Innovative Wastewater Treatment in the Developing World

The century-old technology of chemically enhanced primary treatment can be an effective and economical way to boost wastewater treatment plant performance.

MICHAEL R. BOURKE, DONALD R.F. HARLEMAN, HEIDI LI, SUSAN E. MURCOTT, GAUTAM NARASIMHAN & IRENE W. YU

The addition of chemical coagulants to increase the performance of primary wastewater treatment settling units has gained greater recognition and application in recent years. While the process of adding metal salts as coagulants to increase sedimentation rates is nothing new, the practice had fallen out of favor, largely due the large amounts of additional sludge produced. However, with research and application involving reduced metal salt dosages and advances in polymer technology, many earlier obstacles to use have been overcome. Chemical addition is a particularly appealing approach in developing countries since it provides a non-energy–intensive method to dramatically increase the efficiency of new plants and the performance of existing wastewater treatment facilities. For example, in Brazil chemically enhanced primary treatment has been increasingly applied both to overloaded existing plants and to the design of direly needed new facilities. In addition, early findings from the operation of a major new facility in Hong Kong provide an example of the performance of large-scale facilities designed specifically for chemically enhanced primary treatment.

General Principles of Chemically Enhanced Primary Treatment

The first stage of treatment in a wastewater treatment plant is usually sedimentation, which relies on gravitational settling to remove a portion of the suspended solids, biological oxygen demand (BOD) and nutrients (especially phosphorus and nitrogen) in the influent wastewater. This primary treatment is often followed by a biological treatment stage such as activated sludge and then by disinfection prior to discharge into a water body. In the primary stage, some of the particles that have a higher specific gravity than water will settle to

TABLE 1.
Typical Removal Efficiencies of Primary Treatment

Criterion	Conventional Primary Treatment (%)	CEPT (%)
TSS	60	75-85
BOD	30	55-65
Phosphorus	30	55-85
Nitrogen	30	30

the bottom of the sedimentation tank, forming a sludge blanket that is periodically removed, treated and disposed of, usually in a landfill.

The efficiency of primary sedimentation tanks are a function of the surface overflow rate, defined as the plant flow rate divided by the total surface area of the primary sedimentation tanks. For conventional primary settling, the overflow rate for average dry weather flow is about 40 meters per day (m/d) and typical removal rates are about 60 percent of the influent total suspended solids (TSS), 30 percent of the BOD, 30 percent of the nitrogen content and 30 percent of the phosphorus. The settling process is enhanced by coagulation — the tendency of particles to coalesce. The greater size of coalesced particles causes them to settle faster.

Chemically enhanced primary treatment (CEPT), also called direct or pre-precipitation treatment in Europe, involves the addition of small amounts of chemical agents and polymers to increase the coagulation process. The addition of metal salts — such as ferric chloride, ferric sulfate or alum — decreases the surface potential around the wastewater particles, reducing the resistance that must be overcome before coalescence. Settling can be further augmented by the addition of polymers, which aid in floc formation. The best results are usually achieved when chemical salt addition is followed by a period of rapid mixing to promote coagulation followed by polymer addition and a slower mixing regime to minimize floc break-up. In contrast to conventional primary treatment, a well operated sedimentation basin with chemical addition can achieve removals of 85 percent of the influent TSS, 65 percent of the BOD, 30 percent of the nitrogen and 85 percent of the phosphorus at overflow rates two to three times larger than for conventional primary settling.[1] CEPT is therefore a simple, cost-effective treatment technology for upgrading the removal efficiency and increasing the flow capacity of existing overloaded treatment plants. In the case of new plants, plant size can be decreased by a factor of two or more. In addition, the increased BOD removal by CEPT increases the organic load on any subsequent biological treatment stage, thereby increasing the treatment capacity of existing plants or reducing the size of new plants. Table 1 contrasts the removal efficiency of conventional primary treatment and CEPT.

