SOME REMARKS ON THE BIOLOGICAL PURIFICATION OF SEWAGE.

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By the term sewage we are reminded of certain portions of what to us are waste materials, the products of human, domestic and business activities, and of animal and vegetable life and decay, mixed more or less incidentally with some amount of matter derived from the mineral kingdom.

It needs little reflection to appreciate the fact that such materials have been in constant production ever since life began upon this planet. Under the earlier conditions of comparative isolation of individuals or their congregation in but moderate numbers, the need for special attention to the subject was not felt at all, or felt only in so far as to lead to deposition in some situation sufficiently remote from the dwelling, and to migration of the household to some other place if the accumulation became a nuisance. As communities became larger and adopted the custom of fixed habitations, the continually increasing amount of refuse could no longer be dealt with by mere deposition, and there arose the practice of burial in the earth which is still in pretty general operation. By continued evolution the sites of occupation have become here and there large and abundantly populated cities, producing more refuse than could be disposed of by such simple means, so that in course of time there have been invented on the one hand special means of removing the refuse from the cities, and on the other hand special means of disposing of the refuse so removed. Thus we have come at the present epoch to our sewerage systems devised for water carriage, and at the outfall, when this is not into the sea, to disposal works having for their object the prevention of nuisance and danger by securing purification of the sewage. Our business to-night concerns the most modern kind of installation for this purpose; that which makes use of the purifying propensities of biological processes.

The privilege of submiting this question to your notice we share with Mr. Cook, and by arrangement with him an endeavour has been made to avoid needless repetition of the same facts in our respective papers. Mr. Cook has undertaken to present the essential *data* concerning construction of the installations, together with the results obtained by their use. We have left these matters as far as possible untouched, and limited our remarks to the manner in which the results are obtained. His paper deals with what is done, ours with how it is done. With this object in view we invite your attention first to the nature of the material to be purified, and secondly to the biological processes by which its purification is effected.

Sewage as we now conceive it consists of a motly collection of substances suspended or dissolved in water. The proportion of substances in the water, *i.e.*, the concentration of the sewage, and the variety of the substances, *i.e.*, the composition of the sewage, are different in different places, and in the same place at different times. We could not undertake to review all the diversities in these respects, and so have elected to give special attention to what is known as domestic sewage. But in dealing with this we shall display the essential facts with respect to all kinds of sewage, for, whilst the inclusion of trade effluents for instance may complicate matters, the technical modifications needed for their satisfactory treatment are based upon exactly the same principles as are involved in the purification of domestic sewage.

The constituents of domestic sewage other than water represent the excretions of man and animals, and the bye-products of their habits of life. Amongst the excretions are the undigested residues of food, and the issues of the wear and tear of bodily existence:—bits of muscle, gristle, fibrous tissue and fat from meat; starch, woody fibre, and plant cells from vegetables; detached animal cells from excretory passages; digestion products, bile residues, mucus, odorous and pigmentary fæcal matter from the bowels; and urea, uric acid, hippuric acid, and a host of kindred bodies voided with the urine. The bye-products comprise scraps of unused food, raw and cooked animal and vegetable debris; cooking and kitchen waters; general slops with soap and dirt from our bodies, and from floors, furniture, clothes, etc.; as well as heterogeneous articles such as paper, matches, string, and the "bits" of all sorts which are commonly consigned to the drains.

A complete list of sewage constituents is simply bewildering, but the apparent miscellaneity is reducible to order if regarded from a chemical standpoint. To begin with, the material is partly inorganic and partly organic; and as the latter only is putrescible, it alone we are obliged to purify. The organic matter is primarily divisible into nitrogenous and non-nitrogenous; the former class embracing proteids and their derivatives, and the latter carbohydrates and fats and their derivatives.

