THE INFESTATION OF WATERWORKS BY *DREISSENSIA POLYMORPHA*, A FRESH WATER MUSSEL

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CONTENTS

SYNOPSIS

The nature of the infestation of waterworks by *Dreissensia polymorpha* Pallas, and the appearance and habits of this mussel, are described. A method of determining the age of mussels is put forward, and agrees with other published data on the matter.

The experience of a number of waterworks with mussels is summarized. Details are given of how such an outbreak was dealt with at Great Yarmouth, good results being reported from the use of 50 p.p.m. of flowing chlorine for removal of growths, while 2 p.p.m. prechlorination has kept a main free from further infestation for over four years.

In conclusion, various methods that have been put forward for the control of mussel infestation are discussed.

1. INTRODUCTION

Fortunately, trouble with *Dreissensia polymorpha* in British waterworks is rare, but its rarity makes it no less serious for any engineer confronted with it.

The presence of mussels in a raw water main is usually revealed by the discharge of shells and a noticeable increase in head loss.

The mussel is dark brown or black in colour, and often has a very pretty arrangement of brown and fawn stripes; hence its name of Zebra Mussel (Fig. 1, Plate 1). It attaches itself to firm objects by up to 200 tough elastic fibres of a dark horny material (the byssus), and usually leads a sessile existence. Frequently the mussels fix these byssal threads to other mussels, thus forming clusters in open water, and layers of up to a foot or more on the walls of pipes.

One of the most startling facts about *Dreissensia polymorpha* is the way it overran Europe in a hundred years. It was first reported in Europe by Grossinger (1794)* who met it in the Danube in Hungary in 1790. In 1824 it was found almost simultaneously in North Germany and in the London Docks, and within the next 20 years it had colonized many of our east coast rivers, as well as the Clyde and Mersey. Abroad it had found its way into Denmark, Holland, and France, as well as the river systems of Germany. Its colonization of Lake Balaton in Hungary has been described by Sebestyén (1934, 1935) and by Wagner (1936) and is typical both in its rapidity and extent. It was presumably brought there by boats or nets from the Danube; and by the summer of 1933 only 10 specimens had been collected. Two years later Wagner estimated between 20,000 and 30,000 per square yard.

2. THE LIFE HISTORY AND HABITS OF *DREISSENSIA POLYMORPHA*

In its anatomy the mussel resembles better known lamellibranchs, but two points should be stressed here. The incurrent siphon of the mussel is very sensitive to changes in the chemical nature of the water, so that long before a lethal dose can reach it the mussel has closed and can remain closed for over a week without ill-effects. Secondly, the mussel can withstand long periods without food, keeping a constant store in the intestine in the form of the crystalline style.

The reproduction of *Dreissensia polymorpha* was studied by Korschelt and by Weltner (1891), who showed that it differed from other fresh-water mussels in producing a free-swimming larval stage from eggs fertilized outside the body. The eggs are small and are ejected from the mussel in tiny balls of mucus. Korschelt observed that the larvae develop quickly from these eggs, being about 0·18 mm. across, and looking rather like a rotifer because of their ciliated organ, the velum. They swim with this velum upward near the surface of the water, but retract the velum and sink at the slightest disturbance. The first signs of the shell may be noticed during this period. The length of the free-swimming period is about a week, and at the end of it a rudimentary foot may be noticed. The larvae now live on the bottom and crawl about vigorously using this foot.

It seems that what Korschelt observed in open still water is rather different from what happens in a pipe where the water is flowing. From the evidence of the distribution of growths in a water main and the tank into which it discharges, it would appear that the eggs become entangled in the growths on the pipe and that when they are born, the larvae do not embark into the current but remain in the sheltered water among the grown mussels. A few are carried away to attach themselves when the current slackens, but the majority attach themselves to the older mussels. It seems difficult to imagine

* An alphabetical list of references is given on p. 378.

that they can swim against the current, but after the larval stage is past they are capable of crawling at speeds of 4 cm. per hour and over.

