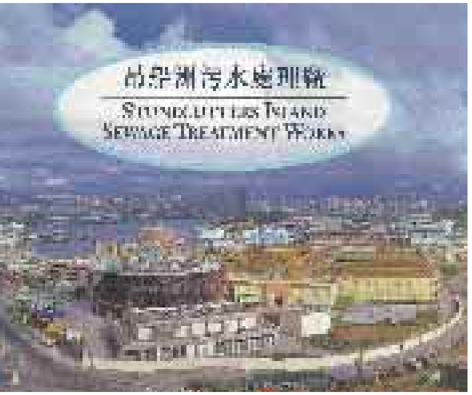
Is chemically-enhanced primary treatment a neglected technology with the potential to provide an appropriate first step in urban wastewater management in cities in developing countries? Or is it a technology that has been evolving over many years and which is already considered alongside other options? In this and the following articles, leading figures in the wastewater community put forward their views on the story of CEPT to date and what the future may hold for this technology.

An innovative approach to urban wastewater treatment in the developing world

● Should cities of the developing world invest in the dominant municipal wastewater treatment technology of western Europe and North America - conventional primary plus activated sludge - or should an alternative approach be taken? **DON HARLEMAN** and **SUSAN MURCOTT** give their views on why recent innovations in chemically enhanced primary treatment offer the appropriate first step.

Population growth in mega-cities and other urban areas of the developing world, and associated water-related pollution and public health problems, are a much discussed topic. The important issue is whether the developing world should follow the model of using the municipal wastewater treatment technology of western Europe and North America, or whether there is an alternative 'sustainable sanitation' approach?

A committee of the US National Research Council (NRC, 1996) reported on 'sustainable water and sanitation services for mega-cities in the developing world'. Unfortunately, the report is long on generalities and short on specifics. The authors indicate that 'water and sanitation professionals must take a broader view of sanitation to prevent disease resulting from a wide range of activities and multiple exposure routes'.



Hong Kong's CEPT treatment plant on Stonecutters Island.

On the role of treatment technology, the authors state that 'technical innovation should be based on carefully considered performance criteria appropriate to maintaining a healthy environment'. The final conclusion notes: 'With appropriate treatment, reclamation and reuse of municipal wastewater for non-potable uses can become an increasingly cost-effective conservation measure.'

'It seems much more useful to try to define the most efficient and cost-effective minimum level of treatment needed to protect public health.'

The issue of appropriate wastewater treatment for the developing world has also been featured in the IWA journal *Water Science and Technology* (Henze et al, 1997). Half the papers address the definition and analysis of sustainability, while the other half deal with the technology. Most of the technology papers are concerned with non-conventional (and very expensive) collection systems designed to separate, treat and dispose of liquid and faecal wastes by different processes. An overview paper by Varis and Somlyody (ibid) addresses the issue of global urbanisation and asks the question: 'Can sustainability be afforded?' They conclude that the conventional urban wastewater infrastructure of the industrialised world is neither sustainable nor transferable. However, they provide no specific answers as to what is affordable or what should be done to solve the water and sanitation problems of mega-cities.

In another exchange by three academic experts in the IAWQ magazine *Water Quality International*, Keinath (1996) 'believes the time has come to seriously consider the direct and deliberate reuse of water for potable uses in the mega-cities of the world'. He contends that 'treating water to high levels of quality…is likely to be less costly than further exploiting distant surface and subsurface waters' and recommends focusing research on the further development of advanced oxidation and adsorption processes and membrane technologies. Okun (1996) agrees with Keinath's basic premise, but contends that reuse should be limited to non-potable uses such as agricultural irrigation because this would require only 'secondary treatment followed by filtration and chlorination' and thus require no new technology. Alaerts (1997) offers a third perspective, stating that it would be 'more cost effective to reduce water demand in factories and in households. Rather than cleaning up a given effluent, we may prefer to promote cleaner production technologies, stimulatein-plant reuse, relocate the plant to less sensitive watersheds, or abolish the industry altogether.' He concludes that 'innovative and cost-effective technologies are essential components in these schemes'. However, he does not identify what these technologies are, nor does he explore the likelihood that developing countries will abolish industries because of environmental concerns.

This article, prompted by disappointment with the lack of realistic and concrete proposals offered by European and North American water experts, puts forward specific technological proposals. These are intended to encourage the continued vital discussion of which treatment technologies are appropriate for solving the urban sanitation problems of the developing world.

While it is true that some cities (Jakarta, for example) lack a sewage collection system, many urban areas have extensive sewerage systems that discharge untreated wastewater and contaminate adjacent rivers, shallow embayments or coastal waters. Only a small fraction of collected wastewater is treated, usually in 'token' secondary plants with conventional primary settling and activated sludge. Such plants frequently suffer from poor performance due to inadequate funds for maintenance and operator training or to biological upsets caused by toxic industrial inputs.

Rather than attempting to prescribe an ultimate effluent end use and its corresponding level of advanced treatment (as in the perspectives of Keinath, Okun and others), it seems much more useful to try to define the most efficient and cost-effective, minimum level of treatment needed to protect public health. Consider Mexico City as an example.

Mexico city - a case study in mega-city needs

The valley of Mexico, with 21 million inhabitants, covers an area of 1300km^2. The city lies on an old lake bed on a high plateau, with no natural drainage or source of fresh water. It would appear to be a prime candidate for reusing sewage for potable water since most of the drinking water is pumped from deep ground water wells or from distant lower surface water sources. The city produces an average of 75m^3/sec of wastewater, and this raw sewage is used to irrigate 85000ha of agricultural land in the neighbouring state of Hidalgo. These crops feed and provide income for the local population. The raw sewage is high in organic, nitrogen and phosphorus nutrients, as well as in faecal coliforms and helminth eggs - a debilitating parasite - in concentrations as high as 250 eggs/litre. Because the soil in the valley is poor, the organic material, nitrogen and phosphorus in the wastewater has greatly improved crop yields - corn production has increased 150%, onion 100%, tomato 94%, and so forth (Landa, H, et al, 1997). The irrigated area receives over 80kg/ha of nitrogen per year.

'There are now a growing number of examples of CEPT being tested and implemented in the developing world.'

Keinath's proposal for reuse of sewage as potable water for Mexico City is mind-boggling when one considers the cost of high-tech tertiary treatment for all or even a significant fraction of the 75m^3/s of raw sewage. The critical issue in Mexico City's use of raw sewage for irrigation is the high prevalence of enteric and parasitic disease among the more than 100,000 agricultural workers in the irrigated areas (CNA, 1995). Mexico City's pressing need is to find a level of treatment that will protect the workers through helminth egg removal and pathogen inactivation, while allowing continued use of the organics and nutrients for irrigation. Okun advocates reuse of sewage for agriculture, but immediately couples it with the need for secondary treatment prior to disinfection. This is consistent with the thinking of most western environmental planners and engineers. However, it must be questioned whether the capital and operating costs for full secondary treatment of the wastewater of Mexico City, given its other infrastructure needs, is a necessary or feasible option.

During visits to Mexico City between 1993 and 1995, the authors urged the National Water Authority to consider and test chemically enhanced primary treatment (CEPT), as a single-stage treatment process that would result in a high level of suspended solids removal, including helminth eggs, and would thereby produce an effluent that could be effectively and economically disinfected. This proposal became the basis for a number of pilot and full-scale tests in Mexico City (Murcott, et al,1996).

Additional pilot plant studies on the use of CEPT alone and in combination with high-rate sand filters have been completed (Landa, H et al, 1997).

