THE HISTORY OF SEWAGE DISPOSAL

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The History of Sewage Disposal

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INTRODUCTION

The History of Sewage Disposal was selected as the subject for this thesis. The first quarter of the work deals strictly with the history of the development of sewerage practice. After modern sewage disposal methods came into operation the theory and operation of the different processes were condensed to thesis form. The information in this thesis comes from recognized authorities in the field of sanitary engineering.

HISTORICAL

Curt Menckel, the antiquarian of engineering, dug up the first record of a sewer on an old Babylonian cylinder. Layard found some arched sewers in Nineveh and Babylon going back to the Seventh Century before Christ. Considerable information on the sewers of Jerusalem has been unearthed by Schick and Warren. The works of this class in Grecian cities are fairly well known, and the great underground drains of Rome have been described repeatedly.

It must be pointed out; however, that these sewers were not connected to residences. It would have been considered an invasion of the rights of an individual to have compulsory sanitation at that time. Livy states that the Roman building regulations only stipulated that the house connections were to be made at the cost of the property owners.

Most of the people used public latrines and the gutters were probably the chief receptacle of the waste of the city, which was then washed into the sewers. These sewers must have been extremely offensive when not flushed for the old Roman water commissioner Montinus posted this order: "I desire that nobody shall conduct away any excess water without having received my permission or that of my representatives, for it is necessary that a part of the supply flowing from the water costles shall be utilized not only for cleaning our city but also for flushing the sewers."

The beginning of modern sewerage practice started in Hamburg, Germany after a fire destroyed a part of that city in

1842. The rebuilding of that portion of the city was intrusted to an English engineer, W. Lindley, who carried it out in such a way as to draw warm praise from engineers of a later period after the test of time had been applied on his plans. Twenty five years after the sewers were completed they were found to be clean and almost without odor by a committee of experts.

The sewerage of Hamburg cannot be looked upon as typical, however. In rebuilding the city it was more the result of business shrewdness and taking advantage of exceptional local conditions to plan sewers and streets as to the needs of the community and the topographical conditions rather than a real appreciation of the value of sanitation.

The history of the progress of sanitation in London affords a more typical picture of sanitation practice around the middle of the Nineteenth Century in the largest cities of both Great Britain and the United States.

The legal basis for sanitary works in England in the Nineteenth Century was a statute passed in Henry VIII's reign in 1531 and amended in that of William and Mary. For three hundred years sanitation was not even thought of, evidently. As late as 1845 there was no survey of the metropolis adequate as a basis for planning sewers. The sewers in adjoining parishes were at different elevations so that junctions were impracticle. Some of the sewers were higher than the cesspools which they were designed to drain, while in others, to be of any use, the sewage would have to run up hill. There were cases of large sewers discharging into small sewers.

John Phillips, the first engineer to make a comprehensive study of London severage needs in an official capacity gave this report in 1847:

> "There are hundreds, I may say thousands, of houses in this metropolis which have no drainage whatever, and the greater part of them have stinking, overflowing cesspools. And then there are also hundreds of streets, courts and alleys that have no sewers; and how the drainage and filth are cleaned away and how the miserable inhabitants live in such places, it is hard to tell.
>
> In pursuance of my duties from time to time, I have visited very many places where filth was lying scattered about the rooms, vaults, cellars, areas, and yards, so thick and so deep that it was hardly possible to move for it. I have also seen in such places human beings living and sleeping in sunk rooms with filth from overflowing cesspools exuding through and running down the walls and over the floors.... The effects of the effluvia, stench, and poisonous gases constantly evolving from these foul accumulations were apparent in the haggard, wan, and swarthy countenances and enfeebled limbs of the poor creatures whom I found residing over and amongst these dens of pollution and wretchedness."

Cholera outbreaks in India in 1847 scared the 1848 Parliament into creating the Metropolitan Commission of Sewers to improve the sanitary condition of London. That body and its successors in the office failed to measure up to their opportunities. They produced reports showing clearly the need of extensive sewerage works and built the Victoria sewer at great expense, which fell into ruins not many years later. Cholera broke out again in London in the summer of 1848 claiming 468 victims. It broke out in the spring of 1849 and before it ended 14,600 deaths were recorded. It broke out again in 1852, gained a foothold in 1853, and in 1854 it claimed 10,675 in the last half of the year. A contaminated water supply was credited with spreading the disease but it was also apparent that the filthy living conditions in most houses, due to the abence of effective sewerage, was a great hinderance in combating the scourge.

In 1855 Parliament passed an act "for the better local management of the metropolis." This laid the basis for the sanitation of London and provided for the Metropolitan Board of Works which soon after undertook an adequate sewerage system. Two men, J. W. Bazalgette and W. Haywood, were responsible for many of the basic assumptions upon which the plans were prepared. The work started in 1852 but no action was taken on the plans until 1859 due to so much criticism from engineers and laymen. In designing the great intercepting and outfall sewers, Bazalgette adopted a mean velocity of 2.2 feet per second as adequate to prevent silting in a main sewer half full. The sewage was estimated at the assumed water consumption, 5 cubic feet per capita daily. One half of this sewage was assumed to flow off within 6 hours. The storm water runoff, for which provision was made, was a rainfall at the rate of $\frac{1}{2}$ inch per day received during the 6 hours of maximum sewage flow, with overflows to discharge the excess due to larger amounts through some of the old sewers directly into the river.

As might be expected, these estimates proved too low and flooding took place in low-lying districts. The minimum mean velocity selected is a little higher than that commonly accepted by present day engineers. Prior to Haywood and Bazalgette's work on the London intercepting sewers, Phillips and Roe were prominently before the public as sewerage experts, and among English-speaking engineers Roe's Table was used for many years in selecting the size of sewers. It was acknowledged to be entirely empirical and was said to be based on Roe's observations of the London sewers during more than 20 years. It gave the areas which could be drained by sewers of various sizes and on various slopes, as indicated by that experience. Roe's Table was not accepted by some contemporary London Engineers, however, including W. Haywood, engineer of the city who said there were no reliable gagings of London sewers in existance and that he had never been able to obtain any accurate information regarding such work from either Phillips or Roe.

Sewerage progress was less opposed elsewhere in England apparently. In 1848 Parliament passed a sanitary code applying to all parts of England and Wales except London, and in 1855 it enacted a nuisance removal law for all England. These laws were the basis of the subsequent sanitary progress outside the metropolis for many years. The development of sewerage undertakings in England was a direct result of the awakening of the people by a succession of epidemics of Cholera, for progress did not begin until that disease had twice terroized the country within a short period.

