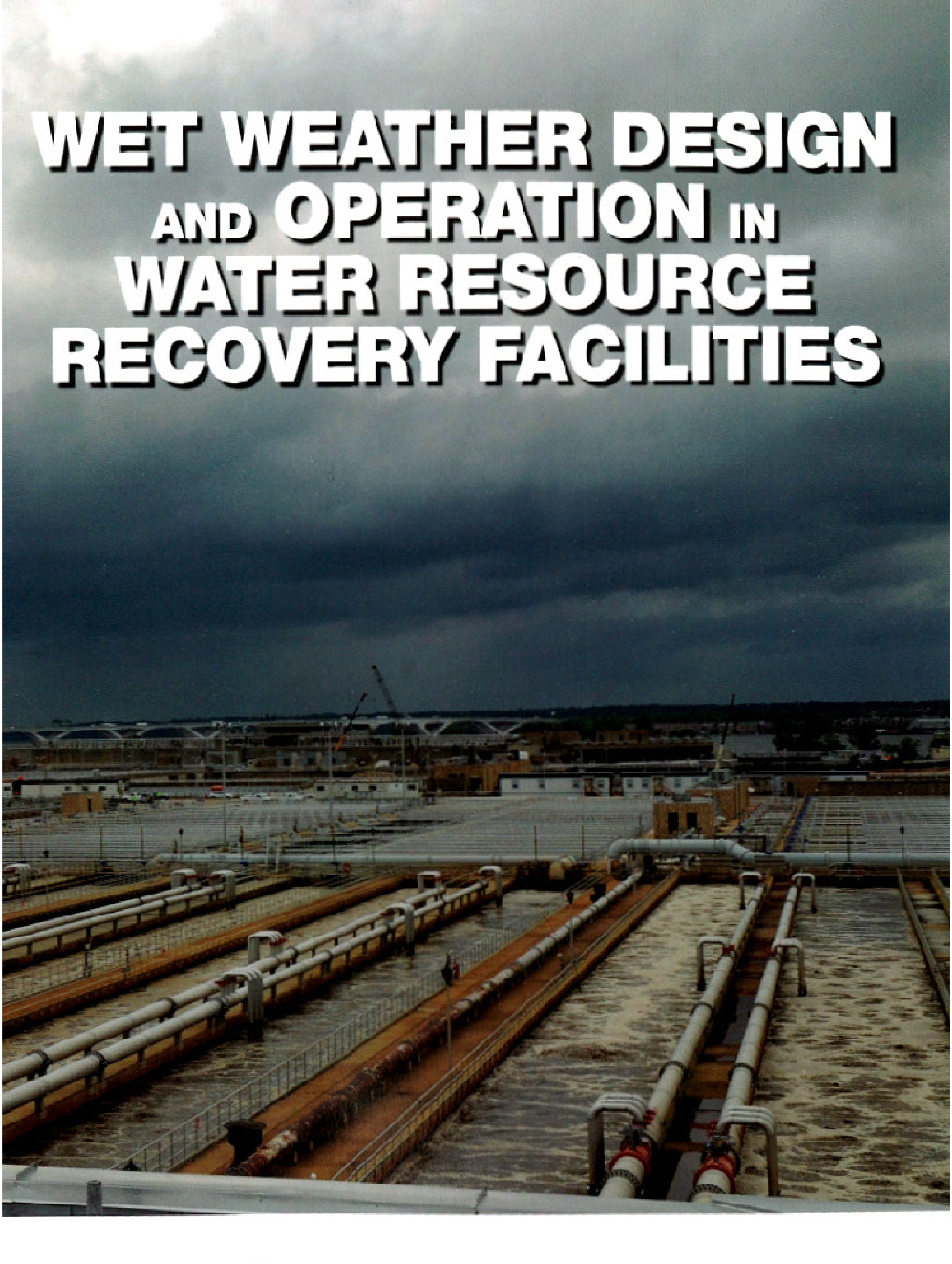
WET WEATHER DESIGN AND OPERATION IN WATER RESOURCE RECOVERY FACILITIES



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WET WEATHER DESIGN AND OPERATION IN WATER RESOURCE RECOVERY FACILITIES

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Primary Treatment

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1.0 INTRODUCTION

Primary treatment encompasses physical–chemical processes accomplishing separation and removal of suspended and floating solids from wastewater. The most common primary treatment process is quiescent sedimentation in primary clarifiers, with skimming devices for removal of floating matter and grease.

The chief measure of primary treatment efficiency is total suspended solids (TSS) removal. However, reduction of the organic and nutrient loads associated with the removed TSS fraction is of high interest because a critical objective of primary treatment is to reduce the loads of these constituents on the secondary system. This is beneficial because aeration basins, volume and blower capacity requirements are reduced. Lower inert and other solids loads allow operation at a higher mixed liquor volatile suspended solids fraction, thus increasing the system nitrification capacity. The phosphorus associated and settled with particulate matter will minimize phosphorus removal, whether by biological or chemical means; in the latter case instance, this reduces chemical demand.

The most common primary settling facility at water resource recovery facilities (WRRFs) is the rectangular or circular primary clarifier. Because the focus of this publication is to address the effects and management of wet weather flows on existing WRRFs, for design details of conventional clarifiers, the reader is referred to *Clarifier Design* (WEF, 2005) and *Design of Municipal Wastewater Treatment Plants* (WEF et al., 2010). Application of plate and tube settlers (Lamella clarifiers) for primary treatment is limited in the United States and Canada; however, because they are of potential interest for wet weather flow management, they are discussed in the following section. Stacked clarifiers are uncommon in the United States and Canada, with the exception of the Deer Island facility in Boston, Massachusetts.

Alternative primary or equivalent treatment concepts include chemically enhanced primary treatment (CEPT) or chemically enhanced settling (CES), ballasted flocculation, vortex separators, fine-screen (or micro-) filtration, and high-rate filtration using novel media; these concepts are discussed either later in this chapter or in Chapter 14.

2.0 EFFECTS OF WET WEATHER FLOWS ON PRIMARY TREATMENT

The primary clarification process can be adversely affected by wet weather flows in the following ways:

- High solids loading in the first flush, causing high sludge blanket levels;
- Scouring of solids from the sludge blanket, resulting in excessive solids in the primary effluent;
- Reduction in overall removal efficiency of biochemical oxygen demand (BOD) and TSS, resulting from elevated surface overflow rates (SORs);
- Excess grit and screenings loadings to primary clarifiers resulting from overloaded preliminary treatment processes; and
- Flooded scum removal and storage boxes.

