SEWAGE SLUDGE TREATMENT AND DISPOSAL

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FOREWORD

The detailed, descriptive information in this book is based on U.S. patents issued since the late 1950s that deal with sewage sludge treatment and disposal.

This book serves a double purpose in that it supplies detailed technical information and can be used as a guide to the U.S. patent literature in this field. By indicating all the information that is significant, and eliminating legal jargon and juristic phraseology, this book presents an advanced, commercially oriented review of modern sludge treatment as depicted in U.S. patents.

The U.S. patent literature is the largest and most comprehensive collection of technical information in the world. There is more practical, commercial, timely process information assembled here than is available from any other source. The technical information obtained from a patent is extremely reliable and comprehensive; sufficient information must be included to avoid rejection for "insufficient disclosure." These patents include practically all of those issued on the subject in the United States during the period under review; there has been no bias in the selection of patents for inclusion.

The patent literature covers a substantial amount of information not available in the journal literature. The patent literature is a prime source of basic commercially useful information. This information is overlooked by those who rely primarily on the periodical journal literature. It is realized that there is a lag between a patent application on a new process development and the granting of a patent, but it is felt that this may roughly parallel or even anticipate the lag in putting that development into commercial practice.

Many of these patents are being utilized commercially. Whether used or not, they offer opportunities for technological transfer. Also, a major purpose of this book is to describe the number of technical possibilities available, which may open up profitable areas of research and development. The information contained in this book will allow you to establish a sound background before launching into research in this field.

Advanced composition and production methods developed by Noyes Data are employed to bring our new durably bound books to you in a minimum of time. Special techniques are used to close the gap between "manuscript" and "completed book." Industrial technology is progressing so rapidly that time-honored, conventional typesetting, binding and shipping methods are no longer suitable. We have bypassed the delays in the conventional book publishing cycle and provide the user with an effective and convenient means of reviewing up-to-date information in depth.

The Table of Contents is organized in such a way as to serve as a subject index. Other indexes by company, inventor and patent number help in providing easy access to the information contained in this book.

15 Reasons Why the U.S. Patent Office Literature Is Important to You –

1. The U.S. patent literature is the largest and most comprehensive collection of technical information in the world. There is more practical commercial process information assembled here than is available from any other source.

2. The technical information obtained from the patent literature is extremely comprehensive; sufficient information must be included to avoid rejection for "insufficient disclosure."

3. The patent literature is a prime source of basic commercially utilizable information. This information is overlooked by those who rely primarily on the periodical journal literature.

4. An important feature of the patent literature is that it can serve to avoid duplication of research and development.

5. Patents, unlike periodical literature, are bound by definition to contain new information, data and ideas.

6. It can serve as a source of new ideas in a different but related field, and may be outside the patent protection offered the original invention.

7. Since claims are narrowly defined, much valuable information is included that may be outside the legal protection afforded by the claims.

8. Patents discuss the difficulties associated with previous research, development or production techniques, and offer a specific method of overcoming problems. This gives clues to current process information that has not been published in periodicals or books.

9. Can aid in process design by providing a selection of alternate techniques. A powerful research and engineering tool.

10. Obtain licenses – many U.S. chemical patents have not been developed commercially.

11. Patents provide an excellent starting point for the next investigator.

12. Frequently, innovations derived from research are first disclosed in the patent literature, prior to coverage in the periodical literature.

13. Patents offer a most valuable method of keeping abreast of latest technologies, serving an individual's own "current awareness" program.

14. Copies of U.S. patents are easily obtained from the U.S. Patent Office at 50¢ a copy.

15. It is a creative source of ideas for those with imagination.

CONTENTS AND SUBJECT INDEX

INTRODUCTION

To an increasing degree municipalities throughout the world are beset by difficulties in disposing of the ever larger quantities of refuse that are being produced. On the one hand, the quantity of refuse being produced per capita increases, whereas on the other hand the requirements made of disposal facilities are becoming more and more strict. In many instances, particularly in metropolitan areas, it is no longer possible to merely cart refuse to a designated dump, because space availability for such dumps is limited and in many instances has been exhausted or very nearly so.