CEPT is very effective in removing helminth eggs, reducing their presence to a range of two to five eggs per litre. Polishing sand filters were added to ensure an effluent with less than one egg per litre. The Mexican authorities made a cost evaluation of CEPT treatment in comparison with conventional primary plus activated sludge treatment for a number of proposed plants (CNA, 1995). For example, for the proposed El Salto plant (with a 15m^3/sec treatment capacity and 5.2m^3/sec mean flow) the construction cost (including sludge disposal) of the CEPT plant was estimated at $70 million. The conventional primary plus activated sludge facility cost was higher by a factor of 1.85. Annual operating costs were $4 million for CEPT and $7 million for the primary plus secondary plant. The annual cost of the CEPT chemicals is more than offset by the high energy cost for secondary aeration tanks.

Southern California – a case study in retrofitting CEPT

In 1985, the passage of California's ocean protection plan required that all treatment plants with ocean outfalls had to achieve suspended solids removal of 75% or greater. At this time, the four largest Southern California plants all had conventional primary treatment. Three, for the city and county of Los Angeles and Orange county, had partial secondary treatment while San Diego had only primary treatment. Because of rapid population growth, the plants were overloaded by a factor of two or more above their original design capacity. Plant operators, faced with poor performance due to overloaded conditions, met the state effluent requirement by turning to a century-old potable water treatment process - the addition of trivalent metal salts - to increase solids removal by coagulation and flocculation. They retrofitted their plants for CEPT treatment quickly and at very low cost.

Physical-chemical treatment of wastewater was a well-known technology that had fallen into disfavour in the second half of the 1900s because lime, the preferred chemical at high doses, produced very large quantities of additional sludge. The new twist in California in 1985 was the combination of a low dose of ferric chloride (~25 mg/litre) as a primary coagulant together with a minuscule amount of an anionic polymer (~0.2 mg/litre) as a flocculant. The CEPT process improved treatment efficiency considerably, with only a marginal increase in primary sludge production over that due to increased solids removal.

At Point Loma, San Diego's overloaded conventional primary plant, suspended solids removal increased to about 85% after the CEPT retrofit. BOD removal increased to more than 55% and phosphorus removal (by precipitation as ferric phosphate) to 85%. Even more impressive was the fact that the increased CEPT pollutant removal efficiencies were obtained at average surface overflow rates of up to 4.5m/h, about three times greater than commonly used in the design of conventional primary settling tanks. (Morrissey and Harleman, 1992).

San Diego occupies a unique place in the history of urban wastewater treatment in the US. In the late 1980s, the city was under intense pressure and a federal court order to comply with the EPA requirement to add an expensive secondary treatment plant. Certain city officials questioned the value of spending two billion dollars to obtain a small increase in BOD removal for an already clean CEPT effluent that was being discharged through a long ocean outfall. Their arguments were:

- extensive monitoring had shown no degradation of the ocean following the 1985 CEPT upgrade,
- since San Diego is at the short end of California's fresh water allocation, it would be more sensible and much less costly to construct a new tertiary plant to treat a fraction of San Diego's wastewater for reuse. Scientists at the Scripps Institute, who had been monitoring the CEPT effluent, strongly supported this viewpoint and San Diego joined with Boston and others in requesting a National Academy of Engineering review of wastewater management in coastal urban areas.

The study was completed (NRC, 1993) and Congress subsequently passed a special secondary treatment waiver for San Diego, allowing it to continue CEPT treatment at Point Loma and to build a new water reclamation plant to treat about 15% of its wastewater for reuse on land.

> 'It is reasonable to ask why, if CEPT is such an efficient and cost-effective treatment technology, it is not more widely known and used.'

Other plants, such as the city of Los Angeles' Hyperion facility, which had partial secondary treatment, were able to double their secondary flow capacity after CEPT implementation. This related to decreased BOD loading to the secondary stage, and the fact that the BOD remaining in the CEPT effluent was largely soluble and readily oxidisable.

The first use of low dose chemically enhanced primary treatment in North America was in several Canadian primary plants. These facilities started using CEPT in the early 1980s (Heinke,G et al, 1980) to reduce the discharge of phosphorus into the Great Lakes. In Europe, a similar process is known as 'direct precipitation'. For example, in Norway, higher doses (100 to 250mg/litre) of metal salt coagulant are used to meet the requirement for 95% phosphorus removal, with no biological treatment. More recently, chemical treatment with lamella plates has been promoted in France and French Canada at very high overflow rates. In these plants, CEPT is followed by aerated biofilters with sludge removal by periodic backwashing. The result, thanks to the elimination of secondary clarifiers, is a compact, although expensive, treatment plant that can be located in congested urban areas.

Impediments to CEPT in the developing world

It is reasonable to ask why, if CEPT is such an efficient and cost-effective treatment technology, it is not more widely known and used. There are several reasons:

- the California CEPT upgrades were carried out by plant operators who provided no exposure of their results in the technical literature
- there are few 'basic research' papers on CEPT because the process cannot be studied generically in university laboratories. Bench-scale and pilot plant tests must be done on site to determine effective coagulant chemicals and dosages
- there is a widespread belief that chemical treatment produces 'too much sludge'. The fact is that low dose CEPT produces only 10 to 15% more sludge than that resulting from the removal of suspended solids
- private engineering design firms are reluctant to use what they consider to be new approaches. A recent study by the American Consulting Engineers Council reported that three-fourths of their respondents avoid using innovative technology because they are afraid they could be sued if something goes wrong. This is a common 'red herring' used to justify the continuation of past practice.
- there is greater profit in designing plant expansions than in retrofitting and upgrading existing plants with CEPT
- the practice in the US is for a municipality to engage a firm on a non-competitive basis to design a plant, ask bids for construction and then operate the plant with city employees. This discourages innovation because the only competition is in the construction. In contrast, the European practice of bidding on a design/build/operate package encourages competition through using cost-effective, innovative treatment processes. European design firms that engage in this type of bidding have their own research laboratories to ensure that they understand and advance the treatment processes they propose.

There are now a growing number of examples of CEPT being tested and implemented in the developing world. Their objective is to protect public health, in a cost-effective manner, by first building the minimum level of wastewater treatment that permits effective removal of pollutants and deactivation of pathogens. Because of the increased surface overflow rate compared to conventional primary treatment, CEPT provides the minimum cost per unit volume of wastewater treated. There is no constraint on future biological upgrades; in fact, CEPT technology ensures that any subsequent biological treatment, if it can be justified, will be more efficient and smaller in both size and cost.

CEPT experience in Hong Kong

In 1994 the UK government of Hong Kong appointed an international review panel (which included the first author). This was intended to resolve a conflict over plans for the collection and treatment of sewage from the most populated areas of Kowloon and Hong Kong island. The long range government plan called for a conventional primary treatment plant within the harbour at Stonecutters island (SCI) and effluent discharge through a long (over 20km) ocean outfall into southern waters. The mainland government complained that the treatment was inadequate and that pollution would be exported from the harbour to Chinese territorial waters.

The panel completed its review in 1995, recommending that:

- the initial treatment at SCI be upgraded to CEPT
- a pilot plant study of the CEPT process be undertaken
- the long outfall be postponed

Subsequently the government redesigned the conventional primary as a CEPT plant and in doing so reduced the number of settling tanks by one third by taking advantage of a higher surface overflow rate (Harleman, Harremoes and Qian, 1997).

In May 1997, Hong Kong completed construction of the world's largest CEPT plant, having a maximum capacity of $40m^3/sec$ and a $20m^3/sec$ average flow. Operating data from the CEPT plant show removals in the order of 85% for suspended solids and 74% for BOD with a dosage of only 10mg/litre of ferric chloride. The surface overflow rate of about 60m/day is roughly twice that for conventional primary treatment. The use of seawater for flushing toilets undoubtedly contributes to the remarkable efficiency of the Hong Kong CEPT plant.

