SECTION XI ENHANCED PRETREATMENT

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SECTION XI ENHANCED PRETREATMENT

A. Introduction

This section provides a discussion on enhanced pretreatment of wastewaters following the typical septic tank (and grease trap if required) pretreatment that is predominately used in on-site wastewater reclamation systems (OWRS) before the wastewater is discharged to the subsurface. An evaluation of the various treatment operations and processes available should be made during the initial phase of designing an enhanced pretreatment facility and prior to selecting the pretreatment operations, processes, and equipment. The purpose of this section is to 1.) provide an overview of various unit operations and unit processes that can be employed to provide enhanced pretreatment, and 2.) call attention to some of the important parameters that affect the design, operation and maintenance of these operations and processes.

It is not intended for this section to provide detailed design criteria for the numerous types of pretreatment facilities usually available as pre-manufactured (packaged) units, although some design criteria are provided for the various processes employed in such units. Detailed design criteria are given in the case of a recirculating granular media filter, a generic facility that is usually designed in-house and constructed on site. There are many references available that will provide detailed design information and procedures and most manufacturers of equipment used for enhanced pretreatment will also provide design assistance. Enhanced pretreatment is normally required when:

1. The wastewater has such a high organic strength (including a high concentration of fats, oils and grease) that it is not feasible to rely upon the usual grease trap-septic tank- SWAS treatment processes for subsurface wastewater renovation.
2. The wastewater has a high concentration of nitrogen that cannot be reduced to the appropriate water quality goal by the usual septic tank-SWAS treatment processes.
3. The soil beneath the SWAS does not have sufficient renovative capacity to remove the phosphorus that is contained in the percolate from the SWAS.
4. The wastewater contains toxic synthetic organic chemicals that must be removed before the wastewater is discharged to a SWAS.

Enhanced pretreatment must be provided where use of reclaimed water is permitted. This is discussed further in Subsection M of this Section.

In selecting pretreatment processes and equipment, the goal should be to utilize such processes and equipment that:

- Yield a consistently high quality effluent that meets water quality requirements as the hydraulic and organic loads vary from low start-up to full design values;
- Are relatively simple to operate;
- Require a minimum of daily maintenance;
- Are not easily upset by unusual variations in such loads;
- If upset, quickly recover; and,
- Are energy efficient.

A guiding principle should be to keep the enhanced pretreatment processes and equipment as simple as possible consistent with effluent requirements.

B. Unit Operations and Unit Processes

1. General

The means used in enhanced pretreatment may consist of physical unit operations, chemical and biological processes or any combination thereof. Those generally used in small-scale pretreatment facilities include:

a. Physical Unit Operations

- Flow Measurement and Sampling
- Flow Equalization
- Pumping
- Mixing
- Gas Transfer
- Flocculation
- Clarification (removal of settleable solids via sedimentation)
- Filtration (may be used for removing residual suspended solids, e.g., post-filtration; as a biological process, e.g. recirculating granular media filters, anoxic reactors.)
- Adsorption

b. Unit Processes

- Chemical (as part of the biological removal of organics and nutrients), including precipitation, adsorption, and pH control.
- Biological (for removal of organics, nutrients)
- Disinfection (may be chemical: e.g., chlorination, or physical; e.g. Ultra Violet Irradiation)

[Note: In larger wastewater treatment plants, unit operations and processes for screening, grit removal, grease removal and primary clarification may be provided. However, in small-scale, on-site treatment facilities, septic tanks and grease traps are normally provided to perform such functions.]

2. Flow Measurement and Sampling

a. Flow Measurement

Continuous flow measurement and recording is a necessary unit operation required for control of enhanced pretreatment facilities. Measurement of the wastewater flow rate should always be provided and in some cases measurement of recycle flow rates will also be required. Such measurements provide the basic intelligence needed to make knowledgeable adjustments to the various physical, chemical and biological processes employed so as to optimize their operation, avoid plant upsets, and meet effluent quality requirements. There are many methods available for flow measurement. They range from simple methods that are relatively easy to maintain and calibrate by plant operating personnel, to complex sophisticated methods that can provide extreme accuracy but require outside expertise for calibration and maintenance. In selecting a flow measurement method, consideration should be given to the level of training and experience that will be required of the plant operators. In most cases, the simpler methods including V-Notch, rectangular and trapezoidal weirs, flow nozzles and flumes will suffice and will provide the level of accuracy normally required for small-scale operations.

The selection of the flow measuring method will depend upon the magnitude and range of the anticipated flows and the location where the flow is to be measured. For relatively small flows, sharp-edged weirs are the usual choice, with the type of weir ranging from a V-Notch at the lower range to rectangular and trapezoidal weirs at the upper range of flows. Where measurement of the plant influent flow is required and for larger flows, consideration should be given to the various flow nozzles and flumes that are available where measurement of the flow depth can be made with devices that are not inserted in the flow path. This is also the case for recycle flows that may contain significant concentrations of suspended solids.

All flow measurement devices should be provided with recording devices that will permit the plant operator to review flow data when analyzing causes of treatment process anomalies. These may be of the chart type, either circular or continuous strip chart, and preferably cover an operational period of a week or more. Electronic data recording devices are also available and may prove suitable in some cases.

b. Flow Sampling

In large plants, flow-sampling equipment often may be dedicated to a particular location in the treatment plant. This is usually not cost effective for the smaller plants under consideration herein. Access for manual flow sampling should be provided at various points in the treatment plant, such as influent, following biological treatment, and effluent.

It is quite helpful to provide a portable automatic sampling device at each plant. Where such devices are provided, a source of electrical power (plug-in electrical receptacles of the ground fault interrupter [GFI] type are ordinarily sufficient) should be provided at each sampling location. Where flow-composited flow sampling is necessary, provisions should be made for conducting the signal from a suitable flow measurement device to the sampling locations. This requires matching the type of flow signal output from the flow measurement device to the type of flow signal that will be recognized by the automatic sampling device.

3. Flow Equalization

The benefit of flow equalization should always be investigated. As discussed in Section X, flow equalization is often cost-effective because it can:

- Dampen the variations in wastewater constituent concentrations.
- Permit downstream processes to operate at more uniform flow rates and contaminant loadings, which is beneficial to the operating stability and efficiency of these processes.
- Result in reducing the size (capacity) of the enhanced pretreatment facilities required.

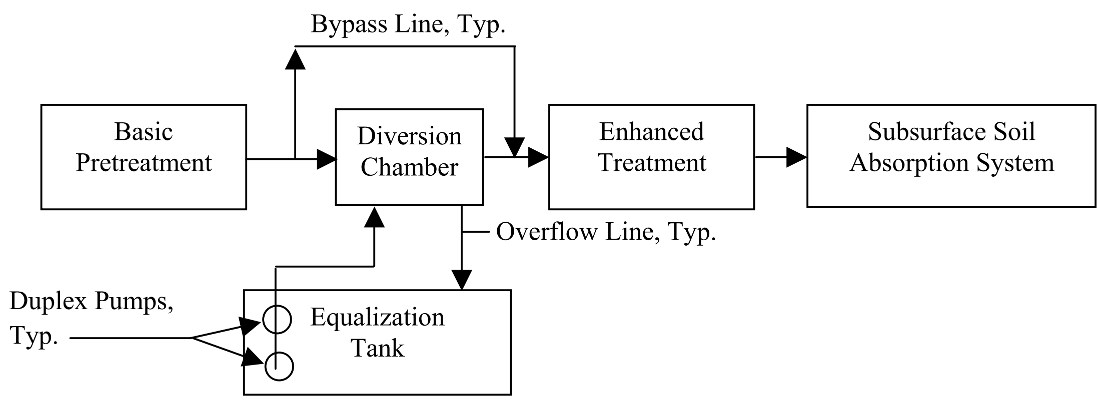
The methodology for determining the volumetric capacity of flow equalization facilities is given in Section X. Factors to be considered in addition to volumetric capacity include:

- Flow control methods for metering flows from the equalization facilities to the downstream treatment facilities.
- Method(s) for removing accumulation of solids from the equalization facilities.
- Control of odors.

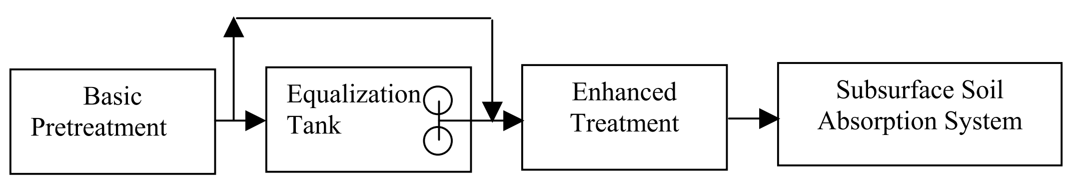
Flow equalization facilities may either be of the sideline or inline type, as shown on the following schematic. The sideline type only receives flows in excess of the average daily flow, while the inline type receives the total flow. The inline type has the greatest effect in dampening wide swings in wastewater characteristics but usually requires pumping of the entire wastewater flow. The sideline type does not have the same effect of dampening the wastewater characteristics as the inline type, but only requires pumping of the flow that exceeds the daily average flow.

Both types of equalization facilities must have provisions for conveying flows in excess of their holding capacity to the downstream treatment units. With careful estimation of flow rates and sizing of the equalization facilities, such overflows should occur rarely, if at all. Facilities to permit intentional bypassing of flows around the equalization basin are necessary in order to permit the periodic removal of accumulated solids and perform other maintenance activities. These facilities can also be used to convey excess flows.

FLOW EQUALIZATION SCHEMATICS



Sideline Flow Equalization



Inline Flow Equalization

a. Sideline Flow Equalization Tanks

Where a sideline equalization tank is utilized, all of the incoming flow is directed to a flow diversion chamber, designed to limit the flow to the downstream facilities to a predetermined average daily flow rate. This can be done by providing the diversion chamber with a weir, orifice or other suitable flow control device for downstream flow control and an overflow device (weir or pipe) for diverting flows in excess of the average daily flow rate to the sideline equalization tank. Flows equal to the average daily flow can be delivered to the downstream treatment facilities via gravity flow provided adequate hydraulic head is made available.

A means for adjusting the rate of flow to the downstream facilities must be provided. This can be accomplished by arranging a manually operated slide gate to operate as a weir, or to vary an orifice opening. A means for measuring the flow rate discharged to downstream facilities should also be provided. Usually, this consists of a simple level-sensing device that delivers a flow depth signal to an indicating and recording device mounted outside of the diversion chamber that is calibrated for the type of flow control device utilized.

Any flow in excess of the desired average daily flow is diverted via the overflow device to the offline equalization tank. When the total flow rate is less than the average daily flow rate, the liquid level in the flow diversion chamber will begin to drop. When this occurs, a liquid level sensor in the chamber will provide a pump start signal to pumps installed in the equalization tank. These pumps will deliver flow from the equalization tank to the flow diversion chamber until the level sensor indicates there is no longer a need for receiving flow from the equalization tank.

For the smaller treatment facilities under consideration herein, the pumps used in the equalization tank are usually of the submersible type, designed for pumping wastewater, and mounted on slide rail systems to permit their removal through an access hatch for ease of maintenance. These pumps operate on the usual automatic alternating cycle method used in most pumping stations; the lead pump operates first, and when it stops, the automatic alternator sets up the lag pump for operation when the next pump start signal is received.

On first glance, selecting the off-line type of equalization would seem to be attractive because all of the inflow would not have to be pumped on a continuous basis. However, there are problems inherent in this method. The flow discharged from the septic tank will be anaerobic and contain dissolved malodorous gases that are easily released to the ambient atmosphere whenever the flow is agitated (such as when the flow passes over or through a flow control device or bypass weir). Therefore, the flow diversion structure should be covered to contain these gases, and the chamber should be vented back to the septic tank, to allow the malodorous gases to escape through the vent stack of the buildings served. It should be noted that these gases are apt to be much greater in volume than those normally released in septic tanks, and thus venting them to the atmosphere via the building vent stack may result in significant odors in the ambient air. In such cases, provisions must be made for odor control.

One of the gases often released is hydrogen sulfide (H_2S), which will tend to condense on the damp, unsubmerged walls and ceiling of the diversion chamber. If any oxygen is present in the airspace of the diversion structure, the H_2S will then be biologically oxidized to sulfuric acid. This will result in the eventual corrosion of the concrete. Therefore, it is necessary to protect these concrete surfaces by lining the walls and ceilings of the diversion structure with a plastic lining that will resist corrosion. The diversion chamber must also be provided with an access opening equipped with a corrosion resistant gasketed cover for periodic removal of solids in a manner similar to that required for septic tanks.

b. Inline Flow Equalization Tanks

In the case of an inline flow equalization tank, pumps are provided to control the rate of flow to the downstream facilities. Pumping the entire flow will permit adjustment of the equalized flow rate by varying the pump delivery rate.

In contrast to the offline equalization method, the inline method provides more flexibility in adjusting the flow to the downstream facilities without experiencing the problem with malodorous and corrosive gases. Careful design of the equalization tank and pumping equipment can avoid agitation of the septic tank effluent and thus avoid release of these gases. Provision of an inflow drop pipe that delivers the inflow to a point below the low liquid level in the equalization tank will prevent agitation at the liquid surface and release of gases into the equalization tank. Since the pump intakes must also be submerged, no agitation of the liquid will occur at this point. If the point of the pumped discharge to the downstream treatment facilities is sufficiently below the liquid level in those facilities, gases should not be released in these facilities. If the downstream facility is a mixed anoxic tank, the mixing device(s) should be such as to not agitate the liquid at the surface of the tank. If the downstream facility is an aerobic tank, the malodorous gases should be oxidized before reaching the atmosphere if sufficient oxygen is available and the discharge into the tank is near the tank bottom.

Since equalization pumps should be able to deliver flow at a relatively constant rate, ideally they should be of the type that have steep head-capacity characteristic curves so that the change in liquid level in the equalization tank will not have a significant effect on pump flow rate. For the smaller treatment facilities under consideration herein, the pumps used for flow equalization are usually of the fractional horsepower, submersible type sewage pumps, mounted on slide rail systems to permit their removal through an access hatch for ease of maintenance. These pumps normally do not have steep head-capacity curves. Further, equalization pumps under consideration herein must be able to deliver at relatively low flow rates. For example, for a design average daily flow rate of 10,000 gpd the equivalent continuous pumping rate would be about 7 gallons per minute, while for a 50,000 gpd flow rate, the equivalent continuous pumping rate would be about 35 gpm. In addition, the total head “seen” by the pump is apt to be fairly low.

Sewage pumps, even the fractional horsepower ones, may have a much greater pumping capacity than required. Throttling a valve on the pump discharge will reduce a pump’s discharge capacity. However, such throttling could force the pump to operate very close to its shut-off head, which is an undesirable condition. Therefore, in most cases a recycling pipe with valve should be installed in the pump discharge piping to allow recirculating some of the flow back to the recirculation tank. In such cases, some throttling of the pump discharge line along with adjusting the valve on the flow recycle pipe will permit adjusting the pumping rate to the desired forward flow rate. The recycle piping should discharge below the low liquid level in the tank to avoid undue agitation of the liquid that could lead to release of entrained gases.

Ideally, variable speed pumps and their associated controls should be used to maintain a constant pumping rate under varying head conditions, but this type of system is usually not warranted for the scale of systems considered herein because of the added cost and complexity.

The range of liquid depths in the equalization tank also has an effect on the ability to maintain an essentially constant flow rate. A smaller range will result in a smaller variation in total head on the pumps and therefore there will be less change in pump delivery rate as the liquid level varies in the tank. The range of liquid depths will be smaller in shallow tanks as compared to relatively deep tanks of the same working volume.

Since in most cases the flow into an equalization tank will come from a septic tank, there should only be a small amount of settleable solids in the flow. Therefore, solids removal will be required rather infrequently. Since the flow discharged from the septic tank may be anaerobic, the equalization tank should be a covered tank similar in construction to a septic tank. Access openings equipped with gasketed covers should be provided for periodic removal of solids in a manner similar to that required for septic tanks. The equalization tank should be vented back to the septic tank, to allow any volatile gases to escape through the vent stack of the building(s) being served. Access openings equipped with gasketed covers will also be required for removal and maintenance of the pumps.

In the case where gravity flow to the downstream facilities via an equalization tank bypass line is not possible, sufficient excess volume should be provided for several hours of peak flow should the pumping system fail. This is necessary in order to provide sufficient response time for repair of the pumping system or to activate standby pumping equipment. It should be noted that the equalization tank also serves as a lift station in this case.

It should be noted that the equalization methods discussed above are not the only ones available, and the designer should review the literature for other methods that may be more suitable for the project at hand.

4. Pumping

Information on pumping systems is provided elsewhere in this section and in Section XII.

5. Mixing

Mixing is used in virtually all enhanced pretreatment facilities. It is used for mixing and maintaining suspensions of non-soluble or partially soluble chemicals in water, to aid in precipitation reactions, and to bring the contaminants in wastewater into intimate contact with chemicals, dissolved oxygen and biomass in various types of reactors. There are many methods and types of equipment used for mixing and their selection will depend to some extent on the processes involved. Mixing facilities can range from high energy mixing of chemicals to much more gentle mixing in bioreactors. Information on mixing in bioreactors is provided in Subsection D and Information on chemical mixing is provided in Subsection E.

6. Flocculation

Flocculation is the gentle stirring of chemicals and biological organisms in contact with wastewater in process reactors. Its purpose is to aid in chemical coagulation processes and for the aggregation of discrete suspended matter into larger clumps of particulate matter (“floc”) to enhance removal of the matter from the liquid in which it is contained by settling in subsequent clarification processes. Flocculation can be accomplished by mechanical and hydraulic means or by aeration.

7. Clarification

Primary clarification (removal of settleable and floatable solids) is usually provided via a septic tank, and grease trap if required, as discussed in Section IX. Clarification is also required to remove suspended solids from the liquids discharged from the aerobic and anoxic processes used for removal of organics and nitrogen, and from any chemical process used for phosphorus removal, except where clarification is carried out in the process reactors (e.g. sequencing batch reactors, membrane bioreactors).

Process design factors for clarifiers following biological treatment processes will depend to some extent upon the type of reactor used for such processes. Where continuous flow dispersed growth reactors are used (e.g. extended aeration mode of the activated sludge process) such factors include:

- Surface loading rate, in gallons per day per square foot of clarifier surface area,
- Solids loading rate, in lb. of suspended solids per square foot of clarifier surface area,
- Weir overflow rate, in gallons per day per linear foot of weir,
- Settled solids removal rate, in gallons per day, and,
- Clarifier depth.

Where fixed film reactors are used (e.g. rotating biological reactors, packed columns) the same factors as listed above apply except perhaps for the solids loading rate. The suspended solids in the liquid discharged from these reactors are a small fraction of those discharged from dispersed growth reactors, thus the solids loading may not be a significant factor if the settleability of the solids is satisfactory. Further discussion of these factors will be given in the discussion of the various suspended and fixed film growth reactors.

8. Effluent Filtration

a. Granular Media Gravity Filters.

A separate filtration step for removal of residual suspended solids in clarifier effluent can be accomplished using either rapid rate granular media filtration or by using the relatively new cloth media disc filters presently available. While membrane filtration can also be used, it is usually not cost-effective except where membrane bioreactors are used for removal of organics and nitrogen. In the latter case, filtration is inherent in the process, as discussed in a subsequent part of this Section.

Granular media filters are often provided to remove most of the suspended solids remaining in the clarifier effluent so as to prevent the possibility of clogging the SWAS and to permit effective disinfection of the treated effluent before it is discharged to the ground. These filters are most often of the down-flow type operated under gravity flow, rather than the pressure flow type of filters sometimes used in potable water treatment. The water to be filtered is discharged to the surface of the filter and travels down through the filter media to a filtered water collection system.

As the solid matter in the wastewater is captured in the filter media, the liquid level above the media rises due to the hydraulic head loss caused by the solids reducing the hydraulic capacity of the media. When it reaches a predetermined level, a level-sensing device actuates a backwash cycle to clean the media of the collected solids. Cleaning these filters involves backflushing the filter with previously filtered water introduced under pressure beneath the filter media. During backwashing, the bed of filter media is expanded and scoured to bring the solids filtered from the liquid to the surface. The surface water above the filter surface that contains the scoured solids is removed by overflow to troughs for further processing to remove the solids from the water. Liquid backwashing is most often preceded with a short period of air scouring of the filter media by compressed air introduced beneath the filter. At least two filter cells should be provided, so that one cell can be backwashed while the remaining cell continues in service.

The controlling parameters for design of a granular media filter include the hydraulic loading and backwash rates, expressed as gallons per minute per square foot of filter surface area (gpm/sq. ft.), the backwash period, and the type, depth(s), effective grain sizes and uniformity coefficients of the filter media.

The hydraulic loading rate recommended by various authorities ranges from 2 to 5 gpm/sq. ft. of filter surface area. A conservative hydraulic loading rate of 2 gpm/sq.ft., with one filter cell out of service for backwashing, is recommended for sizing the surface area of each filter cell. The backwash rate should be ≥ 15 gpm for a period of not less than 10 minutes, and the backwash should be preceded by air scouring of the filter media. The volume of filtered water stored in a clearwell for use in backwashing should be at least equal to the product of the backwash rate x the filter surface area x the backwash period. Equivalent storage should be provided for the spent filter backwash water so that it can be returned at a relatively low flow rate to the head of the plant for solids removal.

