PRELIMINARY ANALYSIS OF THE DEGREE AND NATURE OF BACTERIAL REMOVAL IN FILTRATION PLANTS*

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THE determination of a law of bacterial removal by rapid sand water filtration plants is of great practical importance and utility. Such determinations of plant efficiencies are valuable as indicators not only of present but also of future performance. The objection is, however, often justly raised against the attempt to predict quantitatively the possibilities of bacterial removal, that existing numerical measures of performance are misleading and in some cases even harmful. The calculation of percentage removal from raw water to efficient is an illustration of the type of measure which has arithmetical accuracy, but little logical basis. It is quite evident, however, that it would be desirable to measure quantitatively the performance of a plant in such a way as to obtain a comparative conception of how well or how badly it is being operated. Since at present no agreement exists among operators, designers, or public health officials as to a standard of "good performance"—because in the past, agreement has been prevented by the interminable search for a "standard effluent," itself the subject of disagreement—it becomes necessary to attack the problem of rating or standardizing plant accomplishment from another angle. In this discussion, an initial search is made for certain basic characteristics of rapid sand filtration. The term "rapid sand filtration" is here used more broadly than usually, to describe the entire process from preliminary coagulation through sedimentation or settling, filtration, and disinfection. The measure of variable phenomena by comparison with ideal or "normal" conditions is a procedure common to scientific analysis. The application of this method offers here a fruitful means of testing our ideas of filtration efficiency. The first problem obviously consists in the attempt to determine a possible correlation between the number of bacteria in the final effluent of a filtration plant and the number in the raw water. A numerical statement of a problem should be clearer. If a plant uses a raw water containing 500 bacteria per c.c. and produces an effluent containing 10 per c.c., will the same plant produce an effluent of 20 per c.c., when the raw water content is 1,000 per c.c.? Can one predict, in other words, with any degree of precision, what effluent counts should be normally attainable with varying raw water counts?

Normal Empirical Performance

The normal or ideal performance from which it is possible to obtain hypotheses as to standard empirical accomplishment is not difficult to deduce. The "normal empirical performance" may be defined as the accomplishment of a filtration plant which is known to be operating successfully. Successful operation can be said to exist wherever there is an unquestioned superior bacteriological and physical quality of effluent, consistent performance, excellent control, and scientific observation of operating details. In this analysis, the operating statistics of the filtration plant at Avalon, Maryland, owned by the Baltimore County Water and Electric Company and operated by Mr. S. T. Powell, were used. This plant obtains its raw water from the Patapsco River, a highly polluted stream, ranging in turbidity during the year from 0 to 5,000 parts per million and in bacterial content (20° C.—gelatine—48 hours), from several hundred to 150,000 per c.c. The watershed of the stream is composed largely of cultivated areas, with no large sewage polluting influences. This water is treated with aluminium sulphate, at an average rate of 0.8 grain per gallon, and is then allowed to settle for four hours. After leaving the sedimentation basin it is treated with calcium hypochlorite with an average dose of 0.34 parts per million, and then passes through the rapid sand filters which have a capacity of 2.5 million gallons per day. The plant is controlled scientifically by a trained operator with the aid of modern equipment and laboratory observation. During several years of operation the bacterial content of the effluent has not exceeded, at any time, 20 bacteria per c.c. Presumptive tests for B. coli in lactose broth have indicated positive tests in 1 c.c. less than 2 per cent. of the time during any year. The number and kinds of bacteria are determined in raw water and final effluent every day and general experimental data are constantly collected. It is clear, therefore, that the plant in Baltimore County approaches so closely, from the standpoint of operating results, the ideal plant as to justify the use of its performance as the basis of a law of filtration.

In order to determine with some degree of accuracy the form of a characteristic empirical performance curve, the results of raw water and final effluent counts of the Avalon plant were plotted. In order to avoid plotting, a mass of points which would tend to confuse seven-day averages of both stations, rather than daily results extending over a period of nineteen months in 1915, 1916 and 1917, were used. In plotting these values, approximately 520 daily analyses were summarized. These were obtained in consecutive months and under every phase of operating conditions. No counts were discarded as being unfair or incorrect.

The equation of a straight line, when the results have been plotted on a logarithmic basis, *viz.*, given by:

$$C = \frac{\log y}{\log x},$$

where C is a constant for this particular plant, and y and x are respectively the raw water and final effluent counts. It would appear, therefore, that the "normal empirical performance" is represented by a curve having the equation

$$C = \frac{\log y}{\log x} \text{ or } y = x^{c}.$$

A tentative hypothesis, with regard to bacterial removal by filtration action, may be promulgated, therefore, as follows: "The final effluent count, under normal operating conditions, is an exponential function of the raw water count." This hypothesis provides a means of determining whether or not a plant under scrutiny is, at least, "performing normally," where normal performance would be interpreted as conformity to the logarithmic curve of filtration.

A Fallacious Assumption

The "normal performance" curve demonstrates the fallacy of assuming that the difficulty of removal of bacteria is relatively the same regardless of the number of bacteria in the raw water. Although this assumption is rarely publicly proclaimed, it is usually summoned, however, to the aid of those plants which, for one reason or another, are so unsuccessful as to require a specious hypothesis, fairly reasonable to the layman, to support their claims to maximum efficiency of 99 per cent. plus. The practical results of a scientifically controlled plant certainly seem to lead to the conclusion that increases in raw water bacterial content decrease the corresponding

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