The foot, after this first period of rapid growth, ceases to grow further, and by the end of the season of its birth the mussel has attached itself by byssal threads. Moreover, by the end of this first season the shell, which was originally almost circular, has taken on its typical shape.

Dreissensia attaches itself to almost any firm object, including reeds and the other fresh water mussels *Anodonta* and *Unio*. The threads are at first white with a slight base plate, and about 12 per day can be put down by an adult mussel. These slowly turn brown and probably shrink slightly. In open tanks and in lakes the mussels avoid the top 3 ft. so that their presence is rather difficult to detect.

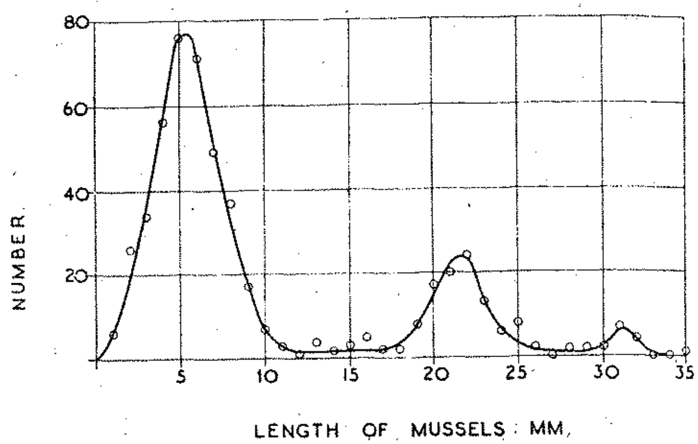

Fig. 2

The food of this mussel has never formed the subject of research, but Frenzel (1897) has stated that they feed on sub-microscopic silt of vegetable origin, and they have been seen to reject extremely small diatoms. They can live for very long periods of apparent starvation. A number of specimens were placed in water which had passed through primary and secondary sand filters and had a residual of 0·3 p.p.m. chloramine. This was in the autumn, and the jar was placed in a dark corner and forgotten until it was needed 18 months later. It was then found that three-quarters of the water had evaporated. Several of the mussels were placed in tap water and all so treated were found to be alive.

It has been stated by several authors that *Dreissensia* prefer clean, lightly moving water with a firm bottom, and Wilhelmi (1923) has amplified this statement by giving chemical analyses, although his results are not strictly comparable with those obtained from current British analyses.

Wilhelmi also recognized the need for some method of determining the age of mussels before a logical explanation of their activities could be attempted. He instituted research into a system of "year rings," but the results were apparently not published. The author measured the length of 500 mussels found in a raw water main where they had lived undisturbed. The number in each millimeter length was then plotted (Fig. 2) and each age group showed as a typical biometric curve. From this it could be concluded that during their first year the mussels reach an average length of 5·5 mm., and in their second year 22 mm. The third year length seems to be 31 mm., but beyond this the method cannot be easily applied. It will be appreciated that this is only a rough method and results from actual observations on growing mussels will be available in a few years. The lengths given above agree with Wesenberg-Lund (1939), who states that they reach a length of 5 to 10 mm. during their first year.

3. TROUBLES CAUSED BY THE MUSSEL IN WATERWORKS

The earliest, and perhaps the most sensational, record of trouble with *Dreissensia polymorpha* in waterworks was that at Hamburg by Kraepelin (1886). Hamburg supplied Elbe water direct into the distribution system without treatment, and left it to the consumers to carry out any filtration they might desire. The result was that a typical "pipe community" developed in the distribution mains, which besides *Dreissensia* contained *Spongilla*, *Cordylophora*, *Bryozoa*, *Bythinia*, and *Asellus*. A list of 60 species was given by Kraepelin. One of the greatest worries was blockage by them of house services. After the institution of slow sand filtration the growths gradually disappeared from the mains.

