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Individual Home Wastewater Treatment by the "Aquarobic" Extended Aeration System

by

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INDIVIDUAL HOME WASTEWATER TREATMENT BY THE "AQUAROBIC" EXTENDED AERATION SYSTEM

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ABSTRACT

Continued population growth in rural suburban areas and recreation communities necessitates the use of effective private waste water treatment systems. The effectiveness of an "Aquarobic" system serving a single family residence in Rennie, Manitoba was evaluated for one and a half years. Effluent quality, percent removals, water consumption, removal rates, and yield were determined.

The Rennie Aquarobic was found to remove 85% of influent BOD_5 and 79% of influent VSS resulting in an effluent with 65 mg/L BOD_5 and 45 mg/L VSS. The effluent contained 30 mg/L NO_3 and 1.4 mg/L NH_4. The soluble COD removal rate in the aeration basin was found to be 5 wt substrate removal/wt substrate day. Maximum yield was found as Y_{max} = .71 wt VSS/wt BOD_5. Water consumption in the home was 28.3 $\frac{\text{I. Gal}}{\text{capita day}}$. The "Aquarobic" system operated without major problems. The total yearly costs of the Aquarobic were approximately four times that of a septic tank.

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INDIVIDUAL HOME WASTEWATER TREATMENT BY THE "AQUAROBIC" EXTENDED AERATION SYSTEM

CHAPTER 1

1. Introduction

The continuing trend of population growth in the rural suburban areas, and the continued growth of recreation communities, has increased the demands for design of private waste water treatment systems. A proposed method for rural and resort individual home waste water treatment is the use of package extended aeration plants and sand filters.

1.1. Statement of Problem

Approximately 50 million Americans and 4 million Canadians are presently using septic tank systems for household sewage disposal (1)*. Septic tank effluent contains solids, soluble organic and inorganic compounds, plant nutrients and pathogenic microorganisms. Further effluent treatment, by percolation through the soil, is required to prevent health and pollution hazards. An estimated 50% of

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* The numbers in parentheses in the text indicate references listed in the Bibliography.

these septic waste disposal systems do not work properly (2). Failure of septic disposal fields, as evidenced by ponding of raw sewage on top of the disposal field, is described by McGauhey (3) as being attributable to the following:

(a) anaerobic clogging of the infiltrative surface due to continuous inudation;

(b) overloading of the system because of inadequate surface area;

(c) consolidation of trench bottom during construction; and,

(d) consolidation of trench sidewall by trenching machinery.

A more subtle failure leads to contamination of ground and surface waters. The effectiveness of the soil as a treatment system is dependent on environmental factors such as soil and air temperature, availability of oxygen, depth to groundwater and others. With continued effluent application, the soil may lose its treatment abilities. Groundwater contamination appears inevitable since the "soil is not equally effective for the removal of all constituents in the percolate" (1). Nitrates and pathogenic microorganisms are of particular concern in groundwater contamination. In recreational areas with extensive shoreland developments nutrient contributions from septic tanks are of concern with regard to lake eutrophication.

A possible solution to some of the problems associated with septic tank and field disposal systems is to:

(1) enhance the initial treatment system thus reducing the amount of subsequent treatment required in the field and thereby decreasing the rate at which the soil loses its treatment abilities;

(2) enhance the treatment capabilities of the disposal bed by the addition of materials, by controlling the hydraulic loading cycle and by proper sizing of the disposal bed.

The use of extended aertation package treatment plants such as the Aquarobic is one method of increasing the initial effluent treatment. In conjunction with increased initial effluent treatment a sand filter containing ion-exchange materials can be employed to further decrease the required treatment in the disposal bed. The hydraulic loading cycle can be controlled by programming the rate of effluent discharge from the treatment process while the proper disposal bed size can be determined from the optimum hydraulic loading per unit area. For satisfactory final waste disposal, the Aquarobic treatment plant and sand filter must optimize these factors. To determine whether the desired level of treatment actually occurs in field situations it became necessary to test and evaluate the system.

1.2. Reasoh for Study

Increased treatment effiency, as obtained by extended aeration, is a means of minimizing deleterious environmental effects associated with individual home waste water disposal systems. The extended aeration process for waste water treatment has been studied in considerable detail under varying conditions (26). The unusual factors associated with individual home extended aeration treatment which made this study necessary are:

(1) the non-diluted nature of individual home waste water (as compared to the dilution and increased homogeneity of multiple dwelling waste water);

(2) infrequent maintenance; and,

(3) the actual design and physical characteristics of the waste treatment plant.