The type, effective grain size and uniformity coefficient of the filter media recommended by various authorities varies, but the consensus seems to favor coarse-to-fine filtration using two or more layers of different media, each layer having a different specific gravity, effective grain size and uniformity coefficient.·Dual media filters usually consist of a bottom layer of sand and a top layer of anthracite. The granular material used in multi-media filters are usually specified by the manufacturer, but usually consists of anthracite, sand, and garnet. The recommended effective grain sizes for a dual media filter using sand and anthracite range from 0.5 to 1.0 millimeters (mm.) and 1.0 to 2.0 mm respectively, and it is recommended that the uniformity coefficient of both media not exceed 1.7. The manufacturer usually specifies grain sizes and uniformity coefficients for multi-media filters. The filter media are supported by layers of aggregate, graded coarse to fine, or by other suitable means that will prevent the media from escaping the filter.

b. Cloth media disc filters

Cloth media disc filters have been placed into service over the past 25 years at hundreds of installations in Europe. Within the last decade they have been accepted for use and installed in a number of wastewater treatment plants in the U.S.

The filter cloth media is attached to both sides of vertical discs that have a hollow structure. A number of such discs are mounted on a central hollow shaft in a filtration chamber. The liquid to be filtered enters the tank and flows through the filter media into the inside of each hollow disc under a gravity head. A collection header is connected to the hollow area of each disc via the hollow central shaft and serves to collect the filtrate and convey it out of the filter chamber. The filter unit is controlled by an automatic system that can cycle the filter through cycles that include normal operation, solids wasting, backwash and a pressure spray wash.

During the filtration operation, the discs are submerged in the liquid and there is no movement of any mechanical devices within the filter chamber. Thus relatively quiescent conditions prevail that are conducive to gravity settlement of the heavier solids. As filtration proceeds, solids accumulate on and within the depth of the filter cloth, forming a mat that enhances the filtration process. As the mat is formed, the hydraulic head loss through the cloth increases and this causes the liquid level in the filter chamber to rise. When the liquid reaches a predetermined level, the automatic control unit cycles the filter into a backwash mode.

During backwash, the discs remain submerged and are rotated very slowly (1 rpm) by a drive unit connected to the central hollow shaft on which the discs are mounted. While the discs are rotating, water collected in the filtrate header is drawn back through the filter cloth by suction headers located on either side of each disc, thus backwashing the filter cloth from inside to outside. The reversal of flow removes the majority of the suspended solids that have accumulated on the surface and within the filter cloth. Solids that have accumulated on the surface and within the filter cloth that may not have been removed during the normal backwash cycle are periodically removed by a pressure spray washing system. (Some newer systems with improved filter cloth have eliminated the pressure spray washing system.) Periodically, a sludge pump activated by the control system removes the settled solids through a manifold located in the hopper bottom of the tank.

These filters have been found to be very effective in removing suspended solids. Tests were conducted at two wastewater treatment plants in Florida, which included comparison test runs with both cloth filters and conventional sand filters at various loading rates. The results demonstrated that the cloth media disc filter effluent compares favorably with the effluent of conventional granular media filters, both with respect to efficiency of TSS removal and effluent TSS concentration. As a result, cloth media disc filters have been approved by the Florida DEP for use in lieu of conventional granular filters for producing reclaimed water for reuse in residential and commercial irrigation as well as other purposes. Cloth media disc filters have also been in use for several years in a wastewater treatment plant in Connecticut that produces a very high quality effluent, with turbidities normally below 2 NTU. They produce a filtrate that is equal to or better than that of a rapid rate granular filter while occupying a much smaller floor area.

The design parameters for cloth media disc filters include the hydraulic loading rate (gpm/ft^2 of filter surface area) and solids loading rate (lbs/ft^2 of filter surface area/day). Typical hydraulic loading rates for effluent from extended aeration activated sludge treatment facilities are 4.0 gpm/ft^2 for average daily flows and 6.0 gpm/ft^2 for the peak flows. A typical solids loading rate is 1.8 lbs/sf^2/day on an average sustained flow basis.

Cloth media disc filter units are available for installation in concrete chambers constructed on-site or as packaged units in steel chambers. However, the units may not be cost-effective at the low end of the range of flows encountered in facilities used for onsite wastewater renovation systems. New cloth media drum filter units are being developed that may be more cost-effective than cloth media disc filters for smaller flows.

9. Disinfection

Disinfection is the use of a chemical or physical process to destroy or inactivate pathogenic microorganisms (pathogens). It should be noted, however, that disinfection does not necessarily destroy all microorganisms, such as in sterilization. In the case of wastewater treatment, the goal is to prevent the spread of pathogenic microorganisms, and thus it is their destruction or inactivation that is of concern.

Where only a septic tank and a SWAS are used for onsite wastewater renovation, some of the viable pathogens are eliminated in the septic tank. The greatest amount is eliminated or inactivated in the biomat that forms at the infiltrative surface of a SWAS and in the unsaturated soil zone beneath the SWAS. Some of the remaining pathogens are eliminated or inactivated when the percolate from the SWAS commingles with the ground water and travels in the saturated zone to a point of concern. When enhanced pretreatment of the wastewater is required, often to reduce the concentration of nutrients (nitrogen, phosphorus) in the treated wastewater and sometimes to reduce the organic loading on the SWAS, the formation of a biomat will be severely reduced. However, pretreatment to meet the water quality goals set forth in the Department's Design Standards for enhanced pretreatment will be considered equivalent to the pathogen reduction normally obtained in the biomat.

In certain instances, disinfection of effluent from enhanced pretreatment facilities may be required. Situations where disinfection must be provided include:

- When the Department permits the use of reclaimed water for any beneficial re-use (e.g. irrigation of vegetation, recycling for use in toilets and urinals).

In the case of on-site wastewater treatment, where the renovated wastewater will reach and mix with the ground water, it is important that the disinfection process does not create chemical byproducts that have been found harmful to living organisms. For example, disinfection using chlorine is problematic because there are a number of organic compounds in wastewater that can react with chlorine to form toxic compounds. De-chlorination after chlorine disinfection will not prevent the formation of such byproducts. Thus, where disinfection is required prior to discharging pretreated wastewater to the ground water, it should be determined that no harm will be done to the subsurface environment by the disinfection process. Further information on disinfection is given in Subsection H.

<u>10. Adsorption</u>

Adsorption processes have seldom been used for enhanced pretreatment facilities, the exception being the Zenon Cycle-Let® facilities that include activated carbon adsorption as a polishing step to produce an effluent suitable for re-use in non-potable water facilities.

Adsorption is the attraction and accumulation of one substance on the surface of another. The adsorption process that may be found useful for enhanced pretreatment is adsorption of toxic organic chemicals by granular activated carbon. Activated carbon has a preference for organic compounds and therefore is very effective in removal of toxic organic compounds in wastewater that cannot be easily removed by biological or chemical processes. Since adsorption is a surface phenomenon, granular activated carbon is particularly suitable for this purpose because of its extremely high surface area per unit mass. Granular activated carbons have surface areas ranging from 500 to 1,400 square meters per gram, equivalent to a range of 56 - 157 acres per lb. Activated carbon is made from a variety of carbonaceous materials and thus the quality of the carbon and its ability to adsorb the wide variety of toxic organic chemicals will depend upon its source material as well as the method of production.

Another adsorption process that is emerging for use in enhanced pretreatment facilities is the adsorption of phosphorous on beds of reactive media. Additional discussion of adsorption processes for removal of toxic organic chemicals and P can be found in Subsections G and I.

11. Chemical Processes

Chemical processes used for enhanced pretreatment usually are required for control of biological processes (pH control, external carbon sources to sustain the denitrification process), for disinfection, and for removal of phosphorus where required. Therefore, discussion of such chemical processes is included under the latter headings. Chemical processes may also be used to process commercial laundry wastewater. In such cases, information is usually available from vendors who specialize in such processes and provide a turnkey treatment facility.

a. Storage and Handling of Chemicals

The storage and handling of chemicals must be accomplished in a manner that is consistent with the health and safety of the personnel who operate and maintain wastewater treatment facilities and the general public. Many of the chemicals used in wastewater treatment processes may be highly corrosive, volatile and flammable, or combustible in the presence of organic materials. In addition, some of these constitute a danger to human health due to inhalation of vapors or dusts, ingestion, or skin or eye contact and their unintended release (spills, overfeeding) can be harmful to the environment. The Material Safety Data Sheet (MSDS) obtainable from the manufacturers for each chemical proposed for use at a wastewater treatment facility should be consulted for specific requirements for their storage and handling. In most cases, separate rooms should be provided for storage of chemicals. Sufficient room for storage of chemicals must be provided so that sufficient chemicals will always be available between periods of replenishment. Spill containment facilities, adequate ventilation and provisions for prevention of ignition should be incorporated into the design of such rooms.

- Spill containment facilities should be provided in chemical storage and feed areas and should be capable of safely containing the entire volume of the largest container of each chemical. Spill containment facilities should not be connected to any floor drains, since the spilled chemical from one containment area may not be safely mixed with a possible spill from another containment area, and their mixing in the floor drain waste holding tank may cause a hazardous condition to develop.
- Adequate ventilation should be provided for maintaining a safe environment and to remove explosive vapor and dust concentrations. Where vapors are heavier than air, ventilation intakes should be provided at the floor level. All ventilation facilities should discharge to a safe outdoor location, away from work areas and other nearby inhabited areas and where there is no ignition source nearby.

The requirements of safety codes should be scrupulously followed in areas where flammable or combustible liquids and solids are stored or where explosive vapors or hazardous dust concentrations can possibly be encountered. The safety codes include the National Electric Code (NEC), the Flammable and Combustible Liquids code and recommended practices promulgated by the National Fire Protection Association (NFPA) and all state and local building codes. Only non-sparking tools should be used in such cases, and all containers should be grounded to guard against the possible ignition due to the discharge of static electricity. Containers used for flammable or combustible liquids should be provided with a means to prevent the formation of static electricity in the container when such liquids are discharged into the container. Such provisions usually consist of a tube, grounded to the container, which will convey the liquid being discharged to below the liquid level in the container to avoid splashing.

b. Chemical Feeding Equipment

Chemical feeding for enhanced pretreatment onsite usually involves equipment such as chemical mixing (dilution) and feed tanks, chemical feed pumps (typically of the positive displacement type), and associated piping. Care must be taken to assure that all of the materials used in such equipment and piping, with particular emphasis on all wetted parts, including seals, are compatible with the chemical being used, to avoid problems with corrosion and clogging.

Where highly flammable and potentially explosive chemicals are used (e.g.: methanol), all equipment and piping should be grounded and located in a separate room accessible from outside of the areas in which the enhanced pretreatment facilities are located. All electrical equipment and associated wiring should be explosion proof, UL listed for Class I, Division I, Group D locations. The room should be ventilated to the outside atmosphere and the vent piping should be equipped with an UL-listed flame-arresting device.

Where chemicals composed of a suspension of diluted solids are used that may tend to separate (plate out, or precipitate) from the suspension, (e.g.: magnesium hydroxide, lime) provisions should be made for introducing warm water to the pumping and piping system to remove any clogs that may have developed.

All chemical feed pumps should be provided with pressure relief, anti-siphon, and backpressure valves on the discharge side of the pumps. Where the pump manufacturer will not provide an anti-siphon valve because of the materials being pumped (usually in the case where the pumped liquid is a suspension of solids in water), a separate valve should be provided that will operate under such conditions. A check valve, installed in the reverse position, can provide the anti-siphon function in this case. The discharge from pressure relief valves should be piped back to the chemical feed tank. All chemical feed pumps should be equipped with splashguards to protect the plant operator and adjacent equipment in case of a leak or seal failure. The feed pumps should be provided with a means of varying their pumping rate over at least a tenfold range, using either a stroke or frequency adjustment, or both. The pumps should be securely supported on the chemical feed tank cover or independently supported by a wall or floor mounted stand immediately adjacent to the feed tank.

Tanks containing chemicals should be covered preferably using the same material as the tank. The cover should be easily removed for inspection of the tank interior. Where mixing is required, it is usually accomplished with fractional-horsepower electric motor operated mechanical mixers independently supported by wall or floor mounted stands immediately adjacent to the tanks. The stands should be constructed with sufficient strength to withstand the long-term vibration typical of mixer use and should have a chemical resistant coating compatible with the chemicals being mixed. Operation of the mixers should be initiated using a “manual-off-automatic “selector switch that will permit both manual control and operation by a repeat cycle timer capable of continuous, 24 hour duty in programming the number of pumping cycles required by the process design. In cases where the feed rate will be automatically controlled from flow pacing or other instrumentation, the pump should be equipped to operate based on the signals received from such instrumentation.

Pipe and tubing should be flexible wherever possible and in all cases should be arranged for easy removal and replacement. Pipe and tubing supports should be provided as recommended by the manufacturer of the pipes and tubing. Where chemicals are being conveyed under pressure, the carrier pipe and tubing containing the chemicals should be enclosed in flexible containment piping to avoid accidental release of the chemicals should the carrier pipe develop a leak or burst. The containment piping should also be compatible with the chemical being conveyed in the carrier pipe and should consist of a continuous length of piping wherever possible, to eliminate joints between the chemical feed area and the reactor receiving the chemical. Where joints in piping or tubing are exposed, they should be provided with splashguards. In the case where highly flammable and potentially explosive chemicals are being conveyed under pressure, the carrier pipe should consist of a flexible hose (compatible with the chemical) provided with a stainless steel overbraid, equipped with all necessary couplings and adapters. Suitable warning labels, in a format approved by OSHA, should be mounted on the chemical feed equipment and piping, identifying the chemical being conveyed and the hazards involved.

Provisions should also be made for the safety of plant operating personnel that will be handling chemicals. Such provisions include, but are not necessarily limited to, emergency eyewash stations, emergency showers, emergency medical kits, protective clothing, gloves and safety goggles, and fire extinguishing equipment and should conform to any Federal, State and local safety regulations.

Further information on chemical feed systems is provided in Subsections E and I.

12. Biological Processes

Biological processes are used for removal of organic compounds that exert a carbonaceous biochemical oxygen demand (CBOD) and for removal of nitrogen compounds that exert a nitrogenous oxygen demand (NOD) from domestic wastewater. Aerobic processes have a much higher reaction rate than anaerobic processes, do not produce strong or offensive odors, and are therefore more suitable for removal of organics from domestic wastewater.

Removal of nitrogen involves both aerobic and anoxic processes. While biological processes may also be used to remove phosphorus, the operation is considered too complex for use in the scale of enhanced treatment facilities under discussion herein.

Enhanced pretreatment processes for removal or reduction of CBOD and NOD include suspended growth processes, fixed film processes, and hybrids that combine both fixed film and suspended growth processes. The suspended growth process provides an environment in which the microorganisms that remove the impurities from the wastewater are held in suspension in intimate contact with the wastewater to be treated in a bioreactor.

The fixed film system provides an environment in which the microorganisms are attached to some type of media, with the wastewater either passing through the media or the media passing through the wastewater flowing through the bioreactor.

a. Removal of Organic Materials

Various heterotrophic bacteria and higher life forms (e.g.; protozoa and rotifers, some microscopic and some macroscopic in size), hereinafter for simplicity collectively referred to as “microorganisms” or “microbes”, that utilize the organic compounds present in wastewater in their metabolic processes are responsible for the removal of organic materials. Microbes grow by coupling the reactions that produce energy with those reactions involving cell synthesis (U.S. EPA-1993 a). In these processes, the microbes utilize the organic compounds as sources of energy and food for cellular maintenance and synthesis of new cells in a series of oxidation-reduction (redox) reactions.

Chemical energy needed to support the microbial life processes is obtained in the process of oxidizing organic matter from a series of reactions that involve the release of electrons from electron donors (the carbon compounds) to electron acceptors. The electrons are transported via an electron transport chain, utilizing several steps involving various enzymatic reactions, to an ultimate electron acceptor. In aerobic heterotrophic reactions, the ultimate electron acceptor is free (dissolved) oxygen.

The effectiveness of the microbial processes in removal of organic compounds from the wastewater will depend upon the environment in which they exist. The environmental conditions of concern include moisture, dissolved oxygen (D. O.) concentration, pH, temperature, presence of required microbial cell nutrients (nitrogen, phosphorus, various micro-nutrients), and the chemical characteristics of the wastewater.

All of the microbes responsible for removal of organic materials require moisture (water) to remain viable. A sufficient dissolved oxygen (D. O.) concentration in the water is critical to the life processes of the microbes. Generally speaking, a D. O. concentration of 2-3 mg/L is sufficient to maintain a reasonable efficiency of the microbial processes. A higher D. O. concentration may serve to optimize the removal of organics, but may not provide an overall advantage because of the energy (electrical power) costs involved.

While most microbes will function in a pH range 4-9.5, the optimum pH for aerobic microbial processes usually lies between 6.5 and 7.5. This is within the pH range of domestic wastewater and thus pH is not usually a limiting condition for removal of organics. However, as discussed under the following subsection b., pH can be a limiting condition for the nitrification process.

Temperature has a significant effect on the metabolic processes of the microbes. A 10°C rise or fall in temperature from a reference temperature will cause the microbial reaction rates to double or halve, respectively. Optimum temperatures vary with the type of microorganisms, but temperatures below 10° C can significantly reduce the reaction rate. While high temperatures will also have a deleterious effect, they are usually much higher than the ambient temperatures experienced in domestic wastewater treatment.

The major nutrients required to sustain the microbial life processes include nitrogen and phosphorus. Where the carbon content of the organic wastes are represented by the five-day biochemical oxygen demand (BOD_5), for every 100 mg/L of BOD_5 5 mg/L of nitrogen and 1 mg/L of phosphorus are required. Various micro-nutrients (e. g.: sulfur, potassium, calcium, sodium, magnesium and other trace metals) are also required. All of these nutrients are generally found in domestic wastewater.

The chemical characteristics of concern include the presence of slowly biodegradable organic materials and substances that are toxic to the microbes. Slowly biodegradable organic materials may not be removed, or may only be partially removed in the aerobic treatment processes. An example of this is organic nitrogen, as discussed in b. below. Toxic chemicals have been found to adversely affect the operation of some enhanced pretreatment facilities constructed in Connecticut that serve commercial establishments. As indicated in Section IV, the Department is aware of several instances where cleaning chemicals (e.g. quaternary ammonium compounds) discharged to the building sanitary sewer systems inhibited the biological treatment processes, resulting in degradation of the quality of the treated effluent. Domestic wastewater discharged from RV wastewater holding tanks is another case where toxic chemicals may be encountered.

b. Removal of Nitrogen

Both physical/chemical and biological processes can accomplish nitrogen removal. However, physical/chemical processes are not considered to be suitable for OWRS because of the cost of such processes, the operational problems inherent in such processes, and the need for highly skilled operation. In fact, while physical/chemical processes were once considered to be attractive for nitrogen removal at municipal wastewater treatment facilities, they have largely been abandoned in favor of biological processes.

As stated in Section II, to remove nitrogen via biological processes, nitrogen (ammonium-N) in the wastewater must first be oxidized to nitrates in the nitrification process, and then reduced to nitrogen gas in the denitrification process. Most of the nitrogen in wastewater receiving pretreatment in a septic tank is in the form of the ammonium ion (NH_4^+), with some organic nitrogen, and sometimes trace-to-small amounts of nitrite (NO_2^-) and nitrate (NO_3^-) also present. Most of the particulate organic nitrogen is hydrolyzed to soluble organic nitrogen in the septic tank. Some of the soluble organic nitrogen is then mineralized to ammonium-N in the septic tank, and most of the remaining soluble organic nitrogen is mineralized in the nitrification process. A relatively small amount of organic nitrogen in domestic wastewater is refractory (generally 1-2 mg/L) and thus will pass through the nitrification-denitrification process without alteration.

Nitrification is accomplished in a two-step sequential aerobic process.

Ammonium (NH_4^+)------> Nitrite (NO_2) ------> Nitrate (NO_3)

In the first step, ammonium-nitrogen (NH_4^+) plus oxygen is utilized by autotrophic bacteria (e.g. Nitrosomonas) to produce nitrite (NO_2) plus water + hydrogen ions. The autotrophic bacteria obtain their carbon for cell synthesis from inorganic sources such as carbon dioxide (CO_2), present in wastewaters rather than from the organic carbon utilized by the heterotrophs. The autotrophs obtain their energy from oxidation of ammonium (the electron donor), with electrons released in the process, and oxygen is used as the electron receptor.

In the second step, autotrophic bacteria (e. g.: Nitrobacter) oxidize nitrite to nitrate. This process results in the consumption of approximately 4.6 lbs. of free (dissolved) oxygen and 7.1 lbs. of alkalinity (as $CaCO_3$)/lb. N oxidized. (Note that 7.1 lbs. of alkalinity is the calculated theoretical (stoichiometric) amount, and that overall alkalinity consumption is generally somewhat less.) The consumption of alkalinity tends to lower the pH of the water (unless there is sufficient alkalinity available in the wastewater so that at least 50-mg/L alkalinity remains after nitrification is complete). The optimum range of pH for nitrification = 6.5-7.5. Nitrification will be significantly inhibited when the pH drops below 6.0 or increases to above 8.0. When the pH drops below 6.0, nitrification rates decline significantly and, below a pH of about 4.5, nitrification is usually completely inhibited. Thus, if calculations indicate that there is insufficient alkalinity available in the wastewater being nitrified, it will be necessary to add alkalinity (in the form of lime, sodium bicarbonate, sodium hydroxide (caustic soda) or magnesium hydroxide) to sustain the nitrification process.

The nitrification process is also sensitive to the amount of dissolved oxygen present. The maximum growth rate of the nitrifiers is reported to occur at D. O. concentrations ≥ 8 mg/L while the minimum concentration required to assure that the nitrification process is not oxygen limited is typically considered to be 2 mg/L. Maximizing the nitrifier growth rate may appear desirable. However, maintaining a high D. O. concentration in a nitrification reactor may not be cost effective because of the additional energy costs involved in providing the higher D. O. concentration and the increased carbon source requirements needed to purge any excess D. O. in the denitrification process.

Denitrification is accomplished in a multi-step process; e.g.:

Nitrate (NO_3^-)-->Nitrite (NO_2^-)-->Nitric Oxide (NO)-->Nitrous Oxide (NO_2)-->Nitrogen gas (N_2).

