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Independent Physical-Chemical (IPC) Treatment of Municipal Wastewater

Design and Operations Feedback

INDEPENDENT PHYSICAL-CHEMICAL (IPC) TREATMENT OF MUNICIPAL WASTEWATER

FEEDBACK TO DESIGN/OPERATIONS

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SUMMARY

This report presents the results of an investigation of 11 Independent Physical-Chemical (IPC) Treatment Plants, conducted as part of a nationwide advanced waste treatment (AWT) effectiveness evaluation sponsored by the U.S. Environmental Protection Agency (U.S. EPA). The results of the investigation indicated that virtually all of these plants are experiencing difficulties with one or more of their treatment processes.

IPC treatment, as the name implies, involves the utilization of only physical and chemical treatment processes (e.g., clarification, filtration, carbon adsorption, ion-exchange, etc.) for the treatment of wastewater. This document briefly outlines the problems encountered at IPC plants and provides a limited discussion of the impacts of these problems on the plant's performance.

Problems associated with chemical treatment of wastewater, specifically with lime, are related to handling and feeding of this material, and result in poor process performance that adversely affects the downstream processes. The granular activated carbon (GAC) process, commonly used in IPC plants, has been afflicted with odor and corrosion problems associated with hydrogen sulfide formation. In some instances, the process has not attained the degree of soluble organic material removal anticipated. In addition, the granular tertiary filtration process has not met design performance criteria. This latter problem has occurred due to the inability of this process to cope with inconsistent effluent quality from upstream processes, and the lack of adequate flexibility in handling varying flow and solids loadings.

Potential remedies to the problems identified by this investigation are also outlined in this document. These remedies should be applied only after an engineer experienced with the design and operation of IPC processes has thoroughly evaluated a facility to determine which solutions are practical and cost-effective.

EPA has identified 14 IPC publicly owned treatment plants (POTW's) operating in the United States (22). This report examines the performance of 11 of these 14 IPC facilities, and explores the capabilities and limitations of the IPC process. Descriptions of the unit processes, discharge requirements, and performance characteristics for each plant are included in Appendix A.

The goals of this report are to:

- Identify design deficiencies, equipment performance deficiencies, and operating problems relating to the IPC process based on information from site visits.

- Suggest methods of improvement (as related to design, equipment, and plant operations) so that they may be used as feedback to the operators of existing facilities.

Performance data for this feedback report were collected during an investigation of advanced waste treatment (AWT) technologies, as part of a U.S. Environmental Protection Agency (U.S. EPA) AWT effectiveness evaluation. Eleven of the 14 identified IPC plants in the United States were visited, and their treatment processes, performance, deficiencies, and problems documented. This information, supplemented with published data and other available information, provided the basis for this report.

1.0 INTRODUCTION

Independent Physical-Chemical (IPC) wastewater treatment systems typically include preliminary treatment (such as bar screens, comminutor, and/or grit chamber), chemical precipitation, clarification, granular media filtration, activated carbon adsorption, and effluent disinfection (chlorination). Not every IPC plant contains all of these processes; however, these are the most common components, and will usually be found in some combination.

The IPC approach gained widespread interest in the early 1970's as an alternative to conventional biological treatment processes. At that time the eutrophication of receiving waters was identified as a serious problem caused by the presence of phosphorus in synthetic detergents commonly found in domestic wastewaters. The IPC process using lime precipitation was considered one of the methods of wastewater treatment for phosphorus removal. The perceived advantages of the IPC process over biological processes are summarized as follows:

- More readily adaptable to variations in wastewater flow and composition.
- Less susceptible to upsets from industrial wastes.
- Efficient removal of heavy metals by chemical precipitation.
- Does not require treatment for stabilization of sludge. Sludge is dewatered easily and can be disposed of in landfills.
- Less space requirements.
- Removes phosphorus from the effluent, thus mitigating the eutrophication problem.

Based on the observation of several IPC plants, it appears that the plants are having problems meeting effluent discharge requirements (17) and are also faced with the high cost of disposing of large quantities of chemical sludge (11). It is evident that some of the process units in IPC plants, particularly the granular activated carbon process, are not performing as expected due to design deficiencies and improper operation and maintenance.

2.0 PROCESS DESCRIPTION

2.1 PROCESS COMPONENTS

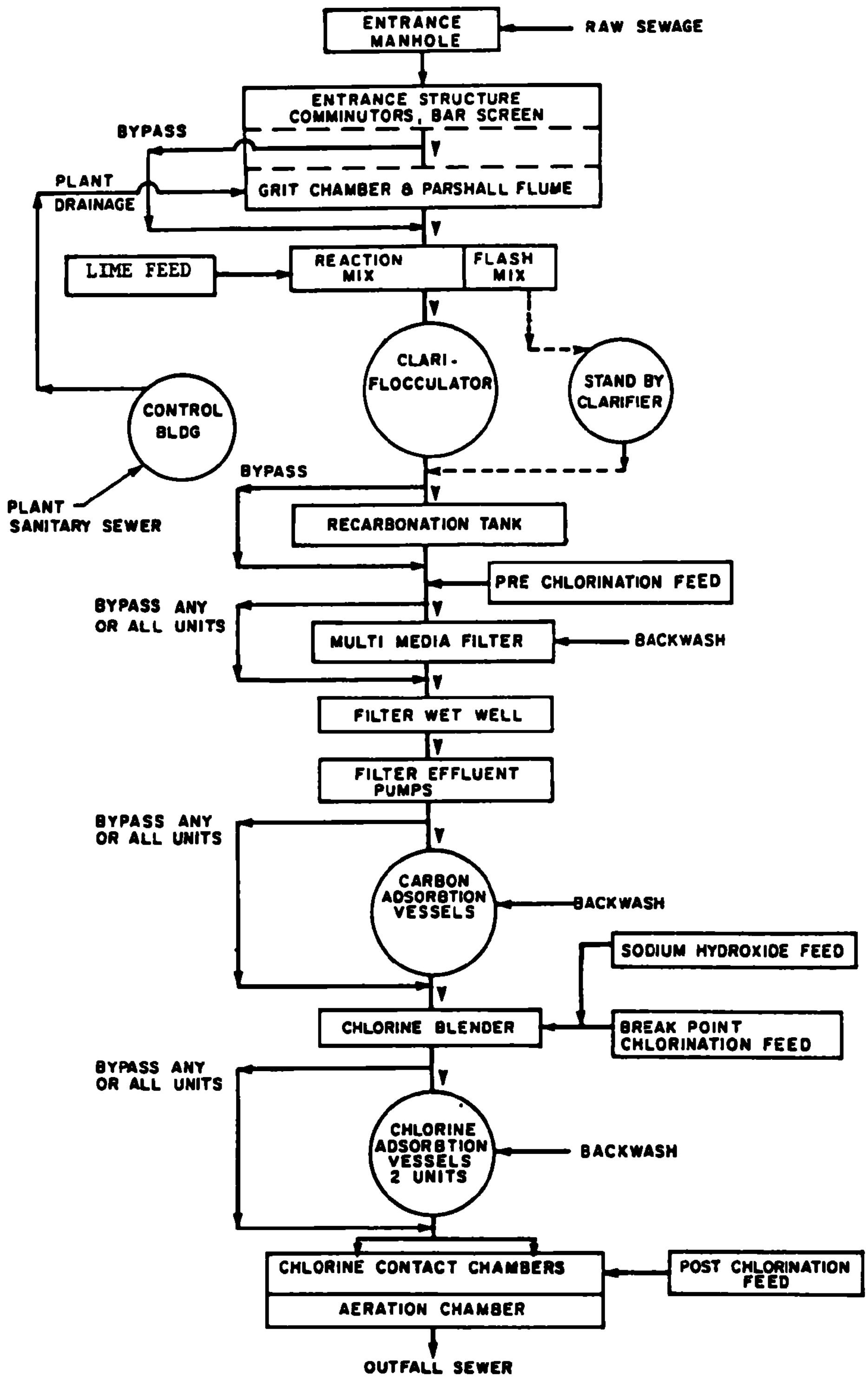
IPC treatment plants are comprised of a combination of different physical and chemical treatment processes, the selection and order of which usually depends on wastewater influent characteristics and the effluent discharge requirements. There is no standard unit process sequence for IPC plants. However, based on the information from the plants surveyed, the typical process units used in IPC plants are the following:

- Screening.
- Comminuting.
- Grit chamber.
- Chemical precipitation.
- Clarification.
- Tertiary filtration.
- Granular activated carbon with carbon regeneration.
- Chlorination.