The sewerage system of Paris was also inargurated as a result of a Cholera epidemic. The first attempt to study the sewerage needs of the city comprehensively apparently was made in 1808, when there were 14½ miles of drains with about 40 outlets into the river Seine, and during the next 24 years about 10½ miles more of drains were constructed. In 1832 the ravages of Cholera awakened the authorities to a partial realization of the city's insanitary condition. The following year a topographical survey was made and, with the aid of the maps based upon it, five systems or divisions of severage were planned, based on topographical features of the territory rather than on the administrative boundaries which caused so much delay in the development of rational severage works at London.

The new severs built in Paris from 1833 onward were made 6 feet or more high wherever possible, in the belief that the workmen employed in cleaning them would discharge their duties more efficiently if they could labor without being forced to take unnatural positions.

Although there has been a great deal of criticism of the large Parisian sections, it has generally not been taken into account that the severs of that city were built with a view to removing street refuse as well as sewage and rain water.

An interesting feature of the work inaugurated in 1833 was its recognition of the principle of interception. Longitudinal drains of large section were laid out parallel to the river and only 3 of the 40 old mouths of independent severs were left in service, the remaining systems being made to discharge into the intercepters. The rain water falling on the roofs was taken at first through leaders to the gutters, but later was diverted in some cases to the large "house drains" with sections big enough for a man to walk through, connecting the houses with the severs but used only for delivering waste water and not for excrementitious matter. The latter was discharged for many years into cesspools, one frequently serving for an entire block of houses.

About 1820, after the whole subsoil of Paris was on the point of becoming putrid with cesspit matter, the Parisians commited the mistake of insisting on cesspool construction by ordinance. The odors from the cesspools finally became so offensive that a new system of sewerage was developed.

At that time European sanitarians were divided into two schools, advocating respectively the "dry" and the "water-carriage" methods of collecting excrementitous matter. In the former this matter is collected and removed in pails, and in the latter it is flushed into the sewers. The "dry" method was used only when it was impractical to discharge sewage into the city sewerage system due to topographical obstacles difficult to overcome.

Little is known of the early sewerage works in the United States. Often they were constructed by individuals or the inhabitants of small districts, at their own expense and with little or no public supervison.

There was a tendency in this country, as elsewhere to construct the early sewers of needlessly large dimensions. One of the oldest sewers in Brooklyn was in Fulton Street. Although it drained an area of less than 20 acres and was on a grade of 1 in 36, it was 4 feet high and 5 feet wide. For many years the largest sewer in Manhattan was that in Canal Street, built somewhere between 1805 and 1810; it was 8 by 16 feet in section and by 1850 was in very bad condition.

In some cases, the sewers were not only very large at their outlets but were continued of the same size to their heads. It was impossible to secure adequate velocity in such sewers unless they were laid on steep grades, and consequently some of them became offensive when the sludge accumulating in them underwent decomposition. In some cases, in fact, the slopes were in the wrong direction.

It should be noted that sewers sere constructed orginally, both here and abroad, for the removal of storm water. All excreta was excluded from the London sewers until 1815, from those of Boston until 1833, and Paris until 1880. In 1847, the connection of houses and cesspools to the sewers was required by law in London, while in Baltimore even as late as 1922 20,000 houses remained unconnected with sewers.

The first application of engineering skill to the design of American sewers was in 1857, when Julius W. Adams was appointed to prepare plans for the sewerage of Brooklyn, N. Y. For many years thereafter the Brooklyn sewers served as models. In 1858 E.S. Chesbrough submitted his first report on a comprehensive sewerage system for Chicago, Illinois. In 1874 J. Herbert Shedd established the basic principles for the design of a sewerage system at Providence, R. I. Two years later a committee consisting of Messrs. E.S. Chesbrough, Moses Lane, and Dr. C.F. Folson, reported on the sewerage of Boston, Mass., advocating the general plan now in effect.

The United States suffered, just as England did at an earlier date, from the improper design of separate systems of sewerage in which the house sewage and rain water are kept separate. Just who designed the first system of sewers for removing house sewage separately is not definitely known, but the principle was advocated as early as 1842 by Edwin Chadwick. He has been called the "father of sanitation in England", and unquestionably played an important role in arousing that country to the need of greater cleanliness, not only in cities, but in rural districts as well.

Chadwick, then a man of convincing address, treat self reliance, enthusiasm, and strong imagination, had little technical knowledge. As a result he advocat ed, even in meetings of engineers, so-called hydraulic principles and some features of design that were wholly incorrect, which at last resulted in his being publicly branded as a quack at a meeting of the Institute of Civil Engineers at which he was in attendance.

However, the principle of the separation of house sewage from rain water, advocated by Chadwick, was meritorious for many places that it was developed along rational lines by a member of leading English engineers. Sir Robert Rawlinson, whose "Suggestions as to Plans for Main Sewerage, Drainage, and Water Supply", published by the Local Government Board did much to prevent the laying of sewers of too small size and poor alignment, without proper facilities for cleaning which is likely to be necessary in all such works.

The separate system received much study by American engineers, as was natural in view of their reliance on English practice for precedent. Fortunately, however, the difference between the character of the rainfall in England and the United States was known here and its influence on the design of sewerage works was appreciated. The English rains are more frequent but less intense, and hence our storm-water drains must be larger for like topographical conditions.

Wherever the surface drainage could be cared for satisfactorily at a low cost without the use of large combined sewers receiving both sewage and rain water, there was a manifest advantage in adopting the separate system, providing only the sewers and leaving the building of storm water drains for the future. This was done at about the same time (1880), in designs prepared by Benezette Williams for Pullman, Illinois, and George E. Waring, Jr. for Memphis. The Memphis system was the most conspicuous although a comparative failure, a fact which the people of that city naturally suppressed for business reasons for many years.

By 1882 the main lines in some places were reported by the city engineer, Niles Meriwether, to be taxed to their full capacity. The inadequate capacity of the larger sewers resulted in the construction of a relief sewer during 1885-1886. Engineers familiar with the conditions were convinced that some of Colonel Waring's favorite details had proved defective, and that the Rawlinson type of separate system, with larger pipes laid without vertical or horizontal bends between successive manholes, was preferable. The partial failure of the so-called Waring system was demonstrated, therefore, in about 5 years' experience at Memphis. This was a little longer than was required to demonstrate the same thing at Croyden, England, 30 years before the Memphis experiment. The National Board of Health felt some distrust regarding such systems soon after its formation, and accordingly it sent Rudolf Hering to Europe on a tour of investigation, which lasted nearly a year. On his return he prepared an elaborate report on the principles of severage and their exemplification in the best works of Europe, which outlined the respective fields of the separate and combined systems.

