NATURAL PURIFICATION OF FLOWING SEWAGE

S. C. PILLAI, G. J. MOHANRAO, A. V. S. PRABHAKARA RAO,
C. A. SASTRY AND P. V. R. SUBRAHMANYAM
Department of Biochemistry, Indian Institute of Science, Bangalore

AND

C. V. NATARAJAN
Formerly Deputy Director, Department of Public Health, Bangalore

[This article embodies observations made over a period of a decade and throws light on some of the fundamental principles of sanitation. The article would, therefore, be of interest to sanitary authorities throughout the world, although the set of conditions, which revealed those principles, have been provided by the peculiar method of sewage disposal particularly at Bangalore.

It also happens that almost exactly 100 years ago, a similar but empirical observation on natural purification of flowing sewage was made in England. That was, of course, before the days of our knowledge of any microbial activity which is now known to be the most important factor governing environmental sanitation and hygiene.]

INTRODUCTION

IN the course of the discussion of a paper "On the application of town sewage to a large agricultural area, comparing its strength and dilution with the ordinary farm manurial resources; with considerations of its effects on farm profit" read before the Royal Society of Arts on March 7, 1860, one of the members of the audience, P. H. Holland, remarked: "He would in conclusion only allude to the fallacy which Mr. Sidney had put forth upon the authority of Mr. Hawksley. That gentleman, an engineer, had put forward a notion which must be astounding to every chemist. It was this, that if sewage ran away for a distance of about 10 miles, it was no longer sewage, but almost plain water. That was one of the most astounding assertions he had ever heard made".[1] Except this rather empirical statement about the behaviour of flowing sewage, which was discussed presumably against the background of the prevailing ideas of the changes in soil and sewage, there is practically no information on the natural purification of sewage in the literature. The object of this communication is to give a brief account of the conditions, particularly at Bangalore, under which some 16 million gallons of sewage now daily flows down on the outskirts of the town and purifies itself naturally without any treatment, and to indicate the operation of a principle of sanitation as evident from continued observations over a period of about ten years.

CONDITIONS AT BANGALORE

Bangalore is an inland town situated on the Deccan Plateau at a height of about 3,000 feet above sea-level, having an average annual rainfall of 33·3 inches, most of which occurring during May to October. The maximum temperature reached on individual days during the warmest months of April and May is 102·4° F. and the minimum temperature touched on individual days during the coolest months of December and January is 46° F. The rapidly growing town of Bangalore has now a population of about 1·4 million people and its present daily water consumption is about 17 million gallons. The water-supply is derived mostly from the Arkavati River about 22 miles west of Bangalore.

Most areas of Bangalore are provided with underground sewerage system. The bulk of the sewage is taken to three outfalls at the suburbs of the town, two of these sewage outfalls being on the southern side and the third outfall being on the south-eastern side of the town. From these outfalls the sewage is allowed to flow down in three natural channels having varying gradient, *viz.*, 1-in-50, 1-in-100 and 1-in-800. The land surface in and around Bangalore has unusual depressions and elevations, and this topographical feature has apparently been utilised for the disposal of the town sewage since the early days of the introduction of the sewerage system in 1922.

There is no river or stream near the sewage outfalls or around the channels taking the sewage. At the various points along these channels the sewage is drawn by the farmers in the neighbourhood (over 500 families) for irrigating the land and raising crops, such as vegetables and fruits, including occasionally sugarcane and rice. There is no organised system of sewage irrigation: the farmers inprovise their own methods for taking out the sewage from the channels, when necessary.

Investigations at Bangalore

It has been observed that the turbid, foul liquid flowing in these channels becomes clear and is oxidised to an appreciable extent after its flow over a distance generally of 1 to 5 miles, depending on the gradient of the channel, and the purified effluent is used by the villagers in the vicinity for washing purposes.[2] In view of these and other observations,[3] a close study of the process of natural purification of flowing sewage was made, and the main results are given here. The physical features of the sewage channels at Bangalore, the zones in the channels broadly divisible in accordance with the stages of purification, the fauna and flora in them and the average results of analysis (obtained over a period of about ten years) of the sewages at different points in the channels are given in Tables I to IV. Photographs showing the condi-

TABLE I

The physical features of the sewage channels up to the regions in which the sewages are purified