In addition, dechlorination ion exchange and post-aeration are also used in some plants to meet the site-specific effluent requirements. The IPC treatment process relies to a great extent on chemical coagulation and sedimentation to remove suspended and colloidal solids. Filtration is commonly utilized as a process to remove the residual suspended solids in the effluent after the clarification process. The granular activated carbon system is used in place of a biological process for the removal of soluble organics. When exhausted, the carbon with its adsorbed organics is incinerated in a carbon regeneration furnace. Of the eleven plants evaluated for performance, six of the plants have filtration before carbon adsorption; three do not have any filtration systems; one plant has filtration after carbon adsorption; and one plant has filtration both before and after carbon adsorption. A typical schematic flow diagram of an IPC plant is shown in Figure 1.

2.2 PROBLEMS WITH IPC TREATMENT PLANTS

The results of the AWT effectiveness evaluation (18) indicated that there are many problems associated with the IPC treatment technology that adversely affect its performance. Table 1 presents a summary of these problems as they relate to the major



Source: Lozier Engineers, Rochester, New York

Figure 1. Typical advanced IPC system flow schematic.

Table 1

Problem Summary of Independent Physical-Chemical (IPC) Treatment Plants Visited During the AWT Effectiveness Project[1]

Unit Process Component	Total Number of Plants	Number of Plants with Problems	Percent of Plants with Problems
Lime feed system	8	5	63
Other chemical feed system	9	3	33
GAC system	11	10	91
Filtration system	6	3	50
Process linkages[2]	11	5	45

[1]Based on 11 operating IPC POTW's in the United States that were visited.

[2]Process linkages refer to the interdependence of unit processes in a treatment system.

component process units in the system. As illustrated in Table 1, almost all of the plants had problems with their granular activated carbon systems. Three major problem areas at IPC plants have been identified, as follows:

- Lime handling system.
- Granular activated carbon system (GAC).
- Tertiary filtration system.

In each of these systems, problems are identified, and the causes of the problems and the impacts of these problems on the performance of the IPC plant are discussed. Remedies are suggested for mitigating the deficiencies noted. Special consideration has been given to remedies that facilitate improvement of existing IPC treatment facilities.

3.0 PROBLEMS AND REMEDIAL MEASURES ASSOCIATED WITH THE LIME HANDLING SYSTEM

This section discusses the problems and remedial measures associated with lime handling systems. The specific components of lime handling systems discussed are the following:

- Lime loading and unloading.
- Lime storage and dry feeders.
- Lime slaking.
- Lime slurrying.
- Lime slurry transport.
- Lime slurry feed.

A summary of the problems and remedies are given in Appendix B.

3.1 LIME LOADING AND UNLOADING

3.1.1 Problems

Problems that occur while loading and unloading lime are the following:

- One of the major problems experienced with loading and unloading lime is the generation of lime dust. Manual handling of bagged lime is a source of dust in the loading/unloading area. In the case of bulk lime handling, the problem of dust is primarily attributed to the malfunctioning of baghouses installed on top of lime storage bins. If the baghouse filters are not emptied frequently, they are unable to collect the dust, thereby causing dissipation of dust in the loading/unloading area.

- Sharp elbows and bends in lime transport piping to the storage bin are subject to severe damage caused by abrasion, depending on the type of lime used (hydrated lime is generally less abrasive than quicklime).

- Maintenance and repair of lime transport piping is difficult if the piping is located at high elevations or is otherwise inaccessible.

3.1.2 Remedial Measures

Remedial actions that may be taken to alleviate these problems are the following:

- An efficient dust collection system is essential for a bulk lime storage bin. A hood and baghouse installed on the top of the storage bin should be manually checked after every loading operation to ensure that the contents of the dust collection bag are discharged back into the storage bin. Shaking the bag helps to discharge the contents easily. The bag should be replaced periodically.

- A safety valve should be provided on the top of the lime storage bin to prevent rupture of the bin in case of buildup of excessive pressure due to malfunctioning of the baghouse.

- Sharp elbows and bends in dry lime transport piping should be avoided. Piping with sweep turns of a minimum 3 to 4 foot radius is recommended to reduce mechanical wear and decrease resistance to flow. Piping should be reinforced with additional plates at bends to minimize excessive wear by abrasion. Use of materials with high abrasion resistance should be considered for bends.

- The top of the lime storage bin and transport piping should be easily accessible for maintenance purposes.

3.2 LIME STORAGE AND DRY FEEDERS

3.2.1 Problems

Problems involving lime storage and dry feeders are the following:

- In lime storage bins, the flow of lime to the feeders is interrupted by "arching" or "bridging" above the hopper opening. Sudden "flooding" of the feed hopper occurs when the arch breaks. This problem is particularly common when lime in the form of fine powder is used. Granular and pebble lime are generally free-flowing materials.

- Clogging of the feed hopper opening and feeder valve in the storage bin. This problem occurs due to the entry of moisture into the storage bin which causes the lime powder to "cake," thereby preventing free-flowing conditions.

3.2.2 Remedial Measures

Remedial measures to overcome these problems include the following:

- The lime storage bin should have a conical bottom with a 60° slope to facilitate easy flow of material into the feed hopper.

- A "live bin" system or bin vibrator at the bottom of the storage bin will prevent arching and bridging of lime above the feed hopper opening.

- A volumetric type of feeder is preferred over the gravimetric type, since the former is more reliable and easier to operate and maintain.

- A rotary valve may be installed between the feeder and lime slaker to prevent the entry of moisture into the feeder.

3.3 LIME SLAKING

3.3.1 Problems

The following problems can occur in the lime slaking operation:

- Excessive mechanical wear of grit conveyors in detention- and paste-type slakers.

- Maintaining airtight conditions in a slaking system and operating it under negative pressure is difficult. Thus, moisture from the slaker travels back to the lime storage bin causing "caking" of lime and resulting in clogging of feed hoppers.

- Probes used for indicating slurry levels in slakers malfunction due to encrustation and scaling.

- Cleaning of slakers for maintenance is a labor-intensive operation; encrustations of lime on tank walls, valves, and orifices normally have to be manually chipped, scraped, and removed from the slaker. This cleaning problem is further aggravated if some parts of the slaker are not easily accessible.

- Instrumentation panels located on or adjacent to the slaker are often covered with dust and grit. This contributes greatly to malfunctioning of lime control systems.

3.3.2 Remedial Measures

Measures to resolve these problems include the following:

- The lime slaker should be sufficiently offset from the lime storage bin and feeder to prevent the steam and moist lime vapors from the slaking operation traveling backwards to the storage bin. This measure will help to avoid the problem of "caking" of lime in the feeder and storage bin.

- Maintaining the required slaking temperature is essential for complete hydration of quicklime. The optimum slaking temperature range is 175°F to 185°F.

- Water-to-lime ratio for slaking should normally range between 3:1 and 4:1 for detention-type slakers. However, recommendations for optimum slaking conditions for the type of lime used should be obtained from the vendor supplying the slaker.