DEVELOPMENT OF METHODS OF SEWAGE TREATMENT

Until about 1920 the disposal of the sewage of most cities, was carried out by the easiest method possible, without much regard to unpleasant conditions produced at the place of disposal. Irrigation with sewage was apparently practiced at ancient Athens, but there is very little definite information on any methods of disposal on land down to about three hundred years ago, when sewage farming was successfully introduced at Bunzlau, Germany. The earliest municipal work of the kind in Great Britain was on the Craigentinny meadows of about four hundred acres extent, receiving the sewage of a part of Edinburgh for about a century. The subject of disposal received only occasional local attention, however, until the constructions of sewerage systems after the cholera epidemics of 1832-1833 and 1848-1849. Owing to the small size of British streams, their pollution by the sewage discharged into them soon became a nuisance. Interference with agricultural and manufacturing uses of water was apparently at first given more attention than possible danger to health. The comprehenseive Nuiscances Removal Act of 1855 nor the Rivers Pollution Prevention Act of 1876 made sewage treatment compulsory. A royal commission made these recommendations in 1865:

"First, that whenever rivers are polluted by a discharge of town sewage into them, the towns may reasonably be required to desist from causing that public nuisance.
Second, that where town populations are injured or endangered in health by a retention of cesspool matter among them, these towns may reasonably be required to provide a system of sewers for its removal."

In 1880 the discovery of the bacillus of typhoid fever, by Eberth in Germany, marked the beginning of a new era in sanitation. Previously, the relation of pollution to disease had been but faintly understood, as the science of bacteriology was in its infancy, and its application to matters of stream pollution and sewage disposal had not been grasped. In 1877 Schloesing and Muntz, in France, and in 1882, Robert Warington, in England, proved conclusively that the oxidation of ammonia and organic matter was affected by the agency of living organisms, and Warington proceeded to devise practical methods whereby living organisms could be utilized for the nitrification of the organic matters in sewage. Later, through the studies at the Lawrence Experiment Station of the Massachusetts State Board of Health, the fundamental biological conditions underlying the oxidation processes of sewage treatment became established.

Two methods of treating sewage had been in vogue before this time. The irrigation of land by sewage was the older of these, but the precipitation of the solids and some of the dissolved matter by chemical treatment and subsequent sedimentation attracted more attention owing to its exploitation by promoters as well as to the favorable opinion of it held by many careful and conservative engineers.

The density of population in England and the very small amount of land well suited for sewage farming and filtration led to particular interest in intensive methods of treatment, whereby in plants of comparatively small area the sewage was rendered suitable for a final treatment on land, which was practically compulsory for most English systems discharging into fresh water. This constraint was exercised by the Local Government Board, without whose approval money could not be raised for public works except by a special act of Parliament. The Board required a final land treatment until recently. Consequently septic tanks, trickling filters, and contact beds, which were rapidly developed after the underlying biological factors had been determined, were received with acclamation and tested on a practical scale that was unwarranted, for instance, in Germany.

The disposal of sewage in the United States did not receive so much attention 40 years ago as in England, because the extent of the nuisance caused by its discharge into the relatively large bodies of water was not so marked. Also we had greater area of land suitable for broad irrigation or intermittent filtration on beds grated in situ, and because of relatively cheap materials suitable for the construction of artificial treatment beds in some localities where pollution was objectionable. Its importance was foreseen by the Massachusetts State Board of Health early in the seventies. It's secretary, Dr. C.F. Folsom, made a careful study of disposal in Europe, which resulted, in 1876 in a report which was the most complete statement that had been made of the state of the art at that time. Irrigation and filtration were introduced in a few places, but it was not until certain rivers in Massachusetts became quite offensive that any work on a large scale was undertaken. The first extensive treatment plant utilized chemical precipitation and was built at Worcester, Mass., in 1889-1890, from the plans of Charles A. Allen with the advice of James Mansergh of London and Professor Leonard P. Kinnicutt of Worcester. It was about this time (1877), that the Massachusetts State Board of Health, which had been given large powers of control over the disposal of sewage, established the Lawrence Experiment Station for the study of both water and sewage treatment. The influence of the research work done there has been deep and far reaching, as above noted, being particularly noteworthy for the prominence given in early years to intermittent filtration, a method of disposal neglected in England on account of the limited tracts of land suitable for its practice. The increasing demand for sewage treatment and the impracticability of procuring sufficient areas of suitable soil for land treatment in many localities led to the rather wide adoption of more intensive methods of treatment.

SEPARATE SLUDGE DIGESTION

As the decomposition or digestion of organic matter is produced by natural organisms, the process of digestion has been in existence since the beginning of life, where-ever natural physical, chemical, or climatic conditions have permitted the development of these organisms in organic material. Man utilized this process in the disposal or treatment of sewage sludge long before he knew that a micro-organism existed or understood its activities. The reduction in volume of solids in privys and cesspools under certain favorable conditions and the rapid accumulation of solids in exposed vaults or pits during cold weather, were evidences of the activities of the natural process.

Cameron, an English engineer, is credited as being the first to discover, in about 1895, that by settling the organic matter out of sewage and retaining the settled matter in a tank, certain anaerobic organisms would break down the organic compounds into liquid and mineral compounds.

The production of odors, the stale over-septicized effluents at times, and the difficulties attendant with the disposal of sludge mixed with undigested matter arising from the use of this method of settling and digestion caused engineers to study and experiment in remedial measures and devices.

In 1899 the first attempt at scientific study of separate sludge digestion was made at Lawerence Experiment Station, Massachusetts. A few years later, Travis, another English engineer, designed a two-story hydrolytic tank at

Hampton, England. In 1907, the Imhoff type of two-story tank, designed and patented by Dr. Karl Imhoff, German engineer, was first placed into operation at Recklinghausen, Germany. The Imhoff tank design was a big step in the solving of mechanical devices for separation of settleable solids from the sewage, prevention of over-septicized effluents, and a method of selecting well digested sludge for drying on sludge beds. The uneven rates of sludge digestion, the foaming of the gas vents, odors caused by gases of decomposition, the necessity for providing large sludge storage capacities, which frequently resulted in excessive construction costs, led to further scientific research.