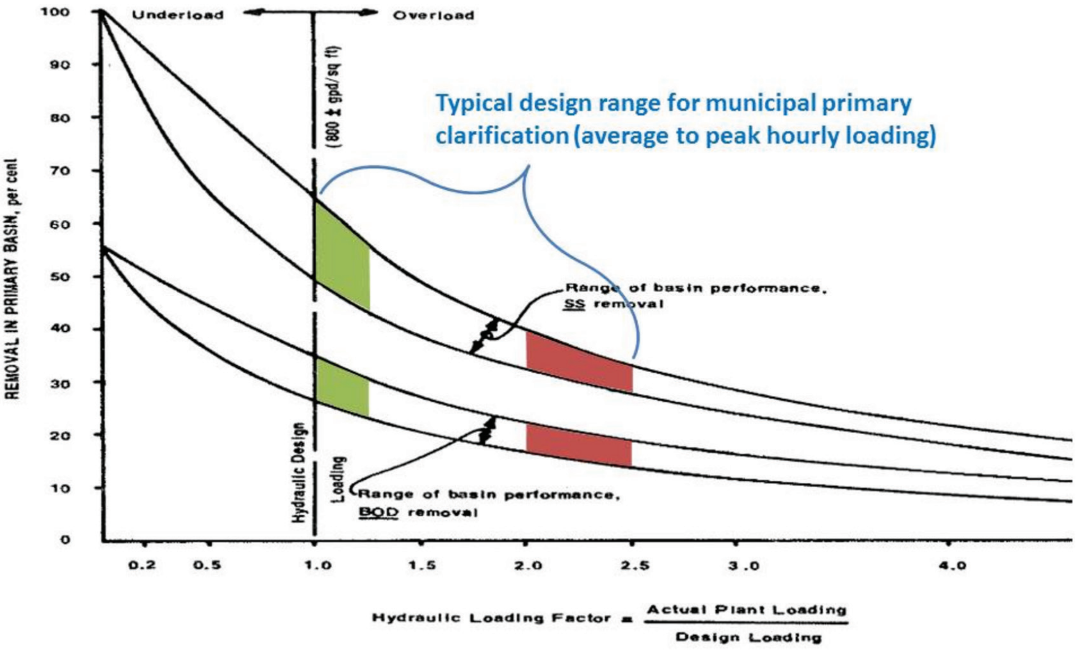
These are discussed in the following subsections.

2.1 Effect on Primary Clarifier Removal Efficiency

2.1.1 Effect of Overflow Rate

Overflow rate is considered to be the primary design parameter affecting performance of the sedimentation process. Figure 12.1 presents historically used relationships (U.S. EPA, 1978) between overflow rate and TSS and BOD removal efficiencies. The TSS removal efficiencies, typically in the 45 to 65% range for the design (average) conditions, decrease to 30 to 45% at peak hourly flows. For BOD, the corresponding guidance is 25 to 35% at the design flows, with 15 to 25% at the peak flows.

Although the guidance presented in Figure 12.1 should, in general, be valid for removal efficiency of the influent with the same characteristics, data from full-scale facilities frequently reveal only a weak correlation between the overflow rate and TSS removal efficiency (Wahlberg et al., 1997). This



Source: Shading and notes added to U.S. Environmental Protection Agency (1978) *Field Manual for Performance, Evaluation and Troubleshooting at Municipal Wastewater Treatment Facilities*, EPA 430/9-78-001, Figure 17

FIGURE 12.1 Traditional guidance showing the relationship between overflow rate and primary clarifier performance in terms of TSS and BOD removal efficiency. A U.S. EPA-recommended (at that time) design overflow rate of 32.6 m/d (800 gpd/sq ft) is shown on this graph; in practice, most primary clarifiers will operate at overflow rates lower than this during dry weather operation (Fitzpatrick et al., 2012).

is because influent characteristics, including raw wastewater TSS concentration, particle distribution including nonsettleable fraction, flocculating properties, and temperature can have a significant effect on the TSS removal efficiency. These factors and state-of-the-art modeling of primary clarifier performance are discussed in detail in *Design of Municipal Wastewater Treatment Plants* (Chapter 12; WEF et al., 2010) and Chapter 2 of *Clarifier Design* (WEF, 2005).

It is particularly important to recognize that quiescent settling (i.e., primary clarification unaided by chemical addition) is capable of removing only this fraction of TSS that is settleable. Nonsettleable TSS consist of fine and colloidal matter and are operationally defined as the fraction of the TSS that does not settle upon 30 minutes of flocculation (w/o chemicals) followed by 30 minutes of settling (WEF et al., 2010). The settleable fraction varies significantly, particularly in response to wet weather events, making performance prediction and modeling challenging.

Chemical addition in the form of coagulant and/or polymer, dramatically increases the proportion of settleable solids, allowing for a significant increase in TSS removal efficiency at the same overflow rate or, more importantly, from the perspective of this publication, facilitates adequate TSS removal at significantly higher SOR. The CEPT is discussed in more detail later in this chapter.

In addition to nonsettleable TSS, other characteristics of the raw wastewater change significantly, as discussed in more detail in Section 3.0. It was observed (as summarized in, Chapter 3 of *Clarifier Design* [WEF, 2005]) that solids present in the wet weather flows are typically of larger size and better settleability (grit-like material scoured in the initial phases of a wet weather event) than dry weather influent. Dramatic variability in influent solids settleability during wet weather events undoubtedly contributes to the typically weak relationship between overflow rate and performance.

In summary, it could be stated that, on average, as the overflow rate increases, percent removal efficiency will tend to decrease, although a considerable variability in the actual performance could be expected resulting from a number of site-specific and event-specific factors.

In assessing the effect of primary clarification overload, or inferior performance during wet weather events, it should be recognized that primary treatment at a WRRF is primarily there to lower loadings of pollutants of concern on the downstream processes (and many WRRFs do not have primary clarification at all). Consequently, inferior performance of primary clarification during wet weather events is of concern only as far as it causes problems at the downstream processes (which is typical). A significant exception is when part of the primary effluent is diverted around the secondary treatment, and its quality could directly affect the receiving waterbody.

2.1.2 Effects of Temperature, Total Dissolved Solids, and Other Parameters

As discussed in Chapter 9, wet weather flows are typically colder, which increases water viscosity and thus lowers settling velocity of particulate matter. Wet weather flows, particularly the first flush, could also have a higher concentration of total dissolved solids (TDS), particularly if deicing salts were in use. Both temperature and TDS concentration could cause the specific density of the incoming wastewater to be different than the clarifier contents, causing density currents resulting in a poorer performance. On a related note, windy conditions frequently accompanying wet weather events could themselves cause unwanted circulation of the clarifier contents. Effects of changes in other wastewater characteristics, such as pH, are difficult to quantify.

2.2 Effect on Primary Fermentation

At some enhanced biological nutrient removal (EBNR) facilities, primary clarifiers are used as prefermenters or "activated primary sedimentation tank", a practice originally described by Barnard et al. (1984). The additional volatile fatty acids (VFAs) generated in the activated primary tanks by a slow recirculation of the settled sludge back to the clarifier influent are directed to the anaerobic and/or to anoxic zones to enhance the rate of biological phosphorus removal and denitrification, respectively. At the wet weather flow conditions, the efficiency of the VFA production by primary clarifiers could decrease significantly. This results from the higher rate of primary solids accumulation, which necessitates a higher sludge withdrawal rate to prevent solids buildup (and washout) from the primary clarifier. Additionally, the rate of fermentation will be negatively affected by lower raw wastewater temperatures typically associated with wet weather flow. Finally, the concentration of VFAs in the primary effluent will be lowered because of the dilution. All these factors will decrease the supply of VFAs to the downstream EBNR processes, exacerbating a negative effect of wet weather flows on these processes.

2.3 Floatables Control

Wet weather events cause an increased load of floatables reaching the head of the facility, particularly during the first flush conditions. These include grease and scum and particulate floating matter that was not removed during preliminary treatment. Most of the preliminary systems (bar screens) are equipped with diversion features, which could be activated during severe flow conditions, significantly increasing quantities of floating debris reaching the primary clarifiers. Scum baffles protecting effluent weirs should be continuous and of adequate depth to prevent floatables from escaping the clarifier.

