Chemically Enhanced Primary Treatment of Wastewater in Honduran Imhoff Tanks

by

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ABSTRACT

Imhoff tanks represent approximately 40% of the wastewater treatment infrastructure in Honduras. This thesis evaluates the usage of solid aluminum sulfate as a means to achieving national effluent regulations in Imhoff tanks in the municipality of Las Vegas, Santa Barbara. The report contains a brief background on both Imhoff tanks and chemically enhanced primary treatment and a discussion of the governing technical considerations. The residents of Las Vegas produce a very high amount of relatively dilute domestic wastewater (approximately 1,000 liters/person/day). Bench scale testing and pilot testing during January 2008 in the Las Vegas Imhoff tanks found that a dosage of approximately 150 mg/l alum (17% Al_2O_3) was necessary to treat Las Vegas' domestic wastewater. However, solution preparation and chemical injection were found to be difficult to achieve under current conditions and the cost of alum in this quantity is prohibitively expensive. The final recommendations to the municipality of Las Vegas include encouragement to conserve water and a comprehensive plan to better maintain the Imhoff tanks in order to achieve higher levels of treatment.

This thesis also documents the author's efforts to ascertain the status of Imhoff tanks in the rest of Honduras in terms of their size, design, and maintenance. During January 2008 three other Imhoff tanks in the department of Santa Barbara and one in the department of La Páz were visited and all were found to be in varied states of disrepair. However, several hold the potential to be rehabilitated after the removal of sludge.

Thesis Supervisor: E. Eric Adams
Title: Senior Research Engineer and Lecturer of Civil and Environmental Engineering

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1 INTRODUCTION

1.1 Project Background

An Imhoff tank is a structure designed to provide primary wastewater treatment. It is a sedimentation tank with a steeply sloped floor resting above a sludge digester. During the 1930's, Imhoff tanks represented 50% of all wastewater treatment facilities in the United States (Herrera, 2006). While the majority of Imhoff tanks within the U.S. have since been abandoned or modified to adapt to changing treatment objectives and regulations, within Honduras they continue to represent a significant portion of wastewater treatment infrastructure.

During the 2005-2006 school year, students from the MIT Master of Engineering (MEng) Program in Environmental Engineering studied the water quality of Lake Yojoa, the largest freshwater lake in Honduras. During their study, students Tia Trate and Mira Chokshi recognized that the bordering municipality of Las Vegas was a major polluter of Lake Yojoa. Two Imhoff tanks in parallel receive wastewater from the urban center of Las Vegas before discharging into a creek that empties into the lake.

Lack of proper maintenance and community knowledge has led to a widespread state of disrepair in Honduran Imhoff tanks both in Las Vegas and elsewhere. Recognition of this situation led Aridaí Herrera, a Honduran native, to focus his graduate work at the University of Texas-Austin on the rehabilitation of Imhoff tanks. Herrera tailored his research to the municipality of Las Vegas and at the end of 2006 produced a detailed rehabilitation and maintenance plan for the Imhoff tanks. In his role as consultant to Las Vegas, he relayed a request to MIT for assistance in considering options for a total system expansion. As part of the appeal, he requested documentation of baseline flows and loads as well as treatment options for incorporating the remaining unconnected population of Las Vegas into the system.

The municipality of Las Vegas has both short-term and long-term treatment goals. In the short-term, the city aims to provide treatment for the existing load on the Imhoff tanks. In the long-term, the municipality's goals include both full treatment of wastewater for the currently connected homes and enterprises and service area expansions so that all of the wastewater generated in the municipality is being treated. Realistically there are long lead times associated with obtaining funding for the construction of new infrastructure. Therefore, Herrera was interested in the effectiveness of chemically enhanced primary treatment (CEPT) within Imhoff tanks as an interim solution towards meeting national effluent regulations. Additionally, he was curious whether CEPT could accommodate sufficiently large surface overflow rates so that the Imhoff tanks might also be able to accommodate modest service area expansions.

Matthew Hodge and Anne Mikelonis, both MIT Environmental Engineering MEng students, spent the 2007-2008 school year responding to Herrera's appeals. January 2008 found them in Honduras meeting with stakeholders and performing lab and fieldwork. Hodge's work focused on documenting flows and loads in Las Vegas and evaluating various options for total system expansion and sludge maintenance. Mikelonis' work focused on evaluating the applicability of CEPT within Imhoff tanks through bench scale and pilot testing. A detailed timeline of the MIT involvement with Lake Yojoa, Honduras and the onsite activities of the team during January are documented in Appendix A: Project Timeline.

1.2 Report Objective

This report serves to specifically evaluate the applicability of CEPT in Honduran Imhoff tanks. It contains a brief background on both Imhoff tanks and CEPT and a discussion of the governing technical considerations. Additionally, the report documents the methodology utilized and the results from bench scale and pilot testing of CEPT during January of 2008 in the Las Vegas Imhoff tanks. Finally, the report documents the author's efforts to ascertain the status of Imhoff tanks in the rest of Honduras in terms of their size, design, and maintenance.

2 OVERVIEW OF SANITATION IN HONDURAS

2.1 Country Background

Honduras is a country in Central America, bordered by Guatemala, El Salvador, Nicaragua and both the Caribbean Sea and Pacific Oceans (see Figure 2.1 Map of Honduras (Honduras, 2007)). It is divided into 18 departments, 298 municipalities, 3,731 towns, and 30,591 rural communities. The 2006 population estimate for Honduras is 7.4 million people. Honduran's live on 112,492 km^2 making it the second largest country, by size, in Central America (World Bank, 2006).

Figure 2.1 Map of Honduras

The government is a democratic republic and the country's economic activities center around agriculture, forestry, hunting, fishing, and manufacturing. Honduras is one of the poorest countries in the Western Hemisphere with a per capita income of $1,170 and 50% of the population living below the poverty line (2006). Consequently, poverty reduction has been and remains the primary development initiative within Honduras. Initiatives to improve water treatment and sanitation services have been a recent phenomenon. A prerequisite for their success in competing for development dollars has been the ability of the project sponsor to demonstrate a close linkage between particular water and sanitation programs and the overarching national goal of poverty alleviation.

2.2 Coverage

In 2004, it was estimated that approximately 68% of Hondurans had access to some form of sanitation services. Approximately 25% of coverage is through domestic connections (such as flush toilets) and the remaining 43% is via latrines. Within urban areas, it is estimated that 88% have coverage. However, sewage transport should not be confused with treatment. It is estimated that only about 10% of collected wastewater is actually treated (SERNA, 2005). This lack of treatment pollutes surface and subsurface water bodies and land.

2.3 Institutions

There have been numerous pilot projects and large-scale water and sanitation initiatives within Honduras run by a variety of organizations ranging from church mission groups to USAID and including many development groups sponsored by other countries. The Honduran water and sanitation sector receives most of its momentum from an assorted collection of international development organizations seeking to assist Honduras in achieving the Millennium Development goals. The national sector itself is spearheaded by a diverse and fragmented set of Honduran institutions.

The Honduran water and sanitation sector underwent a major reform in 2003 due to increasing international pressure from donor agencies. Sector reform was largely driven by the World Bank's "Poverty Reduction Strategy Plans" and was required for qualification of debt relief. In order to make a strong case for several of the projects proposed, Honduras had to create a new regulatory agency, and restructure the national water utility, SANAA, to include a planning agency. These efforts were not in vain as ultimately Honduras was one of the few countries that qualified for debt relief. In April 2005, Honduras attained its Heavily Indebted Poor Country Completion point and in July 2006 it benefited from the Multilateral Debt Relief Initiative (which translates into development project funding) (World Bank, 2006). Only time will tell if the new agencies will prove sustainable. A more detailed overview of the key institutions involved in the Honduran water and sanitation sector is provided below.

SERNA- Secretaria de Recursos Naturales y Ambiente

SERNA is the environmental protection agency of Honduras. It is charged with protecting a wide variety of broadly defined national sectors such as water, energy, climate and atmosphere, and biodiversity. One of its main missions is to enforce the general environmental protection law established in 1993. In 2005, the organization published a 173-page report on the state of the environment in Honduras (SERNA, 2005). This assessment was funded by the United Nations Environment Program and is one of the better available public compilations of recent countrywide statistics in each sector.

SANAA – Servicio Nacional de Acueductos y Alcantarillados

SANAA is the national autonomous water and sanitation service created by the government of Honduras in 1961 (Water for People, 2006). It historically operated approximately half of the water supply and sewerage systems in Honduras. However, due to the major sector reform in 2003 much of SANAA's service scope is being decentralized and transferred to the municipalities. This is in part due to SANAA's reputation for poor service and over staffing (SANAA, 2007b). The Law of the Portable Water and Sanitation Sector created in 2003 mandated this shift. It specifies that the transfer should take place by 2008. After 2008, the main role of SANAA will be as a technical resource for the municipalities.

CONASA – Comisión Nacional de Agua Potable y Saneamiento

Formed as a result of the 2003 Direct Legislation (118-2003) that redistributed SANAA's power, CONASA's intended purpose is to function as the planning entity within the new governance structure for this sector. Its mission is to formulate and promote plans and political strategies for the water and sanitation sector. Additionally, the agency is supposed to be the coordinator of public and private organizations operating in this sector and develop methods for the economic evaluation of water and sanitation projects (CONASA, 2007).

ERSAPS – Ente Regulador de los Servicios de Agua Potable y Saneamiento

ERSAPS was created in 2003 under the water and sanitation reform to function independently from the Ministry of Health and act as a regulatory resource for local system operators of all sizes. The organization was charged with providing the World Bank with the 2006 evaluation report on the transfer of systems from SANAA to the municipal level. Its website provides community leaders of large municipalities and small rural water boards with a comprehensive listing of applicable water and sanitation laws and regulations. It has also assembled several "Technical Manuals" for the municipalities describing these laws and offering advice for implementation. These technical notes do not offer engineering assistance, but rather guidelines for good governance (ERSAPS, 2005).

RAS-HON – Red de Agua y Saneamiento de Honduras

Within Honduras, RAS-HON is a legally incorporated national network designated by Presidential directive as an accessory to the Ministry of Health. RAS-HON was formed in 1992 due to much institutional confusion and limited capacity within the water and sanitation sector. The group was created because of multi-agency identification of the need for a professional network of Environmental Engineers. International development organizations such as the World Bank Water and Sanitation Program, United Nations Development Program, USAID, PAHO/WHO, and UNICEF met with government agencies and nongovernmental organizations in order to create this space for open collaboration. Honduras was the first country in Central America to adapt this sort of forum and it has since spread throughout the region. RAS-HON independently starts activities such as investigations and holds educational seminars (RRAS-CA, 2006).

2.4 Funding

FHIS – Fondo Hondureño de Inversión Social

FHIS, the Honduran Social Investment Fund, is run through the office of the President. It is an important actor in the water and sanitation sector because it receives much of the international aid from groups such as the World Bank. In the last two years, there have been several major loans approved by the World Bank for Honduras that directly affected the Honduran water and sanitation sector. These include the Barrio-Ciudad Project and the Water & Sanitation Sector Modernization Project (FHIS, 2008). FHIS was created in 1990 and there were some complaints that providing funds directly to municipalities for construction, as FHIS did, undermined the roles and missions of non-governmental organizations working in this sector. In 2000, FHIS started trying to reintegrate these groups and their participatory methods into the funding process (Water for People, 2006).

Barrio-Ciudad Project

Approximately $97 million zero-interest credits were provided to Honduras in support of its Poverty Reduction Strategy. Those credits are dedicated to four different purposes, one of them being the Barrio-Ciudad Project. It is comprised of $16.5 million dollars earmarked for improving the life of urban poor. The project runs from 2005 until 2011 and includes funds for extensions and improvements to city water and sanitation services. Specifically, the project's planned funding allocations were: improved water supply 40%, sanitation 30%, and sub-national government administration 30%. (Barrio-Ciudad, 2005) In December 2007, the information about the project on the World Bank Website was updated. The funding allocation percentages were shifted substantially to: sub-national government administration 80%, water supply 12% and sanitation 8%. The purported rationale for the shift was obliquely referenced on page 1855 of the World Bank 2007 annual report. Supposedly, part of the original proposal included a municipal loan program as part of a larger total loan request than was ultimately granted by the World Bank. Therefore, when the entire package was reduced, more of the smaller amount of loan money was redistributed to the neighborhood-upgrading component (World Bank, 2007). Of course, this rationale, if true, begs the question of why water supply and sanitation improvements were deemed to be less important/feasible to the poor in the reallocation process.

Water & Sanitation Sector Modernization Project

This project was approved by the World Bank on June 21, 2007 so it is in the initial stages. The timeframe for the program is six years and it calls for a total of $39 million to improve water and sanitation services. $9 million of this is earmarked for natural disaster protection. It is important to remember that in 1998 Hurricane Mitch devastated Honduras and the country is still recovering. The remaining $30 million dollars of the loan is to help municipalities with populations between 40,000 to 300,000 to become autonomous water and sanitation service providers to their residents (World Bank, 2007).

2.5 Existing Systems

According to SERNA's 2005 "state of the environment" report, the country operates 41 wastewater treatment systems including 18 Imhoff tanks, 18 waste stabilization ponds, and 5 other technologies (SERNA, 2005). This last category includes the capital of Tegucigalpa, which has an activated sludge treatment plant. However, in Honduras different sources report statistics that do not necessarily agree. During January 2008, an engineer in the infrastructure group of FHIS provided the MIT team with a detailed list of the wastewater treatment facilities in Honduras. The list is from a 2000 survey of wastewater treatment facilities in Honduras by SANAA and includes 51 locations. It is more than likely the most recent and comprehensive survey of such infrastructure in Honduras. Somewhat ironically, it should be noted that the list is still incomplete (for example the Las Vegas Imhoff tanks were not listed). The physical conditions found at each site are unknown.

Interviews during January 2008 with engineers at FHIS and SANAA revealed strong preferences on their part for the use of waste stabilization ponds wherever possible. Imhoff tanks are viewed as a technology of the 1990s whereas the past decade has witnessed the successful implantation of numerous ponds in Honduras. The engineers cite that the ponds are able to provide long enough residence times to kill pathogens and that they store more sludge and therefore do not need to be cleaned as often as Imhoff Tanks. In Honduras, the majority of rivers provide plenty of natural reaeration so factors such as biochemical oxygen demand (BOD) are not as crucial of an issue as pathogen removal (P. Ortiz, personal communication, January 23, 2008). The complete listing of locations and type of treatment systems in Honduras are listed in the Table 2.1 Honduras Wastewater Treatment Systems.

Table 2.1 Honduras Wastewater Treatment Systems (SANAA, 2007a)

2000 SANAA Inventory of Wastewater Treatment Plants		
Municipality	*Department*	*Type of System*
Tela	Atlantida	Waste Stabilization Ponds
Tela	Atlantida	Mixed Aeration/Oxidation
La Ceiba	Atlantida	Imhoff Tank
La Ceiba	Atlantida	Mixed Aeration/Oxidation
La Entrada	Copán	Waste Stabilization Ponds
La Entrada	Copán	Imhoff Tank
Corquin	Copán	Imhoff Tank
Santa Rosa	Copán	Waste Stabilization Ponds
Tocoa	Colón	Imhoff Tank
Sonaguera	Colón	Waste Stabilization Ponds
San Pedro Sula (Col. Fesitranh)	Cortés	Trickling Filter
Villa Nueva	Cortés	Waste Stabilization Ponds
Choloma	Cortés	Waste Stabilization Ponds
Puerto Cortés	Cortés	Waste Stabilization Ponds
San Francisco de Yojoa	Cortés	Imhoff Tank
La Lima	Cortés	Imhoff Tank
San Pedro Sula	Cortés	Trickling Filter
Siguatepeque	Comayagua	Waste Stabilization Ponds
Taulabe	Comayagua	Waste Stabilization Ponds
Villa de San Antonio	Comayagua	Waste Stabilization Ponds
El Paraíso	El Paraíso	Waste Stabilization Ponds
Danlí	El Paraíso	Waste Stabilization Ponds
Teupasenti	El Paraíso	Imhoff Tank + Constructed Wetlands
Choluteca	Choluteca	Waste Stabilization Ponds
Guaymaca	Francisco Morazan	Imhoff Tank + Constructed Wetlands
El Zamorano	Francisco Morazan	Imhoff Tank
Tegucigalpa	Francisco Morazan	Activated Sludge
Sabana Grande	Francisco Morazan	Imhoff Tank
Marcala	La Páz	Imhoff Tank
Gracias	Lempira	Imhoff Tank
Lapaera	Lempira	Imhoff Tank
Las Flores	Lempira	Imhoff Tank
Nueva Ocotepeque	Ocotepeque	Imhoff Tank
San Marco de Ocotepeque	Ocotepeque	Waste Stabilization Ponds
Intibuca	Intibuca	Imhoff Tank
La Esperanza e Intibuca	Intibuca	Imhoff Tank
Catacamas	Olancho	Waste Stabilization Ponds
Juticalpa	Olancho	Waste Stabilization Ponds
Salamá	Olancho	Waste Stabilization Ponds
Colinas	Santa Barbara	Septic Tank
Santa Barbara (Barrio El Llano del Conejo)	Santa Barbara	Imhoff Tank
Santa Barbara (Barrio Galeras)	Santa Barbara	Imhoff Tank
Gualala	Santa Barbara	Imhoff Tank
Roatan	Islas de Bahia	Waste Stabilization Ponds
Nacaome	Valle	Waste Stabilization Ponds
San Lorenzo	Valle	Waste Stabilization Ponds
El Nispero	Yoro	Imhoff Tank
Victoria	Yoro	Waste Stabilization Ponds
El Negrito	Yoro	Waste Stabilization Ponds
Morazán	Yoro	Waste Stabilization Ponds
Olanchito	Yoro	Waste Stabilization Ponds

2.6 National Wastewater Regulations

Table 2.2 Honduras Wastewater Regulations (Secretaría, 1997), lists the national effluent regulations. Enforcement of these regulations falls under the jurisdiction of ERSAPS. In reality, there is little monitoring or penalty imposed on systems that do not conform.

Table 2.2 Honduras Wastewater Regulations

Effluent Regulations	
Parameter	*Max Permitted*
BOD_5	50.0 mg/l
COD	200.0 mg/l
Total Kjeldahl Nitrogen	30.0 mg/l
Ammonia as Nitrogen	20 mg/l
Total Phosphorous	5.0 mg/l
pH	6.0 – 9.0
Sulfates	400.0 mg/l
Aluminum	2.00 mg/l
Settable Solids	1.0 ml/l/h
Suspended Solids	100.0 mg/l
Total Fecal Coliforms	5000/100 ml

3 OVERVIEW OF IMHOFF TANKS

3.1 Background

Karl Imhoff invented and patented the Imhoff tank in Germany in 1906 (Herrera, 2006). Over the years Imhoff tanks have had varied designs but characteristic to all is a two-story construction of a sedimentation chamber above a sludge digestion chamber. Figure 3.1 provides a view from the influent/effluent end.