In April 2000 the Hong Kong government appointed a new international review panel (again including the first author). This was set up to address completing the collection and treatment of all of Hong Kong island's sewage and meeting ammonia water quality standards. The Government plan again proposed constructing the long southern outfall to achieve ammonia objectives through multi-port diffuser dilution. In November 2000, the Panel submitted its report (International Review Panel, 2000) and recommended elimination of the long outfall, by-passing secondary treatment and going directly to nitrification of the CEPT effluent at SCI using compact biological aerated filters. Discharge of the tertiary effluent will meet water quality standards at the local SCI outfall. The Government, in its initial response (EPD Hong Kong, 2001) decided to move ahead with the IRP recommendations. In view of the IPR, this may ultimately result in a savings on the order of one billion US dollars.

CEPT experience in Brazil

Bench-scale and full-plant CEPT demonstration tests have been successfully completed, first in Sao Paulo, under the sponsorship of the state wastewater agency (SABESP, 1996). Subsequently, in Rio de Janeiro in 1997, the World Bank requested a demonstration of CEPT technology at an existing treatment plant. The objective was to show whether CEPT technology should be used in future treatment plants designed to solve severe eutrophication problems within Guanabara bay. One of the major treatment objectives is low-cost phosphorus removal, phosphorus being the limiting nutrient controlling the large algal blooms that cause oxygen depletion and odours in the bay. Tests of CEPT showed that it is possible to remove about 90% of the phosphate as well as high levels of TSS and BOD (Harleman and Murcott, 1998). The first two CEPT treatment plants in Rio have been constructed by CEDAE, the state agency, and are now in operation.

In 1998 it was decided to use the Brazilian CEPT experience to provide Master of Engineering thesis opportunities for Massachusetts Institute of Technology students. Site visits to design, test and collect data on innovative treatment processes were made. The focus was on municipalities that have overloaded and poorly functioning plants. In Brazil, most wastewater treatment in medium size cities is by open lagoons at the edge of the urban area. The usual method of upgrading existing lagoon performance and treatment capacity is by cleaning and reconstructing the lagoons and installing surface aeration units. However, in addition to the initial costs, most cities cannot afford the large annual costs to run and maintain the aerators.


A polluted waterway in Beijing.

Students obtained data on anaerobic and facultative lagoons serving a coastal community having a large variation in seasonal population. A numerical model (Ferrara and Harleman, 1980) was used to predict the performance of the wastewater treatment lagoons. The calibrated model was then used to design two treatment upgrade alternatives for a city that had planned to upgrade existing lagoons by installing aerators. (Chagnon, 1999)

In the first treatment upgrade alternative, a small CEPT tank is placed in front of the first lagoon. This reduces the solids and BOD load on the lagoons and eliminates the need for aerators. The second alternative used an in-lagoon CEPT concept whereby chemical coagulants are added directly at the inlet of the first lagoon, again eliminating aerators. This type of CEPT lagoon, first successfully used in Scandinavia (Hanaeus, 1991), would be expected to perform better in the warmer climate of Brazil. A comparative cost study showed that both alternatives were less expensive, in capital and O&M costs, than the original aerated lagoon design (Cabral et al, 2000).

Conclusions and recommendations

Public health is the major water-related environmental concern in urban areas of the developing world. In many instances, drinking water and receiving water sources are contaminated by raw or inadequately treated wastewater effluents. Even when conventional primary treatment exists, its effluent cannot be effectively disinfected.

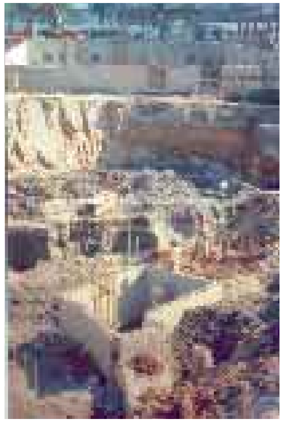
The objective of initial wastewater treatment investments, or upgrades of existing treatment facilities, should be a high-flow rate, low-cost treatment technology such as CEPT, which provides a high level of suspended solids removal, thereby permitting effective pathogen inactivation by disinfection.

The issue is not one of chemical versus biological treatment. Chemically enhanced primary treatment is the most cost-effective first step. It can always be followed at a later stage by more advanced biological treatment processes if they can be justified and afforded.

Most CEPT studies in developing countries have been carried out on a short-term ad-hoc basis, with little time and effort devoted to exploration and research. There is a clear need to develop long-range research and field studies at a number of existing treatment plants with different raw waste characteristics.

The following topics are recommended for further research:

- the interaction of metal salts as coagulants and anionic polymers for use as flocculants. This would explore the optimisation of combinations of metal salts and polymer dosages for maximum removal efficiency at high surface overflow rates
- the trade-off between various proportions of metal salts and cationic polymers as primary coagulants. This would offer potential savings in sludge production that might offset the higher cost of the polymers
- the efficiency improvements in CEPT technology through controlled mixing of coagulants and flocculants. This would demonstrate the effectiveness of mixing and flocculation devices upstream of settling tanks
- the effectiveness of recycling waste potable water treatment sludge and/or CEPT sludge. There is evidence that either may be effective in reducing coagulant doses
- the efficiency of combining CEPT with primary effluent filtration, or with aerated biofilters. The latter effectively uses the highly soluble BOD remaining after CEPT and, by backwashing, eliminates the cost and space required for secondary clarifiers
- the cost and energy savings of CEPT versus activated sludge wastewater treatment plants
- the interaction of CEPT and wastewater lagoons with either pre-lagoon CEPT treatment or in-lagoon chemical treatment. Collection of data on operating CEPT/lagoon combinations, in order to improve numerical modelling of lagoons to optimise final effluent quality and ultimate sludge disposal
- the potential uses of processed CEPT sludge for agricultural applications. Collection of data on the effectiveness of nutrients in the sludge
- disinfection by UV, or other options, following CEPT treatment ●


Construction of one of the CEPT plants in Rio de Janeiro, Brazil.

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The future of chemically enhanced primary treatment: evolution not revolution

● Has CEPT been overlooked in general and by the North American consulting engineering community in particular? Engineering consultants **DENNY S PARKER, JAMES BARNARD, GLEN T DAIGGER, RUDY J TEKIPPE** and **ERIC J WAHLBERG** respond to the preceding article by Don Harleman and Susan Murcott, reviewing practical experiences with CEPT and concluding that the answer is 'no' on both counts.

Harleman and Murcott challenge the professionals in the wastewater industry to adopt a specific technology, chemically enhanced primary treatment (CEPT). Their opinion is that its lack of broader acceptance is due to a dearth of publications covering the practice; absence of basic research; concerns over sludge production; risk-adverse design consultants; the profit motive of design consultants that are aligned with more expensive solutions; and the lack of competitiveness in technology applications in the US.

There is value in reviewing any technology, innovative or well proven, and encouraging its unfettered consideration. However in this case, Harleman and Murcott move well beyond an objective technical assessment of CEPT technology. Their claim that this technology has been neglected by international water quality experts led to us being invited by a member of Water21's Editorial Panel to submit this discussion. We accepted, and believe the authors should be held to account for a blanket attack on the professional integrity of a broad class of environmental engineering professionals.

> 'If this negative public reaction had not occurred, there would be many more holders of ocean waiver permits in the USA today (and likely more CEPT plants).'

The senior author of this feature has been involved in process development of particle separation processes throughout 31 years of consulting engineering practice, including involvement in various CEPT projects throughout his career. All of our firms have been involved in investigation, research and applications for CEPT. We will demonstrate that CEPT is both a well-established tool and one that is well documented in the literature. Furthermore, we will show by our involvement in projects that have included CEPT that we do not regard it as a high-risk venture. And finally, those who broadly question the ethics of design consultants should back it up with more than mere opinions and statements of generalities. Indeed, challenging another party's professionalism without well-documented and substantiated information starts the accusers down a very slippery slope.