The first step was the design of the true type of separate sludge digestion plant, i.e., the sedimentation of the settleable solids in a tank designed for efficiency in rapid sedimentation, with the continuous removal or removal at frequent intervals, of the sludge by gravity or mechanical methods, to a separate digestion tank. The isolation of the sludge in a separate tank facilitated the study and research in the causes and changes of biological growths, chemical reactions, and other physical factors that speed or retard the process of digestion. The knowledge of these governing factors has been acquired from the work of chemists, bacteriologists, and research engineers during 1920-1930. Those scientists, by accurate laboratory experiments and actual operation of plants on a comparatively large scale, have given the designing engineer definite formulae and facts for use in design of a sludge digestion plant and have furnished the operator with comparatively simple devices for tests and instructions for control of the chemical and biological balance.

STRUCTURAL DESIGN PROGRESS

Through the necessity of disposing of accumulated undigested sludge, lagooning was probably the first crude attempt at separate sludge digestion. The design was simple-a dug pit or areas surrounded by embankments and "let nature take its course". Ample isolation of these lagoons was essential. Sludge lagooning is still practiced at a few plants. Up until about 1926 it was the method of digesting and disposing of sludge from the activated sludge plants at Houston, Texas, and is still used at some of the smaller activated sludge plants as well as some of the other types of treatment plants.

The design of the two-story tank was the first development of separate sludge design. The general types are circular with radial flow, rectangular with horizontal flow, and horizontal flow with circular digestion compartments. The upper compartment, comprising the settling chamber was originally designed for a retention period of two to four hours, but later experiments demonstrated that a large proportion of settleable solids are deposited in the first hour, so the period of retention has been shortened for the benefits of a fresher effluent and economy in construction. The settling chambers were provided with steep sloping bottom walls suspended over the lower lapping openings at the

bottom to allow the settling of the solids to pass down into the digestion chamber and prevent gas-laden sludge particles from re-entering the settling compartments.

The capacities of the sludge digestion compartments in the early designs in America, were based upon the experience and recommendations of Imhoff as adopted for conditions in Germany or approximately one cubic foot capacity per contributing capita. For conditions in the United States, it was soon apparent that larger capacities were necessary due to greater strength of sewage and perhaps more sever general physical and climatic conditions and in general, the practice has been adopted in this country of designing sludge digestion capacities for two to two and one half cubic feet per capita.

Foaming in the gas vents has brought forth various devices for scum breaking; liming, gas release by vacuum, and design of larger gas vent areas being some. Among the first comprehensive studies as to the conclusions made on the causes of foaming were those made by Eddy, whose work and conclusions derived therefrom were published in Trans. Am. Soc. C. E. 1925 Vol. 88.

The control of gas odors from Imhoff tanks later brought about the installation and development of gas collection and burning devices.

As sewage sludge presented an annoying problem in sewage treatment, the separation of sludge into separate compartments for digestion, thereby treating it as a more or less separate problem, was probably the real reason for the development of the true separate sludge digestion design. Although some of the early designs were occasioned by the necessity of providing additional sludge storage due to under-designed sludge capacities of other types of plants or the overlooking of older plants.

The design of the settling chambers may be of the radial-flow or horizontal-flow type. The transfer of the settled sludge to the digestion chamber may be accomplished by gravity from hoppers in the bottom of the tank, or by mechanical means, operated continuously or at intervals as the local conditions may require. The latter process is the most popular and satisfactory in the majority of present installations.

The form of digestion tank may be rectangular or circular, depending upon size of plant, local physical conditions and economy of construction.

The early design digestion tanks were without covers or with only a loose board cover. In more recent installations the benefits of heating and keeping the scum submerged for more rapid and thorough digestion, as well as the collection of gas for odor control, heating, and other utilization of the gases have brought forth the use of tight covers of the floating, or the submerged type.

To accomplish the more rapid and uniform digestion of sewage sludge, to control the digestion temperature, to regulate the mixing and seeding, and to control the chemical balance, to control the odors and gases, and to utilize the gases for heating and power, and to deliver an innocuous odorless product, these factors have transformed the design of a sewage treatment plant from the simple lay-out of a settling basin and decomposing vat, to a design with the intricacies and completeness of a modern industrial plant. Such has been the progress in design.

RESEARCH DEVELOPMENTS

The discovery that the decomposition of organic materials was caused by living organisms was probably the first step toward the more recent research experiments and developments. Biologists classified these organisms as anerobes. Analysis by chemists determined the resultant compounds, which were produced by the decomposition process. However, it has been only within the last few years that the research and experimental work have led to definite, workable information that is rapidly solving the annoying problems of sludge digestion and disposal.

In the cycle of digestion of fresh sludge, the first products give an acid reaction, followed in the later stage by the production of an alkaline reaction. Rudolfs* derived from experiments at New Jersey Sewage Station, that the most rapid digestion occurs when the reaction is slightly alkaline, with a pH of 7.3 to 7.6. Baity** observed from experiments that rapid digestion occurred when the reaction was between pH 6.9 and 7.4.

*Willem Rudolfs, Chief Dept. of Sewage Disposal, New Jersey Agricultural Experiment Station.
**H.G. Baity, Assoc. Professor, Sanitary Engineering, Univ. of North Carolina.

Karl Imhoff in "The Arithmetic of Sewage Treatment Works" recommends for good digestion a pH value of 7.0 to 7.6.

In order to maintain a proper balance for most rapid digestion or to rectify an acid condition, lime is used in a number of plants. However, in the natural process of sludge digestion there are two opposite reactions. Rudolfs, Baity, Fair,* Fischer,** and others, have demonstrated in experiments as well as in actual plant operation that the devices for seeding, mixing, and proportioning of fresh with well ripened alkaline sludge, this balance may be maintained without artificial control. Imhoff recommends the daily addition of fresh sludge not to exceed 10% of the volume of sludge in the tank. The effects of temperature on the rate of sludge digestion is another valuable factor that has been demonstrated and proved by research experiments as well as in the actual operation of plants.

In addition to the established facts for the digestion of primary sludge, Rudolfs and Heisig*** have experimented with the digestion of screenings and activated sludge at Milwaukee, Wisconsin, and have obtained favorable results. Their conclusion is that in the digestion of activated sludge it digests more rapidly than fresh sewage and no greater digestion capacity is required. Imhoff recommends returning the excess activated sludge to the preliminary

*Gordon M. Fair, Assoc. Prof.of Sanitary Engineering, Harvard Univ.
**Anthony I. Fischer, Research Engineer, The Dorr Co. N.Y.C.
***H.M. Heisig, Research Chemist, Milwaukee Sewage Commission.

clarifier and providing practically double capacity in the digester over that required for primary fresh sludge.