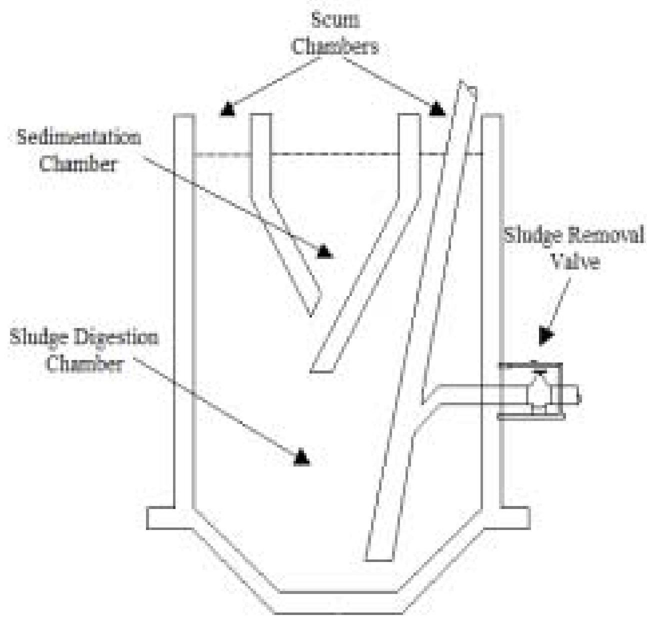


Figure 3.1 Imhoff Tank Schematic

Imhoff tanks function on the premise that the larger particles of total suspended solids (TSS) are removed by first entering the sedimentation chamber and then falling through a small opening into the sludge storage and digestion chamber. In turn, the removal of solids in this manner also decreases the oxygen demand of the wastewater. The removed solids are anaerobically stabilized in the sludge storage chamber through natural biochemical and microbiological reactions until the chamber fills up.

3.2 Mechanics

Flow through the upper sedimentation chamber can be achieved by longitudinal horizontal flow, vertical flow (although rarely utilized), or radial flow. In some locations influent and effluent weirs have been used to distribute flow uniformly throughout the sedimentation chamber (Metcalf, 1935). The sedimentation chamber's depth must be shallow enough as not to inhibit vertical distribution of flow but also deep enough so that the slow-motion settling zone is not encroached. The 1935 version of the Metcalf & Eddy textbook advises against the use of baffles to aid sedimentation because they tend to produce sub currents. In order to avoid solids accumulation and decomposition in the sedimentation chamber, it is recommended that a squeegee be used to periodically clean the sides of the sedimentation chamber (1935).

The sludge chamber includes a sludge-storage space and a neutral zone between the storage area and the slot entrance into the sedimentation chamber. In order to utilize the entire tank and avoid an uneven distribution of settled solids it is recommended to reverse the flow every month. It is theoretically possible through employment of the force of gravity to empty the sludge storage chamber by using valves located at the bottom of the tanks. Sludge is removed by flowing through pipes, which extend a short distance inside the hopper. Gas produced within the sludge storage chamber is released through vents into a scum space that must be skimmed every few days to remove floating particles of digested sludge. Care must be paid to keep the water level in the system constant in order to avoid the exchange of contents between the sedimentation and digestion chambers. Differences of hydrostatic pressure can result in surges of sludge up through the slots (Metcalf, 1935). Imhoff tanks are normally constructed with a minimum of two tanks in parallel. This allows the operators to clean one tank without shutting down the entire system.

Expected treatment levels from a properly maintained Imhoff tank are the same as those for isolated sedimentation tanks without a sludge digester. Typically, an Imhoff tank will provide a TSS removal rate of 20% - 70% and 10% - 40% for BOD_5 (Reynolds, 1996). The actual removal rate for a specific tank will be a function of influent water quality and tank detention time. In the absence of any additional treatment, the sedimentation process will not yield substantial reductions in other important water quality indicators such as total coliform counts or nutrient loading from phosphorus and nitrogen.

The solids that settle into the bottom storage chamber of the Imhoff tank are termed sludge and undergo anaerobic digestion. Anaerobic digestion is a four-stage process of hydrolysis, acidogenesis, acetogenesis, and methanogenesis that causes considerable change to the physical, chemical, and biological properties of the sludge (Mara, 2004). Microbes that thrive in the absence of molecular oxygen liquefy the solids, digest the soluble solids and produce gas. The two main groups of microbes that do this work are organic-acid-forming heterotrophs and methane-producing heterotrophs. Complex organic substrates such as carbohydrates, fats, oils and proteins are broken down by the organic-acid-forming heterotrophs. These microorganisms are resilient to a wide range of pH. The methane-producing heterotrophs produce methane and carbon dioxide from the organic acids. These microorganisms grow slowly and require pH ranges of 6.7 to 7.4 and serve as the rate-limiting step in the anaerobic digestion process. Before digestion the volatile solids constitute 65-75% of the sludge’s composition whereas after digestion the volatile solids are reduced to 32%-48%. The end result of successful anaerobic digestion is stable solids that will not degrade and from which water will easily separate (Reynolds, 1996). After the digestion process is complete, the sludge may be removed from the Imhoff tank and be dewatered on a sludge drying bed or by other equivalent means.

3.3 Design Criteria

Table 3.1 includes design criteria that were adapted from the 3rd edition of "Wastewater Engineering: Treatment, Disposal, and Reuse." by Metcalf and Eddy, Inc (Tchobanoglous, 1991).

Table 3.1 Design Criteria for Unheated Imhoff Tanks (Herrera, 2006)

Design Parameter	Value	
	Range	Typical
Settling compartment		
Overflow rate peak hour, m^3/m^2-hr	1 – 1.75	1.36
Detention time, hours	2 - 4	3
Length to width ratio	2:1 - 5:1	3:1
Slope of settling compartment ratio	1.25:1 to 1.75:1	1.5:1
Slope opening, cm	15 - 30	25
Slot overhang, cm	15 - 30	25
Scum baffle		
Below surface, cm	25 - 41	30
Above surface, cm	31	30
Freeboard, cm	45 - 60	60
Gas vent area		
Surface area, percent of total surface area	15 - 30	20
Width of opening,[a] cm	45 - 75	60
Digestion section		
Volume (unheated), storage capacity - m^3/capita		6 months of sludge
Volume[b]	0.06 – 0.10	0.07
Sludge withdrawal pipe, cm	20 - 30	25
Depth below slot to top of sludge, m	0.30 – 0.90	0.60
Tank depth		
Water surface to tank bottom, m	7 – 10	9

[a] Minimum width of opening must be 45 cm to allow a person to enter for cleaning.
[b] Based on a 6-month digestion period.

3.4 Advantages

Imhoff tanks remain a viable treatment option in certain developing communities for several reasons. An Imhoff tank is a low maintenance, low cost option in comparison to activated sludge treatment. Primary treatment through sedimentation offers the possibility of reducing the negative environmental and human health effects of untreated sewage to low enough levels that natural processes such as dilution and biodegradation can accomplish adequate remaining treatment. Of course, the effectiveness of these latter treatment modalities depends significantly on the natural assimilation capacity of receiving land and water bodies. Additionally, Imhoff tanks do not need the large amounts of flat land that waste stabilization ponds or constructed wetlands require. In the mountainous terrain of Honduras this advantage is significant. They also provide storage and gravity removal mechanisms for digested sludge that plain sedimentation basins do not. Further, with proper planning Imhoff tanks may later be coupled with applicable forms of secondary and tertiary treatment as need and capital becomes available to a community for investment in the facilities required for such treatment.

4 OVERVIEW OF CEPT

4.1 Introduction

Chemical treatment of wastewater involves the use of coagulants such as metal salts to bind together suspended solids. Larger conglomerations of suspended solids will produce increased particle removal through gravitational settling. In the CEPT process, the high removal rates of suspended solids (commonly around 80%) are accompanied by an increased removal of BOD (around 40-60%). Examples of chemical additives to wastewater are alum, ferric chloride, ferric sulfate, and lime. Adding chemicals to wastewater is not a new treatment process. As early as the 1870s, there are reports of its use in England. In fact, during the early 1900s it was also commonly utilized in the United States. This was before the development and widespread adoption of biological treatment (Parker, 2001). The most common complaints associated with the early use of CEPT were chemical expense and large quantities of sludge produced that required disposal (Harleman, 2001). However, research suggests that chemical costs can be reduced through employment of lower dosages of chemicals than traditionally used. Those original chemical dosage levels were on the order of magnitude of 200-300 mg/l of the metal salt. During the 1980s, in the United States lower dosages of metal salts (on the range of 20-40 mg/l) were coupled with polymers as flocculants (Harleman, 1998).

4.2 History

Documentation exists for the use of low-dose CEPT during the 1960s when the Great Lakes of the Midwestern United States were experiencing a substantial amount of eutrophication. The equipment vendor Dorr Oliver championed the process of adding small amounts of lime before activated sludge treatment in order to meet phosphorus treatment objectives. During the same time, Dow Chemical developed a CEPT process featuring the addition of ferric chloride and polymer to untreated wastewater. Dow's process was piloted in Michigan and later its use was expanded to other Midwestern cities in the United States. Furthermore, several plants were developed during the 1980s in Windsor and Sarnia in Ontario, Canada that also utilized CEPT to help address the eutrophication of Lake Huron (Parker, 2001).

CEPT has also been at the forefront of controversies within the United States over the necessary degree of treatment of wastewater before disposal through ocean outfalls. In California engineers and scientists at the Point Loma plant in San Diego successfully obtained a waiver from Congress to avoid the construction of a secondary treatment facility. This was done through demonstrations that there would be no degradation of the ocean following CEPT. Their argument attacked the mandate for use of technology based wastewater treatment modalities rather than the establishment of percent removal goals based on the assimilative capacity of the receiving waters. Additionally, during the time of the Boston Harbor cleanup in Massachusetts, the late Professor Donald Harleman from the MIT Civil and Environmental Engineering department campaigned vigorously for the incorporation of CEPT into the treatment scheme. He asserted that CEPT plus an ocean outfall or CEPT plus secondary treatment plus outfall would save money. Ultimately in this situation CEPT was not incorporated but the concept received international attention (Morrissey, 1992).

About the same time as the Boston Harbor cleanup, the efforts of Professor Harelman's research group at MIT focused on the application and applicability of CEPT to the developing world. During the mid-90s current MIT lecturer Susan Murcott performed pilot studies in places such as Mexico City, Hong Kong, and several cities in Scandinavia. Her work involved numerous bench scale tests and a few pilot applications of CEPT, as well as the gathering of CEPT case studies.

In Mexico City, it was estimated that the operation and maintenance costs of a CEPT plant were comparable to those of a conventional activated sludge plant due to predictions that savings in energy expenses would recover the increased chemical costs. On the other hand, the capital costs of a CEPT plant were forecast to be half as much of that of an activated sludge plant due to the reduced number of necessary sedimentation basins. During pilot testing CEPT was able to achieve similar amounts of removal of helminth eggs (a significant problem for Mexico city) as activated sludge plants. While CEPT removed less organic matter, this was actually viewed as beneficial since peasant farmers utilize the wastewater effluent for agricultural irrigation (Murcott, 1996).

The Stone Cutter's Island plant in Hong Kong started operating in July of 1997. At the time it was the world's largest CEPT plant with a maximum capacity of 40 m^3/sec. Initially the plant was not going to incorporate CEPT. However, after a favorable report by an international review panel CEPT was incorporated into the design. Through the use of a combination of ferric chloride, an anionic polymer, and seawater, the number of required settling tanks was reduced from 58 to 38. On average, from 1997 –2000 the plant saw 84% suspended solids removal efficiency and 75% BOD removal efficiency attributed to CEPT (MIT, 2003). Experiences in Scandinavian countries produced similar results. Through low-dose CEPT more suspended solids and BOD were removed. As a result, surface overflow rates could be increased thereby reducing the number of necessary sedimentation basins (Murcott, 1994).

A number of CEPT studies have been conducted as MIT MEng thesis projects. The bulk of these projects center around fieldwork conducted in Brazil. Their foci range from the modeling of CEPT in waste stabilization lagoons to full conceptual models of plants for particular cities. Students have also researched the use of seawater as a coagulant aid in the CEPT process (MIT, 2003). While CEPT has seen widespread global use, the vast variations of application in terms of the quantities and combinations of chemicals and the locations of the injection points in the treatment process are staggering. This may be directly attributed to the numerous regional differences in water quality, varied treatment objectives, and chemical availability. CEPT can be effectively studied by breaking down the process into the various physical phenomena involved. There is substantial research available on flocculation, coagulation, and sedimentation of wastewater. This research may be used as a framework when considering the use situation of CEPT coupled with an Imhoff tank. The remainder of this chapter attempts to summarize some of the key issues that were identified as a result of a literature review and relate them to the use of CEPT as part of wastewater treatment in an Imhoff tank.

4.3 Coagulation/Flocculation

Wastewater is composed of some suspended material that is naturally settleable and some that is nonsettleable. A significant portion of the nonsettleable suspended material is colloidal matter. Colloids range in size from 10^{-6} mm – 10^{-3} mm and tend to have a high specific surface area. Colloids also have a tendency to develop an electrostatic charge and adsorb substances. It is desirable to remove colloidal particulates because they may harbor pathogens and exert an oxygen demand. However, colloids stay in suspension because the repulsive force of other colloids produce a stabile electrostatic force that prevents settling through operation of gravity. The relative stability of a colloidal suspension can quantified through calculating its zeta potential:

$$\zeta = \frac{4\pi q d}{D}$$

ζ = zeta potential
q = charge per unit area
d = thickness of layer surrounding the shear surface through which the charge is effective
D = dielectric constant of the liquid. (Reynolds, 1996)

The greater the zeta potential the more stable the suspension.

The process of destabilization and initial aggregation of colloidal and fine suspended solids is called coagulation. Through the addition and rapid mixing of a coagulant, the zeta potential is decreased enough so that van der Waals forces can attract the particulates, thus helping them to coalesce. Most naturally occurring colloids are negative while most coagulant salts (when added to water) dissociate, undergo hydrolysis, and create positively charged complexes (Reynolds, 1996). These highly positive charges are then absorbed on the surface of the negative colloids. Additionally, particles aggregate through interparticle bridging until a "floc" consisting of the enmeshed suspended particles is precipitated.

The process of flocculation is furthered by a slow stirring or gentle agitation to bring the destabilized particles together. The goal is to produce a rapid-settling floc. Settling of a floc is governed by Stoke's law for Reynolds Numbers less than 0.3 (Tchobanoglous, 1991).

$$V_c = \frac{g\,(\rho_S - \rho)d^2}{18\mu}$$

V_c = terminal velocity of particle
ρ_s = density of particle
g = acceleration due to gravity
μ = dynamic viscosity
d = particle diameter
ρ = density of fluid

Given that the settling velocity is directly proportional to the square of the particle diameter, in order to produce a rapid-settling floc the goal of flocculation goal is to grow the size of the flocs.

As the diameter of the particles grow the settling characteristics of the particles are classically determined experimentally through a settling column.

Flocculation basins are typically furnished with mechanical agitators (i.e. paddle wheels), pneumatic agitators, or baffles in order to provide gentle mixing. The main design parameter, the velocity gradient (G), is used to evaluate the degree of mixing.

$$G = \sqrt{\frac{P}{\mu V}}$$

P = power imparted to the wastewater
V = basin volume
μ = absolute viscosity of the wastewater

The velocity gradient is proportional to the rate of particulate collisions and the total number of collisions is proportional to the product of G and the detention time T (Reynolds, 1996). Care must be taken because if G is too large flocs may break apart.

For Imhoff tanks without chemicals, coagulation and flocculation occur more or less simultaneously in the upper sedimentation chamber of the tank rather than in a separate flocculation basin. Two types of particle contact produce agglomeration of particles: velocity gradients in the tank and differential settling rates (EPA, 1975). In general, due to the larger particulates in wastewater, flocculation occurs with relative ease and the required values of "G" multiplied by detention time "T" are much less than those for drinking water treatment (GT = 10,000-100,000 for wastewater vs. 30,000-210,000 for drinking water) (Reynolds, 1996). Still, wastewater treatment designs also frequently utilize mechanical agitators. Other techniques such as ballasted flocculation of wastewaters streams are employed to augment natural flocculation processes.

Imhoff tanks commonly utilize either the influent channels and/or the sedimentation chamber for coagulation and flocculation. In the case of water treatment it has been demonstrated that flocculation can occur in the influent channel if chemical addition is far enough upstream (Shultz, 1992). For wastewater treatment, this can be viewed as both a blessing and a curse. While it is a good thing that new basins do not necessarily need to be added, a substantial amount of sludge could form within the channel and removal mechanisms would need to be incorporated into the design and operating protocols.

4.4 Chemicals

A wide variety of chemicals have been successfully used for CEPT. Aluminum sulfate "alum" is the most frequently used coagulant because it is generally the cheapest and is readily obtainable in lump, ground, and liquid forms. The optimum pH range for alum is 4.5 to 8.0 (because it is relatively insoluble over this range). Iron salts on the other hand are effective over a wider pH range. For example, ferric sulfate and ferric chloride are relatively insoluble on a pH range of 4 to 12. Additionally, the flocs formed by iron salts are denser than those of alum and therefore settle more rapidly. Flocculant aids are frequently added in low dosages (less than 0.3 mg/l) in order to reduce the necessary quantities of primary coagulants and obtain optimum coagulation. However, most polyelectrolytes are synthetic chemicals and prohibitively expensive in developing countries (Reynolds, 1996). Occasionally natural polymers from plants and animals (i.e. fish eyes) are utilized (Shultz, 1992). Adjustment of alkalinity and pH is typically done through the use of lime. Most case studies by MIT students in Brazil found that a substantially smaller quantity of ferric chloride as the coagulant produced similar suspended solids and BOD removal rates as compared to alum (MIT, 2003). Ultimately however, in order to determine the optimal dosage of coagulant for a particular wastewater stream, it must be put through bench scale jar testing and pilot runs.

4.5 Sedimentation

Thomas Camp largely developed the theories driving the design of sedimentation basins. Through the demarcation of an ideal settling zone and by considering the trajectory of the slowest settling particle that would be completely removed, he was able to demonstrate the relationship between sedimentation velocity and the theoretical performance of sedimentation tanks. As a result he emphasized the surface-overflow rate: flow/area, rather than hydraulic retention time, as the driving factor in designing an ideal sedimentation tank. The design parameters proposed by Camp are widely utilized in industry to design sedimentation tanks. Over many years of practice, it has also been recognized that Camp's theoretical values are not so easily obtained. Camp's initial assumptions included prerequisites for the application of his theories that are commonly not achieved in the field. Camp recognized that when flocculation occurs it complicates the model of designing sedimentation tanks solely based on surface overflow rates. Secondly, he assumed that all particles reaching the bottom of the ideal settling zone remained indefinitely removed. In practice however, scouring does occur and affects the performance of settling basins. Finally, he assumed that an adequate velocity distribution is achieved at the inlet (Dick, 1982). Thus, his assumptions led Camp to encourage the use of shallow basins, which rely on high forward velocities for particle agglomeration. However actual trends in the U.S. seem to favor deeper tanks that rely on differential settling for particle agglomeration. These designs are based on the proposition that at high forward velocities there is little flocculation achieved. Studies show that raw sewage agglomerates slowly under differential settling conditions so detention time can have a significant effect on settling tank performance (EPA, 1975).

