the presence of a substance, increasing amounts are shown by +, ++, or +++.
In the case of production of acid from carbohydrates these signs have a definite value; thus + = final *p*H value not lower than 6·0, ++ = final *p*H value 5·0–6·0, +++ = final *p*H value less than 5·0. G = gas produced.

Species No.	Motility	Approximate length (μ) and shape	Liquefaction	Gelatin stab after incubation for 7 days	Action on litmus milk after incubation for 14 days	Production of acid on carbohydrates in mineral salt solution after incubation for 4 days										Reduction of nitrate after incubation for 7 days	Ammonia from alanine after incubation for 4 days	Indol formation after incubation for 4 days	Acetyl-methyl-carbinol from fumarate after incubation for 2 days	Growth on agar slopes	Gram stain
						Glucose	Fructose	Lactose	Sucrose	Raffinose	Arabinose	Xylose	Dulcitol	Mannitol	Sorbitol						
1	0	4·0 rod	0	thread	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Abundant, filiform, convex, smooth, opaque, yellow	0
2	0	1·7 rod	0	thread	acid curd; litmus reduced	+++ G	+++ G	+++ G	+++ G	+++ G	+++ G	+++ G	0	+++ G	+++ G	+++	+	++	+	Moderate, echinate, convex, smooth, opaque, white	0
3	+	1·8 rod	0	thread	acid; litmus reduced	++ G	++ G	++ G	++ G	++ G	++ G	++ G	0	++ G	++ G	+++	+	0	+	Moderate, echinate, convex, smooth, opaque, white	0
4	+	3·0 rod	+	infundibular	acid curd	+++	+++	+++	+++	0	+++	0	0	+++	0	+++	+	++	0	Moderate, echinate, flat, smooth, translucent, grey	0
5	0	0·7 rod	+	infundibular	peptonized	+	0	0	0	0	0	0	0	0	0	0	0	+	0	Moderate, filiform, convex, smooth, opaque, transparent with age, orange	0
6	+	0·9 rod	+	cup	litmus reduced	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Moderate, filiform, with raised edges, smooth, opaque, white	0
7	0	0·6 coccoid	0	thread	0	+++	0	0	0	0	0	0	0	0	0	++	+	0	0	Moderate, echinate, convex, smooth, opaque, white	0
8	0	0·9 coccoid	0	thread	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Scanty, filiform, convex, smooth, opaque, grey	0
9	+	1·6 rod	+	infundibular	peptonized; litmus reduced	+	0	0	++	0	0	0	0	0	0	++	+	0	0	Abundant, filiform, flat, smooth, opaque, pinkish brown	0
10	+	2·0 rod	+	saucer	peptonized	+++	+++	0	0	0	+++	0	0	++	+	++	+	0	0	Abundant, echinate, flat, smooth, opaque, white	0
11	+	1·0 rod	0	thread	alkaline	0	0	0	0	0	0	0	0	0	0	0	+	0	0	Moderate, dentate, convex, smooth, opaque, white	0
12	0	0·9 rod	0	thread	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Moderate, filiform, raised, smooth, opaque, reddish orange	+
13	0	0·9 coccoid	0	thread	0	0	0	0	0	0	0	0	0	0	0	+	0	0	0	Moderate, echinate, flat, smooth, opaque, white	0
14	0	1·2 Sarcina	+	cup	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Moderate, filiform, convex, smooth, opaque, yellow	+
15	0	0·9 Sarcina	0	thread	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Moderate, filiform, convex, smooth, opaque, white	0