- Lime slakers should be airtight and operate under negative pressure in order to prevent moisture and dust from entering the work area or working backwards into the lime feed system or lime storage bin. Aspirators, though often used, have not always been successful in maintaining a negative pressure. It is suggested that a fan be used to draw vapors from the slaker and help maintain a negative pressure in the slaker.

- Sonic-type level sensor systems can be used to avoid encrustation problems commonly experienced with probes.

- Instrumentation panels and electrical control systems should be located away from slakers and preferably be housed separately to avoid entry of dust and moisture from the slakers.

- Slakers should be located so that they are easily accessible for maintenance.

- Spare screw conveyor parts should be stored or readily available as replacements because screw conveyors for grit removal are prone to abrasive mechanical wear.

3.4 LIME SLURRYING

3.4.1 Problems

In most treatment process applications, lime is introduced as a slurry. In the slurrying operation, slaked quicklime or hydrated lime is mixed with water and agitated in a covered tank to form a slurry of a concentration suitable for feeding (usually 5 to 10 percent by weight). Problems associated with lime slurrying operations are as follows:

- Probes used for level control in slurry tanks are coated with scale and rendered ineffective.

- Maintenance of agitator motors, level controllers, etc. in elevated slurry tanks is a problem due to poor accessibility.

- Severe abrasion of the tank can occur if fiber-reinforced plastic (FRP) tanks are used for lime slurry preparation, especially when quicklime is used; hydrated lime tends to be less abrasive.

3.4.2 Remedial Measures

Measures to alleviate problems in the lime slurrying operation include the following:

- Sonic-type slurry level sensor systems are preferable to conventional probes that become encrusted frequently.

- Lime slurry tanks should be covered to prevent splashing of slurry. For the slurrying of powdered hydrated lime, a vent with a dust collection bag is required to trap the dust generated. The bag should be located away from the point where the lime enters the slurry tank and should be checked and cleaned regularly.

- Lime slurry tanks should be constructed of corrosion-resistant metal and not of fiber-reinforced plastic (FRP) to prevent abrasion problems, particularly if quicklime is used.

- Access should be provided for the maintenance of agitators, level controllers, and other equipment in the slurry tank.

- Water used for preparing lime slurry should not contain excessive levels of carbonates, sulfates, or any other ingredients that could react with the lime to cause precipitation and scaling.

3.5 LIME SLURRY TRANSPORT

3.5.1 Problems

Transportation of lime slurry presents one of the most difficult problems in a lime handling system, as noted below:

- Scaling of pipes is a severe problem common in most lime slurry transport systems. Scaling may be due to the following:

  - Leakage of air into pipes around the pump seals or through other appurtenances. Carbon dioxide in the air reacts with lime to precipitate calcium carbonate as scale on the inner walls of pipes.

  - Settling of solids from the lime slurry during off cycles.

- Scaling and deposition of solids in sharp bends and elbows is very common in lime slurry transport lines. Right angle bends at the bottom of vertical pipes are extremely prone to the deposition of lime solids.

- Small diameter piping is reported to be one of the major causes of frequent clogging of lime slurry transport pipes in many wastewater treatment plants.

- Cleaning of scale accumulated in lime transport lines is extremely difficult and labor-intensive, particularly when long lengths of metal pipes are used without cleanouts.

3.5.2 Remedial Measures

Measures that may be employed to overcome these problems are as follows:

- Lime transport piping should be at least 1-1/2 to 2 inches in diameter to avoid frequent clogging problems.

- Flexible hoses should be used for lime slurry transport piping wherever possible. Long straight lengths can be of rigid piping. Flexible hoses have the major advantage of being easier to maintain when clogging occurs. Agitation of a flexible hose can release plugs caused by an air lock or solids deposition in a lime transport line. Scale accumulated on the inner walls of a flexible lime transport pipe can be removed by flexing the hose, which is not possible with rigid pipe. Flexible hoses are also easier to replace than rigid pipes. Transparent/translucent type flexible hoses help to locate plugs in the line faster. However, flexible hoses require more supports than rigid piping.

- Lime transport lines should be installed with minimum bends. Sharp elbows and vertical runs should be avoided. "Cleanouts" should be provided in lime slurry transport lines as often as possible, particularly at the bottom of vertical runs to facilitate cleaning of lime deposits.

- Periodic cleaning of lime slurry pipelines using devices called "pigs" would help to maintain a clean slurry transport system. "Pigs" are plastic-rubber products with abrasives spirally embedded in the surface. It is moved by water pressure through the pipe and removes the scale by a scouring or augering action.

- It is recommended that lime transport lines be operated continuously. Deposition of solids and scaling occur when the line is out of service for only a few hours. A recycling loop is one of the methods used successfully to maintain continuous operation of a lime transport system during off cycles.

- Provision for flushing lime slurry transport lines is essential to prevent excessive build-up of scale in pipes, valves, and other parts of the conveying system. If the lime transport system does not have a recirculating loop, automatic devices should be installed to flush the line with water immediately after each operational cycle. If a loop system is not used, provision should be made to manually flush the loop with water after each lime feed operation. Periodic flushing of the lines with corrosion inhibited dilute hydrochloric acid to clean the residual scale is desirable to maintain a trouble-free lime transport system.

3.6 LIME SLURRY FEED

3.6.1 Problems

The controlled addition of lime slurry to a treatment process is generally carried out using feed pumps and control valves. Problems experienced with lime slurry feed systems are as follows:

- Scaling and clogging of pumps and metering valves. Clogging is particularly common when the feed system is used intermittently.

- In pH-controlled lime slurry feed systems, encrustation of the pH probe (with lime solids and calcium carbonate scales) results in erroneous pH readings and thus improper dosage of lime to the process.

- Progressive cavity-type metering pumps have high maintenance requirements due to stator wear.

- Slurry feed metering valves with variable flow rate control are easily clogged due to lime deposits in the constricted areas of the valves.

3.6.2 Remedial Measures

Measures to alleviate problems in the lime slurry feed system are as follows:

- Take-off points for lime slurry feed should be located on the vertical portion of transport loops and as close as possible to the point of application. Provision should be made for backflushing the take-off assembly for cleaning purposes.

- Feed control valves should be operated in a fully opened or fully-closed mode. Pinch valves are preferable for this operation. Constricted valve openings tend to clog due to scaling and deposition with lime solids.

- The problem of malfunctioning pH probes due to scaling can be solved by alternate use of two pH probes. One probe can be cleaned and calibrated while the other is being used. pH probes are to be cleaned frequently with dilute acid and rinsed with water.

- Diaphragm-type metering pumps provide better control of feed than progressive cavity or other types of pumps, and are less expensive to maintain.

- Rotary cup-type feeder or similar slurry feed systems are preferable, wherever possible, over chemical feed pumps because the latter are susceptible to clogging problems.

4.0 PROBLEMS AND REMEDIAL MEASURES ASSOCIATED WITH THE TERTIARY FILTRATION SYSTEM

This section discusses the problems and remedial measures associated with the tertiary filtration system in an IPC wastewater treatment plant. The filtration system is divided into two operations, namely, the filtration cycle and the backwash cycle, in order to separately address the problems and remedies for each operation. A summary of the problems and remedies is given in Appendix C.

4.1 FILTRATION CYCLE

4.1.1 Problems

Problems that occur during the filtration cycle are as follows:

- Media clogging is a widespread filtration problem that results in increased head loss through the bed and thus decreases the length of the filter run. Media clogging can result from the following:
  - Microbial growth in the filter bed.
  - Solids carryover from prior treatment processes, especially when process upsets occur.
  - Oil and grease carryover from prior treatment processes.
  - Precipitation of calcium carbonate, calcium sulfate, calcium hydroxide, etc. on the filter bed due to malfunctioning of a prior unit treatment process.
- Hydraulic surges in influent flow to filters caused by a lack of flow equalization facilities result in operating difficulties and poor effluent quality.
- Uneven spacing of wash water troughs on the filter bed creates differential velocity gradients, causing carryover of sand media during backwashing.
- Improper design of the filter underdrain system causes migration of filter media to the underdrains and clogging of backwash nozzles.