	Channel having the gradient		
	1-in-50	1-in-100	1-in-800
Volume of sewage* (million gallons daily)	4	6	6
Width of the channel (feet)	4 to 12	8 to 20	4 to 10
Depth of the channel (feet)	0·3 to 1·5	0·3 to 2	0·5 to 4
Nature or type of bed ..	More rugged and stony at several points	Not so rugged and stony as in 1-in-50 gradient channel	Least rugged and stony
Depressions permitting sedimentation	At 0·67 mile from the outfall a considerable area of depression at certain points 1½ feet deep	Sewage stagnates at a few points	At 2·17 miles from the outfall there is a natural settling tank about ½ mile long, ¼ mile wide and 3 to 4 feet deep
Dams ..	No dams	One dam 100 feet wide at 3·5 miles from the outfall. Three other similar dams after 6 miles from the outfall	No dams
Distance from the outfall at which sewage is completely purified (in miles)	1·29	4·75	4·46
Time taken by sewage to reach the point of complete purification (hours)	0·7 to 1	2·75 to 3·25	4 to 5
Destination of the channel ..	Joins 1-in-100 channel at the point 3·25 miles from the latter's origin	Joins a river about 20 miles away from the outfall	Joins a rain-fed tank 4·46 miles away from the outfall

* The sewage is mostly domestic in character and composition. About 5,000 gallons of waste water from a small tannery is introduced into the channel 1-in-50 after 0·92 mile from the outfall. About 0·3 million gallons of waste water from 3 small-sized textile mills is introduced into the channel 1-in-100 between 1·25 and 3·25 miles from the outfall. These quantities of industrial wastes did not indicate any effect on the purification of sewage.

TABLE II

The zones in the sewage channels broadly divisible in accordance with the stages of purification

Zone and stage of purification	Channel having the gradient		
	1-in-50	1-in-100	1-in-800
		Distance in miles from the outfall	
The first zone (preliminary changes leading to clarification and oxygenation)	0 to 0·67	0 to 3·50	0 to 2·71
The second zone (clarification and oxygenation)	0·67 to 0·92	3·50 to 4·00	2·71 to 3·50
The third zone (nitrification) ..	0·92 to 1·29	4·00 to 4·75	3·50 to 4·46
The point at which the purified effluent is used for washing purposes*	1·29	4·75 and beyond	4·46

* Pathogenic organisms have not been found at the point where the liquid is used for washing purposes. This has been ascertained with the kind assistance of the authorities of the Public Health Institute at Bangalore, to whom the authors' thanks are due.

TABLE III

Fauna and flora in the sewage channels

(The list includes the organisms more frequently seen, and the list is by no means exhaustive)

Organisms	The first zone	The second zone	The third zone
Bacteria ..	Bacterial forms (as generally found in domestic sewage)* Occasionally *Salmonella typhi* and *Vibrio choleræ*	Aerobic forms generally	Aerobic forms generally
Sewage fungus ..	Sphærotilus sp.	Not seen generally	Not seen generally
Algæ ..	Not seen generally	do.	Species of Oscillatoria, Ulothrix, Urospora, Stigeoclonium and Pinnularia‡
Protozoa :			
Rhizopoda ..	Species, *e.g.*, of Amoeba and Arcella	These protozoa decreased	Not seen generally
Mastigophora ..	Species, *e.g.*, of Bicosoeca and Euglena	do.	do.
Ciliophora ..	Species, *e.g.*, of Colpoda, Colpidium, Coleps, Stylonychia, Paramecium Vorticella ; and occasionally species of Opercularia, Epistylis and Carchesium	These protozoa increased. But the species of Carchesium and Epistylis developed in strikingly large numbers forming masses of growth†	Much less growth of these protozoa
Rotifera ..	Not seen generally	Species of Rotifers	Not seen generally
Worms ..	Aulophorus sp.	Aulophorus sp.	do.
Insect Larvæ ..	Mosquito (Culex sp.); Bloodworm (Chironomus sp.)	Chironomus sp.	Mosquito (Anopheles sp.).
Other forms ..	Not seen generally	Snails ; fish (*Gambusia affinis holobrookii*); frogs; water hyacinth	Fish ; frogs ; water hyacinth

* In the first zone the bacteria predominated. † In the second zone, the protozoa, colonial Vorticellids predominated (species of Epistylis and Carchesium attached to the surfaces of stones, leaves, snails, etc.). ‡ In the third zone the algæ predominated.

TABLE IV

Results of analysis of flowing sewage at different points in the channels

(Results of chemical analysis expressed as p.p.m.)