History & Recent Developments in CEPT

The use of chemicals to increase the level of coagulation and flocculation in municipal wastewater was widespread in England as early as the late nineteenth century. However, with the advent of biological treatment in the early part of the twentieth century, the practice fell out of favor.[2] At the time, large dosages of chemical coagulants were added to obtain high removal efficiencies, resulting in large amounts of additional sludge. When lime was used, this increase could be as much as 100 percent. The expense of treating and disposing the sludge, typically a major part of the operating cost of a wastewater treatment plant, made coagulant addition uneconomical in the face of advances such as the activated sludge process. In addition, chemical dosages had to be individually tailored to the plant, requiring additional expense and expertise. By the 1930s, unaided gravitational settling followed by a biological unit became the norm for wastewater treatment.

Recent advances in the use of ferric or aluminum salts in conjunction with polymer technology has resulted in very low coagulant dosages. Chemical sludge volume has been reduced, and the previously prohibitive cost of additional sludge treatment and disposal has been largely overcome. Not only does the proper addition of chemical salts and polymers increase the efficiency and overflow rate of the primary sedimentation basin, but in doing so it decreases the load placed on any subsequent biological stage of treatment. This decrease in load translates into higher per-area plant efficiency — *i.e.*, a smaller CEPT facility can handle the load of a larger conventional one. Conversely, existing conventional facilities that are retrofitted to incorporate CEPT can handle overflow rates higher than the original design. As seen in Table 1, CEPT also greatly improves the phosphorus removal efficiency of the primary sedimentation process. This improvement is especially significant since it can reduce the need for expensive tertiary treatment. Indeed, the savings in terms of costs and space now make CEPT a cheaper option than conventional treatment in many cases.

It often takes a landmark case to prove the effectiveness of a new approach, and CEPT was no exception. In 1985 at the Point Loma wastewater treatment plant in San Diego, plant operators were faced with new stringent effluent requirements from the State of California and the U.S. Environmental Protection Agency (EPA) but little additional funds to meet them. The operators adapted well known potable water treatment processes by experimenting with the addition of metal salts combined with a small dose of polymer in their primary sedimentation basins and reported increased removal efficiency at three times the design overflow rate and minimal amounts of additional chemical sludge.[3,4] Ultimately, this modification was so successful that Congress waived the usual requirement for secondary treatment, saving the city an estimated two billion dollars and allowing the construction of a tertiary water reclamation facility that now reuses about 15 percent of the total wastewater flow, instead of discharging it into the ocean. Because chemical addition research at Point Loma was conducted independently by plant operators, it received little coverage in the technical engineering literature. Thus, it is only recently that awareness of CEPT is entering the general municipal wastewater treatment consciousness.

There is renewed focus on CEPT in the developing world, especially in Brazil, where it is becoming a particularly appealing approach to low-cost wastewater treatment. Not only is it more cost-effective than a conventional treatment train, but the technology of chemical addition is non-energy intensive. Moreover, burdened existing plants or wastewater treatment lagoons can be retrofitted with minimal effort. New plants, direly needed in this fast-industrializing part of the world, are being designed to incorporate chemical addition from the outset. Remarkably, awareness of CEPT has grown to the extent that even small, private plants are choosing to include it in their treatment processes. The particular appeal of CEPT in the developing world is that it produces an effluent that, unlike conventional primary effluent, can be effectively disinfected. With increasing recognition of CEPT as a high-performance, low-cost alternative, the expense of additional biological treatment for the sake of an incremental additional removal of BOD can rarely be justified.

CEPT in Brazil

São Paulo — Jar & Full-Plant Tests at the Ipiranga Facility. The Ipiranga wastewater treatment facility, also called E.T.E Jesus Neto, has been serving the city of São Paulo for over 70 years (see Figure 1). Greater São Paulo, the largest city in South America, has a population of about 17 million distributed in 339 municipalities.[5] The Iparanga plant is one of only a handful of treatment plants that currently service this area, and plant performance has been steadily declining due to the burgeoning wastewater inflows. Data from the period from 1993 to 1996 show that Ipiranga's primary sedimentation basins were achieving removal efficiencies of only 20 percent of influent TSS, in contrast to the 60 percent that is usually achieved in a well operated plant. BOD and chemical oxygen demand (COD) removals were also low — at 20 percent and 30 percent, respectively. In response to falling removal efficiencies, the state environmental authority (SABESP) agreed to a study designed to show that retrofitting the existing facility with CEPT was the most economical alternative to improve efficiency since this method would not require the expansion of the secondary activated sludge treatment unit.