- Many operators have little or no training in the operation of filtration systems. This lack of knowledge and training can cause ineffective filtration and inhibit operators from making the alterations necessary to improve filtration operations. This inflexibility can compound problems during periods of process upsets.

4.1.2 Remedial Measures

Measures that may be employed to alleviate these problems are as follows:

- The problem of frequent clogging of media and buildup of head loss can be reduced by considering the following measures:

  - Judicious selection of the type of filter media. Multimedia filters normally perform better than conventional single media sand filters in tertiary wastewater applications.

  - Applying a disinfectant, usually chlorine, to the filter influent to control microbial growth in the filter bed. The disinfectant should be applied on a periodic basis or whenever microbial growth is detected.

  - The treatment processes ahead of the filter should be designed to provide better removal of suspended solids. Removal of high concentrations of carry-over solids by filtration systems is not cost effective. The preceding treatment process should also remove oil and grease prior to the filtration system. Once coated on the filter media, oil and grease cannot be removed by normal backwash methods.

- The problem of poor effluent quality due to hydraulic surges in the influent to the filter can be mitigated by incorporating the following measures:

  - Influent flow to filters should be recorded and an automatic controller should be provided to ensure an even flow distribution among filters. In cases where flow exceeds the design hydraulic capacity of the filters, diverting the additional flow to a surge tank should be considered in the design of the system.

- Designing the filter system with the option to operate filters in a parallel or series mode. In case of increased suspended solids loading to the filter due to sudden process upsets, series operation could help to meet the requirements for effluent quality. However, additional filters would have to be provided to enable operating filters in series.

- Wash water troughs should be spaced uniformly over the filter bed. Leveling of the troughs is critical to filter operation and troughs should be checked and adjusted regularly.

- Clogging of backwashing nozzles due to media migration can be minimized by utilizing nozzles fitted with a protective plate on top.

- All operator(s) who work with the filtration process must be familiar with filtration technology and the operation of their system. Full knowledge of the system will permit the operator to make operational modifications necessary to improve the performance of the system. This technical skill will be especially helpful during periods of upsets in preceding treatment processes. The operator(s) must be able to assess the situation, modify the filtration system operating protocol, and, if necessary, decide when and what part of the flow should bypass the filtration system.

4.2 BACKWASH CYCLE

4.2.1 Problems

Problems associated with the backwash cycle are the following:

- Backwash systems designed to operate on the basis of a single criterion, either a fixed time interval or a predetermined head loss, sometimes result in improper frequency of backwash. For example, the backwash cycle may not be initiated until the preset time interval although the filter may require backwashing due to high head loss that may have built up.

- If the backwash rate and/or duration is not sufficient, the bed will not be thoroughly cleaned. Conversely, too high a backwash rate because of an incorrect setting on a backwash system with no rate-limiting control can result in media loss, gravel mounding, or gravel displacement.

- Incorrect operation of the auxiliary backwashing systems, such as surface-water wash, air scour, or subsurface agitation, can cause the following problems:

  - Incomplete backwashing resulting in reduced filter run times. This problem could occur if the auxiliary backwash system is not operative during the initial fluidization stage of backwashing, thus causing insufficient removal of foreign material from the bed.

  - Loss of filter media. If the auxiliary air scour is operated during the second stage of backwashing when the wash water is flowing into the troughs, the filter media would be carried over with the wash water.

- Upstream process upsets can occur because of excessive hydraulic loading on treatment units that receive backwash wastewater from tertiary filters.

- Improper selection of the material of construction for backwash nozzles results in corrosion and dislodging from their support structures causing inadequate backwashing.

4.2.2 Remedial Measures

Measures that may be taken to alleviate these problems include the following:

- Backwash frequency should be controlled on the basis of both head loss and a fixed time interval, whichever is needed first. Effluent quality should be monitored and a provision for manual override for backwashing should be available to overcome upset conditions in the filter operation.

- Maintaining the correct operational sequencing is important for effective backwashing. The operator(s) should observe the filter instrumentation during each backwashing cycle to ensure that the correct operational sequence occurs. At a minimum, a monthly visual check should be made of each filter cell for a complete backwash cycle to ascertain that all systems are operating correctly.

- The correct rate and duration of backwashing are essential for good filter system operation. The operator(s) should frequently check all of the settings of the rate and timer controls to ensure that they are appropriate. The controls and instrumentation should be recalibrated as required to ensure that the system is functioning properly. The operator(s) should adjust the rate of the backwash flow to compensate for the change in water viscosity because of changing temperatures. The rate should be decreased during the cooler part of the year and increased during periods of warmer weather so that a comparable degree of bed expansion is achieved throughout the year during backwash.

- Timer systems used for controlling the duration of backwash should be adjustable for the total duration as well as the duration of high and low rate cycles in backwashing. This design feature builds an additional flexibility into the operation of the filter, which is often very helpful in mitigating problems.

- An interlock control system is recommended to ensure that the designed maximum number of filters to be backwashed at any given time is not exceeded.

- It is recommended that backwash wastewater be collected in a surge tank and recycled to other process units at a controlled rate. This will help to minimize problems created by significant hydraulic surges due to discharge of backwash wastewater from the tertiary filters.

- Materials of construction used for backwash nozzles, underdrains and their support structure, and the filter walls must be compatible with each other to avoid corrosion problems caused by galvanic action and electrolysis. Backwash nozzles should be securely mounted on the supporting structure.

5.0 PROBLEMS AND REMEDIAL MEASURES ASSOCIATED WITH THE GRANULAR ACTIVATED CARBON SYSTEM

IPC treatment plants were designed and built to provide a secondary or higher level of treatment of wastewaters without the use of biological treatment processes. Secondary treatment typically required not less than 85 percent removal of BOD_5 and total suspended solids (TSS) and monthly average effluent BOD_5 and TSS concentrations not to exceed 30 and 30 mg/L, respectively (2). GAC systems were intended to provide sufficient soluble BOD removal to meet these secondary treatment requirements. Some engineers and researchers have expressed doubt over the ability of GAC systems to remove sufficient soluble BOD to meet these secondary effluent requirements, and the more stringent advanced effluent requirements that some IPC treatment plants must meet (6).

Appendix A provides a summary of the effluent BOD and SS requirements and treatment plant performance of the IPC plants visited. An evaluation of the information given in Appendix A is presented in Table 2. It should be noted that out of the eleven IPC plants visited, five plants had taken the GAC unit off-line. In order to make a realistic assessment of the performance of the IPC plants, this evaluation is based on the information from the six fully operational plants. Based on Table 2, the following observations on the performance of IPC plants are made:

- Only 33 percent of the plants met all BOD and SS requirements.
- 80 percent of the plants met the BOD concentration requirements, but only 33 percent could meet the percent removal criterion for BOD.
- 80 percent of the plants met the SS concentration requirements, and 83 percent met the percent removal criterion for SS.

It was observed that only two out of the four plants designed for secondary treatment met the effluent requirements. The two plants designed for tertiary effluent requirements did not meet the effluent standards.

It is evident that a large fraction of the plants are unable to meet the percent removal criterion for BOD although most meet the effluent concentration limits. One possible explanation for

Table 2

Summary of IPC Facility Performance[1]

Effluent Requirement	Total Number of Plants with Requirement	Number of Plants Not Meeting Requirement	Percent of Plants Not Meeting Requirement
All BOD_5 and SS effluent requirements	6	4	67
BOD_5 limit	5	1	20
Percent BOD_5 removal requirement	6	4	67
Suspended solids limit	5	1	20
Percent SS removal requirement	6	1	17

[1]Based on operating data from six fully operational IPC facilities; five of the 11 plants visited had taken their GAC units off-line.

the failure to meet the percent removal criterion could relate to influent strength. A weak influent (BOD and SS <160 mg/L) makes it more difficult to achieve a given percent removal criterion since relatively lower absolute effluent concentrations must be produced. Of the plants that failed to meet the percent removal criterion, all but one had influent BOD concentrations of 160 mg/L or less.

