

Pretreatment for Wastewater Reclamation and Reuse

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Abstract

The recent trend toward the use of reclaimed municipal wastewater for purposes such as landscape and food crop irrigation, groundwater recharge, and recreational impoundment often requires tertiary or advanced wastewater treatment. These water reuse applications result in exposing the public to reclaimed wastewater, thus assurance of microbiological and, particularly, virological safety is of utmost importance. The principal treatment processes and operations for reuse in these situations are similar to surface water treatment for potable water supply; both normally include chemical coagulation followed by flocculation, sedimentation, filtration, and disinfection. Because of the considerably higher and variable concentrations of organics and turbidity in wastewater, optimization of the chemical coagulation-flocculation and filtration of secondary effluent has been difficult to achieve in practice. The high degree of pathogen removal achieved by a properly operated treatment system ensures the safety of the reclaimed wastewater.

To achieve efficient virus removal or inactivation in tertiary wastewater treatment, two major operating criteria must be met: (1) the effluent must be low in suspended solids and turbidity prior to disinfection to reduce shielding of viruses and chlorine demand and (2) sufficient disinfectant dose and contact time must be provided for wastewater. To satisfy the first criterion, tertiary filtration with adequate chemical coagulation normally follows secondary treatment.

The lack of practical information on the optimization of these process trains has, however, hampered the establishment of more cost-effective wastewater reclamation methods for tertiary treatment. The purpose of this paper is, therefore, to review the recent studies conducted in California on the performance of tertiary treatment systems for wastewater reclamation and reuse. Following the Pomona Virus Study [6, 7, 8], three recently completed studies: the Health Effects Study [9], the Las Virgenes Filtration-Disinfection Study [15], and the Monterey Wastewater Reclamation Study for Agriculture [10, 14] are examined.

Introduction

There are a number of factors which affect the implementation of municipal wastewater reclamation and reuse projects. Generally, the impetus for water reuse in industrialized countries has resulted from four motivating factors:

- 1) Increasing costs of freshwater development.
- 2) Desirability of establishing comprehensive water resource planning, including water conservation and wastewater reuse.
- 3) Availability of high quality effluents.
- 4) Avoidance of more stringent water pollution control requirements such as needs for advanced wastewater treatment facilities.

The general factors affecting wastewater reuse decisions include: (1) local and regional water supply conditions, (2) water quality requirements for intended water reuse applications, (3) existing or proposed wastewater treatment facilities, (4) requirements for degree of treatment and process reliability, (5) potential health risks mitigation, (6) public acceptance, and (7) financing reuse facilities including sale of reclaimed water.

The recent trend toward the use of reclaimed municipal wastewater for purposes such as landscape and food crop irrigation, groundwater recharge, and recreational impoundment often requires tertiary or advanced wastewater treatment. These water reuse applications often result in exposure to reclaimed wastewater; thus assurance of microbiological and, particularly, virological safety is of utmost importance. Principal treatment processes and operations for tertiary treatment of municipal wastewater for reuse and treatment of surface water for drinking water are similar; both normally include chemical coagulation followed by flocculation, sedimentation, filtration, and disinfection. Alternatively, direct filtration with lower chemical doses and without sedimentation is also used. It is known that both bacterial pathogens and viruses are removed in these processes in varying degrees. The high degree of pathogen removal achieved by a properly operated treatment system ensures the safety of the reclaimed wastewater.

In many instances, however, optimization of the chemical coagulation-flocculation and filtration of secondary effluent has been difficult to achieve in practice. Lack of information on the optimization of these processes in wastewater reclamation and reuse has hampered the establishment of more cost-effective wastewater reclamation methods for tertiary treatment. Therefore, the purpose of this paper is to review the recent studies conducted in California on the performance of tertiary treatment systems for producing reclaimed water that has an extremely low probability of bacterial and viral contamination.

Virus Concentrations in Municipal Wastewater

Although virus concentrations have been reported to be lower in municipal wastewater from U.S. sources than from many other countries, over 100 types of enteric viruses can be present in untreated municipal wastewater [1, 2]. Many of the enteroviral diseases reported have not been associated directly with water route transmission. However, Hepatitis type A, the virus causing infectious hepatitis, and documented to be transmitted by contaminated water, is the virus reported most frequently. Diseases associated with Rotavirus and Norwalk agent are becoming of increasing concern to public health officials. There are undoubtedly incidents of waterborne transmission of viruses that are not recognized, investigated, or reported [3].