Rotterdam has experienced trouble with them since 1887, when De Vries (1890) noticed *Dreissensia* growing in the covered canals of the raw water system. The fauna and flora were similar to those in Hamburg but there was a preponderance of *Crenothrix*, which grew over everything and had been the cause of the investigations. De Vries noted that as the canals went farther from the sedimentation basins, the mussels decreased in numbers and the sponges were smaller. Although he found *Gammarus* and *Asellus* on the downstream side of the slow sand filters, he stressed that there were no signs of mussels, sponges, or Bryozoa. The director of the Drinkwaterleiding der Gemeente Rotterdam informs the author that at the present time the raw water system has to be cleaned three times during the summer months to prevent tastes and odours caused by the death and decay of the organisms lining the walls. He mentions that since the primary filters were installed in 1931, growth does not take place downstream of these.

In November 1895 a putrid taste was noticed in the water of the northern and western districts of Berlin. Samples gave high counts of bacteria and indicated that the cause must be decaying animal flesh at the Tegel works. Careful examination of the works showed th suction mains from the lake to be occupied by hundreds of thousand of mussels. The works had been shut down for 27 days previous to the outbreak, causing the death and decay of the mussels due to lack of oxygen. The trouble was eliminated by scraping the pipes, and the works went over to deep well water in 1901 so that no more trouble was experienced.

At the Müggelsee works of Berlin, the raw water suction pipes were examined and found to be in a similar condition. They were therefore scraped each time the works shut down. The layer of mussels there was about 10 cm. thick.

Stilgoe (1925, 1930) gave a short account of troubles experienced by the Metropolitan Water Board and mentioned that they had had a 36-in. diameter main reduced to 12 in. The presence of mussels and algal troubles influenced the siting of new primary filtration plant, which was placed as near to the source of raw water as possible. Since that date chlorination has been used most effectively agains the mussels, their destruction having been incidental to the Board's system of prechlorination.

At Great Yarmouth raw water is pumped from the river Bure through 9 miles of 24-in. diameter main into an open sedimentation reservoir of 20 m.g. capacity. From this reservoir, water is draw by pumps through ½ mile of 24-in. diameter main and delivered o to rapid gravity filters.

For nearly 40 years the works had operated without any troubl whatsoever resulting from biological growths either in the main or reservoir. In 1944, however, the 24-in. diameter main from th reservoir was found to contain a layer of mussels averaging 5 in. thic at the reservoir outlet, decreasing to negligible numbers 400 yard distant. The main was divided into nine sections, scraped an brushed, and the cut lengths of pipe replaced, using Johnson couplin to facilitate subsequent maintenance.

When the loss of head through this main showed a considerab increase in May 1947, the pipe was again inspected and was foun to be in a rather worse state than it had been in 1944 (Fig. 3, Plate 1 As an experiment, a length was blanked off and filled with Voxs to give 50 p.p.m. of chlorine. This was left standing for three day when it was found that, although most of the mussels were dea scraping would still be required to remove them. The scrapin proved difficult, there being such a quantity of mussels that a scoo had to be dragged into the masses and then reversed out, usin winches. On this occasion, 20 cu. yd. of mussels were remov from approximately 300 yd. of 24-in. diameter main. Before bei put back into service, the main was filled with 20 p.p.m. of chlori and allowed to stand for 7 days prior to flushing.

Inspection of the raw water pumping main between the river a the sedimentation reservoir revealed that at one point half a mile fr the source there were about 150 mussels per linear yard, with sm growths of spongilla. The work of scraping this 9-mile long m