However, contrary to the need for free (dissolved) oxygen in the nitrification process, the denitrification process must proceed under anoxic conditions; that is, the dissolved oxygen concentration must be ≤ 0.3 mg/L and there must be nitrates present. The facultative bacteria that accomplish the denitrification process will use free (dissolved) oxygen in preference to the chemically bound oxygen in nitrites and nitrates for their metabolic processes. Thus, if dissolved oxygen in any significant amount (≥ 0.3 mg/L) is present, the denitrification process may not be completed. (It should be noted that denitrification has been found to occur in aerobic bioreactors. This is thought to occur in anoxic microsites that exist within the aerobic biomass, or to result from a yet to be understood biochemical reaction. However, this occurrence is not usually taken into account in designing the small scale biological treatment processes of interest herein, except in the case of recirculating granular media filters, as will be discussed in a following subsection.)

The energy needed for facultative bacteria cell growth (synthesis) is obtained from conversion (reduction) of nitrate to nitrogen gas. However, in order for the denitrification process to proceed, there must also be a source of readily assimilable (easily biodegradable) carbon, as well as phosphorus and various micro-nutrients available for cell synthesis. Domestic wastewater itself may provide a sufficient carbon source and usually will contain sufficient phosphorus and micro-nutrients to permit a substantial reduction in nitrogen. If sufficient carbon is not available in the wastewater, various types of external carbon can be added to sustain the denitrification process

Where a high degree of nitrogen removal is required, an external readily assimilable carbon source is normally required, since the denitrification rate for such sources is several times greater than the rates ordinarily experienced using the carbon in domestic wastewater. An ideal external carbon source material for the biological denitrification process is one that is readily assimilable by the denitrifying microorganisms, is free of nitrogen and substances toxic to the bacterial process, and is of uniform quality; that is, the concentration of readily assimilable carbon should not vary significantly. The carbon source material most often used in the past at wastewater treatment plants has been methanol.

Methanol has a very high concentration of soluble (readily assimilable) organic carbon, is uniform in composition, exhibits high denitrification rates, produces less excess biological cell growth than most other carbon sources and is readily available as a market product at a reasonable cost. However, there is some concern with the use of methanol in a denitrification process where the process effluent will be discharged to the groundwater without further treatment. The possibility exists that the quantity of methanol fed to an anoxic reactor could exceed the organic carbon requirements of the process and therefore some of the methanol would pass through the anoxic reactor and be discharged to the groundwater. This is of concern because of the toxic nature of methanol.

Many researchers have investigated the use of various other sources of external carbon for denitrification[1], including commercially produced chemicals and various industrial process byproducts and wastewaters.

Commercially produced carbon sources include chemicals such as Acetic Acid, Citric Acid, Ethanol, Ethyl Acetate, Isopropanol, Lactic Acid, Propylene Glycol, Sodium Acetate, Corn Syrup, and Sugar. Chemical and physical characteristics for some of the commercially produced chemicals that can be used as a carbon source are given in the following table,

TABLE XI-1

Chemicals Cited as External Carbon Sources for Denitrification of Nitrified Wastewater

Chemical Name	Formula	(L), (S)[1]	Molecular Weight	% Carbon	Sp. Gr. @ 20°C	Solubility in Water
Acetic Acid (Glacial)	$C_2H_4O_2$	L	60.05	40.0	1.05	Miscible
Cane Sugar (Sucrose)	$C_{12}H_{22}O_{11}$	S	342.3	42.0	1.587	(2)
Citric Acid (Anhyd.)	$C_6H_8O_7$	S	192.12	37.51	1.665	162g/100 ml*
Ethanol (SDA 35A)[3]	C_2H_6O	L	46.07	52.14	0.796	Miscible
Ethyl Acetate	$C_4H_8O_2$	L	88.10	54.53	0.902	1ml/10 ml*
Isopropanol	C_3H_8O	L	60.09	59.96	0.8	Miscible
Lactic Acid	$C_3H_6O_3$	L	90.08	40.00	1.12-1.23	Miscible
Methanol	CH_4O	L	32.04	37.48	0.796	Miscible
Propylene Glycol	$C_3H_8O_2$	L	76.09	47.35	1.036	Miscible
Sodium Acetate (Anhyd.)	$C_2H_3NaO_2$	S	82.04	29.28	1.53	76g/100 ml**

* @ 25°C

** @ 0°C

(1.) L = Liquid, S = Solid

(2.) Solubility in water; 179.2 g/100 g @ 0°C, 190.6 g/100g @10°C, 203.8g/100g @ 20°C

[1] McCarty et al.-1969; Sollo et. al - 1976; Driscoll and Bisogni-1978; Monteith et al.-1980; Skrinde and Bhagat-1882; Beauchamp et al-1989, Paul, et al.-1989; Christensson, et al.-1994; Cuervo et al.-1999.

Industrial byproducts and wastewaters that have been suggested for use as carbon sources include corn silage derivative, brewery and distillery wastes; cellulosic materials such as coconut shells, pecan shells, sawdust and wood chips; used newspaper, residuals from molasses production, and residuals (such as whey) from production of dairy products.

The attractive advantages associated with using industrial wastes as a source of carbon are that it results in the degradation of the waste while aiding in the removal of nitrogen from wastewater, and it may in some cases be the least expensive carbon source.

However, there are problems associated with the use of industrial wastes and byproducts as carbon sources. These include:

- A lower concentration of readily assimilable carbon than commercially produced carbon sources.
- A lack of uniformity (consistency) in carbon concentration.
- Contamination with undesirable substances (toxic metals, organic chemicals toxic even in trace amounts, etc.).
- May not be permanently (continually) available.

Therefore, where industrial waste/byproducts are proposed as sources of carbon, the Department will review them on a case -by-case basis. If the Department approves the use of such a source, it may require that the enhanced pretreatment facilities be designed to permit changeover to commercially produced carbon sources in the event the originally proposed carbon source becomes unavailable or unsuitable.

The Department will also review proposed use of commercially available carbon sources with respect to their toxicity to human health and the environment and use of any such source may not be made without receiving approval from the Department.

In selecting an external carbon source, it is important to consider the soluble carbon content, the energy obtained by the microorganisms during the oxidation-reduction reactions, the denitrifier growth rate (amount of biomass produced), and any threat to the public health or the environment that may result from impurities contained therein.

Sufficient carbon should be provided in excess of the stoichiometric requirement determined from balanced chemical reaction equations to insure that the denitrification process will be nitrate-limited rather than carbon limited. For example, the actual use of methanol has been reported to range from 1.3 to 1.6 times the stoichiometric amount. Similar ratios have been reported for ethanol. Excess carbon source remaining after denitrification is complete should be removed in an aerobic reactor following the anoxic reactor.

It should be noted that completion of the denitrification process results in the recovery of approximately 50% of the alkalinity consumed in the nitrification process.

C. Approval of Enhanced Pretreatment Processes and Equipment

1. General

The Department will approve enhanced pretreatment processes and equipment on a case-by-case basis where the need for enhanced pretreatment has been demonstrated to the satisfaction of the Department. Approval will be based on the enhanced pretreatment effluent quality goals and the demonstrated ability of the proposed processes and equipment to attain those goals.

Enhanced pretreatment processes for $CBOD_5$ and nitrogen reduction that have been approved by the Department include suspended growth processes, fixed film processes, and hybrids that combine both fixed film and suspended growth processes. Those enhanced pretreatment processes and associated equipment that have been utilized in applications that were approved by the Department in the past include [2]:

- Amphidrome™ (fixed film sequencing batch bioreactor usually preceded by septic tank(s) with or without preceding grease trap(s)).
- Bioclere™ (fixed film bioreactor usually preceded by septic tank(s) with or without preceding grease trap(s)).
- Clarigester™ (A primary clarifier, with a lower compartment used to store solids in a manner similar to a septic tank)
- Disinfection facilities, including ozonation and ultra-violet irradiation facilities.
- Extended Aeration facilities, packaged type (suspended growth aerobic bioreactors followed by clarifiers) preceded by septic tank(s) with or without preceding grease trap(s).
- FAST™ (hybrid system incorporating both fixed film and suspended growth processes, usually preceded by septic tank(s) with or without preceding grease trap(s)).
- Filtration facilities, including rapid rate granular single media, dual media or multi-media type filters, or cloth media disc filters, normally following the processes listed above.
- Recirculating granular media filters (RGMF) following basic pretreatment in septic tank(s) with or without preceding grease trap(s). These include recirculating filters using either a sand media, in which case they are referred to as Recirculating Sand Filters (RSF), or a gravel media, in which case they are referred to as Recirculating Gravel Filters (RGF). These have been of a generic type as compared to packaged or pre-manufactured enhanced pretreatment facilities.
- Rotating Biological Contactors [RBC] (fixed film bioreactors operating in an aerobic mode, anoxic mode, or both, followed by clarifiers), preceded by septic tank(s) with or without preceding grease trap(s).

[2] The mention of trade names, trade marks, proprietary products and processes and does not constitute endorsement or recommendation of use by the Department unless specifically stated otherwise herein.

- RUCK system® (fixed film system incorporating an intermittent sand filter and upflow packed bed anoxic reactor, preceded by septic tank(s) with or without preceding grease trap(s)).
- Zenon Cycle-Let® (membrane bioreactor (MBR) suspended growth system followed by additional advanced treatment processes, preceded by a septic tank or trash tank with or without preceding grease trap(s)).

Notwithstanding the listing of enhanced pretreatment facilities that have been previously approved, the Department reserves the right to approve or disapprove any proposed enhanced pretreatment facilities based on the merits of each individual application and for good cause shown.

D. Design of Enhanced Pretreatment Systems

1. General

Most enhanced pretreatment systems used in onsite wastewater renovation systems (OWRS) consist of one or more commercially produced prefabricated units containing all necessary operating equipment, piping internal to the equipment, and tankage. The exceptions to this are the generic recirculating granular media filters that are constructed on-site. Therefore, the design of prefabricated systems is approached from a somewhat different perspective than the design of the much larger centralized wastewater treatment systems.

In the design of the larger centralized wastewater treatment plants, considerable effort is usually made to establishing a very substantial and detailed database on anticipated wastewater flows and characteristics. In some cases, bench top and pilot studies are conducted to develop detailed process data (e.g. microbial growth, decay, and reaction rates, hydraulic detention time, solids retention time, sludge settleability studies, etc), that will then be used for actual design of reactor tankage, and sizing of piping and equipment. This is a “luxury” that is not usually available to the engineer responsible for designing enhanced pretreatment facilities for an OWRS, due to budgetary restraints.

It also is a fact of life that prefabricated “packaged” treatment systems are usually more cost-effective options for such facilities, both in terms of the procurement cost of the systems and their installation on the project site. Usually all that is required to install the prefabricated “packages” is to place them in the correct locations and at the correct elevations and connect them to the site sanitary sewers, electrical power supply and SWAS. (This last statement is an oversimplification, of course, but is used to emphasize the difference between a packaged treatment system and one that is constructed on-site from basic materials and equipment.)

However, there is a downside to the use of packaged wastewater treatment facilities. This equipment is often designed in a modular fashion to encompass incremental ranges of flow rates and wastewater characteristics and thus cannot be tailored to the particular application in mind. Also, the turndown ratio for such facilities (the ability to operate properly at flows and organic loadings considerably lower than the design flows and loadings) may be limited, although this limitation can often be remedied by using flow equalization and/or multiple units.

Further, the engineer is depending upon the manufacturer's technical staff to select the correct model for his project that will provide the desired effluent water quality. In some cases, the design criteria used by the manufacturer's staff may be somewhat optimistic as compared to the results obtained under "real life" situations. The engineer designing an OWRS that will incorporate packaged wastewater treatment facilities should inquire as to the criteria used for design of these facilities and the treatment efficiency to be expected. This information should be compared with published results found in the literature for the same type of system, wastewater flow and loading.

Reliable manufacturers and vendors of packaged wastewater treatment facilities will request certain information about the flow rates and nature of the wastewater to be treated. The type of information requested may or may not encompass all of the variables that the engineer may wish to be considered in the design of the treatment facilities. Therefore, it is incumbent upon the engineer responsible for designing the enhanced pretreatment facilities to ensure that the manufacturer/vendor are provided with full information on the flows and biochemical characteristics of the wastewater and the ambient conditions at the site where the treatment facilities will operate. The engineer should also make known his preference for the types of equipment and auxiliary facilities he wishes to have incorporated into the packaged unit.

2. Information Provided to Manufacturers and Vendors

The following information should be provided by written communication to the manufacturer/vendor:

- The types of processes required.
- Average Daily Design Flow Rate at Design Year and during initial years of operation.
- Maximum Daily Design Flow Rate at Design Year and during initial years of operation.
- Maximum Hourly Design Flow rate at Design Year and during initial years of operation.
- Minimum Daily Design Flow rate at Design Year and during initial years of operation.
- Expected seasonal variation in the flow rates listed above.
- The number of hours of each day wastewater will be received at the treatment facility
- Types of facilities to be served (sources of wastewater) and influent wastewater characteristics, including daily average and peak values for:
    - Carbonaceous Biochemical Oxygen Demand ($CBOD_5$) (Total and Soluble)
    - Chemical Oxygen Demand (COD) (Total and Soluble)
    - Total Solids
    - Total Suspended Solids (TSS)
    - Total Nitrogen (generally, ammonia-N and organic N, but also include nitrites/nitrates if expect to be present in other than trace amounts)
    - Total Phosphorus
    - pH,
    - Total Alkalinity, as $CaCO_3$
    - Sulfides
    - Seasonal wastewater temperatures (max, min, avg.)
- Seasonal ambient air temperatures (max, min, mean)
- Altitude and seasonal variation of relative humidity at plant location (required for design of diffused air systems)
- Site Constraints (available area, site access, etc.)

- Electrical Power Supply Characteristics (e.g.: single or three phase, voltage)
- Required Effluent Water Quality, including:
  - $CBOD_5$
  - TSS
  - TN
  - TP
  - pH
- The choices of any alternates of materials or equipment offered by the manufacturer.
- Any special requirements for interior and exterior surface coatings and other corrosion protection of the reactor and any components that will be submerged in the wastewater and mixed liquor.
- Any special guarantee requirements. (See subsection O for a further discussion of such requirements.

3. Enhanced Pretreatment at Seasonally Operated Facilities

Where the facilities to be served are operated on a seasonal basis, the processes selected should be easy to start up and maintain in a stable condition under low microbial mass conditions. Suspended growth bioreactors can be "seeded" with microorganisms obtained from a similar type of bioreactor operating in a stable condition and treating the same type of wastewater. This involves transferring the requisite volume of mixed liquor suspended solids (MLSS) from the operating plant to the seasonal plant when restarting the process.

An example of a fixed film process that can be used in such instances is the recirculating granular media filter because it is an inherently stable process. Both start-up and shutdown are simple to accomplish and there is less likelihood that any startup problems that are encountered will cause problems with any downstream processes or the SWAS due to escape of suspended solids. It may take several weeks for fixed film media to develop the required microbial population that is necessary for an effective biological process. Therefore, it will be necessary to seed the process by importing septic tank effluent from another similar facility so that the process will be up and running when needed. Such seeding may not be necessary if even a small amount of wastewater is being treated in the off-season.

4. Suspended Growth Aerobic Systems.

Suspended growth aerobic systems used for treatment of wastewater employ activated sludge processes in a mixed and aerated bioreactor (aeration tank). The liquid contained in a suspended growth bioreactor is termed "mixed liquor" and consists of a mixture of wastewater and suspended and colloidal solids, including biodegradable and non-biodegradable solids, and suspended microorganisms (biomass) that are collectively referred to as the mixed liquor suspended solids (MLSS), or "activated sludge".

The biomass actually consists of both living and dead microorganisms and thus only a fraction of the biomass is actively involved in waste removal or stabilization. The biomass actually responsible for waste removal or stabilization is included in the volatile solids, referred to as mixed liquor volatile suspended solids, or MLVSS.

The mixed liquor is stirred to maintain intimate contact between the MLSS and the contaminants in the wastewater and provided with sufficient oxygen to maintain the metabolism of the microbes as they oxidize the organics and nitrogen in the wastewater.

The stirring also helps the individual microbes in the biomass to flocculate so that they can be removed from the liquid in which they are suspended by the subsequent clarification process, for without adequate flocculation the individual microorganisms would be very difficult to remove.

In order to maintain a balanced process, excess biological growth resulting from the reproductive capacity of the microbes, termed "waste activated sludge (WAS)", must be removed from the reactor via settling (sedimentation) in clarifiers and wasted to side-stream waste sludge processes.

Oxygen is usually introduced into the bioreactor via air diffused into the liquid by low-pressure air blowers discharging to diffusers submerged within the bioreactor, with the diffused air also providing the required mixing. Other methods of introducing air and mixing involve mechanical aerators, jet aeration and the use of submerged turbine aerators. By far the most common method used in small packaged plants involves air blowers and submerged diffusers.

a. Extended Aeration

There are several modes of the activated sludge (AS) process. However, in most cases, where suspended growth aerobic systems are used as enhanced pretreatment in on-site wastewater renovation systems, the extended aeration (EA) mode is selected.

The BOD_5 removal efficiency of the EA process is ≥ 95 % for a properly designed, operated and maintained facility and almost complete oxidation of ammonium (residual ammonium normally ≤ 1 mg/L) is also obtained except when temperature of the liquid in the reactor drops below 10°C. Nitrification is thus inherent in the EA process under normal operating conditions.

The EA process is relatively simple to operate and also produces the least WAS. Generally, no primary treatment is provided except for removal of large solids, which can be accomplished in a septic tank or in screening facilities that precede the EA facility. Where a septic tank does not precede the EA process, the large solids must be removed by screening or by reducing the size of the solids (comminution).

The EA process can be accomplished in a continuous flow reactor, or in a sequencing batch reactor (SBR). If a continuous flow reactor is selected, sedimentation must be accomplished in a separate clarifier, where the activated sludge is allowed to settle under relatively quiescent conditions. Most of the settled sludge is then returned to the bioreactor (returned activated sludge, RAS) while some is wasted (WAS) to side stream facilities for further processing. A very small fraction (usually less than 1%) escapes as suspended solids in the wastewater discharged from the clarifier. If a SBR is used, there is no need of a separate clarification stage, as settling is accomplished in the SBR reactor during periodic shutdown of the mixing/aerating cycles.

Factors that must be considered in the design of the EA activated sludge process for domestic wastewater, besides effluent water quality requirements, include:

- Selection of reactor type (continuous flow reactor, sequencing batch reactor),
- Loading criteria (F/M ratio),
- Solids retention time (SRT),
- Hydraulic retention time (HRT),
- Reactor volume and freeboard,
- Oxygen requirements and method of oxygen transfer to the mixed liquor,

- Separation of MLSS from the wastewater,
- RAS flow rate, as a percentage of wastewater flow rate,
- WAS flow rate, in volume per day,
- Alkalinity of the Mixed Liquor, and
- Temperature of the Mixed Liquor.

The selection of the type of process (es) and reactor(s) will depend upon the design flow rates, the effluent characteristics required, relative ease of operation and maintenance, the space available for the reactor and auxiliary facilities, economics, and designer's choice. Where space is limited, a sequencing batch type of reactor (SBR) or membrane bioreactor (MBR) may be desirable, since the biological processes and clarification can take place in the same reactor structure. Chemicals can also be added to these reactors for removal of phosphorus if required.

Another type of bioreactor sometimes used in the EA process is the oxidation ditch, but it is seldom used for the small scale plants involved in enhanced pretreatment for on-site wastewater renovation systems.

The biological loading of an activated sludge process is expressed as the food to microorganism ratio (F/M), in mass units, with the food being the organic matter in the wastewater and the microorganisms being the MLVSS, which are assumed to represent the active mass of microorganisms present. (This assumption is not exactly correct, as the percent of the total MLVSS that is biologically active is an important consideration in the process).

While the EA process can operate at F/M ratios of 0.10 or less, in most cases a F/M ratio of 0.05 or less is utilized. Operation of the activated sludge process at F/M ratios of 0.10 or less results in the microorganisms existing in the endogenous respiration phase, where the microorganisms have little food and consequently use their own cellular material as a food source. This results in a maximum oxidation of organic and nitrogenous compounds and a minimum of excess sludge to be wasted and processed. Any further stabilization of the WAS required is usually accomplished in aerobic sludge digesters. Because of the large aeration volume used and the long solids retention time, the process is not easily upset. However, once upset, it may take some time to restore the process to a stable operating condition.

Volumetric loading is another method of expressing the organic loading. Experience has indicated that a volumetric loading range of 5-15 lb. BOD_5 per 1000 cu. ft. of reactor volume per day is suitable for EA plants. This provides a check on the volume determined on the basis of the hydraulic retention time.

The Solids Retention Time (SRT) is the average length of time that a microorganism remains in the aerobic bioreactor. It is calculated by dividing the mass of solids in the reactor (concentration of solids in the reactor x the volume of the tank) by the mass of solids wasted per day (gallons per day of WAS x concentration of WAS), resulting in units of days. Proper attention must be given to the units of measure to correctly calculate the SRT. The SRT for the EA process will normally range from less than 20 to 30 days or more, with a shorter SRT being used in the warmer summer months because of the higher microbial growth and reaction rates that occur at higher temperatures.

The SRT is a critical operating parameter in the activated sludge process and must be maintained in a relatively narrow range to maintain the process in stable operation. If the WAS rate is too low, there will be a buildup of MLSS in the bioreactor and this will affect the types of organisms present and can severely hinder the ability to remove the MLSS from the treated wastewater in the clarifier. If the WAS rate is too high, there will be a decline in the MLSS resulting in a “washout” of active biomass that will adversely affect the ability of the process to efficiently oxidize all of the organic and nitrogenous compounds in the wastewater. Washout is of particular importance if nitrification is required, as the autotrophic nitrifying bacteria are only a small fraction of the overall biomass, have a slower growth rate than heterotrophic bacteria and thus their loss must be avoided.