The actual viral concentration in untreated municipal wastewater varies considerably in different locations and seasons. In the United States, reported virus concentrations range from a low of about 200 plaqueforming units per liter (PFU/l) in cold climate to 7,000 PFU/l in warm months [4, 5]. However, reported virus concentrations must be viewed with care. There is no universal procedure for the cultivation of all viruses. Each procedure is selective with respect to the viruses enumerated and is affected by the method of concentrating the viruses in the sample, selection of a host cell, and the type of culture techniques used [4]. In addition, because low concentrations of naturally occurring viruses are expected in the tertiary treatment effluents (e.g., less than 0.5 PFU/l), overall concentration factors of 15,000 to 75,000 are often necessary when 379 l samples are processed. The average overall recovery efficiency was reported to be about 20 percent in this circumstance [6, 7, 8]. However, in the recently completed Health Effects Study [9], a newly developed portable virus concentrator was capable of concentrating up to 3,790 l of well water and 1,137 l of wastewater with average virus recoveries of 83 percent and 42 percent, respectively, as determined with seeded poliovirus.

In unchlorinated secondary effluent, viruses were detected in 27 samples out of 60 samples in the Pomona Virus Study [6] in California. The geometric mean of the natural virus concentration that yielded plaques was about 5 PFU/l. Polio-, Reo-, Echo-, and Adenoviruses were identified. Animal viruses were also isolated from unchlorinated activated sludge effluent from the Castroville Wastewater Treatment Plant in California where the Monterey Wastewater Reclamation Study for Agriculture (MWRSA) was conducted. The influent to the two pilot tertiary treatment plants (unchlorinated activated sludge effluent) contained measurable viruses 80 percent of the time sampled, averaging 22 PFU/l ranging from 1 to 734 PFU/l and the highest virus concentrations were found in October and November, the warmest months in this region [10].

At the Orange County Water Factory 21 in California, a total of 35 unchlorinated secondary effluent samples were analyzed for enteric viruses and 27 samples were found to be positive during the study period. The geometric means of virus concentration were 0.025 to 0.015 most probable number of cytopathic units (MPNCU) per liter for the Buffalo Green Monkey Kidney (BGM) and RD cell lines, respectively, when activated sludge effluent was tested. It was also reported that the activated sludge effluent contained 1.5 log orders of magnitude less viruses than the trickling filter effluent [11].

Viruses were also isolated routinely from unchlorinated secondary effluent samples collected for the Health Effects Study [9]; they ranged from 0.1 to 17 PFU/l. With improved virus concentration and assay methods, detection of viruses in treated effluents is expected to increase.

Treatment Processes Capable of Producing Essentially Virus-free Effluent

Because viruses have been detected in unchlorinated secondary effluents and even in chlorinated secondary effluents, it is prudent to remove them where a high degree of public exposure to the reclaimed water is expected. Viruses are associated with

suspended and colloidal solids and also may be embedded in organic solids and human excrement [12, 13]. Thus, removal or inactivation of viruses from wastewater depends on the level of wastewater treatment, residual solids concentration, and disinfection.

To achieve efficient virus removal or inactivation in tertiary treatment, two major criteria must be met: (1) the effluent must be low in suspended solids and turbidity prior to disinfection to reduce shielding of viruses and chlorine demand, and (2) sufficient disinfectant dose and contact time must be provided for wastewater.

Virus removal or inactivation during municipal wastewater treatment has been studied in field-scale operations and even more intensely in laboratory bench-scale units. There are potential problems in the extrapolation of virus data derived at one treatment plant to other similar treatment plants. The non-specificity of *in situ* virus enumeration is an important cause of the difficulty. Differences in virus removal data from one plant to another may be a reflection of the types of viruses present in a given wastewater, and also a reflection of virus species resistance to the treatment processes. In laboratory or in large scale seeding studies, a specific type of virus (usually vaccine strains of poliovirus) is used. The extrapolation of these data is subject to the aforementioned problem. The most important aspect of virus seeding experiments is that non-zero virus concentrations can be achieved even in highly treated effluents allowing calculations of virus removal efficiency. It should be pointed out, however, that the virus concentrations used were far in excess (usually in a range of 10^4 to 10^{11} PFU/l) of the indigenous virus concentrations common in municipal wastewater, thus the similitude of virus removal and/or inactivation is not exactly known [5, 16].