The use of sand filters to polish effluent from domestic sewage treatment systems has also been studied (5, 6, 7). Factors which necessitated further investigation of the sand filter are:

(1) the effect of extended aeration treated effluent, on the sand filter;

(2) how the filter is affected by hydraulic loading, temperature, availability of oxygen and other factors; and,

(3) the quality of sand filter polished effluent.

CHAPTER 2

2. Purpose and Extent of Investigation

2.1. Purpose of Investigation

The primary objective of this investigation was to experimentally verify the waste treatment efficiency in a field installation Aquarobic treatment plant and sand filter. Further objectives were; to evaluate rural individual home water consumption, the nature of domestic sewage, required maintenance, and costs of the Aquarobic.

2.2. Extent of Investigation

The Aquarobic unit and standard sand filter were installed in Rennie, Manitoba on August 28, 1976. Installation of the system was performed by personnel from the Manitoba Department of Mines, Resources, and Environmental Management, with the assistance and supervision of a representative from Aquarobic. The plant was monitored from September 1976 to February 1978. Samples were taken from the influent, effluent, and aeration basin for analysis. Water consumption in the home was recorded, and an operation and maintenance log was maintained during the evaluation period.

CHAPTER 3

3. Literature Review

3.1. Introduction

A thorough evaluation of the experimental data obtained necessitates an indepth review of the fundamentals of biological treatment, filtration, effluent treatment in the soil, and effects of the effluent on the environment. This was accomplished by a literature search of work done by other investigators.

3.1.1. Activated Sludge Process

The objectives of biological treatment of wastewaters are to coagulate and remove the non-settleable colloidal solids and to stabilize the organic matter. The activated sludge process may be described as a system in which flocculated biological growths are recirculated and contacted with the organic wastes in an aerobic environment (8). The activated sludge is removed from the effluent stream by physical sedimentation. All or a portion of this activated sludge is recirculated to the reaction basin, and the remainder of the activated sludge is removed from the process. Microorganisms commonly found in activated sludge include fungi, protoza, rotifers and most importantly bacteria. The types of microorganisms that are present and the relative predominance of these microorganisms are an indication of the nature of the raw waste water and the treatment process (9, 10).

3.1.2. Activated Sludge Population Dynamics

Competition for food, whether for the same food or in terms of a prey-predator relationship, is the primary factor in population dynamics. In competition for the same food, the ability to process a maximum quantity of food at a maximum rate under a given environmental condition will ensure survival. Bacteria metabolize the fastest and will generally predominate over fungi in environmental conditions optimum for bacterial growth. This predominance of bacteria is important to the activated sludge process due to the poor settling characteristics or tendency to "bulk" of fungi dominated systems (10). In the prey-predator relationship, the plants process soluble food and the animals process solid food such as the plants. The prey-predator relationship helps to adjust the food-microorganism concentration, thereby stimulating greater waste organics food utilization (10). In this way the predators help to minimize the organic substrate concentration in the reactor and assist in producing a clarified effluent.

The nature of the substrate and the environmental conditions will also affect the population dynamics. The type of substrate (i.e. organic or inorganic) will determine if heterotrophic or autotrophic organisms are dominant. In wastewater treatment, heterotrophs are generally the most important group due to the availability of organic compounds. Autotrophs, such as the nitrifying bacteria, will also be present, but in smaller numbers. A substrate that is deficient in nitrogen, will normally stimulate the growth of fungi, which require approximately half as much nitrogen as bacteria (9). The nature of the organic substrate will also determine what species of bacteria become predominant.

Environmental conditions such as pH, temperature, and dissolved oxygen levels are also important in population dynamics. Fungi can compete better in low pH (optimum pH 5.6) environments and survive in environments with pH ranging from 2 to 9 (9). Bacteria can be either anaerobic, aerobic or facultative while fungi are almost strictly aerobic (9). This indicates that by permitting an activated sludge system to go anaerobic, fungae predominance can be shifted to bacterial predominance. Temperature will determine whether psychrophilic, mesophilic or thermophilic bacteria become dominant.