The typical scum and floatables control devices are a scum box with a beach plate (Figure 12.2), common in circular clarifiers, and rotating (or tilting) scum troughs, which are used mostly in rectangular clarifiers (see Figure 12.3). Other mechanisms such as a paddle wheel or a telescopic valve are less common. Where manual activation of rotating scum troughs is practiced (or override is available), these devices may have to be activated with an increased frequency at high flows.

2.4 Sludge Generation and Handling

Solids loading on the primary clarifiers will increase significantly during wet weather flows, particularly resulting from the first flush effect in initial

FIGURE 12.2 Scum box and beach plate at a small primary clarifier (courtesy of Monroe Environmental, Monroe, Michigan).

hours (see Chapter 2). This will lead to accelerated accumulation of solids in the clarifier, so deeper clarifiers (i.e., clarifiers with longer high-rate treatment [HRT], SORs being equal) will be better able to accommodate such loadings and disengage the sludge blanket from hydraulic currents that will occur at higher flows. The rate of primary sludge withdrawal should be increased to prevent elevated blanket levels and scouring of the solids. Higher overflow rates and less opportunity for thickening will result in more dilute sludge generated at a higher volumetric rate. This can overtax downstream thickening and sludge processing facilities, particularly anaerobic digesters, if adequate thickening and/or storage facilities are not available (see Chapter 16).

During the wet weather events, preliminary treatment facilities may be operating at the upper limits of their capacities (see Chapter 11), resulting in grit carryover and increasing primary sludge generation. If sludge degritting is not practiced, anaerobic digesters (if used) will be burdened with extra inert solids. Primary sludge yield and composition during wet weather events is discussed in Chapter 16.

FIGURE 12.3 Rotating scum trough (courtesy of Jim Myers & Sons, Inc., Charlotte, North Carolina).

2.5 Effects on Downstream Processes

As discussed previously, the main function of primary clarifiers is reduction of pollutant loading on the secondary process and retrieval of degradable organic matter for energy recovery through anaerobic digestion. During the early part of a wet weather event, higher loadings and lower primary clarifier efficiency will increase the solids and organic loading on the secondary system, resulting (in activated sludge systems) in an initially accelerated generation of mixed liquor solids and a change in their composition (see Chapters 13 and 16).

Higher flows will have a pronounced effect on secondary clarifiers, potentially requiring a range of measures such as conversion to a step-feed or contact stabilization mode or activation of polymer addition, as discussed in Chapter 13. Wet weather events could cause nitrifier washout and nitrification failure. Reduced hydraulic retention time and, frequently, lower temperatures associated with wet weather events could exacerbate problems maintaining nitrification, denitrification, and biological phosphorus removal, as discussed in more detail in Chapter 13.

2.6 Effects of Other Processes

2.6.1 Co-Settling with Waste Biosolids

In older WRRFs using tricking filter or rotating biological contactor fixed film systems, a common practice was to direct waste sludge from the final clarifiers to the primary clarifiers for co-settling. Wet weather flows will significantly increase sloughing of biomass from fixed film processes caused by hydraulic shear. If this elevated solids load were transferred to the primary clarifiers at the time of high flow, it would exacerbate hydraulic and solids load stress on the clarifiers and could contribute to solids loss from the primary clarifier. If practical, waste solids from fixed film processes should be stored in the final clarifier or directed to any other available storage facility during wet weather events. Although co-thickening of waste activated sludge is less common, a similar strategy should be applied to those facilities.

2.6.2 Effect of Backwashes and Other Sidestreams

Similar consideration should be given to other return streams, such as filter backwashes or streams from sludge processing facilities. Filtration facilities will likely be heavily taxed during wet weather flow conditions both hydraulically and because of the elevated TSS concentration. If possible, frequency of backwash should be controlled to a lowest level practical by tolerating a higher pressure loss or adjusting timer settings to minimize additional flows to the primary clarifier.

3.0 OPTIONS FOR WET WEATHER FLOW MANAGEMENT AND TREATMENT

3.1 Additional Primary Treatment Capacity

3.1.1 Additional Primary Clarifiers

Where possible, a straightforward resolution of limited wet weather primary clarification capacity, particularly when peak to average flow ratios are greater than 5:1, is the deployment of additional or enhanced sedimentation facilities (Fitzpatrick et al., 2008). This may be feasible at older facilities with abandoned primary clarifiers or similar structures or where some clarifiers are offline during typical flow conditions resulting from adequate capacity. An example includes the city of Auburn, New York, where an old, abandoned primary treatment facility was retrofitted to accept and treat excess wet weather flows (U.S. EPA [2000]; see also the case study in Section 5.2). Provisions for emptying or flushing intermittently used tanks after wet weather events should be considered (Leffler and Harrington, 2001). However, purposeful construction of additional primary clarifiers for wet weather flow treatment is unlikely to be economical given the availability of other processes and approaches discussed in subsequent sections. In particular, coagulant and polymer addition to the existing primary clarifiers (CEPT) has been demonstrated to be an effective approach, as detailed in Sections 3.2 and 4.3.

3.1.2 Lamella Settlers

Plates or tubes installed at an angle in a clarifier (or a part of it) will significantly increase the effective settling area available within the same footprint. Additionally, short settling distances promote close contact and flocculation of solids. Such an arrangement, commonly known under the trade name Lamella (Parkson Corporation, Fort Lauderdale, Florida), is frequently used in potable water treatment. Application in wastewater treatment is limited by concerns about solids, floatables, and oil and grease buildup and/or fouling by biological growth, although more than 100 applications in primary (and a few in secondary) clarification are known (WEF, 2005). Almost all of these are in Western Europe, primarily in France, with a few in Canada and none in the United States. However, many ancillary or tertiary wastewater treatment processes in use in the United States, such as Actiflo or Densadeg, use Lamella inserts in the clarification section of their treatment train.

The basic configuration typically consists of rows of inclined, parallel plates or crossing plates forming bundles of tubes. They are typically installed at the clarifier surface at a depth of up to 2 m. Various flow patterns are being used, with the upflow-cross-flow pattern appearing to offer the best ability to separate both settleable and floating matter. Fine screening and good grit and oil and grease removal before the Lamella is important for successful operation. In wastewater applications, provisions for easy access to the Lamellas for maintenance and flushing is critical. Figure 12.4 illustrates a Lamella application offered for primary treatment in Europe.

The overflow rates achievable by a Lamella may be up to 10 times higher than for conventional clarification and effective overflow rates of up to 15 m/h (8800 gpd/sq ft) were reported. This is a result of the effect of the combined, vertically projected surface area of the Lamella plates/tubes. However, the space savings offered by these devices are significantly less than theoretically calculated from the effective surface area because additional footprint is necessary to accommodate additional flow distribution and inlet and outlet structures. In addition, Lamella packs are frequently installed only in a part of the overall tankage, as illustrated in Figure 12.4. For details concerning Lamella modeling and design calculations, the reader is referred to *Clarifier Design* (WEF, 2005).