Importance of High Quality Secondary Effluent

In the evaluation of virus removal capabilities in the coagulation-filtration system, the County Sanitation Districts of Los Angeles County conducted a series of tests related to the determination of optimal alum and polymer dosages and their relation to the headloss buildup in the filter. The investigation known as the Pomona Virus Study [6, 7, 8] provided useful information on the performance of tertiary treatment systems related to virus removal efficiency and reliability. The performance of the chemical coagulation, flocculation, sedimentation, and filtration system (T-22 System) operated at various alum doses ranging from 55 to 255 mg/l was reported. Each series of headloss data for the dual-media filter represented the observed headloss at the end of the first 7.5 hours of a filter run. A filter effluent turbidity of 0.2 – 0.4 FTU was achieved at an alum dosage of about 155 mg/l and a polymer (Calgon WT-3000 anionic polymer) dose of 0.2 mg/l.

The performance of the dual-media filter with direct filtration mode (coagulation and filtration without sedimentation, Fe Process) indicated that the filter effluent turbidity of 0.2 FTU or less could not be achieved at any of the alum and polymer doses evaluated. In the absence of alum, however, filter effluent turbidities ranging from 0.2 to 0.8 FTU were observed [6]. In other words, the optimization of coagulation-flocculation and filtration processes in a direct filtration

system was not readily established. It appears that flocculation time prior to the dual-media filtration was not long enough for effective turbidity removal, although short flocculation time-filtration processes have been designed and operated successfully in water treatment.

A similar difficulty in process optimization was experienced in the Monterey Wastewater Reclamation Study for Agriculture (MWRSA). To improve turbidity and virus removal efficiency with direct filtration, it was necessary to add a mechanical turbine rapid mixer and flocculation chamber prior to the dual-media filter. A series of tests were conducted to determine an optimal combination of operational parameters including alum/polymer dosages, energy inputs, and flocculation time [10, 14].

To produce essentially virus-free effluent using the direct filtration system, the secondary effluent must be of a high quality. To meet a filtered effluent turbidity of less than 1 NTU, the water quality of secondary effluent, based on the available data, must be in the neighborhood of: suspended solids 10–15 mg/l, turbidity 3–6 NTU, and total COD 40–80 mg/l. In full-scale operating plants, a secondary effluent turbidity of about 5 NTU or less is recommended to meet consistently an average operating turbidity of 2 NTU in the filtered effluent using the direct filtration system. It appears that the secondary effluent turbidity of 10 NTU is an economic dividing line in this case above which improved operation of secondary treatment is more cost-effective and warranted [16].

If secondary effluents do not meet the water quality ranges cited above, more costly complete treatment, the T-22 system, must be employed. The tertiary treatment system required would be high-dose chemical coagulation, flocculation, sedimentation, and filtration followed by chlorination, and costs can be excessive for most reuse applications.

Table 1 summarizes the concentrations of BOD, TSS, and turbidity of the secondary effluent, filtered effluent (FE system), and T-22 effluent in the MWRSA. A consistent ratio of about 2 to 1 can be observed in the performance of the two tertiary treatment sequences (FE and T-22) in terms of their respective total suspended solids and turbidity.

With regard to the 2:1 ratio observed with turbidity and TSS between the two treatment trains, it is believed that this difference is due to the high dose of chemicals and the sedimentation process in the T-22 scheme, and the resultant difference in filterability.

Virus Removal in Tertiary Treatment and Disinfection

In the Pomona Virus Study [6, 7, 8], a series of experiments were conducted to determine the virus removal efficiency of the tertiary treatment systems. The overall virus removal efficiencies for both the complete treatment (T-22) and the direct filtration (FE-process) were virtually the same when residual chlorine doses of about 10 mg/l and a two-hour chlorine contact time were used. Approximately, 5.0 to 5.2 log removal of seeded poliovirus was observed in these pilot-scale experiments. When an average combined chlorine residual of 5.0 mg/l and a two-

Table 1. Log-normal probability distribution of treatment data in the Monterey Wastewater Reclamation Study for Agriculture [10, 14]