No phase of sewage treatment has received more study and the progress and the improvements have been more rapid in the past few years, than the problem of sludge digestion. The laboratory experiments have been correlated with actual operation conditions to determine and establish the important factors in the digestion of sewage solids.

The use of sewage gas for fuel has come under some rather intensive study in recent years. The first use as a fuel was in connection with the hot water boilers which heated digester coils and all or part of the treatment plant buildings. Then internal combustion engines were developed using sewage gas with only minor modifications from the engines that use liquid fuels. These engines are used mostly for driving generators, pumps, and blowers.

With the present developments being made and the interest being shown in separate sewage digestion, we may expect further progress in the future.

MODERN DEVELOPMENTS

Generally speaking, oxidation of sewage is accomplished by two treatment processes, (1) filtration and (2) activated sludge.

Filtration units may take the form of (a) intermittent filters, (b) contact beds, or (c) trickling filters. An intermittent filter is a specially prepared bed of sand, or other fine grain material, on the surface of which sewage is applied intermittently, and from which the sewage is removed by a system of underdrains. This treatment is among the earliest developed, but it has been restricted to localities where satisfactory filtering sand is available. In 1934 at least 610 municipal intermittent sand filter plants were in operation, of which 76% were in 7 states. The chief advances in this process, during its existence of 50 years, were in drainage and methods of dosing, accompanied by an appreciation of the value of pre-settling to increase the rate of dosing and thereby decrease the required area. The largest number of plants is to be found in the smaller cities of Texas where they are called Dunbar beds. Here, a favorable climate, large area, and available filtering material offer desirable conditions for these plants.

The Texas State Department of Health recommends that Dunbar beds consist of 18 inches of coarse sand, 12 inches of graded stone, and 18 inches of 3-inch stone, with the terra-cotta pipe underdrains. The dosage rate recommended for settled sewage is 1.2 million gallons per acre per day to deliver a moderate-grade effluent.

In the operation of an intermittent sand filter one dose per day is considered an ordinary rate of application, although some plants operate with as many as four doses per day per filter, and others on one dose at long and irregular intervals. It is not always necessary to rest the filter for any length of time unless signs of overloading and clogging are shown. The intermittent dosing action may be obtained by the action of automatic siphons, by other automatic processes, or by the manual operation of valves. The sewage is distributed on the beds through a number of openings in the sides of distributing troughs resting on the surface of the filter. The sewage is withdrawn from the bottom of the filter through a system of underdrains, into which it enters after its passage through the bed. There are no control devices on the outlet, as the rate at which sewage is delivered to it controls production. The action of the dosing apparatus should respond quickly to variations in sewage flow. As the doses are applied to a sand filter, a mat of organic matter or bacterial zoolea is formed on the surface of the bed. The mat is held together by hair, paper, and the tenacity of the materials. It may attain a thickness of a quarter to a half inch before it is necessary to remove it. As long as the filter is draining with sufficient rapidity this mat need not be removed, but if the bed shows signs of clogging, the only cleaning that may be necessary will be the rolling up of the dried mat.

In winter the surface of the bed should be plowed up into ridges and valleys. The freezing sewage forms a roof of ice which rests on the ridges, and the subsequent applications of sewage find their way into the filter through the valleys under the ice. In a properly operated bed the filtering material will last indefinitely without change. If a filter is operated at too high a rate, however, although the quality of the effluent may be satisfactory, it will be necessary at some time to remove the sand and restore the filter.

The effluent of a properly designed and operated plant is clear, colorless, odorless, and sparkling. It is completely nitrified, is stable, and contains a high percentage of dissolved oxygen. The efficiency of bacterial removal is between 98 and 99 per cent.

A contact bed is a water-tight tank filled with coarse material, the tank being alternately filled, allowed to stand full, emptied, and allowed to stand empty while the solids in the sewage are deposited on the contact material and subsequently oxidized during the period of standing empty. It was developed by Dibdin in England in 1892. Interest in contact filters is mainly historical since the beds mark a transition in the development of sewage treatment from sand filters to trickling filters. During the "contact period", when the filter is standing full, fresh suspended matter is deposited on the contact material and is worked on by anaerobic organisms. AT the next contact period the material that has been exposed to the air and has been oxidized during the period of standing empty may be washed off the contact material and carried out with the effluent on the next emptying of the tank. The rate of filtration on contact beds, being about 750,000 gallons per acre per day, is relatively slow in consideration of the poor quality of the effluent produced. Attempts to increase this rate by distributing the sewage over the surface of the bed and allowing it to trickle through the contact material led to the production of the trickling filter. As a result of the success of the trickling filter and other more satisfactory methods of treatment, contact beds are no longer in common use.

TRICKLING FILTERS

By a definition a trickling filter is: "An artificial bed of coarse material, such as broken stone, clinkers, slate, slats, or brush, over which sewage is distributed and applied in drops, films, or spray, from troughs or dippers, moving distributors, or fixed nozzles and through which it trickles to the underdrains giving opportunity for organic material to be oxidized by bio-chemical agencies". The trickling filter was originally developed to reduce the area required by intermittent sand filters. Early development work by Col. George E. Waring, Jr., and the Mass. State Board of Health in 1891 and 1892 was important. The first municipal trickling filter plant to go into operation in this country was at Reading, Pa., in 1908 and one of the earliest and best landscaped American installations was the so-called Pennypack plant at Philadelphia, Pa., about 1912.

Much experimental and demonstrative work was done between 1905 and 1918 at Columbus, Ohio; Gloversville, N.Y.; Brooklyn, N.Y.; Philadelphia, Pa.; Worcester, Mass.; Akron and Cleveland, Ohio. Hundreds of municipal installations followed in rapid succession.

During the past 50 years trickling filters have rendered valiant service as a device for the secondary treatment of sewage. They produce a highly oxidized and nitrified effluent of high stability, low B.O.D. and low suspended solids. A humus sludge is procuced in the filters which discharges continuously or seasonally; this material must be removed from the filter effluent by sedimentation or mechanical straining, leaving a supernatent or filtrate that can be sparkling clear.

Filters have demonstrated the ability to handle this treatment task under adverse conditions of variable and shock loadings, weather changes, and other trying conditions. The problems of operation include: manual maintenance of distribution facilities, prevention of surface pooling, control of psycodo flies, and the prevention of odors.

There are two types of trickling filters in general use today: (1) the standard or conventional filter which is designed to receive flows of about 2 m.g.a.d. and an applied B.O.D. of something less than 600 lb. per ac. ft. and (2) high rate filters which are designed for volume loadings from 10 to 30 m.g.a.d. and B.O.D. loadings from 3,000 lb. per ac. ft. upward. High rate filters are relatively new, the first plant scale installation having been made about 1936.