All of these complications directly apply to the use of CEPT in an Imhoff tank. Addition of chemicals causes flocculation within the Imhoff tank making the prediction of the amounts of settling much more challenging. Inlet and outlet designs may not evenly distribute the flow. Further, if operated at high overflow rates Imhoff tanks may still experience solids scouring despite the settling of sludge by inclined plates into a separate digester.

5 LAS VEGAS

5.1 Geography

Las Vegas (Figure 5.1 (Google, 2008)) is located in the department of Santa Barbara, which is the 9th most populated department in the country. The municipality of Las Vegas is located just west (14º 52' N, 88º 4' W) of the largest freshwater lake in Honduras, Lake Yojoa. Lake Yojoa is situated 125 kilometers northwest of the capital of Honduras, Tegucigalpa, and 75 kilometers south of the industrial capital of Honduras, San Pedro Sula.

Figure 5.1 Las Vegas

The region of Las Vegas gained the status of township on September 8, 1987 and formally became a municipality on December 17, 1997 (Herrera, 2006).

Lake Yojoa is a valued natural resource in the area and a major center for industry and tourism in Honduras. The municipalities of Santa Cruz de Yojoa, Cortés, Taulabé, Comayagua, and San Pedro de Zacapa all border the lake. Some of the most notable businesses in the vicinity include Aqua Finca, Saint Peter Fish, a tilapia fish farm owned by a Swiss proprietor that has operated in Honduras since 1997. Additionally, the mining operation, American Pacific Mining Corporation, AMPAC, began operations in the area in 1948. Since then AMPAC has experienced several operational changes. The mine has been owned and operated since 1990 by the trans-Canadian organization, Breakwater. It is the biggest mine in Central America, primarily mining zinc, and provides employment to more than 200 people from Las Vegas (Trate, 2006). El Mochito, the neighborhood in which AMPAC is located, falls within the jurisdiction of the municipality of Las Vegas. Therefore the mine provides substantial funding for city projects.

5.2 Population

The total population of urban Las Vegas is approximately 17,400 and is spread among the four neighborhoods of El Mochito, San Juan, Las Vegas Central, and Las Vegas North. The neighborhood of Las Vegas Central makes up the urban center for the municipality. In addition to some residential housing, shops, the central park, the main soccer field and the municipal building are all located in this area. The number of dwellings in Figure 5.2 refers only to legal connections to the water system.

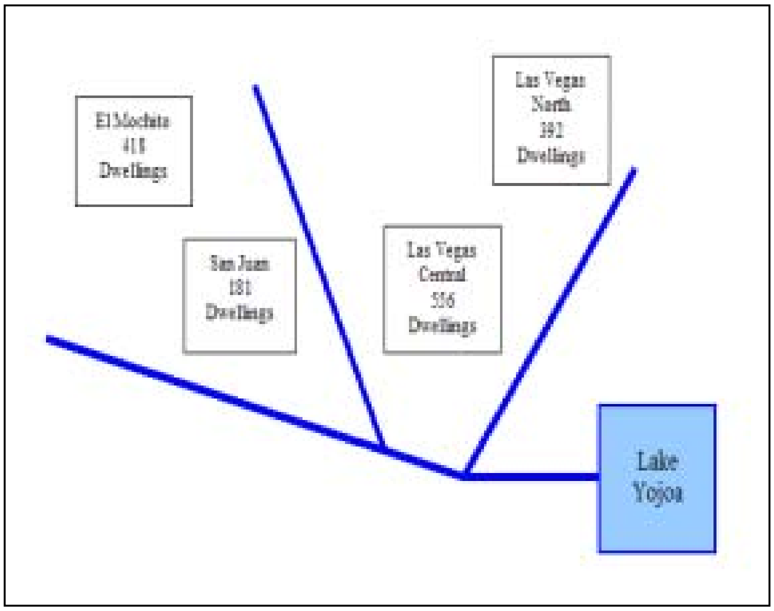


Figure 5.2 Las Vegas Urban Neighborhoods

5.3 Water and Wastewater Treatment

The water supply for the municipality of Las Vegas is currently not treated but comes from mountain springs. The city engineers are considering chlorination for portions of the distribution system. Bottled water from vendors is readily available. No investigation into how many people use tap water versus purchasing water was conducted nor is the author aware of another study. One major concern of the city engineers is severe scaling in the water pipes, which is forcing frequent replacement.

Currently wastewater treatment in Las Vegas consists of two Imhoff tanks constructed in parallel and which service a group of dwellings in Las Vegas Central. City engineers estimate the Imhoff tanks service roughly 3,600 residents (6 residents per dwelling times 600 dwellings). Wastewater in the neighborhoods of El Mochito and San Juan are serviced by septic tanks or discharge directly into the river. A wastewater collector is currently under construction for the neighborhood of Las Vegas North through a grant from the government of Taiwan. A major question is where the wastewater will go for treatment, if any, after this new collector is built. In the short term, it will probably go directly into the river. The city engineers expressed interest in whether the existing Imhoff tanks could handle this additional flow. If it could not be routed to the existing Imhoff tanks, they were also interested in knowing our opinions on what other forms of wastewater treatment infrastructure they should consider building. In reality, all of the current wastewater systems in Las Vegas are best described as wastewater collection devices that in some cases provide only a minimal amount of treatment through removal of solids.

5.4 Imhoff Tanks

The Imhoff tanks (Figures 5.3 – 5.6) were built in Las Vegas in 1992 with capital funds provided by FHIS. The system consists of two tanks in parallel originally designed to serve 4,000 residents producing 250 liters/person/day of wastewater. They were designed by the SANAA engineer Pedro Ortiz and constructed under the supervision of the nongovernmental organization Agua Para el Pueblo (APP). According to the Executive Director of APP, their construction was part of a program to create construction jobs in the area (J. Nuñez, personal communication, January 23, 2008). Originally there were plans to build a large septic tank with a drainfield on land adjacent to the Imhoff tanks. However funds ran short and this was never completed. A road now occupies this piece of land.

Figure 5.3 Las Vegas Imhoff Tanks

Figure 5.4 Top View (Influent lower left corner, Effluent upper right corner)

Figure 5.5 Inside View of Sedimentation Chamber

Figure 5.6 Sludge Valves

5.4.1 Service Area

As noted above, the Imhoff tanks service a part of Las Vegas Central (the area between Piedras Amarillas and Raices Creek). A more detailed depiction of this area is provided in Figure 5.7. Exact locations of upstream piping connected to the Imhoff tanks are not documented. Again, it is estimated that roughly 600 houses are connected to the system (and at 6 people per household 3,600 people). Some of these connections are illegal.

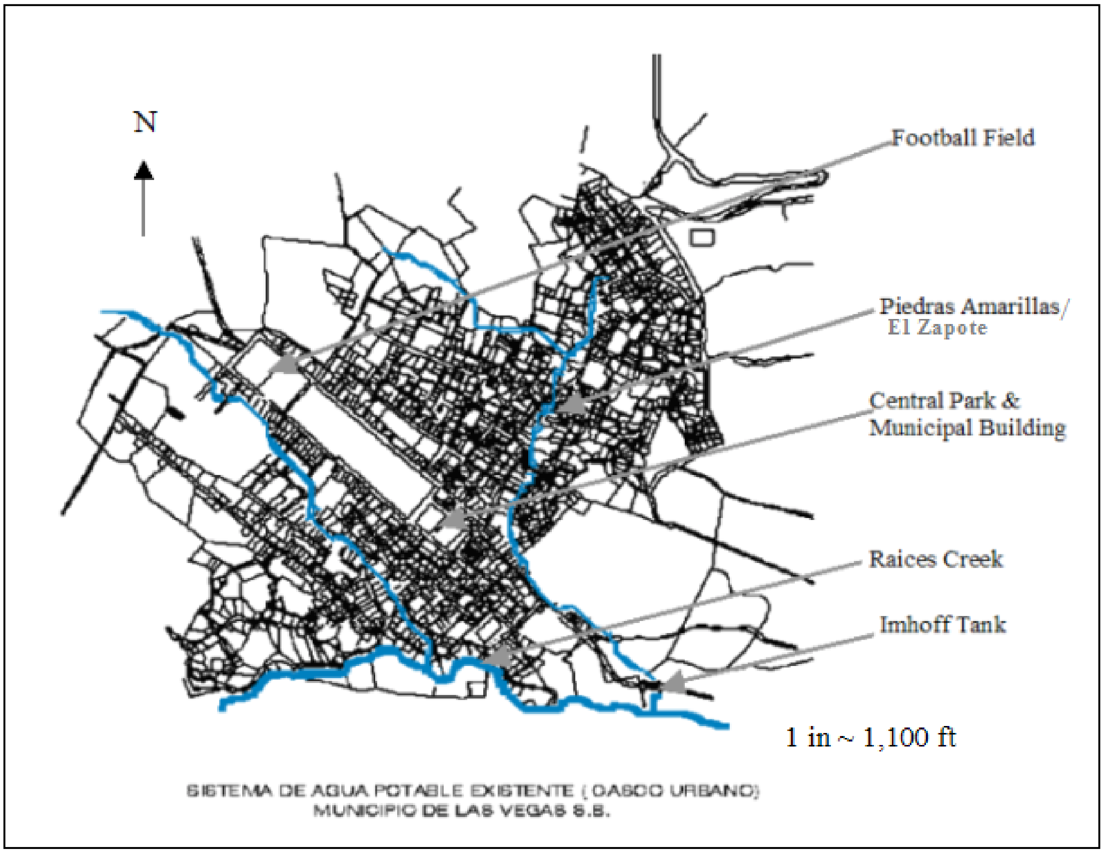


Figure 5.7 Imhoff Tank Service Area

5.4.2 Dimensions

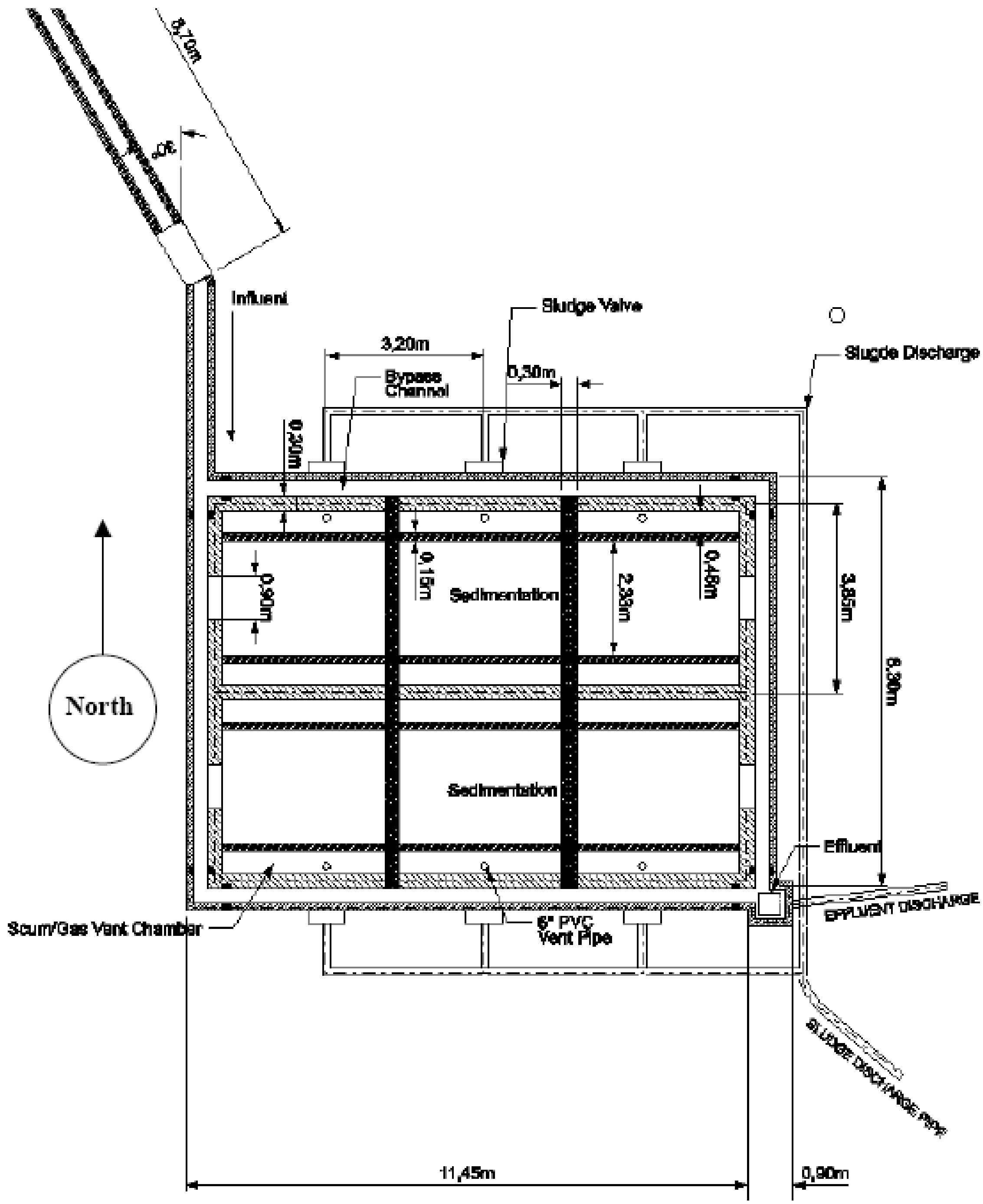


Figure 5.8 Plan View Las Vegas Imhoff Tanks (Herrera, 2006)

Ari Herrera measured the dimensions for the plan view in Figure 5.8 during the summer of 2006. Each Imhoff tank contains three conical wells to which sludge valves and discharge pipes are connected. The dimensions for these wells are shown in Figure 5.9. The depth dimensions in Figure 5.9 are taken from the original construction plans supplied by the contractors APP. The surface area in the plan view of Figure 5.9 includes the scum and bypass channels for one tank.

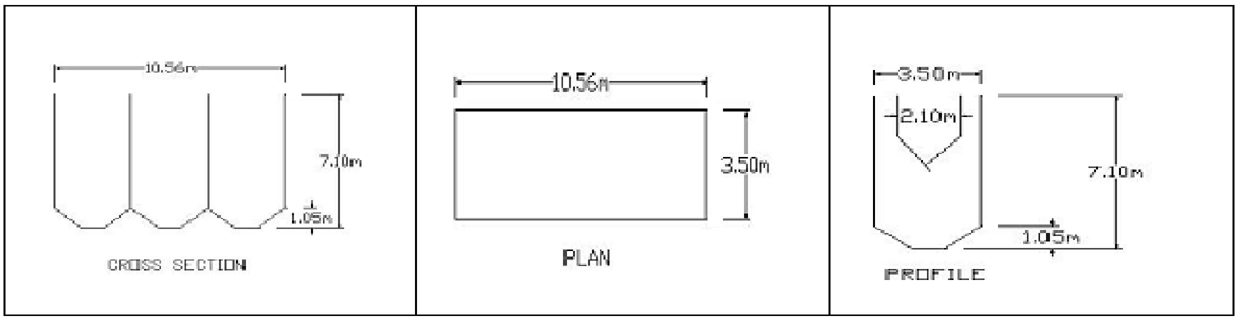


Figure 5.9 Dimensions of One Las Vegas Imhoff Tank

The channel upstream of the Imhoff tank is shown in Figure 5.10. The channel is constructed of a 12-inch diameter cast-in-place concrete pipe. There are three uncovered openings in the channel. The three elevation points marked "E" were measured relative to an arbitrary datum of 100 m at the box farthest from the Imhoff tank. These elevations were taken from the top of the concrete structure not the water surface.

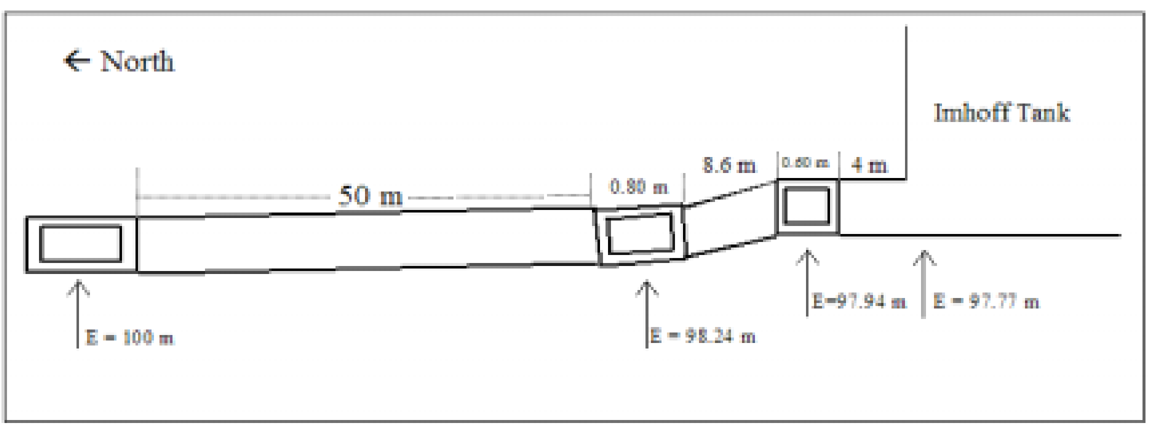


Figure 5.10 Dimensions of Upstream Channel (not to scale)

5.4.3 Flows

Experco International, a Canadian environmental engineering consulting firm, measured the flows on the Imhoff tank in a 2003 study. The graphs in Figure 5.11 show flow data for roughly a 26-hour period. The depth data suggests that the flows were calculated by measuring the height of water in the influent channel coupled with a travel time or other method to determine velocities. It is unknown what type of equipment was used to obtain these measurements. The flow to the Imhoff tank throughout the day is not constant, however it is possible to see a distinct diurnal pattern. Based upon the 2003 study, from 6am – 5pm one should design for a peak flow of 142 m^3/h. From 5pm – 12am there are significant fluctuations, but one could design for an average flow of 69 m^3/h. As the city is sleeping from 12am – 6am the flow in the system drops down to around 20 m^3/h.