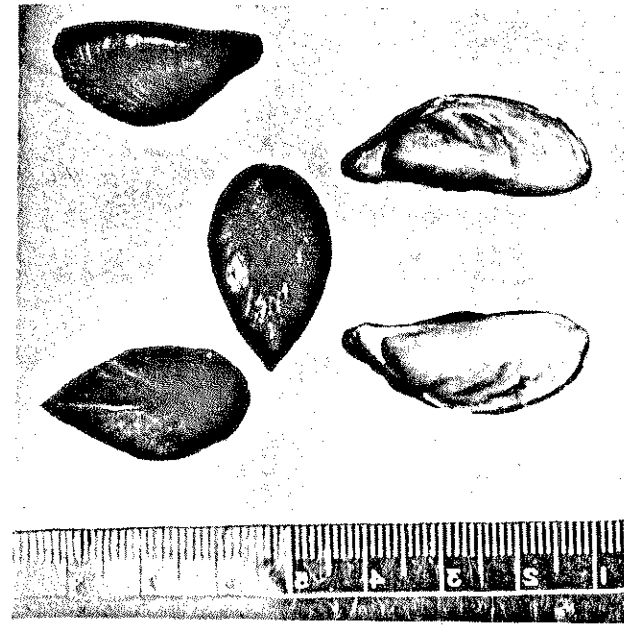

Fig. 1. *Dreissensia polymorpha Pallas*

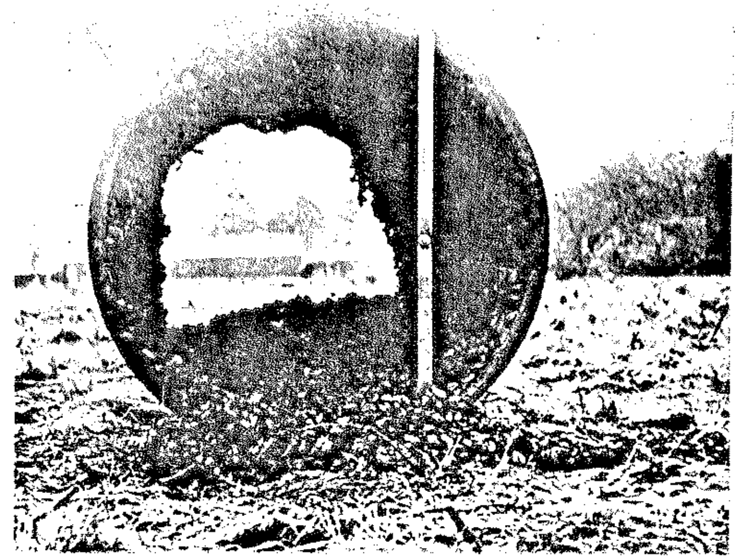

Fig. 3. 24-in. diameter reservoir outlet main in 1947, before scraping

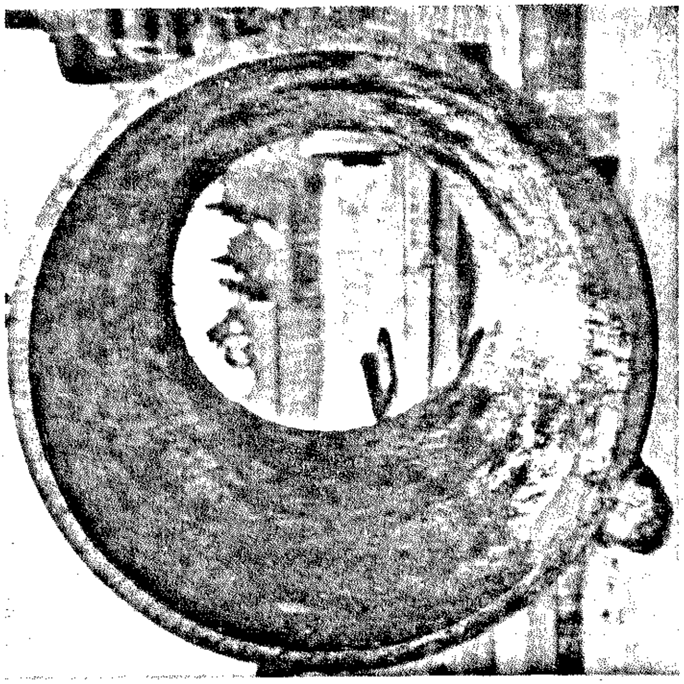

Fig. 5. The same main in March 1952

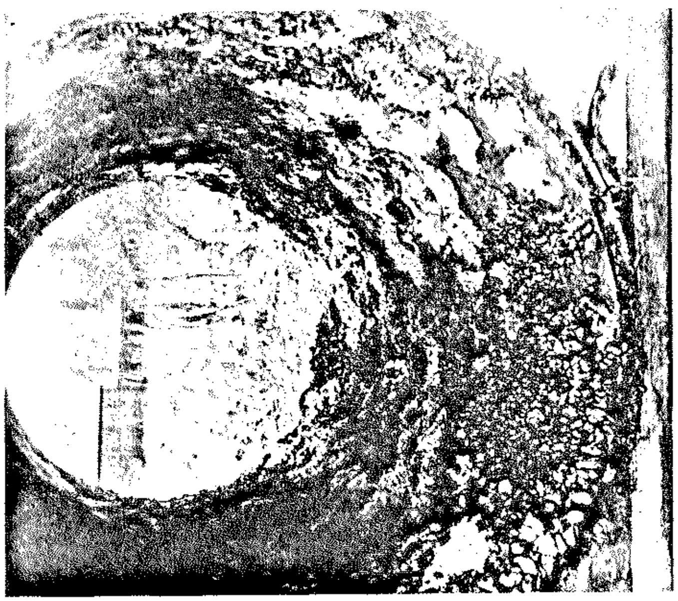

Fig. 4. The same main as shown in Fig. 3, Plate 1, before treatment in January 1950. The white patches are sponges

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presented so formidable a task that the engineer was obliged to consider the possibility of treatment by chlorine. In this matter he was advised by Dr. R. C. Hoather, who also kept a close watch on the treatment of the main. It was believed that, providing the existing growths could be destroyed, the shells would, in the course of time, be carried along the main into the reservoir and prechlorination of the supply at the source would prevent reinfestation by destroying the larvae.

Accordingly the entire length of this pumping main was charged from the source with water dosed with 20 p.p.m. of chlorine, a residual of not more than 7 p.p.m. being obtained at the reservoir end after 3 days. After 7 days contact, the main was flushed to waste at the rate of 200,000 g.p.h. with water containing 3 p.p.m. of chlorine (subsequently reduced to 2·5 p.p.m.) until the discharge of mussel and sponge growths ceased.

Twenty-two days after beginning the treatment the main was again brought into service, a continuous dose of 2 p.p.m. being applied to destroy any mussels which had survived and any mussel larvae entering the system from the river.

Two years later, this main was chlorinated again to give a residual of 20 p.p.m. and was left shut for 10 days. When it was flushed, no mussels were washed out and inspection of the interior of the main at each end of the line has since revealed that it is now entirely free of all growth, thus showing the effectiveness of chlorine treatment for this purpose.

