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The Effect of Detergents on Aeration: A Photographic Approach to the Problem

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There is now an extensive literature on the influence of detergents on the biological purification of sewage, and among the many papers on this subject two are of special interest in this connection.

First we have the fundamental investigations made by Holroyd and Parker[1],[2]. Holroyd uses a factor K as a yardstick of the dissolving of oxygen which is by definition: "The rate of increase of dissolved oxygen concentration in parts per 100,000 per hour occurring in a given aeration system at a defined point on the aeration curve, namely, at that instant when the dissolved oxygen concentration in the water is 1 ppht. below saturation value for the system".

Holroyd investigated the effect of Teepol, Lissapol, Bentonite, and Turkey Red Oil and determined their influence on the dissolving of oxygen from diffused-air bubbles into water. The effect is very notable and approaches its maximum at about 20 p.p.m. Compared with other aeration systems (heaving water, stagnant-film surface) the diffused-air system is influenced most.

We also know the papers of Degens *et al.*[3], who state that the presence of alkylarylsulphonates causes a permanent decrease in the rate of solution of oxygen undergoing purification. On the other hand, the effect of alkyl sulphates becomes less the longer aeration is continued, due to the capacity of the bacteria of the activated sludge floc to dissimilate its components. Similar information is lacking on the behaviour of non-ionics like Lissapol.

However, as we have nowadays a mixture of alkyl sulphates and alkylarylsuphonates in sewage the final effect will be that the effluent, if the sewage is treated in the usual way, will be less purified than in the past, and Degens *et al.* describe diffused-air experiments in which they could only obtain the former good results by aerating three times as long as usual, implying the necessity for a threefold increase in aeration capacity. It is, therefore, important to study the fundamental processes which take place at the air/water boundary layer, with and without detergents.

In aeration research we express the oxygenation capacity of a given system in a way somewhat different from that used by Holyroyd, namely, as expressed by Kessener and Ribbius as early as 1935[4]. This O.C. is the amount of oxygen in grams which dissolves per cubic metre of water per hour at zero dissolved oxygen concentration. It depends on the oxygen deficit in the water and may be expressed by the following equation:—

$$O.C._{IO} = 26.1\frac{1}{t_l - t_o} \log \frac{C_{sat}-C_o}{C_{sat}-C_t} \sqrt{\frac{k_{IO}}{k_t}}$$

We first determined the influence of the three types of detergent mostly used nowadays, namely, a sec. alkyl sulphate (type Teepol), a sec. alkylarylsulphonate (type Tide, Omo), and Lissapol as a non-ionic—all as pure substances without "builders". For these chemicals we are greatly indebted to Royal Dutch Shell Laboratories at Amsterdam and Levers Zeepmaatschappij at Vlaardingen.

In Table 1 are given the results obtained by aerating a water column about 100 by 23 by 23 cms. with a section of a dome diffuser as used at Manchester, which was put at our disposal by Mr. McNicholas and for which our gratitude is expressed.

Together with the results obtained in the presence of 4 and 10 p.p.m. detergent in this apparatus, results are also given which were obtained when A.F.A. (anti-foaming agent) had been added to a rotating brush system (see Table 5). Higher alcohols were the active principle in the A.F.A.

Table 1

Decrease in O.C. in Diffused Air Aeration (Manchester Dome Diffuser) Caused by Detergents

				Per cent
I	1.	Blank		100
	2.	4 ppm. Alk-ar-sulph.		88.8
	3.	Do.	+ 3 ppm. A.F.A.	76.7
II	2.	4 ppm. Alk. sulph.		86.9
	3.	Do.	+ 3 ppm. A.F.A.	77.1
III	2.	10 ppm. Alk-ar-sulph.		56.6
	3.	Do.	+ 8 ppm. A.F.A.	45.3
IV	2.	10 ppm. Alk. sulph.		53.3
	3.	Do.	+ 8 ppm. A.F.A.	37.2
V	2.	10 ppm. Lissapol		42.6
	3.	Do.	+ 8 ppm. A.F.A.	36.6

The values in Table 1 are expressed as percentages of the original O.C. value in pure water. The decrease in O.C. due to detergent is not counteracted when foaming is suppressed by A.F.A. On the contrary, the oxygen uptake is further depressed.

