The chemical & bacteriological condition of the air on the City & South London Railway / by W. Scott Tebb.

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CHEMICAL & BACTERIOLOGICAL CONDITION OF THE AIR

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CITY & SOUTH LONDON RAILWAY.

BY

W. SCOTT TEBB, M.A., M.D., CANTAB., D.P.H., FELLOW OF THE INSTITUTE OF CHEMISTRY, PUBLIC ANALYST TO THE METROPOLITAN BOROUGH OF SOUTHWARK.

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I was requested by the Public Health and Sanitary Committee of the Southwark Borough Council to report on the condition of the air on the City and South London Railway. I therefore communicated with the General Manager, Mr. Jenkin, who kindly offered every facility, and I should like to take this opportunity of thanking the railway authorities and officials for their co-operation in carrying out these investigations.

The Southwark portion of the railway consists of two iron tubes for the most part parallel, about ten to eleven and a half feet in diameter, and running at a varying depth from the surface of from forty-seven to one hundred feet. The tube at intervals widens out into stations, four of which, viz.:—London Bridge, Borough, Elephant, and Kennington, are situated within the Borough of Southwark. The Company has no artificial system of ventilation, but there is a constant interchange taking place between the air of the Tube and the external air, and this is effected partly by air currents produced by the moving trains and partly by differences of temperature.

The examinations were carried out between the 26th of January and the 10th of February of the year 1903, and include :—

1. Estimations of Carbonic Acid Gas.

2. Bacteriological examinations.

In every case controls were made and nearly all the experiments were done in duplicate. Thus in the railway stations our *modus operandi* would be to collect two samples of air, to test for carbonic acid, and to expose two plates containing the nutrient material for the growth of the micro-organisms and afterwards to repair upstairs and carry out the same operations outside on the pavement in the vicinity of the station. I may here mention that there was no rain or snow to complicate any of our experiments in the street.

Besides the estimation of carbonic acid and the bacteriological examinations, records were taken of the temperature, the relative humidity, and the air currents produced by the moving trains. It is not necessary to go into any details of these examinations, but I may perhaps give a broad outline of the results. The average temperature was 61 degrees

Fahrenheit on the platform of the stations, and 49 degrees in the street. The relative humidity or the proportion of moisture of that required to produce saturation was also considerably greater in the stations, the average being 84 per cent. in comparison with 76 per cent. moisture in the open air.

The air currents on the platforms of the stations and in the passages were measured by the anemometer. The rate of movement, which depended largely on the proximity of the train—being greatest when the train was just about to enter station—varied from one to eight miles an hour.

There is probably a slight draught in the Tube independently of that produced by the trains, for on the occasion of my visit at 2.10 a.m. on February 6th, I found a current moving at the rate of over half a mile an hour, at the south end of London Bridge Station, just within the tunnel.

It is now proposed to consider under separate headings the number of bacteria, and the condition of the air with regard to carbonic acid gas. The date, time, and result of separate analyses are given at the conclusion of the Report, and in the following pages I will merely summarise the results, and state my general conclusions.

Micro-organisms.

The method adopted for enumerating the micro-organisms is that given by Dr. Newman in his valuable article on "The Air of Bakehouses" in *Public Health*, for December, 1902. Agar plates in duplicate were exposed to the air in question for exactly half an hour; the plates were afterwards incubated at 37 degrees centigrade for twenty-two hours, and the colonies were then counted by the help of Pakes' discs. These experiments were made in the railway carriages, in the stations, and in the external air in the vicinity of the stations. This method enumerates the micro-organisms which fall on to an area of nine and a half square inches of nutrient agar, during the period of half an hour; of course it can give no idea of the number of bacteria present in a definite quantity of air, but for purposes of comparison between the air of the Tube and the outside air, the method is as reliable as any of the other processes in vogue.