The sedimentation reservoir was cleaned at intervals of about two years, at the same time as the outlet main therefrom, and great pains were taken to destroy all the mussels. Most of them could be scraped off, but the brickwork was carefully examined for small mussels and was brushed down with water containing 50 p.p.m. of chlorine. The floor was covered with 3 in. of heavily chlorinated water for 3 days. Despite these precautions there is evidence that some mussels survived, and this is hardly to be wondered at when it is remembered that 8 acres had to be searched for a camouflaged animal, perhaps only 1 or 2 mm. long.

In 1948 the 24-in. diameter raw water main from the reservoir to the treatment works was cleaned for the first time by chlorine, using a portable gas chlorinator. A dose of 33 p.p.m. was injected at the reservoir outlet and continued until a residual of 20 p.p.m. was observed at a 12-in. washout ½ mile distant. The main was left closed with this dose for 13 days, only 1 p.p.m. being detected at the end of this period when the main was flushed out and put back into service.

In January 1950, examination of this main showed that there were several hundred mussels per yard at the reservoir end, and the size of these suggested that they had survived the chlorine treatment ucted out in 1948 (Fig. 4, Plate 2). The main was accordingly dosed with 50 p.p.m. of chlorine until 40 p.p.m. appeared at the drain. It was then shut down for 9 days, but at the end of this period living mussels were still to be found on the section of main removed for inspection. It was decided to repeat the treatment immediately, fresh chlorine being introduced at 50 p.p.m. and the main left with this dose in it for a further 7 days. It was subsequently proved that this treatment was not 100 per cent. effective.