When photographs were taken of the bubbles produced from the dome diffuser material it appeared that the emerging bubbles varied in size and shape (Figs. 1-5).

To simplify the conditions under which the experiments were to be made and to obtain the most uniform results, tests were now conducted with compressed nitrogen blown through a hypodermic needle with a very small orifice (0.11 mm. diameter No. 20) under an accurately adjusted back pressure of 112 cm. water column (variation 1 cm.).

The bubbles formed by the needle jet were very uniform and had always the shape of a rotating ellipsoid, which was not the case when using bigger pores as then the bubbles often have a hollow base and it becomes difficult to calculate the volume per bubble.

Flash photographs were made of these rising bubbles with an electronic flash apparatus (Blaupunkt-Reporter) which has a flash time of only 1/5,000 second. On the negative material (Kodak PX film) the image is concentrated on the emulsion surface, so that a developing time of 12 minutes at 18°C. was chosen. Negatives were obtained at uniform density, which is of importance when measuring bubble dimensions. The bubble size was determined by using a special micro projection lens on a 5 × 5 cm. slide projector, which gave an enlargement of about 15 times. Thus it was possible to determine the size of the bubbles accurately as a centimetre scale in the bubble track was photographed at the same time (Figs. 6 and 7).

It was also necessary to measure the number of bubbles ascending in a known height of column and their velocity of ascent. The number in a layer of, say, 1 cm., could easily be determined by counting, if care was taken not to produce too many bubbles. The velocity was obtained by making a time exposure of 1/10 second while the bubble track was illuminated by photoflood lamps (Figs. 8 and 9). The exact exposure was verified by photographing two small electric bulbs adjusted on a synchrome motor which rotated accurately at 100 r.p.m. This exposure was 0.954 second with the twin-lens 6 × 6 camera used.

From these data it was possible to calculate the total bubble volume. A check on the calculation was obtainable by collecting all the bubbles with a funnel at the surface discharging into an inverted water-filled measuring jar suspended over it.

Since it is necessary to control the conditions of the experiment carefully when studying the behaviour of the bubbles in water, care was taken to establish equilibrium between the bubble nitrogen atmosphere and the dissolved gas. Nitrogen was therefore blown through the already de-aerated water for one hour before starting so that equilibrium had been established between the bubbles and the dissolved nitrogen.

When we wish to study the solution of pure oxygen in water which has been de-oxygenated with nitrogen the photographic method cannot be used, as although the oxygen dissolves into the water from the bubble, it is not in equilibrium with the dissolved gases already in the water.

In total, about 4,000 bubbles were measured and their volumes calculated. The results are given in Table 2.

TABLE 2

INFLUENCE OF DETERGENTS ON BUBBLES OF NITROGEN RISING IN TAP WATER

Conc'n.	Bubble vol. in cm³.	No. in layer of 1 cm.	*v* in cm. per minute	Vol. per minute	% recovered
I	Na-alkyl sulphate				
0 ppm.	0.01575	1.182	1983	36.91	98.4
10	0.01685	1.238	1791	37.36	99.6
20	0.01683	1.137	1935	37.07	98.9
53.7	0.01682	1.184	1779	35.43	94.5
II	Na-dodecyl benzenesulphonate				
0 ppm.	0.01500	1.495	1613	36.17	96.4
10	0.01570	1.323	1716	35.64	95.0
20	0.01510	1.291	1780	34.70	92.5
53.7	0.01640	1.296	1705	36.24	96.6
III	Non-ionic detergent (Lissapol N)				
0 ppm.	0.01606	1.196	1881	36.13	93.6
10	0.01535	1.182	1793	32.53	86.7
20	0.01690	1.250	1797	37.96	101.2
53.7	0.01820	1.234	1781	39.99	106.6

From these figures we see firstly that the accuracy is sufficiently good. Secondly, we may conclude that with the concentrations and bubble sizes used there is no striking influence on the bubble volume, their number, or their speed of ascent. A closer analysis of the photographs obtained—Figs. 1, 2, 3, 4, 6, 7, 8 and 9—however, shows distinct differences. The first remarkable fact is that the greater the detergent concentration the more rectilinear the ascent of the gas. The bubble "waggles" less and this will undoubtedly influence the dissolving of the oxygen. The boundary layer is much more rigid and this is proved by the changed ratio between the measurements of the long and short axes of the bubbles given in Table 3.