Harleman and Murcott's selective use of literature citations only inadequately reflects the extent of contributions in technology development for the developing world. It is patently unfair to demonstrate that there is little interest on the part of the water quality profession in appropriate technologies by picking a single IWA conference volume on futuristic concepts for integrated wastewater system design, when its principal focus was not on wastewater treatment technology for centralised treatment plants. There have been a number of IWA conferences that presented a very wide array of centralised treatment technologies specifically proposed as appropriate technology for developing countries (Wang et al, 1991, Ho and Mathew, 1993, El-Gohary, 1995, Lima et al, 1996, Mara et al, 1996 and Khanna and Kaul, 1996).

Research has reflected the following treatment technologies for centralised treatment: oxidation ponds, aerated lagoons, anaerobic lagoons, land treatment and disposal, anaerobic reactors of various configurations, pond treatment prior to reuse, activated sludge including sequencing batch reactors, evaporation systems, solids processing systems and separate industrial wastewater treatment systems. Our review revealed that CEPT is not featured in these volumes. This may indicate either that it has limited application or that it is considered already at the state of development where the technology can be transferred to developing countries without further research. Or, on the other hand, will Harleman and Murcott imply in their rebuttal that the 300-plus investigators with papers in these IWA volumes have a bias against CEPT or that they lack creativity?

Reading Harleman and Murcott's article might lead the reader to believe that all relevant applications of CEPT began with the work of Canadian engineers in the early 1980s (though they did indeed make valuable contributions) or by the operators of Californian treatment plants in the mid-1980s (who also made valuable contributions) or as a result of Professor Harleman's recent advocacy of CEPT. In fact, our review shows a steady and consistent development and practical application of CEPT beginning at least 35 years ago. Our own reference list shows 76 investigators (consulting engineers, municipal engineers, scientists and operators) who have advanced CEPT technology. These investigators (many with multiple contributions) are from the following countries or regions: US (59), Canada (7), Scandinavia (7), Israel (2), Australia (1) and Bulgaria (1). A technology assessment should have at its heart a thorough literature review and an acknowledgement of prior work. Will Harleman and

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Murcott acknowledge in their rebuttal that almost without exception they have overlooked the work of these investigators?

History of CEPT development

The earliest reported practice of CEPT seems to be in England as early as 1870, and it is also stated that it was used extensively in the 1890s and early 1900s in the US before the development of biological treatment. It is also stated that CEPT had a resurgence in the 1930s in the US (Metcalf and Eddy,, 1991), but for these periods of practice we could find no useful technical articles in our libraries or files.

CEPT: a response to eutrophication concerns

In the 1960s, with eutrophication problems in the Great Lakes, specific objectives for phosphorus reduction appeared on the near-term horizon for many municipal dischargers. This was before the development of proven systems for biological phosphorus removal, and technologists turned to chemical addition for reliable treatment. A major equipment vendor, Dorr Oliver, advanced an innovative two-step system consisting of CEPT followed by activated sludge treatment. Termed the 'phosphate extraction process', it was postulated that if the pH was adjusted to between 9.5 to 10 with lime in the primary clarifier, carbon dioxide generation in the aeration basins would be sufficient to decrease the pH to an acceptable range while achieving 90% phosphorus removal across the entire process (Albertson and Sherwood, 1967). Basic research at bench-scale explored such variables as the effect of lime dosage and pH on residual BOD, COD and phosphorus along with the influence of sludge recirculation to the CEPT flocculation zone.

> **'The reader should conclude from this review that the CEPT technology has been well developed after at least 35 years of basic and applied research at bench, pilot and field-scale.'**

At the same time, chemical suppliers developed application technology. For instance, the Dow Chemical Company developed its CEPT concept around low dose applications of ferric chloride as the primary coagulant, with supplemental anionic polymer. The investigators named it 'The Dow process for phosphorus removal'. Starting initially with basic research at bench-scale, the work progressed almost immediately to full-scale tests at Grayling and Lake Odessa, Michigan (Wukash, 1968, Dow Chemical Company, 1967a, and Dow Chemical Company, 1967b). These studies dealt with the practical issues of locating appropriate coagulant addition points in plants without designed-in flocculation facilities. Dow extended its work at Buffalo, New York, Benton Harbor, Michigan and Cleveland, Ohio. At Fe dosages of 14 to 20mg/l with 0.5mg/l of anionic polymer, 64% to 80% suspended solids (SS) removals were obtained compared to 0% to 40% in the controls (Johnson et al, 1969, Dow Chemical Company, 1970a and 1970b). It was found that performance was highly sensitive to the polymer addition point, and if polymer was added to the process too far ahead of the primary sedimentation tanks, floc breakup would occur in the conveyance facilities.

Later, Heinke et al (1980) conducted CEPT testing at the Windsor, Sarnia and CCIW plants in Ontario. At the Windsor plant, optimum performance was achieved with ferric chloride (17mg/l as Fe) and 0.3mg/l of anionic polymer. It should be noted that Heinke et al (1980) confirmed the earlier work in the Dow process in that it was shown that CEPT increases the particle settling rates and removal efficiency. Further, they showed that the technology allowed higher surface overflow rates than had been previously employed in primary clarifier design in Canada.

In parallel with the work of Dorr Oliver and Dow Chemical, Allied Chemical made strides with its aluminum products (Allied Chemical Corporation, 1970). Success was demonstrated with alum in CEPT applications, such as at Windsor, Ontario (Allied, Chemical Corporation, 1973).

Wilson et al (1975) reported successful full-scale trials using CEPT with alum and polymer at Tampa, Florida. CEPT was shown to be capable of SS and BOD removal levels of 83% and 44% respectively. Later, basic research in the laboratory by Dentel and Gosset (1987) showed that regions of raw wastewater coagulation with alum were similar to that occurring in water treatment, provided some of the differences are accounted for.

Parallel European development of CEPT technology started in the early 1970s and was concentrated in Scandinavia, largely out of concerns over algal blooms. Erickson (1973) reported on early CEPT trials in Sweden. Testing resulted in the full-scale application at two plants, using low iron dosages. While not much benefit was seen in terms of SS removal improvements with CEPT, after subsequent biological treatment the final effluent phosphorus objectives were realised. Odegaard (1992) reported on developments in Norway, where 28 plants provided CEPT alone without subsequent biological treatment. This report reflects years of practical work with CEPT optimisation. It was believed that for the weak, fresh and cold wastewater typically found in Norway, CEPT technology was particularly appropriate. Average BOD and SS removals of 82% and 87% were obtained because of the low concentration of soluble BOD, albeit with much higher chemical dosages than used in the Dow Process in the US.

Odegaard's (1998) basic research on CEPT has looked at the influence of organic polymers as supplements to metal salt additions. He showed a considerable enhancement to floc settling rates, allowing higher surface overflow rates than when the metal salt was used alone, confirming earlier practical experience in the US. Of perhaps more significance, it was shown at bench-scale that cationic polymers could be substituted for metal salts to minimise sludge production when no phosphorus removal was required. The best removals overall were achieved with a combination of metal salts and organic polymer. As shown earlier in the US, using polymer as a supplemental coagulant could minimise metal salt usage.

Orange County Sanitation District's Water Reclamation Plant No. 1, located in Fountain Valley, California. Chemically Enhanced Primary Treatment (CEPT) effluent is blended with activated sludge effluent to meet federal 301(h) waiver permit requirements for monthly average TSS and BOD concentrations of 60 mg/L and 100 mg/L, respectively. Two sets of primaries are shown. To the lower left are 10 covered rectangular primaries, while to the upper lieft are three covered circular tanks.
Brown and Caldwell recently completed CEPT optimization studies to support the design and construction of an extension of the rectangular primary tanks in the field adjacent to them. The District owns another plant nearby (Plant 2) that also blends CEPT and secondary effluents to meet the same permit requirement.