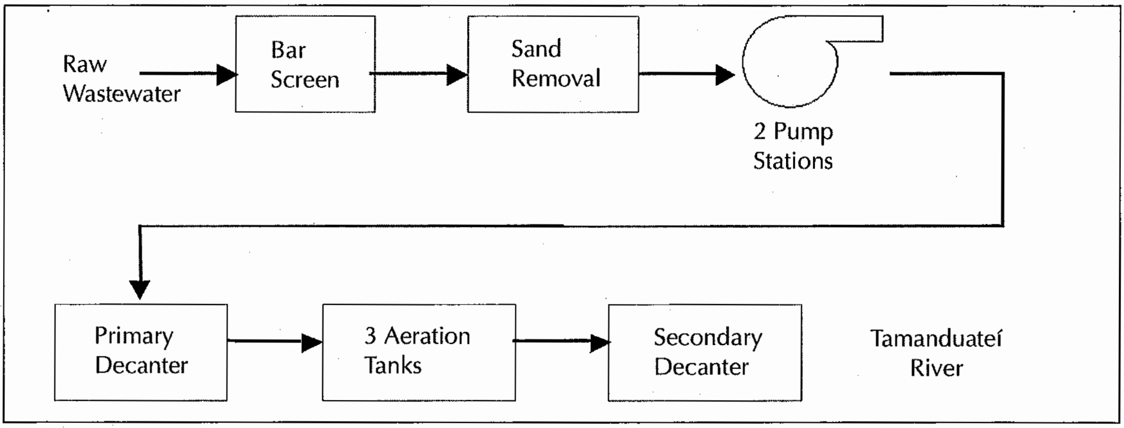

FIGURE 1. Schematic of the treatment train at the Ipiranga treatment plant.

Full-scale tests of a CEPT retrofit began in 1996 to optimize the chemical dosage regime. Based on jar-test studies, dosages were varied between 25 and 50 milligrams per liter (mg/L) of ferric chloride (dosed proportional to flow at the pumping station) and 0.25 and 0.5 mg/L of anionic polymer. As shown in Table 2, the full-scale test results were extremely encouraging. With a dosage of 50 mg/L of ferric chloride and 0.25 mg/L of polymer, 62 percent of influent BOD was removed in the primary stage alone. When the polymer dosage was increased to 0.5 mg/L, the BOD removal efficiency dropped slightly (to 58 percent) but an excellent TSS removal efficiency of 80 percent in the primary treatment stage was achieved. This marked increase in primary treatment performance resulted in removal efficiencies of both BOD and TSS in excess of 90 percent after the biological treatment unit. Prior to CEPT, the removal efficiency after secondary treatment was only 70 percent for BOD and 60 percent of the suspended solids. The two types of polymers used were an emulsion-based product manufactured in Brazil (designated "E" in Table 2) and a polymer that was soluble in water (designated "S" in Table 2) and that was manufactured in the United States.[6-8]

São Paulo — Jar Tests at the Pinheiros Facility. The Pinheiros wastewater treatment plant was constructed in the 1970s to serve the city of São Paulo and handles a flow of 110,000 cubic meters per day (m^3/day). The waste is of residential and industrial origin, with the former

TABLE 2.
Results of Full-Plant CEPT Tests at the Ipiranga Treatment Plant in São Paulo, Brazil

Dose of Ferric Chloride (mg/L)	Dose & Type of Polymer (mg/L)	Flow Rate (L/sec)	COD Removal Rate (%)	BOD Removal Rate (%)	TSS Removal Rate (%)
None Added	None Added	25	34	37	52
None Added	None Added	50	27	28	36
25	0.5 (E)	50	45	44	50
50	0.5 (E)	50	52	52	64
25	0.25 (S)	50	58	60	52
50	0.25 (S)	50	63	62	69
50	0.5 (S)	50	62	58	80

Note: E = manufactured in Brazil; S = water soluble & manufactured in the United States.