Although 80 percent of the fully operational plants satisfied effluent BOD concentration requirements, two facts must be noted. First, all of the plants meeting this criterion were operating well below design flow capacity. Secondly, in all but one case, the influent strength was relatively weak (BOD and SS <160 mg/L). It is impossible to project performance for full strength, design flow conditions given the available operating data.

Although the evaluation just discussed considers performance data only from the six fully operational plants, the reasons for the other five plants not being fully operational must also be considered. The GAC units in these plants had severe problems and had to be taken out of service. Some of these problems related to operational difficulties (e.g., plugging of the carbon bed, odor generation, corrosion of contactors, excessive costs due to frequent regeneration of the carbon, etc.). In other cases, the GAC unit simply could not achieve the treatment levels required, and the expense of keeping the unit on-line could not be justified. In all five cases the GAC unit, which is primarily responsible for soluble BOD removal, did not function as intended. This raises a question as to the capability of the GAC process to meet the appropriate effluent requirements for BOD removal.

The following discussion of problems and suggested remedial measures for GAC systems has been subdivided according to the different components of a typical GAC system. A specific section is included on the carbon adsorption process itself. The effectiveness, or ineffectiveness, of the carbon adsorption process in removing soluble organics is a key issue. The process components discussed include the following:

- Adsorption process.
- Carbon contactor.
- Backwash system.
- Carbon regeneration system.
- Instrumentation and control system.

Appendix D includes a summary of problems and suggested remedies for the different components of the GAC system.

5.1 ADSORPTION PROCESS

5.1.1 Problems

The major operational process problem with the GAC system is the inadequate removal of soluble BOD_5 in the treated effluent. This single problem significantly affects the overall performance of IPC plants and is considered a major deficiency of the IPC process. The following discussion focuses on the carbon adsorption process itself and its ability to remove soluble BOD.

According to theory, activated carbon removes soluble organics from solution in three steps. The first step is the transport of the solute through a surface film to the interior of the carbon. The next step is the diffusion of the solute within the pores of the activated carbon. The third step is the adsorption of the solute on the interior surfaces bounding the pore and capillary spaces of the activated carbon. Several factors can affect the effectiveness of soluble organic matter adsorption by activated carbon. These factors include the following (21, 22):

- The characteristics of the material to be adsorbed including molecular weight, molecular size, and polarity. Activated carbon is not effective for the removal of low molecular weight soluble organic compounds. A wastewater with a high percentage of these compounds is a poor candidate for activated carbon treatment.

- The nature of the carbon itself (adsorptive capacity, regeneration characteristics, structural properties, and physical condition). All activated carbons do not have the same properties; these properties vary depending on the type of carbon. Utilizing an inappropriate activated carbon can significantly reduce GAC system performance.

- Wastewater characteristics such as temperature and pH.

- Performance of prior treatment processes and the BOD and suspended solids loadings to the GAC system.

- Biological activity within a GAC system may significantly enhance the removal of soluble organics and nonadsorbable (e.g., nonpolar and low molecular weight) compounds, but can also cause physical fouling and reduction in active surface of the carbon bed. The most prevalent explanation is that adsorption causes increased biological removal through a substrate concentration effect on the reaction rate (1, 8). This biological activity has been postulated as the mechanism responsible for the constant, long-term removals observed in activated carbon systems (8, 16). However, some researchers have hypothesized that slow mass transfer into micropore regions accounts for the constant removal of organic substances over extended time periods (10, 13, 14, 15). At this time, it is not possible to conclude which mechanism is responsible for the constant, long-term soluble organic removals. It is important to recognize that this mechanism, although not well understood, has the potential to enhance BOD_5 removal in IPC systems(4).

5.1.2 Remedial Measures

Remedial measures to improve the efficiency of the GAC system for soluble BOD removal are discussed in this section.

- Plant modifications to improve BOD removal include the following:

  - Possible changes to the chemical precipitation and clarification systems including improvements to upgrade the current system and switching from lime to a different chemical that may prove more effective.

  - Revising the order of the treatment processes to decrease the pollutant loading to the GAC system, such as placing the filtration system ahead of the carbon contactors, may improve the BOD removal performance of the GAC system, thus enabling the plant to meet its BOD discharge objective.

- Chemical additions to enhance soluble BOD removal (3, 4, 5). Peroxide, oxygen, ozone, or sodium nitrate can potentially improve carbon system performance by controlling microbial growth in GAC systems. The control of microbial growth includes both the enhancement and elimination of microbial activity. Anaerobic microorganisms, when established in a carbon contactor, can cause the generation of hydrogen sulfides. Addition of sodium nitrate has been very effective in preventing microbial reduction of sulfates to hydrogen sulfides under anaerobic conditions (4). Aerobic microbial growth can have either a positive or negative effect on the GAC system effluent. Aerobic microbial activity can lead to the biological assimilation of organics by microorganisms in the contactor and prevent sulfide formation. This biological assimilation can help to reduce the BOD_5 in the GAC system effluent. However, aerobic microbial growth can interfere with adsorption capability of the carbon bed and increase backwash and/or regeneration requirements.

  An aerobic condition can be created in the carbon contactor by adding air, oxygen, etc. to the carbon system influent which, in turn, can ensure the growth of aerobic microorganisms in the contactors (3, 5). Chemicals have also been added to decrease the wastewater pH to slightly below neutral levels to increase the adsorptive characteristics of the activated carbon (21).

- The carbon should be regenerated at required intervals to ensure a fresh, readily adsorbing carbon. It is important that any carbon lost during regeneration be replaced. The type of activated carbon installed with the system should also be studied. Carbon structural properties, performance, and cost are not necessarily related. Sometimes a structurally sound and inexpensive carbon is selected at the sacrifice of performance. The plant operators may have to change the specific activated carbon type, at possibly greater cost, to meet effluent requirements.

- Pretreatment of selected wastewater sources for the removal or alteration of nonadsorbable compounds. This procedure may require an industrial or combined wastewater testing program to:

  - Determine by isotherm testing if activated carbon can still effectively treat the wastewater as originally designed, and to determine if the nonadsorbable compounds are entering the treatment plant.

  - Determine by gas chromatography/mass spectrometry testing which compound(s) are not adsorbed by the activated carbon system.

  - Determine industrial source(s) of nonadsorbable compound(s).

  - Develop a treatment or pretreatment program to remove or alter the nonadsorbable compound(s). Appropriate regulations must be available or enacted to enforce the pretreatment program.

5.2 CARBON CONTACTOR

5.2.1 Problems

The following problems are associated with the carbon contactor:

- Corrosion of carbon contactors has been observed in a number of POTW's. Dry carbon is not corrosive. However, partially dewatered carbon is extremely corrosive. Under conditions of continuous exposure, it may produce pitting in unprotected mild steel plate by electrolytic corrosion at a rate as high as 250 mils per year.

Corrosion can also be caused by hydrogen sulfide. Hydrogen sulfide gas develops when sulfates present in the influent wastewater are biochemically reduced by sulfate-reducing bacteria. Conditions promoting or accelerating hydrogen sulfide production in GAC contactors include (17, 21):

- Anaerobic conditions, i.e., the absence of oxygen in the GAC system influent.
- High concentrations of BOD and sulfates in the GAC system influent.
- Long detention times.