Parameter	No. samples	Percent chance of parameter value being less than or equal to that listed below						Maximum value
		50	80	90	96	98	99	
BOD ₅ [mg/l]								
SE	74	14.3	22.3	28.0	35.9	42.1	48.6	53
Total suspended solids [mg/l]								
SE	302	13.4	19.5	23.7	29.2	33.4	37.7	38
FE	286	1.6	3.1	4.3	6.3	8.0	10.0	17
FC	275	4.4	7.6	10.1	13.8	16.8	20.2	59
T-22	273	0.8	1.5	2.1	3.0	3.8	4.7	12
Turbidity [NTU]								
SE	286	3.8	5.5	6.7	8.2	9.3	10.5	12.0
FE	282	1.1	1.7	2.2	2.9	3.4	4.0	9.4
T-22	262	0.6	0.9	1.1	1.5	1.7	2.0	3.4

Key: NTU Nephelometric Turbidity Units
 SE secondary effluent
 FE filtered effluent with flocculator installed
 FC flocculator-clarifier effluent
 T-22 Title-22 effluent (with 50-200 mg/l alum + 0.2 mg/l polymer followed by flocculation, sedimentation, and filtration)

hour contact time were used, differences in the virus removal efficiencies between two different treatment systems became apparent.

The average removal of poliovirus 1 in the coagulation-flocculation and sedimentation system (complete treatment) was in the range of 1.3 to 1.5 log removal or about 95 percent. The direct filtration removed about 1 log of virus removal or 90 percent. The seeded secondary effluent (unchlorinated) had viral counts in the range of 1.3×10^5 PFU/l whereas the geometric mean of the background level of naturally occurring viruses was 5 PFU/l [6].

The Monterey Wastewater Reclamation Study for Agriculture (MWRSA) conducted extensive virus monitoring with respect to: (1) pilot plant influent and effluent for the presence of animal enteric viruses, (2) poliovirus seeding studies designed to estimate virus removal efficiency in the tertiary treatment systems including complete treatment and direct filtration, (3) a study of poliovirus survival on *in situ* crops at Castroville, California [10].

Both the complete treatment system (T-22 System) and the direct filtration system (FE System) were seeded with vaccine-strain poliovirus to determine their virus removal and inactivation efficiencies. It was found that the direct filtration system was somewhat less efficient with an average of 6.1 log removal compared to the complete treatment train which removed about 7.5 logs. It was suspected that the difference in virus removal efficiency was due to the improper flocculation time inherent to the direct filtration design used in MWRSA. In addition, the low chlorine residuals (about 5 mg/l) used in the disinfection step with 90 minute theoretical contact time appear, on the average, to be less effective (6.1 to 3.2 log reduction). With optimization of the flocculation process and/or higher chlorine residuals (about 10 mg/l), it is expected that the virus removal capabilities of the

tertiary treatment system at MWRSA will improve and become comparable to those of the Pomona Virus Study.

Ancillary to the performance and reliability study of full-scale advanced wastewater treatment system at the Orange County Water Factory 21, monitoring for viruses and parasites was conducted and the effectiveness of their removal by the advanced wastewater treatment processes was determined. From the data obtained in this study, it appears that a very low virus level (approximately 2 viruses per day in 57,000 m³ of water) may pass through the last treatment barriers, the reverse osmosis unit and chlorination process. Enteric viruses were detected in the advanced waste treatment effluents only once during the three-year study [11].

The Las Virgenes Filtration-Disinfection Study is being conducted to determine the optimum filtration and disinfection criteria for the Tapia Water Reclamation Facility in California that would meet the State of California Wastewater Reclamation Criteria shown in Table 2. The most restrictive wastewater reclamation criteria specify a tertiary process train that results in an effluent that is essentially free of viruses. At the Tapia Facility, the tertiary process consisted of coagulation with 4 mg/l chlorine and 1 mg/l alum, filtration with single-medium deep bed filters, and disinfection [15]. The results of the microbiological investigations will be used for determining the filtration and disinfection requirements which involve intensive virus monitoring. The target operating conditions for the tertiary processes are: filtration rate 167–224 l/min/m²; alum addition 1 mg/l; chlorine residual 5.5–11.0 mg/l.

