

Chemical Changes Effected.—The free ammonia is usually reduced 75% to 90% and in many cases this ammonia is found as nitrates in the effluent. The nitrates do not invariably increase as it has been found that when the free ammonia content of the raw water is very low an actual reduction in the nitrate content has taken place. The albuminoid ammonia and the organic matter generally as estimated by the oxygen absorbed method are also materially reduced, but not so effectively as the free ammonia. The soluble mineral constituents remain unchanged except in cases where waters containing noticeable amounts of free carbonic acid gas are filtered through sand containing limestone or dolomite; then the water is hardened a little by the bicarbonates of lime or magnesium taken into solution, but as this is accompanied by a reduction in the corrosive properties, due to removal of free carbonic acid, the sum total of the qualities of the water is unchanged.

The chemical changes are not themselves important, as there is no evidence that they affect the hygienic properties of the water in the slightest degree, but inasmuch as they are coincident with certain bacteriological conditions it is important that they should remain normal.

Bacterial Purification.—It is now generally acknowledged that the zoogaea or gelatinous films covering the sand particles are responsible for the reduction in bacterial content of the water supplied to a filter. The microscopic particles present are carried down by the velocity of the water and if the momentum of the particle (MV) is greater than the adhesive forces of the film upon which it impinges, the particle is carried forward. Dr. Kemna (Trans. Assoc. Water Eng., 1907, p. 330) considers that the reduction of bacterial content in gravel strainers is independent of the speed of percolation and concludes that the product MV is infinitesimally small compared to the adhesive forces prevailing. However true this may be for the coarse gravel strainers of the Puesch-Chabal process the experience with fine sand filters is that the diminution of bacteria decreases with an increase in the rate of filtration.

Some of the earliest experiments dealing with this phase of filtration are recorded by Fraenkl and Piefke (Zeit. für Hyg., Vol. VIII., 1890) and these show that the number of bacteria in the effluent was approximately proportional to the square root of the rate of filtration. The examinations were only made for a very short period, however, so that these experiments are only worthy of record as the first attempt to put filtration on a scientific basis. Hazen, as a result of his experiments at Lawrence (Mass. Board of Health, 1892-1893), considered that the number of bacteria passing increases rapidly with increasing rate and slowly with decreasing sand thickness and increased size of sand grain. As a tentative hypothesis he suggested the following formula:

$$\text{Per cent. of bacteria passing} = \frac{1}{2} \frac{(\text{rate})^2 \times \text{effective size of grain}}{\text{thickness of sand in inches}},$$

the rate being expressed in U.S. gallons per acre per day. This formula gave fairly good approximation with the actual results obtained at Lawrence and also for general European practice after allowance had been made for germs passing from the underdrains. Clark (New Eng. Water Assoc., Vol. 24, page 589) experimented with filters using Merrimac River water at rates ranging from 3,000,000 to 16,000,000 U.S. gallons per day. His results are shown in the following table:—

TABLE I.
Merrimac Water—Lawrence Results.

Effective size of sand.	Filter No.	Rate in imperial gallons per acre daily.	Bacteria per cubic centimeter in effluent.	Bacterial efficiency.	B. Coli in 1 c.c. age of positive tests).
0.28	A	2,500,000	48	99.1	5.0
0.25	B	4,200,000	85	98.4	24.0
0.22	C	6,300,000	105	98.1	25.0
0.22	D	8,400,000	110	98.0	25.0
0.22	E	13,400,000	280	95.0	38.0

Between 2.5 and 4.2 million gallons per acre per day and 8.4 and 13.4 million gallons per acre per day the number of bacteria passing is directly proportional to the rate, but for the intermediate period the percentage of bacteria passing increases more slowly than the rate.

A series of exhaustive experiments carried out by Hardy at Washington, D.C., (Trans. Am. Soc. C.E., Vol. LXXII., page 301) seem to show that up to 10 million gallons per acre per day the bacteria passing did not increase directly as the rate but somewhat slower and that further increases in the rate had little effect on the bacteria passing.

TABLE II.

Filter No.	Rate. Million imperial gallons per acre per day.	Percentage of bacteria in effluent.	Percentage of original turbidity in effluent.	Millions of gallons filtered per acre per run.
1	0.88	3.3	5.0	177.15
2	2.72	1.7	5.0	252.35
3	5.58	2.4	9.5	272.30
4	8.47	2.7	9.1	347.69
5	21.80	2.7	22.2	311.79
6	32.12	3.0	15.7	301.60

It is possible that in these, and in other experiments on this subject, the methods of calculating averages have had an appreciable effect on the results recorded. It should always be borne in mind that the average should represent the condition of the total volume of water filtered, and to obtain this, samples should be taken after the filtration of a unit volume of water and not, as is invariably the case, after the lapse of a unit of time. With the unit of time method, the greatest error would be produced when the maximum and minimum rates differ appreciably from the average.

In the Washington experiments the variations are given in the following table:

TABLE III.
Filter No.

Rate. Millions of U.S. gallons per acre per day.	1	2	3	4	5	6
Maximum	1.35	3.95	7.96	12.60	37.50	118.90
Minimum	0.62	2.30	3.73	5.77	6.68	7.10
Average	1.06	3.26	6.69	10.17	26.10	38.54
Ratio of average to						
Maximum	1.27	1.21	1.21	1.23	1.44	3.09
Minimum	0.58	0.71	0.56	0.57	0.26	0.18
Average = Unity.						

The variations in the two highest rates are very high and detract considerably from the value of the results if the samples were taken in the usual way.

Much work has been done on this subject by the Provincial Board of Health of Ontario and the results as reported by Dallyn in the annual report for 1912 are worthy of careful study. The experiments cover a considerable period but only during the earlier months was a natural water used. Later, the chlorinated city water was used and finally a mixture of chlorinated water and sewage.