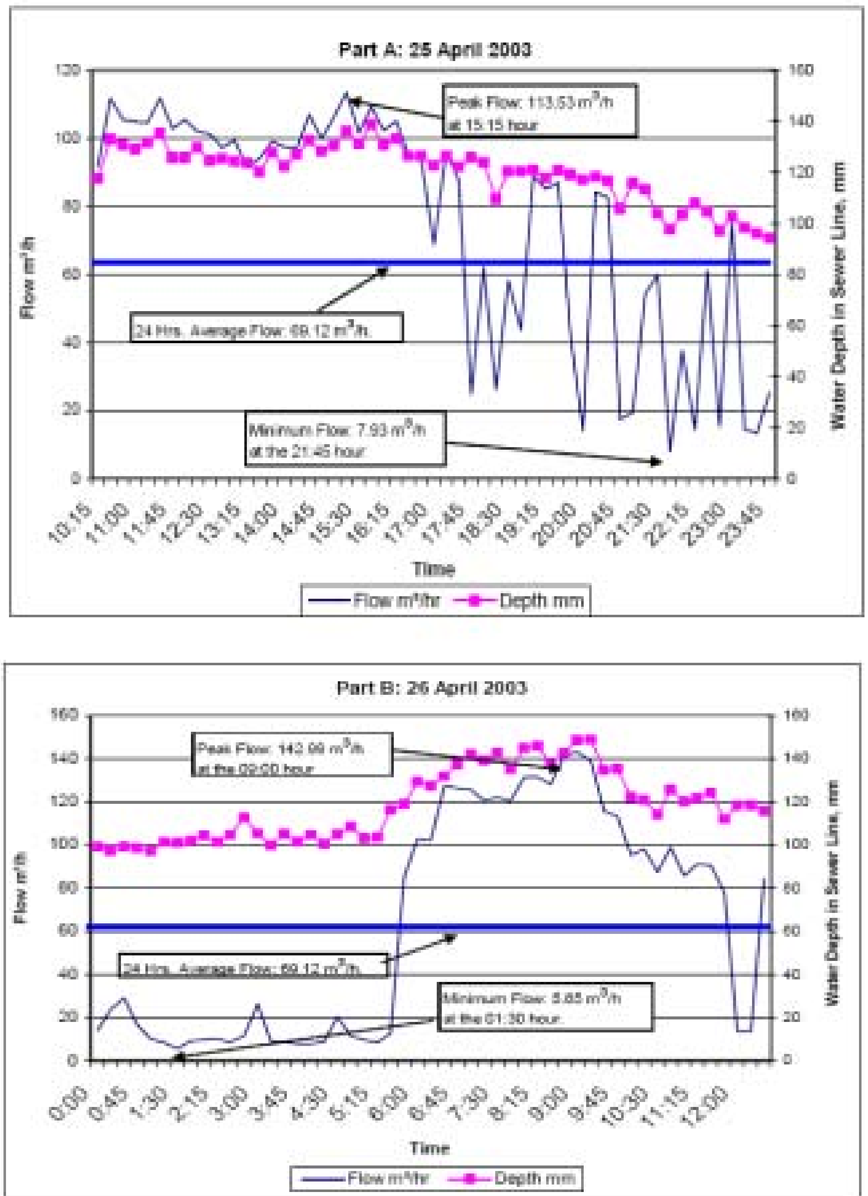


Figure 5.11 Las Vegas 2003 Flows (Herrera, 2006)

Matthew Hodge also measured flows during January 2008. Small tangerines were dropped in a straight portion of the influent channel. The depth of water and travel time along a known distance were recorded and used to calculate the flows. It should be noted that the tangerines might not precisely represent the flowrate since they floated along the top of the water, which would contain the fastest moving layer of the water column.

Table 5.1 January 2008 Flows (Hodge, 2008)

Date	Time	Flow Rate m^3/h
1/16/2008	09:30	191
1/16/2008	14:30	191
1/17/2008	04:30	103
1/17/2008	10:00	173
1/19/2006	14:00	161
1/20/2008	10:00	180
1/21/2008	09:30	164
1/25/2008	15:00	145
1/29/2008	10:45	170
1/29/2008	12:00	156
1/29/2008	12:30	149
1/29/2008	13:00	153

The results suggest a similar pattern to the day as Experco's 2003 study. However, the actual quantities of flow are higher. The average value during the peak period of 6am – 5pm was 180 m^3/h. This may be due to the seasonal differences between April and January, more connections since 2003, increased water usage, or differences in the method of measuring flow. Additionally at 4:30 am, when one would expect low flows due to nighttime inactivity, the flow to the system was measured to be 103 m^3/h!

This staggering amount of early morning flow can be attributed to a combination of factors. According to the plumbers in Las Vegas from November – January many residents de-pulp coffee beans in their homes. In order to harvest the beans, the coffee berry must first be de-shelled. Many farmers bring the coffee berries home and leave them under running water throughout the night. The combination of softening and mechanical separation induced by the flowing water removes the shell. However, it also uses a lot of water. Dry methods exist for de-pulping coffee, but reputedly at the expense of altering flavor. During January 2008, the scum chambers in the Imhoff tanks accumulated a lot of coffee beans (Figure 5.12), suggesting this is a major issue. Other reasons for high flows during the nighttime include a large number of leaky faucets in the town as well as groundwater infiltration into the waste stream.

Figure 5.12 Coffee Beans in Scum Chamber

The data from the Experco 2003 study and January 2008 Hodge study do not represent the variations in seasonal flow. During the rainy season (May-September) the plumbers mentioned that the majority of the freeboard in the sedimentation tank is utilized. One is also able to visually observe these high water marks on the interior sides of the tanks. Fred Stottlemyer, director of the International Rural Water Associations Honduras projects, has worked in Honduras for over 10 years. He estimates that during the rainy seasons surface and groundwater infiltration increases flow into the system by 200% (F. Stottlemyer, personal communication, January 11, 2008). This quantity would not only place an extremely large amount of "extra" water flow on the system, but also substantially dilute the actual wastewater loads.

5.4.4 Loads

During the same 2003 study mentioned above, Experco measured the load on the Imhoff tank. The sampling regime for this study is unknown so it is not clear if the results are from a single grab sample or averaged over the course of the study. All samples were preserved by the norms established by "Standard Methods." The data for Experco in Table 5.2 is taken from Herrera (2006).

The work in January 2008 focused on total suspended solids (TSS), total coliforms, and BOD/COD as performance metrics. The reported values are averaged from all of the tests run by Mattthew Hodge (TSS_{in} n = 5, TSS_{ef} n = 6, COD_{in} n = 3, COD_{ef} n = 5, BOD_{in} n= 4, BOD_{ef} n = 2, TC_{in} n = 1, TC_{ef} n = 3) (Hodge, 2008). Measurements were taken using the following methods before any structural changes (such as the introduction of baffles and gates that will be described in section 5.4.5 Maintenance):

Total Suspended Solids

The most prevalent and recommended method to measure TSS is the "Total Suspended Solids Gravimetric Method" (Standard Method 2540). This method was used for the influent and effluent testing of the Las Vegas Imhoff tank. TSS is a measure of both suspended solids and dissolved solids. Typical municipal wastewater has a TSS of between 450 and 1250 mg/L (Reynolds, 1996).

Chemical Oxygen Demand

Chemical Oxygen Demand (COD) is a measure of the oxygen required to chemically oxidize all of the organic material in a water sample. To test the COD of water samples in this project the HACH Chemical Oxygen Demand Colorimetric Method (Method 8000) was used.

Biochemical Oxygen Demand

Biochemical Oxygen Demand (BOD) is a measure of the oxygen needed for aerobic microbes to fully decompose organic wastes in water. This is a more relevant water quality measurement than COD, but requires more time (typically a BOD 5 day test) than COD tests. The method that was used to test BOD_5 was Standard Method 5210.

Total Fecal Coliforms and E. Coli

Total Fecal Coliforms is a measure of the total microbial activity in a water sample. It is used as a surrogate for a measure of pathogens in the water. Typically an absence of coliforms correlates to an absence of pathogens. The approved method for measuring coliforms is the "Membrane Filter Technique for Members of the Coliform Group" (Standard Method 9222). Due to limitations of onsite laboratory equipment, another testing method was utilized in place of the standard method. 3M E.Coli/Coliform Petrifilm Count Plates were used to measure total fecal coliforms in this project.

Table 5.2 Las Vegas Imhoff Tank Loads (Herrera, 2006 & Hodge, 2008)

			Experco 2003		MIT January 2008	
Parameter	**Units**	**Regulation**	**Influent**	**Effluent**	**Influent**	**Effluent**
pH		6.0 - 9.0	7.36	7.26	8.0	
Conductivity	µs/cm		474	479		
Settlable Solids	mL/L/hr	1	3.5	2.5		
Total Suspended Solids	mg/L	100	205	110	190	140
Ammonia Nitrogen	mg/L	20	8.96	10.64		
TKN	mg/L	30	10.64	11.76		
Nitrites	mg/L		<0.01	<0.01		
Nitrates	mg/L		0.01	0.07		
Total P	mg/L	5	3.50	3.70		
Fecal Coliforms	UFC/ 100 mL	5E+03	4E+07	5E+07	5E+08	1.8E+09
Fats and Oils	mg/L	10	29.56	27.43		
COD	mg/L of O_2	200	220	227	320	260
BOD	mg/L of O_2	50	123	138	150	120

At the times of our measurements, the Imhoff tanks were not performing as well as they were in 2003 for TSS and Fecal Coliforms. The tanks were achieving an average of 26% removal of

TSS whereas in 2003 it was 46%. The tanks were also experiencing an increase of 260% for fecal coliforms whereas in 2003 the increase was only 25%. However, it is difficult to make a direct comparison because we do not know if the Experco results are representative of average conditions during 2003. The poor performance may be connected to high flow through the system. High flow results in shorter detention times and in turn less settling. Additionally high flow can cause scouring, which causes partially digested sludge to surface and be discharged with the effluent before it has time to settle. During January these types of plumes were observed (Figure 5.12) and are suspected to have caused the increase in fecal coliforms. COD and BOD_5 performance during 2008 improved, but neither meets applicable regulatory standards.

Figure 5.13 Scouring

5.4.5 Maintenance

Sludge Removal

The Las Vegas Imhoff tanks did not receive maintenance until December 2007. As preparation for the MIT January 2008 tests, the municipality cleaned the digestion chambers for the first time since construction in 1992. The procedure took three men two days. Sand and other compacted solids clogged the valves at the base of the tank that were constructed for sludge removal. This resulted in several of the discharge pipes needing replacement after the cleaning. The sludge was emptied from the digestion chamber by rope and bucket. After removal it was buried along side of the Imhoff tanks since a sludge drying bed does not exist. Despite lack of sludge removal for 16 years, the tanks are in good structural condition. Hodge recommended to the municipality that it removes sludge (approximately 47 m^3) semi-annually and design and build a sludge drying bed adjacent the Imhoff tanks (Hodge, 2008).

Flow

The distribution of flow between the two Imhoff tanks is inherently uneven. This results in unequal residence times and less than optimal removal of solids. There are several correctable causes of uneven flow distribution. The first is poor quality and improperly utilized flow gates. Flow gates should be located in eight positions in the bypass channel that surrounds the sedimentation chambers. The flow gates should be used to bypass the sedimentation chambers during cleaning. They should also be used to reverse the flow so that solids will be deposited along the entire length of the digestion chamber rather than primarily in the effluent end.

Flow gates were all together missing at the start of January 2008. We constructed wooden gates in January, but it was difficult to create a seal and so many short-circuited. Placing a rubber tire along the cement-wood interface did not help to correct this issue. The plumbers of Las Vegas came up with the idea of using bags of sand as further means to block the flow behind each wooden flow gate. The bags are easier to remove and did a better job than the wooden flow gates alone. Finally, if the proper placement of flow gate locations in order to maximize their effectiveness is not intuitively obvious, (Herrera, 2006) contains sketches trying to explain placement procedure. The MIT team recommended that the municipality maintain eight flow gates consisting of the wooden planks and bags of sand (Figure 5.14) and to use them monthly to reverse the flow through the system.

Figure 5.14 Wooden + Sand Bag Flow Gate

Additionally, the inlets into the sedimentation chambers do not facilitate even flow distribution between and within the two Imhoff tanks. Wooden baffles with two rows of holes were installed during January 2008 to even out the flow (Figure 5.15).

Figure 5.15 Inlet Baffles

Approximately 13 holes per row were installed using a hand drill. They were approximately one inch in diameter and spaced one inch apart. The positioning and size of the holes were determined through trial and error. First a single line of holes was created, then a second. The original boards did not provide enough free board in the influent channel when the holes became clogged, so the boards were cut shorter. The ultimate goal is to have an even amount of flow in both Imhoff tanks and for that flow to spread across the entire width of the sedimentation chambers. While the baffles do help to even out the flow distribution they also clog very easily because the overall system does not possess a grit chamber. Plastic bags and large pieces of feces block the holes after several hours. Once the holes are blocked the water flows over the top of the baffles. Nevertheless the flow between the tanks was still better distributed than without the baffles. Cleaning the baffles requires poking a stick in the holes and removing plastic bags. It was observed that this transforms the influent channel into a grit chamber where many more solids are deposited. An effort must be taken to clean the influent channel out on a daily basis and the baffles several times a day.

Scum

Gases generated during sludge digestion produce bubbles that rise to the surface of the tank carrying with them partly digested pieces of solids. The majority of the gas and solids rise in the scum chamber portion of the tank. As a result a layer of solid crust forms in the scum chambers (Figure 5.16). This layer must be routinely broken up in each of the four scum chambers to afford an easy escape of gas from the digestion chamber. The operator can construct a scraper similar to the one shown in Figure 5.16 that is used by the operator in Marcala, La Paz. It is recommended to removal scum from the four scum chambers and sedimentation chamber bi-weekly.

Figure 5.16 Inner Scum Chambers

Figure 5.17 Scum Scraper

Sedimentation Chamber

In order to achieve the highest possible levels of solids removal from the sedimentation chamber an operator needs to routinely clean the tanks. A rubber squeegee can be used along the sloping walls of the settling compartment to remove any solid material. This can be performed while the tanks are full of water. This prevents scouring and deposits the material into the lower digestion chamber where it can be properly digested. Secondly, the operator should ensure that the slot between the sedimentation chamber and digestion chamber remains free of obstruction. Dragging a chain or prodding with a long metal stick are two possible methods (Herrera 2006).

Records

Keeping accurate and updated records of the conditions at the Imhoff tanks is crucial to further optimization of the system and fixing any problems that may arise. The operator should document each day which of the tasks described above were preformed and any difficulties that arose during the maintenance operation. It was also advised to record the following statistics:

- Daily, flow into the system
  - Experiment with designing a weir, but at least do the following:
  - Record the date and time of measurement.
  - Drop a tangerine or other small piece of fruit into the straight portion of the influent channel.
  - Record the distance traveled, time to travel this distance, and depth of water in the pipe.
- Monthly, height of sludge in the digestion chamber
  - Insert a long rod into the tanks until the bottom of the digestion chamber is hit.
  - Remove the rod and record the length of the rod that is covered in sludge
  - Repeat at the influent and effluent ends of each tank.
- Semi-annually, quantity of sludge removed from system.

5.4.6 Receiving Stream/Water Quality Issues

Las Vegas holds a reputation around Lake Yojoa as being one of the lake's largest polluters. Raices Creek receives the effluent from the Imhoff Tank and for this reason is often referred to by local children as "poop creek." The creek discharges into Lake Yojoa 8 km downstream (Herrera, 2006). COD was measured before the Imhoff tank and at three locations downstream. The results are shown in Figure 5.17 (Hodge, 2008). Dissolved oxygen was not measured during January 2008. However, the bed of the river is rocky and contains many natural waterfalls (Figure 15.18) probably enough to provide suitable reaeration.

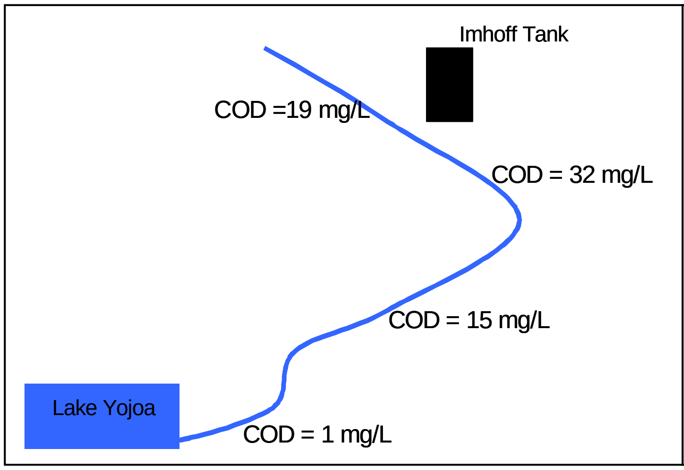


Figure 5.18 COD in Raices Creek

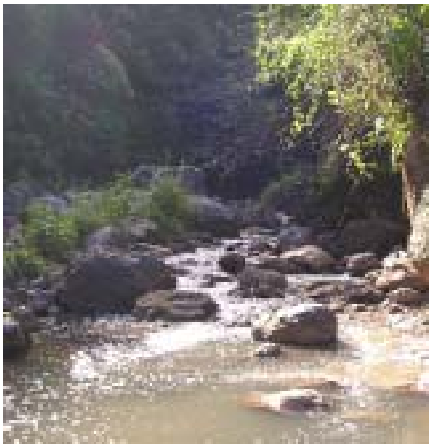


Figure 5.19 Raices Creek

6 CEPT AT LAS VEGAS

The primary goal of the investigation was to determine if CEPT is an appropriate, immediately available interim step towards meeting national effluent regulations in Las Vegas. An additional goal of the study was to determine whether through employment of CEPT the existing Imhoff tanks could sufficiently accommodate current surface overflow rates as well as long-term service area expansions. The recommendations are based upon study conclusions with respect to the following factors:

1) Availability of local coagulants
2) Dosage of coagulant and cost
3) Potential TSS and COD removal efficiencies
4) Additional sludge production
5) Feasibility of chemical injection

This chapter presents findings from the bench testing and pilot scale testing conducted during January 2008 in Las Vegas as they relate to these five factors.

6.1 Chemicals

During January several attempts were made to obtain local coagulants. The only readily available substance was solid alum, which is widely used in water treatment plants in Honduras. Attempts to obtain iron based metal salts were futile. MIT met with several environmental engineers from San Pedro Sula, the construction company Lazarus and Lazarus, as well as AMPAC but none of these contacts knew of any local suppliers of coagulants other than solid alum. The municipality of Las Vegas provided the alum for the bench and pilot scale tests. A limited quantity was obtained by Las Vegas' city engineer as a gift from the water utility in San Pedro Sula, which ultimately effected the length of the pilot test.

The company Tecno Quimica is the largest chemical supplier in Honduras and has offices in both Tegucigalpa and San Pedro Sula. They sell alum in 50 kg bags at 500 Lempiras per bag. (There are approximately 20 Lempiras to the dollar) (E. Rodas, personal communication, April 24, 2008). Additionally Cornell University engineers who have been working in Honduras for the past year said that their shipments of alum from Tecno Quimica either came from Chile or Columbia. They had observed that there was a drastic difference in effectiveness depending on the source. They commented that the product from Columbia repeatedly failed to produce satisfactory flocs in their water treatment plant and was thus inferior (J. Erickson, personal communication, January 10, 2008).

The bags of chemicals used in Las Vegas (Figure 6.1) trace back to Chile. According to their website, Fábricas Arteaga is the largest and oldest producer of aluminum sulfate in Chile. Don Domingo Arteaga Infante a 1923 graduate of the University of Michigan founded the company in 1935. The website for the company also shows that they carry only one form of solid alum that has the following product specifications:

Chemical Formula: $Al_2(SO_4)_3 \cdot 14H_20$; 17% as Al_2O_3
Characteristics: Solid, Monoclinic Crystal
Uses: Paper Industry, Water Treatment
Chemical Composition: Iron <0.05% as Fe^{+3} Alkalinity <0.2% free Al_2O_3
Grade: Iron Free (Fábricas, 2008)

Jar tests were preformed with the solid alum obtained in Honduras as well as solid alum from Brazil (from a past MIT MEng trip). Since the quality of the solid alum in terms of active ingredients from both Honduras and Brazil were unknown, upon return to the United States the samples were sent to the laboratory Alpha Analytical to be analyzed for total aluminum. The results show 78,000-mg/kg total aluminum in the solid from Honduras (compared to 90,020 mg/kg indicated by 17% Al_2O_3 in the product specifications) and 81,000-mg/kg total aluminum in the solid from Brazil.