● Media clogging occurs in GAC systems in the IPC plants. It is primarily caused by development of microbial growth in the carbon bed. Media clogging increases the head loss through the carbon bed and thus decreases the length of the operating cycle. Some clogging problems are the result of backwashing deficiencies, including:

  - Lack of backwashing facilities.
  - Design of an ineffective backwash system (no auxiliary wash or scour systems provided).
  - Backwash rate and/or duration are not sufficient to thoroughly clean the bed.

5.2.2 Remedial Measures

Measures that may be employed to alleviate problems associated with the carbon contactor are as follows:

● Carbon contactors, when constructed of mild steel, should be covered with protective coatings of sufficient thickness, such as coal-tar epoxy paint. The contactor surface should be prepared prior to applying any coating, to ensure that the coating will adhere to the contactor surface. This preparation should include repairing any defects found on the contactor surface, cleaning the contactor interior, and surface preparation appropriate for the coating to be applied. Dewatering bins, wash tanks, and quench tanks should also receive a protective coating. Fiberglass tankage may also be acceptable from a design standpoint.

- Potential remedies for controlling hydrogen sulfide generation can be made by either chemical additions or operating modifications. Chemical additions have been used with limited success to control anaerobic microbial growth, which is the principal cause of hydrogen sulfide generation. A better approach is to maintain aerobic conditions in the column, thus limiting the growth of hydrogen sulfide-producing bacteria (because they require anaerobic conditions to grow).

- Operating modifications can also be used to control hydrogen sulfide production in GAC systems, such as:

  - Increase the frequency of backwash, as needed.

  - Backwash GAC columns more thoroughly by use of surface wash, if available. The plant should consider installing this equipment if not already in place.

  - Reduce the GAC system detention time by removing certain carbon contactors from service if the detention time is too long.

  - Preaerate the influent wastewater to the GAC system utilizing a mechanical system.

  - Addition of sodium nitrate ($NaNO_3$) to the influent of the GAC system.

  These measures will aid in maintaining aerobic conditions in the GAC contactor, which, in turn, will decrease hydrogen sulfide generation (4, 21, 22).

  Media clogging can be limited by the proper operation of the backwash system. Processing the correct rate and duration of backwashing is mandatory for good GAC system operation. Considerations should be given to modifying the system to include an auxiliary wash system if none is provided. Microbial growth can be controlled by applying the above methods for hydrogen sulfide control.

5.3 CARBON TRANSPORT SYSTEM

5.3.1 Problems

Problems that occur in the carbon transport system are as follows:

- Clogging of the carbon transport system pipes occurs with GAC systems at many plants. The causes of this problem are primarily design related and include the following:

  - Undersizing of carbon slurry lines.

  - Poor carbon transport system design, i.e., use of short radius and 90° elbows or insufficient fluid velocity.

  - Lack of cleanouts in the carbon transport system.

- Clogging of the carbon slurry pumps used in GAC systems. The use of the wrong type of pump and/or small diameter influent and effluent piping causes pump clogging problems.

- Abrasion wear of carbon slurry pipes. The use of unlined mild steel pipe and short radius, right angle bends in the slurry transport system result in excessive wear.

5.3.2 Remedial Measures

Measures that may be taken to alleviate these problems are as follows:

- Coated cast iron steel pipe or glass-lined or rubber-lined steel pipe are preferred for carbon transport systems. Mild steel or FRP pipe should never be utilized as a carbon transport pipe. Abrasion is greatest at bends. Long radius fittings at changes in direction of flow, along with extra heavy elbows and tees are recommended. Rubber or ceramic-lined impellers are also recommended for carbon slurry pumps (21).

- Several improvements can be made to alleviate clogging of the carbon transport pipes. Increasing the transport line size (a minimum pipe diameter of 2 inches is recommended) and decreasing the carbon-to-water slurry ratio can help to prevent clogging in carbon slurry pipelines.

5.4 BACKWASH SYSTEM

5.4.1 Problems

Clogging of the backwash and/or surface wash nozzles is a problem in the carbon contactor. Carbon media and/or solids that leave the contactor are responsible for clogging nozzles and wash mechanisms. The carbon migrates to the contactor underdrains due to structural failures in the media support system, where it is picked up by the incoming backwash water and causes clogging of the distribution nozzles.

5.4.2 Remedial Measures

Preventing carbon loss can remedy the clogging of backwash and/or surface wash nozzles that is caused by solids and media migration through the underdrain and into the backwash system. Screens can be added to critical locations to prevent media and solids migration. Cleanouts should be placed in order to permit the screens to be cleaned. Frequent backwashing (especially after loading the carbon) will remove carbon fines from the bed and decrease carbon clogs. These preventative measures should also decrease carbon losses within a GAC system, thus reducing operating costs.

5.5 REGENERATION SYSTEM

5.5.1 Problems

The regeneration system is a source of carbon loss during operation. Some carbon loss is expected during regeneration operations, but incorrect furnace operating conditions can result in excessive carbon loss.

5.5.2 Remedial Measures

Preventing excess furnace operating temperatures, timely removal of the regenerated carbon from the furnace, and proper handling of the regenerated carbon can keep carbon loss during regeneration to a minimum.

5.6 INSTRUMENTATION AND CONTROL SYSTEM

5.6.1 Problems

Maintenance operations at many treatment plants are not adequate to keep the system functioning properly. Insufficient maintenance can result in nonfunctioning or ineffective instrumentation systems, inoperable valves, pumps that do not work, etc. These systems can impact on operations and cause the system to discharge a poor quality effluent.

5.6.2 Remedial Measures

An adequate maintenance program should be established to ensure that the instrumentation and control systems function properly. It is especially important that these systems function properly. These systems allow the plant operator(s) to control and monitor the GAC process.

6.0 SUMMARY OF FINDINGS AND CONCLUSIONS

Based on the previous discussion, the following conclusions on the overall performance of IPC treatment systems may be made:

- The performance evaluation of IPC plants indicates that most of the plants have numerous operational problems with various process units. Chemical feed systems, particularly lime handling systems, have been especially difficult to operate and maintain. The operation and maintenance costs of the IPC plants have been very high due to the high costs of chemicals, and excessive maintenance requirements. The survey showed that 6 out of the eleven IPC plants evaluated had decommissioned one or more of their process units due to severe operational problems or excessively high costs of operation.

- From the standpoint of effluent quality, only two out of the six fully operational IPC plants meet their specified effluent discharge limitations. Both of these plants were designed for secondary treatment levels. The two operational plants designed for tertiary treatment levels did not meet the discharge standards. Many IPC plants have problems attaining percent removal requirements, while meeting the effluent concentration requirements for BOD_5 and SS. This may be attributed to weak influent strength (BOD_5 of 160 mg/L or less), which was observed at most plants visited.

- One possible explanation for the lower than expected BOD removals in many IPC plants appears to be because carbon adsorption may not be effective for removal of low molecular weight soluble organics which exist in domestic, as well as industrial wastewaters. Air or oxygen-containing compounds may be fed to the carbon adsorbers to enhance aerobic biological activity and consequent removal of low molecular weight biodegradable organic material. However, increased levels of biological growth within the carbon bed can also require more frequent carbon regeneration requirements.

- The operation of IPC plants requires qualified operating personnel trained specifically for dealing with physical-chemical processes. This type of training is significantly different from the training and experience commonly received from operating biological treatment processes. This deficiency has been observed in several of the IPC plants visited.

- It is recommended that the performance of IPC plants should be evaluated by an engineer experienced in physical/chemical treatment technology, and appropriate remedial measures taken accordingly.

The following conclusions and recommendations are made for the design and operation of specific unit processes in the IPC plants:

- Frequent backwashing and maintaining aerobic conditions in GAC contactors can minimize the hydrogen sulfide generation problem.