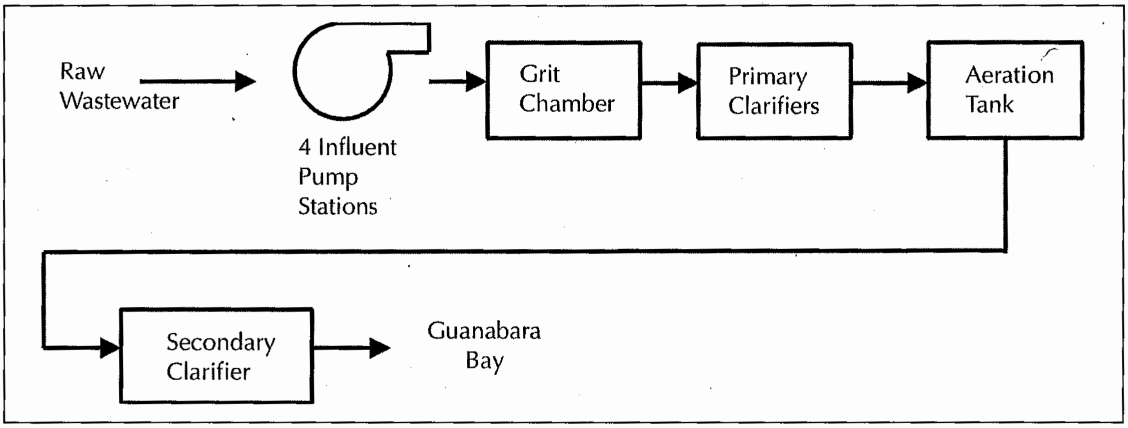

FIGURE 2. Schematic of the treatment train at the ETIG treatment plant.

contributing 70 percent of the flow. The facility is designed for sand removal, contains a conventional primary settling basin and secondary treatment. The primary sedimentation basin achieved removal rates of 32 percent of the influent BOD, 28 percent of COD and 33 percent of TSS. Due to its inadequacy in meeting effluent standards and maintenance problems (only one of three sludge digesters were operational), plant operation was discontinued in 1995 and wastewater rerouted to the Barueri plant through the construction of an underground feed channel. However, with the Brazilian government's interest in exploring treatment alternatives, the plant was chosen as a testing site to determine CEPT feasibility. While the problems of handling two different influent streams prevented full-scale tests of CEPT, bench-scale tests conducted in 1995 showed promise. A dosing regime of 25 mg/L of metal salt combined with between 0.3 and 5 mg/L of anionic polymer achieved removal rates of over 75 percent of the influent BOD in the first influent stream. This satisfies the 60 mg/L effluent BOD limit for the state of São Paulo without recourse to secondary biological treatment. TSS removals for the first influent stream were also reported at greater than 70 percent, far in excess of the 48 percent achieved with unaided gravitational settling.[9]

Rio de Janeiro — CEPT Retrofit of the ETIG Facility. Guanabara Bay in Rio de Janeiro suffers from extensive environmental contamination and algae growth due to high nutrient inputs, especially that of phosphorus. Discharge of untreated or poorly treated waste of industrial and residential origin has resulted in high levels of coliform, eutrophication problems and low dissolved oxygen in the surrounding waters. The bay's wastewater treatment facility at Ilha do Governador, ETIG, which was constructed in 1980, has been hard-pressed to meet effluent requirements. Four pumping stations provide the influent to the treatment train, which consists of a grit chamber, and a conventional primary settling basin followed by an activated sludge process. The effluent from this process is discharged into the Guanabara Bay.

To address increasing evidence of contamination in the bay and the poor performance of the facility, the state of Rio de Janeiro chose ETIG as a test site to explore the possibility of using CEPT in new plants. Extensive jar tests were conducted to optimize the chemical dosage for phosphorus removal and it was shown that removals of about 90 percent could be expected.[10] Subsequently, a full-plant test was performed. This test was comparative; the influent was divided into two streams, one which was fed to a conventional settling tank and the other was routed through a parallel sedimentation tank with the addition of metal salts and polymer. This full-scale procedure was run during December 15-21, 1998. In January 3-9, 1999, both streams were dosed with chemicals. Ferric chloride was dosed at 35 and 59 mg/L for both streams. Although the testing period was too short to provide much data, indications were that removal efficiencies were doubled. In con-