The Hydraulic Retention Time (HRT) is the average time the wastewater remains in the bioreactor for treatment. It is calculated by dividing the volume of the aeration tank by the wastewater flow rate and is usually expressed in units of hours. In the EA process, the HRT will normally be in the range of 16 - 24 hours or greater. It should be noted that contrary to the SRT, which can be varied by the plant operator by adjusting the WAS rate, there is no control over the HRT once the volume of a continuous flow aerobic bioreactor has been established. On the other hand, both the SRT and the HRT can be varied if the bioreactor is a SBR. This is one of the benefits of a SBR.

The reactor volume is determined from the design flow and the desired HRT and is calculated by multiplying the hydraulic detention time by the design wastewater flow rate, is expressed in units of liquid volume, and does not include any freeboard allowance. Therefore, a freeboard of at least 18 inches should be provided above the operating liquid level to contain any froth or scum that may develop on the surface of the mixed liquor. As in other similar calculations, attention must be given to the units of measure to correctly calculate the volumetric requirement.

The oxygen requirements for the EA process are the highest of all the activated sludge process modes. This is because the oxidation of organics is carried out essentially to completion, meaning that the ultimate BOD (UBOD) must be met, rather than the 5-day BOD. The organic ultimate oxidation demand is equivalent to approximately 1.3-1.5 lb. oxygen per lb. of BOD_5. In addition, the nitrification that inherently occurs in the EA process results in a high oxygen demand, as approximately 4.6 lb. of oxygen are required per lb. of nitrogenous compounds oxidized. Thus, for example, for a septic tank effluent having a BOD_5 concentration of 175 mg/L and a TN concentration of 30 mg/L, the combined organic and nitrogenous oxygen demands are estimated to be equivalent to about 2.1-2.3 lb. of oxygen per lb. of BOD_5 in normal domestic wastewater. For wastewaters of higher organic strength or nitrogen content, the total oxygen requirement should be calculated using the separate oxygen demands for organics and nitrogen.

As previously discussed, oxygen transfer to the mixed liquor in the EA bioreactor is usually accomplished by means of diffused air. Considerable effort is expended in the design of large activated sludge plants in evaluating the various types of air diffusers (e.g. fine bubble, coarse bubble) for their efficiency in diffusing the air into the mixed liquor. This is done in an effort to minimize the electrical power costs involved in delivering the air to the diffusers. Consideration is also given to the costs of maintaining the diffusers, with fine bubble diffusers usually requiring higher maintenance costs.

However, because of the relatively small size of the EA plants involved in enhanced pretreatment for on-site wastewater renovation systems, the coarse bubble type of diffuser is normally provided. While the oxygen transfer efficiency of the coarse bubble diffusers is considerably lower than that of fine bubble diffusers, the latter are more susceptible to clogging, and thus the maintenance of coarse bubble diffusers is less involved. This is a major factor in small EA plants where a sole plant operator is usually responsible for both operation and maintenance and may only be present for a relatively short time each day. The type of blowers used to deliver the air to the diffusers in small EA plants (rotary, positive displacement type) are also different than those used in large AS plants (centrifugal type) because of smaller volume of air required to meet the dissolved oxygen requirements of the process.

Separation of the MLSS from the wastewater is one of the most important factors in the AS process and can sometimes be particularly troublesome in a continuous flow type of EA plant where a separate clarifier is required.

Parameters that affect the performance of a clarifier are:

- The settling characteristics of the MLSS,
- The dissolved oxygen (D. O.) concentration in the MLSS,
- The mass (solids) loading rate,
- The liquid loading rate,
- The weir overflow rate,
- The depth of the clarifier below the weir level (sidewater depth),
- The provisions (or lack thereof) for removal of floating solids and scum,
- The RAS rate,
- The WAS rate,
- The temperature of the mixed liquor, and,
- Provisions for rapid collection and removal of the settled MLSS (sludge).

The only parameters under the control of the plant operator, once the clarifier has been designed and constructed, are the settling characteristics of the MLSS, the D. O. concentration, and the RAS and WAS flow rates. Therefore, careful design of the clarifier is quite important to the overall activated sludge process.

The solids loading rate is determined by dividing the total solids applied to the clarifier by the surface area of the clarifier, and is expressed as mass of solids (MLSS) per unit area per unit of time (e.g. lb. MLSS./sq. ft./hr). The liquid loading rate is expressed as liquid volume per unit area per unit time (e.g. gallons / sq. ft./day). The weir overflow rate is expressed as liquid volume/unit length of weir/unit time (e.g. gallons/lf of weir/day). For EA packaged plants, the design parameters recommended in the literature for clarifier design (NEIWPCC-1998; Crites and Tchobanoglous-1998) are as follows:

Clarifier Loading Rates:

Loading	Average	Peak
Solids, lb./sf/hr	0.5	1.2
Liquid, g/sf/d	200	450
Weir, g/lf/d	< 10,000	≤ 20,000

The clarifier sidewater (liquid) depth should be not less than 10 ft., not including freeboard allowance. Adequate baffles should be provided where the mixed liquor enters the clarifier to prevent velocity currents from disturbing the settling process and provisions should be made for rapid removal of the settled MLSS and for removing scum and floating solids from the surface of the clarifier.

The RAS and WAS flow rates are critical to the operation of all activated sludge process modes. The return rate for the EA process is highest of all the activated sludge modes. In addition to selection of the RAS rate, the method of transferring the RAS from the clarifier is quite important. Some EA packaged plants use airlifts for removing the RAS and WAS from the clarifier and pumping it back to the bioreactor. However, the ability of an airlift to provide a reasonable variation in flow rate is problematic because of the limited turndown ratio; therefore the use of pumps is preferred.

RAS Rate: Capacity to vary from 30 to 150% of Average Daily Flow.

WAS Rate: Capacity to vary up to 25% of Average Daily Flow.

Type of Pumps: Solids-handling centrifugal sewage pumps.

Velocity of flow in RAS and WAS piping: ≥ 2 ft/sec.

The alkalinity in the wastewater helps to control the pH of the mixed liquor, particularly in the case of nitrification where acids are formed during the oxidation of ammonium to nitrates. If there is insufficient alkalinity in the wastewater to buffer the pH changes, provisions must be made for addition of an alkali to the mixed liquor.

The temperature of the mixed liquor is an important factor. Temperatures below 20°C adversely affect the oxidation rates while temperatures below 15° C adversely affect the nitrification rates. Below 10°C, there is a considerable adverse affect on both oxidation and nitrification rates although some oxidation and nitrification will continue at temperatures of 5°C or less. Temperature of the mixed liquor will also affect the settling rate in the clarifier due to viscosity effects. Temperature also enters into the design of the aeration facilities because of its affect on the dissolved oxygen content in the mixed liquor and the design of the air blowers. Therefore, the seasonal variations in ambient air temperatures must be taken into account in the design of the facilities.

The most troublesome problems with clarifiers serving continuous flow bioreactors have to do with formation of foam and scum and bulking of the MLSS. Foaming and scum formation often occurs on bioreactor and clarifier surfaces. A light colored froth or foam usually forms during the initial start-up of continuous flow bioreactors, but this is only transitory and will normally not remain a problem once the MLSS has reached the design concentration. Foam suppression systems consisting of a piping system equipped with nozzles that spray plant water (clarified effluent) onto the foam will usually control this foam.

An excess of filamentous organisms (generally some types of bacteria and fungi) causes a more persistent foaming problem that can occur both in the bioreactor and clarifier. A well-formed biomass in the mixed liquor (MLSS) consists mostly of bacteria with a small percentage (~5%) of the higher life forms such as protozoa and rotifers, and these organisms will tend to cluster into floc particles that settle out of the mixed liquor during the clarification process. Some filamentous organisms in the biomass are useful in that they tend to bind the small floc particles into larger and stronger ones, enhancing the settleability of the MLSS. If no filamentous organisms are present, the floc will tend to be very small in size and subject to being broken up during the aeration process, resulting in problems with producing a clear clarifier effluent. However, when they become excessive, filamentous organisms cause persistent foaming problems and bulking of the MLSS floc in the clarifier, hindering the settling process in the clarifier.

The foam that results from excessive filamentous organisms is usually a viscous, brown-colored foam that is difficult to break up in the bioreactor with the typical water spray type of foam suppression system. Such foam, if discharged from the bioreactor to the clarifier, can form to such a depth as to overflow the final clarifier weirs, resulting in a high concentration of suspended solids in the effluent and the loss of biomass. When this occurs the activated sludge process will be adversely impacted, to the detriment of any downstream processes, and the effluent quality will be degraded.

Therefore, a means of controlling the formation of this foam must be included in the design of an activated sludge process. Controlling the amount (concentration) of filamentous organisms will also control bulking of the MLSS in the clarifier, as bulking is usually caused by too many filamentous organisms that produce a diffused floc with poor settling properties.

Bulking can result in the settled MLSS rising and overflowing of the clarifier weirs. This is the so-called "burping" effect that results in a loss of viable biomass, a poor quality effluent, and severe problems with downstream processes such as filtration and disinfection.

Provisions should be made for controlling the formation of foam, including the collection, removal and disposal of the foam from the bioreactor. It has been found that introducing a chlorine solution into the foam will often result in controlling the growth of the filamentous organisms. This method of foam control is problematic where the treated wastewater will be discharged to the subsurface because of the concern with formation of toxic byproducts of the chlorination process and the persistence of these byproducts in the ground water.

Most of the filamentous microorganisms are obligate aerobes that thrive in conditions where dissolved oxygen is present in concentrations too low to support other types of aerobic bacteria. Thus, one natural method of controlling their growth is to expose them to anoxic or anaerobic conditions. Under such conditions the competition of facultative and anaerobic microorganisms for the available food supply will result in a substantial reduction of the filamentous microorganisms.

In large activated sludge plants, this is accomplished in reactors termed "selectors" that precede the main bioreactor. This same procedure can be used where small packaged activated sludge facilities are used. The selector can also serve as an anoxic reactor to denitrify the MLSS. It is also possible to use aerobic selectors, where a relatively high D.O. concentration is maintained. This favors the growth of aerobic microorganisms with better flocculating and settling properties than the filamentous microorganisms.

Where equalization is provided following the septic tank, the equalization tank might also be designed to serve as the "selector" provided its capacity is increased to accomodate the recycled flow and proper baffling and a means of mixing the tank contents are provided. In the same manner, an equalization tank can be designed to also serve as an anoxic reactor when nitrogen removal is part of the treatment requirements provided additional volume is made available for the denitrification process. Thus, an equalization tank upstream of an aerobic bioreactor can be designed to serve several useful purposes.

It should be noted that rising sludge can also be caused where nitrification has occurred in the aerated bioreactor if the settled MLSS (sludge) is allowed to remain too long in the bottom of the clarifier. Under such conditions denitrification will occur and the nitrogen gas, rising as it is released, will cause clumps of sludge to float to the top of the clarifier and escape over the effluent weirs. To prevent this from occurring, it is important that the settled sludge be removed (as RAS and WAS) from the bottom of the clarifier as quickly as possible. Thus the clarifier must be provided with an effective means of rapidly collecting and removing of the sludge.

b. Sequencing Batch Reactors

The sequencing batch reactor (SBR) process is a variant of the activated sludge process that operates on a batch basis. All phases of the SBR process take place in sequence in the same reactor instead of the wastewater moving through a series of reactors and clarifiers for completion of the treatment process phases, as is the case in the usual activated sludge treatment process.

There are two types of sequencing batch reactors. In the standard fill and draw SBR operation, flow through the reactor is halted during the phases where the mixed liquor is allowed to settle and during decanting of the clarified wastewater.

In the other type of operation, referred to as the intermittent cycle extended aeration system (ICEAS), flow is continuous through the SBR reactor during all of the batch treatment phases. The SBR process is very versatile, in that oxidation of organics and ammonia-nitrogen, denitrification, phosphorus removal and clarification can take place in the same reactor.

In the standard SBR mode of operation, where flow to the reactor is halted during the settle and decant phases, ideal conditions are provided for clarification of the SBR effluent under quiescent conditions. In the ICEAS mode of operation conditions for clarification of the SBR effluent are not as ideal as for the case where flow is interrupted during the settle and decant phases. However, both modes provide a very good effluent quality.

The standard SBR mode of operation involves five basic phases, including FILL, REACT, SETTLE, DECANT and WASTE. A sixth phase (IDLE) may be used when the flow to the treatment facilities is considerably below the design flow. Control of the process is via a microprocessor (programmable logic controller, or PLC). The FILL phase can be divided into sub-phases, such as STATIC FILL (no mixing), MIXED FILL and REACT FILL, to accomplish certain treatment objectives. All of these SBR phases are described below.

The STATIC FILL sub-phase begins with a certain amount of biomass in the SBR reactor, with the DECANT or IDLE phase having just been completed. At this time, the biomass exists as a layer of MLSS at the bottom of the reactor, having accumulated there during the previous SETTLE and DECANT phases. A layer of clarified liquid exists above the solids layer, and the water quality in the upper portion of this liquid layer is essentially the same as the quality of the SBR effluent that has just been decanted. The layer of biomass provides the means to initiate the biodegradation of the pollutants contained in the incoming batch of wastewater.

During the STATIC FILL sub-phase, wastewater is introduced at the bottom of the SBR reactor without mixing. This sub-phase is used as a means to condition the existing biomass by reducing the number of filamentous microorganisms that may be present in the mixed liquor. As previously stated under subsection D.4a, excessive amounts of filamentous microorganisms can hinder settling of the biomass.

In the STATIC FILL sub-phase, the food supply (pollutants present in the wastewater) is high, the dissolved oxygen content is very low, and this favors the growth of a mass of facultative bacteria. The facultative bacteria multiply more rapidly than filamentous organisms and in doing so take in and store most of the available food supply, thus in effect "starving" the filamentous organisms. Thus the STATIC FILL sub-phase acts as a means of "selecting" the type of microorganisms desired.

During the MIXED FILL sub-phase, the influent wastewater is rigorously mixed with the existing contents of the SBR reactor without adding oxygen. Thorough mixing of the influent wastewater with the mixed liquor allows removal of organics and conversion of organic nitrogen to ammonia nitrogen to take place under these conditions by the action of the facultative bacteria in the biomass. Denitrification of nitrates that may be present in the mixed liquor can also occur during this phase.

The REACT FILL sub-phase consists of continuing to feed wastewater into the SBR reactor and mixing the reactor contents while aerating the mixture to dissolve oxygen into the mixed liquor. The dissolved oxygen supports the oxidation processes of the facultative fractions of the biomass that convert organic pollutants to carbon dioxide, water and new microbial cell mass, and the nitrification processes of the aerobic nitrifier fraction of the biomass in the oxidation of the ammonia-nitrogen to nitrates.

The REACT phase (aerobic phase) consists of continuing to mix and aerate the mixed liquor in the SBR reactor without feeding of the wastewater to the reactor. Further removal of organics and nitrification of ammonia-nitrogen takes place in this phase until oxidation of the organic pollutants and nitrification of the ammonia-nitrogen present is essentially complete.

It should be noted that the removal of organics takes place throughout most of each batch treatment FILL and REACT sub-phases, while nitrification and denitrification take place only in certain of the sub-phases of each cycle. To accomplish nitrogen removal using the influent wastewater as a carbon source for the denitrifiers, the FILL and REACT sub-phases are alternated several times within one batch treatment cycle by turning the source of oxygen on or off. During each aerobic period some of the organics are oxidized and ammonia-nitrogen is nitrified, while during each period when no oxygen is being supplied the SBR reactor reverts to an anoxic condition and the nitrates formed during the aerobic period are denitrified and some additional removal of organics takes place.

The SETTLE phase consists of stopping the mixing and aeration of the mixed liquor and allowing the biomass to settle to the bottom of the SBR reactor. One of the major advantages of the standard SBR system is the creation of essentially perfect quiescent conditions during the SETTLE phase. During this phase, there is no inflow of waste, no mixing and no aeration occurring. This permits rapid settlement of the suspended bio-mass without any disturbance.

During the DECANT phase, the fully treated and clarified wastewater is skimmed from the upper portion of the clarified liquid in the SBR reactor by floating decanters without disturbing the settled bio-mass at the bottom of the reactor.

The WASTE phase can take place near the end of the DECANT phase, or during the IDLE phase, when the biomass layer at the bottom of the reactor has reached its highest concentration. During the WASTE phase, some of the biomass is removed from the reactor by pumping settled solids in the bottom of the reactor to sludge processing facilities. This wasting is done to remove excess biomass that has grown during the various FILL, MIX and REACT phases so as to maintain the correct amount of biomass in the reactor.

The IDLE phase is not needed as an operational phase but is rather that period between completion of the DECANT phase and the beginning of the next FILL phase. The IDLE phase only occurs when actual flows are substantially less than the design flows. (During an extended IDLE phase, it may become necessary to periodically aerate the mixed liquor to prevent it from becoming anaerobic.)

The various FILL, MIX and REACT phases, the SETTLE phase and the WASTE phase are controlled on a time basis, and the time spent in each phase can be readily adjusted to suit required operating conditions by reprogramming the PLC. The actual time of the DECANT phase is usually controlled by the liquid level in the reactor following completion of the various FILL, MIX and REACT phases. The liquid level in the reactor can also be readily changed to suit required operating conditions.

Also, when unusual peak flows occur, such as from extraneous inflow during storm conditions, the SBR programmable logic controller can be set to reduce the cycle times so as to be able to accommodate the increased flow. Where a single tank SBR system is used, a flow equalization basin is required upstream of the SBR to store the influent flow during the react, settle, decant & waste phases of each cycle. Because of the intermittent high rate of discharge that occurs during the decant cycle, an equalization tank is also usually provided following the SBR reactor(s) so as to avoid over-sizing of downstream facilities (e.g.: filtration, disinfection).

In the ICEAS mode of SBR operation, the reactor is separated into two zones, PREREACT and MAIN REACT, by a baffle wall. The wastewater flows continuously into the PREREACT zone, which acts as a selector to limit the growth of filamentous microorganisms. The mixed liquor from the PREREACT zone flows through openings in the baffle wall and into the MAIN REACT zone. Oxidation of organics and ammonia-nitrogen, and denitrification, is accomplished in the MAIN REACT zone by alternating on-off periods of air diffusion into the mixed liquor that produce periods of aerobic and anoxic conditions.

After a period of time, aeration is stopped and a SETTLING phase is initiated, allowing the MLSS to settle to the bottom of the reactor, leaving a layer of clear water on top. A floating decanter removes the uppermost clear water from the reactor. Excess biomass is periodically removed from the bottom of the reactor. The ICEAS SBR purportedly requires a smaller reactor volume than a standard SBR.

Phosphorus can be removed in either mode of SBR operation by either biological or chemical methods, or both, depending upon the degree of removal required. The air on/off cycles can be managed to provide an anaerobic condition for biological removal of P. Where an effluent P concentration $\leq$ 1 mg/L is required, chemical addition is usually necessary. The SBR process is capable of producing an effluent with concentrations of BOD_5, TSS and TN $\leq$ 10 mg/L.

c. Membrane Bioreactors

A membrane bioreactor (MBR) consists of a continuous-flow suspended growth (activated sludge) bioreactor coupled with a membrane micro-filtration system. The key feature of a MBR is the employment of a low pore size membrane for high efficiency solids separation. Thus, an MBR unit replaces the conventional arrangement of separate bioreactor, clarifier and post-filtration facilities. This eliminates the sludge settling process and allows elevated levels of biomass to be utilized without causing problems with poor settling of the MLSS. A MBR can be operated with MLSS concentrations of 15,000 mg/L or higher, and at a long SRT, resulting in low overall sludge generation. The MBR process operates with the biomass in the endogenous growth phase similar to an EA facility, but usually at a longer SRT and much higher MLSS concentration than that of an EA facility and with no MLSS recycled. A programmable logic controller (PLC) monitors and automatically controls most of the MBR functions making the system fairly easy to operate.

Since the biochemical reactions and solids removal occur in the same reactor, this results in a substantially smaller footprint than the typical EA facility. A MBR is also more stable than an EA facility since it avoids the problems with clarifier upsets and maintaining the proper RAS rates. Further, the excess solids removed from a MBR are more fully digested than those of other AS processes because of the long SRT employed.

Also, because of the much higher MLSS concentration that can be carried in the MBR, it is more capable of absorbing shock loadings. Grit and coarse solids removal is required to precede the MBR. This can be accomplished in a septic tank or separate grit and fine screening removal facilities.

There are basically two types of membranes systems used. Both use hollow membrane units having pore sizes in the fractional micron range ($\leq 0.4\ \mu$) that exclude all particulate matter. In one type, the mixed liquor is pumped at relatively high pressure through the interior of the membrane and clear water permeates through the membrane into a collection system while excess mixed liquor is recirculated back to the bioreactor. In the other type of membrane system, the membranes are submerged in the bioreactor, in direct contact with the mixed liquor; clear water permeates to the inside of the membrane under a differential pressure produced by pumping of the permeate, with all solids remaining in the bioreactor.

An MBR can be designed for removal of organics, nitrogen and phosphorus. Removal of organics and nitrogen is accomplished by operating the MBR in both aerobic and anoxic phases. In this case, the bioreactor is divided into two sections by a baffle wall. The first section is operated as an anoxic reactor to promote denitrification. Mechanical mixing is usually provided, rather than mixing using aeration. In the second, aerobic section, aeration by diffusion of air under low pressure into the mixed liquor provides the oxygen and mixing required for removal of organic matter and nitrification of ammonia-nitrogen by facultative and aerobic microorganisms.

Mixed liquor in the second section is recycled (by pumping) back to the first section for denitrification. The dissolved oxygen in the mixed liquor is depleted rapidly in the first section, because of the high concentration of MLSS and the resulting high D.O. demand, resulting in anoxic conditions being established.