The purification of both classes consists of the disruption of the complex associations of the constituent elements and their rearrangement in much more simple combinations. The elements entering into the composition of nitrogenous organic matter are essentially carbon, hydrogen, oxygen and nitrogen, with often sulphur, and occasionally phosphorus as well; and the end products of their purification are the elements in a free state, or in such simple combinations as nitrates, carbonic acid, and water. The elements entering into the composition of non-nitrogenous organic matter are carbon, hydrogen, and oxygen; and the end products of their purification are carbonic acid and water. From one extreme to the other is a very far cry and, as might be expected, there is formed, between each original complex substance and its simple end products, a whole series of intermediate bodies which exhibit less and less intricate associations of the elements at each successive stage of the purifying process.

For the purposes of this paper the purifying process is regarded as comprising the passage of the sewage first through a "septic" tank, and then through a filter. In crude sewage the component materials are partly in suspension, partly in solution in the water. The larger suspended matters may need to be removed by screens, or in the case of heavy materials by deposition in silt pits; this preliminary treatment being more especially necessary in public installations for the removal of rags, road detritus, sand, etc. After this the sewage passes into the septic tank where it is left to itself for some hours. Here, in the first instance, occurs a subsidence of suspended matters which form a sludge containing both inorganic and organic matter. The latter, as well as the organic matter in solution, soon begins to decompose. Gases evolved in this process rise to the surface and pass into the atmosphere. Solid matter rendered buoyant by entangled gas bubbles is continually floating upwards, discharging its freight of gas, and subsiding again. Sometimes such masses remain attached to the scum which meanwhile is forming on the surface. This scum consists of the lighter solids, corks, matches, animal and vegetable fibres, and debris matted together into a gelatinous mass which in course of time may become many inches, or even several feet, thick; and which like the sludge slowly undergoes decomposition. Between the sludge and the scum the passage of gas bubbles and solid masses produce circulating currents comparable to those which occur in slowly boiling fluids. Observations have shewn that in public installations the decomposition of the sludge reduces its bulk by approximately 50 per cent. In domestic installations the reduction would probably be greater but variable according to circumstances. The gas produced consists variably of methane (CH_4), (57 per cent.) free nitrogen (32 per cent.), carbonic acid (8 per cent.), free hydrogen (·34 per cent.), sulphuretted hydrogen, and free oxygen, (1 per cent.). It is inflammable, and may be collected and used for illuminating purposes.

The effluent from the tank is a dark coloured offensive fluid, laden with decomposing material, which is, or should be, almost entirely in solution. The passage of this fluid through a new filter does not produce much alteration of it, but with use the filtering material becomes coated with a living slime which, when fully formed, or "ripe," acts upon the passing effluent in such a way as to convert it to a clear fluid free from objectionable odour, and containing no putrescible matter.

In the analytical statements with which we are all familiar the changes the sewage thus visibly undergoes are expressed in chemical terms according to a conventional arrangement. As a rule the only inorganic constituents considered are chlorides, and rarely such salts of calcium and magnesium as contribute to "hardness." Nitrogenous constituents are expressed as free or saline ammonia, fixed or albumenoid ammonia, total nitrogen, organic nitrogen, and as nitrites and nitrates. Non-nitrogenous organic matter is not precisely discriminated, but is accounted for, partly at least, as organic carbon, or more commonly under the heading "oxygen consumed." The sulphur and phosphorus of organic compounds are classed as sulphates and phoshates along with the same substances derived from inorganic sources. An important further item gives the amount of solid matter, and distinguishes whether and in what proportions it is dissolved or in suspension.

In comparative statements between crude sewage and the purified effluent the interpretation of the results is based upon the transference of material from one of these groups to another. For instance organic nitrogen or albuminoid ammonia, and also to some extent the free ammonia, are regarded as standing for the nitrogen in material not yet purified, whilst nitrites and nitrates, especially the latter, represent the nitrogen in purified combinations. Effective purification is indicated by reduction of the amounts of the substances in the unpurified category, and increase in the amounts of those in the purified list. Similarly the purification of non-nitrogenous (as well as of nitrogenous) matter is indicated by a lessened absorption of oxygen, because the stable products resulting from the decomposition have a less capacity for oxygen than their more complex originals. The purifying effect upon solid matter is marked by a transference from the suspended to the dissolved class.