The following table gives the average number of micro-organisms in the air of the street, on the railway platforms, and in the carriages:—

Air of	Number of Experiments.	Micro-organisms.
Streets	54	459
Railway Platforms ...	46	114
Carriages	8	218

Forty-six plates were exposed in the stations with an average of 114 colonies to each plate, whereas in the air of the street the mean of fifty-four experiments was 459 colonies. In the carriages the average of eight tests was 218 to each plate. The number of experiments reduces any risk of error, hence it appears that the air in the street contains a larger number of bacteria than the air in the stations in the Tube. There were only eight tests made in the carriages, but they generally bear out this conclusion :—

The above figures may be sub-divided so as to give the number of micro-organisms at different periods during the day and night ; the statistics of the air in the streets would then work out as follows :—

Hours.	Number of Experiments.	Micro-organisms.
2 a.m. to 6 a.m. ...	2 ..	52
6 a.m. to 10 a.m. ...	12 ...	412
10 a.m. to 2 p.m. ...	10 ...	455
2 p.m. to 6 p.m. ...	14 ...	427
6 p.m. to 10 p.m. ...	16 ...	574

Thus from 2 a.m. to 6 a.m., when there was hardly any traffic, the bacteria were only about one-ninth of the number found in the day time.

Similar averages for the stations of the Tube have also been calculated :—

Hours.	Number of Experiments.	Micro-organisms.
2 a.m. to 6 a.m. ...	4 ...	54
6 a.m. to 10 a.m. ...	8 ...	249
10 a.m. to 2 p.m. ...	10 ...	102
2 p.m. to 6 p.m. ...	12 ...	54
6 p.m. to 10 p.m. ...	12 ...	111

The bacteria are thus seen to be only one-fourth as numerous below in the stations as they were in the street ; they were also less in number between 2 a.m. and 6 a.m. and at times of slack traffic between 2 p.m. and 6 p.m. In order to interpret these results the whole subject of micro-organisms in the air might in this place be briefly reviewed.

Speculations have long been made as to the existence of organised particles in the air,* but it is only in comparatively recent years and particularly from the researches of Professor Tyndall† that any great

*Boerhave speaks of the "corpuscles . . . which float up and down perpetually in this air." *Elementa Chemiae*, 1732, vol. 1, p. 484.

† Philosophical Transactions, 1876, p. 27.

advance in our knowledge of the subject has been made. He found that certain particles were present in the atmosphere, and that if these gained access to organic fluids a fermentative change or putrefaction resulted, whereas if the particles were excluded the organic fluid remained unaffected or sterile. The particles in question have been shown to be particles of dust which consist principally of mineral and other debris, but also in addition numerous bacteria capable of growth and multiplication when transferred to a suitable soil. It has been proved by Hesse that when a room is kept quiet, the organisms will settle down in a few hours; on the other hand when there is much disturbance of dust, the bacteria in the air will be largely augmented. This is illustrated by some experiments of Carnelley, Haldane and Anderson. A determination was made of micro-organisms in the classroom of the High School at Dundee, and 11 bacteria were found in each litre of air. The boys were then told to stamp their feet on the floor, with the result that in the second determination 150 were found in each litre. These facts have an important bearing on our experiments, which shew generally that the largest number of bacteria were to be found in the daytime and at periods of the greatest traffic.

This experience, coupled with other evidence mentioned, points to the conclusion that the number of bacteria depends principally on two factors, viz. :—(1) The presence of dust. (2) The disturbance of dust by traffic. These conditions are not so frequently present in the Tube air, and hence its comparative freedom from bacteria, but to what extent the air is less harmful on this account it is more difficult to say.

Since bacteria have been discovered in association with certain infective diseases, the popular idea has arisen that the air is deleterious in proportion to the number of bacteria present; it is not my intention, however, and this is hardly the proper place, to discuss the germ theory of disease, but this I think I may say without contradiction, that among scientific authorities at the present day there are very serious doubts whether the bacterium by itself and independently of any condition of soil in which it is planted, can give rise to disease in man. A notable case of the difficulties besetting the bacteriologist may be instanced by the *vibrio* of cholera. It was at one time confidently predicted that this was the actual cause of the disease, and it was thought that a great discovery had been made. Lord Lister himself finally demolished this theory at the Annual Meeting of the British Association at Liverpool in 1896, when he stated that besides the mere presence of the *vibrio* "various other conditions are necessary to the production of an attack of cholera." The same may probably be said of other infective diseases with which we are acquainted. Even if it could be shewn, therefore, that the air contained a number of so-called "pathogenic bacteria," it would not necessarily be more dangerous on that account. There are, moreover, other considerations which indicate that the air is not an important factor as a medium of infection. According to an estimate made by Flügge,* "the average number of bacteria in the air is 100 to the cubic metre, so that a man during a life-time of seventy years inspires about twenty-five millions of bacteria, the same number contained in half-a-pint of fresh milk, or in each ounce of the ordinary milk sold." The number of the micro-organisms in the air, is therefore relatively speaking very small, and even of these a considerable proportion are moulds and other forms usually considered harmless. Further, it has been shewn that expired air is free from organisms, the majority being stopped during inspiration at the entrance of the respiratory tract by a process of filtration in the nasal cavaties. It appears from the various reasons adduced that the air is not an important medium by which infection takes place, and therefore the comparatively small number of bacteria found on the Tube Railway is not a matter to which very great significance need be attached.