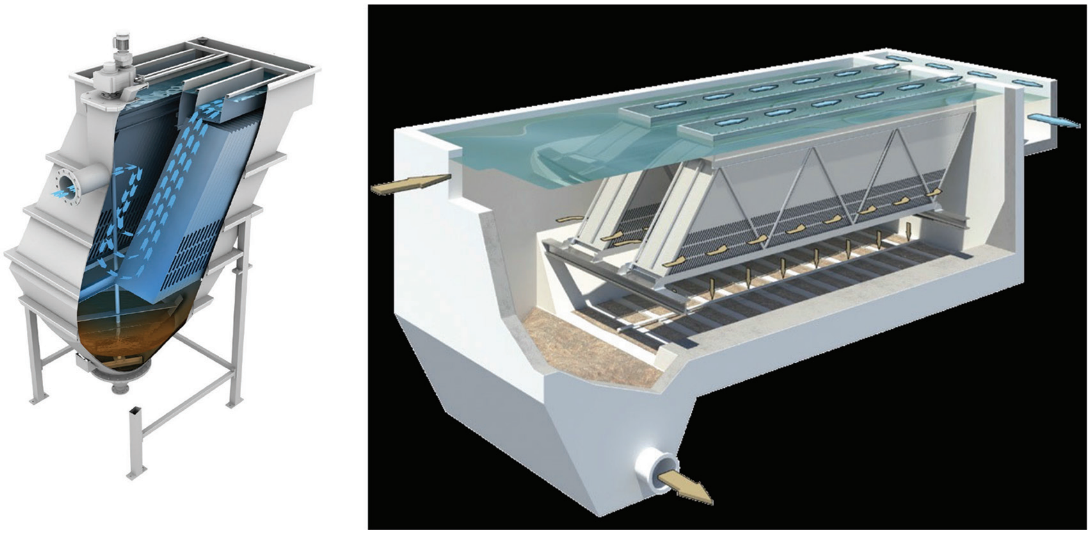


FIGURE 12.4 Plate- and tube-type settlers (courtesy of Hydro International, Ely, Cambridgeshire, U.K.).

Chemical addition ahead of Lamella plates will improve solids separation, just as it would be the case with conventional settling. Tests performed at King County, Washington, facilities demonstrated that the use of plates greatly increased the already impressive allowable SOR for CEPT treatment, from 8.5 to 34 m/h (5000 to 20 000 gpd/sq ft) (Crow et al., 2012). The acceptable performance was defined here as a TSS removal efficiency better than 50% on a consistent basis.

3.1.3 Swirl Concentrators

Swirl concentrators, also known as *vortex solids separators*, originate and are primarily used for stormwater and combined sewer overflow (CSO) treatment, although they could be incorporated to the conventional wastewater treatment train either as the main-line or bypass process.

Vortex separators accomplish separation of grit and readily settleable solids by inducing centrifugal motion of wastewater in a cylindrical vessel with tangential inlet structure. Some vortex separators include floatables removal and serve as flow regulators for CSO application. Chemical addition could improve their performance in terms of TSS removal.

3.1.4 Fine Screens

There is a continuum between coarse or bar screens used for preliminary treatment (as covered in Chapter 11) and fine screens and microscreens used for an increasing TSS removal in raw wastewater. Fine screens are typically used to remove material that may create operational and maintenance problems in downstream processes, particularly in systems that lack primary treatment. Recently, screen sizes with openings of 6 mm and even 3 mm are becoming standard for preliminary treatment (Chapter 11). Fine screens with an opening of 1 mm (0.04 in.) are commonly deployed for protection of membrane bioreactors (MBRs) and would typically require two-stage screening. Fine screens with openings below 1 mm are technically microscreens and can reduce suspended solids to levels near those achieved by primary clarification (U.S. EPA, 2003) and, as such, are discussed here in more detail.

Conventional microscreens are commonly used for polishing of secondary treatment effluent to eliminate biological flocs from escaping a clarifier, although their popularity in this application is declining. They consist of a fabric or wire mesh screen installed on a rotating drum.

Recently, microscreens designed for filtering raw wastewater have been introduced. Figures 12.5 and 12.6 show schematics and photograph, respectively, of the M2R microscreen (M2 Renewables, Lake Forest, California). Screened and degritted wastewater is filtered through a continuous belt screen made of polyester. The removal efficiency claimed by the manufacturer is comparable to primary clarification (40 to 70% TSS removal), although this is expected to be a function of the mesh size (belts with openings down to 105 µm were tested). The screen filters out solids, which are scraped from the mesh, dewatered with an auger screw, and discharged as cake with 30 to 40% dry solids. A backwash system is used to prevent clogging of the screen, with availability of hot water recommended to aid in the removal of oil and grease. The M2R microscreens have been piloted at several locations and are reported to be used at several industrial sites.

Another provider of emerging equipment of similar construction is Salsnes Filter AS of Namsos, Norway (represented in North America by Trojan Technologies). This construction uses fine mesh with 100- to 500-µm openings attached to an inclined rotating wire cloth belt (U.S. EPA, 2013).

The appeal of microscreen technology for wet weather primary treatment is that it requires much less surface area and it is claimed to cost less than primary clarifiers with equivalent capacity (U.S. EPA, 2013). However, long-term, continuous operating experience at municipal WRRFs is needed to assess wider application of this technology for raw wastewater treatment, taking into account maintenance requirements and odor control implications.

Advancements in high-rate filtration technologies, such as compressible, cloth, and upflow floating media filtration, as applied to wet weather flow treatment, are discussed in Chapter 14.

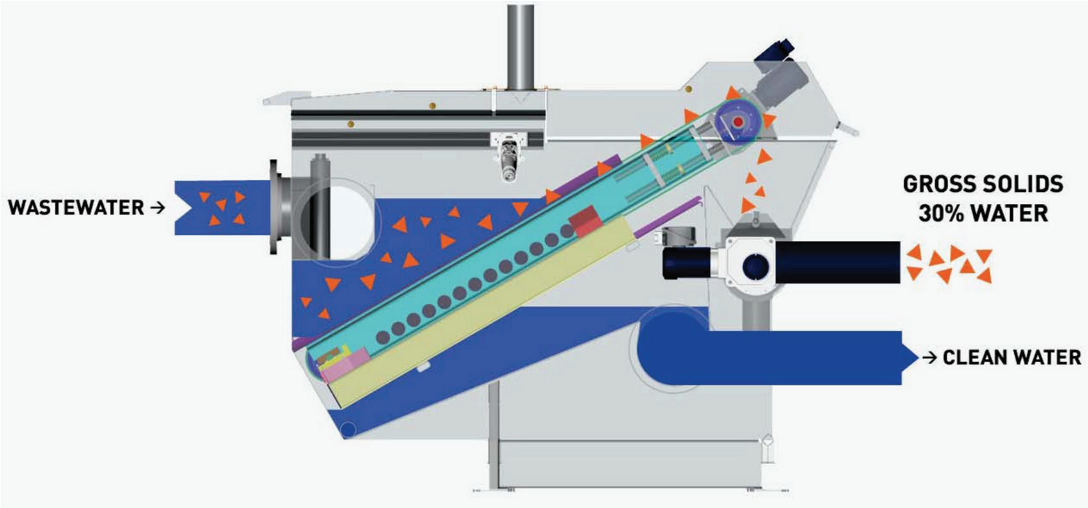


FIGURE 12.5 Schematics of a M2R microscreen for raw wastewater treatment (courtesy of M2 Renewables, Lake Forest, California).

FIGURE 12.6 A photograph of a M2R microscreen for raw wastewater treatment (courtesy of M2 Renewables, Lake Forest, California).

3.1.5 Other Primary Treatment Concepts

There are several additional processes and flow management schemes that can provide partial removal of TSS and thus can be considered treatment equivalent to primary clarification. These include retention treatment basins (RTBs) and high-rate clarifier systems.