Although inorganic and non putrescible, the chlorine is of material assistance in intrepreting the results. It undergoes no change in amount in passing through the septic tank and filter, and thus affords an index to the comparability of the crude sewage and the two effluents. The chlorine figure should be the same in all three. But if, for instance, the filter effluent contain less chlorine than the crude sewage, it is at once evident that the effluent is more dilute than the sewage. The two analyses to be compared in such a case do not deal with the same thing; they do not compare like with like; so that in interpreting the results an adjustment must be made in accordance with the chlorine indications. The following remarks of Dr. Sidney Barwise on this subject are sufficiently pointed to deserve quotation. "The chlorine itself is of little importance; there is no necessity for its removal, and no process of purification can remove it. Its determination however, is important, because it serves as a valuable index of the strength of ordinary domestic sewage. For instance, one frequently sees in the advertisements of "patented" processes of purification, an analysis published of the wonderful purity of a sewage effluent which contains a small amount of chlorine, and beside it an analysis of the raw sewage which contains a much larger amount of chlorine. Obviously the effluent and sewage do not correspond, and the effluent has been obtained from a weaker raw sewage than that of which the analysis is published. In a paper read at the Sanitary Institute Congress at Liverpool, in 1894, on a "patented" process of sewage purification, the chlorine in the raw sewage was given as thirty parts per 100,000; whilst that in the effluent from the "patent" filter was given as 3·9 parts per 100,000. The effluent must have been from a sewage of between one-seventh and one-eighth of the strength of that purporting to be the sewage before purification. From this it will be seen that the determination of chlorine is always an important one, as, if the percentage of purification effected by any process is to be guaged, the chlorine in the effluent must be practically the same as that in the sewage. It is a pity that this elementary fact has not been more generally appreciated by the advocates of many patented processes, as the analysis they published prove too much." (The purification of sewage, 1904, p. 14).

Properly made statements referring to biological purification compare the crude sewage, the tank effluent, and the final filtered effluent. Characteristically they exhibit the following features. The chlorine as already mentioned is the same in all three analysis. The albumunoid ammonia is successively less in each case, by 50 per cent. in the tank effluent, but is markedly less (by 70 per cent.) in the filtrate. Nitrites and nitrates perhaps absent to begin with and generally lacking also in the tank effluent make their appearance in the filter effluent. The oxygen consumed is less (20 per cent.) in the tank effluent, and markedly less (by 90 per cent.) in the filtrate. Suspended matters are very much lower (90 per cent.) in the tank effluent, and a slight further reduction may be shewn in the filtrate.

From these results it appears that in passing through the tank the principal changes are reduction of the amount of albuminoid ammonia with slight increase of free ammonia; some reduction of the amount of the oxidisable organic matter, and solution of nearly all the suspended solids. In passing through the filter the further changes are disappearance of nearly all the remaining albumunoid ammonia and of the free ammonia, and appearance of the oxidation products nitrites and nitrates; whilst the organic matter in general becomes so profoundly changed that its products are pretty fully charged with oxygen, that is, are chiefly present as carbonic acid and water. In the tank hydrolysis produces disintegration and solution; in the filter the tank products are vigorously oxidised. As we have previously noted certain products pass off as gas and so are not accounted for by the usual analysis. Generally, then, we may conclude that the result of the whole process is to break up organic matter into its element, or convert it into such simple combinations as nitrates, carbonic acid, and water. The nearer the final products are to those mentioned the more successful has been the purification. In this connection mention may be made of what is known as the incubator test. The rapidity with which organic matter absorbs oxygen is believed to be related to its state as regards putrescence. Putrifying organic matter absorbs oxygen more rapidly than do stable organic combinations. Hence in the ordinary test the oxygen absorbed in three minutes is regarded as indicating the organic matter in actual putrescence as distinguished from the undecomposed organic matter which take four hours for full absorption of oxygen. The incubator test is based upon these views. To apply it the oxygen absorbed in three minutes is first determined. Then the fluid, in a bottle filled full and tightly or hermetically stoppered, is set aside for a week at a temperature of 80°F. Any putrescible organic matter in the fluid will decompose during this period, and for lack of oxygen to oxidise it will remain in a putrescent state in the bottle. After a week's keeping the oxygen absorbed in three minutes is again determined. If no putrescent matter be present the figure obtained will be no greater than that given by the original fluid. If putrescent matter be present as it will be revealed by a higher figure. By applying this test to the filter effluent valuable information is afforded as to the efficiency of the purification.