The per capita production of sewage in the United States varies from less than 100 gallons per day for a residential area to well over 300 gallons per day for a highly industrialized area. While the original need for sewage-purification plants stemmed largely from the prevention of disease and the general concern for public health, the growing shortage of water and the pollution of our lakes, rivers and streams has greatly accelerated the demand for efficient, low cost treating facilities in all but the smallest rural communities.

Sludge is the major by-product of industrial and domestic water and waste treating processes. In fact, one of the major problems in a well-run water pollution control program is the sludge conditioning method used in dewatering sludges. The term sludge dewatering process as used in the art means any process which reduces the water content of the sludge from its usual value of 93 to 99 percent by weight to about 90 percent by weight or less. That is, it concentrates the sludge solids to about 10 percent by weight or greater.

Wastewater sludge is basically characterized according to three factors which are: (1) sludge source, (2) sludge processing, and (3) degree of treatment. By sludge source is meant whether the sludge is from municipal (domestic) wastewater or industrial wastewater or a combination thereof. The sludge processing characteristic defines whether the sludge is raw untreated sludge, anaerobic or aerobic digested sludge, air flotation sludge or digested elutriated sludge.

The degree of treatment indicates whether the sludge is primary sludge, activated sludge, waste activated sludge, chemically precipitated sludge, trickling filter humus or a combination of one or more of these such as waste activated sludge combined with primary sludge. It is generally accepted that each individual sludge has a different characterization and this sludge character more or less dictates the dewatering process used.

The various mechanical dewatering processes now commonly used in the art are gravity filtration, vacuum filtration, centrifugation, flotation, and sedimentation. However, regardless of the mechanical process used for dewatering, it has become standard practice in the art to chemically condition the sludge prior to dewatering. This chemical conditioning of the sludge enhances the mechanical dewatering process dramatically. The water content of the sludge can be reduced from concentrations in the neighborhood of 93 to 99 percent water to those of about 60 to 90 percent or less by proper chemical conditioning prior to mechanical dewatering.

A desirable and convenient way of disposing of organic and other combustible waste materials is by complete combustion of these materials, in such a manner that the only residue is a relatively lightweight ash, which may be trucked away and disposed of as landfill and the like. Any particulate materials which would otherwise exit the incineration process through the flue system may be suitably wet scrubbed with water. This serves to reduce the temperature and remove entrained particles from the effluent stream. Alternately these particulates may be electrostatically precipitated in order that the gaseous discharge of the incineration process does not produce atmospheric pollution.

Since these incineration processes are nonproductive, and do not usually produce commercially useful by-products, it is most desirable to maintain the construction cost of incineration systems, and the cost of operating these incineration systems, as low as possible, in order to achieve optimum economy of operation, while maintaining optimum efficiency of waste disposal within the limits of air pollution emission standards established by federal and state agencies.

In some instances, services may be provided for collecting liquid, semiliquid and solid organic and other combustible wastes from plant sites and other waste-producing sites at which it is not economical to build incinerators, and for trucking these collected wastes to central incinerator facilities at which the wastes from many industrial plants and/or other waste-producing facilities are incinerated, with each manufacturing plant and other facility paying a fee for the hauling away and incineration of its wastes.

In other instances, large industrial plant complexes produce wide varieties of combustible wastes in large quantities which can economically justify the construction and operation of on site waste incineration facilities. In these circumstances it is desired to achieve optimum combustion efficiency of combustible materials at the minimum initial cost for incineration equipment, and minimum operating cost for day-to-day operation of these incinerator units.

ACTIVATED SLUDGE PROCESS

The activated sludge process uses a heterogeneous microbial population to oxidize soluble and colloidal organics to carbon dioxide and water in the presence of molecular oxygen. Turbulent mixing holds the organisms in suspension and also provides the necessary oxygen required by the cells for respiration. During the oxidation process a portion of the organic material is synthesized to form new cells while the other organic material oxidized by the microorganisms is used to provide energy for synthesis and motility. Part of the synthesized mass undergoes endogenous respiration, and the remainder forms excess sludge. In a continuous process the excess sludge flows out of the aeration tank and settles under quiescent conditions in a final clarifier. A portion of the solids is recycled to the aeration tank, and the remainder must be further treated for final disposal.