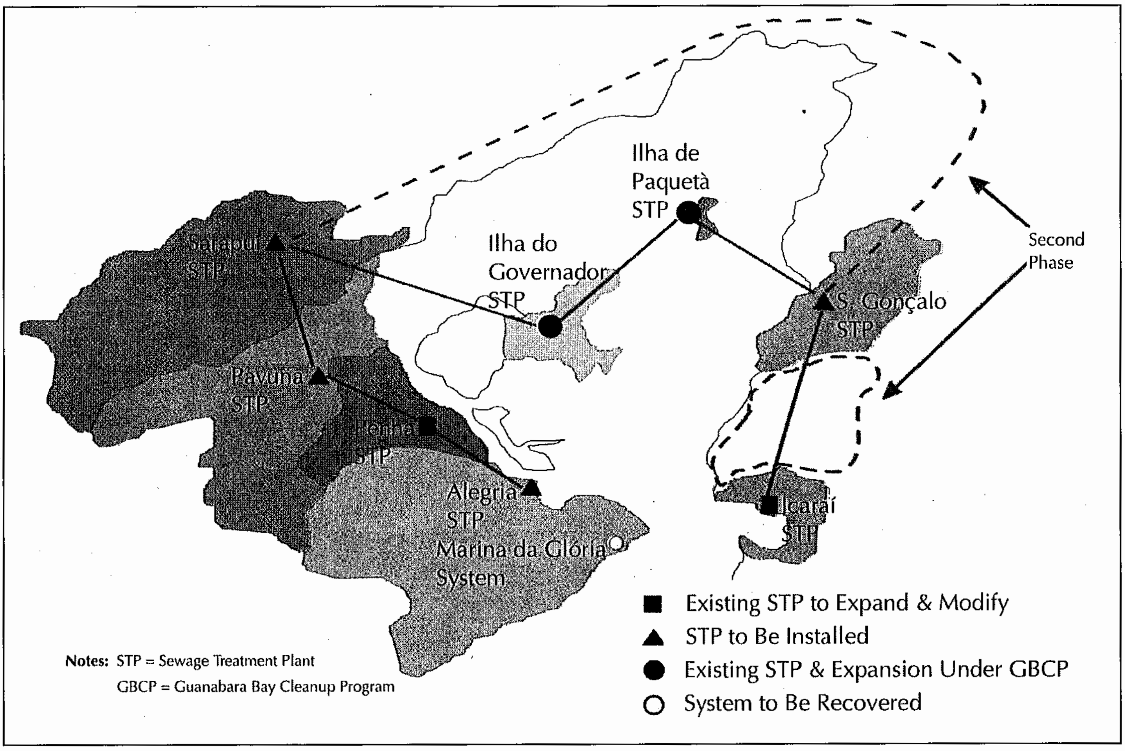

FIGURE 3. Location of the treatment plants in Rio de Janeiro.

trast to unaided primary settling which achieved maximum removal rates of 43 percent of the influent TSS, 44 percent of the BOD (though as low as 37 percent and 29 percent) and only 29 percent of the COD, the chemically dosed stream reported levels of as high as 76 percent of TSS, 75 percent of BOD and 65 percent of COD.

Rio de Janeiro — Construction of New Facilities at Pavuna & Sarapui. Based on the promise that CEPT has shown in bench and full-scale studies, the state of Rio de Janeiro constructed new plants designed for CEPT. The most advanced of these projects are the Pavuna and Sarapui plants in Rio de Janeiro. Each plant has a treatment capacity of 1 cubic meter per second (m^3/s), or 23 million gallons per day (mgd), and a cost of about $30 million. The location of these facilities is outlined in Figure 3. The construction of these two facilities is expected to make a significant contribution to alleviating the present water contamination problem; the Sarapui plant is designed to handle wastewater that is currently discharged into streams and rivers that flow only a short distance before emptying into Guanabara Bay. Due to the previous lack of an organized sewerage system, the influent to the Pavuna facility previously discharged into open ditches with obvious groundwater contamination consequences. The two plants will serve the inhabitants of 90 neighborhoods in the municipalities of Rio de Janeiro. Additional infrastructure for the plants includes over 800 kilometers of new sewerage, the lack of which hinders wastewater treatment efforts, and over 135,000 new household connections. Three and a half kilometers of pumping line have been installed.[11]