Carbonic Acid Gas. †

This gas is a normal constituent of the atmosphere, and varies under different circumstances between two and five volumes per 10,000. Carnelley, Haldane and Anderson, from a series of experiments at Dundee, found a normal range of from 2·2 to 5·6 parts per 10,000. In the course of my experiments at Southwark, fifty-one analyses were made of the external air in the neighbourhood of the railway stations, and the average was 3·8 per 10,000. I have calculated out the figures for periods of four hours during the day and night.

Hours.	Number of Analyses.	Carbonic Acid per 10,000.
2 a.m. to 6 a.m.	2	3·1
6 a.m. to 10 a.m.	11	3·5
10 a.m. to 2 p.m.	10	3·6
2 p.m. to 6 p.m.	14	4·3
6 p.m. to 10 p.m.	14	3·9

The figures for the air in the streets, therefore, show a range of from 3·1 to 4·3 parts of carbonic acid per 10,000, the purest air being found

* Grundriss der Hygiene, pp. 161, 162.

† Pettenkoffer's method of estimating carbonic acid was used with bottles of about eight litres capacity.

in the very early morning and the highest proportion of carbonic acid between 2 and 6 p.m. We now pass on to the examination of the air of the railway for carbonic acid, the samples being taken on the platforms of the stations and also in the carriages. The following table gives the average of results. In the last column are set out figures showing the excess of carbonic acid in the air of the stations and carriages of the Tube as compared with that found in the streets—that is to say, the impurities due to the presence of human beings:—

	Number of Analyses.	Carbonic acid per 10,000	Carbonic acid per 10,000 in excess of normal.
Railway platforms ...	46	7·9	4·1
Carriages ...	22	11·6	7·8

The statistics for the stations have also been arranged in periods of four hours:—

Hours,	Number of Analyses	Carbonic acid per 10,000.	Carbonic acid per 10,000 in excess of normal.
2 a.m. to 6 a.m. ...	4	3·5	0·4
6 a.m. to 10 a.m. ...	8	5·9	2·4
10 a.m. to 2 p.m. ..	10	8·5	4·9
2 p.m. to 6 p.m. ...	12	8·9	4·6
6 p.m. to 10 p.m. ...	12	9·3	5·4

The carbonic acid gas in the stations is thus shewn to exhibit a progressive increase from early morning to late at night. The impurity is very slightly above normal during the night, and with the commencement of traffic it increases; this goes on until 2 p.m. The slackness of the traffic in the afternoon occasions a slight fall until 6 o'clock, and after this hour the rush of passengers brings the impurity to a maximum between 6 and 10 p.m. As shewn above the average for the stations was 7·9 and for the carriages 11·6 parts of carbonic acid per 10,000.

We now have to consider whether these amounts of carbonic acid due to respiratory impurity are injurious to health, and here we are faced with the difficulty that science has not yet solved the nature of the poison given off from the animal body, the inhalation of which has been shewn to produce such deleterious effects; all we know is, and this is the point on which authorities are agreed, that the amount of carbonic acid gives a rough idea of the extent to which the air has been polluted. The symptoms commonly associated with a close atmosphere are headache, a sense of oppression and discomfort, slowness of the heart's action, and in some cases nausea. Every medical man is familiar with the fainting attacks so common in churches and other public assemblies, this condition is usually attributed to a vitiated state of the atmosphere. When the breathing of bad air becomes habitual or chronic, as in those whose work has to be undertaken in confined situations, another and more serious train of symptoms is observed. The patient after a time becomes pale and loses his appetite; and in some cases there is impairment of nourishment and loss of flesh; in this condition he is liable to influenza and catarrhs, and possibly lays the foundation of consumption or some other serious disease.