Phosphorus can be removed chemically by flocculation using metal salts as discussed in another part of this section. However, a smaller amount of a metal salt is required as compared to P removal in non-membrane processes, since it is not necessary to produce a large floc for gravity settling. The carbon required by the denitrifying microorganisms is normally provided by the incoming wastewater, although in some cases an external carbon source is required.

The membrane pores are prevented from being fouled by applying the diffused air in a manner that will maintain scouring velocities within the mixed liquor in the vicinity of the membranes. A reversed, pulsed flow is also used to clean the membranes in place.

Periodically, the membranes must receive a more through cleaning (using chemical cleaning). However, depending upon the type of membrane modules used, provisions are made for easy removal for cleaning and reinsertion of the cleaned membrane modules or for chemical cleaning in-place.

MBR systems used in enhanced pretreatment facilities for onsite wastewater renovation are available as pre-manufactured (packaged) systems and the manufacturer provides design of such systems. The key design parameters are: (1.) type of membrane used; (2.) hydraulic and organic loading rates; (3.) the ability to provide uniform distribution of dissolved oxygen and mixed liquor around and across the membrane modules submerged in the MBR; (4.) the ability to prevent fouling of the membrane pores; (5.) the life cycle of the membranes; and, (6.) the ability to easily maintain and replace the membranes when necessary.

With proper operation and maintenance, a MBR process is capable of producing an exceptionally clear effluent, suitable for reuse as reclaimed water for non-potable purposes. It will remove all suspended solids, virtually all organics, most of the nitrogen, and provide a several log reduction in the number of pathogens present in the wastewater.

As previously discussed, the temperature of the mixed liquor in continuous-flow, suspended growth bioreactors is an important factor in the overall process efficiency. Therefore, the bioreactors should be protected from low temperatures by installing the reactor tankage in or below the ground surface. Where installed below ground, provisions must be made for easy access to the reactor for maintenance purposes.

5. Fixed Film Bioreactors

Fixed film bioreactors include rotating biological contactors (RBC), recirculating granular media filters (RGMF), trickling filters (TF) and packed bed reactors (PBR). While some of the design parameters for fixed film bioreactors are similar to those for suspended growth bioreactors, it is important to note the difference in the manner in which the organic loading rates are defined. For suspended growth bioreactors, the loading rate is expressed as the ratio of the load (e.g. organic, nitrogenous) to the biomass suspended in the mixed liquor (MLVSS). In a fixed film bioreactor, the equivalent loading rate is the ratio of the unit mass loading rate to the specific surface area of the media (unit surface area per unit of media volume) which will differ for each particular type and shape of media used.

A RGMF is efficient in removal of organics and nitrification, and also can achieve denitrification (usually resulting in at least 40-50% removal of total nitrogen). (Denitrification has been found to occur in some fixed film aerobic bioreactors at anoxic microsites within granular media filters and in the inner portions of the fixed biofilms where dissolved oxygen has not penetrated.)

Where the denitrification obtained in a RGMF is insufficient to meet nitrogen removal requirements, recirculation of the RGMF effluent back to the septic tank will increase the removal of total nitrogen, with up to 70% or more removals attainable. Such removals will depend upon the ratio of soluble BOD_5 concentration to nitrogen concentration, the recirculation rate to the septic tank, and the hydraulic residence time of the recirculated effluent in the tank. Where a high degree of nitrogen removal is required, a packed bed anoxic reactor is often used for further denitrification of the RSF effluent.

An aerobic RBC is efficient in removal of organics and nitrification, and an anoxic RBC is efficient in denitrification. As in the case of a RGMF, recirculating of the nitrified effluent from the aerobic RBC back to the septic tank can provide a fair degree of denitrification, but packed bed reactors are normally used for denitrification where a high degree of nitrogen removal is required.

a. Rotating Biological Contactors (RBCs)

The rotating biological contactor (RBC) type of treatment plant has been used for wastewater treatment for more than 3 decades in the United States. A rotating biological contactor consists of corrugated plastic media discs vertically mounted on a horizontal shaft and slowly rotated while partially or fully submerged in a tank through which the wastewater flows.

Thus, the RBC is characterized as a continuous-flow, fixed film bioreactor. The rotating media is available with both standard and high-density surface area configurations. Rotation is provided either by mechanical drives or by air drive systems that used low pressure compressed air directed at cups fixed to the media discs. The RBC process is somewhat simpler to operate than a continuous flow suspended growth bioreactor because there is no need to recycle the biomass.

The media is usually divided into several stages, depending upon the nature and degree of treatment required. Biological growth develops naturally on the rotating surfaces and by utilizing the organic and nitrogenous pollutants present in the wastewater as a food source, removes or alters the composition of the pollutants. Rotation of the plastic media allows the biological growth to come in intimate contact with the wastewater and also results in the shearing of excess biological growth from the media. The mixing action of the rotating media keeps these excess growths in suspension until the treated wastewater flow carries them out of the RBC tank for separation and disposal.

Where the metabolic processes of aerobic microorganisms are employed for oxidation of organic pollutants (BOD_5) and ammonia present in the wastewater, the RBC is operated in an aerobic environment. In this case, the rotating media is approximately 40 % submerged in the wastewater and rotation of the media exposes the biological growth directly to the air for absorption of oxygen. Where denitrifying microorganisms are used for the removal of nitrogen, the rotating media is usually submerged so as to exclude the presence of oxygen.

Flow equalization should be incorporated into the design of a RBC facility. The flow equalization tank will not only smooth out the daily flows and loadings, but can also serve as an anoxic reactor for denitrification, if sufficient volume is provided in the tank for such purpose. Plant scale operations have shown that it is possible to obtain significant denitrification, up to 70% or more, by using the wastewater, which has a substantial concentration of dissolved organic pollutants, as a carbon source. This mode of operation requires recycling part of the nitrified effluent from the aerobic portion of the RBC plant back to a tank containing wastewater.

While recycling back to the septic tank is an option, this will affect the removal of settleable and floatable solids. Another option is to recycle back to a flow equalization tank equipped with mixing facilities and designed to also function as an anoxic reactor. Denitrification will proceed if the hydraulic retention time of the nitrified wastewater in the equalization tank is sufficiently long to allow the denitrification process to proceed.

Use of the flow equalization tank as an anoxic reactor will permit thorough mixing of the reactor contents and this will increase the efficiency of the denitrification process. Mixing can be accomplished hydraulically by providing multiple points of recycle into the equalization tank or by mechanical means. A method for periodically removing settled solids from the equalization tank should be provided.

As discussed earlier in this section, use of the soluble BOD_5 in the septic tank effluent as a carbon source in an anoxic reactor located upstream of an aerobic bioreactor, in this case the RBC, would reduce the organic loading on the RBC facilities. However, there is usually insufficient soluble carbon (soluble BOD_5) available for complete denitrification, and the septic tank or anoxic reactor tank effluent will contain residual nitrates and possibly nitrites as well. Therefore, where a greater nitrogen reduction is required, the feeding of an external carbon source will be required.

1. Aerobic RBC for Oxidation of Organics and Nitrification

The controlling parameters for design of an aerobic RBC for oxidation of organics and nitrification, exclusive of required effluent quality, are as follows:

- The soluble BOD_5 and ammonia-nitrogen mass loadings, expressed in lbs./day/1000 square feet of active surface area of the media, including average and peak loadings,
- The dissolved oxygen content in the RBC bioreactor,
- The number of media stages and the density (surface area) of the media,
- The rotational velocity of the media,
- The liquid detention time in the RBC tank, defined as a tank volume to media surface area ratio (gal./sq. ft.),

- The pH of the wastewater, and,
- The wastewater temperature during the colder months of the year.

The soluble BOD_5 ($SBOD_5$) loading limit for the first stage of an aerobic RBC recommended by RBC manufacturers' ranges up to 4.0 lbs./day/1000 sq. ft. However, studies by the U.S. EPA and others have shown that the $SBOD_5$ loadings recommended by the RBC manufacturers may sometimes result in less than adequate process performance due to the oxygen demand in the first stage(s) exceeding the oxygen transfer capability of the RBC. EPA recommended that the media stages be conservatively designed for an $SBOD_5$ loading in the range of 2.5 to 3.0 lbs./1000 sq. ft., particularly when there may be sulfur compounds present in the influent wastewater, as would be the case for septic tank effluent. The design loading used for sizing of the media surface area should be not more than 2.5 lb. $SBOD_5$ /1000 sq. ft. at the average day design flow and not more than 3.0 lb. $SBOD_5$ /1000 sq. ft. at the maximum day design flow. Standard density media should be utilized for removal of BOD because the heavy biological growth that occurs in the stages used for BOD removal would tend to clog the higher density media.

When wastewater receives pretreatment in a septic tank, some of the non-soluble BOD_5 is removed and some is hydrolyzed to $SBOD_5$ by the action of the facultative bacteria present in the tank. Thus, the $SBOD_5$ in the effluent of the septic tank will usually be higher than that in the raw wastewater. This should be taken into account when calculating the $SBOD_5$ loading applied to the aerobic RBC.

The loading rate recommended for nitrification by one of the leading manufacturers of RBC equipment is 0.30 lb. of ammonia-nitrogen (NH_3-N) /day/1000 sq. ft. of media. Studies by the U.S. EPA and others have confirmed this loading rate as being reasonable and the nitrification stages of the aerobic RBC media should be designed so as not to exceed this rate. Because a much lighter biological growth occurs during the nitrification phase, the more cost-effective higher density media should be used.

The total nitrogen (TN) concentration in the raw wastewater will include NH_4^+, organic nitrogen (ON), and in some instances, NO_3^-. When this wastewater receives pretreatment in the septic tank, some of the non-soluble organic nitrogen will be removed in the tank and virtually all of the remainder will be converted to NH_4^+ by the action of the bacteria present in the tank or by the bacteria in the RBC reactor. Thus, the NH_4^+ concentration of the wastewater in the RBC bioreactor will be higher than that in the raw wastewater and will be close to the TN concentration, the difference being the amount of refractory organic nitrogen.

The prerequisite for a high degree of nitrogen removal (de-nitrification) is essentially complete nitrification, which in turn requires a high degree of organics removal. Where such high removals are required, the RBC manufacturers recommend that the media be arranged in 3 to 4 stages, and prudent design would call for four stages. Provisions must also be made for the addition of an alkali to the wastewater prior to the nitrification media stage(s) to counter the destruction of alkalinity resulting from the nitrification process so as to avoid depressing of the pH below the low end of the desirable range for nitrification. (This pH range has been previously discussed under Subsection B12.b.)

Studies have shown that increases in the liquid volume-to-media surface area ratio beyond 0.12 gal./sq./ft./day did not increase removal efficiencies at a given hydraulic loading rate. Therefore, this ratio is adequate for sizing of the RBC tank.

As previously discussed, the pollutant removal efficiencies of wastewater treatment facilities that depend on biological processes are substantially affected by the temperature of the wastewater. The wastewater temperatures that occur during the colder periods of the year control the process design. The RBC manufacturers recommend that the media surface areas be increased when the operating temperature may be less than 55°F (~13°C) and provide curves for temperature correction factors. Since the average temperature of septic tank effluent in Connecticut can drop to as low as 50° F (10°C), the media surface areas of the organic oxidation and nitrification stages of the aerobic RBC should be increased based on the correction factors for that temperature.

One of the earlier major problems associated with RBC operation was the failure of the shafts on which the rotating media are supported. This was mainly due to underestimation of the effects of the heavy, often unequally distributed biological growth that occurs on the media. While the RBC manufacturers have increased the strength of these shafts to overcome such failure, it is still necessary to monitor the weight imposed on the shaft. Monitoring of the weight supported by the shaft is accomplished by utilization of a hydraulic or electronic load cell device, installed beneath the bearing on the idler end of the shaft, that provides an output to a load-indication display device.

While the wastewater is normally discharged into the upstream end of the RBC tank and then flows under gravity from one media stage to the next, provisions should be made for step feeding the wastewater to the individual baffled compartments containing each media stage. This will permit adjusting the loading on the media in each compartment for more efficient operation and to mitigate the occurrence of noxious odors in the first stage compartment due to overloading of the media.

As previously discussed, provision should also be made for recycling a portion of the effluent from the RBC to an upstream anoxic reactor and also back to the first stage to provide oxygenated liquid that will also mitigate the occurrence of noxious odors. Means should also be provided for removal of an excessive buildup of biomass on the media discs. This can be accomplished by use of a pressurized jet of water or compressed air directed on the media by a hand held wand.

RBC facilities should be protected from the weather, particularly cold weather temperatures. They can be installed within a building or within containment structures buried in the ground and provided with insulated covers that are easily removed for maintenance and repair. In either case, adequate ventilation should be provided.

2. Anoxic RBC for De-nitrification

The controlling parameters for design of an anoxic RBC for de-nitrification are much the same as for an aerobic RBC except that the mass loading rate of concern is that of the nitrate-nitrogen NO_3^- in the effluent of the aerobic RBC. The NO_3^- loading rate recommended by a leading manufacturer of RBC equipment is about 1.0 lb. /day/1000 sq. ft. of media. However, studies by the USEPA and others raise doubt as to whether the assumptions used to derive this loading rate are appropriate. Accordingly, a safety factor of at least 50% should be used for sizing the media surface area. Thus, the design loading rate should not exceed 0.67 lb/day/1000 sq. ft. at 55° F. As discussed above, a temperature correction factor should be used to increase the design media surface area to provide for a lower wastewater temperature. The anoxic RBC should be designed with several stages, and the final stage should be operated as an aerobic RBC to remove any excess external carbon source that may be contained in the effluent from the anoxic stages.

3. Flexibility of Operation of RBC Facilities

It is recommended that flexibility be provided in the design of RBC facilities to enable them to operate in three different modes. In mode No 1, effluent from the pretreatment (septic) tank would flow through the aerobic RBC first, with the nitrified effluent flowing to an anoxic RBC for denitrification. In this mode, a supplemental source of carbon would be required.

In mode No. 2, effluent from the septic tank would flow first to the anoxic RBC that would also receive recycled nitrified effluent from the aerobic RBC. The recycled effluent would be denitrified in the anoxic RBC using the septic tank effluent as source of carbon; thus some of the $SBOD_5$ will also be removed. The effluent from the anoxic RBC would then flow to the aerobic RBC for oxidation of the remaining $SBOD_5$ and the NH_3^-.

A portion of the aerobic RBC effluent would be recycled back to the anoxic reactor, as discussed above, and the remainder would be discharged to any downstream treatment facilities that may follow the RBC units. Available information indicates that the recycle rate should be at least 200% of the average daily wastewater flow rate and the ability to recycle at up to 300% should be provided. Actual experience will indicate whether this mode of operation will be able to meet the project denitrification requirements without requiring addition of a supplemental source of carbon. If successful, this would eliminate, or at least substantially reduce, the cost of providing a supplemental source of carbon.

In mode No. 3, nitrified effluent from the aerobic RBC would be recycled back to the septic tank or flow equalization tank for denitrification, as previously discussed. Plant scale tests have shown that, using recycle rates of up to 300%, this mode of operation has the potential for substantial reduction of nitrates (~ 70%) without the use of a separate RBC anoxic reactor or a supplemental source of carbon. Again, actual experience will indicate whether this mode of operation will be able to meet the project denitrification requirements. If successful, this could eliminate the operation and maintenance costs associated with the anoxic RBC where denitrification to ≤10 mg/L total nitrogen is not required.

4. Final Clarifier

A gravity type final clarifier is usually provided to remove most of the suspended solids in the RBC effluent. These solids are relatively low in concentration compared to the MLSS concentrations discharged from suspended growth bioreactors and thus sludge bulking is not a problem. Since the clarifier will follow the de-nitrification process, the problems associated with rising sludge in a clarification tank with a long sludge detention time (due to de-nitrification occurring at the bottom of the tank) will not be experienced and special mechanisms for rapid sludge removal will not be required.

Therefore, the controlling parameters for design of the clarifier should be the surface overflow rate, expressed as gal./day/sq. ft. of clarifier surface area, and the weir overflow rate, expressed as gal./day/ L.F. of weir. The clarifier overflow rates and weir overflow rates recommended by various authorities vary, but generally range from 400 to 800 gal/day/sq. ft. and 5,000 to 20,000 gal/day/L.F. respectively (based on the average daily design flow rate). The overflow rate selected will depend upon the maximum concentration of suspended solids permitted in the clarifier effluent. In order to minimize solids carry-over in the clarifier effluent, the clarifier should be designed so as not to exceed the lower end of the range of values given above. The sidewater depth of the clarifier should be at least 10 ft.

5. Recirculating Granular Media Filters (RGMF)

Treatment of septic tank effluent by intermittent filtration using a recirculating granular media filter can accomplish the removal of organic matter and nitrification required as well as partial de-nitrification and filtration. Intermittent filtration is the intermittent application of wastewater to the surface of a specially prepared bed of granular material, which is underdrained to collect and discharge the effluent from the bed.

There are many intermittent granular media filters used throughout the United States to treat wastewater from many types of residential, commercial and institutional establishments. Most of these utilize sand media and are known as “single pass” sand filters. The process is highly efficient and capable of producing a high quality effluent while requiring substantially less skill and time for operation and maintenance as compared to other treatment processes producing effluent of comparable quality.

This process is often used to “polish” septic tank effluent prior to disinfection and discharge to surface waters where such discharges are permitted. Purification of the wastewater is accomplished through the mechanisms of straining, absorption, and by the biochemical processes of microbes living within the filter bed.

Until relatively recent times, intermittent sand filters were designed either as the open bed or buried type and were operated in a once-through or “single-pass” mode, where the pretreated wastewater was applied to the filter and the filter effluent discharged directly to downstream facilities. When used to polish septic tank effluent, the filters were usually of the buried type, since the application of septic tank effluent to open sand filters resulted in the creation of substantial odors. However, the surface layers of sand tended eventually to become clogged and either required raking to break up the clogged layers or replacement of the top few inches of sand. This can become a costly maintenance problem when the filter is of the buried type.

An innovative concept of intermittent sand filter operation, developed in Illinois about 50 years ago (Hines and Favreau -1974) employed recirculation of the filter effluent back through the sand filter bed in several applications, or passes. This type of filter became known as a recirculating sand filter, or RSF. Today, RSF can be a misnomer, since various types of granular media have been substituted for the sand. Currently, a more descriptive name may be “recirculating granular media filter, or RGMF”.

A typical RGMF consists of a septic tank, a recirculation tank equipped with pumps, one or more granular media filter beds, an electrical control system, and a means for diverting the return flow (filtrate) from the RGMF to either or both the recirculation tank or to other downstream facilities. Except for the recirculation pumps, and perhaps one, very simple automatically operated flow diversion valve in the recirculation tank, there are no other mechanical facilities involved other than some manually operated flow isolation valves.

The recirculation tank provides for storage of the septic tank discharge and recycled filter effluent between recirculation pump cycles. The recirculation pumps (typically of the submersible "effluent pump" type) are usually controlled by a time clock that can be set to provide the desired recirculation rate. Septic tank effluent flows into the recirculation tank and is then pumped to and distributed over the surface of the filter media. As the wastewater flows down through the media, most of the suspended solids are removed, and most of the pollutants that exert biochemical and nitrogenous oxygen demands (BOD_5, NOD) are oxidized to carbon dioxide, water and nitrates.

In addition, in most cases some of the nitrates formed during the treatment process are reduced to gaseous nitrogen, carbon dioxide and water by biological denitrification. The liquid is also oxygenated to a reasonably high degree as it passes through the filter media.

The filter consists of one or more compartments containing a bed of filter media installed over an underdrain system that collects the filtrate and returns all or a portion of it (depending on the flow diversion method selected) to the recirculation tank where it mixes with the septic tank effluent. Mixing of the recirculated oxygenated filtrate with the septic tank effluent results in a relatively fresh liquid being applied onto the surface of the filter, thus mitigating the odor problems normally associated with applying septic tank effluent onto open bed filters. Thus, there is no need to bury a RGMF below ground surface and it is designated as a“ free access” type of filter that permits ease of maintenance of the filter media.

Treatment of the wastewater applied to the filter results from several complimentary processes, including straining, sedimentation, adsorption onto the media particles, and, most importantly, the metabolic processes of the biomass that develops in the filter media. Most of this biological activity occurs at the surface and in the upper portion of the filter media. A complex population of organisms develops and dwells on and within the filter media. The biological population in a RGMF has been found to include numerous species of single celled bacteria and such higher life forms as protozoa and rotifers. Macro-organisms such as nematodes (round worms) and annelids (earthworms) have also been found to exist in the filter. The most important of these biological organisms, from a treatment standpoint, are the bacteria. Some of these microorganisms attach themselves to the filter particles, which thus act as tiny fixed film reactors, while others may be found in liquid micro-sites in the smaller spaces between the filter particles. While some of the organisms can and do exist in an anaerobic or anoxic state, the most important ones are those that flourish under aerobic conditions.

The processes that take place in a RGMF are essentially the same as those that occur, in a single-pass intermittent sand filter, with one major difference. Both types of filters are highly capable of reducing BOD_5, and suspended solids concentrations by 90-95% or more and of converting 90-95% or more of the ammonia-nitrogen present in the wastewater to nitrates. However, the RGMF can also provide a substantial reduction of nitrates through biological denitrification. This makes a RGMF attractive where it is necessary to limit the concentration of nitrates in the treated wastewater.

The effluent from a properly designed, operated, and maintained RGMF is of high quality, odorless and quite clear in appearance. Typically, 90-95% or more of the five-day Biochemical Oxygen Demand (BOD5) and Total Suspended Solids (TSS) and a significant percentage of the pathogenic bacteria in the applied wastewater are removed by the cleansing mechanisms of the filter. This high quality can be obtained using either sand or other type of granular media if the filter is designed for the type of media selected. A septic tank- RGMF treatment system is also very efficient in converting the ammonia-nitrogen and organic nitrogen in the applied wastewater to nitrates, with typical conversion of nitrogenous compounds to nitrates of 90-95% or better during all but the coldest periods of the year.