Retention treatment basins are designed to capture excess flow for storage and partial treatment for TSS and/or disinfection. They are not mixed or aerated and have provisions for removal of any accumulated solids following the wet weather event. Because RTBs are typically used for treatment of CSO or stormwater at remote locations (i.e., they are not part of a WRRF), they are not further discussed in this publication (U.S. EPA, 1999). In contrast, the offline retention or equalization basins, discussed in Chapter 10, are designed solely for storage and subsequent treatment in the main facility and are mixed or aerated. They are not designed for removal of any TSS, although, in practice, some settling is unavoidable and such flow storage and equalization facilities are typically equipped with sludge removal and cleaning provisions, as discussed in Chapter 10.

There are various treatment processes, primarily for removal of TSS, which enhance the conventional gravitational settling by various chemical and mechanical means and are typically referred to as *HRT* or *enhanced high-rate treatment* (*EHRT*) processes. Chemically enhanced primary treatment is discussed in detail in the subsequent section. Other HRT (EHRT) processes include various forms of ballasted flocculation and filtration with novel media. The original target application for these processes was frequently treatment of CSOs and stormwater, although they could be incorporated to the conventional wastewater treatment train either as the mainline or side-stream process. The aforementioned vortex separators are also sometimes classified as HRT processes, although their performance could be inferior to other HRT processes (hence, introduction of the designation EHRT for high-rate, high-performance processes). Design and application of HRT (EHRT) processes at WRRFs is discussed in more detail in Chapter 14.

3.2 Chemically Enhanced Primary Treatment

Chemically enhanced primary treatment is useful for facilities that have already invested in primary clarifier capacity. Capacity can be increased by a factor of 2 to 4 depending on the peaking factors associated with wet weather flow conditions and the hydraulic constraints of existing primary facilities. Wet weather SORs can be elevated to as high as 9.3 m/h (5500 gpd/sq ft) from the typical dry weather SORs of 1.7 m/h (1000 gpd/ sq ft) or less. Figure 12.7 shows a comparison of TSS removal performance vs SOR in CEPT systems vs conventional primary clarifiers. Chemically enhanced

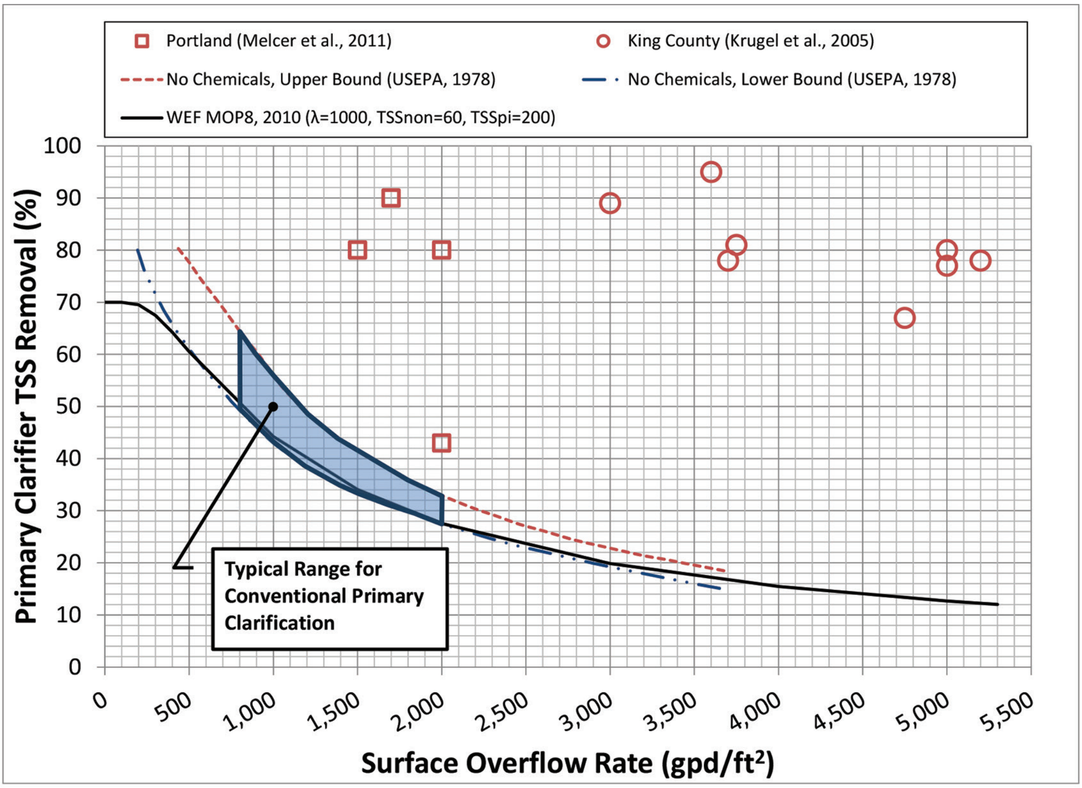


FIGURE 12.7 Comparison of CEPT systems with conventional primary clarifiers.

primary treatment data are drawn from the two case histories in this chapter and, for comparison, this figure also shows conventional sedimentation curves from U.S. EPA's *Field Manual* (1978) along with a theoretical performance curve based on the equations found in Chapter 12 of *Design of Municipal Wastewater Treatment Plants* (WEF et al., 2010). As illustrated by this figure, CEPT has significantly higher performance capabilities than gravity settling alone and can typically be expected to double or triple the capacity of a primary clarifier.

If these constraints can be addressed at a reasonable cost, then CEPT is a more cost-effective solution to managing wet weather flows than constructing new high-rate clarification facilities. An alternative way of implementing CEPT with new primary clarifiers is to consider designing them to be operated in a dual-use mode. At low flow, they are operated without chemicals; as flows increase, each clarifier is progressively converted to operating with chemicals. This was done effectively at King County, Washington's, greenfield Brightwater facility in the Seattle metropolitan area (Krugel et al., 2005).

3.3 Maximum Overflow/Underflow Rates

Table 12.1 summarizes overflow rates and performance achievable by the different primary treatment processes discussed previously. For completeness, the table also includes related physicochemical HRT and EHRT processes discussed in more detail in Chapter 14, where Figure 14.1 provides more details on design criteria of such processes.

TABLE 12.1 Summary of expected performance of various physical and chemically enhanced separation processes used in wet weather treatment. For discussion and qualifications, refer to Chapters 12 and 14.

Separation process	Hydraulic loading rate (overflow rate) during wet weather events (except as noted)	
	m/h	gpd/sq ft
Conventional primary clarification, dry weather flow	0.68–1.4	400–800
Conventional primary clarification, wet weather events	1.4–3.4	800–2000
CEPT	3.4–9.3	2000–5500
Plate or tube settlers (Lamella)	up to 15	up to 8800
Vortex separators (w/o chemicals)	4–10[*]	2400–5900[*]
Vortex separator (w/ chemicals)	4–40[*]	2400–24 000[*]
Microscreens	N/A	
Plate or tube settlers (Lamella) with chemicals (CES)	Refer to Table 14.1	
Dense (recirculated) sludge		
External ballast		
Compressible media filtration		
Cloth media filtration		
Floating media filtration		

[*] WEF, 2006

4.0 DESIGN AND MODIFICATION CONSIDERATIONS

4.1 Regulatory Considerations

The regulatory framework for operation of WRRFs at wet weather flows is provided in Chapter 2. As discussed there, the practice of diverting part of the wet weather flow around secondary treatment is controversial, but it remains a fact of life for many facilities compelled to protect biological treatment processes. In such instances, primary sedimentation may be the only treatment (apart from disinfection) provided for part, or all, of the flow reaching a WRRF during a wet weather event. Therefore, adequate performance of primary treatment under such circumstances is critical for meeting the relevant permit limits. As discussed in Chapter 2, lower influent concentrations of TSS and 5-day BOD during the wet weather events could exacerbate any percent removal requirements.