Figure 6.1 Honduras Alum

6.2 Bench Scale Testing

6.2.1 Field Conditions

In Las Vegas there are three openings in the channel upstream of the tank (refer to Figure 5.10). Table 6.1 lists the corresponding GT values for injecting chemicals at these locations and Appendix B: Calculations for Field Mixing Conditions contains the calculations used for estimating these values.

Table 6.1 Field Mixing Conditions

Mixing in Influent Channel			
Position	*G* (sec^{-1})	*T (sec)*	*GT*
Closest Box	220	4	880
Middle Box	200	12	2,400
Farthest Box	230	58	13,340

The surface overflow rate (SOR) for the Imhoff tanks in Las Vegas varies throughout the day. The lowest observed flow was 103 m^3/h at 4:30 am and the peak flow was observed to be 191 m^3/h at 9:30 am. The surface area available for sedimentation is approximately (2.33 m width) x (10.5 m length) x (2 tanks) = 49 m^2. Therefore the corresponding peak SOR is 0.06 m/min and the low flow SOR is 0.035 m/min.

6.2.2 Jar Testing Methods

Samples of wastewater were collected in a large plastic garbage bin at varied times throughout January. The samples were taken from the influent channel approximately 15 m upstream of the entrance to the Imhoff tanks. Bench scale testing was performed using the 4-2L beaker Phipps & Bird jar testing apparatus (Model 7790-100) shown in Figure 6.2.

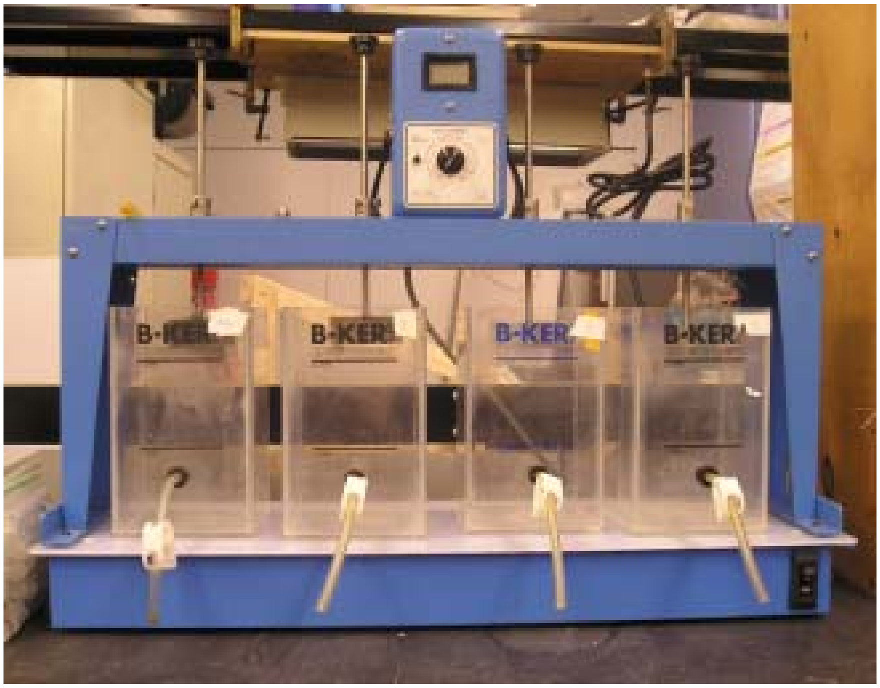


Figure 6.2 Phipps and Bird Jar Testing Apparatus

Before filling the beakers the wastewater was mixed using a broom handle. In order to have uniform samples the bottom few liters were routinely discarded due to elevated levels of settled solids. The samples were analyzed both qualitatively and quantitatively. Visual tests were initially performed to set the test ranges for the chemicals. Once the range was better defined, the initial pH, turbidity, suspended solids (SS), and COD were taken of the raw water sample for comparison after varied dosages of chemicals. These parameters were measured by the following methods:

Total Suspended Solids

The methods for the influent and effluent water analysis discussed in Section 5.4.4 utilized the most prevalent and recommended method: "Total Suspended Solids Gravimetric Method" (Standard Method 2540). While this method is the accepted method, during jar testing the HACH Suspended Solids Photometric Method (Method 8006) was used. This method was substituted due to the unavailability of an analytical balance and oven in the lab space and the need to take many samples rapidly. The results should be comparable, though the photometric method may produce slightly higher results as it may detect more colloidal matter.

Chemical Oxygen Demand

To test the COD of water samples in this project the HACH Chemical Oxygen Demand Colorimetric Method (Method 8000) was used.

pH

pH is the negative logarithm of the hydrogen ion concentration. It measures the acidity or alkalinity of a liquid. Water is acid if pH is under 7, is neutral if pH equals 7, and is alkaline if pH is above 7. The digital pH meter DPH-1 from ATAGO was used to measure the pH of the samples. It has an accuracy of +/- 0.1 pH.

Turbidity

Turbidity is a measure of the clarity of water, which is disrupted by both suspended and colloidal matter. A HACH portable turbidimeter, model 2100P, was used to measure turbidity. This turbidimeter operates on the nephelometric principle of turbidity measurement (the ratio of scattered light to transmitted light). The range of the unit is 0 – 1000 NTU with an accuracy of +/- 2% of readings (HACH, 2004). The calibration of the turbidimeter is based on three samples of standard turbidity (20, 100, 800 NTU) and was performed at the start and periodically checked throughout the experiments.

Mixing

A standard mixing regime was utilized during the jar tests. Before chemical addition the jars were stirred to suspend and solids that had settled during the set up of the experiment. Afterwards the chemicals were injected into the jars and the samples stirred for 30 seconds at 100 rpm. Visual observation during jar tests showed 100 rpm for 30 seconds mixed the chemicals well throughout the beakers. This supplied a GT value of 3,000 as obtained from the calibration curve provided by the manufacturer (Figure 6.3 (Phipps, 2007)). Actual rapid mixing speeds and durations depend on the injection point of the chemical in the field and the estimated conditions were presented in Table 6.1.

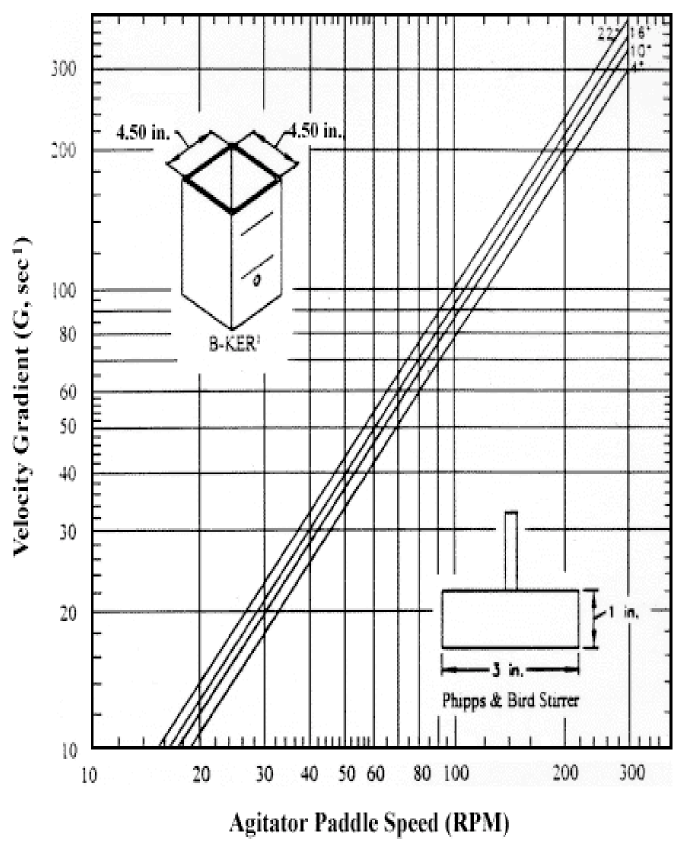


Figure 6.3 G-Curve

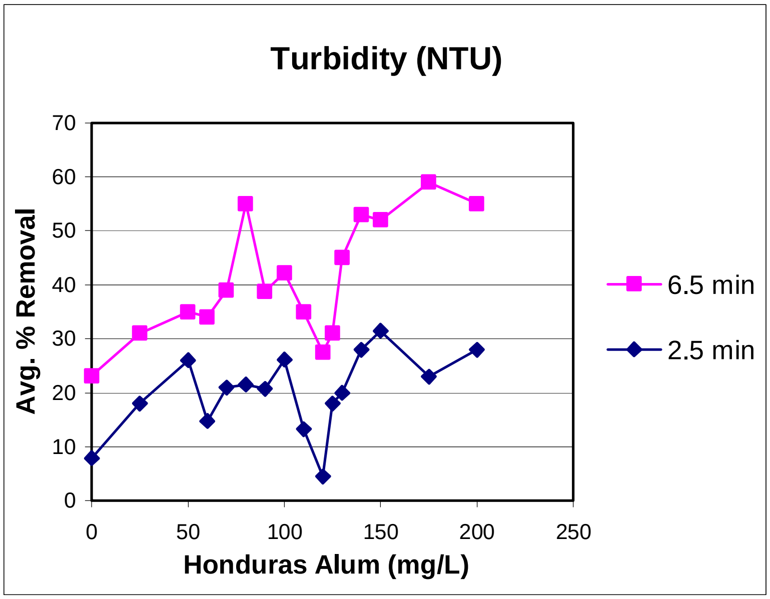
A period of slow mixing following rapid mixing is standard in jar tests, but this is associated with flocculation basins. Since the Imhoff tank system is only a sedimentation tank the samples were allowed to settle immediately following the rapid mixing step.

Settling

The settling times were chosen based on the existing peak SOR (0.06 m/min) and the recommended peak SOR of 0.02 m/min (Tchobanoglous, 1991). At the 2 L mark the jars are 6 inches deep. Since SOR = depth/time, a retention time of 2.5 minutes gives a SOR of 0.06 m/min and for a retention time of 6.5 minutes the SOR is 0.02 m/min.

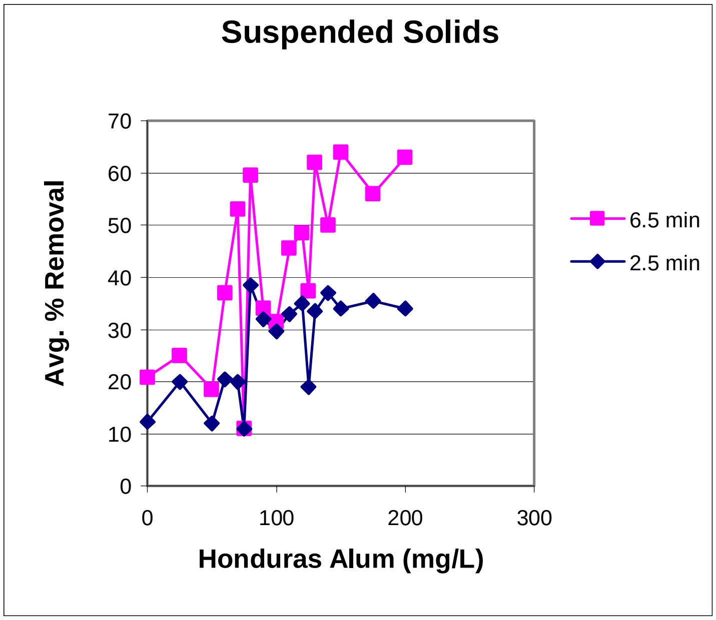
6.2.3 Jar Testing Results

Initial NTU, SS, and COD values for the raw samples were recorded (Appendix C: Jar Testing Raw Data). The final values of these parameters were measured after 30 seconds of mixing followed by settling for 2.5 and 6.5 minutes. The difference between initial and final values divided by the initial value was used to calculate the % removal for each jar test. All of the jar tests performed at a particular dosage were then averaged. The results for the solid alum from Brazil can be found in Appendix D: Brazil Alum Jar Testing Results. The results for the solid alum obtained in Honduras are graphed below according to mg dry solid per liter wastewater. The graphs are accompanied by a table that gives the number of trails represented per point on the graph.



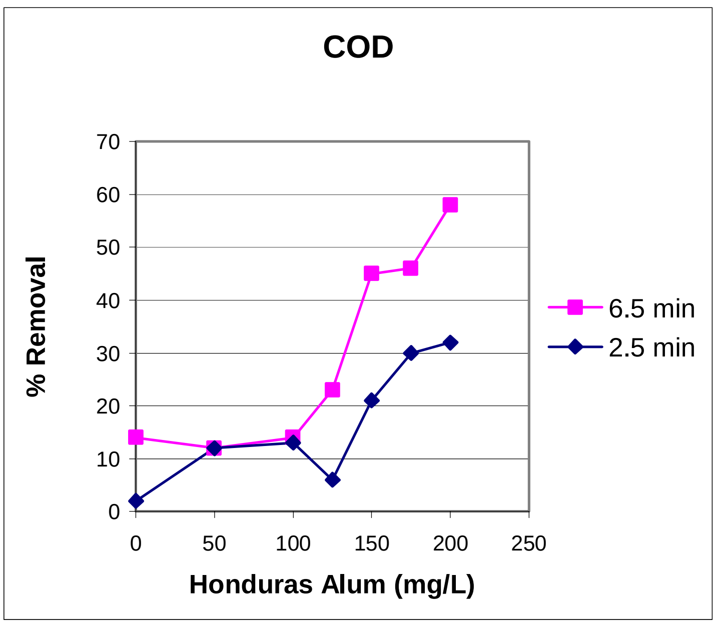
Dosage (mg/L)	# pts. 2.5 min	# pts. 6.5 min
0	11	11
25	1	1
50	1	1
60	4	1
70	1	1
80	4	2
90	4	4
100	7	5
110	4	4
120	2	2
125	1	1
130	2	2
140	1	1
150	2	2
175	1	1
200	1	1

Figure 6.4 Average % Removal of Turbidity by Honduras Alum



Dosage (mg/L)	#pts. – 2.5 min	#pts. 6.5 min
0	13	13
25	1	1
50	1	1
60	2	2
70	1	1
75	1	1
80	2	2
90	4	4
100	6	6
110	5	5
120	2	2
125	3	3
130	2	2
140	1	2
150	3	2
175	2	2
200	1	2

Figure 6.5 Average % Removal of Suspended Solids by Honduras Alum



Number of Samples: 1 per point
Initial SS: 138
Initial COD: 290
Initial NTU: 134
Initial pH: 8.1

Figure 6.6 % Removal of COD by Honduras Alum

6.2.4 Discussion

It is to be expected that with more testing the outlying high and low points on the suspended solids and turbidity graphs would fall more along a curve. This is easier to see if the data is averaged over larger dosage intervals such as in Figures 6.7 and 6.8. For example, the value at the 75 mg/L point represents the average of the values for 60, 70, 80, 90, and 100 mg/L from either Figure 6.4 or 6.5.

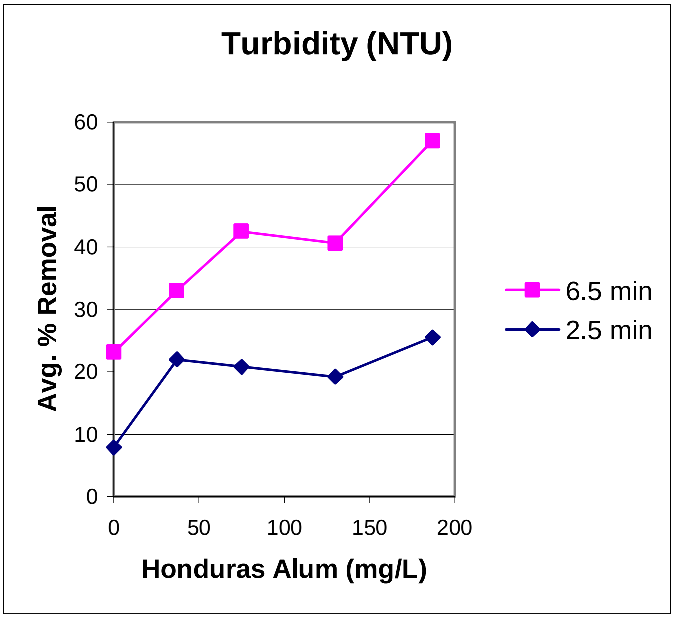


Figure 6.7 Dosage Averaged Turbidity Results

Range (mg/L)	Dosage (mg/L)	# pts. 2.5 min	# pts. 6.5 min
0	0	11	11
	25	1	1
37	50	1	1
	60	4	1
	70	1	1
75	80	4	2
	90	4	4
	100	7	5
	110	4	4
	120	2	2
	125	1	1
130	130	2	2
	140	1	1
	150	2	2
	175	1	1
187	200	1	1

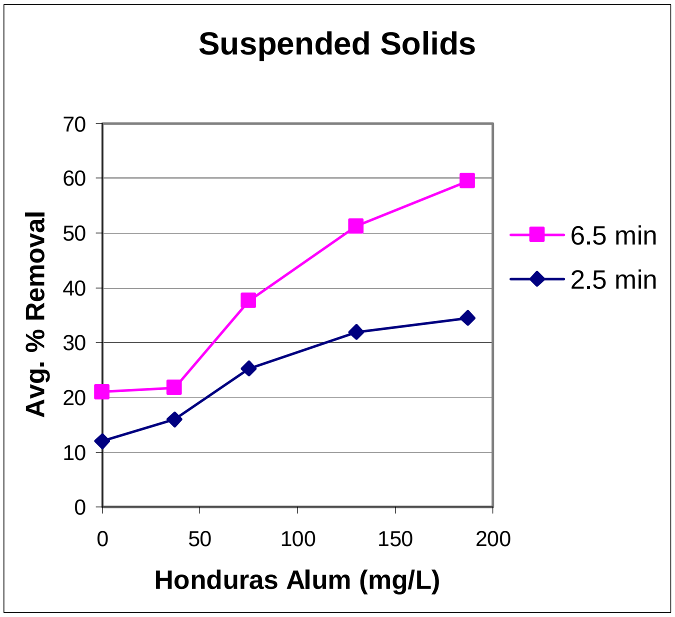


Figure 6.8 Dosage Averaged Suspended Solids Results

Range (mg/L)	Dosage (mg/L)	#pts. 2.5 min	#pts. 6.5 min
0	0	13	13
	25	1	1
37	50	2	2
	60	2	2
	70	1	1
75	75	1	1
	80	2	2
	90	4	4
	100	6	6
	110	5	5
	120	2	2
	125	3	3
130	130	2	2
	140	1	2
	150	3	2
	175	2	2
187	200	1	2

National Regulations

Figure 6.6 and Figure 6.8 are useful for predicting the amount of Honduras alum necessary to achieve national effluent regulations of 100 mg/L for TSS and 200 mg/L for COD (turbidity is not regulated for wastewater discharges in Honduras). At average influent conditions of 190 mg/L for TSS and 320 mg/L for COD, the loads on the Las Vegas Imhoff tank are not particularly concentrated for typical domestic sewage. However, they still need 38% removal rates for COD and 47% removal rates of TSS in order to meet Honduran regulations. The jar tests predict that at Las Vegas's current SOR of 0.06 m/min (2.5 min settling) CEPT by itself will not help to achieve the regulations. However, the Imhoff tanks in Las Vegas are actually already achieving an average of 26% removal of TSS and a 19% removal of COD. This is closer to the values predicted by zero chemical jars in the 6.5 minute curve. Since the zero chemical jars at the current SOR under performed the actual average COD and TSS removal values, the jar tests conducted could also be underestimating the effect of CEPT in the actual system. As mentioned in Section 4.5, there are limitations to predicting achievable settling based solely on SOR when flocculation occurs in the sedimentation chamber. It is therefore not entirely surprising that the jar tests do not precisely correlate with the Imhoff tank's systemic results. Moreover, if a pilot test of the system did actually follow the 6.5 minute curve (results are presented in Section 6.3.3), the tests indicate there could be upwards of 60% removal of COD and TSS.

pH

An important parameter that influences the effectiveness of aluminum sulfate is pH. The dosages of alum fall just within the sweep zone (sweep zone coagulation refers to the enmeshment of negative colloids as the metallic hydroxide precipitate forms). The "X" in Figure 6.9 is for a dosage of 150 mg/L of solid Honduras alum.