Generally, some denitrification also occurs. Data obtained from experimental laboratory studies and operation of full scale recirculating granular media filters have shown total nitrogen reductions through the RGMF of 40-70 % or more without special provisions for denitrification. How denitrification occurs in a RGMF has yet to be fully understood, but it appears to be an autogenous effect that may occur either in the recirculation tank or the filter media, or both. The conditions required for denitrification can occur in the recirculation tank under anoxic conditions that may sometimes prevail when the BOD of the septic tank effluent depletes the dissolved oxygen in the nitrate-laden filtrate. Similar conditions can occur at anoxic micro-sites in the filter media where facultative bacteria, soluble carbon and nitrates are also present.

The major problem encountered with an RGMF (as well as with a single pass intermittent sand filter) is clogging of the surface or upper portions of the filter media. Since some of the particulate matter carried in the liquid applied to the filter surface is inert and thus non-biodegradable, it is inevitable that such matter will accumulate in the filter. In addition, the non-degradable byproducts resulting from growth, death and decay of the biological organisms will also accumulate in the filter and this accumulation also tends to clog some of the pore spaces in the media. Polysaccharides and other slimes produced by the bacteria also cause clogging of the filter (Miller, 1992, Mitchell, 1964).

If the unit organic loading applied to the filter is too high an over-abundance of biological organisms will develop. This will increase the production of bacterial slimes and other byproducts of bacterial action that cause surface clogging (Tyler, et al-1977) and cause a reduction of the hydraulic conductivity of the filter media. This will result in a slow draining filter in which the time available for air to enter the filter media is reduced.

If the clogging becomes severe, liquid will pond on the entire surface of the filter and severely restrict the passage of air into the filter media. Under such conditions the filter will become anaerobic and its performance will become significantly degraded.

Experience has indicated that clogging of the filter media may occur in the late winter-early spring of each year. The reason for this phenomenon is not fully understood. One hypothesis is that during the colder weather, the metabolism of the biomass in the filter is slowed down while the organic loading remains essentially the same as during warmer methods. Not being able to oxidize all of the organics because of their slower metabolism, the excess organics are stored in excessive extracellular bacterial slimes that increase as the cold weather progresses, resulting in the seasonal clogging observed. Regardless of the cause, the operator of a RGMF should anticipate that this might happen and make provisions for alleviating the clogging conditions.

Experience has shown that if clogging occurs to the extent that it cannot be remedied by periodic raking of the filter surface, occasional removal of the top inch or so of the media may restore the RGMF to normal operation. If that does not alleviate the clogging problem, discontinuing flow to the filter for a period of a month or more, depending upon ambient temperature, will result in rejuvenation of the media.

Therefore, as a preventative maintenance procedure, multiple filter compartments should be provided, with provisions of isolating each compartment from the wastewater and filtrate flow so as to permit it to rest for a period of one to two months, depending upon seasonal temperatures. After the resting period, the rejuvenated compartment can be placed back into service and another compartment taken out of service and allowed to rest.

To maintain the quality of the filter effluent, the filter compartment being placed back into service should receive reduced surface loading rates for a period of time, depending upon seasonal temperatures, until it ripens (re-establishes the biotic population). During that time, the filter next in sequence to be rested should remain in service. After some length of time, usually measured in years, the media will have to be replaced due to clogging by the accumulation of non-biodegradable matter.

Since one compartment will be out of service, prudent design would consider reducing the hydraulic and organic loading rates used for overall design of the RGMF so that the loading rates applied to the remaining compartments do not exceed the maximum rates recommended herein.

It is important to design an RGMF to operate under aerobic conditions with clogging potential minimized. This can be accomplished by assuring:

- the filter is properly sized to accommodate the hydraulic and organic loadings,
- uniform distribution of the wastewater- filtrate mixture over the entire filter surface,
- provisions are made for adequate circulation of air through the media,
- the potential for the fouling of the filter surface by weeds, leaves and other airborne debris is minimized, and,
- adequate access to the filter surface is provided for ease of maintenance.

The factors that must be considered in design of a RGMF include:

- Hydraulic Loading Rate
- Organic Loading Rate
- Recirculation Rate
- Recirculation Method
- Recirculation Tank Volume
- Dosing Intervals
- Media Gradation
- Media Depth
- Underdrain System
- Method of Flow Distribution to Media
- Harsh Weather Conditions
- Fouling of Media Surface by Extraneous Matter

Recirculating granular media filters used for treating residential wastewater are normally sized on the basis of the hydraulic loading rate of septic tank effluent applied to the surface of the filter. This loading rate typically ranges from 3-5 gallons per day per square foot (gpd/sf), and conservative designers will select a rate near the lower end of this range.

(Note that the hydraulic loading rate is based on the wastewater flow rate, rather than on the recirculated flow rate.) For example, normal residential septic tank effluent BOD_5 concentration is about 150 mg/L. If a surface loading rate of 4 gpd/sf were selected, the maximum organic loading rate given below would not be exceeded.

However, the organic loading must also be considered where the wastewater characteristics differ from that of residential wastewater. The organic loading is expressed as the amount of BOD_5 applied to the filter.

Values given in the literature range up to 0.005 pounds of BOD_5 per day per square foot of filter surface area. Prudent design would suggest selecting a loading rate below the upper end of the range. Thus, it is necessary to compare the hydraulic and organic loading rates and select the controlling rate for design of the filter.

The ratios of the recirculated flow rate to the wastewater flow rate cited in the literature range from 3:1 to 5:1. For example, for a recirculation rate of 4:1(4 parts of filtered effluent mixed with one part of septic tank effluent) the recirculation flow rate will be five times the design daily flow rate.

The recirculation method used can have a subtle effect on the RGMF effluent quality. There are two methods used for controlling recirculation of the filter effluent, including the use of a flow-splitting device or a simple and automatically operating floating ball diversion valve.

In the case of a flow-splitting device (usually a chamber containing a moveable gate, adjustable weirs or orifices, or similar mechanisms), a portion of effluent is directed back to the recirculation tank while the remainder is discharged to downstream processes, if any, and thence to the SWAS. Where a floating ball diversion valve is used, all of the filtrate flows back to the recirculation tank that contains the diversion valve. The floating ball is contained in a cage that allows it to float up and down with the liquid level. When the liquid level in the recirculation tank is low, the flow diversion valve remains open and all of the filtrate is returned to recirculation tank through the open valve. When the liquid in the recirculation tank reaches a predetermined level, the floating ball rises and seals against the rim of the downward facing recirculated filtrate inlet fitting. This prevents further return of the filtrate and diverts it to the downstream facilities.

The advantage of the flow splitting method of recycle flow control is that it conserves hydraulic head. The invert of the flow splitter chamber is controlled by the elevation of the RGMF effluent underdrain piping, rather than by the elevation of the recirculation tank that must be below the elevation of the septic tank outlet piping. Since the septic tank effluent and recycled filtrate is pumped to the RGMF from the recirculation tank, the filter and the flow splitter chamber can be elevated above the recirculation tank and thus the downstream facilities can be located above the elevation of the septic tank outlet piping. The disadvantage of the flow splitter method is that, regardless of the rate of flow into the recirculation tank from the septic tank, during each recirculation cycle, some of the filtrate bypasses the recirculation tank and continues on to downstream facilities.

The advantage of using an automatic flow diversion valve is that, at times of low wastewater flows, all of the filtrate continues to be recirculated. During such periods of low flow, the wastewater receives additional “polishing” treatment, resulting in an enhanced filtrate quality. However, in using this method, some hydraulic head is lost because of the lower elevation of the diversion valve in the recirculation tank.

It is often recommended in the literature that the recirculation tank volume for a RGMF serving a residence should be at least equal to the design daily flow volume. In this case, the recirculation tank also functions as an equalization tank. Another method of determining the working volume has been used successfully in designing several RGMF installations in Connecticut that serve commercial facilities having a much greater design flow. This volume is calculated as the sum of the filter dose volume required for the design maximum time interval between successive dosing cycles plus a volume equal to the maximum amount of wastewater that could be expected to be discharged into the recirculation tank during that same maximum time interval. The latter volume is usually based on the peak hourly flow rate of the wastewater.

In addition to the working storage volume, the recirculation tank should be sized to retain sufficient liquid at all times so as to submerge the pump volutes in order to reduce the chances of the pumps becoming air-bound. Also, some freeboard between the liquid level at maximum storage capacity and the level of activation of a high level alarm float switch, and between the high alarm level and the invert of wastewater piping, should also be provided. A 6-inch freeboard allowance in each case is usually sufficient.

Provisions should also be made to account for possible malfunction of the recirculation pumps or electrical equipment. This can include provision of a high level overflow to an emergency holding tank of sufficient capacity to provide time for a response to the malfunction condition. In some cases, the Department may permit the high level overflow to discharge to the SWAS provided it will receive assurance of a very short response time. To provide for the malfunctioning pumping equipment, the recirculation tank should be equipped with dual, slide rail mounted submersible pumps operating on alternate cycles, and suitable access hatches. A discussion on wastewater pumps and appurtenances is given in Section XII.

The intervals between dosing of the commingled septic tank effluent and recycled filtrate from the recirculation tank onto the surface of the filter media commonly range from 30 minutes to 2 hours. Sufficient time should be provided between dose cycles for the filter media to drain and become completely re-aerated before the next cycle is initiated.

A simple timing device (normally a time clock) that actuates the automatic pump alternator that is part of the recycle pump control system controls the dosing intervals. Thus, the time clock must be capable of initiating at least 48 pumping cycles per day.

The filter dose volume is the total recirculated flow volume per day divided by the number of dosing cycles per day. The dose volume should be equivalent to that needed to cover the entire surface of the filter media, in order to use the media in the most efficient fashion and maintain the environmental conditions (food supply, nutrients, and moisture) required by the population of organisms in the filter.

The interval ultimately to be used is normally selected based on the results obtained from fine-tuning the actual operation, and may require changing with the seasons. An electronic type of time clock will provide significant flexibility in establishing dosing times and cycles and should be used. The dosing cycle should provide sufficient time for the filter media to drain and become completely re-aerated before the next cycle is initiated.

The gradation of the granular media is a designer’s choice, subject to certain restrictions. The gradation is usually expressed as the percentage (by weight) distribution of media grain sizes. The controlling grain sizes include those passing the #5, #10,#18, #60, and #100 U.S. Standard Sieves. The percentage by weight of the media grains that pass a # 10 and # 60 sieve are designated as the d_{10} and d_{60} size respectively. The d_{10} size is designated as the effective size and the ratio of d_{60}/d_{10} is designated as the uniformity coefficient. The larger the d_{10} size, the coarser the media, while the media sizes become more uniform as the uniformity coefficient becomes smaller.

The range of d_{10} sizes for sand media is 1.0 to 2.0 mm, and 2.0 to 4.0 mm for pea-gravel media, with a uniformity coefficient ≤ 3.0 and not more than 2% should pass the #100 sieve. Thus, the media should be carefully and thoroughly washed, repeatedly if necessary, to remove virtually all of the fine material that may be included in the raw material from which the media is obtained. The media also must be sound, durable, and free from soft, thin, flat or elongated particles, with a hardness value > 3 on MOH's scale of hardness.

The media depth used in a RGMF ranges from 24 to 30 inches. While most of the treatment in a RGMF appears to occur in the top 6-12 inches of the media, additional depth will serve two purposes. Additional depth will provide a polishing effect on the filter effluent, enhance the removal of pathogens, and will permit occasional removal of the top layer of the media for a period of years without compromising the treatment process. Thus providing additional depth will under normal operating conditions prolong the time before complete replacement of the media is required.

The functions of the underdrain system are to support the filter media and prevent migration of the finer particles of the media out of the filter, to provide a means of collecting the filtrate and to provide a means of venting the filter. Ventilation of the filter is important so that fresh air can diffuse and be drawn into the filter media after each dosing cycle to provide the oxygen required by the biomass in the filter.

A properly designed underdrain will consist of several graded layers, normally not more than four, of progressively smaller sized stones from bottom to top of the underdrain system, with the total depth usually around twelve inches and a filtrate collection system.

Perforated pipes are installed at the bottom of the stone underdrain to collect the filtrate. These filtrate collector pipes are connected to a header that discharges to a main drain that returns the filtrate to the recirculation tank. The end of each perforated filtrate collector pipe opposite from the header connection is connected to a vertical vent riser that extends above the surface of the filter media and is open to the atmosphere. These vents aid in circulation of fresh air through the filter media after the filtrate has drained from the filter, and it is important that the perforated collector pipes and vents be spaced in such a manner as to insure that adequate venting of the filter media occurs.

The gradation of the underdrain stone will depend upon the type of filter media used. The following gradations have been found satisfactory. Stone size refers to U.S. Standard Sieve size designations.

Underdrain Stone for Sand Media:

Layer	Depth, in.	Stone Size, in.
Bottom	3	$1^{1}/_{4}$
Second	3	3/4
Third	3	1/2
Top	3, min.	1/4

Underdrain Stone for Pea Gravel Media:

Layer	Depth, in.	Stone Size, in.
Bottom	4	$1^1/_4$
Second	4	3/4
Top	4, min.	1/2

The underdrain stone must be sound, durable, and free from soft, thin, flat or elongated particles with not more than 1% passing the #200 mesh sieve. As in the case of the filter media, the stone should be carefully and thoroughly washed, repeatedly if necessary, to remove virtually all of the fine material that may be included in the raw material from which the media is obtained.

Underdrain piping should consist of perforated PVC pipe, ≥ 4 inches in diameter, installed approximately 6 ft. on centers. The discharge end of each underdrain should connect to a header pipe that will convey the filtrate back to the recirculation tank or flow splitting chamber. The other end of each underdrain pipe should be connected to a vertical riser that extents above the top of the media. These risers will permit the underdrain piping to also provide ventilation of the filter media. It is advisable to provide valves at the end of each underdrain pipe to permit isolation of each filter compartment.

Flow distribution of the mixture of wastewater and recycled filtrate onto the filter surface has been accomplished by numerous methods. The simplest method used in the past for open intermittent sand filters consisted of gravity flow pipes with outlets (tee branches or perforations) discharging to splash blocks supported on the surface of the filter media. This method is not adequate for the coarser media used in an RGMF, because it leads to unequal distribution of the liquid onto the filter surface. Such unequal distribution results in over-utilization of part and under-utilization of the remainder of the filter surface and often leads to progressive clogging of the filter surface. A more suitable method is pressure flow distribution via a network (manifold and laterals) of piping, having closely spaced small orifices (perforations), which receives the wastewater/recycle mixture under pressure and distributes it fairly evenly over the filter surface. In some cases, shields are placed over the orifices to further aid in distributing the liquid over the filter surface. In cold climates, such piping is often covered with coarse aggregate to protect against freezing of the pipe orifices.

Another suitable method utilized for flow distribution is a system of pressure flow distribution manifold and laterals, equipped with riser pipes and spray heads spaced above the filter media in such a pattern as to provide a uniform distribution of the wastewater/recycle mixture over the entire filter surface. In this method, the flow distribution manifold and laterals are buried between the bottom of the filter media and the top layer of the media support gravel. This is an excellent method of flow distribution, and also provides oxygenation of the applied wastewater. This method must be used when pea gravel is used as the filter media, in order to insure that short-circuiting does not occur due to the high hydraulic conductivity of this media. An isolation valve should be installed on the inlet to the flow distribution manifolds to permit isolation of each compartment.

Care must be taken to insure that the spray head orifice is large enough to prevent clogging by solids carried in the wastewater and/or by microbial growths and that the spray head is installed in such manner as to prevent freezing during cold weather operations. To prevent freezing problems from occurring, spray heads should be installed in an upright position on the riser pipes and the entire flow distribution system should be designed to be self-draining, upon completion of a dosing cycle, to a distance below the filter surface where non-freezing temperatures prevail.

A very simple but effective spray head consist of a 3/4 inch diameter PVC threaded pipe nipple with a slot cut into the side of the pipe nipple at a slight upward incline from a horizontal plane. The slot has a depth of approximately 1/2 the internal diameter of the pipe nipple. The pipe nipple is capped just above the slot opening with a threaded PVC pipe cap, which can be easily removed should spray head cleaning be required. When operated at a pressure of 6 psi, the spray heads provide a good spray pattern over an arc of almost 180° and, when spaced at 6-ft. center-to-center, complete coverage of the filter surface is obtained. Wider spacing of the spray heads can be used with higher operating pressures. The spray head method does produce some aerosol that should be contained within the filter area. This matter is addressed below.

There are a number of variations on the configuration of the filter itself. The filter may be constructed at grade within earthen dikes or within a depression made by excavating below existing grade. In such cases, a plastic watertight membrane liner is used to contain the filter media and underdrain facilities and is supported by the soil bottom and sidewalls of the excavation or the dikes.

In other cases, the filter may consist of a structure consisting of a concrete floor slab and walls constructed of concrete, concrete blocks or timber. (Where timber structures are used, they may also be lined with a plastic watertight membrane liner.)

Most filter structures have a rectangular footprint. The filter surface may be left open to the atmosphere, may be covered with a layer of gravel, may have removable covers or may be located within an enclosure. While successful operation of uncovered filters under cold weather conditions has been reported (e.g.: Louden-1984), many filters located in areas which experience cold winter weather conditions are provided with removable covers or with fixed covers providing headroom for maintenance. All of the filters constructed to date in Connecticut are provided with covers.

Covers serve to exclude precipitation, contain aerosols, retard heat loss (including protection against cold winds), and keep the filter free from wind borne debris such as leaves, paper and plastic wrappers, etc., which when deposited on the filter surface tend to cause uneven distribution of the wastewater. In addition, the covers should be opaque to exclude sunlight so as to prevent the growth of weeds and algae, problems often associated with uncovered filters. Where walls are used to enclose the filter media, they should be surrounded by earth fill extending to an elevation not less than the surface elevation of the filter media in order to provide insulation under cold weather conditions.

If covers are provided, however, they must be designed to provide easy access to the filter surface. They should be relatively light and easily removed or hinged at one end so they may be propped open to permit maintenance of the filter. If fixed in place they must provide ample headroom so that the operator does not have to continually stoop while working within the filter.

Several of the filters constructed in the State have been retrofitted with easily installed prefabricated enclosures consisting of corrosion resistant metal frames covered with a heavy duty, weather resistant plastic coated fabric. These have been in use for several years and to date have withstood the ravages of severe storms, cold weather and exposure to the environment within the filter. The fabric covers are fastened to the metal frames and filter substructures in a manner that permits their easy removal for repair or replacement. These enclosures permit operating personnel to stand in a comfortable manner while maintaining the filters.

Where the inherent denitrification that occurs in a RGMF is insufficient to meet effluent total nitrogen limits a portion of the filtrate can be recycled back to the septic tank, or preferably to an anoxic reactor, for further denitrification. Experience obtained from a technology demonstration project funded by the Department indicated that a total reduction of up to 70% or more of the nitrogenous compounds might be obtained in this manner. Where a greater reduction is required an anoxic reactor fed with an external carbon source will be required.

The portion of the filtrate to be recycled might be calculated from a mass balance of the amount of nitrates in the filtrate and the soluble BOD_5 available in the septic tank for denitrification, providing the ratio of soluble BOD_5/ NO_3 is known. However the available soluble BOD_5 may vary from time to time and most probably by season of the year, as colder temperatures will affect the biological activity of the microorganisms responsible for converting the particulate BOD_5 to soluble BOD_5 in the septic tank.

In addition, the amount needed to reduce the nitrates to nitrogen gas will depend upon wastewater characteristics and ambient operating temperatures. Also, additional soluble BOD_5 will be needed to remove the dissolved oxygen in the recycled filtrate the amount of which is also somewhat dependent upon ambient temperatures. Therefore, a method of varying the recycled portion of the filtrate should be provided to "fine-tune" the recycle rate base on actual experience.

It should be noted that recirculating some of the filtrate back to the septic tank for denitrification would result in a significant reduction of the organic loading on the RGMF, since BOD_5 will be consumed in the denitrification reaction. This can result in reducing the filter surface area if organic loading would otherwise have controlled the surface area required.

Operation and maintenance of a RGMF is not an involved task. Generally, O&M requirements include inspection of the filter surface and spray heads on a weekly basis and cleaning them as needed, checking the recirculation tank pumps and equipment on a monthly basis, checking the solids and scum levels in the septic tank (and grease trap if required) on an annual basis, periodic cleaning of the filter media, overseeing the sampling and testing and filing the discharge monitoring reports required by the State discharge permit.

The advantages of an RGMF include:

- A highly reliable, stable process that produces a high quality effluent.
- Less skill and time required for O & M (ease of operation).
- Tolerance of peak hydraulic and organic loadings.
- A minimum of mechanical and electrical operating equipment
- Protection of downstream facilities from high suspended solids loadings, as clogging first occurs on the filter surface and provides ample warning for remedial action.

The disadvantages of a RGMF include:

- More land area required than most other types of treatment facilities.
- May have higher capital costs.
- Not suitable for high degree of nutrient removal.
- Possible periodic odors if not properly maintained.

It should be noted that there are several variants of the RGMF process that have been developed in various parts of the U.S. Most of these have to do with modifications for more efficient nitrogen removal. Engineers involved in designing an OWRS are encouraged to search the literature to become familiar with the various ways that a RGMF can be configured to meet specific goals so as to be able to fully evaluate the RGMF process with respect to other enhanced pretreatment processes.

c. Trickling Filters

The trickling filter (TF) was one of the earliest fixed film bioreactors used to provide biological treatment of wastewater. A TF consists of a bed of media, contained in a reactor of either circular or rectangular cross-section, where wastewater is applied in a uniform method onto the top of the bed and trickles down through the media on and in which a biomass has been established.