CEPT as part of a physical/chemical flowsheet for secondary treatment

The development of CEPT continued in the US in the 1970s. Some of the work took place because of the interest in using CEPT as the first step in a treatment scheme, followed by activated carbon. For example, the work of Shuckrow and Bonner (1971), Feige and Berg (1973) and Burns and Shell (1973) is of interest. Here, various coagulant comparisons were made such as low dose iron to lime and alum to lime at pilot- and full-scale. Basic research in the laboratory by Bowen and DiGiano (1975) involved settling column tests and adaptation of the water treatment jar testing procedures of Tekippe and Ham (1970) for CEPT. This allowed the development of design methodologies that enabled the engineer to select optimum coagulant dosages, pH values, flocculation intensities and sedimentation times for CEPT. It was shown that alum could not sustain as high a clarifier surface overflow rate for the same removal as that obtained with lime and also that alum sludges were more difficult to dewater.

The use of CEPT followed by activated carbon did not prove an unqualified success in warmer climates, with septic wastewater. Over ten municipal plants were built with this flowsheet, all but one of which failed due to process or mechanical reasons and were taken out of service. Roll and Crocker (1996) describe the efforts of plant staff to keep the Niagara Falls plant in effective operation under very trying circumstances.

CEPT coupled with biological treatment for advanced wastewater treatment

At the same time as the work on physical chemical treatment was being undertaken, Californian investigators continued to work on CEPT followed by biological treatment. The CEPT work was at full-scale, with lime as the primary coagulant and focused on optimising CEPT to maximise the effectiveness of downstream nitrification (Horstkotte et al, 1974). With the use of lime at pH 10.2 and with iron as a supplemental coagulant, BOD and SS removals with CEPT were 66% and 87% respectively, compared to 40% and 75% in the control. When primary effluent pH was less than 11.0, acid production and carbon dioxide generation in the activated sludge process was sufficient to rapidly decrease the pH in the aeration basins to a normal operating range. Research was extended to include demonstration of centrifugal sludge classification and lime recovery through recalcination in a multiple hearth furnace (Parker et al, 1974a, 1975). This test work served as the basis for the design of two large wastewater treatment plants, one in California and one in Australia (for an example, see Eisenhauer et al, 1976 and Philp, 1985). The work also formed the basis of a USEPA report on process design on CEPT with lime (Parker et al, 1974b).

The California work looking at CEPT followed by a nitrifying process has been followed up by a number of engineers and research investigators. Interest moved from using lime in the primary treatment process to the use of aluminum or iron compounds (usually supplemented by polymer) largely because this simplified sludge management. The senior author was involved in process design in the 1980s for two secondary treatment plants constructed downstream of CEPT using

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Lima, FF, Filho, FAP., van Haandel, A and Almeida, SAS,

iron salts. One is located in Cleveland (Ohio) and is a trickling filter/solids contact plant and the other is in Appleton (Wisconsin) and is a nitrifying activated sludge plant. Andersson and Rosen (1989) reported on how adding ferric chloride to the primary treatment stage brought about organic load reductions as well as phosphorus removal, thereby improving nitrification in two Swedish activated sludge plants. The work was extended to show the significant influence that supplemental polymer addition has in increasing SS removal (Andersson et al, 1997).

Galil and Rebhun (1990) showed that the reduction of levels of organics with CEPT using either lime or alum as the coagulant enable a remarkable reduction in the size of the aeration tank required for nitrification in the downstream activated sludge process. Further, the City of Atlanta (Georgia) has used aluminum and iron products as alternatives in a CEPT mode, ahead of a nitrifying activated sludge plant, to meet interim phosphorus removal requirements at its largest plant as it moves to full biological phosphorus removal. Sedlak (1992) and Daigger and Parker (2000) review other full-scale work using CEPT ahead of the activated sludge process. Also, similar work with fixed film processes (biological aerated filters and trickling filter technology) has been done at Windsor, Ontario, with CEPT at low iron dosages preceding the biological processes. Chemical addition to the primary tank provided a double benefit from the coagulant, in that it reduced both phosphorus and organics, resulting in an optimised design overall for nitrification and phosphorus removal (Newbigging et al, 1995 and Parker et al, 1998).

CEPT for ocean disposal

The late 1960s and 1970s saw another impetus for CEPT development. Agencies discharging effluents to the ocean on the west coast of the US could reasonably predict that regulatory agencies would require treatment to be upgraded from conventional primary to biological processes. Recognising the high cost of secondary treatment and the lack of a demonstrable benefit for high degrees of BOD removal for effluents discharged through deep ocean outfalls, municipalities sought a more cost-effective and appropriate combination of treatment and dilution than existed for their inland counterparts. For instance, CEPT research was done at pilot and plant-scale at San Francisco, California (City and County of San Francisco, 1967, Brown and Caldwell, 1971) and Seattle, Washington (Brown and Caldwell, 1978a). The senior author participated in the pilot-scale CEPT work for both municipalities.

The City and County of San Francisco (1967) modified the Dow Process by deliberately adding seawater with a Fe dose of 8mg/l and an anionic polymer dosage of 0.2 to 0.4mg/l anionic polymer. The test was very successful and resulted in SS removals of 76% to 80%. However, it was later reported that the use of seawater caused severe corrosion to the existing tank's internal equipment.

In Seattle, both lime and alum were tested at pilot scale during different periods. Basic research was conducted into the effects of coagulant dosage, flocculation conditions, solids production, use of secondary coagulants (such as polymer with alum and iron with lime), sludge recycling and the use of seawater to provide magnesium for coagulation in the lime system. It was found that particulate BOD was removed to the same extent as the suspended matter, but that soluble BOD was only marginally removed. Both systems were capable of removing 94% of the influent SS. During the full-scale trials with alum, SS removal levels decreased to 84%, but chemical application points were possibly not optimised during the short test periods.

The dischargers on the west coast of the US were confounded when the USEPA issued uniform secondary treatment requirements in 1974 that allowed no exceptions for deep ocean disposal. Publicly elected representatives, utility managers and engineering consultants lobbied for a change in the law to allow for lower-cost alternatives to full biological treatment such as CEPT, or blends of biological and primary effluents. During the same period, the senior author was the project manager for wastewater facilities planning for the City of Santa Cruz and Santa Cruz County (California). We argued against the USEPA's rigid position that only biological secondary treatment alternatives be considered. We favoured CEPT, consisting of low dosage iron and polymer as a more cost-effective alternative. The compromise was for the city to include the alternative in the project report as an initial step (Brown and Caldwell, 1978b). Once the US Congress passed the 'ocean waiver' discharge permit provision and the USEPA promulgated the implementation regulations, the City of Santa Cruz engaged the senior author's firm to prepare their application and to complete the design. Pilot- and field-scale studies were used to optimise the use of pre-aeration for flocculation with low dosage iron, followed with polymer addition prior to the existing primary tanks (Volpe et al, 1987). The constructed plant easily met California's required monthly average 75% SS removal criterion with coagulation with low ferric chloride and polymer.

> **'It could be an appropriate first step of treatment in individual cases, but no claim should be made for universal applicability, as there are many competing technologies.'**

However, getting an ocean waiver approval process established by the US Congress provided no assurance that a permit for discharge would ultimately be obtained. Often, public hearings associated with the consideration of the discharge permits by USEPA brought out an electorate activated by environmentalists who took the position that anything less than secondary treatment was bad for ocean water quality. Rather than suffer continual controversy, a number of agencies backed away from the ocean waiver process and either declined to apply for waivers, abandoned their applications mid-process or did not renew them after one or two permit terms. If this negative public reaction had not occurred, there would be many more holders of ocean waiver permits in the USA today (and likely more CEPT plants).