TABLE 3

AVERAGE LONG AND SHORT AXES (IN CMS.) OF NITROGEN BUBBLES IN WATER, WITH AND WITHOUT DETERGENTS

A.	Pure water	0.3977 by 0.1882
	10 ppm. sec. alkyl sulphate	0.3517 by 0.2579
B.	Pure water	0.3747 by 0.2446
	10 ppm. alkylarylsulphonate	0.3589 by 0.2594
C.	Pure water	0.4220 by 0.1985
	10 ppm. Lissapol N.	0.3453 by 0.2509

These measures were taken directly after their blanks, and although these blanks varied somewhat, the addition of detergents in all cases resulted in a more spherical shape. There was no essential difference in this effect at the bottom and at the top of the aeration column, although in the long run the detergents which are brought to the surface with the bubbles may accumulate there.

The picture we obtain from the foregoing is that the detergent molecules in the water close in on the bubbles, covering part of their surface. These bubbles rise in that condition to the surface with a considerably decreased capacity for oxygenating the water. If one could remove the surrounding detergent molecules, so that a clean bubble surface could be formed again, the oxygenation capacity could be restored. The Kessener brush aeration system appears to offer such a possibility.

The Kessener brush provides an aeration system in which the water is constantly agitated by rotating elements which are fixed on an axle. The diameter of the brush was originally 32 cm., later 36 or 42 cm.; and nowadays even 50 cm. diameter brushes are produced. The original shape of the stainless steel combs may also be improved and the speed of rotation increased so that systems of aerating water or sewage at much higher intensities become possible, implying smaller aeration tanks. Aeration with rotating elements may find more application in the future than up to now.

There was at our disposal an experimental tank of about 2.5 cubic metres capacity with a brush one metre in length, adjusted above the deeper end of the tank (Fig. 11). With a bristle diameter of 42 cm., rotating at 120 r.p.m. under normal conditions the O.C. of this system was 600 grams oxygen per hour per metre of brush.

When we added 2½, 4 or 10 p.p.m. detergents to the tapwater in the tank the O.C. increased considerably, and about twice the quantity of oxygen was being dissolved at 10 p.p.m.

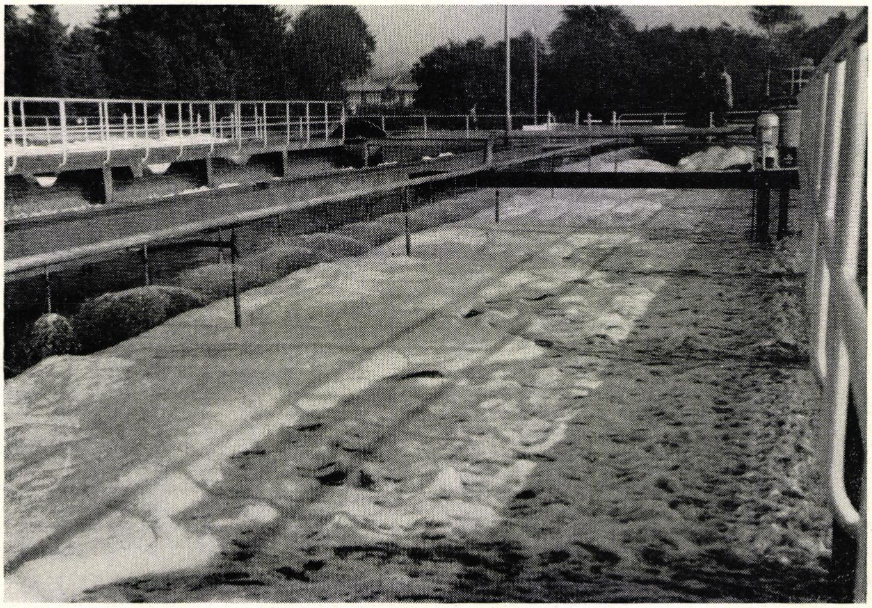

Fig. 10. Kessener Brush Aeration Purification Plant at Hilversum.