Depending upon the types and distribution within the media of microorganisms that make up the biomass, a trickling filter can be designed to oxidize both organics and nitrogenous compounds. It should be noted that the name “trickling filter” is a misnomer, as a TF does not generally perform a filtration function. One notable exception is when sand or fine gravel is used as the medium, such as in a RGMF that in fact operates in much the same way as a TF but also serves as a filter.

Various types of media are used in modern trickling filters. The media originally used included rock (broken stone) and other granular media. Media used in modern trickling filters include:

- Fabrications of synthetic plastic sheets into modules of tubular configurations, or wooden slats arranged as stacked pallets, having high unit surface areas and porosity;
- Individual pieces of plastic material of various shapes and sizes;
- Open cell foam blocks,
- Crushed glass;
- Crushed brick; and
- Lightweight expanded shale or clay aggregates.

Where heavy media are used, the beds are usually of shallow depth. Where lighter weight media are used, the beds can be much higher. Most of the packaged trickling filter (TF) reactors available for small scale enhanced pretreatment facilities now employ some type of synthetic media.

Soon after wastewater is initially applied to the bed, the surfaces (and inner void spaces) of the media become coated with a zoogleal biomass, slimy in appearance. Similar to other packed bed type of reactors, the biomass is made up of bacteria and higher life forms that utilize the carbon in the wastewater as a source of food and energy. The oxygen required by the biomass for their metabolic processes is obtained from natural or forced circulation of air through the voids in the media.

The biomass removes organic matter by adsorption of particulate organic matter and assimilation of soluble organic carbon. As mentioned above, a TF can also be operated so as to nitrify the nitrogenous compounds in the wastewater. Eventually the biomass growth reaches such thickness that it begins to slough off the media and flow down with the liquid to the bottom of the reactor. The continuous sloughing of the biomass from the media is a required part of the process, since excessive accumulation (thickness) hinders the treatment process by limiting or preventing oxygen from reaching the inner portion of the biomass.

The biologically treated wastewater is collected at the bottom of the reactor and either all of it proceeds on to a downstream clarification process or a portion is recirculated in one or more passes over the bed while the remainder is discharged downstream. The contact time of the wastewater with the biomass on the media is fairly short, and thus a substantial amount of active biomass must be present in order for the process to be efficient in oxidation of organics and nitrogenous compounds. Where a high degree of treatment is required, recirculation must be employed.

In the once through, or single pass mode, the wastewater is periodically applied (dosed) onto the surface of the TF and the treated effluent collected at the bottom of the TF is discharged to downstream facilities. In the recycle mode, a portion of the TF effluent is recycled to a flow equalization tank and is returned to the TF for one or more times (passes), while the remainder (the "forward flow", equivalent to the influent wastewater quantity) is discharged to downstream facilities. The efficiency of treatment approves with the recirculation ratio (usually ranging from 1:1 to 4:1) and the dosing rate employed; in this respect the effect of dosing rates and recirculation is similar to that obtained in an RGMF. The recirculating mode permits a decrease in the surface area of the TF but requires more or higher capacity pumping equipment for application of the wastewater to the top surface of the TF.

Recirculation rates and frequency of dosing will affect the ability of a TF to fully nitrify the effluent. Oxidation of organics typically occurs in the upper portion of the TF media while oxidation of nitrogenous compounds (nitrification) occurs near the bottom. Increased recirculation rates can result in a smaller depth of the TF media required for oxidation of organics, leaving an increased depth for the nitrification process that results in enhanced nitrification. However, where denitrification is required, excessive recirculation rates and dosing frequencies can result in an excessive D.O. in the TF effluent that will affect the efficiency of the denitrification process.

The components of a TF include the reactor structure, media, media support system, underflow collection system, pumping equipment, the device(s) used to distribute the wastewater onto the TF surface, and, the equipment used to deliver forced air into the TF if that method of aeration is employed.

The clarifiers that receive the effluent from the trickling filters are designed on the same basis as those used in the RBC process. Since the biomass is attached to the media, recycling of settled biomass, as in suspended growth bioreactors, is not required.

Factors to be considered for design of trickling filters include:

a. Wastewater characteristics
b. Type of filter media (material, porosity [percent of void space], specific surface area [unit surface area/unit volume])
c. Filter depth
d. Method of applying wastewater to surface of TF
e. Hydraulic loading rate (total volume of liquid, including recirculation, per unit of time per unit of filter cross-sectional area
f. Organic loading rate (unit mass BOD_5/unit volume of TF or, alternately, unit mass BOD_5/unit of media surface area)
g. Nitrogenous loading rate (unit mass NH_4-N/ unit volume of TF or, alternately, unit mass NH_4-N /unit of media surface area)
h. Recycle rate
i. Dosing method
j. Method of aerating the TF (natural or forced air movement)
k. Temperature

The treatment efficiency of trickling filters can vary substantially, but a properly designed and operated TF reactor facility is reputed to provide up to 85% -90% or more removal (oxidation) of organics and nitrogenous compounds. The use of crushed brick as a potential means of removing phosphorous, as discussed by Anderson, et. al. (1998) is worthy of consideration. However after a period of time the phosphorus sorption capacity of the brick would be reached and it would have to be replaced. The effect of shielding of the brick, by the biomass, from sufficient contact with the wastewater may also be of concern. Lightweight expanded aggregate also has a similar potential for P removal.

Problems with trickling filters include possible generation of odors and growth of nuisance organisms (e.g. filter flies, snails) and excessive growth of biomass that does not slough off of the media. Odors can be of particular concern when septic tank effluent is applied to the surface of the TF bed. Many of the packaged types of TF are covered and suitable for burial below ground, which may tend to mitigate the filter fly nuisance problem, and they can also be vented to odor removal facilities. If snails are encountered, provisions must be made for their removal before the effluent reaches any mechanical equipment. Uneven and irregular sloughing of media can impact the efficiency of the process, and continual organic overloads can lead to clogging of the media due to excessive biomass growth. The application of wastewater containing a concentration of fats, oils and grease (FOG) higher than normal residential wastewater may also cause clogging problems, thus interfering with the biomass metabolism and reducing the efficiency of the process.

d. Packed Bed Anoxic Reactors for Denitrification

Studies have shown that pretreated, nitrified wastewater can be effectively denitrified using a packed bed (fixed film) reactor (PBR) operating in a low oxygen (anoxic) environment.

A packed bed anoxic reactor consists of a reactor vessel filled with inert packing material through which the nitrified wastewater is passed under saturated flow conditions. The packing material, which may consist of stone or various types of artificial media manufactured from plastics or ceramics, provides the surfaces on which a film of the denitrifying bacteria can grow in the absence of dissolved oxygen. The packing is completely submerged in the wastewater, thus avoiding exposure of the bacterial films to atmospheric oxygen.

Factors to be considered in the design of packed bed reactors for denitrification include:

- Wastewater characteristics,
- Type of bioreactor (shape, direction of wastewater flow; e.g. upflow or downflow),
- Type of media (shape, size, specific surface area (surface area per unit volume of media), porosity),
- Total packing depth,
- Temperature,
- Denitrifier growth rate,
- Denitrification rate,
- Specific Surface Loading Rate (unit mass of NO_3-N applied /unit surface area of media,
- Hydraulic Loading Rate (gal/sf of gross reactor area perpendicular to direction of flow, and,
- Empty Bed Detention Time (detention time of the wastewater, based on the gross volume of the reactor.)

Denitrification rates for various types of packing materials and operating temperatures have been experimentally determined by a number of researchers. Sutton et al. (1975) conducted a significant study on low temperature biological denitrification of wastewater using pilot scale packed bed reactors containing various packing materials. The results of his studies and those obtained by others have been summarized and published by the U.S. EPA (1975, 1993.) Studies have shown that 90-95% or more of nitrate-nitrogen can be removed in a packed bed reactor operating at hydraulic detention times as short as several hours or less. However, operating a backed bed denitrification reactor at short detention times (synonymous with a high mass loading rate of nitrate) results in a buildup of bacterial cells until eventual plugging of the reactor occurs (Requa and Schroeder-1973). Therefore, a much longer hydraulic detention time may be desirable, particularly where the reactor is not cleaned on a frequent basis. Studies have shown that a high nitrate removal efficiency can be obtained when the reactor is operated at a hydraulic detention time of several days with much less accumulation of biomass (Lamb, et al - 1987).

Nitrate-laden wastewater is often introduced into packed bed denitrification reactors at the bottom of the packed bed reactor and flows in an upward direction through the packing material under saturated flow conditions that enable anoxic conditions to be maintained. The upward direction of flow will also aid the nitrogen gas resulting from the denitrification process to rise in concurrent flow with the liquid until it escapes to the atmosphere above the surface of the liquid. Since temperature has a significant effect on the rate of denitrification, it is desirable to bury the reactor in the ground. A means of gaining access to the reactor for removal of excess biomass is required.

e. Fluidized Packed Bed Bioreactors

A fluidized packed bed bioreactor is a unique type of PBR operated in a submerged upflow mode for denitrification of nitrified wastewater at relatively high rates because of the high concentration of denitrifier biomass (as much as 25, 000 mg/L or more) that can be contained in the reactor. This permits the use of smaller reactor volumes than other types of packed bed reactors. In a fluidized PBR, the packing material is expanded by the upward flow of fluid through the bed, thus enhancing the removal of nitrogen gas and excess biomass. Periodically, the PBR is "bumped" by an air backwash to assist in the stripping of gaseous nitrogen from the media.

Because fluidized packed bed reactors used for small scale enhanced pretreatment facilities are of the proprietary, packaged type with varying media characteristics and methods of operation, design parameters will vary. Sizing criteria utilized by the manufacturer is generally based on consideration of reaction kinetics, empirical methods, pilot test data and performance data from full-scale facilities. The loading rate is usually expressed as mass NO_3-N/unit of volume, often given as lb. NO_3-N/1000 cu. ft. of media.

The beds should be capable of being backwashed and provisions must be available to skim and remove the solids washed to the top of the bed. Carbon required for denitrification can be from external sources or by feeding of settled wastewater. However, if wastewater is used as a carbon source, provisions must be made to nitrify the unoxidized NH_4-N and then to reduce the NO_3-N that will otherwise bleed through with the effluent.

E. Chemical Feed System for pH and Alkalinity Control

As previously discussed in this section, the nitrification process has a strong effect on the pH of the wastewater by increasing the hydrogen ion concentration and thus decreasing the pH. Low alkalinity source (potable) water will exacerbate the pH problem, as there will be less alkalinity available to buffer the increased hydrogen ion concentration. While the alkalinity of the wastewater will be increased due to the waste discharges, there may still be insufficient alkalinity present in the wastewater for complete nitrification to occur. Therefore, provisions should be incorporated in the enhanced pretreatment facilities for storage and feeding of an alkaline chemical as necessary to permit control of the pH of the wastewater.

Either sodium bicarbonate or magnesium hydroxide are most suitable as the alkali source for small facilities with limited operational control, as these chemicals are non-toxic, non-corrosive, and, if overdosed, will not raise the pH above the range required in the nitrification process. While consideration should be given to an increase in the sodium content of the ground water from the use of sodium bicarbonate, it is unlikely that a major increase in sodium content of the ground water will result from the small quantities of sodium bicarbonate used in enhanced pretreatment for on-site wastewater renovation facilities.

F. Enhanced Pretreatment for Food Processing and Serving Establishments.

As previously discussed in Sections IV and IX, the high organic content of wastewater discharged from food processing and serving establishments have often caused early failure of the subsurface wastewater absorption systems (SWAS) serving such establishments. Therefore, the long-term acceptance rate (LTAR) used for design of a SWAS for such establishments must be significantly down-rated, resulting in large areas required for the SWAS.

Major constituents of such wastewaters are fats, oils and grease (FOG), and high concentrations of FOG reaching the SWAS have resulted in complete clogging of the infiltrative surfaces. To avoid such failures, FOG must be removed to the greatest extent practicable. Underground grease traps, if properly sized and maintained will intercept and remove a significant portion of FOG. However, FOG removal in underground grease traps to concentrations that will not significantly affect a SWAS (20-30 mg/L or less) is problematic. Therefore, enhanced pretreatment should be considered for removal of FOG for such establishments.

One method (Nibbler™) developed for such purposes, reputed to be successful for reduction of FOG concentrations by greater than 90%, utilizes a grease trap, flow equalization tank equipped with pumping equipment, a hybrid type of attached and suspended growth aerobic process carried out in upflow type bioreactors, and a clarifier. The effluent from this process reputedly has been found to be no stronger than residential wastewater. The aerobic bioreactors consist of tanks in which buoyant media, held in place just below the liquid surface by plastic retainers, provide a large surface area to support the biomass required for aerobic digestion of the FOG and other organic matter. An air blower and air tube arrangement creates aerobic mixed liquor that circulates through the media providing the oxygen required for the aerobic biomass with sufficient turbulence to promote sloughing of the biomass from the media. The sloughed biomass collects at the bottom of the reactor and is periodically removed by a septic tank pumper truck. The clarifier provides protection of the SWAS from solids escaping from the bioreactor. Another method used successfully at a restaurant in Connecticut consists of an underground grease trap discharging to a septic tank followed by a secondary grease trap that discharges to a recirculating granular media filter. This treatment system has been in operation for 20 years and produces a high quality effluent, with $\geq$ 90% removal of BOD_5 and TSS and total nitrogen removal $\geq$ 40%. No ponding has occurred in the SWAS underlain by medium sand that receives the RGMF effluent.

G. Enhanced Pretreatment for Removal of Toxic Chemicals

Where toxic organic or inorganic chemicals are anticipated to be present in the domestic wastewater, the design engineer should provide specific information on the types and concentrations of such chemicals and the methods to be used for their removal from the wastewater.

Because of the wide range of such toxic chemicals, it is not feasible to present in this document a review of methods available for their removal from the wastewater. In general, such methods may include physical, chemical and biological treatment processes. Chemical removal processes may include chemical addition, mixing, precipitation, flocculation, sedimentation and filtration. Physical processes such as adsorption using activated carbon or other special media may be warranted in some instances. It is also possible that the microorganisms used in biological processes for removal of non-toxic organics and nitrogen may become acclimated to such chemicals, if they are present in trace amounts, and remove them along with the non-toxic organics. However, before relying on biological processes, laboratory and/or pilot plant tests should be conducted to determine if such treatment is possible without subjecting the biological processes to stresses that will prohibit them from providing the efficient removal of non-toxic organics and nitrogen expected from such processes.

If the toxic organic chemicals are contained in a small sidestream contribution to the overall wastewater flow, pretreatment of that sidestream by adsorption on granular activated carbon may be the most effective method for their removal. Small activated carbon reactors are commercially available and once the removal capacity of the carbon is exhausted, the reactors may be exchanged with the vendor for new or recharged reactors. A filtering process to remove suspended solids that could adversely affect the carbon adsorption process should precede activated carbon adsorption reactors.

It is virtually impossible to predict the adsorption capacity of the carbon media due to the wide range of toxic chemicals that may be present in the wastewater, unless a pilot testing program is conducted. Absent pilot testing, a granular carbon should be selected that is suitable for adsorption of a broad range of toxic organics.

H. Enhanced Pretreatment for Pathogen Removal/Inactivation

1. General

Disinfection is normally not provided where wastewater is discharged to SWAS, since both the biological mat that forms at the soil/leaching system interface and the natural soil beneath and downgradient of a properly designed SWAS are very effective in removing pathogenic bacteria and viruses. However, experience indicates that the usual biological mat does not develop where a highly treated wastewater is discharged to a SWAS. Therefore, it is prudent to provide an additional safety factor to ensure that the groundwater at the boundaries of the zone of influence of the SWAS will meet water quality goals.

2. Chlorination-Dechlorination

Disinfection using chlorine is problematic because there are a number of organic compounds in wastewater that can react with chlorine to form toxic compounds. Further, chlorination may not be the most effective means of disinfection where parasitic protozoa (e.g.: *Cryptosporidium parvum*, *Giardia lamblia*) and viruses are the pathogens of concern.

The Department does not typically approve the use of chlorination where wastewater is discharged to a SWAS.

3. Ozonation

Ozone (O_3) is a very strong disinfectant and functions by direct oxidation of the cellular walls of bacteria, by damage to the nucleic acids of bacteria and viruses, and by causing other deleterious effects on living organisms. Destruction or inactivation of pathogens by ozone occurs rapidly, usually within 30 minutes or less. The major factors to be considered in design of an ozone disinfection process are dosage rates, mixing, and contact time.

Ozone must be generated on-site for immediate use, as it is unstable and decomposes rapidly to oxygen in water and air. Ozone generators at wastewater treatment facilities generally operate by imposing a high voltage alternating current across a dielectric discharge gap in the presence of very dry air or oxygen. The effectiveness of the process depends on the susceptibility of the pathogens, the concentration of ozone and the contact time of the pathogens with ozone.

Ozonation of pathogens is accomplished by feeding ozone via diffusion into the wastewater in a small chamber that provides sufficient contact time. As in all chemical disinfection processes, thorough mixing of the diffused ozone with the liquid to be disinfected is important to assure all pathogens are contacted with ozone for the required contact time. Any residual ozone gas that escapes from the liquid in the chamber must be destroyed before it is released into the atmosphere, because it is extremely irritating to respiratory organs and may be toxic. For the same reason, leakage of ozone from the ozone generator must be monitored and immediate steps taken to correct any leaks. Ozone in gaseous form is also explosive, but at concentrations well above the normal concentrations used for ozone disinfection.

Ozone generators are available as pre-manufactured units in many sizes and pre-manufactured ozone destruction equipment is also available.

4. Ultra-Violet Irradiation

Ultra-violet irradiation is an accepted means of disinfecting pretreated wastewater. It is a safe technology with respect to disinfected water quality, as it does not produce any residual toxicity and produces negligible chemical by-products. The absorption of UV energy results in photochemical damage to the nucleic acids (DNA and RNA) of the pathogenic microorganisms, thus preventing the pathogens from reproducing and causing an infection in a host.

UV irradiation has been found to be very effective for inactivating bacteria, the pathogenic protozoans Cryptosporidium and Giardia, and viruses. There have been significant studies showing that UV irradiation for disinfection is at least as good as chemical disinfection, and some studies have found UV disinfection to be superior, particularly with respect to viruses and pathogenic protozoans such as Cryptosporidium and Giardia (Dykstra, et. al-2002).

The UV dose is a product of the UV light intensity (I), measured in milliwatts/cm^2 (mW-sec/cm^2) or the equivalent milliJoule/cm^2 (mJ/cm^2), and the exposure time, T, in seconds. Thus, the UV dose is expressed as I T. This method of expressing dosage is analogous to that used for chlorine disinfection, which is expressed in Concentration x Time, or CT.

A UV system basically consists of a closely spaced array or battery of low-pressure mercury arc lamps individually encased in quartz tubes and submerged in a compartment through which the wastewater flows. The UV compartments can consist of a sealed reactor or an open channel. The only maintenance required is periodic cleaning of the quartz tubes and periodic replacement of the lamps themselves, which have a reported useful life of at least 7500 hours.

The ability to “overdose” with UV light and still not adversely affect the water quality allows for a less rigorous control of the disinfection process, with the only result of overdosing being the expenditure of additional power. In most cases, a UV system of the size required to disinfect the effluent from a proposed on-site wastewater treatment facility will have an energy requirement on the order of hundreds of watts, rather than many kilowatts. Therefore, the cost consequences of overdosing are not severe. The system can therefore be designed for peak flow requirements and operated at constant power levels so as to eliminate the need for flow pacing controls, although such control can be provided for UV systems designed for large flows.

The controlling parameters for design of the UV system include:

- the wavelength of the light emitted from the lamps, measured in nanometers (nm.),
- the ultra-violet light intensity, expressed as milliwatts/sq. centimeter,
- the residence time (the period of time that the wastewater is exposed to UV radiation), expressed in seconds,
- the concentration of suspended and colloidal solids in the water, and
- the flow conditions in the UV compartment.

The wavelength for optimal germicidal effect ranges from 250-270 nm. and approximately 85% of the output of a low-pressure mercury arc lamp is at 253.7 nm. Thus, the UV dosage rate is expressed as milliwatt-seconds/sq. cm. at 253.7 nm. The dose rate recommended by the Department is not less than 60 milliwatt-seconds/sq. cm**.** This dosage should be available at 65% UV transmission and 65% of new lamp output. The flow characteristics through the UV compartment should be as close to plug flow as can reasonably be obtained. Unlike chemical disinfection, UV disinfection is independent of temperature and pH of the water. Factors that impact on UV disinfection efficiency are the chemical species in the water, and suspended and colloidal solids. Iron and calcium can form fouling deposits on the quartz sleeves that encase the individual UV bulbs. Suspended and colloidal solids reduce the transmittance of the UV light in the wastewater and serve to protect pathogens encased within the solids. Thus, for effective UV disinfection, the wastewater must have a high transmittance and low solids concentration, and provisions must be made for periodic cleaning of the surfaces of the quartz sleeves.

The UV equipment should be provided with a means of measuring and indicating the UV dose and for indicating “Lamp out” conditions for each mercury lamp included in each UV module included in the disinfection system. The “lamp out” detection system should be capable of providing an alarm signal to a central alarm station in the pretreatment facility.

I. Enhanced Pretreatment for Phosphorus Removal

1. General

Chemical pretreatment for removal of phosphorous (P) is normally not provided for in onsite wastewater renovation systems, since P sorption in the soils beneath and downgradient of the SWAS is usually quite effective. However, as previously discussed in Subsection G.4 of Section X, situations may arise where the ability of the soils beneath and downgradient of the SWAS to remove phosphorous from the percolating wastewater is, or may become, insufficient to meet the Department's water quality goals. In such cases, provision for enhanced pretreatment for P removal may either be initially required, or the design of the OWRS must be such that provisions for P removal can be easily incorporated into the pretreatment facilities in the future.