During the autumn of 1950 the main was chlorinated again, this time using a new technique. Chlorine was injected at the drain end and allowed to trickle the entire length of the main and through the outlets into the empty reservoir. A continous flow of water containing 50 p.p.m. was kept up for 13 days and flushing of the main produced excellent results, mussels being discharged in their shells in large numbers. After flushing, the main was given the same treatment for a further 6 days and a second flushing brought out only a few mussels, but a great number of sponges up to 2 in. diameter.

In March 1952 the inspection pipe had only four mussels living on it and was clear of any trace of the usual pipe community (Fig. 5, Plate 2). These mussels were older than the previous chlorination and are assumed to have come in from the reservoir.

Naturally, trouble from mussels is not confined to water supply undertakings but may affect any users of water. Wilhelmi (1922) has described troubles at the hydro-electric station Glambocksee at Stolp in North Germany. In June 1921 the station had to shut down due to great loss of head in the tunnels and open channels of the headrace. These were found to be covered with a layer of mussels 30 cm. thick, and in the open channels there were barriers of mussels up to 1·5 m. high. The mussels were removed by scraping, although Wilhelmi was anxious to experiment with chlorine. He considered the whole question of removal of mussels and published several useful papers on the subject. The methods which he suggested are commented upon below in the light of experience.

4. METHODS OF CONTROL

(a) Removal of Existing Growths

Scraping. The most obvious method of removing mussels from mains and tanks is to scrape them off. Like other methods, it means that the main cannot be in service during the treatment and the time factor often governs the choice of method. Scraping has the drawbacks of being both very slow and expensive; but the greatest drawback is that it cannot be expected to remove every mussel from the main. It must thus be carried out every few years with no prospect of an end. A main which was scraped at Great Yarmouth was as bad again within three years. For reservoirs and tanks, other methods are often impossible to apply, but scraping offers much better prospects here as the walls can be searched for the last individual.

Drying out. This method has been regarded by earlier workers as being of doubtful value because they had no idea of the time such a method would take, and also they observed in the laboratory that many mussels followed the water surface down. The author's observations, however, give some hope for the method. In practice, the mussels are prevented from going down to the invert by the hold which other members of the community have on them, and where suction mains are involved, these are usually laid to a fall which drains the invert completely. When the mussels find themselves without water, they close up and can live for 14 days in air of 100 per cent. relative humidity. In the open air the mussel loses water quickly and death occurs within 7 days, the mussel then being full of air and the substratum of sponges and cordylophora being friable so that the mussels come away easily from the pipe. It would seem, then, that if this method is adopted there should be adequate ventilation of the pipe, possibly with the type of blower used in relining water mains *in situ.*

Chlorine. When Wilhelmi first suggested using chlorine for removal of mussels, he showed that mussels over 5 mm. in length could resist concentrations of 50 p.p.m. for 1 hour. Work at Yarmouth shows that they can do so for 9 days, although during this period there was a marked fall in the residual. Much better results are achieved when the chlorinated water is in motion. Why this should be so is still being investigated. Continuous dosing with 50 p.p.m. flowing slowly through the main for upwards of two weeks has shown itself to be a reliable method of removal.

Depriving of oxygen. Mussels are adversely affected by waters low in dissolved oxygen content and early workers do not seem to have abandoned the idea of controlling them by this means, even after very disappointing experimental results. A main was taken out of service and kept under deteriorating conditions at Great Yarmouth for four weeks, and at the end of this period many mussels were still alive, although the oxygen content of the water was only 0·8 p.p.m. (i.e. about 7 per cent saturation). It seems, therefore, that closing down a main for long periods can only kill some of the mussels, the dead ones being held in place by their more fortunate neighbours and their bodies giving rise to serious taste troubles, as happened at Berlin.