Much of the development of the activated sludge process is a result of solving operational problems rather than applying fundamental concepts. Activated sludge originated in 1882, when Angus Smith aerated sewage and discovered that the oxidation of ammonia to nitrate was accompanied by the removal of organic matter. The basic process was actually developed and named in London by Ardern and Lockett in 1914.

Initially, the studies were performed on a batch basis using a six-hour retention time, which is still used as a set design parameter by some engineers today. Experimentation with mechanical aeration resulted in the design of the first complete mix plant at Bury, England in 1919. However, the advantages of the complete mix regime were not apparent at that time. Most of the plants being built consisted of long, rectangular aeration units which produced a plug flow regime and what is known as the conventional activated sludge process.

The importance of microbiology to the design and operation of a complete mix plant was not completely realized by design engineers until the early 1950's. In 1923 a study at the University of Illinois established the microbial population dynamics of the activated sludge process as it is known today. Unfortunately, there was a lack of communication between the biologists and engineers resulting in omission of the application of biological principles to the design of activated sludge processes. Even though the importance of microbiology is relatively well established now, some engineers continue to ignore this truth and prefer to simply follow what has been done before.

So that one may fully understand the mechanisms involved in an activated sludge process, a brief description of the microbiology of the process will be presented. The stabilization of organic material and the flocculation of the sludge are related to the growth of microorganisms. Bacteria, which are the primary consumers of organics in an activated sludge process, metabolize their food to grow and obtain energy via a variety of complex cycles and pathways.

To facilitate this conversion, the bacterial cells are equipped with enzymes, organic catalysts known for their efficiency of conversion and their specificity for a particular substrate. Enzymatic reactions are affected by environmental conditions such as temperature and pH; therefore, these parameters are important in operation of an activated sludge process.

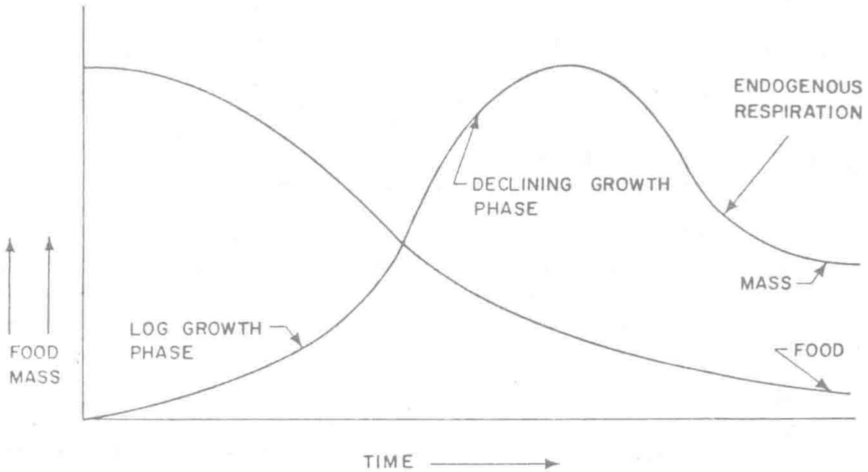
In addition to enzymes, bacterial cells require energy for their biochemical processes. Energy is released from oxidation of the organic material, and this energy is stored by the compound adenosine triphosphate (ATP). After this stored energy is released for cell synthesis, maintenance, and motility, it is reduced to adenosine diphosphate (ADP). The ADP molecule is then available to accept the energy released by oxidation of organic matter and is converted to ATP to complete the cycle. Thus, energy is obtained by assimilation of the organic material, and this energy is used for cell synthesis.

Other microorganisms important for the successful operation of activated sludge are protozoa and rotifers. These animals establish a prey-predator relationship which ensures good settleability of the activated sludge floc. The protozoa and rotifers consume bacteria as their food source, reducing the number of bacteria. However, because of the increase in the food to microorganism ratio, bacterial growth is accelerated, and hence more organic matter is removed from solution.

The growth of microorganisms in an activated sludge system occurs in three phases: log growth phase, declining growth phase, and endogenous phase. In the log growth phase there is always an excess of food for the microorganisms, and the growth rate is at a maximum, limited only by the ability of the microorganisms to process the substrate. When the microorganisms need more food than is available, their rate of growth decreases, which is the declining growth phase. As the food concentration reaches a minimum, growth ceases, the microorganisms metabolize their own protoplasm, and the food concentration is slowly decreased. This is known as endogenous respiration.