CEPT at Private Treatment Facilities — Riviera de São Lourenço. Riviera de São Lourenço, a small, private resort community on the Atlantic Coast about two hours by road from São Paulo, has a reputation for environmental consciousness and includes one of the best small-scale wastewater treatment facilities in the state of São Paulo. The original treatment system consisted of an anaerobic lagoon followed by three facultative lagoons in parallel. These components provide treatment prior to chlorine disinfection and dis-

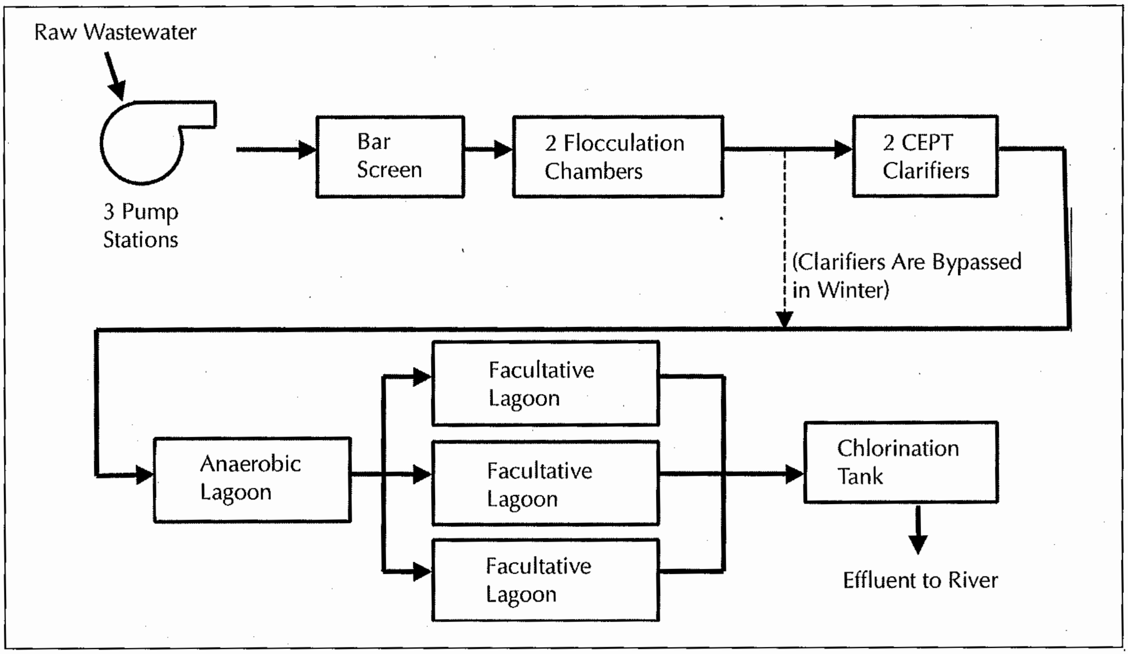

FIGURE 4. Schematic of the upgraded treatment train at the Riviera de Sao Lourenço plant.

charge into the Itapanhau River and thence to bathing beaches on the coast. Treatment efficiency is an increasing concern during the summer months, when the area population doubles to 80,000. Due to the popularity of this resort, the summer population is expected to climb even higher to over 100,000 in the near future. Anticipating the inadequacy of the present system to deal with the increased load from this projected population increase, the treatment train was recently modified to incorporate chemical addition. CEPT was a particularly appealing alternative for Riviera since chemical addition could be discontinued with minimal effort during the off-season winter months. Two CEPT clarifiers were added anterior to the existing lagoon system in January 2000, and early results showed a marked increase in treatment efficiency.