Before proceeding to discuss the mechanism of the changes we have just described, we desire to point out that the processes involved, though newly applied to this particular purpose are by no means new in themselves. The accumulations of the refuse of previous generations are not now recognisable as such. They have for the most part entirely vanished, and the disappearance of organic matter in this way is a fact with which we are all perfectly familiar. If we add to it the further familiar fact that the application of animal excretions to land materially aids the growth of plants, we perceive that what seemed to be a disappearance of organic matter is, after all, only a transmutation of it. The refuse of the animal kingdom is the food of the plant world. If we go still another step and grasp the fact that all animals feed upon plants, directly (herbivora) or indirectly through the bodies of herbivora (carnivora) or both ways (omnivora),—we alight upon the great conception that the matter under consideration is in constant circulation between the animal and vegetable kingdoms. It is easy to understand its transference from plant to animal. The animal economy requires the complex combinations of food stuffs which exist ready formed in plants; animals eat plants as they are. But the conveyance from animal to plant is not such a simple matter, for vegetable physiologists tell us plants cannot directly feed upon the still complex materials of which animal excretions consist. But vegetable physiology displays to us the further interesting fact that plant food consists of nitrates, carbonic acid and water, the very substances which, as we have seen, form the end products of the purification of animal refuse. It must be the case, then, that the changes which take place in the biological installations have their exact counterpart in natural processes. In fact, we know that such processes exist; we know what they are, or at least we have given them names. The series of changes which dead organic matter undergoes in nature we call putrefaction when nitrogenous decomposition is in question, and fermentation when non-nitrogenous matter is being resolved, and to these we have more recently added the term nitrification to distinguish the process of ultimate oxidation of nitrogenous matter.

These changes, we are well aware, are due to the activity of the bacteria and their allies, and it thus appears that the natural functions of these tiny denizens of our sphere is to form a link in the chain of the circulation of the world's food material. They break down the complex combinations of carbon, hydrogen, oxygen and nitrogen, of which animal excretions consist, into the simpler combinations required for the food of plants. In this way they secure the conversion of putrescible organic matter into non-putrescible inorganic matter; and it is their abilities in this direction that we endeavour to utilise for the purification of sewage. The changes which take place in our installations are of exactly the same kind as those undergone by dead organic matter in nature. Hence, although the process as applied to sewage is often regarded as something new and special, it is in reality as ancient as life itself, and so common as to be practically universal.

By regarding the purification from the natural point of view vistas are opened up which, we think, give a clear picture of what biological purification really means. By such a lucid appreciation of it we should be better able to adjust our expectations to the possibilities, and be afforded rational guidance in attacking the problems involved. In this belief we submit to you a brief survey of the essential facts concerning putrefaction, fermentation, and nitrification, premising, however, that they are matters which still need much study in connection with the subject under review.

As already indicated putrefaction connotes the disintegration of nitrogenous organic matter by bacterial action. All bacteria require nitrogen for the construction of their body plasma, but it can enter through the bacterial cell wall only in a dissolved and diffusible condition. To most species of bacteria however the nitrogenous food material is offered either in a solid form or in combinations which render its endosmosis into their bodies impossible. In order to procure this necessary constituent of their food the bacteria are endowed with the powers of dissolving or liquefying the solids, and of transforming them into combinations which they can imbibe. For instance, in the case of bits of meat the nitrogenous material is proteid. Proteid as such is not suitable for absorption into the tissues even of ourselves; it will not pass through the walls of our digestive organs into the blood which alone can carry it to the tissue cells in need of it. In order to secure this passage the proteid is digested by the enzymes or ferments of the stomach and intestine. By "digestion" of proteid is implied its liquefaction and conversion into albumoses and peptones which can diffuse through the walls of the digestive organs and so are capable of being absorbed and applied to the nutrition of our tissues. Bacteria similarly affect their object by secreting enzymes which liquefy the proteid and convert into albumoses and peptones from which they can derive nourishment. In this way there is brought about an initial alteration in the nitrogenous organic matter. The secretions of the bacteria which effect such changes are called proteolytic enxymes.

