Appropriate Wastewater Treatment in Developing Countries: Experiences with CEPT*

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Abstract

Water-borne diseases remain a rampant impediment to economic development in densely populated urban areas of developing countries. Most attempts to mitigate this problem of paramount importance have not succeeded. In devising policy to alleviate the public health problems related with wastewater, an important issue that needs to be addressed 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?

This short paper presents some of the authors' experiences with wastewater treatment related issues in cities of the developing world. Specifically, we relate our experiences concerning the simple and cost-effective technology of chemically enhanced primary treatment (CEPT). CEPT relies on small doses (i. e., $\leqslant$ 50 mg/L) of metal salts, which act to enhance particle settling by coagulation, and therefore treatment effectiveness. A short primer on CEPT is attached. Based on these experiences, we believe that the development of sustainable wastewater-related infrastructure in cities of the developing world is necessary, and we believe that CEPT should be considered as the first stage technology of choice because it is the lowest cost treatment technology that permits effective disinfection of the effluent.

Introduction

A committee of the U.S. National Research Council [NRC, 1996] reported on "sustainable water and sanitation services for mega-cities in the developing world". The authors indicate that "water and sanitation professionals must take a broader view of sanitation to

*Parts of this article have appeared in Harleman and Murcott [2001].

prevent disease resulting from a wide range of activities and multiple exposure routes." 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." While it is true that some cities (e. g., Jakarta) lack a sewage collection system, most 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. While the goals of industrialized world treatment are laudable, we believe that they are unrealistic in the near-term, and they do not address the most pressing need of disinfection. Rather than prescribing an effluent objective and its corresponding level of advanced treatment, it is more useful to define the most efficient and cost-effective first stage level of treatment needed to protect public health.

This short paper relates some of the authors' experiences with wastewater treatment in developing countries. Specifically, we present our experiences concerning the simple and cost-effective technology of chemically enhanced primary treatment (CEPT). It is our experience that most wastewater treatment objectives in developing country cities fall into two categories:

- need to upgrade existing conventional primary treatment plants
- new plant

In most instances, upgrades to existing overloaded conventional primary treatment plants and new plant designs have made use of biological treatment. Our perspectives on Mexico city and Brazil are outlined below; from these experiences, we conclude that a strategy of staged wastewater treatment implementation is the best path to follow. The goal should be one of treating and disinfecting all the wastewater produced in a given urban area, otherwise treated and untreated effluents are co-mingled in the receiving water with no public health benefit.

Mexico City — A Perspective on Mega-city Needs

The Valley of Mexico, with 21 million inhabitants, covers an area of 1,300 km^2. The city lies on an old lake bed on a high plateau with no natural drainage or source of fresh water. 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 75 m^3/s of wastewater and this raw sewage is used to irrigate 85,000 ha of agricultural land in the neighboring state of Hidalgo. These crops feed and provide income for the local population. The raw sewage is high in organic matter, nitrogen and phosphorus nutrients, as well as in fecal coliforms and

helminth eggs, a debilitating parasite, in concentrations as high as 250 eggs/L. Because the soil in the valley is poor, the organic material, nitrogen and phosphorus in the wastewater have greatly improved crop yields — corn production has increased 150%, onion 100%, tomato 94%, etc. [Landa *et al.*, 1997]. The irrigated area receives over 80 kg/ha of nitrogen per year.

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 [Comisión Nacional del Agua, 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 [1996] 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 in 1993—1995, the authors (DRFH & SM) 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 *et al.*, 1997].

CEPT is very effective in removing helminth eggs to a range of 2∼5 eggs/L. Polishing sand filters were added to ensure an effluent with less than 1 egg/L. 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 [Comisión Nacional del Agua, 1995]. For example, for the proposed El Salto plant (15 m^3/s treatment capacity and 5.2 m^3/s mean flow), the construction cost (including sludge disposal) of the CEPT plant was estimated at US$70 million, while the conventional primary plus activated sludge facility cost was higher by a factor of 1.85. Annual operating costs were US$4 million for CEPT and US$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.

Brazil — A Country-Wide Perspective

Bench-scale and full-plant CEPT demonstration tests have been successfully completed, first in São Paulo, under the sponsorship of the state wastewater agency [SABESP, 1996].

Next, 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, the limiting nutrient controlling the large algal blooms that cause oxygen depletion and odors 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.

In l998 it was decided to use the Brazil 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 which 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.

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 which 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].

Lessons Learned

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 first-stage wastewater treatment investments or upgrades of existing treat-

ment facilities should be a high-flow rate, low-cost treatment technology that provides a high level of suspended solids removal, thereby permitting effective pathogen inactivation by disinfection. 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.

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