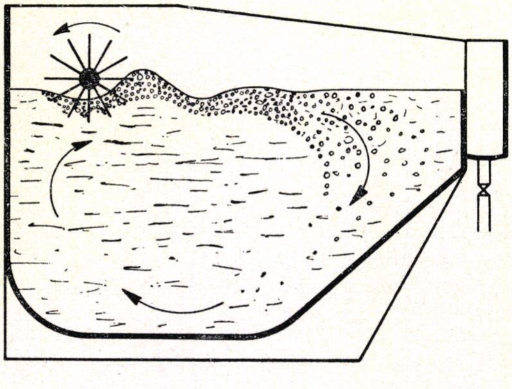

Fig. 11. Experimental Tank with Kessener Brush.

TABLE 4

INFLUENCE OF DETERGENTS ON THE O.C. IN BRUSH AERATION

Conc'n. ppm.	O.C. obtained in test series				
	I	II	III	IV	V
0	600	599	600	603	610
1	653				
2½	830	809	689	716	933
4	850	893	795	824	1170
10	1093	1115	1043	1143	1544

Series	
I	Na-alkyl sulphate.
II	Na-alkylarylsulphonate.
III	Lissapol N.
IV	New batch of Na-alkylarylsulphonate.
V	New batch of Na-alkyl sulphate.

The mixture air/water, which is formed when the combs of the brush are forced through the water, is much finer, and at some distance from the brush a "wall of foam" is formed, which in the case of 4 p.p.m. detergent, may be kept at that distance by the drops spraying from the brush. If the concentration of the detergent is increased to 10 p.p.m. the whole surface of the tank may become covered with foam, partly due to the special shape of the aeration tank. It is also to be noted that the energy consumption of the brush increases slightly when detergents are added.

The conditions under which bubbles are produced by a rotating brush are quite different from those where the bubbles emerge from an orifice into water. Diffused-air bubbles produced in this way are constant in volume, and the influence of the detergents begins when the bubble begins to rise and continues throughout its rise.

On the other hand, turbulence around the teeth of the rotating brush forms the bubbles in that instance and, as the liquid is vigorously agitated under the brush, surface layers are stripped from the bubbles and the renewal of the surface is very intense.

It is also known that anti-foaming agents may prevent foam formation in diffused-air systems, and a test was made to see whether this would also be the case for rotating brush aeration. A quantity of detergent was first added to the tank contents and the O.C. determined. A dose of anti-foaming agent was then added. With the Na-alkylarylsulphonate it was found that the O.C. of the system reverted back to its original value of about 600. The Na-alkyl sulphate was influenced much less by such an addition, and the Lissapol N was not influenced at all, as will be seen from Table 5.

TABLE 5

INFLUENCE OF DETERGENTS AND A.F.A. ON THE O.C. OF ROTATING BRUSH AERATION

		O.C.
I	Na-alkylarylsulphonate (new batch)	
	Blank	600
	2½ ppm. detergent	716
	2½ ppm. detergent + 2 ppm. A.F.A. ..	647
	10 ppm. detergent	1143
	10 ppm. detergent + 8 ppm. A.F.A. ..	617
II	Na-alkyl sulphate (new batch)	
	Blank	600
	2½ ppm. detergent	933
	2½ ppm. detergent + 2 ppm. A.F.A. ..	818
III	Lissapol N	
	Blank	600
	10 ppm. detergent	1043
	10 ppm. detergent + 8 ppm. A.F.A. ..	1021
IV	Anti-foaming agent	
	Blank	600
	2 ppm. of A.F.A.	580

Investigations on the interesting behaviour of this anti-foaming agent will be continued.

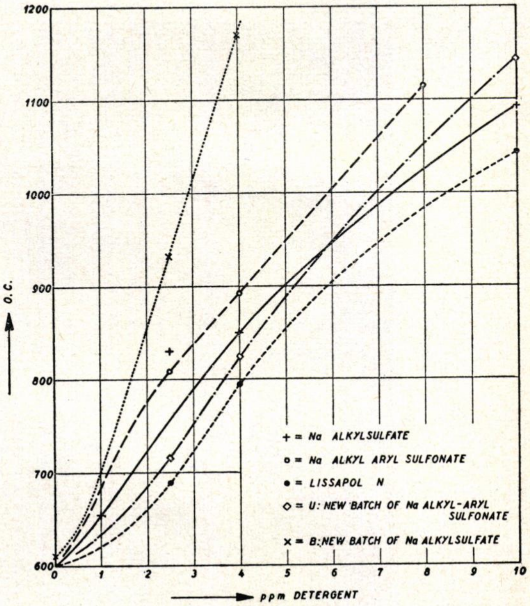

Fig. 12. Influence of detergents on the O.C. in brush aeration.