The bacteria concerned in this action have been called proteid bacteria, by reason of their ability to secure their nitrogenous food from proteid; some species of them being apparently incapable of securing it from any simpler combination. But another series of bacteria whilst not possessed of the power of utilising proteid itself, can utilise the albumose and peptone which form the first products of its decomposition. These bacteria, which have been called peptone bacteria, come in at the second stage and seize upon the albumose and peptone, take their food from them and in the process convert them into substances still lower in the scale, as for instance, amido-acids such as leucin and tyrosin. Similarly another series, the amido-bacteria feeds upon these last products and in turn convert them into ammonia compounds. Beyond ammonia this kind of decomposition does not go.

Although we have thus briefly followed the direct line of the nitrogen, the course taken is far from being so simple as our statement might suggest. Actually the disintegration is complicated by the formation of a host of substances kindred to those mentioned. The complex molecule of proteid may contain two or three hundred atoms of carbon, three or four hundred of hydrogen, some eighty or ninety of nitrogen, seventy or eighty of oxygen, a few atoms of sulphur and occasionally a few of phosphorus. These molecules can cleave into various products, protamins, amido-acids, ureids, creatins, and sulphur and phosphorus derivatives. The protamins yield (through protons and texons), amido-acids, ptomaines, urea, and non-nitrogenous organic acids. Amido-acids, ptomaines, and urea yield ammonia, carbonic acid and other non-nitrogenous matter. The ureids yield urea and non-nitrogenous acid; the urea in turn yielding ammonia and carbonic acid. The creatins yield urea and amido-acids, both of these afterwards decomposing into ammonia and carbonic acid. Thus in all cases, although often by devious courses, the original nitrogen comes to be represented in the effluent by ammonia; as indicated in the brief statement given above. It must be noted also that particular species of bacteria can produce several of the decompositions and operate at more than one stage. Further, purely chemical interactions between the product contribute to the complexity of the process.

The non-nitrogenous organic matter originally present, as well as that split off from the nitrogenous constituents, is meanwhile undergoing fermentation under the influence of the same or other bacteria. The object of the bacteria in this case seems to be to secure the carbon necessary for their tissue construction. It appears that although carbon is present in the nitrogenous organic matter, bacteria cannot readily obtain it from this source; no doubt because its combinations therein are not easily split up by them. If they be obliged to depend upon such matter for their carbon they are half starved and do not flourish. To get their carbon they attack perforce or by preference the non-nitrogenous matter and cause its decomposition. Carbohydrate material is converted by them into lower numbers of the series, and into fatty acids. Thus polysaccharides like starch and disaccharides like cane sugar are converted into mono-saccharides like glucose and laevulose, and these are then changed into alcohol, fatty acids, etc. The capabilities of the bacteria in producing these changes are strikingly shewn by the fact that they can make first sugars, and then gases (methane and carbonic acids) out of cellulose; that is to say wood; a material completely resistant to our powers of digestion. Fats like stearin, palmitin and olein are converted into fatty acids (stearic, palmitic, and oleic), and glycerine. The actual agencies operating in these cases are known as amylolytic or starch splitting and steatolytic or fat splitting enzymes. By their means the non-nitrogenous matter comes to be represented in the effluent by such substances as sugar, alcohols, glycerine, and fatty acids.

The small amount of sulphur present in the proteid is partly split off as sulphuretted hydrogen and evolved in a gaseous state; partly remains in the fluid as sulphide; and partly accompanies the organic matter into mercaptan derivatives. The phosporus when present is split off in combination with nucleinic substances whose little known transformations it presumably follows until the stage of oxidation is reached.