Bacteria are the most important microorganisms in wastewater treatment. This importance stems from their ability to form a readily settled floc and their rapid reproduction (from a few days to less than twenty minutes (9)).

3.1.3. Microbial Growth Patterns

The stabilization of wastes and the survival of pathogenic microorganisms is related to growth. To understand and control microbial growth it becomes necessary to examine microbial growth patterns. McKinney (10) has presented growth in terms of number of organisms plotted against time as illustrated in Figure 1. In terms of numbers of microorganisms, versus time, the growth pattern can be divided into seven distinct phases consisting of: the lag phase, log phase, declining growth phase, stationary phase, increasing death phase, log death phase and death phase. This growth pattern is most suited to batch cultures, such as innoculated cultures, which involve small numbers of microorganisms.

The growth pattern of heterogenous cultures such as found in activated sludge can best be described by a mass of microorganisms versus time growth pattern. This growth phase shows three distinct phases and may also include a lag phase during which time the organisms may be adjusting to the substrate. The three phases are:

(1) log growth phase, during which time an excess of substrate surrounds the microorganism; the rate of metabolism and growth is limited only by the organisms ability to process the substrate. At end of the log growth phase microorganisms are reproducing and utilizing organic substrate at a maximum rate;

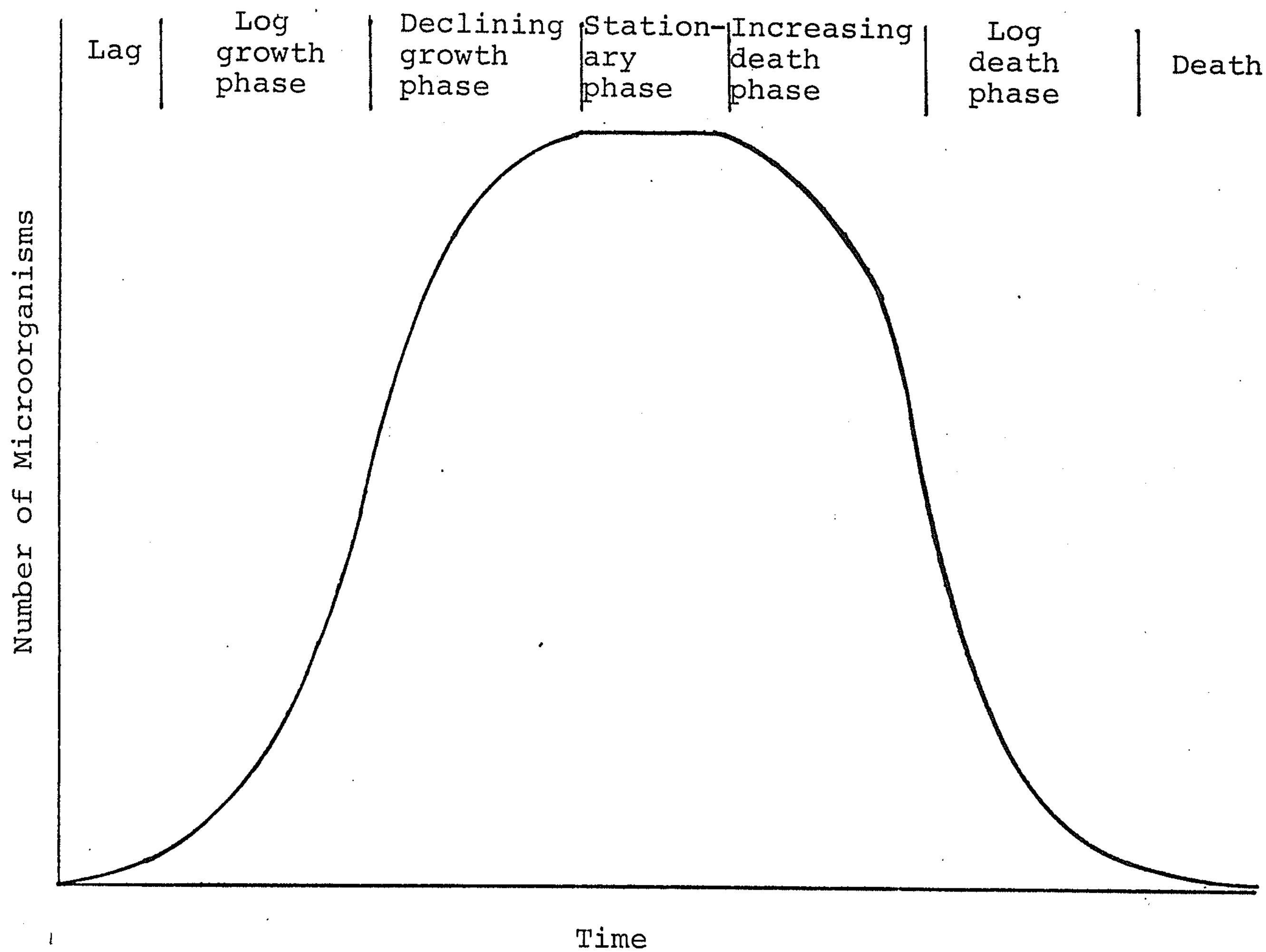

FIGURE 1. Number of microorganism vs. time

(2) declining growth phase, during which the declining organic substrate level causes the rate of growth to decrease. At the end of the declining growth phase the rate of growth approaches zero due to the lowered organic substrate concentration; and,

(3) endogenous phase, during which microorganisms metabolize their own protoplasm since the availability of organic substrate is at a minimum.

The maximum rate of organic substrate stabilization occurs during the log growth phase. This phase would appear to be the most efficient for waste treatment. In fact, treatment in this phase is limited due to the high substrate levels which result in excessive organic concentrations in the effluent. The high microbial growth rate precludes efficient flocculation and clarification of the effluent since the ability of microorganisms to coagulate is partially dependent on the age of the cell (9). The declining growth phase is most commonly used for biological wastewater treatment. In this phase the lower substrate concentration results in a lowered substrate level in the effluent. The lower rate of metabolism allows more efficient flocculation and settling of bacterial cells. At the end of the declining growth phase, sludge production is highest, which may present a problem in terms of sludge handling.