16	+	2·6 rod	0	thread	0	+++	+++	0	+++	+++	+++	+++	0	+++	+++ G	0	+	+	+	Moderate, filiform, flat, smooth, translucent, white	0
17	+	1·1 rod	+	stratiform	curded; peptonized	+++	+++	0	+++	0	+++	0	0	+++	0	+++	+	+	0	Abundant, filiform, convex, smooth, opaque, brownish	0
18	+	0·8 rod	+	stratiform	peptonized; litmus reduced	+++	++	0	0	0	0	++	0	++	0	0	+	0	0	Moderate, echinate, flat, smooth, translucent, white	0
19	+	2·5 rod	0	thread	acid curd; litmus reduced	+++	+++	+++	+++	0	+++	0	0	+++	0	0	+	+	0	Abundant, filiform, rugose edge convex, smooth, opaque, grey, browns agar	0
20	+	1·0 rod	0	thread	alkaline	+	++	0	+	0	+	0	0	0	0	0	+	(+)	0	Moderate, echinate, flat, smooth, translucent, grey	0
21	+	0·9 rod	0	thread	acid curd; litmus reduced	+++ G	+++ G	+++ G	0	0	+++ G	+++ G	+++ G	+++ G	0	+++	+	0	0	Moderate, echinate, flat, smooth, opaque, white	0
22	+	1·5 rod	+	complete	curded; peptonized	+	++	0	0	0	+	++	0	+++	0	+ fluor-escent	+	0	0	Moderate, filiform, raised, smooth, translucent, grey	0
23	0	1·2 rod	0	thread	acid curd; litmus reduced	+++ G	+++ G	+++ G	0	0	+++ G	+++	+++ G	+++ G	+++ G	+++	+	+	0	Moderate, echinate, convex, smooth, opaque, white	0
24	+	1·2 rod	0	thread	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Moderate, filiform, flat, smooth, opaque, grey	0
25	0	1·6 rod	0	thread	acid curd; litmus reduced	+++ G	+++ G	+++ G	+++ G	+++ G	+++ G	+++ G	0	+++ G	+++ G	+++	+	+	+	Moderate, echinate, convex, smooth, opaque, white	0
26	0	1·0 Sarcina	0	thread	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Scanty, filiform, flat, smooth, grey	+
27	0	0·9 coccoid	0	thread	acid curd; litmus reduced	+++ G	+++ G	+++ G	+++ G	+++ G	+++ G	+++ G	0	+++ G	+++ G	+++	+	0	+	Moderate, echinate, convex, smooth, opaque, moist, white	0
28	+	1·2 rod	0	thread	acid; litmus reduced	++ G	++ G	+++ G	+++ G	+++ G	+++ G	+++ G	+++ G	+++ G	+++ G	+++	++	0	+	Moderate, echinate, convex, smooth, opaque, white	0
29	+	0·8 rod	0	thread	acid; litmus reduced	+++ G	++ G	+++ G	+++ G	+++ G	+++ G	+++ G	0	+ G	0	+++	+	0	+	Moderate, filiform, raised, smooth, opaque, white	0
30	0	0·9 rod	0	thread	acid curd; litmus reduced	+++ G	+++ G	+++ G	+++ G	+++ G	+++ G	+++ G	+++ G	+++ G	++ G	+++	+	0	+	Moderate, echinate, convex, smooth, opaque, white	0
31	0	0·8 rod	+	saucer, fluorescent	curded; peptonized	++	++	0	+	0	+	++	0	++	+	0 G	+	0	0	Abundant, echinate, convex, smooth, opaque, cream	0
32	0	0·9 rod	0	thread	alkaline	++	++	0	0	0	+++	+++	0	++	0	+++	+	0	0	Moderate, echinate, flat, smooth, opaque, grey	0
33	0	1·0 rod	0	thread	acid curd	+++ G	+++ G	+++ G	+++ G	++	+++	+++ G	0	+++ G	+++ G	+++	+	+	0	Moderate, filiform, raised, smooth, translucent, white	0

* From the characteristics given in Table LXXVII Species Nos. 2 and 25 appear to be almost identical; there are, however, certain clearly marked differences between them. On agar slopes the growth of Species No. 25 is always stronger and moister than that of Species No. 2; in these cultures the difference in size of the individual rods is increased, the average size of No. 25 being at least 5 μ greater than that of No. 2. Solutions, containing whey or milk, in which the acidity has been neutralized by addition of alkali are always more readily decomposed by Species No. 25 than by Species No. 2. As a further point of interest it may be noted that amœbæ discriminate between the two forms and eat Species No. 25 more readily than Species No. 2.

APPENDIX VII

ACTION OF WASTE WATERS FROM THE MILK INDUSTRY ON CEMENT PRODUCTS

Deterioration of cement products by the chemical action of milk and milk wastes in dairies and cheese factories has frequently been reported. It was decided to carry out some tests on this subject during the present investigation, and arrangements were made for the Department's Building Research Station to prepare cubes of different types of cement mortar for exposure to the action of the liquids in different parts of the two large-scale plants at Ellesmere, and to examine the cubes after exposure.

Two different types of cement mortar were used, one prepared from Portland cement and the other from aluminous cement; each cement was mixed with river sand, graded from $\frac{3}{16}$ in. downwards, in the proportion of 1 part of cement to 2·5 parts of sand. The mortar was gauged to a plastic consistency (12 per cent of water for the Portland cement and 11 per cent for the aluminous cement) and was cast into cubes (length of edge 7·1 cm.) with hand tamping. A hook of tinned copper wire was cast into each cube for the purpose of suspending it in the liquid. The cubes were cured for 1 day in moist air in the moulds and were then allowed to dry out in air for 7 days; the temperature during curing was 18° C. Some cubes were exposed without further treatment and some were treated by the following methods.