The Biofilter, Accelo-filter, and aero-filter represent 3 types of high rate units. The high rate filters all involve the recirculation of the filter or final effluent, or the final tank underflow back to the primary settling tank or directly to the filter.

The Biofilter process was developed in the Middle West in 1927, the first application on the Pacific Coast in 1932 and the actual practical use of the process at San Mateo, California in 1936. There are now 60 biofilter plants in operation. The largest city plant in the East is at Liberty, N.Y., while Fort Bragg will have a capacity of 4 m.g.a.d. Dorr Company and Link-Belt Company are licensed to install this process. The basic patent involves the recirculation of the filter effluent through the primary clarifier, this recycling producing high effective treatment at high capacity. Dosing rates are at 800 gallons per cubic foot of media per 24 hours. The entire bed is active and all of the bed is wetted. Bed depths of three feet are economical and produce high treatment efficiency. Where greater treatment is desired, two-stage bio-filtration is provided. The beds undergo continuous unloading and the filter acts as a decolloider and as the full equivalent of the activated sludge process.

The history of the Accelo filter goes back to the study made by Sir Franklin in 1868 and the further development by the Lawerence Experiment Station, Mass. in 1887. Investigation demonstrated the ability of using standard beds for high rate filtration. The two factors involved in filter operation are the growth of flora on the medium and time of contact of sewage with this flora. High rate filters maintain this flora and do not decrease time of contact. Continuous filtering is beneficial and high rate operation flushes the solids from the beds and serves to reinnoculate the sewage. Repeat passages of the sewage through the filter improves the efficiency. In the Accelo system the best filtration rates are between 10 and 15 m.g. a.d. B.O.D. removals will vary from 1.5 to 2.8 pounds per cubic yard per day. With complete recirculation, the best rate is 10 mgad, the recirculation resulting in 20 mgad passing through the filters. Media size is 3 to 4½ inch, with smaller stone used in the second stage. Beds of from 5 to 6 feet in depth are best, but shallower beds can be used. The International Filter Company has devised a concrete block mold for the bottom of filters, to assure good ventilation. The two-arm distributor is preferred since it gives good flushing action through the bed.

The Aero-Filter process provides for recirculation of clarified filter effluent back directly to the filter, but only during periods of low flow, in sufficient quantities to maintain a minimum of 10 to 13 mgad flow through the filter.

The Aero-Filter distribution system provides for momentary dosing of 20% of the filter surface by distributor arms (four arms and eight branches) and 100% by discs, classed as low rate-high capacity action.

Aero-filters are designed for 18 mgad, with peak flows of 30 to 40 mgad being handled. The filter depth recommended is approximately six feet. Construction costs for deep, narrow beds were described as lower, with recirculation pumping costs higher. The Aero-filter Process requires a minimum of such pumping. The use of large surface area in clarifiers serving high capacity filters is recommended in order to keep down overflow rates.

SEPTIC TANKS

The septic tank process came about midway in the history of sewage disposal coming after trickling filters and before the Imhoff tank. A.N. Talbot started septic tanks at Urbana, Ill. in 1896.

Septic action is a biological process caused by the activity of obligatory or facultative anaerobes as the result of which certain organic compounds are reduced from higher to lower conditions of oxidation, some of the solid organic substances are rendered soluble, and a quantity of gas is given off. Among these gases are: methane, hydrogen sulphide, and ammonia. The biologic process in the septic tank represents that portion of the cycle of life and death in which complex organic compounds are reduced to a more simple condition available as food for low forms of plant life. The treatment of sewage by septic action, when introduced, promised the solution of all problems in sewage treatment. Septic action is now better understood, and it is known that some of the early claims were unfounded.

The principal advantage of septic action in sewage treatment is the relatively small amount of sludge which must be cared for compared to that produced by a plain sedimentation tank or by chemical precipitation. The sludge from a septic tank may be 25 to 30 per cent and in some cases 40 per cent less in weight, and 75 to 80 per centless in volume, than the sludge from a plain sedimentation tank. The most important results of septic action and the greatest septic activity occur in the deposited organic matter or sludge. The biologic changes due to septic action which occur in the liquid portion of the tank contents are of little or no importance. Among the advantages are the comparative inexpensiveness of the tanks and the small amount of attention and skilled attendance required.

The septic tank has fallen into disrepute because of the better results obtainable by other methods, the occasional discharge of sludge in the effluent caused by too violent septic boiling. Occasionally the odors given off by the septic process are highly objectionable and are carried for a long distance.

ACTIVATED SLUDGE

Although the activated sludge treatment is characterized by high operating costs the method is used by many large and small cities. Large cities prefer this method over any other when complete treatment is required. San Marcos, Texas was the first to put a full sized activated sludge plant into successful operation in the year 1917. About the same time at Milwaukee, Chicago, and Houston, extensive research programs were carried out. Due to its adoption by larger cities, seventy five per cent by volume of all sewages undergoing complete treatment use this method. In 1929, twelve states reported 35 activated sludge plants and in 1936 these states reported 85 plants. In the United States today there are over 170 activated sludge plants. This rate of growth is phenomenal when one considers that American Sewerage Practice is well in advance of the theory of the mechanism of the process itself.

In the activated sludge process, sewage flowing through a tank is brought into intimate contact with air and biologically active sludge previously produced by the same process.

The process, as ordinarily carried out, consists of adding sludge to the sewage in proper proportion, introducing sufficient air to provide enough dissolved oxygen to maintain aerobic conditions, and agitation of the mixture until practically all of the suspended and colloidal matter has been flocculated or absorbed by the floc introduced into and formed in the sewage. The mixture is then conducted to tanks where the floc is removed by sedimentation and the clear supernatant water passes away as effluent. That portion of the sludge which is not required for the treatment of the incoming sewage is diverted and disposed of. The theory of activated sludge may be summarized as follows:

"The first and perhaps most noticeable function of the process is that of coagulating or flocculating the suspended and colloidal matters in the sewage. This action is similar in effect to the well-known chemical coagulation with sulphate of alumina or sulphate of iron and lime, and the floc resembles the chemical coagulum, particularly the ferric hydrate from the ferrous iron and lime treatment.