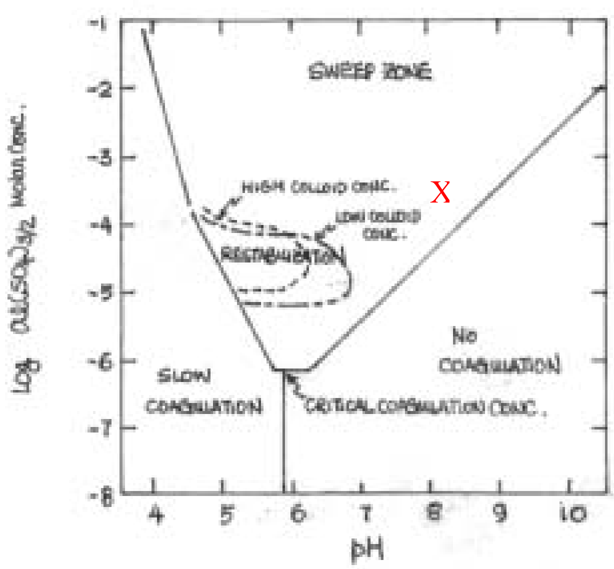


Figure 6.9 Aluminum Sulfate – pH Stability Limit (Sung, 2008)

The optimum pH range for aluminum sulfate is 4.5 to 8.0. Las Vegas' wastewater falls just within the upper end of this range and sometimes slightly exceeds this. The pH of the wastewater decreases at higher dosages of alum. For the Honduras alum the lowest observed pH was 6.6 at a dose of 175 mg/L. This may be an issue if the pH drops much lower in the Imhoff tanks because necessary methanogenic microorganisms thrive in the small range of 6.7 – 7.4. The addition of alum lowers the pH because the aluminum added forms precipitates of aluminum hydroxide that liberate acidity. Further this process is in a constant state of flux. Even if the solid aluminum hydroxide precipitates into the sludge in the digestion chamber, there is a chance that the alum may become soluble again. Consequently, the addition of a base such as lime is a frequent procedure to maintain the alkalinity of the water. Maintaining proper water chemistry becomes critical to the functioning of the system

Varied Influent Conditions

The influent concentrations of suspended solids and COD into the Imhoff tanks are not static. Figure 6.10 shows the effect of influent conditions on removal. Only dosages for which there were at least three trials at different influent conditions were used in this depiction. One can see from this graph that all of the jars document some amount of removal no matter what the influent condition. As might be expected, it is easier to remove more solids from larger initial influent values of suspended solids and that is what the data demonstrate. One explanation is that higher C_{in} indicates there are larger, more easily settled particles in the sample. The trendlines show that the jars without chemicals are the least effective at removing suspended solids and the other trendlines demonstrate that as you increase the chemical dosage more removal is achieved.

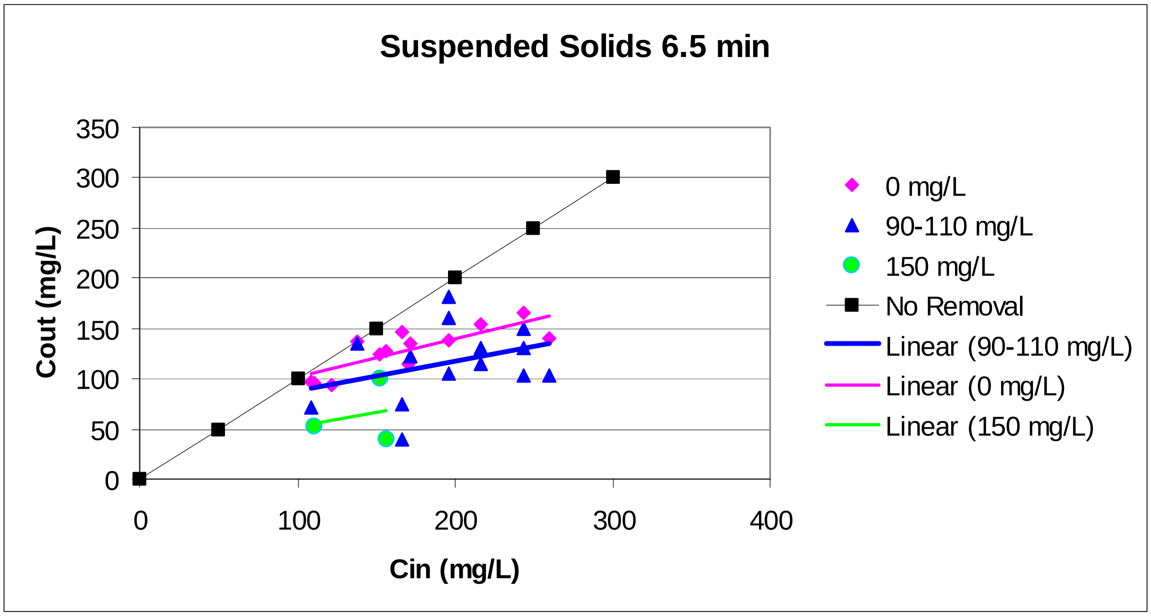


Figure 6.10 Effect of Influent Conditions on Removal

6.3 Pilot Test

6.3.1 Procedure

The pilot test was run using a 65-gallon plastic water storage tank that included a faucet. The tank is shown in Figure 6.11, along with the team of plumbers from Las Vegas who helped with the test. Preparing the solution of alum proved challenging in several aspects. The nearest available piped water source for the test was at the municipality (a 5 minute drive away). Moving 50 gallons of water was quite a process and there were several spills along the way. The actual volume of water used during the test was estimated as being closer to 45 gallons but is not known exactly.

Figure 6.11 Pilot Test Feed System

The goal of the pilot test was to calibrate the curves produced from the bench scale testing. In order to run the pilot test for 1.5 hours (3x the residence time of the system) for Las Vegas' average wastewater flowrate of 180 m^3/h the solution required a high concentration of alum. 48 kg of alum were added to the water to make approximately a 28% solution. According to Table 6.2 (EPA, 1975), alum is theoretically able to dissolve at very high concentrations. However, in the case of the pilot test mixing of the solution was done with a long stick. Despite intensive efforts to suspend all 48 kg of alum the mixture was not completely mixed. Towards the end of the pilot test it was discovered that glue like paste had formed along the bottom of the plastic tank (Figure 6.12).

Table 6.2 Solubility of Alum

Solubility of Alum	
ºF	kg/gal
32	2.71
50	2.95
68	3.27
86	3.80
104	4.57

Figure 6.12 Alum Paste

An EPA document on solids removal recommends that only up to 6% solution of alum be used (EPA, 1975). The size of the tank and difficulty transporting water were obstacles to heeding this recommendation. Despite the paste at the bottom of the plastic tank the upper portion of the alum solution appeared to be uniform. A sample of the liquid portion was analyzed for total aluminum by Alpha Analytical laboratory upon return to the United States. The results show that the pilot test system was dosing at 154 mg/L of solid alum. Originally the chemical was going to be injected in the middle opening in order to approximate bench scale GT values. However, during the pilot test it was injected in the opening nearest to the Imhoff tank as that was the easiest place to transport the water for preparing the solution. The flowrate was kept relatively constant by measuring the flow and adjusting the nozzle to increase the flow when it started to slow down. Initially the flowrate was checked every 15 minutes and then approximately every 5 minutes towards the end of the test. The variability was never more than 25% and the majority of the time within 10% of the targeted flowrate of 2 L/min.

6.3.2 Observations

During the pilot test it was possible to see flocs forming in the Imhoff tanks. Also soap like bubbles formed in the Imhoff tanks (Figure 6.13). On the day of the pilot test the wooden control gate/bags of sand, described in Section 5.4.2 Maintenance, were short-circuiting. Because of this a small quantity of the wastewater also went into the bypass channels. Flow through the bypass channel moved much slower than through the sedimentation tanks. We saw a drastic difference in the clarity of water exiting the bypass channels versus the water exiting the sedimentation tanks. In Figure 6.14 the milky looking flow on the left is from the bypass channel and the flow on the right is coming from the sedimentation chamber. In person the milky looking flow was substantially clearer. This may be an indication that if the residence time could be increased in the Imhoff tanks (as was the case in the bypass channel) CEPT would work better. We also observed that many of the flocs formed in the sedimentation chambers left through the effluent stream rather than having time to settle into the digestion chambers.

Figure 6.13 CEPT "Soapy Bubbles"

Figure 6.14 CEPT "Milky Flow"

6.3.3 Results

Influent and effluent samples were taken every half hour after the alum was added. The flow, COD, and TSS experienced by the system during the course of the test are listed in Table 6.3. (Note: the dosing of alum started at 11:30 am)

Table 6.3 Pilot Test Collected Data

		COD (mg/L)		TSS (mg/L)	
Time	**Flow (m^3/h)**	**Influent**	**Effluent**	**Influent**	**Effluent**
10:30 am	169.2	407	272	200	120
12:00 pm	156.2	493	185	210	110
12:30 pm	149.8	221	120	320	100
1:00 pm	153.0	286	187	130	115

Since both influent and effluent values were recorded at the same time the effluent conditions do not directly correspond to the influent conditions for that parcel of wastewater. In order to estimate the percent removal rates due to CEPT the corresponding influent conditions must be estimated. This estimate was made by using the incoming flow rates as a means for estimating the instantaneous residence time within the system (the total volume of the sedimentation chambers is approximately 100 m^3). The residence times were than coupled with a linear interpolation of influent data in order to approximate the corresponding influent conditions for each effluent value. The circular dots on the influent levels in Figures 6.15 and 6.16 represent these time-adjusted values that were used in calculating percent removal due to CEPT.

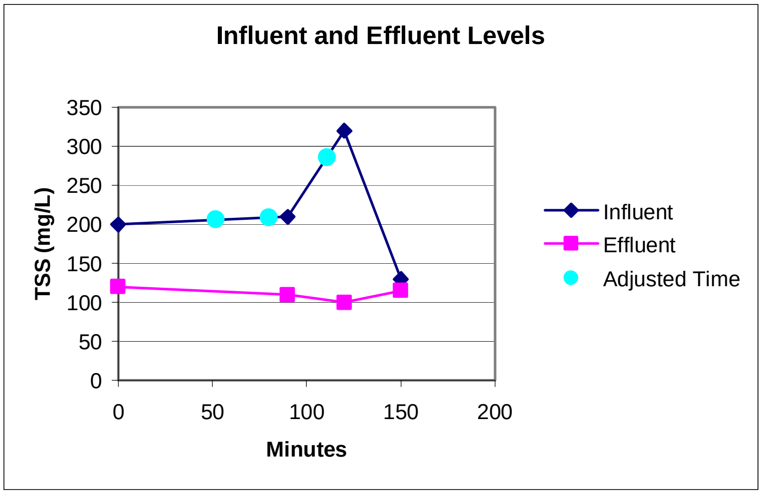


Figure 6.15 Pilot Test TSS Influent and Effluent Levels

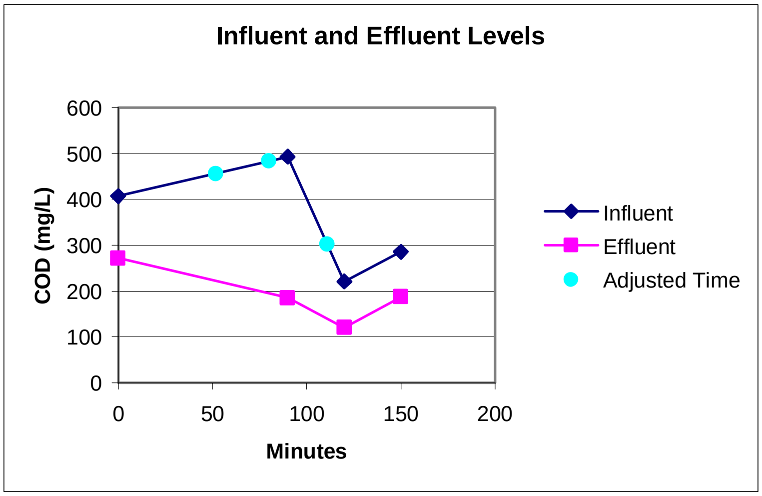


Figure 6.16 Pilot Test COD Influent and Effluent Levels

Table 6.4 reports the results of this method for both COD and TSS.

Table 6.4 COD and TSS Average % Removal for Pilot Test

			COD (mg/L)			TSS (mg/L)		
Time	**Flow (m^3/h)**	**Res. Time (min)**	**Influent** (Adjusted)	**Effluent**	**% Removal**	**Influent** (Adjusted)	**Effluent**	**% Removal**
10:30 am	169.2	35	-	-	-	-	-	-
12:00 pm	156.2	38	456	185	59	206	110	47
12:30 pm	149.8	40	484	120	75	209	100	52
1:00 pm	153.0	39	302	187	38	286	115	60
			% Avg. Removal:		**57**	**% Avg. Removal:**		**53**

6.3.4 Discussion

Looking carefully through Table 6.4 an astute observer would notice that during the pilot test the influent was experiencing an above average slug of COD. The author recalls that the wastewater stream looked substantially more concentrated with feces on the morning of the pilot test than other mornings working at the Imhoff tanks. Therefore for the purpose of comparison with the bench scale jar testing the conditions at 1:00pm will be used in this discussion. At that time there was a 38% removal of COD. For a dosage of 150 mg/L of alum, bench scale testing predicted COD removal of 21% for a SOR of 0.06 m/min and 45% for a SOR of 0.02 m/min. Bench scale testing also predicted a suspended solids removal of 34% for a SOR of 0.06 m/min and 55% for a SOR of 0.02 m/min. The average SOR for the Imhoff tanks on the day of the pilot test was 0.053 m/min. However both the suspended solids and COD removal more closely resembles the jar test predictions for the smaller SOR of 0.02 m/min. These pilot test results suggest that the jar testing curve of 6.5 min corresponds more closely to the actual conditions in the Las Vegas Imhoff tanks.

A primary goal of the use of CEPT is to meet the national effluent regulations of 200 mg/L for COD and 100 mg/L for TSS. All of the COD effluent samples taken while using CEPT during the pilot test achieved this goal while the baseline sample taken at 10:30am did not. TSS only achieved the regulatory standard for one of the three samples, but was close for the other two.

6.4 Sludge Production

A major concern with chemical addition to the treatment process is the effect on the quality and quantity of sludge production. Sludge from chemical precipitation of alum is more gelantinous than primary sludge lacking chemical addition. This may lead to sludge that is more difficult to dewater (Tchobanoglous, 1991).

The amount of sludge produced on a dry basis was calculated for three scenarios: A) "No Maintenance" which refers to the conditions at the Imhoff tank upon arrival to Las Vegas (26% removal TSS). B) "With Maintenance" which refers to the conditions at the Las Vegas Imhoff tank after the baffles and flow gates were installed (40% removal of TSS). C) "With CEPT" which utilizes the results from the pilot test to estimate the effect of chemical addition on sludge quantities (53% removal of TSS). The detailed assumptions and calculations can be found in Appendix E: Sludge Production.

Scenario A) No Maintenance resulted in 184 kg/day of sludge. Scenario B) With Maintenance resulted in 283 kg/day of sludge. Scenario C) With CEPT resulted in 469 kg/day of sludge. It is important to note that while the amount of sludge markedly increased in the CEPT scenario the majority of this increase is due to the increased removal of solids, which is the goal of the treatment. Only 18% of the sludge produced in the With CEPT scenario is due to chemical precipitation. An added bonus of CEPT is that it helps to remove phosphorus. Phosphorus removal represents 2% of the CEPT sludge. See Figure 6.17 for the full breakdown of the estimated characteristics of sludge produced in the With CEPT scenario.

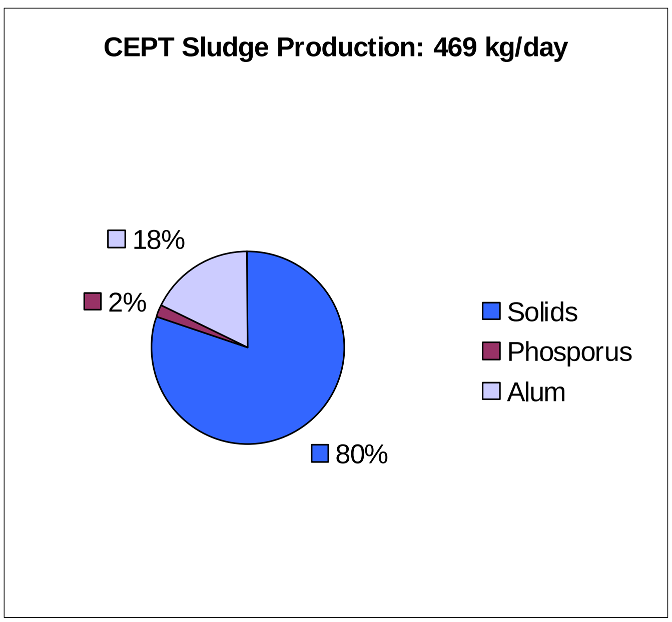


Figure 6.17 CEPT Sludge Production

6.5 Economics

At 190 mg/L average influent of TSS and 320 mg/L average influent value for COD, the loads on the Las Vegas Imhoff tank are not as concentrated as typical domestic sewage in the United States. Nonetheless, they still need 38% removal rates for COD and 47% removal rates of TSS in order to meet Honduran regulations of 100 mg/L TSS and 200 mg/L COD. The bench scale testing and the pilot scale testing suggests 150 mg/l would be an appropriate dosage of alum to achieve these standards. However this is a very costly solution even if run for only 18 hours a day (at night the levels of contaminants are not likely to exceed regulations). The cost of chemicals alone would be: 10 Lempira/kg x 180 m^3/h x 18 h/day x 1000 L/m^3 x 150 mg/L x 1kg/1,000,000mg = 4,860 Lempira/day ~ $243/day.