The City of San Diego, California, was a case where an ocean waiver application was not completed by mandated deadlines and therefore no ocean waiver permit was issued by the USEPA. Highly vocal public opposition discouraged the city from submitting an application. However, prominent scientists at the University of California Scripps Institute of Oceanography strongly advocated its position: its investigations showed that no harm was being caused by the existing deep ocean outfall serving the city's large Point Loma primary wastewater treatment plant. This cut the ground out from under the protesting groups. With this scientific backing, the city decided to reconfigure the system in a manner that would leave Point Loma as a CEPT facility and to take what would have been spent on secondary treatment to build upstream water reclamation plants for a portion of the flow. The city applied for and received from a US federal judge a number of stays in its deadlines for secondary treatment completion at Point Loma, despite the legal and technical opposition of the USEPA. Ultimately, it was successful in getting a waiver granted directly by the US Congress.

The experience of several California ocean dischargers with CEPT using low dosage iron and polymer is summarised and compared by Ooten et al (1993). Recently, progress at one of these CEPT plants was reviewed by Hetherington et al (1999).

Other west coast agencies lacking permits with ocean waiver provisions proceeded with planning for full biological treatment. In California, the City of Los Angeles' Hyperion treatment plant was in this position. In the 1980s, engineers on the staff of city and programme management consultant CH2M Hill did not fail to look at CEPT as a potential technology to reduce the size and cost of the secondary treatment expansion. A detailed comparison was made between the capital and operating costs of CEPT (based on plant experience with low dosage ferric chloride with polymer) and conventional primary systems ahead of

Central Contra Costa Sanitary District's plant as it existed in 1971 during CEPT testing at the site. Three sets of rectangular tanks are shown. The primary tanks on the left were in use for processing most of the District s flows. The primary tanks in the center were available for CEPT testing, one as the control and one for the lime treatment mode of CEPT. The smallest primary tanks on the right supported nitrification/denitrification test at 1.9 ML/d (0.5 mgd). CEPT testing was at full-scale and would support average design flows of 10 ML/d (2.5 mgd).

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activated sludge treatment.

All of the impacts were considered and summarised, such as the marginal increase in sludge with CEPT as well as the reduced oxygen requirements for the planned downstream oxygen activated sludge system. It was found that there was a net total cost increase with CEPT (Chaudary et al, 1989). After more years of operating experience with CEPT and high rate activated sludge treatment, operators at the Hyperion plant returned to a comparison of that process configuration with conventional primary treatment followed by activated sludge. They subsequently developed a proposal that was different to the plan the city had adopted. They showed a sludge production increase, just as in the original study; but in this case found a net total cost decrease (Shao et al, 1996).

The issue was looked at again in the 1990s by the city and its design consultant (Black and Veatch). In the final design of the Hyperion plant, the city decided to provide for ferric chloride addition but also provided adequate secondary treatment capacity to enable the plant to handle design flows if the chemical were not added. The reasoning was that the supply or price of chemicals was uncertain, so the city did not want to have to rely on them. But it was decided to retain the capability to add chemicals. Among the reasons was the fact that iron addition controlled the formation of sulphide and struvite in the digesters. The example of the Hyperion case makes the point that those involved with CEPT applications can have professional differences of opinion. Indeed, the same individual may 'change sides' in an argument when new information becomes available.

> **‘Harleman and Murcott are silent on a more recent development of CEPT, ballasted flocculation, which is being pilot-tested all over the US.’**

The National Research Council (1993) has evaluated treatment technologies that could prove useful for ocean disposal. Engineering studies showed that while CEPT was significantly less expensive than biological treatment, it had no cost advantage when coupled with biological treatment over a conventional primary treatment /biological treatment flowsheet. This was shown to be the case for both the low and high dosage forms of CEPT.

Recently, two of the authors have been involved in re-evaluating CEPT to optimise its efficiency. These investigations have been oriented to identifying organic polymers that could substitute for metal coagulants. They also aimed to extend the usefulness of jar tests and settling column tests to allow more rapid field optimisation of coagulant dosages and application points, and to identify where flocculation opportunities are best enhanced in existing CEPT systems (Wahlberg et al, 1998 and Parker et al, 2000). For the studies on substitution of polymer, no benefit could be shown beyond that achieved by flocculation without coagulant addition. The procedures have been also been used to reconfigure some existing systems and to design new CEPT tanks that employ low iron dosages. The latter work was completed for the Orange County Sanitation District in California, which currently holds an ocean waiver permit.

Summary of CEPT development

Overall, the reader should conclude from this review that the CEPT technology has been well developed after at least 35 years of basic and applied research at bench, pilot and field-scale. There is a wealth of research and practical experience to draw upon. In addition to the cited references, recent design manuals and textbooks do a good job of presenting design approaches for CEPT (for instance, Bouker et al, 1987, Sedlack, 1992, and WEF and ASCE, 1998).

CEPT in Hong Kong

Two of the authors were involved as treatment technology consultants advising the Hong Kong-based firm conducting the independent review of Stage II of the strategic sewage disposal scheme for the Hong Kong government. This occurred at the same time as Professor Harleman's first involvement as an International Review Panel member. The reports of the two groups are bound in the same volume and should be considered together (Pypun, 1995 and Qian et al, 1995).

Harleman and Murcott are in error when they assert that Professor Harleman was instrumental in arguing that the conventional primary treatment planned for Stonecutter's Island in Stage I of the plan should be replaced with CEPT. In fact, the consultant (Montgomery Watson) had planned on CEPT using low lime (pH 9.7) treatment for the first stage of construction.

Harleman and Murcott are correct that it was the panel's recommendation to increase the surface overflow rate of the primary sedimentation tanks and that low dose iron should be used, but the iron was to replace lime as a coagulant. It should be noted that the independent consultants (Pypun, 1995) had previously concluded under Option 9 for Stage II that a shift should be made to low dose iron treatment with polymer at higher surface overflow rates. This was based on our prior US experience with CEPT. The fact that Professor Harleman and the rest of the panel would draw the same conclusions for Stage I is not surprising, since they also had access to information from CEPT practice in the US.

The 1995 Hong Kong review had the same intended effect as the value engineering studies typically conducted in the US and elsewhere, that is, to recommend changes in design that will save the owner money either initially or over the long term. Such peer reviews are a normal aspect of one's professional career.

In the preceding feature, the impression is created that the Hong Kong plant is fully operational. In fact, only a fraction of the wastewater is reaching the plant and it is fresher than it will ultimately be. When the 17km interceptor tunnel is completed, the bulk of the wastewater, containing a portion of seawater, will be discharged to the tunnel and pumped out. Anaerobic conditions and sulphide development can be expected due to the long residence times and high wastewater temperature. A degree of hydrolysis of the particulate matter could result, likely bringing about lower BOD and SS removals than reported by Harleman and Murcott. Once the system is fully operational, these effects should be tested and analysed.

CEPT in developing countries

Harleman and Murcott assert that CEPT technology is particularly suitable for the developing world. It could be an appropriate first step of treatment in individual cases, but no claim should be made for universal applicability, as there are many competing technologies. Selection of a treatment system should involve a careful engineering evaluation that includes a host of considerations, such as desired water quality, affordability, practical aspects of implementation, alternative technologies and, of course, cost considerations. For example in Brazil, anaerobic pre-treatment systems have been developed which remove 60% of the BOD while producing substantially less sludge (Sandino and Yee-Batista, 2000). When this is followed by pond systems, there is low overall sludge production and little or no power usage. In South Africa, anaerobic pond systems followed by algae ponds have resulted in no sludge production in seven years, despite treating very strong wastewater. The addition of a simple trickling filter captured the algae and produced effluents with BOD of less than 10mg/L and ammonia reduced from 70mg/L to less than 5mg/L. The plant used little power and no chemicals (Barnard and Meiring, 1995). On the other hand, Nenov (1995) concluded that CEPT was particularly appropriate for discharges to the Black sea. When compared to activated sludge it had lower capital and operating costs and could achieve relatively high BOD and SS removals at high surface overflow rates.