By the foregoing processes of putrefaction and fermentation the organic matter is resolved more or less completely into ammonia, and simple non-nitrogenous carbon compounds. In the presence of air these substances are still further changed by bacteria into their oxidation products. Just as we saw a series of bacteria, proteid bacteria, peptone bacteria, and amido-bacteria convert nitrogenous organic matter from proteid to ammonia, so now we have to note ammonia bacteria and nitro-bacteria which carry the matter further, in fact up to the final condition of nitrates. The first stage called nitrosification consists of the combination of ammonia with atmospheric oxygen to form nitrites; the second stage called nitrification consists of the combination of the nitrites with more oxygen to form nitrates. The complete process needs the intervention of two kinds of bacteria responsible respectively for the two stages of the process. The ammonia-bacteria or nitroso-bacteria can attack ammonia and oxidise it to but not beyond nitrite, the nitro-bacteria cannot attack ammonia but are able to convert the nitrite into nitrate. By similar processes of oxidation the non-nitrogenous sugars, alcohols, glycerine and fatty acids are converted into carbonic acid and water.

It scarcely needs to be pointed out in relation to sewage purification that the putrefactive and fermentative changes, giving rise to ammonia and carbonaceous derivatives occur principally in the tank, whilst the final oxidations take place in the filter. The restriction of the two kinds of processes to one or other place is not absolutely rigid, but may for practical purposes be regarded as being so. The theoretical end products, nitrates, carbonic acid, and water are reached by the greater part of the material, but insignificant amounts of more complex substances may be present in the final effluent.

The foulness of the tank effluent is a character impressed upon it by the fact that the bacteria concerned work in the absence of free oxygen. All bacteria require oxygen,—they must breathe so to speak,—and the majority take their oxygen from the atmosphere as we do. Some cannot get it elsewhere; many whilst prefering to take it from the air, can at need obtain it from other sources; whilst others again habitually make use of sources other than air, in fact cannot endure the presence of air. The bacteria of the first kind are called obligate ærobes, those of the second kind facultative anærobes, those of the third kind obligate anærobes. In nature the ærobes work upon the surface, the anærobes in the interior, of decomposing matter. In septic tanks the conditions are practically anærobic by reason of the work being done under the surface of the fluid and under the scum; consequently the bacteria in occupation are the facultative and obligate anærobes. As already stated these bacteria obtain their oxygen from sources other than air, and the available source in sewage is the organic matter present. This is exploited for oxygen by the obligate anærobes because they prefer such sources, and by the facultative anærobes because they must use them in default of atmospheric oxygen. It appears, however, that the oxygen is not quite readily yielded to them; its connections with the organic matter resist severance. The task of obtaining it is much more difficult than when, as in the case of the ærobes, the source is the free oxygen of the atmosphere. The consequence is that the anærobes obtaining but little oxygen from each piece of material attacked, are obliged to work over a large quantity of it in order to obtain the amount of oxygen they require. Thus the decomposition effected by them if only superficial, nevertheless affects a great mass of matter. It is, moreover, rapidly produced owing to the greediness of the bacteria for oxygen, or, if we may so express it, owing to their being compelled to breathe. Incidentally this superficial decomposition involves the production of malodourous substances; endol, skatol, and phenol compounds, which with sulphur bodies are responsible for the distinctive offensiveness of the "septic" process.

How far anærobic processes are essential to sewage purification is a disputed point upon which we need not enter in this place. It is very generally applied by means of the septic tank, and if applied the point of importance is to secure the anærobic conditions as strictly as possible in order to force the bacteria to break up the organic matter for oxygen, It is conceivable that there are bacteria which would work best when the oxygen supply is limited rather than actually absent, and by utilising their services the degree of purification might be higher. To some extent perhaps the present tanks supply this condition, but they are meant to work anærobically and are desirably best devoted entirely to that purpose. If we wished to apply the semianærobic conditions just referred to, we could interpose a second tank or bed designed for the purpose.