The following figure illustrates this relationship between food and mass in an activated sludge system. Whereas the conventional activated sludge operates somewhat in each of the three phases of growth from the head of the tank to the end of the tank, complete mix activated sludge operates at a point on the growth curve, preferably between the log growth and declining growth phases for optimum substrate removal and good sludge characteristics.

Metabolic Relationships of Activated Sludge



The activated sludge process has many modifications and flow regimes. The varied modifications will not be discussed here, but there are two distinct flow regimes, or mixing models, used in activated sludge processes which are of primary importance. The first of these mixing models is the plug flow model which is associated with the conventional activated sludge process. In a plug flow system the individual particles of the influent pass through the reaction vessel in the same sequence in which they entered, and there is no intermixing or interaction between the particles. This type of flow regime is difficult if not impossible to actually attain in an activated sludge system, but the long, narrow tanks typical of a conventional activated sludge system have traditionally associated it with plug flow. There is always some mixing or interaction between the particles because of the turbulence required for aeration.

On the other hand, the complete mix flow regime, in which the influent particles are completely mixed with the liquid and suspended matter in the reactor, can be attained in laboratory as well as field scale systems. A complete mix activated sludge plant offers many advantages over the conventional process. An understanding of the operation of each process will reveal the advantages of CMAS. It is important to this study to apply these advantages to possible additional advantages of CMAS units in series.

The conventional process mixes incoming waste with return activated sludge at the head of the aeration tank creating a high food to microorganism ratio. In the presence of excess food the bacteria grow rapidly demanding a large amount of oxygen to complete their metabolism. Providing adequate oxygen transfer at the beginning of the tank is often difficult or impossible. As the waste moves down the length of the tank, biodegradation of the organics approaches completion, and the bacterial mass undergoes endogenous respiration; that is, the cells consume their own protoplasm.

By the time the sludge reaches the end of the tank it has become inactive. It is this largely inert mass which is recycled to be mixed with the high strength waste at the head of the tank. The microbial population never reaches an equilibrium, but is in a continual cycle of growth and starvation. The resulting imbalance between the microorganisms and the organic load is the reason for the irregular operation of the system.

The complete mix activated sludge system alleviates many problems experienced by the conventional activated sludge process. The operational advantages of the CMAS process are accomplished by equalizing the organic load over the entire mass of microorganisms in the aeration tank. Complete mix means that the feed particles and recycled sludge become completely intermixed in the aeration chamber, thereby losing their individual identity.

Attainment of complete mixing is assured when the oxygen uptake rate is uniform throughout the aeration volume, provided that there is sufficient mixing to prevent settling of suspended solids in the aeration tank. An important added advantage of CMAS is its ability to act as a surge tank when the system is subjected to shock loads. The increased load is distributed uniformly over the entire contents of the tank, thereby effecting better use of the dissolved oxygen throughout the tank. In summary, operation of a CMAS system is smoother than the conventional system because of CMAS's stable microbial growth, uniform oxygen demand rate, uniform distribution of food, and reduced sensitivity to shock loadings.

More information on the efficacy of the complete mix activated sludge process in modular mode appears in PB 211 156 (July 1972) which is available from the National Technical Information Service.

The Water Pollution Control Act of 1972 calls for nationwide achievement of the installation of secondary treating facilities in all communities in the country by mid-1977. Recent estimates by the Environmental Protection Agency, using a 200 million dollar estimate per plant for conventional equipment, indicate that the total cost of compliance would amount to 13 billion dollars in the United States.

This book describes over 190 patented processes relating to all phases of industrial and domestic water purification. These processes include large scale community systems as well as special compact units which have been developed for remote locations and watercraft waste disposal.

INCINERATION

FLUIDIZED BED

Nozzle Feed System

L.R. Van Gelder; U.S. Patent 3,709,170; January 9, 1973; assigned to Chicago Bridge & Iron Co. describes a sludge feed system for a reactor having a nozzle, and a conduit communicating with the outside of the reactor and the nozzle for feeding sludge to the nozzle under pressure, the nozzle having a mouth in communication with the interior of the reactor for forming the sludge into a thin layer which breaks up in the reactor.