As discussed in Section X, phosphorus is usually found in raw wastewater as organic phosphorus, polyphosphate, or orthophosphate. For efficient removal of phosphorus, all forms of phosphorus must be biologically converted to orthophosphate. Such conversion will occur in most biological wastewater treatment processes under normal operating conditions and no special effort is required for such conversion.

Phosphorous removal may be accomplished using either biological or chemical processes, or by adsorption on beds of reactive media capable of adsorbing P for a considerable length of time. A small amount of P is also removed in cellular synthesis by the biomass in bioreactors used for oxidation of organics and nitrogenous compounds and for denitrification.

2. Biological Processes

Removal of phosphorus by incorporation into new cellular matter resulting from biosynthesis reactions is usually < 2 mg/L, depending upon the processes involved. Biological processes can also attain phosphorous removal beyond that obtained from cellular synthesis. However the operation of such processes requires skilled operation and more constant attention than is normally available for the small scale enhanced pretreatment facilities used for an OWRS. Therefore, it is not anticipated that dedicated biological phosphorous removal processes will be used for enhanced P removal.

3. Sorption on Reactive Media

As stated in subsection D.5 c, crushed brick and lightweight expanded shale or clay aggregate have been investigated for use as reactive media for removal of P because of their metal oxides and clay content and the results appear to be promising. This method is reputedly able to remove $\geq 95\%$ of the phosphorous in the wastewater contacting the reactive media.

Recently, a proprietary method of using reactive media for P removal has been developed and is now available. The media is a waste product (slag) from steel manufacturing which has a chemical composition high in metal oxides, especially calcium (Leverenz, H and G. Tchobanoglous - 2002).

Reactive media will have a finite life with respect to P removal and will have to be replaced once its P sorption capacity has been exhausted. Estimates of useful life range from 10 to 20 years; however, such media have not been in use long enough to be certain of the actual useful life. This approach to P removal appears to have significant advantages, including:

- The avoidance of chemical usage (resulting in no sludge production),
- Essentially maintenance free, and,
- The passive methodology involved, (which only requires that the wastewater be free of excessive organic compounds and suspended solids that could result in clogging of the media, and sufficient time is available for the adsorption to be completed).

4. Chemical Removal

Chemical removal of phosphorus may be accomplished using various chemical coagulants, the most prominent of which are iron and aluminum salts and lime. The metal salts include aluminum sulfate (alum), sodium aluminate, ferric chloride, ferrous chloride and ferrous sulfate. These coagulants change the soluble phosphorus present in the wastewater to insoluble precipitates, which are then removed by settling in clarifiers and/or by filtration.

Metal salts are usually chosen over lime, particularly for small-scale wastewater treatment facilities. This is due to the greater amount of sludge generated by the use of lime, the high costs associated with equipment and maintenance costs for lime storage, feeding and handling equipment, and because metal salt addition for phosphorus removal is a reliable, well documented technique used throughout the country. Liquid alum is often used for chemical P removal. Since liquid alum is 48% alum in a water solution, a premium is paid on the transportation costs because the water in the alum solution increases the shipping weight of the product. However, this is offset by the relative ease in handling and feeding of liquid alum and its cost relative to other aluminum compounds.

Liquid alum is a clear, light green to light yellow aqueous solution, weighing approximately 11.2 lb./gal, containing about 8.2% soluble aluminum expressed as Al_2O_3 or 4.37% expressed as Al and is available in 55-gallon drums and larger containers, and in bulk delivery to on-site storage tanks. Liquid alum is a corrosive (pH ~ 3.5) solution and its use requires careful design of storage and feeding equipment. Care must be taken in on-site storage and feeding to assure that the temperature of an alum solution is maintained above the point at which it begins to crystallize. Suppliers recommend a storage temperature of 45°F or higher. The material safety data sheet (MSDS) for liquid alum should be obtained from the supplier and the instructions for it’s storage, handling and feeding scrupulously followed to prevent injury to personnel and deterioration of enhanced pretreatment plant facilities.

When liquid alum is used for P removal, stoichiometric calculations indicate that 9.6 lb. of alum will react with 1 lb. of phosphorous, or 9.6 mg/l alum will react with 1 mg/l of phosphorus. In practice, however, the quantities of alum required are higher than the stoichiometry would predict, due to competing reactions of alum with other dissolved solids present in the wastewater. Therefore an Al:P mole ratio of 2.2:1 is often used for design of chemical phosphorus removal using alum.

Using the 2.2:1 ratio, the estimated feed rate of alum would be 2.2 x 9.6 = 21.1 mg/L alum per mg/L phosphorus. Assuming it is desired to remove 1 mg/L PO_4-P concentration in a wastewater flow of 1000 gpd, the amount of liquid alum required would be calculated as follows:

0.001 MGD x 8.34 lb./gal x 1 mg/L PO_4-P to be removed x 21.1 mg alum/mg/L PO_4-P = 0.18 lb./day (equivalent to 0.016 gpd) of liquid alum. These values can be used to ratio up to the lb. or gal. of liquid alum required for any PO_4-P concentration and wastewater flow.

The solubility of the aluminum phosphate precipitate depends on the pH of the water. It is reported that the theoretical optimum pH for removal of phosphorus by chemical precipitation is 6.3 and that the optimum may range from 5.5 - 6.5, although removals will occur above a pH of 6.5. Addition of alum will lower the pH of the water because of neutralization of the alkalinity and release of carbon dioxide. The alkalinity neutralized by this reaction is theoretically 0.5 mg/l (as $CaCO_3$) per mg/l alum added; however, actual consumption may differ from 0.5 mg/l because of competition for the aluminum ions from other side reactions. Thus, following the precipitation and removal of P from the treated wastewater, the addition of an alkali may be needed to bring the pH of the wastewater to the effluent water quality value required by the discharge permit.

Feeding of the alum solution should be accomplished where good mixing with the wastewater will occur. This can be at a weir, flow measurement flume or other similar places where flow agitation occurs. High energy mixing should be avoided where the alum is added to the mixed liquor in an aerobic bioreactor or between the bioreactor and the clarifier to avoid shearing of the MLSS floc. With adequate mixing and subsequent flocculation, clarification and filtration, P removal to a residual of < 1 mg/L can be achieved.

Addition of metal salts for P removal will generate a significant amount of chemical sludge. This has to be taken into account when considering the removal, processing and disposal of the sludge. For addition of aluminum salts to remove P down to around 1 mg/L, the increase in sludge quantities from a suspended growth aerobic process will be about 35%. Removal of P to below 1 mg/L will cause a significant increase in the chemical sludge due to the formation of aluminum hydroxides.

The dose of any chemical used for P removal should be determined from jar tests conducted at various dose rates so as to avoid under-dosing or overdosing of the chemical. The results sought from a jar test are the optimum dose that will result in a chemical floc that will settle well and leave a low P residual in treated wastewater.

Under dosing can result in the formation of a “pin-point” floc that is difficult to remove from the wastewater except where the chemical is added to a membrane bioreactor.

Overdosing can result in the formation of an excess sludge volume and unreacted chemical remaining in the treated wastewater.

J. Solids Processing and Disposal

All wastewater treatment processes utilized for pretreatment of wastewater prior to its discharge to a SWAS produce solids that must ultimately be disposed of off-site in a manner approved by the Department. In the absence of enhanced pretreatment, these solids are removed in grease traps and septic tanks and then disposed of by septage waste removal firms. Where enhanced pretreatment is provided, secondary solids (sludge) are produced, the volume of which will depend upon the process(es) used. These solids are usually in very dilute form containing only a few percent solids concentration at most, and thus will require some means of storage in a slurry form until they can be removed and disposed of in a manner similar to that used for septage.

These solids can be stored in septic tanks, sludge holding tanks, and aerobic sludge digesters. For small facilities, it may be cost-effective to route these slurries back to the septic tank(s), provided the tank(s) have been appropriately sized to contain the additional solids that will collect as a result of settling and floatation. For larger facilities, the choice will be either to route the sludge to aerobic digesters or holding tanks.

Aerobic digestion is used to further stabilize (oxidize) biologically degradable organic compounds remaining in the sludge generated in biological treatment processes. An aerobic sludge digester operates in much the same manner as the extended aeration process, with the main differences being that the sludge is retained in the digester until it is removed for ultimate disposal, the SRT is usually much longer, and recycling only pertains to the periodic decanting of the digester supernatant and its return to the enhanced pretreatment process.

Where suspended growth bioreactors operated at long solids retention times (SRT) are used for enhanced pretreatment (e.g. EA, SBR and MBR processes), the volatile solids content of the sludge has usually been significantly reduced. Therefore, an aerobic digester may not significantly reduce the volume of sludge to be stored, and a holding tank might be the preferred option.

A holding tank can be either an anaerobic or aerobic type. However, since either type will have to be periodically decanted, with the supernatant returned to the wastewater treatment process (es), the supernatant from an aerated holding tank will have less of an adverse impact on these processes. Also, since many onsite enhanced pretreatment facilities will be located in reasonably close proximity to inhabited buildings, the use of dedicated anaerobic holding tanks may be problematic because of the disagreeable odors that usually result from decanting of the supernatant and storing and removing solids from the tank.

The main difference between aerated sludge holding tanks and aerobic digesters is the SRT. Sludge holding tanks are aerated to prevent odors that would likely occur from anaerobic holding tanks. On the other hand, aerobic sludge digesters are usually provided when additional reduction of waste solids is desired and when the digested sludge is proposed for use as a soil supplement. Aerobic digesters require a much longer SRT than is usually provided in an aerated holding tank, and this requirement imposes greater operational control and additional aeration requirements.

For example, assume that an aerobic digester is to be designed to meet U.S.EPA Class B sludge classification (U.S. EPA - 1993b). To meet the pathogen reductions of Part 503 regulations, the SRT required is 40 days at 20° C and 60 days at 15°C. Should the temperature be expected to drop below 15°C, the SRT would have to be increased. To meet the Vector Attraction Reduction requirements of Part 503 regulations, a 38% reduction in volatile solids is required. However, at the present time, the Department has not developed permitting regulations for land application of digested sludge. Therefore, it is doubtful that aerobic digestion would fulfill a useful function for disposal of sludge generated at the scale of enhanced pretreatment facilities used for an OWRS.

An aerated holding tank is usually operated in batch fashion. Batch operation involves three separate steps: sludge feeding, supernatant removal, and solids removal. An aerated holding tank can be used to thicken the waste sludge to reduce the volume of liquid sludge to be removed for ultimate disposal. The thickening process involves turning off the aeration/mixing equipment for a period of time and allowing the sludge to settle. At the end of the settling period, the liquid supernatant is decanted and returned to the enhanced pretreatment facilities. Methods for decanting the supernatant include floating decanters, telescoping valves, weir gates and multiple gated draw-off outlets arranged at several depths below the liquid surface and connected to a main manifold. Solids are removed on a periodic basis, when the volume of thickened sludge is such that relatively clear supernatant can no longer be obtained during a decant cycle.

Waste activated sludge (WAS) removed from clarifiers receiving MLSS from suspended growth bioreactors will usually consist of 1±% solids by weight. This sludge can be thickened to 2% or more in an aerated holding tank. Sludge removed from fixed film bioreactor processes may have a slightly higher percent of solids and a higher percent of volatile solids but will usually not thicken much more than WAS. While this may not appear to be a significant thickening process, thickening waste sludge from 1% solids to 2% solids results in reducing the volume of sludge to half its original volume. This will result in significant cost savings for ultimate disposal. The thickened sludge is removed from the lowest point in the holding tank via sludge withdrawal piping or directly by a septage waste pumping truck, with the latter method being adequate for small scale facilities.

The volume of the tank should be based on the average daily volume of waste sludge produced, including biological solids and chemical sludge if chemical phosphorous removal is practiced and the estimated average solids concentration in the tank. The average solids concentration should be conservatively estimated, usually not more than 2% solids by weight. Tank sidewater depth should be not less than 10 ft. to permit adequate mixing by diffused air. Additional tank wall height should be provided to accomodate any foam that may be generated and to partially shield the liquid surface from the wind if the tank surface is exposed. If at all possible, a buried tank is preferable, with adequate means to gain access to the air diffusion equipment for maintenance purposes. Provisions should also be made for foam suppression by a water spray system using the clarified effluent from the enhanced pretreatment facilities.

Aeration of the holding tank contents should be provided for both mixing and addition of sufficient oxygen to maintain the upper portion of the tank contents in an aerobic condition to prevent development of noxious odors. Submerged coarse bubble diffusers are normally used, since the varying liquid level in the tank will preclude the use of surface aeration. The diffused air requirement ranges from 20 to 30 cu. ft./min/1000 cu. ft. of tank liquid capacity. This should usually provide sufficient mixing capacity and sufficient oxygen to maintain a D.O. concentration of 1-2 mg/L in the tank liquor. However, some additional aeration capacity, up to 40 cu.ft./min./1000 cu. ft of tank capacity, should be provided as a safety factor and for re-suspending thickened solids that collect at the bottom of the tank during the supernatant decant process. The air blowers (normally rotary positive displacement type) should be designed to permit adjusting the air supply for the conditions actually encountered, to avoid excessive power costs.

K. Standby (Emergency) Power Supply

An emergency power generation system must be provided for all electrically powered enhanced wastewater pretreatment equipment where the wastewater generating facilities are served by a public or community water supply system capable of providing water to those facilities during a power outage. An emergency power supply generation system must also be provided for all enhanced pretreatment facilities incorporating biological processes where a prolonged power outage would result in the death of an aerobic biomass. The emergency generator may either be part of the enhanced pretreatment facilities or may be of the portable type, depending upon the electrical load requirements. Where portable generators are used, they should be available for immediate use upon loss of the normal electrical power supply.

Provisions for an emergency power supply should conform to the requirements of the State and local electrical codes and the requirements of the electrical utility providing the normal power supply.

L. New and Emergent Technologies

Technology development in wastewater treatment has burgeoned in the past few years, as new treatment processes and equipment suitable for enhanced pretreatment for onsite wastewater renovation systems are developed, tested and brought to market. In particular, new processes are being developed for nutrient removal, and for creating or enhancing aerobic conditions in and beneath a SWAS.

Hybrid bioreactors have been developed utilizing a combination of suspended growth and fixed film processes that permit reduction in the footprint of the reactor without sacrificing treatment efficiency. Hybrid systems that include oxidation of organics and ammonia-N and reduction of nitrates have also been developed where the reactor for each process is optimized to perform a particular function. Some early hybrid processes developed for individual residences have been improved and may be suitable for large-scale OWRS applications. Specialized, passive methods are now available for denitrification and for removal of phosphorous, using reactive media (e.g. Nitrex™, Phosphex™) without the need for adding chemicals, which only require the wastewater to flow through the media for a sufficient contact period. Facilities for using the new technology are often available as pre-manufactured units sized particularly for the onsite market. While the reactive media reputedly will last for a number of years, eventually its reactive capacity becomes exhausted and it must be replaced.

Continued research is also being conducted on the use of man-made wetlands for enhanced pretreatment of wastewater under year-round climatic conditions similar to those encountered in Connecticut. Drip irrigation systems have been developed for distribution of pretreated wastewater to the upper soil horizons that contain the most suitable soils for wastewater renovation. This method of wastewater distribution to the subsurface may be suitable provided that it can be demonstrated that freezing of the piping and drip emitters will not occur under the various cold season environmental conditions typical to Connecticut.

The engineer responsible for design of enhanced pretreatment facilities should research the recent literature in professional engineering and science journals to keep abreast of new technologies. A recent publication that provides an overview of a large number of new and emergent technologies for enhanced onsite pretreatment of wastewater is that prepared by Leverenz and Tchobanoglous (2002).

M. Beneficial Use of Reclaimed Water

The beneficial use of reclaimed water (wastewater that has received a high degree of treatment and disinfection) is not a new practice. Direct reuse of non-potable water, where there is a direct link from the treatment system to the reuse application, had its beginning in California in 1912 when the City of Bakersfield began using reclaimed water to irrigate crops and pastures. In 1918, California promulgated regulations for reclaimed water reuse, Arizona soon followed and permitted reclaimed water to be used for irrigation projects in the 1920s, and in the 1960s, Colorado and Florida began using reclaimed water in urban settings (Asano, T. – 1998).

Since those early beginnings, there has been a significant increase in the number and type of reuse projects and a considerable body of knowledge has accumulated concerning the safe use of reclaimed water.

A common misconception is that the use of reclaimed water for irrigation is only applicable in water-poor, semi-arid, or arid environments. However, as more communities are faced with increased water supply costs, watershed protection plans, water conservation plans, and public concern about water usage, reclaimed water can provide a recycling solution that is “environmentally friendly” and acceptable to the public. Such use reduces the demand upon existing water supply systems and ground water sources.

The Department may currently permit the use of reclaimed water for beneficial reuse (e.g., irrigation of vegetation, flushing of toilets and urinals). The water quality requirements for reclaimed water use are given in the Design Standards. Any use of reclaimed water will depend upon the nature of the use, and will be considered on a case-by-case basis. Enhanced pretreatment facilities utilized for producing reclaimed water should meet the requirements of the U.S. EPA for Class I Reliability Standards (U.S. EPA -1974).

Where the Department permits use of reclaimed water for any purpose, provisions must be made for discharge of the reclaimed water to the subsurface in an approved manner during times when its use for irrigation or other approved purposes is not needed.

Requirements governing the use of reclaimed water for golf course irrigation are given in the Design Standards.

N. Provisions for Monitoring and Control of Treatment Processes.

The ability to monitor and control enhanced pretreatment processes, and the equipment associated therewith, is vital to successful use of such processes. The means that should be provided for monitoring and control functions will vary with the complexity of the process. However, a common thread runs through the monitoring and control functions of all processes. The operator(s) of enhanced pretreatment processes should have instrumentation and equipment available to be able to determine:

- That the process variables are within operating limits required for process stability and efficiency,
- The operating status of all electrically and mechanically operated equipment,
- That critical liquid levels are within the normal range.

The operator(s) should also be able to easily vary operating conditions as required to maintain process stability and efficiency.

With respect to operating status of equipment and critical liquid levels, the intelligence required should be available to the operator(s) at the site of the treatment facilities and off-site at a monitoring location capable of forwarding such intelligence to plant operating personnel at all hours of the day and night.

Where packaged types of pretreatment facilities are used, most manufacturers will either provide or recommend some type of monitoring and control equipment. However, in some cases, the equipment provided or recommended is rudimentary in nature and consideration should be given to supplementary equipment.

A listing of the monitoring and control equipment that might be used is given below. The listing is not exhaustive, and new types of monitoring and control equipment are constantly being brought to market. The engineer responsible for overall design of a OWRS should review the need for the type of equipment required to monitor and control the particular process(es) employed and then review the literature and contact responsible vendors for detailed information and guidance.

a. Monitoring Equipment

- Flow measurement, indication and recording
- Liquid level detection, display and reporting
- Equipment operating status indicating lights
- Fault detection, display and reporting for all mechanically and electrically operated equipment. This includes, but is not limited to:
    - Loss of normal electrical power supply,
    - Emergency electrical power supply failure,
    - Fire alarms,
    - Equipment overloads,
    - High and low liquid levels,
    - High and low equipment and process operating temperatures, and
    - Failure of equipment to start or stop upon receipt of start/stop initiating signals.
- Alarm panels, with indicating lights actuated by relays or dry contact switches incorporated in electrical motor controls, capable of signaling local and remote alarm detection and notification facilities
- Indoor and outdoor alarm lights and horns
- Dialing alarm monitors or radio transmitters
- Modems
- Running time meters, for all electrically operated equipment
- Event recorders or cycle counters for all electrically operated equipment

b. Control Equipment

- Main electrical circuit breakers, secondary circuit breakers, and manual and automatic motor starters meeting requirements of National, State and local electric codes
- Local and remote Manual-On-Off switches and Manual-Off-Automatic switches for all electrically operated equipment
- Time clocks
- Repeat cycle timers
- Liquid level detection equipment (capable of providing a level indication signal output to operating equipment that control, or are controlled by, liquid levels)
- Programmable Logic Controller (PLC)
- Laptop and desktop computers
- Electrical surge protection for all electrically operated equipment
- pH meters
- Dissolved Oxygen meters
- Turbidimeters
- Pressure switches
- Temperature switches

O. Specifying Processes and Equipment

The engineer responsible for design of enhanced pretreatment facilities comprised of packaged treatment units should prepare specifications for procurement of such facilities. While there are many ways of writing such specifications, they should contain at least the following information and requirements:

- Description of the treatment process(es) and all plant materials, components and auxiliary devices,
- Operating Conditions (as listed in D.2 of this section),
- Submittal requirements for review and approval of all materials and equipment,
- Quality of materials and equipment,
- Special requirements for coatings and other corrosion protection provisions,
- Requirements for installation and start-up of the plant facilities, including participation of the manufacturer’s authorized representative in the installation and start-up,
- Requirements for testing for approval of installation and operation of all equipment, including participation of the manufacturer’s authorized representative and a written report by the manufacturer’s authorized representative on the results of such tests and any recommendations resulting therefrom,
- Requirements for providing operation and maintenance instructions to plant operator(s) by the manufacturer’s authorized representative,
- Requirements for operation and maintenance manuals,
- Equipment guarantees (typically: equipment to be free from defects in design, materials and workmanship for a period of at least 12 months from date of start-up),
- Process performance guarantee (Packaged treatment system guaranteed to produce an effluent quality based on information provided under Operating Conditions), and
- Requirements for spare parts, special tools and supplies.

These specifications, along with the drawings and design data, should be submitted to the Department for review. Any review by the Department, including any review comments or the lack of such comments, will not relieve the engineer, the manufacturer, the vendor, and the facilities owner(s) and their contractor(s) from their respective responsibilities for the proper design, manufacture, installation, operation and maintenance of the packaged treatment facilities.

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