The floc is a sponge-like mass, or, as ecpressed by Stein, 'an open-mesh network' which, in the process of formation, may envelop, entrap, or entrain colloidal matter and bacteria. The sponge-like structure of the floc offers a very large surface area for contact and this floc appears to be able to absorb colloidal matter, gases, and coloring compounds. When the floc is driven about in the liquid it has a sweeping action by which the colloidal substances may be said to be swept out of the water or it may be regarded as passing a filter through the water instead of passing the water through a filter.

Thus the process appears to be primarily of a physical nature. It has been demonstrated, however, that it cannot be carried out under sterile conditions."

Just what the action of bacteria and other organisms may be is not fully understood. One plausible theory is that the bacteria which are contained in the cell-like structure of the floc feed upon the very finely divided matter and thus relieve the floc of its burden of such substances and restore its faculty of absorption to such an extent that, when introduced into the incoming sewage, the floc efficiently performs its function of absorbing the colloidal matter, which also will be consumed by the living organisms which thus cause regeneration of the floc. It is because of these properties that the sludge has come to be called "activated sludge," a term suggested by Ardern and Lockett.

Methods of improving the activated sludge process are constantly being studied. One recent development is "step-aeration" provided for in the Bowery Bay works in New York. Each aeration tank has four passes. The first pass is used for the reaeration of return sludge, and settled sewage is added a portion at a time at the beginning of the second, third, and fourth passes, instead of at one point at the beginning of the first pass. Thus the settled sewage and active sludge are mixed in steps gradually, instead of rapidly at the beginning of the aeration process.

Thirty three years ago it was demonstrated that a considerable reduction in suspended solids and in oxygen demand in sewage could be obtained with aeration periods of two to three hours in the presence of return sludge. Large-scale tests along these lines at the North Side plant in Chicago, and at the Jamaica, Bowery Bay and Wards Island plants in

New York, supplementing certain small scale tests, have demonstrated that effective results can be obtained in the treatment of sewage with an aeration period of 2 to 3 hours and an air volume of less than one half cubic of air per gallon, as compared with the more conventional 6 hour period and one cubic foot of air per gallon.

At each plant the sewage was first passed through sedimentation tanks and after aeration the mixed liquor was settled in final tanks. In these two cases the suspended solids in the aeration tanks were maintained in the vicinity of 400 and 600 p.p.m. respectively with sludge returned from the final sedimentation tanks. This shortened variety of activated sludge has been called "high rate activated sludge" and "modified sewage aeration." It is particularly applicable where the degree of purification required can be somewhat less than that obtainable with the more complete process. All of this development indicates a trend toward economics in construction and operating costs and yet the maintenance of a fairly high degree of purification.

The high rate activated sludge process differs from the standard rate process not only in having a shorter period of aeration and in using less air per gallon, but requires a lower concentration of suspended solids in the mixed liquor and produces a sludge quite different in character.

High rate biological processes are better suited to the treatment of weak sewage or to sewage which has been well settled in primary tanks having detention periods of 1 to 2 hours. Final treatment in settling tanks of 2 hours detention period is needed to remove the settleable solids.

The design of sewage treatment plants in general and of activated sludge plants in particular is tending more and more to the increased use of mechanical equipment. The design of sedimentation tanks, one of the oldest devices in the history of sewage treatment, is undergoing radical changes. Much study is being given to forms of inlet, means of sludge removal, methods of effluent withdrawal, as well as to the shape of the tanks and relations of length, width and depth as affecting efficiency of sedimentation. Tanks suitable for the sedimentation of raw sewage solids may be quite different from those designed to settle out activated sludge from the mixed liquor. It has been customary to collect the effluent from a rectangular sedimentation tank by drawing it off over a weir in the end wall, at the opposite end from the inlet, but some newer designs provide collecting troughs or weirs set longitudionally in the tank, one on each side, and extending from the outlet end toward the inlet end from one-quarter to one third the length of the tank. For final settling tanks, handling mixed liquor from the activated sludge process, the effluent may be collected through a weir trough located transversely in the tank nearer the inlet end where there is less opportunity for the light, flocculent sludge to roll up the end wall and pass out with the effluent.

Sludge in primary sedimentation tanks can be scraped toward the inlet end, that is, in a reverse direction from the sewage flow, and collected in hoppers. The heavier solids settle out rapidly near the inlet end, whereas with activated sludge, the sludge flows toward the outlet end may be collected in hoppers at that end rather than at the inlet end. The final settling tanks in the Bowery Bay works of the City of New York are operated in this manner.

BARGING

One method of sewage disposal good for a mention only is the dumping of sludge at sea by barging. The City of Elizabeth, New Jersey uses this method. In 1942 the total number of trips to sea was 26; the tonnage handled was 89,050, with the average solids content of 8.26%; and the cost involved was $33,830.20.

In order to make cost figures for sludge disposal comparable at different treatment plants it is customary to dalculate the cost per ton of dry solids. The cost of barging sludge per ton of dry solids during the year 1941 amounted to $4.63 and for the year 1942 to $4.34. The cost for sludge disposal by other methods in this country varies from $3.53 to $7.69 per ton of dry solids. This indicates that the cost of sludge disposal as practiced in Elizabeth, New Jersey is relatively low.

SLUDGE DISPOSAL

The most common method of dewatering sludge is to discharge it upon specially prepared beds of sand on which it is air dried. A portion of the water passes into and through the sand and is carried away by a system of underdrains, while another portion evaporates.

The idea of covering sludge drying beds with a glass structure, like a greenhouse, for the purpose of protecting drying sludge from rain, absorbing the heat of the sun, and permitting of operation at all seasons of the year, originated at the Cleveland sewage testing station in 1913. Results there indicated that, for local conditions, one square foot of glass-covered beds was the equivalent to two square feet of open beds. On the basis of these results, covered beds were installed at Alliance and Canton, Ohio, a few years later. Since then, glass-covered beds have come into comparatively wide use.

In addition to the purposes for which glass covers were first constructed over sludge beds, these covers may afford some control over odors produced by sludge drying. Furthermore, they often effect a marked improvement in the appearance of a treatment plant.

Development and research in the past 20 years have produced tremendous advancements in the treatment of sewage. Until recently, except for advancements in digestion and in power generation from digestion gas, very little progress has been made in new or improved methods of sludge disposal. Even in modern disposal practices the final digested sludge is 90% water and contains some 40% volatile matter, which must be taken into consideration in the ultimate disposal. The process of flash drying and incineration got its start in 1872 when a patent for atomized drying was issued to R. Percy of New York. He patented a method of atomized drying of solids, semi-fluids, and fluids by means of hot air, the atomized material being dried while the particles floated in the air. This was followed by similar patents, most of which were based upon the spraying of a liquid or a slurry into a chamber, where it is mixed with a rapidly moving stream of hot air. The dried solids either collected at the bottom of the chamber or were swept out with the moisture-laden air into a cyclone separator.