Other methods. Biological enemies seem rare and up to now only the waterhen (*Fulica atra* L.) has been proved to prey upon them. Many of the methods which have been put forward have not yet been tried in practice. They include adjustment of the *p*H value, increasing the salinity up to 1 per cent, using sodium hypochlorite in place of chlorine, and passing sewage through the infested mains; this last method is not likely to be applied by water engineers.

(b) Prevention of Infestation

Filtration. There is ample evidence that the larvae are held back by both rapid and slow sand filtration, but they do seem able to develop and live for a while in filtered water.

Fine sieves were suggested by Wilhelmi and by Roch as a means of keeping back the larvae. When they wrote, in 1923 and 1924, they could not extend much hope for this method, stating that although the larvae were 0·185 mm. across, the smallest mesh which could be used without causing excessive obstruction to flow was 0·5 mm. Since that time, microstraining fabrics with an aperture of 0·038 mm. have come into regular use and the method is now a practical possibility.

Chlorination. Prechlorination has been found effective by the Metropolitan Water Board; and at Great Yarmouth a 24-in. diameter main carrying raw water for 9 miles has been kept free of growth for 4 years and has apparently prevented pipes downstream becoming reinfested from the river. The dose used in this case was such as to leave no residual at the downstream end, usually 1½ to 2 p.p.m. It should be mentioned, however, that Wilhelmi found larvae still alive after being in 10 p.p.m. of chlorine for 1 hour (residual 7·5 p.p.m.).

Protective coatings. Work was done on this matter in Germany, but the best results claimed were protection for only one year against infestation, and the materials used were such as would impart an offensive taste to the water.

ACKNOWLEDGMENTS

The author wishes to thank the engineer of the Great Yarmouth Waterworks Company, Mr. S. A. S. Walton, *O.B.E.*, A.M.I.C.E., with whose help and permission this article is published, Mr. F. Wall and Mr. C. Rumbelow, upon whose records and specialized knowledge he has freely drawn, and Mr. C. Hedges and his staff at the Great Yarmouth Public Library who have scoured European publications and reference works for much of the bibliography. He is also indebted to the Directors of the Berlin and Rotterdam waterworks, and to Mr. A. van der Werff, for the information they supplied so readily.

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COMMENTS ON "SOME OBSERVATIONS ON THE CORRELATION OF CHEMICAL AND BIOLOGICAL SEQUENCES AT THE WATERWORKS AT LEEDS"

Mr. F. P. Hornby, commenting on the paper by Professor E. A. Spaul published in the last issue of the *Journal**, wrote that the method for making algal counts was of interest, as there was no standard method for making this examination in this country. It was accordingly something of a relief to find that the author had used essentially the same technique as he himself had adopted in Bristol for the last twelve years, where it had proved very satisfactory for organisms such as diatoms. He had found, however, that it was inclined to give low results for some of the blue-green algae. On occasions comparisons had been made with the Sedgwick-Rafter method, which invariably seemed to give higher figures, and he would be interested to know whether the author had had the same experience.

It had been interesting to compare the figures obtained on the Leeds reservoirs with those for Bristol, particularly as the general method of treating the water was very similar. While the Leeds reservoirs contained more organic matter and were higher in colour, the Bristol water, being alkaline, had a higher *p*H and alkalinity with more nitrates, and a phosphate figure varying from 0·03 to 0·10 p.p.m. PO_4. The silica was of the same order in both places. As might be expected, the Bristol waters were more highly productive of algae. Whereas the maximum count of *Asterionella* at Leeds appeared to be of the order of 4,000 cells per ml., numbers at Bristol had risen to 13,000 c. per ml. Incidentally, this was one of the organisms for which micro-straining had been found particularly effective, having made it possible to reduce a count of 12,000 c. per ml. to about 500 c. per ml. before the water went on to the filters.

It appeared from the paper that counts of *Asterionella* of the order of 4,000 c. per ml. had caused filtration difficulty at Leeds, and it therefore would be most interesting to know the filtration rates and lengths of run in these circumstances. Had any attempts been made

* *Journ. I.W.E.*, vol. 6, p. 277.