CONCLUSIONS

The influence of detergents on aeration systems was examined photographically. By making electron-flash pictures of 1/5,000 sec. exposure time, the size of the bubbles could be measured and their shape determined. From a determination of their speed of ascent and their number, the total volume of gas could be calculated. As these experiments were done with nitrogen gas in equilibrium with the water, the total volume could be checked by collecting the gas at the top of the aeration column. The agreement was quite satisfactory. The photographs showed that the size of the bubbles did not alter but that their shape became more spherical. At the same time the path of ascent became more rectilinear. The conclusion was that a surface layer around the bubble forms and exists throughout the whole rise, thus decreasing the oxygenation of the water considerably (50 per cent).

On the other hand, a very effective increase of the oxygenation could be obtained if an aeration system was used in which the renewal of the surface of the bubble is an optimum, namely, with a rotating brush system. With 10 p.p.m. of detergents an O.C. of nearly twice the original value could be obtained. Finally, the question was considered whether the decrease in O.C. for a diffused-air system could be corrected by an anti-foaming agent. It appeared not to be possible. Results were even slightly worse.

With the rotating brush the effect of the Na-alkylarylsulphonate could be neutralised by the anti-foaming agent, the original value of the O.C. being obtained again. The effect on Na-alkyl sulphate was much less, while for a non-ionic detergent no effect could be detected ; the foaming was not influenced and the O.C. remained at about 1,000 grams per hour per metre of brush instead of the original 600.

The consequences of the foregoing for the purification of sewage which contains detergents may be that for diffused-air systems, any action at the surface of the aeration tank cannot improve the dissolving of the oxygen, while anti-foaming agents which are added to the tank contents do not correct the decreased O.C. Only the mechanical trouble of foam formation may be suppressed. The dissolving of the oxygen has decreased and remains low, so the only remedy against an insufficiently purified effluent is a more intensive or longer aeration at greater cost.

For systems which use a rotating brush, the oxygen supply to the activated sludge floc is improved, but if foam formation should require a remedy anti-foaming agent should be avoided if possible as it counteracts the favourable effect of the detergent on the oxygenation. In the Hilversum plant, which uses Kessener brushes, the simple spraying of the side of the tank with sewage through Dresdener sprayers, opposite the brush (see Fig. 10), provided adequate foam control, the effluent being as completely purified (95%) as formerly.

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Fig. 1.
0 p.p.m. Detergent.

Fig. 2.
2.5 p.p.m. Detergent.

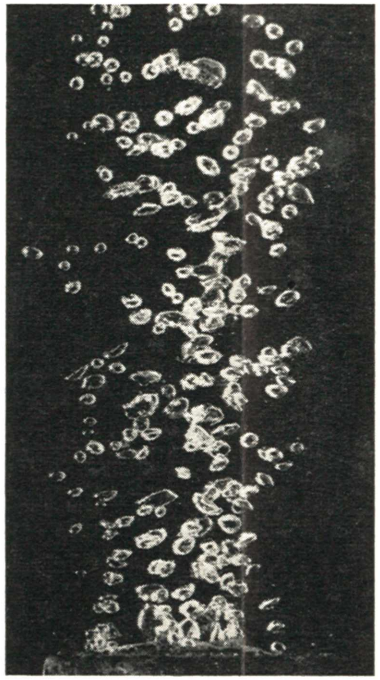

Fig. 3.
4 p.p.m. Detergent.

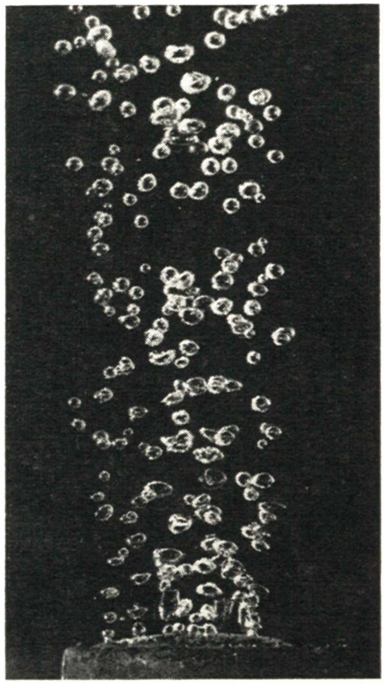

Fig. 4.
10 p.p.m. Detergent.