Somewhat later, this principle of drying began to be applied to the dehydration of wet mineral and organic materials containing larger particles. In the present development of this process, which is called flash drying, the material is dispersed in a mill, beaten and mixed with a blast of pre-heated air, then swept into vortex separating chambers.

In the preparation of sludge for this process, the wet sludge filter cake from the vacuum filter is delivered to a mixer by means of a belt conveyor. In the mixer it is blended with a portion of sludge which has been previously heat dried. Mixing the wet sludge filter cake with the heat dried sludge, in this manner, produces a flaky product of uniform consistency, having a much lower average moisture content than the incoming wet filter cake. In this flaky form it is readily carried through the drying stage by the high velocity of the hot gases. The blended sludge from the mixer is fed to the inlet of the flash dryer where it meets the hot gases from the incinerating furnace. In the flash dryer the sludge particles are dispersed throughout the gas stream to produce the maximum wetted surface contact with the hot gases. From the flash dryer, the gas-borne sludge particles pass to a cyclone separator where dried sludge is removed from the cooled moisture-laden gases. The circulation of gas and sludge, through the drying system is produced by a fan at the gas outlet of the cyclone separator. The elapsed time from the moment the blended sludge enters the flash dryer until it leaves the cyclone separator is a matter of only a few seconds. A part of the dried sludge leaving the cyclone separator is automatically returned to the mixer for blending with incoming wet filter cake and the rest is withdrawn as dried sludge and incinerated. Sludge digestion gas can be used for additional fuel in the incinerator.

GARBAGE DISPOSAL

In 1934 the idea of grinding garbage for disposal with sanitary sewage was first seriously considered by sanitary engineers. Since that time a great deal of study has been given to this interesting subject. Research has shown that garbage, or food wastes, function exactly like sewage solids and that the sewage works is capable of rendering a dual disposal service for the community.

The first requirement for successful disposal of sewage and food wastes as one water-carried waste is the grinding of the latter material into proper pulp. This is done individually in the homes or by wholesale quantities at the sewage disposal plant.

At Lansing, Michigan, since 1939 garbage formerly hauled to hog farms is now delivered to the sewage treatment plant and, following grinding, ejected under pressure to the sludge digestion tanks.

CHLORINATION

The development of chlorination of sewage and the many uses in sewage treatment has been dramatic. New uses are being suggested with startling frequency until we are almost ready to expect anything and many things from chlorine.

The extensive development in the use of chlorine has been due in part to the flexibility of treatment, to the proven success in many types of application and to the curiosity of numerous research workers who are looking constantly for new possibilities of application of this interesting and active chemical.

Certain of the typical or practical present day uses of chlorine in sewage treatment may be listed as follows:

1. Disinfection of sewage effluents.
2. Prevention of sewage decomposition.
   (a) For odor control
   (b) For control of destruction of concrete
3. Reduction of odors from stale or septic sewage.
4. Improvement in the operation of sewage treatment units.

(a) To aid in sedimentation
(b) To improve operation of trickling filters
(c) To reduce sludge bulking
(d) To diminish the effect of strong fractions of sewage such as supernatent licuor from digestion tanks.

5. Oxygen demand reduction.

6. Grease separation.

DISINFECTION--The purpose of disinfection of sewage effluents before discharge is to remove pathogenic and other bacteria and thus prevent bacterial contamination of streams or other bodies of water used for water supplies, bathing places, or shellfish propogation beds.

REDUCTION OF ODORS--Chlorine has the property of being able to neutralize hydrogen sulphide so that odors from hydragen sulphide gas given off by septic sewage may be reduced by the application of chlorine.

SEDIMENTATION--The efficiency of settling tanks might be improved by the use of chlorine in several ways. Three typical possibilites include:

(a) By keeping the sewage fresh through up sewer chlorination, so that the solids will not be broken up by bacterial action hence will settle more quickly.

(b) Chlorine in combination with iron scrap or copperas to form a ferric coagulant or an iron and a sulphate coagulant, which materially increases the amount of pollutional materials settled out.

(c) Chlorine alone in connection with certain trade wastes has been of some aid through chlorination or packing house wastes at St. Paul to produce a better settling condition of the solids.

REDUCTION IN OXYGEN DEMAND--It is feasible to reduce the oxygen demand and where other more economical procedures are not available this method can be used. Chlorine seems to act in two ways. One, it retards or delays the decomposition, therefore, the need for oxygen so that this action takes place over a section of the stream or after the sewage reached a larger water way, and, second, some chemical reaction takes place which produces complex products which are not susceptible to rapid decomposition or may have a slight disinfecting action.

GREASE SEPARATION--A relatively new application of chlorine as an aid in the removal of grease has been tried in several places. The original studies were reported from Woonsocket, Rhode Island, showing that chlorine combined with preaeration were quite effective in the removal of grease. Another experience from Lancaster, Ohio was reported. Other studies have been made at Baltimore and possibly other places. This combined use of chlorine and air for grease removal has been called aero-chlorination.

SUMMARY

The significant steps in the progress of sewage treatment might be itemized as follows:

1868-1870--Development of intermittent sand filters by Frankland.

1872--Irrigation and farming first attempted in the U.S. at the State Insane Asylum, Augusta, Me.

1876--Study of sewage disposal in England by C.F. Folsom for Massachusetts State Board of Health.

1886--Inauguration of Lawrence Experiment Station, Mass. State Board of Health.

1889--Chemical precipitation plant at Worcester, Mass.

1891--Drying of sludge on open beds practiced.

1892--Dibdin's development of the contact bed, in England.

1894--Introduction of the trickling filter, in England.

1896-1897--Septic tanks started. Tank at Urbana, Ill., by A.N. Talbot.

1900--Opening of the Chicago Drainage Canal. Disposal by dilution.

1908--Installation of fine screen at Reading, Penna.

1909--Introduction of Imhoff tank by Karl Imhoff, Germany.

1910--Investigation by Black and Phelps of dilution in New York harbor leading towards B.O.D. control.

1913-1914--Introduction of the activated-sludge process by Ardern and Lockett in England.

1921--Vacuum filtration of sludge commenced.

1923--First attempt to dispose garbage and sewage, by Fox and Davis at Lebanon, Penn. Developed further in 1933 elsewhere.

1933--Incineration of sludge on large scale at Sanitary District of Chicago.

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