The endogenous respiration phase is of greatest significance to this study. In this phase, the food supply can be considered to be in equilibrium with the microorganisms. Since the bacterial cells are facing starvation they may draw upon stored metabolites or the protoplasm of cells that have undergone lysis for energy and reproduction (11). The total mass of this system will thus tend to decrease and a condition favourable to settleability of solids results. The mass decreasing tendency of the endogenous phase would be expected to result in no sludge accumulation, but, in actual practice sludge accumulation does occur even with extended detention periods (14).

3.2. Kinetics of Biological Growth

3.2.1. Principles of Biological Oxidation and Cell Physiology

An understanding of the basic process of biological oxidation and cell physiology is required for evaluating biological growth kinetics. The basic concept of substrate utilization by microorganisms, found in activated sludge, is called oxidative assimilation. Oxidative assimilation consists of two inseparable processes, catabolism and anabolism. Catabolism is the breakdown of organic materials for energy (oxidation), while anabolism is the synthesis of molecules (growth). These reactions are illustrated by the following equations (13):

Organic Matter Oxidation

$$C_xH_yO_z + O_2 \xrightarrow{\text{enzyme}} CO_2 + H_2O - \Delta H$$

Cell Material Synthesis

$$C_xH_yO_z + NH_3 + O_2 \xrightarrow{\text{enzyme}} \text{cells} + CO_2 + H_2O - \Delta H$$

where ΔH = heat of reaction

The net result of oxidative assimilation is increased cellular mass due to continuous reproductions. When the food supply is limited or the source is removed, the cell switches from an external (exogenous) to an internal (endogenous) substrate source. Endogenous respiration results in a decrease of cellular mass as illustrated in the following equation:

Cell Material Oxidation

$$(\text{cells}) + O_2 \xrightarrow{\text{enzyme}} CO_2 + H_2O + NH_3 - \Delta H$$

The cellular mass involved in endogenous respiration is reserve material that may have accumulated to the extent of 50% of the cells dry weight (14). Some investigators believe that endogenous respiration also occurs during the exogenous removal process. In this situation both internal and external oxidative assimilation occurs (13). McKinney (9) states that from a practical point of view, endogenous metabolism has little effect on cellular mass during log growth but becomes significant during the declining growth phase.