It cannot be contended that the average of 7·9 volumes in the stations or even the 11·6 volumes in the carriages is excessive when compared with the quantities commonly found where people are congregated,* but it is considerably above the amount which should be permitted. The standard usually accepted is that of De Chaumont,† who, from the result of his experience of the air of barracks, recommended that six volumes of carbonic acid per 10,000 was the permissible limit of impurity.

My figures show that in the evening from 6 to 10 p.m. the amount in the stations, taking an average of twelve analyses, reached as much as 9·3 volumes. I cannot but think that this quantity of carbonic acid due to human impurities is a matter for the serious consideration of the Company. There is little doubt that the organic matter given off by the skin and lungs is harmful; thus Carnelley, Haldane, and Anderson ‡ remark that "it is probable that poisoning by organic substances given off by the breath and skin has a very great effect in lowering the general health, and predisposing to other diseases. The deaths from 'debility' and 'convulsions' in infants are perhaps in considerable proportions due to the subacute poisoning by these substances."

It is true that we have no means of estimating these deleterious substances, but still they are admitted to be present in the air which has been breathed, and further, that the quantity of carbonic acid found is a measure of this impurity.

After careful consideration of the subject, taking into account the injury to the Public Health produced by this slow form of poisoning, and on the other hand the difficulties the Company will probably have to contend with in devising an adequate system of ventilation, I am of

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* In 1864 Angus Smith and Bernays analysed the air in some of the London Theatres, and the amounts of carbonic acid ranged from 8 to 32 parts per 10,000. Quite recently Wynter Blyth found 14·9 volumes per 10,000 in the Marylebone Town Hall.

† Edinburgh Medical Journal, May, 1867.

‡ Philosophical Transactions, 1817, p. 106.

opinion that means should be adopted to reduce the carbonic acid in the Tube to six volumes per 10,000, that is to say the limit advocated by De Chaumont; at the same time I think that some more efficient method of ventilation should be provided in the carriages.

In my judgment these are not unreasonable recommendations, at all events I am convinced that in the near future the Public will become so educated in matters of ventilation that they will demand to have pure air when travelling to and fro from their daily work, and that the Tubes from competition with alternative means of locomotion above ground will be compelled in their own interests to adopt some such standard as I have suggested.

ANALYSES OF AIR IN THE STREETS OF SOUTH LONDON, 1903.*

District.	Date.	Time.	Carbonic Acid per 10,000.	Micro-organisms.
London Bridge...	Jan. 26th	7.10 am.	3·3	172
			3·6	236
Do. ...	do.	11.50 a.m.	3·9	288
			3·4	316
Do. ...	do.	3.40 p.m.	5.5	384
			4·9	432
Do. ...	do.	7.50 p.m.	5·2	272
			4·7	256
Borough ...	Jan. 27th	3 p.m.	4·2	200
			5·3	192
Do. ...	Jan. 28th	7 p.m.	3·5	368
			4·2	320
Do. ..	do.	11.10 a.m.	3·6	488
			3·8	456
Do. ...	do.	2.50 p.m.	4·5	448
			4·2	353
Do. ...	do.	6.50 p.m.	4·1	736
			4·0	608
Elephant ...	Jan. 29th	9.40 am.	3·8	352
			4·1	320
Do. ...	Jan. 30th	7.10 a.m.	3·5	912
			3·6	800
Do. ...	do.	11 a.m.	4·0	880
			3·6	800
Do. ...	do.	3 p.m.	4·2	1000
			4·0	800
Do. ...	do.	6.50 p.m.	3·9	912
			4·1	1008
Kennington ...	Feb. 2nd	7.20 a.m.	3·5	650
			—	680
Do. ...	do.	11 a.m.	3·5	400
			3·4	400
Do. ...	do.	2.50 p.m.	3·3	504
			3·0	580
Do. ...	do.	6.30 p.m.	3·9	440
			3·9	390
Elephant ...	Feb. 4th	6.20 p.m.	3·6	736
				672

* A few of the earliest samples were, strictly speaking, not collected in the open air, that is to say, the sample was taken just within the door of the Upper Station abutting on the Street.