Referring to Figures 1.1a and 1.1b, enclosed reactor **10** has a lower cylindrical portion **11**, a central conical section **12** and an upper cylindrical portion **13**. The described reactor portions comprise an exterior metal shell with a suitable refractory material lining the interior surface thereof, particularly if the reactor is to be employed in high-temperature reactions or treatments. The bottom **14** of the reactor and the top **15** are of similar construction to the reactor vertical walled portions already described. The reactor is typical of the type used in fluidized bed treatments and particularly in the combustion of waste materials.

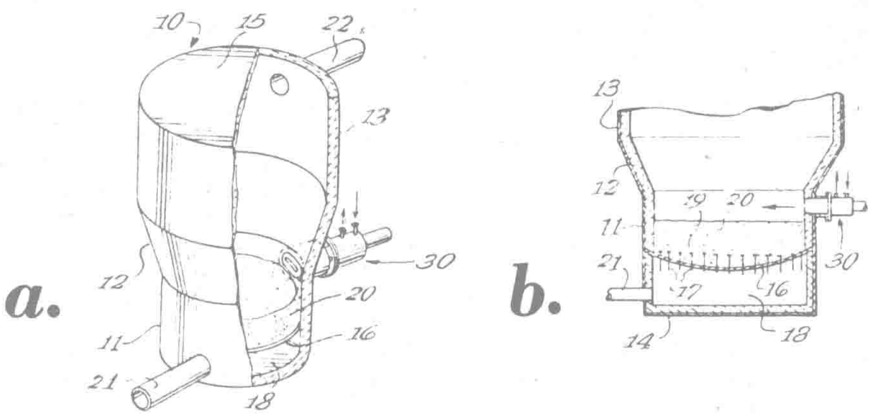
A constriction plate **16** spans the horizontal interior area defined by the lower cylindrical portion of the reactor support. The space between the constriction plate and the reactor bottom constitutes air box **18**. A plurality of vertical tubes **17**, in the constriction plate, communicate at their lower ends with the air box. The upper ends of the tubes, which extend above the constriction plate, terminate in horizontally located small tubular sections **19** through which air is expelled from the air box under pressure to fluidize particulate bed **20** located in the reactor. Conduit **21** feeds air or hot gases or whatever gas is appropriate to the air box. Conduit **22** in the upper part of the reactor is used to withdraw gases and products of combustion from the reactor.

Nozzle **30** is positioned so that its mouth is in communication with the interior of the reactor. As shown in Figures 1.1a and 1.1b, the nozzle mouth is so positioned in the lower portion of the reactor as to be slightly above the top surface of the fluidized bed **20**. However, the nozzle can be so located as to deliver sludge being fed from the mouth directly into the fluidized bed.

With reference to Figures 1.1c and 1.1d, nozzle **30** has a tubular portion **31** which communicates with conduit **32**. The tubular section is circular in cross section and its inner end joins inlet end **32** of nozzle transition element **33** which terminates in nozzle transition element mouth **34**. The inlet end of the transition element is circular in cross section and progressively becomes oval and finally terminates in the mouth which is shaped in the form of an elongated rectangle which is much wider than it is high.

As shown in Figure 1.1c, the top and bottom walls of the transition element converge towards the nozzle mouth while as shown in Figure 1.1d the opposing side walls of the transition element diverge towards the nozzle mouth. The smooth contour of the interior surface of the transition element serves to progressively shape or form a sludge passing through it into a wider and thinner layer as it moves forward so that it is ultimately expelled from the nozzle mouth in a thin disintegratable layer which breaks up into pieces in the reactor. The nozzle mouth is advisably positioned to be approximately flush with the reactor interior surface to avoid undue abrasion of it by the dynamic activity of the fluidized bed.

FIGURE 1.1: SLUDGE FEED SYSTEM



(a) Isometric View, Partially Broken Away, Showing a Reactor Provided with a Nozzle for Feeding Sludge in a Thin Layer to the Interior

(b) Vertical Sectional View Through the Lower Part of the Reactor of Figure 1.1a

(continued)