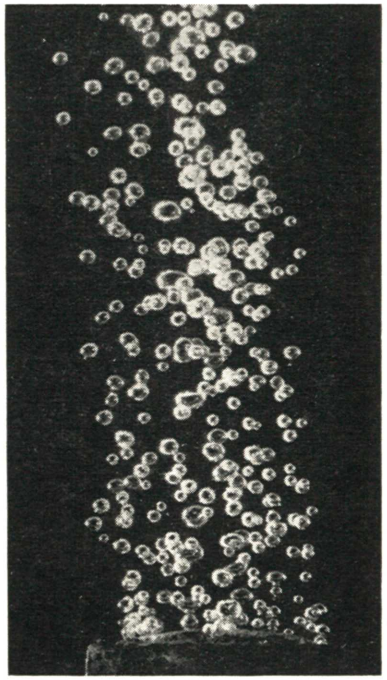

Fig. 5.
100 p.p.m. Detergent.

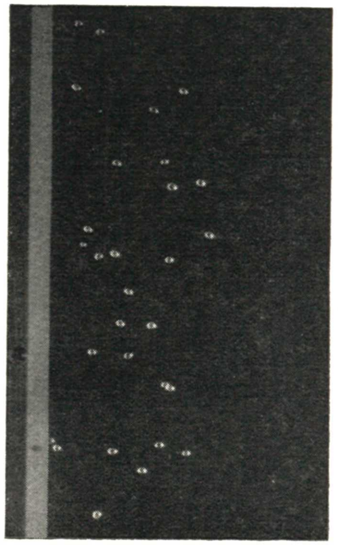

Fig. 6.
Nitrogen Bubbles in Tap water 1/5000 sec. Exposure.

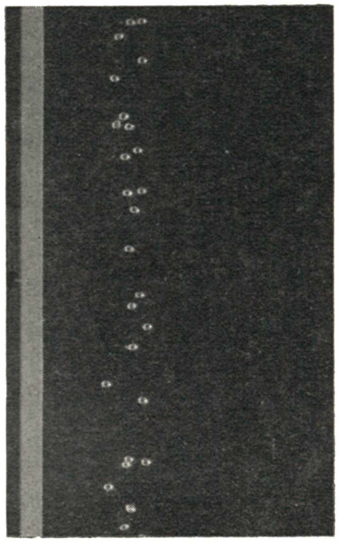

Fig. 7.
Nitrogen Bubbles in Tap water plus 4 p.p.m. Teepol 1/5000 sec. Exposure.

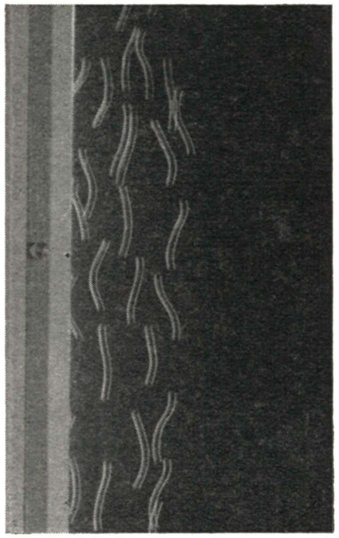

Fig. 8.
Nitrogen Bubbles in Tap water 1/10 sec. Exposure.

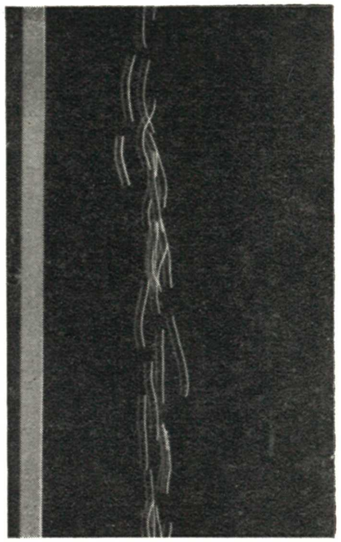

Fig. 9.
Nitrogen Bubbles in Tap water plus 4 p.p.m. Teepol 1/10 sec. Exposure.