Analyses of the Air in the Streets of South London, 1903—*continued.*

District.	Date.	Time.	Carbonic Acid per 10,000.	Micro-organisms.
London Bridge...	Feb. 5th	6.50 p.m.	3·1	192
			3·4	160
Do. ...	do.	9.30 p.m.	3·4	180
			3·6	168
Do. ...	Feb. 6th	2.50 a.m.	3·2	50
			3·0	55
Do. ...	do.	6.20 a.m.	2·8	56
			2·9	84
Do. ...	Feb. 9th	10.50 a.m.	3·2	280
			3·5	240
Do. ...	do.	2.50 p.m.	4·1	280
			3·9	304
Do. ...	do.	5.50 p.m.	4·4	246
			4·1	254
Elephant ...	Feb. 10th	6.5 p.m.	3·7	1200
				1250

Analyses of Air in Stations of the City and South London Railway, 1903.

Station.	Date.	Time.	Carbonic Acid per 10,000.	Micro-organisms.
London Bridge...	Jan. 26th	6.20 am.	4·5	192
			4·3	132
Do. ...	do.	11 a.m.	8·0	92
			8·0	68
Do. ...	do.	3 p.m.	12·1	26
			11·7	38
Do. ...	do.	7 p.m.	10·8	104
			10·2	120
Borough ...	Jan. 28th	6.20 a.m.	7·2	96
			8·5	96
Do. ...	do.	10.30 a.m.	9·1	30
			8·6	30
Do. ...	do.	2.10 p.m.	7·8	43
			7·3	65
Do. ...	do.	6.10 p.m.	9·0	135
			9·5	120
Elephant ...	Jan. 30th	6.40 a.m.	6·3	592
			5·9	544
Do. ...	do.	10.30 a.m.	7·9	336
			7·3	80

Analyses of Air in Stations of the City and South London Railway, 1903.—*continued.*

Station.	Date.	Time.	Carbonic Acid per 10,000.	Micro-organisms.
Elephant ...	Jan. 30th	2.20 p.m.	10·0	58
			9·3	45
Do. ...	do.	6.10 p.m.	8·6	192
			9·3	156
Kennington ...	Feb. 2nd	6.50 a.m.	5·0	170
			5·8	170
Do. ...	do.	10.30 a.m.	8·6	70
			8·6	230
Do. ...	do.	2.20 p.m.	8·0	15
			7·2	13
Do. ...	do.	6 p.m.	9·0	8
			9·4	14
London Bridge ...	Feb. 5th	6.30 p.m.	9·1	184
			8·7	144
Do. .	do.	9 p.m.	8·7	88
			8·9	72
Do. ...	Feb. 6th	2.10 a.m.	4·2	52
			4·0	22
Do. ...	do.	5.40 a.m.	3·0	74
			3·0	70
Do. ...	Feb. 9th	10.10 a.m.	9·7	36
			9·4	51
Do. ...	do.	2.10 p.m.	8·1	50
			8·3	46
Do. ...	do.	5.20 p.m.	8·6	100
			8·3	155

Analyses of Air in Carriages of the City and South London Railway, 1903.

Date.	Time.	Carbonic Acid per 10,000.	Micro-organisms.
Jan. 27th	2.20 p.m.	14·9	336
		13·0	288
Jan. 29th	9 a.m.	9·0	272
		12·8	272

Analyses of Air in Carriages of the City and South London Railway, 1903—*continued.*

		Carbonic Acid per 10,000.	Micro-organisms.
Feb. 4th	5.30 p.m.—6 p.m.	10·3	120
		12·8	130
		11·1	
		12·1	
		10·0	
		14·3	
		11·3	
		17·6	
		8·4	
Feb. 10th	5.10 p.m.—5.40 p.m.	8·6	220
		10·5	110
		12·4	
		12·3	
		12·9	
		10·5	
		8·8	
		9·0	
		11·6	