4.2 Primary Clarifiers

As a standard design practice, primary clarifiers should be designed to perform adequately under peak wet weather flow conditions identified in the planning phase (see Chapter 2). Refer to appropriate Manuals of Practice (i.e., WEF [2005] and WEF et al. [2010]) for detailed design guidance and to Section 2.1.1 and Table 12.1 of this chapter for a discussion of primary clarifier performance at high flowrates. Chapter 5 provides a discussion on hydraulic considerations relevant to flow distribution and inlet and outlet structures of primary treatment facilities.

4.2.1 Stress Testing

Water resource recovery facilities are frequently faced with a mandate to accept increased wet weather flows, typically as a part of flow maximization to limit CSOs. In addition to the desktop design tools discussed previously, the maximum capacity of the existing primary treatment facilities (and the need for any additional facilities or facility modifications) could be evaluated through a full-scale demonstration test. Such tests provide the most direct way of evaluating capacity and needs, taking into account site-specific wastewater characteristics and clarifier design features. Because chemical addition could significantly improve clarifier performance, stress testing is typically done by subjecting an isolated test clarifier to various regimes of flows and chemical addition. Additional details on this are provided in Section 4.3.

4.2.2 Modification of Inlet–Outlet Structures and Use of Computational Fluid Dynamics Modeling

High-flow velocity at peak flow conditions will exacerbate uneven flow distribution caused by any hydraulic asymmetry in flow-splitting arrangements. Upflow distribution structures with flow velocities of no more than 0.3 m/s (1.0 ft/s) at peak flow are a preferred configuration (WEF, 2005).

In designing a primary clarifier, center wells (in circular clarifiers) and various inlet baffle arrangements (in rectangular clarifiers) are used to dissipate flow velocity (momentum) and prevent short-circuiting and sludge scouring. Computational fluid dynamics modeling tools are available (WEF, 2005) for the design or reconfiguration of primary clarifier internal structures for optimal performance at high flow conditions.

4.3 Chemically Enhanced Primary Treatment

The goal of CEPT is to deploy chemicals to improve particle settling in the primary clarifier. The rate of settling is governed by Stokes' Law, which states that the velocity of a settling particle is proportional to its diameter and density. The role of the chemicals is to increase particle diameter and density.

4.3.1 Role of Coagulants

The particles entering a treatment facility possess a small electrical charge. Respecting the laws of magnetism, it is difficult for these particles to coalesce and flocculate because of their natural tendency to repel each other. Consequently, the purpose of adding a coagulant is to neutralize the charge on the particles and render them suitable for flocculation. Examples of the most commonly used coagulants are metal salts, ferric chloride, alum, sodium aluminate, and polyaluminum chloride. Advances in polymer chemistry in the past decade have resulted in the development of cationic polymers that appear to work as well as metal salts in some instances.

4.3.2 Role of Polymer

Having created a body of neutralized particles, it remains for them to be flocculated such that the smaller and colloidal particles that were neutralized by coagulant addition form larger and denser particles. The agent of flocculation is typically an anionic polymer flocculant. Advances in polymer chemistry in the past decade have led to a wide range of anionic high-molecular-weight polymers being made available. A suitable polymer is added downstream of coagulant addition.

4.3.3 Chemical Type and Dose Selection (Jar Testing)

Although the influent BOD and TSS of raw wastewater fall into typical ranges at most treatment facilities, the chemistry of raw wastewater can differ significantly from facility to facility. A coagulant or polymer that works at one facility may not necessarily be successfully deployed at another facility. Therefore, it is important to conduct jar testing to verify the performance of specific chemicals for a specific application. The jar test can be considered as a small-scale simulation of what occurs at full scale. The results of jar tests are scalable to full-facility operating conditions. This simulation is also useful in determining the optimum dose of each chemical. A typical jar test assembly consists of six square sided jars operated in parallel with a common stirring mechanism as shown in Figure 12.8.

A test procedure can consist of the following: a large sample of raw wastewater is collected for each series of jar tests to allow comparison of different dosages and types of chemical for the same sample. The response to a test may be evaluated visually in some instances where rapid screening is desired, but measuring supernatant TSS concentration or turbidity will provide a definitive assessment, as shown in Figure 12.9. Initially, the approach might be to vary the dosage of a candidate polymer for a given dose of a coagulant. This can be repeated for different polymers. Once the best performing polymer had been identified, the response to varying the dose of the coagulant for a given dose of the selected polymer may be evaluated.

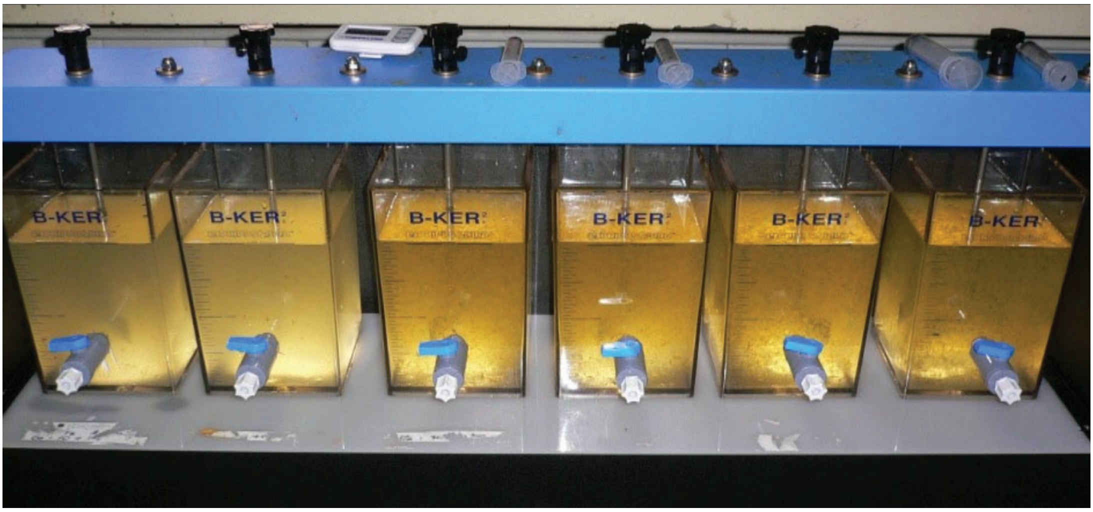


FIGURE 12.8 Six-jar test apparatus.