As part of the effort to maximize the benefit of the CEPT upgrade, more data were collected on-site in January 2000. Jar tests were performed on the Riviera wastewater to optimize chemical dosage.[12] Subsequent full-plant tests calibrated the results of the jar scale study to the larger system for the analysis of the performance of the upgraded system.[13] Furthermore, a site-specific biosolids management study was prepared to maintain and extend Riviera's reputation for ecological goodness.[14] To aid in plant monitoring and decision support, a desktop-computer–based application was created and a model of the lagoon system was created to help understand the true effects of the CEPT upgrade.[15]

Before the implementation of CEPT, the overall treatment efficiency of the combined lagoons during the 1999 Carnival period of February 13-16 was 79 percent for BOD. During the comparable 2000 Carnival period (March 3-7), after the installation of the CEPT clarifiers, removal efficiencies of 85 percent BOD were observed. While the increase in BOD removal efficiency was not large, it must be remembered that it was achieved with a BOD loading of 1,700 kilograms per day (kg/d) as compared to 1,200 kg/d during the Carnival period of the year before (about a 40 percent increase).

In the summer of 2000, the Riviera treatment facility was also briefly the test site for the simplest form of retrofit — the addition of chemical salts directly into the existing lagoon system, a procedure called *in-pond CEPT*. This move was done as an emergency measure since the new CEPT clarifiers were not fully operational during the summer season and plant operators were concerned about meeting effluent requirements. In-pond CEPT is widely used in Scandinavia to improve the efficiency of waste stabilization lagoons during the winter, and studies show that treatment efficiencies are similar to those achieved by chemical addition in a separate clarifier anterior to the treatment train.[16] The drawback of adding chemicals directly to the treatment lagoon is that the sludge blanket at the bottom of the lagoon builds up and must be periodically removed, usually once a year. The advantage is that skilled operators are not required to maintain a clarifier with an automated sludge removal system as in the case of pre-pond CEPT, and the construction and operating costs of the clarifiers can be dispensed with.[17] When 50 mg/L of ferric sulfate and 0.5 mg/L of anionic polymer was added directly into the anaerobic lagoon, COD removal efficiency in that lagoon jumped from 36 percent to 52 percent. Remarkably, TSS removal efficiency was recorded at 77 percent, extremely high for an anaerobic lagoon.

CEPT in Hong Kong

The recent developments in CEPT cannot be considered complete without a discussion of the success story of Stonecutters Island in Hong Kong. The booming economy of Hong Kong and its resulting increase in population to its current levels of 6 million people has created a massive increase in the quantity of wastewater that must be efficiently treated. About 1.65 million m^3/day were being discharged without treatment through local outfalls, prompting beach closures, high bacterial levels and depletion of dissolved oxygen content in the waters around Hong Kong. To address this problem, the Environmental Protection Department (EPD) of Hong Kong formulated a comprehensive wastewater treatment plan that addressed not only the demands of the current population, but planned for projected increases. The 1989 study recommended the construction of two new wastewater facilities with implementation in three stages. Stage I called for the collection and delivery of all wastewater from Kowloon and the eastern portion of Hong Kong Island to a new facility to be built at Stonecutters Island. Treated wastewater was to be discharged a short distance away into the Hong Kong Harbor through an interim outfall. Stage II would involve the construction of a 30-kilometer–long effluent tunnel that would end in a multiport diffuser in the Lema Channel, outside the territorial waters of Hong Kong. Stage III would be the construction of a new facility on Hong Kong Island, which would service the areas not already covered by Stonecutters Island.

The original plans for the Stonecutters Island facility called for conventional primary treatment in 58 sedimentation tanks. It was anticipated that the plant would be dosed with lime at 120 mg/L to raise the effluent pH to 9.7 and provide some degree of disinfection. Lime addition was to be a temporary measure until the Stage II outfall was completed. However, further studies showed that disinfection would be ineffective at this lime dosage and that enormous quantities of chemical sludge would be produced. Faced with the possibility of a new plant that did not meet effluent requirements even at the outset, the EPD appointed an International Review Panel in 1994 to assess the costs and benefits of higher levels of treatment, disinfection and alternative outfall locations.