The authors also mention the recent start-up of two treatment plants (ETE's Pavuna and Sarapui) incorporating CEPT as part of the Guanabara Bay clean-up effort for Rio de Janeiro. It should be noted that a consulting engineering firm (Black and Veatch) recommended this process to CEDAE, the implementing agency, as early as 1996, and had completed preliminary designs almost a year earlier than the pilot testing efforts cited by the authors. These plants were designed with the intention of subsequently building an activated sludge stage.

An obvious example of where CEPT can easily be screened out as a potential treatment alternative is the case of many small island nations that have no infrastructure for in-country production of coagulant chemicals, where all chemicals have to be shipped in at high cost. It is obvious that, in such cases, there are more appropriate technologies.

CEPT and nutrient removal

Harleman and Murcott refer several times to the removal of phosphorus but hardly ever to the removal of nitrogen. Organic carbon compounds are required, and in many instances only limited or no primary treatment is used to ensure sufficient carbon remains to achieve denitrification. The alternative is to import carbon (for instance, methanol) for denitrification. The main energy cost in nitrogen removal is for nitrification, and much of the energy is recuperated during the denitrification process. Not mentioned at all is the effect of chemicals on the pH of subsequent processes for downstream nitrification. There are instances where CEPT must include pH correction to allow nitrification. Denitrification using internal carbon sources is also required in many cases to counter the drop in pH in low alkalinity water. In some cases, these considerations tend to counter the benefits of CEPT.

The references to phosphorus removal are also rather selective. The removal of 85% of phosphorus is sometimes achieved in activated sludge plants without a great deal of effort. Chemical precipitation requires heavy dosages to achieve low effluent phosphorus levels. Two of the authors were involved in recent studies at a plant in Oregon, in the US, where it was shown that by using biological phosphorus removal with chemical polishing, alum consumption could be reduced from 70mg/L to 20 mg/L.

CEPT and chemical phosphorus removal were seriously considered in South Africa in the early 1970s. The main reason for the wide adoption of biological phosphorus removal was the problem of the addition of salt to the wastewater with the chemicals used in CEPT. Recycling in inland situations increases salinity, and using chemicals could further impair the value of the effluent.

Research needs

Harleman and Murcott provide a listing of research needs, but the authors find that most of the topics have already been adequately addressed. Indeed, most of the research areas are no longer basic research issues at all and are most appropriately addressed as part of the study and implementation phases of actual projects. We do agree with the call for more research on UV disinfection of CEPT effluents, since the technology is in the early stages of development for low UV transmittance wastewaters. Also, there has been interesting bench-scale work done with aerating and recycling primary sludge to improve its flocculation potential to increase colloidal and soluble BOD removal in primary clarifiers (Huang and Li, 2000). With the promise

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of enhancing primary treatment without chemical addition, it should be extended at least to pilot-scale.

Curiously, Harleman and Murcott are silent on a more recent development of CEPT, ballasted flocculation, which is being pilot-tested all over the US for treatment of CSOs, SSOs and for excess flows at wastewater treatment plants (for example, see Chang et al, 1998). There is much to be learned as the first full-scale plants go into operation.

Professional discourse on treatment alternatives: turning down the volume

For Harleman and Murcott to impugn the integrity of a class of professional engineers daily engaged in wastewater technology applications does nothing positive to influence decision-makers on the merits of their positions. Indeed, in making inflammatory and undocumented accusations against this group, Harleman and Murcott raise questions about their own professional ethics rather than direct attention to CEPT technology.

The authors have never encountered consulting engineers in their own firms or in firms with which they have worked who would make recommendations about technology that was oriented to increasing their client's costs. On the contrary, every pressure on the design consultant is in the opposite direction, which is to competitively deliver cost-effective projects that demonstrate the value of our services. In fact, those of us in practice know that engineering selections are highly competitive and in many cases the best ideas presented in the competition for selection are the most important aspect of the selection process.

The authors of the preceding feature asserted that doing away with the US practice of design and construction and the adoption of design/build/operate (DBO) schemes would result in the more frequent adoption of CEPT. Recent DBO projects in Dublin and Bangkok seemed to belie this statement. For example, in Bangkok the high temperature and flat topography resulted in highly septic and well-hydrolysed wastewater. On this account, not only did CEPT not feature in any of the designs that were offered, primary tanks were mostly not even considered.

Harleman and Murcott claim that the CEPT technology has been overlooked by international experts, but we have shown that this is not the case. And as demonstrated by the examples reviewed in this feature, design consultants do not view the use of CEPT technology as a high-risk proposition nor do they avoid it because of any particular prejudice. We have pointed to examples where our firms were involved in its development and application. And there are rich sources of information on both the theoretical and practical aspects of CEPT applications to draw on, with many full-scale examples. We are quite willing to recommend its use in cases when a cost-effectiveness evaluation shows it to be appropriate. But any alternative must have a full and fair evaluation before its adoption, including an assessment of existing facilities, effluent requirements and alternative processes. Where CEPT fits, use it!

If Harleman and Murcott want to encourage further consideration of their concepts, they should publish the scientific and technical bases for their broad judgements about the wide applicability of the CEPT technology. This should be published in a journal where other investigators can offer discussions. ●

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CEPT: challenging the status quo

● **DON HARLEMAN** and **SUSAN MURCOTT** provide a rebuttal to the preceding discussion paper by Parker et al, and conclude that their roles as environmental engineering educators must include challenging the status quo.

We welcome the discussion of our paper prepared by five distinguished members of the US environmental engineering consulting profession. Their discussion provides a wealth of supplemental information on the history and development of chemically enhanced primary treatment (CEPT) in the industrialised world. They argue that the future of CEPT is one of evolution and not revolution

We argue in our paper that enormous water pollution problems related to inadequately treated wastewater in the large cities of the developing world requires innovative, revolutionary thinking, not the complacency of 'evolutionary' solutions. Parker et al devote only three paragraphs of their entire discussion paper to CEPT in developing countries - the main focus of our paper. They state: 'It [CEPT] could be an appropriate first step of treatment in individual cases, but no claim should be made for universal applicability, as there are many competing technologies.' What are their 'competing technologies'?

In Brazil, they refer to the use of anaerobic pre-treatment (UASB) followed by pond systems, and in South Africa, anaerobic pond systems followed by algae ponds followed by trickling filters to capture algae. If these are the 'competing technologies', we can confidently restate our claim that CEPT is the most environmentally sound and cost effective first-stage treatment system for large urban areas, where the large space requirements and odour problems associated with anaerobic wastewater treatment processes and wastewater stabilisation ponds make them impractical.

Parker et al cite many IWA conference volumes in the 1990s that purport to deal with centralised wastewater treatment technology appropriate to developing countries. We agree that CEPT is not featured in these volumes and this is the prime reason for writing our paper.

We find it both strange and significant that the words 'public health' do not appear in the Parker et al. paper. Their emphasis is on 'CEPT as part of a physical/chemical flow sheet for secondary treatment,' on 'CEPT coupled with biological treatment for advanced wastewater treatment', and on 'CEPT and nutrient removal'. These advanced wastewater treatment processes are not relevant to the major public health needs of megacities in the developing world. For this reason, we recommend CEPT as a first-stage treatment process that produces an effluent that can be effectively disinfected. The use of CEPT and disinfection, at about half the cost, energy use and operational difficulties of conventional primary and activated sludge treatment, would allow the goal of full treatment in these cities to be attained more rapidly.

CEPT, in addition to providing BOD and TSS removal that equals or approaches secondary treatment levels, is also effective in phosphorus removal. If, at a later stage of urban development, nitrification or denitrification is deemed necessary and affordable, the cost-effective solution would be to skip secondary treatment and go directly to biological aerated filters (BAF), which have the advantage of not requiring additional clarifiers.