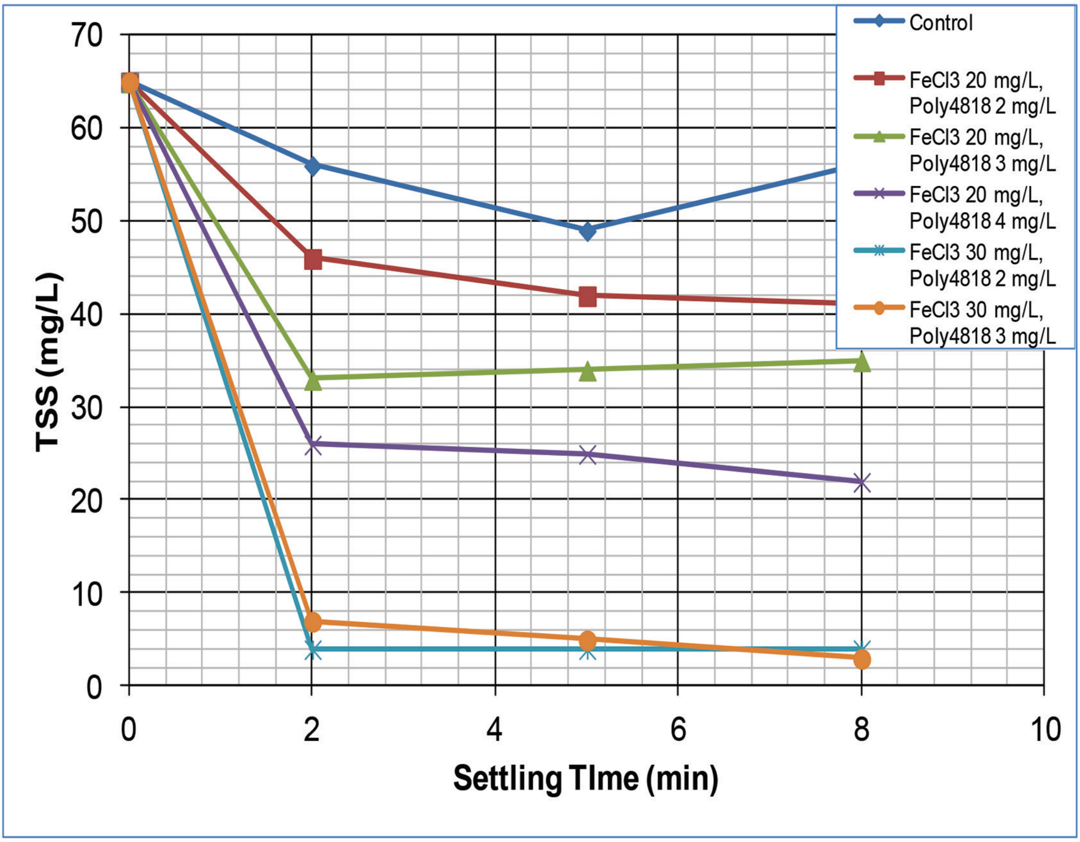


FIGURE 12.9 An example of the change in TSS in residual supernatant for a range of coagulant and polymer doses.

4.3.4 Chemical Dosing and Mixing Requirements in Chemically Enhanced Primary Treatment Systems

The equipment required for CEPT application is similar for pilot testing, full-scale demonstration, and application at full-scale operating facilities. The biggest difference between the different levels of scale is associated with the selection of pump sizes and pipe diameter. At the smaller scale, it can be difficult to find metering pumps that are robust enough to be used in the field while providing reliable flow measurement. Impurities in some coagulants can cause blockage in small-bore pipes. In a full-scale demonstration, a primary clarifier may be isolated and equipped to evaluate the effectiveness of CEPT (see the case study in Section 5.1). Chemical storage and delivery systems are typical of any chemical addition facility as, for example, in the case of sludge thickening and dewatering. If ferric chloride were to be used as the coagulant, delivery lines are typically double-lined and monitored for leaks.

Chemical dose, location, and the amount of mixing/turbulence at the point of addition have a large effect on the performance of the CEPT process. Coagulants should be delivered in an environment that is turbulent to promote rapid mixing and dispersion of the coagulant. Examples of such installations include pump intakes, aerated grit removal tanks, an ogee hydraulic jump, at the entry to a Parshall flume, and the use of an induction mixer or an air sparging device. The flocculant, too, needs to be added at a location that is turbulent to provide rapid dispersion, but it is important that this turbulence dissipates quickly and that the newly formed floc does not experience significant hydraulic disturbances downstream of the polymer addition point to avoid destruction of the floc. Figure 12.10 shows the polymer addition assembly at the Columbia Boulevard Treatment Plant in Portland, Oregon. It is located just at the point where the primary influent emerges from the main influent pipe into the distribution channel of the wet weather primary clarifiers. Similar types of locations should be sought for the polymer addition point.

4.3.5 Instrumentation and Process Control

Instrumentation and controllers for chemical delivery systems are similar to those deployed in sludge thickening and dewatering applications. The rate of addition of coagulant and flocculant is typically flow-paced to maintain the desired dose. Control of the overall CEPT process is currently evolving; the best response characteristic for monitoring primary clarifier effluent quality

FIGURE 12.10 Polymer addition point at the Columbia Boulevard facility.

is the effluent turbidity. Online turbidity sensors are reliable and may be used to collect continuous turbidity data in the influent and effluent.

5.0 CASE STUDIES

5.1 King County's South and Brightwater Plants, Seattle, Washington

King County's 144-ML/d (38-mgd) Brightwater Treatment Plant treats wet weather flows with CEPT. Dry weather flow is treated with MBR technology (Melcer et al., 2004). To minimize the cost of membranes, peak wet weather flows are directed to CEPT and then combined with MBR effluent before disinfection. Full-scale demonstration of CEPT was conducted at King County's South Plant during the winter of 2004–2005 to collect data for the design of the Brightwater CEPT system. High removals of TSS (80 to 90%) and BOD (58 to 68%) (Figure 12.11) were achieved with sequential

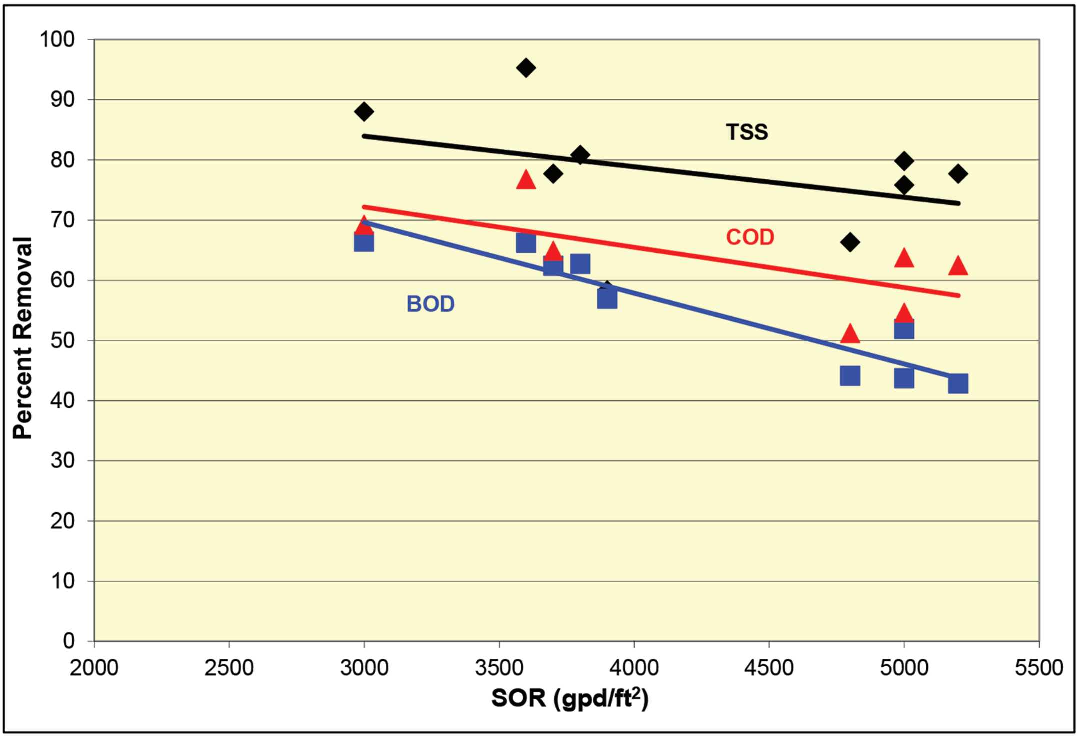


FIGURE 12.11 Performance of South Plant CEPT primary clarifiers with 50 to 60 mg/L $FeCl_3$, 10 to 15 mg/L polyaluminum chloride, and 0.3 to 0.5 mg/L anionic polymer (Melcer et al., 2005).