As might be expected from the amount of oxidation that goes on there, the bacteria concerned in the work of the filter are obligate or facultative ærobes. The amount of ammonia and carbonaceous matter to be oxidised is such that the filter must be well supplied with air. This is effected either by alternate filling (contact) and emptying (æration) of the filter, or by arranging for the distribution of the fluid over the filter in such a way that whilst it is continuously trickling through, it at no time floods the bed or prevents the presence of air in the spaces (percolation). The excess of air in the bed removes the products of the bacterial action; accumulation of which materially impedes their work. The arrangement of these matters to the best advantage are preferably determined for each filter by special idvestigations of it. It is evident from the analytical results that the purification is frequently not carried to the degree shewn to be possible by natural events. The installations as we now know them are not so perfect that they cannot be improved upon, and a detailed study of the conditions in each case offers the most likely prospect of getting the best work out of them.

We have not burdened our paper with the question of the species of bacteria concerned in the decompositions we have endeavoured to describe. For although there is available a certain amount of information about them, there is so much still to be learnt, that the subject at the present time is one for investigation rather than discussion. They are generally self-provided; that is to say, they enter the installation with the sewage, so that the supply of them is generally a matter which regulates itself. In the management of the installations however, it is necessary to remember their existence and their needs, and to provide accordingly. The more important principles to be borne in mind in this connection merit brief reference.

In the first place acidity of the decomposing material is to be avoided. Bacteria hate acids. Any marked degree of acidity of the medium disturbs them so much that they work sluggishly or not at all. Excessive alkalinity is also objectionable to them. The majority of them desire a neutral or nearly neutral medium, although they will support moderate alkalinity. As a rule the changes in the sewage itself regulate this matter, but the artificial neutralisation of acidity may be of importance in dealing with certain kinds of sewage, for example milk factory drainage containing lactic, butyric, and other acids formed from milk.

Secondly bacteria are capable of working only within certain temperature limits. Individual species best perform their functions within the range of a few degrees on each side of what is called the optimum temperature for them. Thus it is said the nitrifying bacteria work most effectively when the temperature is between 85° and 88°F. But the activity of bacteria is generally not seriously impeded unless the temperature approaches maxima and minima not likely to be encountered in this climate.

Thirdly bacteria are susceptible to the influence of light. Direct sunlight is very lethal, often killing them in a few hours. It is said to be able to act through a depth of four or five feet. This fact would appear to afford a good reason for covering the installations in this part of the world.

Fourthly, moisture is essential to bacteria; but in sewage they have it in abundance, so that there is no difficulty on this account. But in view of statements to the effect that the degree of purification is influenced by dilution the question is not altogether removed from consideration in practice.

Fifthly and finally the bacteria must be allowed sufficient time to do their work. Data upon this point are given by various observers, and are useful as guides in the first instance. But obviously the time required depends upon the amount and kind of material to be purified in relation to the number (and species) of bacteria present, and their state of activity for the time being. Whilst getting the utmost out of them it is desirable that they be not overworked. It would seem best therefore to determine the time to be allowed by observations made under the particular circumstances in each case.

The foregoing references to ærobiosis reaction, sunlight, temperature, moisture and time may be regarded as a hint that the successful use of biological installations demands consideration for the little workers concerned in the purification processes. They do not need cherishing exactly; they can very well take care of themselves as a general thing. But in relation to the biological purification of sewage regard for them and their interests means regards for ourselves and our interests. Therefore in our management of the installations we should not be guided by any presumptive rules, nor conduct them as if the working factors could be mathematically expressed once and for all time. The process depends on the activity of living creatures, which, if small, are nevertheless influenced by their needs and surroundings just as higher forms of life are so influenced. It is important to remember this, and to be ever on the watch to safeguard their well being. In public installations, dealing with sewage which varies from time to time, continuous and skilled scrutiny of what is happening at each stage of the process alone can afford the information necessary for the suitable adjustment of the conditions to the requirements of the moment. It is to be recollected that the changes involved are concerned in the circulation of the carbon, nitrogen, oxygen, and hydrogen, that make up the world's food material, and as such are of immeasurable importance in the economy of nature. In order to avail ourselves to the fullest extent of the services of the living agents fulfilling this fundamental office, we must have regard for their necessities of life. If we force them into unnatural situations we must take care that the conditions there are favourable to them, or at least are not such as to impede the activities we wish them to display. If we desire the honey, we must have some thought for the bees.

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