The recommendation of the panel was that the design of the Stonecutters Island facility be upgraded to permanently incorporate CEPT — a recommendation that was implemented in early 1995, with plant operation by 1998. A major pilot plant study in 1996, upon which the review panel based its recommendation, achieved removal rates of 91 percent of influent suspended solids, compared with 71 percent for conventional treatment, and 80 percent of the influent BOD, compared with 42 percent for a conventional treatment train. Furthermore, the number of sedimentation tanks could be decreased from 58 to 38 because of the higher CEPT overflow rate. Not only did this reduce construction costs but also saved valuable space, allowing flexibility in implementing future treatment options — a huge benefit in an area where land is at a premium. The plant is designed for an average dry weather flow of 1,730,000 m^3/d in 2020 and a peak flow of twice that amount. Furthermore, the performance at Stonecutters

Island allowed the EDP to consider other options for Stage III, including the possibility of dispensing with plans for a treatment plant on Hong Kong Island.

Operational results of CEPT treatment at Stonecutters Island have been extremely encouraging. Influent wastewater, containing an average BOD of 143 mg/L, is treated to an effluent level of 42 mg/L, a removal efficiency of 71 percent. Influent suspended solids levels of 212 mg/L are treated to 36 mg/L, an efficiency of 83 percent. These removal efficiencies were attained at an average influent flow of 315,000 m^3/d and are far above those expected in primary treatment. These treatment levels are achieved at overflow rates of 50 to 60 m/d, which is twice that of conventional treatment plants. It has been found that the optimal dosing regime is 10 mg/L of ferric chloride combined with 0.1 mg/L of anionic polymer, extremely low concentrations that make the increase in plant performance and the cost of its operation all the more remarkable.[18]

Conclusions

The success of San Diego's Point Loma plant in 1985 has renewed interest in CEPT as an effective and economical way to increase the performance of wastewater treatment facilities. With dosages as low as 10 mg/L of ferric chloride and 0.1 mg/L of polymer, the new landmark facility in Hong Kong has reported highly effective pollutant removal at twice the original design overflow rate. In fast-industrializing regions of the world, such as Brazil, communities are increasingly discovering that chemical addition can be used to improve the performance of existing over-burdened plants and in maximizing the removal efficiency of their new facilities. Plants at Rio de Janeiro and São Paulo are being modified to include CEPT and new facilities under construction in Rio de Janeiro are being pre-designed to incorporate chemical addition. However, this trend is not limited to Brazil and Hong Kong. Major facilities in Cairo, Egypt and San Juan, Puerto Rico, have incorporated CEPT in their design and new treatment facilities at Mexico City may do the same. It appears that CEPT, a century-old technology that had fallen out of favor, is now back in vogue.

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MICHAEL R. BOURKE *received his Bachelor of Science in Civil Engineering degree from Loyola Marymount University in 1999. He received his Master of Engineering degree in Civil and Environmental Engineering from MIT in 2000.*

DONALD R.F. HARLEMAN *received his B.S. in Civil Engineering from Pennsylvania State University in 1943 and S.M. and Sc.D. degrees from the Massachusetts Institute of Technology (MIT) in 1947 and 1950, respectively. He has been a member of the MIT faculty since 1950, and has served as head of the Water Resources and Environmental Engineering Division of the Department of Civil Engineering and as Director of the Ralph M. Parsons Laboratory, and is now Professor Emeritus.*

HEIDI LI *received her Bachelor of Science in Civil Engineering degree from Queens University in 1999. She received his Master of Engineering*

degree in Civil and Environmental Engineering from MIT in 2000.

SUSAN E. MURCOTT *is a Lecturer in the Department of Civil and Environmental Engineering at the Massachusetts Institute of Technology (MIT). She is also the supervisor of the MIT Nepal Water Project. She received bachelor and master's degrees in Civil and Environmental Engineering from MIT in 1990 and 1992, respectively. She also maintains a consulting practice with her company, Ecosystems Engineering.*

GAUTAM NARASIMHAN *received his Bachelor of Science degree in Chemical Engineering from Rice University in 1999. He received his Master of Engineering degree in Civil and Environmental Engineering from MIT in 2000.*

IRENE W. YU *received her Bachelor of Science in Civil Engineering degree from Cornell University in 1999. She received her Master of Engineering degree in Civil and Environmental Engineering from MIT in 2000.*

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