Portland Cement Mortar

(1) Untreated.

(2) Treated with a solution of sodium silicate. Commercial sodium silicate of a grade sold for the purpose of surface treatment of concrete was diluted in accordance with the instructions given by the manufacturers and was applied in 3 coats at intervals of 24 hours.

(3) Treated with a solution of magnesium silico-fluoride. Three coats of a solution of magnesium silicofluoride, containing 1 lb. per gallon for the first coat and 2 lb. per gallon for the second and third coats, were applied at intervals of 24 hours.

(4) Coated with tar-base paint. The paint was a bituminous solution reputed to contain a coal-tar base.

(5) Coated with bitumen-base paint. The paint was a bituminous solution reputed to contain a bitumen base.

Aluminous Cement Mortar

(6) Untreated.

(7) Treated with a solution of magnesium silicofluoride. The method of treatment was the same as that used for the cubes of Portland cement mortar.

All the cubes of mortar were placed in the large-scale treatment plants in June 1937, 14 weeks after they had been treated by the various methods. They were examined after a period of exposure of 7 months and again after a total period of exposure of 15 months. During the period in which the cubes were exposed, the following crude liquids were treated in the large-scale plants:

1st month: Mixture containing three volumes of milk washings with one volume of whey washings.

2nd to 4th month: One volume of milk washings with one volume of whey washings.

5th to 8th month: One volume of milk washings with three volumes of whey washings.

9th to 14th month: Whey washings only.

14th and 15th months: One volume of milk washings with three volumes of whey washings.

One cube of each type was placed in each of the following positions:

(*a*) In storage and balancing tank for crude liquid.
- (i) Near surface of tank and intermittently immersed in liquid.
- (ii) Nearer bottom of tank and always completely immersed.

(*b*) In primary sedimentation tanks for crude liquid.
- (i) At surface of tank and only partially immersed in liquid.
- (ii) Below surface of liquid and always completely immersed.

(*c*) Under surface of filtering medium in both filters; the top of each cube was about 1½ in. below the surface of the medium and each cube was almost directly under the track of a jet of the rotary distributor.

(*d*) In aeration tank of the activated sludge plant, near the inlet.
- (i) At surface and only partially immersed in liquid.
- (ii) Below surface of liquid and always completely immersed.

The approximate range of temperature and of *p*H value of the liquid at each of these positions is shown in Table LXXVIII.

TABLE LXXVIII. *Conditions of Exposure of Cubes of Cement Mortar in Experimental Plants at Ellesmere*

Position of cubes	Conditions of exposure	Temperature of liquid to which cubes were exposed (° C.)	*p*H value of liquid to which cubes were exposed
Storage and balancing tank for crude liquid	Completely immersed Intermittently immersed	Inlet to tank, 10 to 59 Outlet from tank, 6·5 to 43	Range, 4·2 to 6·6; usual value about 5·0
Primary sedimentation tank	Completely immersed Partially immersed	6·5 to 39	Range, 4·2 to 6·6; usual value about 5·0
Filter No. 1 Filter No. 2	Buried about 1½ in. under surface of filtering medium	2 to 25	Range, 4·4 to 6·8; usual value about 5·8
Aeration tank of activated sludge plant, near inlet	Completely immersed Partially immersed	6 to 29	Range, 6·4 to 8·6; usual value about 7·3

In the storage and balancing tank the temperature of the crude milk washings or whey washings was usually relatively high and the liquid was always acid in reaction; the strength of the liquid, as measured by the test for biochemical oxygen demand, was greatest in this part of the plant. In the primary sedimentation tank for crude liquid the strength and *p*H value of the washings were about the same as in the storage and balancing tank, but the temperature was rather lower. After treatment in the primary sedimentation tank the crude liquid was diluted with purified effluent before distribution on the primary filter. The temperature of the diluted liquid was usually lower, and the *p*H value was usually higher, than in the undiluted liquid in the primary sedimentation tank. Each of the two filters, Nos. 1 and 2, was used as a primary filter for a period of 2 or 3 weeks; the order of the filters in series was then reversed and the filter was used for a similar period as a secondary filter. The average biochemical oxygen demand of the liquid distributed on a filter in the primary position was about 25 parts per 100,000 parts, though comparatively large fluctuations occurred from time to time; the biochemical oxygen demand of the effluent from the primary filter, which was distributed on the secondary filter, varied from 1 part to 4 parts per 100,000. The average biochemical oxygen demand of the liquid supplied to the aeration tanks of the activated sludge plant was about 50 parts per 100,000, but the biochemical oxygen demand of the liquid in contact with the specimens was less than this, since the incoming crude liquid was diluted by the partially purified liquid in the aeration tanks. The liquid in the aeration tanks was usually neutral or slightly alkaline in reaction.