dual-coagulant (ferric chloride, polyaluminum chloride) and anionic polymer addition at a primary clarifier peak hour SOR of 147 m/h (3600 gpd/sq ft) (Melcer et al., 2005). Without chemicals, TSS and BOD removals at peak SOR were approximately 50 and 25%, respectively. At higher SORs of 204 m/h (5000 gpd/sq ft), TSS and BOD were approximately 65 and 40%, respectively, in the CEPT clarifiers.

Biochemical oxygen demand removal was shown to depend on the particulate BOD fraction. For the South Plant, approximately 62% of the influent wastewater BOD is particulate. Without chemicals, BOD removals were less than 62%. However, up to 68% BOD removal was achieved at SORs of less than 163 m/h (4000 gpd/sq ft), indicating that all particulate BOD, and a small portion of colloidal BOD, had been removed. Lower BOD removals at SORs greater than 163 m/h (4000 gpd/sq ft) were attributable to the inability of the primary clarifiers to capture and settle particulate BOD at the higher flows.

The Brightwater CEPT installation was brought online during 2012 and performance has been identical to the South Plant demonstration data.

5.2 Columbia Boulevard Wastewater Treatment Plant, Portland, Oregon

The capacity of the secondary treatment system at the city of Portland's Columbia Boulevard Wastewater Treatment Plant is limited to 380 to 455 ML/d (100 to 120 mgd). At the time that dry weather flow primary clarifiers were installed, flows in excess of this were directed to 50-year-old primary clarifiers that are now retained only for processing wet weather flows and are referred to as *wet weather primary clarifiers* (WWPCs). The city has installed two large CSO interceptors increasing the peak flow to the Columbia Boulevard facility from 1325 to 1700 ML/d (350 to 450 mgd) and elevating the WWPC peak SOR to 122 m/d (3000 gpd/sq ft). In 2008, new regulatory TSS and BOD removals of 70 and 50% removal, respectively, were anticipated for the WWPCs. Historical BOD and TSS removals by the WWPCs were relatively low even at low SORs; Figure 12.12 shows that, in 2006, the proposed removals could be achieved at a relatively low 24.5 m/d (600 gpd/sq ft) for TSS and 49 m/h (1200 gpd/sq ft) for BOD and were unlikely to meet the required removals at the higher SOR condition (Melcer et al., 2010).

Chemically enhanced primary treatment was investigated to take advantage of existing primary clarifiers that can be made to operate at higher efficiencies with chemical addition during high-flow scenarios, precluding the need to invest in high-rate clarification or additional conventional primary clarifiers. Bench-scale jar tests were conducted in 2008 to determine

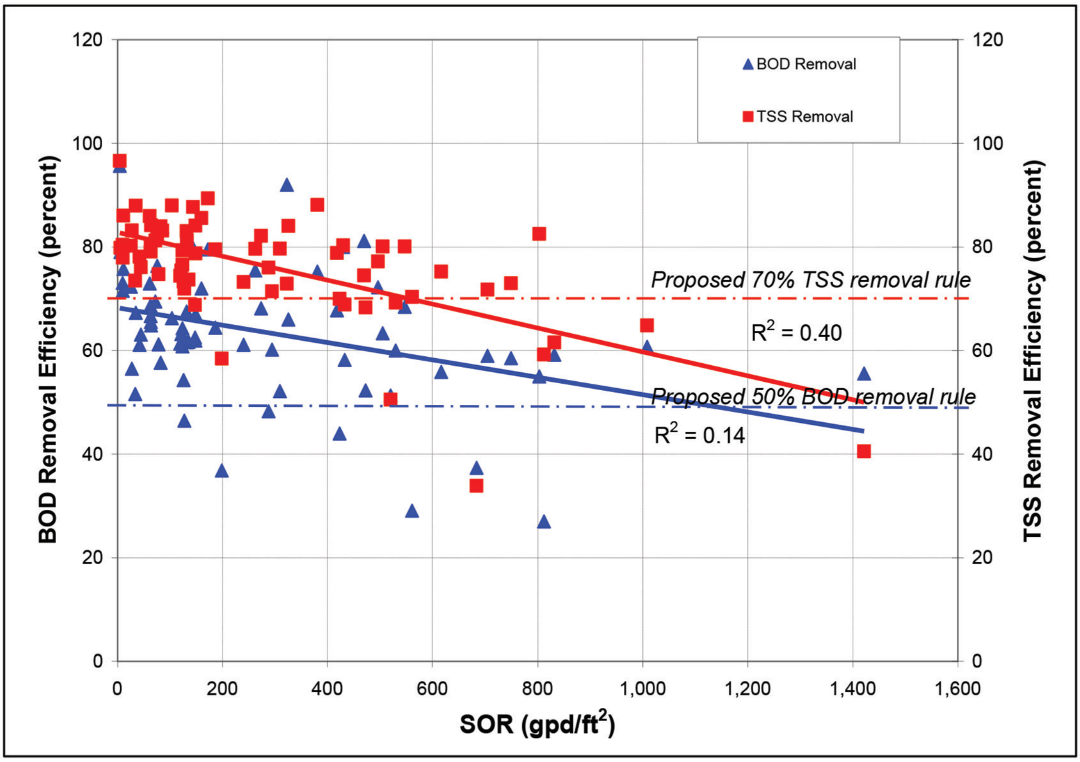


FIGURE 12.12 Performance of existing WWPCs at the Columbia Boulevard facility in 2006 (Melcer et al., 2010).

which chemicals were suitable for the WWPC influent and at what dosages. Ferric chloride and anionic polymer were identified as the most appropriate chemicals (Melcer et al., 2010). In 2009, they were tested in the field during wet weather events to verify the bench-scale test results and to evaluate the best hydraulic location for introducing them to the primary influent. The maximum SOR experienced was 118 m/d (2900 gpd/sq ft); unfortunately, significant high-flow events were not experienced during all four events observed. With the exception of the March 15, 2009, event, the CEPT system consistently achieved greater than 80% TSS removal and greater than 65% BOD removal during the trial (greater than the target levels). Removal performance appeared to be related to the degree of influent dilution. During the trial, the ferric chloride dose was gradually reduced from 50 to 25 mg/L. The polymer dose was more stable, with the best results observed at a concentration of 1.2 to 1.3 mg/L.

The full-scale system was installed in 2012, but has not yet experienced significant wet weather events because of the drought conditions in the Portland area during the winter of 2012 to 2013.

Similar investigations have been conducted at the Metropolitan District C's Hartford, Connecticut, water resource recovery facility (Newman et al., 2013) and are underway at the Northeast Ohio Regional Sewer District's (NEORSD) three Cleveland, Ohio, water resource recovery facilities (Melcer et al., 2012). Modified CEPT facilities are currently in design in Hartford and under construction at the NEORSD facilities.

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