To put this in perspective the residents legally connected to the Imhoff tank pay only $1 per month for wastewater treatment. At approximately 550 legal connections this would only cover the cost of chemicals for two days per month of chemical treatment. Identifying illegal users and converting them to paying customers would help contribute to chemical expense, but not enough. Moreover, there is a need for more than chemicals in order to run a proper CEPT treatment program for the Imhoff tanks in Las Vegas. There is a need for a properly trained operator and construction of infrastructure improvements for solution preparation and storage and a chemical feed system. These changes would cost money too. Those costs were not estimated as part of this study.

6.6 Conclusions

The high cost of chemicals from the current Honduran supply chain for the dosage required to achieve national effluent regulations at the Las Vegas Imhoff tanks makes a CEPT compliance solution extremely cost prohibitive. Further the lack of other readily available coagulants also prohibits optimization of CEPT through chemical selection. While the additional maintenance due to increased sludge production seems manageable, without the addition of a closer water supply for solution preparation, chemical injection is not very feasible. Costs for chemicals and a closer water supply aside there are also many conditions in the Imhoff tanks that would need to fixed before the adoption of a CEPT treatment regime. These include the addition of bar screens to convert the influent bypass channel into a grit chamber. Necessary additions to the tanks should also be made that are devoted to the evening of flow between and across the sedimentation chambers. Once made, these two changes alone would improve tank performance. At a minimum, better maintenance of the Las Vegas Imhoff tanks as they currently stand would also improve their performance, MIT made that recommendation over CEPT because it seemed within its means to implement immediately.

Additionally, a common best practice in the management of wastewater is to eliminate excessive flows. Flows are considered excessive if they can be prevented more cheaply than they can be treated (EPA, 1975). A campaign for conservation within the city of Las Vegas that includes fixing leaky faucets could save a substantial amount of water in the long term. Also, diverting the water used from coffee depulping away from the Imhoff tanks would greatly reduce treatment costs.

7 STATUS OF IMHOFF TANKS

There are Imhoff tanks in at least 22 locations in Honduras (Table 7.1). During January 2008, the systems in the departments of La Páz and Santa Barbara were visited. These Imhoff tanks were constructed in the late 1980s and early 1990s. Maintenance was minimal at all of the tanks and the structural integrity of two of the five systems was severely dilapidated and perhaps not worth fixing. However, for Las Vegas and Barrio Galeras in Santa Barbara and for Marcala in La Páz full rehabilitation of those existing Imhoff tanks should at least be considered.

Table 7.1 Imhoff Tanks in Honduras (adapted from SANAA, 2007a)

Honduran Imhoff Tanks		
Municipality	*Department*	*Type of System*
La Ceiba	Atlantida	Imhoff Tank
La Entrada	Copán	Imhoff Tank
Corquin	Copán	Imhoff Tank
Tocoa	Colón	Imhoff Tank
San Francisco de Yojoa	Cortés	Imhoff Tank
La Lima	Cortés	Imhoff Tank
Teupasenti	El Paraíso	Imhoff Tank + Constructed Wetlands
Guaymaca	Francisco Morazan	Imhoff Tank + Constructed Wetlands
El Zamorano	Francisco Morazan	Imhoff Tank
Sabana Grande	Francisco Morazan	Imhoff Tank
Marcala	La Páz	Imhoff Tank
Gracias	Lempira	Imhoff Tank
Lapaera	Lempira	Imhoff Tank
Las Flores	Lempira	Imhoff Tank
Nueva Ocotepeque	Ocotepeque	Imhoff Tank
Intibuca	Intibuca	Imhoff Tank
La Esperanza e Intibuca	Intibuca	Imhoff Tank
Santa Barbara (Barrio El Llano del Conejo)	Santa Barbara	Imhoff Tank
Santa Barbara (Barrio Galeras)	Santa Barbara	Imhoff Tank
Gualala	Santa Barbara	Imhoff Tank
Las Vegas	Santa Barbara	Imhoff Tank
El Nispero	Yoro	Imhoff Tank

While each site contained many of the same basic defining characteristics of Imhoff tanks (i.e. two story construction, sludge valves, bypass channels etc.), at some locations these features where better designed than at others. The remainder of this section discusses specifics of each location visited (other than Las Vegas) and presents a checklist for the assessment of Imhoff tanks that should be used for visits to the remaining sites.

7.1 Marcala, La Páz

The Marcala Imhoff tank is a massive below grade structure. In Figure 7.1 the portion of the structure above ground is entirely unused freeboard. The influent enters from the lower left and the effluent flow exits from the upper left corner of the photo into a river. The flow is distributed between two chambers. An example of the inlet design is displayed in Figure 7.2. The system is packed full of solids, which have even overflowed into boxes that house the sludge valves (Figure 7.3). During January 2008 the number of households connected to the system was not determined. During February 2008 the Phoenix professional chapter of Engineers without

Borders started working on evaluating remediation options for the Marcala Imhoff tank. As part of their work the engineers measured the peak flow into the system to be 192 m^3/h (D. Aturaliye, personal communication, March 5, 2008). The total surface area of the sedimentation tanks is 52 m^2. These are very similar conditions to Las Vegas.

Figure 7.1 Marcala Imhoff Tank

Figure 7.2 Marcala Inlet

Figure 7.3 Marcala Sludge Valve

7.2 Barrio El Llano del Conejo, Santa Barbara

The Imhoff tank in Barrio El Llano del Conejo was constructed in 1998. Its maintenance does not fall under the direct jurisdiction of the municipality of Santa Barbara, but rather a neighborhood "junta." Junta's in Honduras are locally elected water/sanitation boards. During their term community members serving on juntas are responsible for the maintenance and finances of their water and wastewater systems. According to an official at the neighborhood office of the National Registry of Persons the tank was built with funds from the UK based non-governmental organization called Plan International. 400 households are connected to a two-tank system (in total 5.8 m x 5.8m). However the tanks were not constructed properly. The sloped walls of the sedimentation chambers were never completed (Figure 7.4). This has essentially rendered the system into an uncovered septic tank that does not receive maintenance. A sludge drying bed does not exist and the effluent is discharged into a shallow creek.

Figure 7.4 Incomplete Sedimentation Chamber in Barrio El Llano del Conejo

7.3 Barrio Galeras, Santa Barbara

The Imhoff tanks in Barrio Galeras (Figure 7.5) contain many well-designed features. The system consists of four Imhoff tanks in parallel evenly distributed over 5.5m x 9.1m The sedimentation portion is 5.5m x 1.5m. While the system is currently completely full of solids, there is evidence of an unused sludge drying bed adjacent the system. Unlike any of the other systems surveyed, Barrio Galeras includes a built-in means to measure flow. Figure 7.6 shows the v-notch weir in the influent channel. Flow needs to be measured to ensure it is working properly, still it is a promising feature. Another unique feature is a bypass before entering the sedimentation chambers (Figure 7.7). The system contains slots for flow gates, but does not contain any. The effluent flows into a stream. The number of houses connected to the system was not determined.

Figure 7.5 Barrio Galeras Imhoff tank

Figure 7.6 Barrio Galeras V- Notch Weir

Figure 7.7 Barrio Galeras Bypass

7.4 Gualala, Santa Barbara

The Imhoff tank in the municipality of Gualala was built in 1982 and looks very similar to the tank in Barrio El Llano del Conejo (Figure 7.8). It is even the same size (5.8m x 5.8m). It was built to service 170 houses. It is packed full of solids and a local resident reported it had not been cleaned for two years. Since it is full of solids it was impossible to determine if the sedimentation chamber walls had been properly constructed. Regardless, the structure has a broken wall (Figure 7.9) and would require extensive rehabilitation measures if it were ever to work properly. The effluent from the Imhoff tank discharges into a large river.

Figure 7.8 Gualala Imhoff Tank

Figure 7.9 Gualala Broken Wall

7.5 Site Investigation Protocol

Site Investigations during January 2008 led to the development of the following historical information, critical conditions, and operating characteristics that should ideally be documented for all 22 Imhoff tank locations.

Background
- Construction Date
- General Contractor
- Design Engineer
- Design Drawings
- Funding Organization
- Project Costs
- Local Entity in Charge of Maintenance
- Maintenance History
• Sludge Removal (Frequency and Quantity)
• Scum Removal (Frequency and Quantity)
• Reversal of Flow (Frequency)
• Pipe/Valve Replacement (Frequency and Quantity)
- Connections
• # of Households
• # of People
• # and Type of Industries
- Use of Stabilized Sludge
- Resident's Water & Sanitation Fees
- Water Use Metered

Technical
- # of Tanks
- Tanks in Series or Parallel
- Dimensions
• Surface Area of Sedimentation Chambers
• Surface Area of Scum Chambers
• Depth of Sedimentation Chambers
• Slope of Sedimentation Chamber Walls
• Depth of Digestion Chamber
- Influent Flowrates
- Influent & Effluent Loads
• Total Suspended Solids
• Biochemical Oxygen Demand/Chemical Oxygen Demand
• Total Coliforms
- Locations and Use of Flow Gates
- Distribution of Wastewater Between and Within Tanks
- Presence and Use of Sludge Drying Bed
- Sludge Valves Working Properly

- Structural Condition of Concrete (Any Cracks, Broken Walls, Etc.)

Future

- Available Land for Expansion
- Community Desires and needs
- Current and Potential Partner Organizations

In addition to the inventory listed above, photos from all angles of the tanks should be taken. Collecting this information in a standardized format will be useful in promoting and planning movement to rehabilitate Imhoff tanks in Honduras.

7.6 Conclusions

The five sites visited during January 2008 exhibit a huge need and potential for future efforts to rehabilitate Imhoff tanks. The remainder of the locations should be visited to confirm whether their situation is similar before a comprehensive plan is developed for rehabilitation. Figure 7.10 shows the distribution of Imhoff tanks in each department in Honduras. The department of Santa Barbara has the most with four systems. Las Vegas is very centrally located. Las Vegas is in a position to be a leading example in this initiative. Based on geography and the fact that out of all of the sites visited in January Las Vegas was the best maintained, the municipality could continue to improve its sanitation system and through its experiences help other municipalities to do the same.

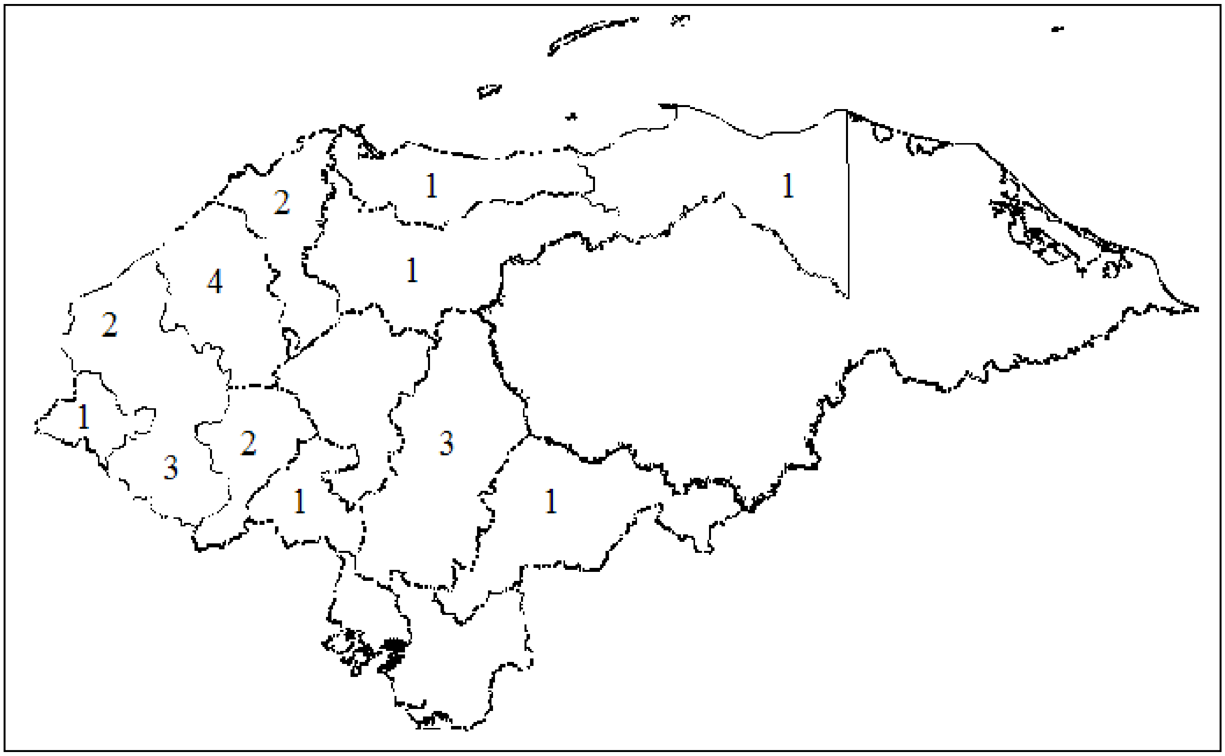


Figure 7.10 Department Distribution of Imhoff Tanks

8 CONCLUSIONS

In the mountainous terrain of Honduras Imhoff tanks are apt to remain a viable wastewater treatment technology in mid-sized municipalities. In order to produce the maximum amount of treatment through these structures, they must be properly maintained and creative new solutions need to be integrated into their original designs. In January 2008 the Las Vegas Imhoff tanks were receiving four times more flow than their original designs contemplated. During a pilot test of CEPT, this additional flow was treated to within the national effluent regulations for COD and very close to the regulations for TSS. However, in order to do so the addition of 150 mg/L of alum was required. This is an unsustainably high quantity in terms of cost and solution storage, preparation, and injection.

During the course of the CEPT study, we learned that simple actions such as creation of a grit chamber within the influent channel, frequent cleaning, the addition of flow gates and the design of baffles to better distribute the flow are very viable steps which would further achieving compliance with effluent regulations. Additionally, with high groundwater infiltration, coffee depulping and leaky faucets, much could be done in the municipality to eliminate excessive flows and thus reduce the demand for treatment. Future useful work in Las Vegas may include a tracer study within the Imhoff tanks to more accurately understand the residence time within the system. A redesign for the inlets for better flow distribution would also have a major impact on the effectiveness of the system. Further, continuous measurement of flow as well as more loading data would also be very useful for making decisions about modifications. Another major concern is the increase in coliforms after passing through the system. While one may speculate, this issue would be moot with less flow. A device designed to prevent exchange between the sedimentation chamber and digestion chamber may also eliminate this issue. It might be as simple as extending one of the sloped walls of the sedimentation chamber to block the ascending plumes. Although CEPT is likely to remain economically infeasible, it would still be interesting to run several more pilot tests to confirm the correlation between the jar tests. Additionally, it would be interesting and helpful to gauge the effect of more mixing by injecting the chemicals at different locations along the influent channel. Similarly, if flow could be reduced in the system the removal efficiencies of CEPT at higher retention times could also be gauged.

Imhoff tanks represent approximately 40% of the wastewater treatment infrastructure in Honduras and are in a state of disrepair. Las Vegas has the opportunity to be a leader in Imhoff tank rehabilitation in Honduras. The sites visited during January 2008 indicate that before all else drying beds or other methods of appropriate sludge disposal should be designed. Then the sludge should actually be removed at each site on a regular schedule. If flows and loads warrant system expansion, that option should only be explored after a period of proper maintenance and minor modifications in order to get the existing Imhoff tanks into an optimum working condition.

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APPENDIX A: PROJECT TIMELINE

MIT Involvement with Lake Yojoa, Honduras

Time	Activity
Fall 2005	MIT Master of Engineering Program in Civil and Environmental Engineering identifies Lake Yojoa as a potential thesis project for students completing their MEng Degree in Environmental Engineering.
Winter 2005-2006	Dr. Eric Adams, Tia Trate, Mira Chokshi, and Aridaí Herrera conduct on site study focused on stakeholder identification and lake water quality (nutrients and thermal profile)
Spring 2006	Tia Trate and Mira Chokshi complete report on stakeholders and lake water quality. The report quantifies nitrogen levels in the water as well as the thermal profile of the lake. Additionally, Trate and Chokshi identify seven stakeholders that have interest in environmental health of lake. These stakeholders are: Aquafinca, AMPAC mine, Las Vegas, Las Marias, a hydropower plant, and a restaurant association. Reports are available from: http://dspace.mit.edu/handle/1721.1/35495 http://dspace.mit.edu/handle/1721.1/35078
Summer 2006	Aridaí Herrera returns to Lake Yojoa to study the wastewater treatment facility of Las Vegas, a potential source of pollution cited by Chokshi and Trate.
Winter 2006	Aridaí Herrera completes report that describes the existing wastewater treatment facility in Las Vegas, an Imhoff Tank. The report also recommends remediation approach for existing wastewater treatment in Las Vegas.
Fall 2007	Aridaí Herrera recommends follow-on project working with Las Vegas to examine options for improving the existing wastewater treatment in Las Vegas. This project is accepted by MEng students Anne Mikelonis and Matt Hodge.
Winter 2007-2008	Dr. Eric Adams, Anne Mikelonis, Matt Hodge, and Aridaí Herrera return to Honduras to assess options for improved wastewater treatment in Las Vegas. While in Las Vegas, the municipality requests comprehensive preliminary study of options for wastewater treatment throughout Las Vegas.

Spring 2008	Anne Mikelonis and Matt Hodge complete preliminary assessment of wastewater treatment options for Las Vegas.

On Site Activities of Team January 2008

Date	Activity
January 7	Team of Aridaí Herrera, Anne Mikelonis, Matt Hodge, and Dr. Eric Adams arrive in Honduras. Team meets with Diana Betancourt from NGO Water for People and Manuel Lopez, an independent consultant to Aguas de San Pedro.
January 8	Team meets with municipality of Las Vegas leadership including Mayor Carlos Fuentes and Chief Engineer Alexis Rodriguez. During the meeting, project goals are explained and refined.
January 9	Team meets with Aquafinca Manager Israel Snir to update him on project and request assistance in finding lab equipment. Aquafinca agrees to supply the use of an analytical balance during the team's time in Honduras.
January 10	Team meets with Ramon Cordona, Infrastructure Director for the Honduran Social Investment Fund (FHIS) and Hugo Chavez, an engineer for FHIS, to discuss wastewater treatment in Honduras and the goals of the Las Vegas project.
January 11	Team examines another Imhoff tank in Marcala Honduras. Team returns to Las Vegas to have second meeting with the Mayor and indicate the questions they will answer while on site. The questions they specify are: 1) Removal efficiency of the existing tanks 2) Downstream water quality analysis 3) Options for sludge handling 4) Identification of local sources of coagulants 5) CEPT testing (bench and/or pilot scale) 6) Conceptual design of a full scale system for CEPT application
January 12	Team visits El Progreso and La Lima at the recommendation of FHIS to see good examples of popular treatment technology, waste

	stabilization ponds. Aridaí Herrera and Dr. Eric Adams return to the United States.
January 15– 22	Team collects influent and effluent water samples, measures flow and conducts jar tests to determine appropriate dosing of chemicals for CEPT pilot test on Imhoff Tank. Matt Hodge begins to collect necessary information for preliminary design of wastewater treatment system for Las Vegas. Anne Mikelonis designs pilot test for CEPT.
January 23	Team travels to Tegucigalpa and meets with original contractor that built Imhoff Tank in Las Vegas, Agua Para el Pueblo (APP) and acquires original design drawings of tank. Team also meets with Pedro Ortiz, a senior manager for the National Agency of Water Supply and Sewerage (SANAA) to discuss wastewater treatment in Honduras.
January 24-28	Matt Hodge conducts preliminary screening of appropriate wastewater treatment technologies for Honduras and Anne Mikelonis prepares to conduct pilot test of CEPT in Imhoff Tank.
January 29	Team conducts pilot test of CEPT in Imhoff tank.
January 30	Team visits other Imhoff tanks in the department of Santa Barbara
January 31	Team makes final presentation to Mayor and municipal staff of Las Vegas.
February 1	Team meets with AMPAC mine and presents findings to engineering staff of mine at the request of the Mayor of Las Vegas.
February 2	Anne Mikelonis and Matt Hodge return the United States.