Observations on the condition of the cubes of mortar after exposure for periods of 7 months and 15 months are given in Tables LXXIX, LXXX, LXXXI, and LXXXII.

In the storage and balancing tank for crude liquid the cubes of untreated Portland cement mortar were severely attacked, the surface of the mortar being softened and the aggregate exposed, in some cases to a depth of ¼ in. The attack appeared to be due to leaching and softening, since it was progressive from the surface and did not affect the interior of the specimens. Specimens treated with sodium silicate and magnesium silicofluoride were rather more severely attacked than were untreated specimens. The tar-base paint was almost completely removed by softening or powdering, but the exposed surface of the mortar had not been so severely attacked as the untreated mortar, since the paint had afforded protection during the early part of the period of exposure. Bitumen-base paint was intact on specimens completely immersed in the liquid, but patches of the paint had been removed from the cubes which were immersed intermittently. Coating with bitumen-base paint appeared to be the most effective of the methods of treatment of Portland cement mortar tried. Specimens of untreated mortar made with aluminous

TABLE LXXIX. *Results of Exposure of Cubes of Cement Mortar to Waste Waters in Storage and Balancing Tank*

Nature of specimen	Specimens immersed intermittently		Specimens completely immersed	
	After exposure for 7 months (A)	After exposure for 15 months (B)	After exposure for 7 months (C)	After exposure for 15 months (D)
Portland Cement Mortar				
1. Untreated	Slight softening and erosion	Marked erosion and exposure of aggregate	Soft to depth of about 0·1 in.	Marked erosion to depth of 0·13 in.; aggregate exposed
2. Treated with sodium silicate	Rather more softening and erosion than in 1A	Marked erosion and exposure of aggregate; similar to 2A	Aggregate exposed; softening to a further depth of 0·1 in.; worse than 1C	Slightly worse than 1D
3. Treated with magnesium silicofluoride	More softening and erosion than in 1A	Similar to 2A	Similar to 2C	Similar to 2D
4. Coated with tar-base paint	Much paint gone but no appreciable erosion	All paint gone but only slight softening of surface	Paint soft and powdered in places; erosion of surface where mortar exposed	Paint nearly all gone; mortar nearly as bad as 1D
5. Coated with bitumen-base paint	Paint gone in a few spots and mortar eroded; otherwise sound	Much paint gone but no erosion where paint had been only recently removed	Slight blistering but intact	Paint intact
Aluminous Cement Mortar				
6. Untreated	Sound	Sound	Sound	Sound
7. Treated with magnesium silicofluoride	Sound	Sound, but slight roughening of surface	Sound	Sound

cement were not attacked during exposure for 15 months in the storage and balancing tank; specimens treated with magnesium silicofluoride were slightly roughened on the surface when intermittently immersed in the liquid but were unaffected when completely immersed.

In the primary sedimentation tank for crude liquid the attack on cubes of Portland cement mortar was less severe than in the storage and balancing tank. Treatment with sodium silicate or with magnesium silicofluoride did not appreciably affect the extent of corrosion of the mortar. Coatings of tar-base paint were partly removed after exposure for 15 months, but bitumen-base paint was almost intact after this period of exposure and the underlying mortar was not appreciably affected.

In specimens buried beneath the surface of the medium in the two percolating filters the rate of attack on the mortar was less than in the storage tank and primary sedimentation tank. No change in the condition of the specimens was visible after exposure for 7 months, but there was slight softening and erosion of the surface of the mortar after 15 months. No significant reduction in the rate of attack resulted from treatment of the mortar with sodium silicate or with magnesium silicofluoride. Both tar-base and bitumen-base paints were partly removed, but the deterioration of the underlying mortar was materially less than in specimens of untreated mortar.