Distance in miles from the outfall	pH value	Turbidity*	3-min. permanganate value	4-hr. permanganate value	Biochemical oxygen demand	Dissolved oxygen	Ammoniacal nitrogen (N)	Albuminoid nitrogen (N)	Nitrite nitrogen (N)	Nitrate nitrogen (N)	Total bacteria (millions per ml.)
					Channel having 1-in-50 gradient						
0·0	7·0	185	28·7	64·9	244	0·0†	34·2	14·0	Nil	Nil	34·0
0·17	7·4	122	17·3	36·3	167	2·1	24·9	10·4	Nil	Nil	20·0
0·38	7·5	104	13·2	24·4	128	2·7	22·8	8·5	Nil	Nil	16·0
0·67	7·5	88	9·7	17·9	99	3·6	20·5	7·0	0·02	Nil	10·0
0·92	7·8	40	5·1	11·3	32	6·0	9·7	1·94	0·20	0·37	2·0
1·29	7·8	17	2·8	9·0	15	6·7	6·3	0·56	0·44	0·61	0·003
					Channel having 1-in-100 gradient						
0·0	7·3	190	25·1	50·9	219	0·0†	41·3	17·4	Nil	Nil	29·1
1·25	7·5	136	16·0	32·6	147	1·4	33·4	10·4	Nil	Nil	22·3
2·25	7·8	115	14·5	30·8	113	1·8	24·7	7·2	Nil	Nil	13·3
3·00	8·1	102	11·1	24·8	98	2·5	17·3	5·9	Nil	Nil	12·5
3·25	8·0	88	9·8	21·2	86	2·9	15·5	4·2	Trace	Trace	—
3·50	7·9	74	7·3	18·7	74	3·4	14·3	3·2	0·04	0·25	6·5
3·75	7·9	29	4·3	13·7	31	5·5	12·8	1·5	0·10	0·29	—
4·75	8·0	20	2·7	9·9	19	6·5	7·3	0·59	0·32	0·50	0·005
					Channel having 1-in-800 gradient						
0·0	7·1	269	36·0	73·9	272	0·0†	54·8	18·0	Nil	Nil	35·3
0·88	7·4	188	25·2	48·9	185	2·0	37·2	10·8	Nil	Nil	27·0
2·17	7·4	106	15·5	35·0	139	2·7	28·9	8·0	Nil	Nil	15·0
2·71	7·6	72	8·9	21·5	99	3·7	18·4	5·4	0·04	Nil	10·0
3·50	7·8	47	5·3	14·3	38	6·8	12·8	0·93	0·50	0·10	0·05
4·46	8·0	23	3·0	11·1	18	6·8	9·1	0·45	0·43	0·57	0·01

* Turbidity : Values obtained by using Klett-Summerson photoelectric colorimeter with 420 filter.

† Dissolved oxygen : Occasionally the sewage samples at the outfalls contained negligible amounts of oxygen.

tions at four points in the channel having 1-in-50 gradient are given in Figs. 1 to 4.

the sewage (at 10–25% level, by volume) and the mixture gently shaken or into which air was

FIG. 1

FIG. 2

FIG. 3

FIG. 4

FIGS. 1–4. Fig. 1. One of the sewage outfalls at Bangalore: the sewage flows down in an open channel having 1-in-50 gradient. Fig. 2. At 0·67 mile from the outfall, the sewage gushes down a rugged stony area. Fig. 3. Photo micrograph of *Carchesium* sp. (× about 80) found in fluffy masses down the stony area. Fig. 4. The clear, purified effluent (at 1·29 miles from the outfall) being used by washermen.

In the light of the evidence accumulating at Bangalore the more important factors influencing purification of the flowing sewage include: (1) adequate agitation or turbulence of the sewage and other conditions in the channel, which facilitate the dissolution of oxygen to the extent of about 3·5 p.p.m., and (2) the consequent development in large numbers of ciliate protozoa notably of the species of *Carchesium* and *Epistylis* which are always found in activated sludge.[4] When these protozoan colonies were taken out, washed and introduced into bubbled for 1½–6 hours (depending on the number of the organisms), it was observed that the sewage was clarified and oxygenated almost to the same extent as under the natural conditions in the channels. The flocculating activity of the protozoa and the clarification of the sewage also seemed to explain the relatively high nitrogen contents of the soils under the flowing sewage in the zone of clarification and to bring about nitrification and other changes, *e.g.*, rapid removal of amino acids[5,6] from the sewage, in the succeeding stages of purification in the channels. The quality of the final effluents from these channels was similar to that from the activated sludge process.