- Lime handling systems are prone to problems of equipment malfunction and, in general, require frequent maintenance and operator attention due to the inherent nature of the chemical and its limited solubility in water. Lime slurry transport and feed systems are the major problem areas in the lime handling system. Scaling and clogging of pipes is a chronic problem in the lime handling system. Problems of lime slurry transport systems could be minimized by the following:

    - Maintaining continuous operation of the system utilizing recirculation loops.

    - Using flexible hoses.

    - Periodically flushing the lines with water.

- Providing a minimum number of bends.
- Using piping at least 2 inches in diameter.

- The design of a filtration system in IPC applications should be based on the consideration that wastewater filters require provisions for flexibility in operation to handle process upsets and meet effluent discharge criteria.

- The filtration system, if used at an IPC plant, should be placed prior to the GAC system to decrease the pollutant loading to the GAC system.

- Incorrect backwashing protocol can cause media clogging, media loss, gravel mounding and displacement, and mudball formation in the tertiary filtration system. In order to ensure that the filter is backwashed at the appropriate time intervals, the frequency of backwashing should be controlled on the basis of both head loss and a fixed time interval, whichever occurs earlier. Settings of the rate and timer controls for backwashing should be checked regularly for correctness.

In the course of this study many design-, operational-, and equipment-related problems have been observed at independent physical-chemical treatment facilities. Implementation of the remedial measures recommended in this report should significantly improve the performance and operational reliability of these facilities. However, there is some question concerning the ability of IPC processes (specifically, the granular activated carbon process) to remove low molecular weight soluble organics to the extent necessary to achieve advanced treatment design criteria. It is recommended that this question be addressed in further studies (i.e., pilot-scale studies and field studies).

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APPENDIX A

UNIT PROCESSES AND TREATMENT PERFORMANCE OF IPC PLANTS

Unit Processes and Treatment Performance of IPC Plants

Treatment Plant	Present/ Design Flow (mgd)	Unit Process in Treatment Order	Parameter	Influent (mg/L)	Effluent (mg/L)	Permit Limit (mg/L)	Compliance with Effluent Requirements: Concentration	Compliance with Effluent Requirements: Percent Removal[2]
1[1]	10/12.5	Preliminary treatment Chemical (lime) precipitation Recarbonation-clarification (upflow) Activated carbon adsorption Chlorination Dual-media filtration	BOD_5 SS	211 263	50 30	30 30	No Yes	No Yes
2[1]	10.0/15.3	Preliminary treatment (municipal flow) Chlorination (municipal flow) Primary sedimentation (municipal flow) Chemical (lime, alum, and polymer) precipitation-clarification (industrial and municipal flows) Activated carbon adsorption (industrial and municipal flows - downflow) Post-aeration (industrial and municipal flows)	BOD_5 SS	135 450	40 20	8 8	No No	No Yes
3	3.75/6.0	Preliminary treatment Chemical (ferric chloride and polymer) precipitation-clarification Horizontal pressure filtration First stage activated carbon adsorption (upflow) Breakpoint chlorination Dechlorination (second stage activated carbon adsorption upflow) pH adjustment	BOD_5 SS	160 220	18 10	10 20	No Yes	No Yes

[1]Activated carbon system not utilized.
[2]All plants are assumed to have a requirement to meet a minimum of 85 percent removal of BOD_5 and SS unless specified otherwise.

Unit Processes and Treatment Performance of IPC Plants (continued)

Treatment Plant	Present/ Design Flow (mgd)	Unit Process in Treatment Order	Parameter	Influent (mg/L)	Effluent (mg/L)	Permit Limit (mg/L)	Compliance with Effluent Requirements: Concentration	Compliance with Effluent Requirements: Percent Removal[2]
4	0.31/0.60	Preliminary treatment	BOD_5	168	16	25	Yes	Yes
		Chemical (lime and ferric chloride)	SS	239	2	30	Yes	Yes
		precipitation-clarification						
		Dual-media filtration						
		Activated carbon adsorption (downflow)						
		Dual-media filtration						
		Ion exchange columns						
		Chlorination						
5	0.05/0.05	Hydrosieve						
		Chemical ($FeCl_3$ and polymer)	BOD_5	216	20	95 percent	---	No
		precipitation-clarification	SS	346	13	95 percent	---	Yes
		Activated carbon adsorption (upflow)						
		Chlorination						
6[1]	6.5/10.0	Preliminary treatment	BOD_5	131	70	30	No	No
		Chemical (alum, $FeCl_3$, and polymer)	SS	160	21	30	Yes	Yes
		precipitation-clarification						
		Microstraining						
		Activated carbon adsorption (downflow)						
		Breakpoint chlorination						
		Dechlorination						
		Post-aeration						
7[1]	0.5/1.0	Preliminary treatment	BOD_5	250	75	10	No	No
		Chemical precipitation-clarification	SS	200	30	10	No	Yes
		Multimedia filtration						
		Activated carbon adsorption (downflow)						
		Breakpoint chlorination						
		Dechlorination						
		Post-aeration						
8	8.1/13.0	Preliminary treatment	BOD_5	155	30	30	Yes	No
		Chemical (alum, $FeCl_3$, and polymer)	SS	130	20	30	Yes	Yes
		precipitation-clarification						
		Sand filtration						
		Activated carbon adsorption (upflow)						
		Chlorination						

[1] Activated carbon system not utilized.
[2] All plants are assumed to have a requirement to meet a minimum of 85 percent removal of BOD_5 and SS unless specified otherwise.

Unit Processes and Treatment Performance of IPC Plants (continued)

Treatment Plant	Present/ Design Flow (mgd)	Unit Process in Treatment Order	Parameter	Influent (mg/L)	Effluent (mg/L)	Permit Limit (mg/L)	Compliance with Effluent Requirements: Concentration	Compliance with Effluent Requirements: Percent Removal[2]
9	0.35/0.5	Preliminary treatment Chemical ($FeCl_3$ and lime) precipitation-clarification Activated carbon adsorption (downflow) Chlorination	BOD_5 SS	120 150	25 75	30 30	Yes No	No No
10	0.5/2.0	Preliminary treatment Chemical ($FeCl_3$ and polymer) precipitation-clarification Granular media filtration Activated carbon adsorption (upflow) Chlorination	BOD_5 SS	137 145	11 7	30 30	Yes Yes	Yes Yes
11[1]	11.0/16.0	Preliminary treatment Chemical ($FeCl_3$) precipitation-clarification Activated carbon adsorption (downflow) Chlorination	BOD_5 SS	130 121	52 33	20 20	No No	No No

[1]Activated carbon system not utilized.

[2]All plants are assumed to have a requirement to meet a minimum of 85 percent removal of BOD_5 and SS unless specified otherwise.

12 Westerly WWTP (Cleveland) 35.0/50.0 Prelim
Chem (2-stage lime & polymer) precip-clarif
Pressure filtration
Activated Carbon adsorption (downflow)
Ozone Disinfection

	Eff	Permit
BOD		
SS		

APPENDIX B

LIME HANDLING SYSTEMS: IDENTIFIED PROBLEMS AND SUGGESTED REMEDIAL MEASURES

Lime Handling System: Identified Problems and Suggested Remedial Measures

Identified Problem	Suggested Remedial Measures
Lime Loading and Unloading	
Dust.	Install and maintain a dust collection baghouse system on lime storage silo/bin.
Mechanical wear of transport piping.	Avoid sharp elbows and bends in piping. Install additional plates at bends for reinforcement.
Delay in repair and maintenance of lime transport piping.	Install ladders, catwalks, and platforms for quick access during maintenance work.
Lime Storage and Dry Feeders	
Arching over hopper openings.	Install vibrating hoppers or "live bin" systems.
Clogging of feed hopper, valves, and screw feeders.	Prevent entry of moisture into feeder by installing rotary valve between feeder and slaker, or offsetting location of slaker from feeder.
Lime Slaking	
Unreliable slaked lime delivery.	Maintain proper temperature and water-to-lime ratio in slaker. Operate slakers under negative pressure to prevent entry of moisture into feeders. Periodic cleaning of slakers.
Mechanical wear of grit conveyors and other moving parts.	Use better quality lime with lower grit content, if possible. Spare screw conveyor should be available for replacement.
Malfunctioning of probes used for indicating levels of slurry.	Clean probes regularly. Consider use of sonic-type level sensors.
Instrumentation for control systems coated with lime dust.	Locate instrumentation panels away from high dust areas. Enclose panels in housing.
Lime Slurrying	
Malfunctioning of liquid level control systems in slurry tanks.	Clean probes regularly. Consider use of sonic-type level sensors. Provide overflow piping to handle emergency conditions.
Inaccessibility of agitator drives and other equipment located on slurry tanks.	Install ladders, catwalks, and platforms to facilitate access for maintenance.
Mechanical wear of FRP slurry tank walls.	Construct erosion-resistant steel slurry tanks to prevent abrasion problems.