For all combinations of conditions studied, the data, so far, indicated that at least 99.9% of the total coliforms entering the tertiary process were removed during coagulation, pre-disinfection, and filtration. After additional chlorine was added, following filtration, to maintain a target residual chlorine of 11.0 mg/l in the contact basin, an additional 94.2 to 95.9% removal was achieved after one hour in the contact basin. When the target residual chlorine level was 5.5 mg/l, 89.4% of the total coliforms were removed after one hour of contact time.

Enteric viruses were detected in all 12 unchlorinated secondary effluent samples analyzed. All samples were positive for enteric viruses, with a geometric mean concentration of 0.03 MPNCU/l [15].

Water Quality Criteria for Irrigation

The health significance of an extremely small probability of virus contamination and few orders of magnitude difference in virus removal efficiency has not been established. It is highly uncertain, however, that additional epidemiological and laboratory studies would yield significant new information on the relationship between viruses in reclaimed municipal wastewater and disease. The long-term health effects of ingesting or being exposed to such reclaimed wastewater are unknown, but will always be of concern regardless of the final water quality.

A basic objective of the State of California regulations, entitled “Wastewater Reclamation Criteria” (issued by the Department of Health Services, 1978), is to assure health protection without unnecessarily discouraging wastewater reclamation. The regulations specify wastewater reuse standards for uses involving agricultural

and landscape irrigation, impoundments, and groundwater recharge. The regulations include water quality standards, treatment process requirements, sampling and analysis requirements, operational requirements, and treatment reliability requirements. The required degree of treatment increases as the likelihood of human exposure to the wastewater increases. The treatment and quality requirements for the irrigation uses covered by the Wastewater Reclamation Criteria are summarized in Table 2. The reclamation criteria are intended to assure an adequate degree of health protection from disease transmission and do not specifically address the potential effects of reclaimed water on the crops or soil in agricultural and landscape irrigation.

Table 2. Wastewater treatment and water quality criteria for irrigation *

Treatment level	Total Coliform (Median MPN/100 ml)	Type of use
Primary		Surface irrigation of orchards and vineyards, fodder, fiber, and seed crops
Oxidation and disinfection	≤23/100 ml	Pasture for milking animals Landscape impoundments Landscape irrigation (golf courses, cementeries, etc.)
	≤2.2/100 ml	Surface irrigation of food crops (no contact between water and edible portion of crop)
Oxidation, coagulation, clarification, filtration**, and disinfection	≤2.2/100 ml	Spray irrigation of food crops
	max. = 23/100 ml	Landscape irrigation (parks, playgrounds, etc.)

* Excerpted from "Wastewater Reclamation Criteria", California Administrative Code, Title 22, Division 4, Environmental Health (1978)

** The turbidity of filtered effluent cannot exceed an average of 2 turbidity units (NTU) during any 24-hour period.

In the most stringent requirements, such as for spray irrigation of food crops and landscape irrigation of parks and playgrounds, tertiary effluent that is "pathogen-free" is required (as shown in less than 2.2 total coliform, MPN/100 ml on seven-day average and the number of coliforms does not exceed 23 MPN/100 ml, in any sample). It is assumed, in this case, that essentially virus-free effluent is obtained through various combinations of tertiary treatment and disinfection.

The unit cost of tertiary treatment trains which produced reclaimed water of essentially virus-free quality was estimated in the MWRSA. The full 1.3 m³/s (30 mgd) capacity of the wastewater reclamation facilities is expected to be required for irrigation during an average of 250 days per year. The costs of producing filtered effluent (FE system) is estimated to be \$0.06/m³, and \$0.09/m³ for the T-22 System [10].

Summary and Conclusions

Because of uncertainties associated with risk assessment of viruses in reclaimed wastewater, improvements in wastewater treatment technology and operation of both conventional and tertiary wastewater treatment plants are warranted. By optimizing wastewater treatment and the coagulation-filtration processes coupled with effective chlorination, it is reasonable to expect that essentially virus-free reclaimed water can be produced in a cost-effective manner. The preferred methods of achieving essentially virus-free reclaimed wastewater are (1) to focus more attention on improving the quality of secondary effluent and operational reliability and (2) to optimize chemical coagulation-flocculation in direct filtration systems. Both of these measures would allow for the use of lower chlorine dosages in disinfection without jeopardizing virus removal and/or inactivation efficiency.

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