APPENDIX B: CALCULATIONS FOR FIELD MIXING CONDITIONS

$$G = \sqrt{\frac{P}{\mu V}}$$

D = pipe Diameter = 12 in = 0.3 m

u = velocity = $\frac{50m}{45\sec}$ = 1.11 $m/\sec$

μ = dynamic viscosity of fluid @ 20.2 ºC = 1 x 10^{-3} ($N * \sec/m^2$)

ρ = 998 kg/m^2 @ 20.2 ºC

N_R = Reynolds Number = $Du\rho/\mu$ = $\frac{(0.3m)(1.11m/s)(998kg/m^2)}{(1x10^{-3} N * \sec/m^2)}$ = 332,334

ε = roughness height for rough concrete = 0.60 mm (Hwang, 1996)

ε/D = $\frac{0.60mm}{305mm}$ = 0.002

f (from Moody Diagram) ~ 0.02

γ = specific weight of water = 9.8 kN/m^3

Q = flow rate = 180 m^3/h = 0.05 $m^3/\sec$

Closest Box

V = volume m^3 = (45/50 $\sec/m$)(4 m)(0.05 $m^3/\sec$) = 0.2 m^3

h = headloss = f($\frac{L}{D}$)($\frac{u^2}{2g}$) = (0.02)($4m/0.3m$)($\frac{1.11^2\ m^2/s^2}{2*9.8m/s^2}$) = 0.02 m

P = (9.8 kN/m^3)(0.05 m^3/s)(0.02m)(10^3 N/kN) = 9.8 W

G = $\sqrt{\frac{9.8W}{(0.2m^3)(10^{-3} N * s/m^2)}}$ = 220 $\sec^{-1}$

T = $\frac{0.2m^3}{0.05m^3/s}$ = 4 sec

GT = (4s)(220s^{-1}) = 880

Middle Box

V = volume m^3 = (45/50 $\sec/m$)(13 m)(0.05 $m^3/\sec$) = 0.6 m^3

h = headloss = f($\frac{L}{D}$)($\frac{u^2}{2g}$) = (0.02)($13m/0.3m$)($\frac{1.11^2\ m^2/s^2}{2*9.8m/s^2}$) = 0.05 m

P = (9.8 kN/m^3)(0.05 m^3/s)(0.05m)(10^3 N/kN) = 25 W

G = $\sqrt{\frac{25\,W}{(0.6m^3)(10^{-3}\ N*s/m^2)}}$ = 200 sec^{-1}

T = $\frac{0.2m^3}{0.05\,m^3/s}$ = 12 sec

GT = (4s)(200s^{-1}) = 2,400

Farthest Box

V = volume m^3 = (45/50 $\sec/m$)(64m)(0.05 $m^3/\sec$) = 2.88 m^3

h = headloss = f($\frac{L}{D}$)($\frac{u^2}{2g}$) = (0.02)($64m/0.3m$)($\frac{1.11^2\ m^2/s^2}{2*9.8\,m/s^2}$) = 0.27 m

P = (9.8 kN/m^3)(0.05 m^3/s)(0.3m)(10^3 N/kN) = 150 W

G = $\sqrt{\frac{150\,W}{(2.88m^3)(10^{-3}\ N*s/m^2)}}$ = 230 sec^{-1}

T = $\frac{2.88m^3}{0.05\,m^3/s}$ = 58 sec

GT = (58s)(230s^{-1}) = 13,340

APPENDIX C: JAR TESTING RAW DATA

Test Date: 1/17/08 6:00am

Mixing Regime: 0.5 min 100 rpm

Sample: Influent; 1/16/08; 2:30 pm

Settling: 2.5 min; 7.5 min

Chemical: Honduras Alum

	Dosage (mg/L)	pH_{final}	2.5 min (NTU)	7.5 min. (NTU)
Raw	0	7.6	156	135
Jar 1	20	7.3	146	126
Jar 2	40	7.1	139	118
Jar 3	60	7	112	82.3
Raw	0	7.4	147	138
Jar 1	60	7.1	134	104
Jar 2	80	6.9	117	86.3
Jar 3	100	6.7	119	71.2
Raw	0	7.3	158	133
Jar 1	60	7.1	143	90
Jar 2	80	6.9	149	94.5
Jar 3	100	6.7	79.3	38.3

Test Date: 1/17/08 10:30 am - 4:00 pm

Mixing Regime: 0.5 min 100 rpm

Sample: Influent; 1/17/08; 10:00 am

Settling: 2.5 min; 6.5 min

Chemical: Honduras Alum

Initial NTU:	224
Initial SS:	196
Initial pH:	7.6

	Dosage (mg/L)	pH_{final}	2.5 min (NTU)	6.5 min (NTU)	2.5 min (SS)	6.5 min (SS)
Raw	0	7.6	190	154	137	138
Jar 1	90	6.9	185	153	154	160
Jar 2	100	6.8	168	148	178	181
Jar 3	110	6.8	182	144	110	105

Initial NTU:	213
Initial SS:	244

Raw	0		181	159	189	166
Jar 1	90		181	135	208	150
Jar 2	100		169	132	246	131
Jar 3	110		156	120	142	103

Initial NTU:	203
Initial SS:	216

Raw	0		176	150	194	155
Jar 1	90		176	147	169	129
Jar 2	100		171	120	166	131
Jar 3	110		169	124	132	115

Test Date: 1/18/08 10:00 am
Sample: Influent; 1/18/08; 9:00 am
Chemical: Honduras Alum

Mixing Regime: 0.5 min 100 rpm
Settling: 2.5 min; 6.5 min

Initial NTU:	183
Initial SS:	260
Initial pH:	7.7

	Dosage (mg/L)	2.5 min (NTU)	6.5 min (NTU)	2.5 min (SS)	6.5 min (SS)
Raw	0	166	143	177	140
Jar 1	110	201	126	182	103
Jar 2	120	179	108	138	103
Jar 3	130	148	94.2	138	84
Initial NTU:	186				
Initial SS:	156				
Raw	0	161	138	156	128
Jar 1	130	147	109	125	69
Jar 2	140	134	88.2	98	50
Jar 3	150	99.7	63.9	72	39

Test Date: 1/19/08 7:00 am
Sample: Influent; 1/18/08; 9:00 am
Chemical: Honduras Alum

Mixing Regime: 0.5 min 100 rpm
Settling: 2.5 min; 6.5 min

Initial NTU:	174
Initial SS:	171
Initial pH:	7.6

	Dosage (mg/L)	pH_{final}	2.5 min (NTU)	6.5 min (NTU)	2.5 min (SS)	6.5 min (SS)
Raw	0	7.6	169	137	146	115
Jar 1	60	7.1	151	114	130	86
Jar 2	70	7.1	138	107	136	80
Jar 3	80	7.1	124	77.2	97	57
Initial NTU:	199					
Initial SS:	166					
Raw	0		163	157	159	146
Jar 1	80		137	91.1	110	79
Jar 2	90		124	83.9	113	74
Jar 3	100		95.9	50	61	40

Test Date: 1/19/08 3:00 pm
Sample: Influent; 1/19/08; 2:30 pm
Chemical: Honduras Alum

Mixing Regime: 0.5 min 100 rpm
Settling: 2.5 min; 6.5 min

Initial NTU: 111
Initial SS: 109
Initial pH: 7.8

	Dosage (mg/L)	pH_{final}	2.5 min (NTU)	6.5 min (NTU)	2.5 min (SS)	6.5 min (SS)
Raw	0	7.8	113	97.8	106	97
Jar 1	75	7.4	116	102	97	97
Jar 2	100	7.1	111	85.8	85	72
Jar 3	125	6.9	missed reading	54.9	82	43

Initial NTU: 122
Intial SS: 111
Initial pH: 7.6

Raw	0	7.4	120	95.5	101	96
Jar 1	125	6.7	99.6	84.3	84	63
Jar 2	150	6.7	101	75.9	80	52
Jar 3	175	6.6	94.3	50.1	65	32

Initial NTU: 132
Initial SS: 122

Raw	0	7.6	132	98.9	108	94
Jar 1	200	6.5	94.7	59.8	86	35
Jar 2	50	7	98	85.3	91	76
Jar 3	25	7.2	108	90.7	98	92

Test Date: 1/21/08 10:15 am

Mixing Regime: 0.5 min 100 rpm

Sample: Influent; 1/21/08; 9:30 am

Settling: 2.5 min; 6.5 min

Chemical: Honduras Alum

Initial NTU:	134
Initial SS:	138
Initial pH:	8.1
Initial COD:	290

	Dosage (mg/L)	**2.5 min (COD)**	**6.5 min (COD)**	**2.5 min (SS)**	**6.5 min (SS)**
Raw	0	290	252	137	137
Jar 1	50	255	256	140	139
Jar 2	100	253	249	133	136
Jar 3	125	273	223	127	127

Initial SS:	152
Initial COD:	323

Raw	0	310	275	143	124
Jar 1	150	254	179	122	101
Jar 2	175	226	176	107	90
Jar 3	200	220	137	95	69

Initial NTU:	146
Initial SS:	172

		2.5 min (NTU)	**6.5 min (NTU)**	**2.5 min (SS)**	**6.5 min (SS)**
Raw	0	144	128	145	135
Jar 1	60	150	137	142	131
Jar 2	110	146	130	140	123
Jar 3	120	136	126	132	109

Test Date: 1/14/08 4:30pm
Sample: Influent; 1/14/08
Chemical: Brazil Alum

Mixing Regime: 0.5 min 100 rpm
Settling: 7.5 min.
Intial pH: 8.4

	Dosage (mg/L)	pH_{final}	7.5 min (NTU)
Raw	0	7.6	110
Jar 1	10	7.3	108
Jar 2	20	7.3	101
Jar 3	30	7.1	106

Test Date: 1/15/08
Sample: Influent; 1/14/08
Chemical: Brazil Alum

Mixing Regime: 0.5 min 100 rpm
Settling: 7.5 min
Initial pH: 8.4

Raw	0	7.4	111
Jar 1	40	7.1	68.3
Jar 2	50	6.9	55.6
Jar 3	60	6.9	44.9

Test Date: 1/28/08 5:00 pm
Sample: 1/28/08 Influent 4:30 pm
Chemical: Brazil solid Alum

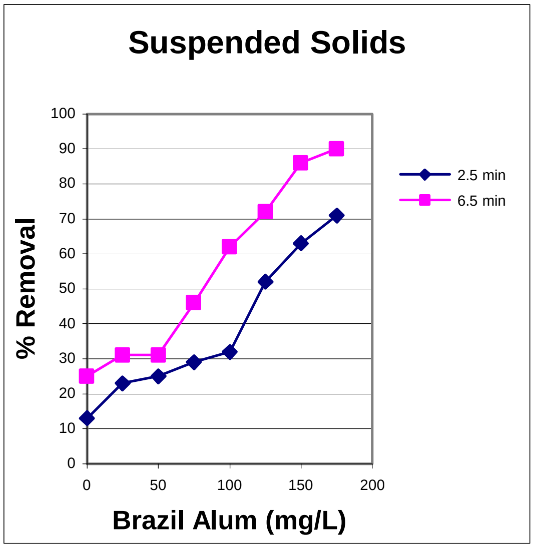
Mixing Regime: 0.5 min 100 rpm
Settling: 2.5 min, 6.5 min

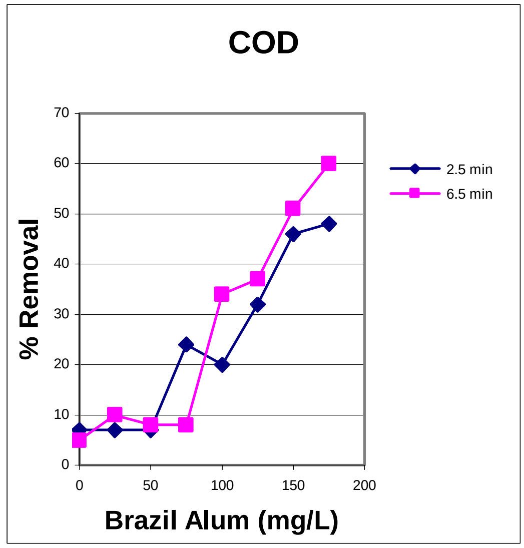
Initial SS:	126
Initial COD:	177
Initial NTU:	127
Initial pH:	8

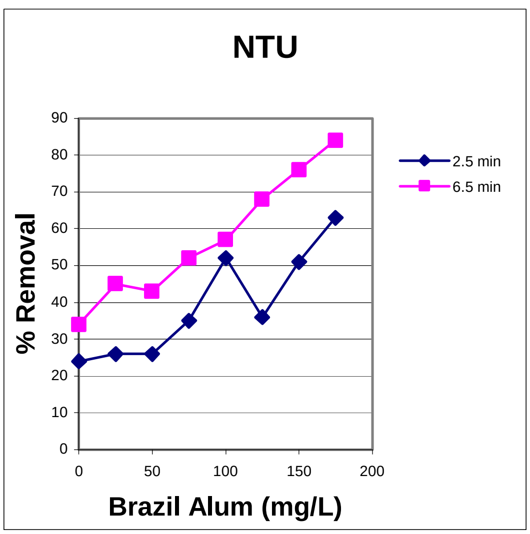
	Dosage (mg/L)	pH_{final}	2.5 min (NTU)	6.5 min (NTU)	2.5 min (SS)	6.5 min (SS)	2.5 min (COD)	6.5 min (COD)
Raw	0	8	97	83.8	109	94	165	168
Jar 1	25	7.7	94.3	70	97	87	165	159
Jar 2	50	7.4	94.6	73	95	87	164	163
Jar 3	75	7.2	82.9	61	89	68	135	163
Jar 1	100	7.1	61	54	86	48	141	117
Jar 2	125	6.9	81	41.1	60	35	121	111
Jar 3	150	6.9	62.6	30.8	47	18	95	86
Jar 4	175	6.7	46.5	19.8	36	12	92	70

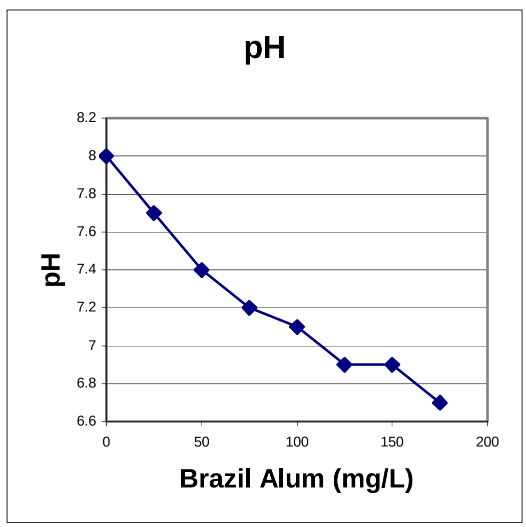
APPENDIX D: BRAZIL ALUM JAR TESTING RESULTS

Number of Samples: 1 per data pt.
Initial SS: 126
Initial COD: 177
Initial NTU: 127
Initial pH: 8









*Note: Along the 6.5 minute curve the Las Vegas Imhoff tanks could achieve up to 60% removal of suspended solids for the alum from Honduras and 90% for the alum from Brazil. It seems unlikely that the alum from Brazil would consistently perform 30% better than the alum from Honduras as the chemical analysis from Alpha Analytical labs showed that it only has about 4% more total Aluminum, the active ingredient. Also, the removal rates for the Brazilian alum come from a single test run, therefore more testing would need to be preformed to assert superior performance. Ultimately, the only readily available coagulant is the alum from Honduras so it would only be worthwhile to do this if there was a chance for opening a new import route. At 0.02 m^3/min COD removal for both the alum from Honduras and Brazil would be about 50%. Interestingly, not much COD removal occurs until 125 mg/L. NTU decreases as dosage increases at similar removal rates as suspended solids.

APPENDIX E: SLUDGE PRODUCTION

Assumptions:
Average Daily Flow = (180 m^3/h x 18 h) + (80 m^3/h x 6 h) = 3,720 m^3/day
TSS_{in} = 190 mg/L
P_{inf} = 3.5 mg/L (Experco 2003)
CEPT % $P_{removal}$ = 60 (Murcott, 1993)

A) No Maintenance
% Removal TSS = 26
M_{sludge} = (0.26)(190 mg/L)(3,720 m^3/day) (1000 L/m^3) (10^{-6} kg/mg) = **184** kg/day

B) With Maintenance
% Removal TSS = 40
M_{sludge} = (0.40)(190 mg/L)(3,720 m^3/day) (1000 L/m^3) (10^{-6} kg/mg) = **283** kg/day

C) CEPT
% Removal TSS = 53
$M_{TSS\ removed}$ = (0.53)(190 mg/L)(3,720 m^3/day) (1000 L/m^3) (10^{-6} kg/mg) = 375 kg/day
$M_{Phos\ Rem}$ = (1.4)(0.6)(3.5 mg/L)(3,720 m^3/day)(1000 L/m^3)(10^{-6} kg/mg)) = 11 kg/day

0.15 g/L / 594 $g/mole$ = 2.5x10^{-4} $mole/L$ $\dfrac{1\ mole\ Al_2(SO_4)_3}{1\ mole\ AL_2(SO_4)\cdot 14H_2O}$

(392 $\dfrac{g\ Al_2(SO_4)_3}{mole}$) (2.5x$10^{-4}$ $mole/L$) = 85.5 mg

$M_{Al2(SO4)3}$ = (0.26)(85.5 mg/L)(3,720 m^3/day)(1000 L/m^3)(10^{-6} kg/mg)) = 83 kg/day

Total = **469** kg/day

*Note the factors 1.4 and 0.26 come from the following:

1.4 comes from p. 744 of (Tchobanoglous, 1991) from the mole ratio of Al:P for the typical alum dosage requirements for 75% removal of phosphorus.

$Al_2(SO_4)_3\cdot 14H_2O + 3\ Ca(HCO_3)_2 \leftrightarrow 3\ CaSO_4 + 2\ Al(OH)_3 + 6\ CO_2 + 14\ H_20$

2 $Al(OH)_3$ = 156 $g/mole$
$Al_2(SO_4)_3\cdot 14H_2O$ = 594 $g/mole$
156 $g/mole$ / 594 $g/mole$ = 0.26