Biological treatment of wastewaters is a combination of interrelated operations that may differ in spatial distribution, proceed at different rates, and be accomplished by structurally dissimilar biomasses (11). Three different principal processes are of importance in biological treatment. These processes are:

(1) the transfer of impurities from the waste water to the biomass by interfacial contact and associated adsorptions and absorptions;

(2) the preservation of interface contact quality; and,

(3) the conversion of the biomass into settleable or otherwise removable solids.

The primary or transport process is rapid and effective, if the interface between the liquid and biomass is large, if the organic substrate concentration to be removed from one phase to the other is large, and if no obstructive liquid films and/or concentrations of interfering substances build up on the interface. Preservation of contact quality is accomplished by oxidation of organic matter and cell synthesis. These reactions are carried out by highly efficient and specific enzyme catalysts. Two types of enzymes, extracellular and intercellular, are involved in these reactions. The extracellular enzymes are responsible for hydrolysis of macromolecules (among other functions) while intercellular enzymes are responsible for release of energy in the cell. Enzyme activity is affected by substrate concentrations, pH, the presence of elements that result in inhibition, and other factors.

Enzyme kinetics are not well understood but it appears that over all kinetic rates are limited by various transport steps (14). Contact quality is also preserved due to the tendency of dissolved matter concentration to change in a fashion that decreases surface tension in the floc. An example is nitrate which increases the surface tension of the interface and thereby transfers back into solution. CO_2 and other gases escape because of their lower partial pressure in the contiguous atmosphere. The conversion of biomass into a settleable floc proceeds in synchrony with the other processes, such as conversion of biomass, into settleable solids. The "binder" for bacterial floc particles appears to be the capsule or slime layer found on some cells. The slime layer is a variable and is effected by the environment, and appears to be more significant and extensive in old or resting cultures.

These three processes are of great importance in determining the overall kinetic rate. It appears that the interfacial transfer or adsorption process is the rate limiting step.

3.2.2. Basic Kinetic Model Equations

Environmental conditions such as pH, temperature, mixing, and nutrient and oxygen concentrations must be controlled to ensure optimum conditions for the organisms, which results in efficient waste treatment. To ensure that the organisms will grow they must remain in the reactor for a period of time dependent on the microbial growth rate. Effective waste treatment, under properly controlled environmental conditions, can be ensured by controlling the biological growth rate (9). The development of kinetic growth equations, which can be used for predicting growth, is dependent upon the following three fundamental factors (15):

(1) growth rate;

(2) a relationship between an essential nutrient and growth; and,

(3) growth yield applied in conjunction with material balances.

Monod (16) was one of the first researchers to investigate the use of kinetic models for continuous cultures. Gates and Marlar (17) have presented the following equations based on basic relationships which define the interaction between nutrient utilization and bacterial growth, and the dependency of the growth rate constant on the concentration of the growth controlling nutrient, as proposed by Monod:

$$ds/dt = \frac{1}{Y}\left(\frac{dx}{dt}\right)^{*} \qquad \text{..... (1)}$$

$$K = \frac{K_{max} S}{K + S} \qquad \text{..... (2)}$$

where S = nutrient concentration mg/L

t = time

Y = organism yield (mg organism/mg nutrient removed)

* Variables have been changed to agree with those used throughout this study.

K_{max} = maximum growth rate constant ($time^{-1}$)

dx/dt = change in microbial concentration $\frac{mass}{time}$

K = the saturation or nutrient constant (mg nutrient/L)

These basic fundamentals have been applied to many models in sanitary engineering. Equations of a similar form were developed by Michaelis-Menten to describe enzyme-catalyzed reactions (14).

Microbiologists have traditionally used the following expression to describe the log growth phase of biological mass (18):

$$\frac{dx}{dt} = K^1 x \qquad \text{..... (3)}$$

where $\frac{dx}{dt}$ = net growth of microorganisms per unit volume of reactor (mass/volume-time)

K^1 = specific growth rate ($time^{-1}$)

x = concentration of microorganisms (mass/volume)

As the microorganisms proceed into the declining growth phase the specific growth rate, K^1, decreases and the influence of endogenous respiration increases. The previous equation thus becomes less applicable and a new relationship that accounts for endogenous respiration must be employed.

An empirically developed relationship between biological growth and substrate utilization which is applicable through all phases of the growth curve is (9, 18):

$$\frac{dx}{dt} = Y \frac{ds}{dt} - kdX \qquad \text{..... (4)}$$