The least severe conditions were found in the aeration tanks of the activated sludge

TABLE LXXX. *Results of Exposure of Cubes of Cement Mortar in Primary Sedimentation Tank for Crude Liquid*

Nature of specimen	Specimens partially immersed		Specimens completely immersed	
	After exposure for 7 months (A)	After exposure for 15 months (B)	After exposure for 7 months (C)	After exposure for 15 months (D)
Portland Cement Mortar				
1. Untreated	Aggregate exposed below level of liquid; sound above level of liquid	Slightly worse than 1A	Slight softening but no erosion	Slight softening of faces of cube and some erosion near edges
2. Treated with sodium silicate	Similar to 1A	Similar to 1B	Similar to 1C	Similar to 1D but less erosion
3. Treated with magnesium silicofluoride	Similar to 1A	Similar to 1B	Similar to 1C	Similar to 2D
4. Coated with tar-base paint	Paint slightly blistered but still intact	Paint gone at edges; mortar soft where exposed	Little change in condition of specimen	Most of paint intact but mortar soft where paint had been removed
5. Coated with bitumen-base paint	Paint gone in some places above level of liquid, but mortar sound	Similar to 4B	Paint blistered but intact	Paint almost intact
Aluminous Cement Mortar				
6. Untreated	Sound	Sound	Sound	Sound
7. Treated with magnesium silicofluoride	Sound	Sound	Sound	Sound

plant. The amount of attack on the specimens was small in every case, but some softening and erosion occurred in cubes of untreated Portland cement mortar. Under these conditions of exposure the rate of attack of Portland cement mortar was reduced by treatment with sodium silicate or with magnesium silicofluoride. Tar-base and bitumen-base paints, though partly removed after exposure for 15 months, gave complete protection against softening of the mortar during this period. Aluminous cement mortar was unaffected under the conditions of the test.

Summarizing the results of the experiments, the greatest rate of attack occurred in specimens exposed to liquid in the storage and balancing tank where the acidity, concentration of organic matter, and temperature were highest. Under the most severe conditions, treatment of Portland cement mortar with sodium silicate or with magnesium silicofluoride had a slightly adverse effect on the resistance of the mortar, but gave some protection under less severe conditions of exposure. Tar-base paint and bitumen-base paint afforded protection to the mortar for a short time, but were removed by softening and powdering under the more severe conditions of exposure within the period of the tests, and attack of the mortar then occurred in some cases. Bitumen-base paint was more effective than tar-base paint. The only completely satisfactory material tested was untreated aluminous cement mortar, which was unaffected under any of the conditions of exposure.

[*Tables* LXXXI *and* LXXXII *follow*]

TABLE LXXXI. *Results of Exposure of Cubes of Cement Mortar below Surface of Filtering Medium in Double-Filtration Plant*

Nature of specimen	Filter No. 1		Filter No. 2	
	After exposure for 7 months (A)	After exposure for 15 months (B)	After exposure for 7 months (C)	After exposure for 15 months (D)
Portland Cement Mortar				
1. Untreated	Sound	Surface soft and eroded to a depth of less than 0·03 in.	Sound	Similar to 1B but slightly worse
2. Treated with sodium silicate	Sound	Similar to 1B less severely attacked	Sound	Similar to 1D
3. Treated with magnesium silicofluoride	Sound	Similar to 2B	Sound	Similar to 1D
4. Coated with tar-base paint	Sound	Paint intact except on top surface of cube; mortar hard	Some paint gone; mortar sound	Some paint gone but condition of mortar better than 1D
5. Coated with bitumen-base paint	Sound	Some paint gone; mortar soft where exposed	Similar to 4C	Some paint gone and the remainder easily scaled off; mortar only slightly affected
Aluminous Cement Mortar				
6. Untreated	Sound	Sound	Sound	Sound
7. Treated with magnesium silicofluoride	Sound	Sound	Sound	Sound

TABLE LXXXII. *Results of Exposure of Cubes of Cement Mortar in Aeration Tanks of Activated Sludge Plant*

Nature of specimen	Specimens partially immersed		Specimens completely immersed	
	After exposure for 7 months (A)	After exposure for 15 months (B)	After exposure for 7 months (C)	After exposure for 15 months (D)
Portland Cement Mortar				
1. Untreated	Sound	Slight erosion of edges at bottom of cube	Slight softening of surface; aggregate exposed on upper face of cube	Similar to 1C but attack slightly more severe
2. Treated with sodium silicate	Sound	Similar to 1B	Similar to 1C but attack less severe	Similar to 1D but attack slightly less severe
3. Treated with magnesium silicofluoride	Sound	Sound	Similar to 1C but attack very slight	Similar to 2D
4. Coated with tar-base paint	Paint gone from upper surface of cube; mortar sound	Similar to 4A	Sound	Paint blistered off in a few places; mortar sound
5. Coated with bitumen - base paint	Similar to 4A	Similar to 4A	Sound	Similar to 4D
Aluminous Cement Mortar				
6. Untreated	Sound	Sound	Sound	Sound
7. Treated with magnesium silicofluoride	Sound	Sound	Sound	Sound

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