> **Based on extensive experience in developing countries, we have seen too many conventional primary and activated sludge plants that are treating only a fraction of the municipal wastewater.**

Parker et al have criticised us for including, as one of six impediments to CEPT in the developing world, the comment that profit motive may drive the use of inappropriate treatment technology. They refer to this as a 'blanket attack on the professional integrity of a broad class of environmental engineering professionals'. We certainly do not intend a blanket attack on US or European professionals. We can, however, provide support for our statement from the following: 'To find solutions to their environmental problems, developing countries usually seek the assistance of engineers and scientists from developed countries. Many times, however, either out of ignorance of the local condition or due to financial motivations, these experts come out with solutions which are far from being considered as the "most appropriate". As a result, the basic objective of protecting the environment is not achieved.' (Curi, 1985)

Based on extensive experience in developing countries, we have seen too many conventional primary and activated sludge plants that are treating only a fraction of the municipal wastewater. In most cases the effluent from these plants is ultimately mingled with and overwhelmed by the remaining raw sewage discharges to form a stream or river with no discernible protection of the public health. For example, in Sao Paulo, about 30% of the wastewater flow is treated to secondary level, yet the Tiete River flowing through the city centre is

The Gao Bei Dian conventional primary plus activated sludge treatment plant serving a quarter of Beijing, China.

essentially an open sewer. Similarly, in Beijing, about 25% of urban wastewater is treated in a token activated sludge plant at Gao Bei Dian, while the remaining raw sewage is discharged directly to canals and rivers. Many other examples could be cited. We have also observed that there is a bias against CEPT related to a perception of second-class status because it has not been widely adopted in the western world.

Parker et al refer to the treatment plant costs in the National Research Council (1993) study in which we and Glen Daigger participated. Parker et al state: 'Engineering studies showed that while CEPT was significantly less expensive than conventional primary plus biological treatment, it had no cost advantage when coupled with biological treatment.' We agree with the first-half of the quotation. The NRC total cost figures provided by Mr Daigger do indeed show that the cost of CEPT is 60% of conventional primary treatment plus activated sludge. The second half of the quotation simply reinforces our argument that CEPT should not be followed by activated sludge, because there is no environmental benefit in a CEPT and activated sludge plant that produces a small increase in TSS and BOD removal at great expense. The 1993 NRC cost figures also show that the capital cost of CEPT is somewhat greater than that of conventional primary treatment. This is no longer true. The NRC costs do not reflect the fact that CEPT results in a downsizing of the plant because overflow rates at least twice those of conventional primary treatment are now common (Harleman et al 1997).

> **We must all work harder to convince regional and local authorities that the normal technologies of the western world are not necessarily the most effective first step.**

We appreciate the careful documentation of the development of the city of Los Angeles' Hyperion plant by Parker et al. Here, the early experience with CEPT clearly showed the downsizing capability of CEPT in both the primary tanks and in the size and efficiency of the activated sludge plant. The excuse for not taking advantage of CEPT in the final plant because of uncertainty in the supply or cost of chemicals is weak. Fortunately the same argument has not been put forward to avoid using the same chemicals in potable water treatment.

Likewise the Parker et al argument against the use of CEPT by small island nations is weak. CEPT has been successfully demonstrated at full-scale by the authors in Hawaii's two main treatment plants at Sand island and Honouliuli (Harleman and Murcott 1996). Because of the higher cost of shipping metal salts, we tested ferric chloride, and as an alternative, cationic polymers. Our recommendation was to use 2 to 3 mg/litre of cationic polymer as the sole coagulant. This low dose gave 80% TSS removal and 50% BOD removal. A recent study in The Netherlands (Mels and van N, 2000) also compared ferric chloride and cationic polymers. They showed that in terms of chemical costs, the reduced dosage (4 mg/litre) of polymer and the higher polymer cost (7.5 times higher than the ferric per mg of active product) was about equal to the higher dosage and lower unit cost of the iron salt. There is also a saving in sludge processing because the polymer produces no additional chemical sludge.

A further argument in favour of CEPT by island states or nations is that of energy savings outweighing chemical costs. At present, Hawaii imports more than three-quarters of its energy resources in the form of fossil fuels. Conventional primary treatment and activated sludge uses considerably more energy than CEPT. Thus, the cost of importing chemicals is cheaper than the cost of importing fossil fuels. In addition, most of Puerto Rico's municipal wastewater plants are using CEPT as a low cost way of upgrading overloaded plants.

In regard to 'CEPT in Hong Kong', Parker et al state: 'Harleman and Murcott are in error when they assert that Professor Harleman was instrumental in arguing that conventional primary treatment planned for Stonecutters island in Stage I of the plan should be replaced with CEPT. In fact, the consultant (Montgomery Watson) had planned on CEPT using low lime (pH9.7) treatment for the first stage of construction.'

The Montgomery Watson (MW) plan (referred to above) was reviewed by Professor Harleman as a member of the first Hong Kong International Review Panel (IRP) in 1994/95. Several major problems ultimately led to its rejection:

- ● the use of lime was intended as a temporary measure at Stonecutters Island (SCI) to provide a degree of disinfection (ineffective in our opinion at a pH of 9.7) of the effluent until such time as a long (over 20km) and expensive ocean outfall could be constructed. At that time the SCI plant would revert to conventional primary treatment, thus losing both the downsizing capability and increased pollutant removal of the coagulant.
- ● a dose of 120 mg/litre of lime is required to obtain a pH of 9.7. Although MW calls this 'low dose', it produces an enormous quantity of hard-to-dewater sludge. In fact, the sludge produced by the lime is equal to that produced by TSS removal (assumed to be 65%.)

The acronym CEPT (which we first proposed more than ten years ago) was never intended to include the use of lime (either low or high dose) as a primary coagulant. In our terminology, CEPT means use of iron or aluminum salts and/or polymers at a low dosage. The Hong Kong CEPT plant at SCI, which uses only10 mg/litre of ferric chloride and produces an effluent essentially equivalent to secondary treatment, is a prime example.

> **There is a bias against CEPT related to a perception of second-class status because it has not been widely adopted in the western world.**

It is not our intention to engage in a 'we got there first' debate; however, in relation to comments on our work in Brazil we would like to set the record straight. In relation to the recent start-up of two CEPT plants in Brazil, Parker at al. state: 'It should be noted that a consulting engineering firm (Black & Veatch) recommended this process - as early as 1996 - almost a year earlier than the pilot testing efforts cited by the authors.' In fact, we made our first presentation and full plant tests promoting the use of CEPT in Brazil in 1995 (Harleman and Murcott, 1995).

Parker et al write: 'If Harleman and Murcott want to encourage further consideration of their concepts, they should publish their scientific and technical bases for their broad judgements about the wide applicability of the CEPT technology.' We have already published extensively on chemical wastewater treatment, both in peer-reviewed publications and technical reports. We did not feel the need to revisit or cite all our previous publications or early CEPT history in this Water21 article. More than 20 CEPT publications can be found on our websites at:

http://web.mit.edu/civenv/html/people/faculty/harleman.html

http://web.mit.edu/civenv/html/people/faculty/murcott.html

We are delighted that engineers at the consulting firms represented in Parker et al are actively engaged in the developing world. We must all work harder to convince regional and local authorities that the normal wastewater treatment technologies of the western world are not necessarily the most effective first step in protecting the public health of their constituency.

As environmental engineering educators, we are not in competition with the reputable environmental engineering consultants who prepared the rebuttal to our paper. While they design and build treatment plants, we train present and future generations of engineers to think outside the box. Our role is to challenge the status quo, to raise hard questions, to point out critical issues and possible directions. But whether we are consultants or academics, our ethical responsibility as engineers and as human beings should be to address and solve critical water pollution problems not only in our nation but in the rest of the world.

We welcome this exchange of ideas not simply as a means to promote a specific technology but more generally to put forward the pressing need for innovative, revolutionary thinking in order to solve the water pollution and public health problems of the 21st Century. ●

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