Lime Handling System: Identified Problems and Suggested Remedial Measures (continued)

Identified Problem	Suggested Remedial Measures
Lime Slurry Transport	
Clogging of lime slurry transport lines.	Operate transport lines continuously. Install recirculation loops. Use flexible hoses for transport piping. Minimize length of slurry transport lines. Avoid sharp bends and elbows to prevent accumulation. Provide cleanouts in piping. Use large diameter piping to prevent frequent clogging. Flush transport piping after each use with water. Consider use of covered troughs for lime slurry transport.
Lime Slurry Feed	
Clogging of lime slurry feed piping, pumps, and valves.	Locate take-off points for slurry feed as close to point of application as possible. Use open/close-type feed control valves -- avoid variable flow control valves. "Rotodip" or similar type feed systems are preferable to progressive cavity-type feed pumps.
Malfunctioning of pH meters used for lime feed control.	Use two pH probes in cyclic order.

APPENDIX C

FILTRATION SYSTEM: IDENTIFIED PROBLEMS AND SUGGESTED REMEDIAL MEASURES

Filtration System: Identified Problems and Suggested Remedial Measures

Identified Problem	Suggested Remedial Measures
Design Aspects	
Frequent clogging of media and buildup of excessive head loss.	Multimedia filters should be considered. Design filters to operate either in parallel or series. Improve quality of influent to filter by incorporating modifications to processes ahead of filter.
Hydraulic surges in influent flow to filters.	Provide equalization facilities ahead of filter.
Improper frequency of backwashing.	Backwash frequency should be controlled on the basis of predetermined head loss and a fixed time interval, whichever is necessary earlier.
Loss of media during backwashing.	Wash water troughs should be uniformly distributed over the entire area of the filter bed. A backwash rate controller should be provided.
Clogging of backwash nozzles due to migration of media.	Use of nozzles fitted with a protective plate on top is recommended.
Corrosion of backwash nozzles.	Use of compatible materials of construction for nozzles, underdrain support structure, and filter bed to avoid electrolysis and galvanic corrosion is recommended.
Operating Aspects	
A. Filtration Cycle	
Media clogging.	Microbial growth in filter bed -- Add a disinfectant, usually chlorine, to the filter influent periodically. Backwash to remove residual chlorine. Solids carryover -- The prior treatment process should be modified to improve its performance. Removal of these solids by filters is not effective. Oil and grease carryover -- The prior treatment processes should remove these constituents. Chemical precipitation on filter -- The chemical conditions of the precipitation system should be adjusted to ensure that all precipitation occurs in the precipitation system.
Excessive filtration system downtime due to equipment problems.	An adequate maintenance program should be established and followed.
Incorrect operation of the filtration system.	The operator(s) should receive training in filtration theory and system operation. The operator(s) should be aware of the system's capabilities so they can modify it, especially during periods of prior treatment process upsets, and in response to a change in conditions.

Filtration System: Identified Problems and Suggested Remedial Measures (continued)

Identified Problem	Suggested Remedial Measures
B. Backwashing Cycle	
Incorrect operational sequencing during filter backwashing.	The operator(s) should observe the instrumentation during backwashing to ensure that the correct operational sequence occurs. A monthly visual check should also be made of each filter cell for a complete backwash cycle to ascertain that all systems are operating correctly. A pole that rises above the media should be attached to the arm of a submerged auxiliary wash or scour system to aid in observing its operation.
Incorrect rate and duration of backwashing.	Operators should be aware of correct backwashing rates and duration. The settings of the rate and timer controls should be checked regularly to ensure they are correct. Operators should change backwash rates as temperatures fluctuate to compensate for the change in water viscosity with temperature.
Incorrect operation of backwash system.	Operators should be trained in the operation of the backwash. They should be made aware of the system's capabilities and how to modify its operation in response to a change in conditions.
Excessive backwash system downtime due to equipment problems.	An adequate maintenance program should be established and followed.

APPENDIX D

GRANULAR ACTIVATED CARBON SYSTEM: IDENTIFIED PROBLEMS AND SUGGESTED REMEDIAL MEASURES

Granular Activated Carbon System: Identified Problems and Suggested Remedial Measures

Identified Problem	Suggested Remedial Measures
<u>Carbon Contactor</u>	
BOD removal goal not achieved.	The activated carbon should be tested for adsorptive capacity; more frequent regeneration of the carbon; add oxygen to the GAC influent.
Hydrogen sulfide generation in the carbon contactor.	Maintain aerobic conditions in the carbon contactor by addition of oxygen, air, or peroxide to the GAC system influent; add sodium nitrate to the influent to prevent sulfide formation; increase the frequency of backwashing; backwash GAC contactor more thoroughly by the use of a surface wash; reduce the GAC system detention time.
Corrosion of the carbon contactor.	Spark test to determine defects in the contactor coating; patch defects in the contactor coating; reseal the contactor with better coating material; use synthetic connectors within the contactor; eliminate the potential for hydrogen sulfide generation.
Accumulation of solids in the carbon contactor (media clogging).	Use surface washers and increase backwash frequency.
Structural failure of the carbon contactor underdrain and influent piping.	Modify underdrain and air grid system, redesign and reconstruct underdrain supports; replace defective piping with pipe of increased wall thickness; specify a structurally stronger grade of pipe; add additional pipe supports.
<u>Carbon Slurry Transport System</u>	
Clogging of the carbon slurry transport pipeline.	Increase transport line size (minimum suggested diameter is 2 inches); decrease carbon slurry concentration; avoid the use of short radius right-angle bonds.
Abrasion of the carbon slurry pipeline.	Use black steel or lined steel pipe; long radius fittings should be used at changes in direction of flow, along with extra-heavy elbows and tees.
Clogging of the carbon slurry pumps.	Decrease the carbon slurry concentration; modify the carbon slurry pump (i.e., change the impeller or utilize larger size intake or discharge piping); replace the pump if the original cannot be modified to improve its performanoe.

Granular Activated Carbon System: Identified Problems and Suggested Remedial Measures (continued)

Identified Problem	Suggested Remedial Measures
<u>Backwash System</u>	
Clogging of backwash and/or surface wash nozzles.	Prevent the carbon from leaving the contactor; add screens to remove solids from the backwash and surface wash influent; provide cleanouts to permit cleaning of the screens.
Incorrect rate and/or duration of backwashing.	Operators should check rate and timer controls frequently to ensure they are accurate; backwash controls and instrumentation should be periodically recalibrated.
<u>Regeneration System</u>	
Excessive carbon loss.	Operate the carbon regeneration furnace at the specified conditions; store enough spent carbon to permit more continuous operation of the regeneration furnace.
<u>Instrumentation and Control Systems</u>	
Nonfunctioning instrumentation and control systems.	An adequate maintenance program should be established and followed.