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ABSTRACT: The Pueblo Chemical Agent-Destruction Pilot Plant is being constructed for demilitarization of chemical weapons stored at the U.S. Army Pueblo Chemical Depot, Pueblo, Colorado. The Pueblo stockpile consists of projectiles and mortars filled with blister agents (93.4% of total stockpile), explosives (4.2%), and propellants (2.4%). Agents contain approximately 98% distilled mustard, *β,β'*-dichloroethylsulfide. 2% is a mixture of distilled mustard and bis 2-2-chlorethylthioethyl ether. The process chosen for demilitarization involves collection of the chemical agent from the munitions, hot water hydrolysis of the agent to produce an agent-free hydrolysate, caustic neutralization of hydrolysate, biological treatment of the hydrolysate to reduce organic content, and effluent treatment to separate salts and recover water for reuse. The biological process selected for hydrolysate treatment is the Immobilized Cell Bioreactors. This paper will describe the design of the bioreactors for use at the Pueblo Chemical Depot. The design is based on laboratory and pilot testing results, which provided determination of organic loading rates, hydraulic retention times, aeration and nutrient requirements, operational parameter ranges and controls (temperature, dissolved oxygen, and pH).

INTRODUCTION

Since 1985, the U.S. Department of Defense has been engaged in a program to destroy the U.S. stockpile of chemical weapons. Initially, incineration was selected as the preferred "baseline" destruction technology for all stockpiled chemical weapons stored at eight locations in the continental U.S. and one at Johnston Atoll.

However, the incineration process has met with strong public and political opposition. In 1996, Congress enacted legislation that led to the formation of the Assembled Chemical Weapons Assessment (ACWA) program. ACWA established a rigorous program for evaluating, selecting, and demonstrating technologies suitable for destroying the remaining stockpiles.

Initially, more than 20 treatment unit processes were demonstrated as part of the ACWA program. ACWA selected neutralization, biotreatment, and supercritical water oxidation for destroying the chemical weapons stored at the two remaining sites. After additional testing,

evaluation of the test results, assessments for safety, environmental, and operational risks, neutralization and biotreatment processes were selected for the U.S. Army Pueblo Chemical Depot (PCD) while neutralization and supercritical water oxidation processes were selected for the Blue Grass site in Kentucky (Earley, 2003).

In September 2002, the Bechtel Pueblo Team (Bechtel, URS, Battelle, and Parsons) was awarded the Pueblo Chemical Agent-Destruction Pilot Plant (PCAPP) contract. The scope of work includes designing, constructing, systemizing, pilot testing, operating, and closing the plant that would safely and efficiently destroy the stockpile of chemical weapons currently in storage at PCD.

PCAPP will utilize neutralization to destroy munitions containing 2,600 tons of mustard agents and Honeywell's patented Immobilized Cell Bioreactor (ICB) to treat the resultant hydrolysate. The agents and explosives stored at PCD's stockpile consist entirely of projectiles and mortars filled with blister agents. Only munitions containing HD (distilled mustard, β,β'-dichloroethylsulfide) and HT [a mixture of HD and T (bis 2-2-chlorethylthioethyl ether)] are stored at the PCD. 97.8% of mustard agent is HD and only 2.2% is HT. The mustard munitions also contain inorganic residues (e.g., iron oxide) that are collectively referred to as agent 'heel' material. This sludge-like material can represent up to 26% of the total weight of agent material contained in PCD munitions (Earley, 2003).

Currently, the plant is under construction and work is progressing on a variety of facilities to support chemical agent processing, energetic processing, munitions and energetic storage, biotreatment, entry control, utilities, laboratory, systemization, maintenance, and other tasks.