OBSERVATIONS MADE AT OTHER PLACES IN INDIA

The evidence collected on the flowing sewage at the Mysore sewage farm, Shimoga, Bhadravati and Madurai[7] also indicated that the extent of agitation of the sewage during its flow is a basic factor in the process of natural purification as it influences the initial oxygenation of the sewage, development of the protozoa and the consequent changes leading to purification. When, however, sewage flowed down in a more or less contour channel, it was not oxygenated or purified to any appreciable extent even after its flow over a distance of 5 miles.[7]

SIGNIFICANCE OF THE OBSERVATIONS

Natural purification of flowing sewage is thus essentially an aerobic process and, under the most favourable conditions, it would proceed rapidly, as observed in the channel having 1-in-50 gradient, and give results attainable only by the activated sludge process. The above observations are of scientific interest as well as of practical importance as they not only relate to a sanitary principle in Nature and its bearing particularly on the modern methods of sewage disposal but indicate the possibility of increasing the efficiency of the activated sludge process and other methods of aerobic treatment of sewage.

1. Mechi, A., *J. Soc. Arts*, 1860, **8**, 261.
2. Pillai, S. C., Monanrao, G. J., Prabhakara Rao, A. V. S., Natarajan, C. V. and Madappa, I. B., *Indian Med. Gaz.*, 1953, **88**, 507.
3. Pillai, S. C., *Ibid*, 1952, **87**, 411.
4. ———, *Curr. Sci.*, 1941, **10**, 84; 1942, **11**, 437; 1949, **18**, 382.
5. Anandeswara Sastry, C., Subrahmanyam, P. V. R. and Pillai, S. C., *Sewage and Industrial Wastes*, 1958, **30**, 1241.
6. Subrahmanyam, P. V. R., Anandeswara Sastry, C., Prabhakara Rao, A. V. S. and Pillai, S. C., *J. Water Pollution Control Federation*, 1960, **32**, 344.
7. Pillai, S. C., *Investigations on Sewage Farming*, Indian Council of Agricultural Research, 1955.

ON A CLASS OF ASYMMETRICAL FACTORIAL DESIGNS

K. KISHEN

Chief Statistician to Government, U.P., Department of Agriculture, Lucknow

KISHEN AND SRIVASTAVA[1,2] have developed general methods for the construction of asymmetrical factorial designs. One of the methods given by them is for the construction of the class of $q \times 2^2$ factorial designs—the treatments being all combinations of the three factors A $(0, 1, 2, \ldots, q-1)$, B $(0, 1)$ and C $(0, 1)$—in $2b$ blocks of $2q$ plots each by use of the associated BIB design $v = q, b, k, r, \lambda$. They have illustrated the method by constructing the design 7×2^2 in 14 blocks of 14 plots each by use of the associated BIB design $v = 7$, $b = 7$, $k = 3$, $r = 3$, $\lambda = 1$ and have shown that in this design the loss of information on BC is given by

$$\text{L (BC)} = \frac{1}{49} \qquad (1)$$

and that on each of the 6 degrees of freedom of ABC by

$$\text{L (ABC)} = \frac{8}{49}, \qquad (2)$$

so that the total loss of information on the partially confounded degrees of freedom for BC and ABC in this design is unity, which is a property of balanced designs. In general, for the $q \times 2^2$ design in $2b$ blocks of $2q$ plots each, constructed from the associated BIB design $v = q, b, k = t, r, \lambda$, it can be shown that

$$\text{L (BC)} = \frac{(q-2t)^2}{q^2} \qquad (3)$$

and

$$\text{L (ABC)} = \frac{4t\,(q-t)}{q^2\,(q-1)}, \qquad (4)$$

the total loss of information being, as before, unity.

It would be seen from (3) that when q is odd, the minimum loss of information on BC would be $1/q^2$ for $t = (q-1)/2$. Also, when q is even, this minimum loss would be 0 for $t = q/2$. These would be called *optimum* designs and can be constructed when the associated BIB designs exist. In the latter case, *i.e.*, when q is even, optimum designs can be constructed with only b blocks of $2q$ plots each, thus reducing the number of blocks otherwise required by half. In this note, only designs for $q \leqslant 19$ have been discussed as optimum or near optimum designs can be constructed only in these