The following steps will be used in destruction of the chemical agent at PCD:

1. **Removal of Energetics:** Robotic equipment removes energetics (explosives) from the weapon. The energetics will be disposed of at a permitted off site facility.
2. **Removal of Mustard Agent:** The inside of the weapon is remotely accessed, and mustard agent is washed out with high-pressure water.
3. **Neutralization of Mustard Agent:** The mustard agent is neutralized first with hot water and then neutralized with a caustic solution. The byproduct is called hydrolysate.
4. **Biotreatment:** The hydrolysate is biotreated using a fixed-film bioreactor system to break down organics. The treated water is recycled in the plant.
5. **Disposal of Metal Parts:** Metal parts are heated to 1,000°F for 15 minutes and recycled.

HYDROLYSIS

Previously, two methods of neutralization of mustard through hydrolysis have been demonstrated; in hot water at 90°C and in a caustic solution. PCAPP will use hot water hydrolysis to destroy the chemical agent. The product of caustic hydrolysis has been shown to be less biodegradable than that of the hot water hydrolysis.

The hydrolysis process results in an irreversible chemical reaction in which the mustard agents are destroyed and a byproduct called hydrolysate is formed. The hydrolysate produced by the neutralization of both types of mustard is a turbid amber liquid that is approximately 90% water and salts (mainly sodium chloride and iron salts). HD mustard is hydrolyzed to an organic chemical called thiodiglycol (TDG), while HT mustard is hydrolyzed to TDG and a similar compound, T-alcohol.

In the hot water reaction, HD is converted to TDG ($HOCH_2CH_2SCH_2CH_2OH$), a readily biodegradable compound, and hydrochloric acid (HCl). The reaction proceeds to completion with no detectable agent (< 200 ppb) remaining in the product. Upon completion of the hydrolysis step, HCl is neutralized by the addition of NaOH. Typically, the water hydrolysis reaction is done at an HD

concentration of 3.8 weight %, but concentrations up to 15 weight % have been tested and shown to produce similar results with respect to TDG yield (Earley, 2003).

At PCAPP, the agent concentration will be 8.6 weight %. Both HD and HT mustard agents will be hydrolyzed in 8 reactor batches per day at peak operating rates, when projectile/mortar disassembly machine processes 64 rounds per hour of 155 mm HD munitions, approximately 2,250 pounds of HD is processed per batch.

The reactors operating in batch involve two primary steps: agent hydrolysis (the reaction of agent with water) and neutralization of the hydrolysis reaction products with NaOH. Mustard agents are fed into reactors and mixed first with hot water at 175°F. Then, a 25 weight % solution of NaOH is added towards the end of the batch cycle to complete destruction of reaction intermediates such as sulfonium ions (SR_3^+). R is an organic substitute such as methyl (CH_3) attached to sulfur. After the caustic addition, the agent hydrolysate pH will be between 10 and 12. The resulting hydrolysate is tested to ensure it contains no detectable mustard agent. The PACPP is expected to generate an estimated 8,400,000 gallons of mustard hydrolysate. This includes decontamination solution and treatment process condensates.

IMMOBILIZED CELL BIOREACTOR

After neutralization, the hydrolysate is treated in the ICB system, which is an aerobic fixed-film bioreactor packed with 2-inch polyurethane foam cubes and plastic spacers (bio rings). The diluted hydrolysate is pumped into aeration chambers of the ICB treatment system containing a mixed culture of microorganisms attached to the fixed-film media. TDG and other complex organic compounds are broken down into simpler forms in the ICB. Periodically portions of the biofilm slough off the media when the biofilm becomes too thick to support its own weight. The treated water from the ICB is evaporated and recovered for recycle in the plant, leaving various salts and biosolids behind for disposal. The ICB offgas containing trace amount of organics is treated by vapor-phase carbon adsorption.

The ICB technology has been in commercial use for more than 14 years to treat industrial wastewater from coal tar distillation plants, creosote and pentachlorophenol plants, chemical plants producing acrylic polymers, dye intermediates, lubricants, chlorinated solvents, and textile plants. The ICB operating under anoxic conditions (e.g., without dissolved oxygen) also been used to remove selenium form industrial wastewater.

The two fundamental parameters of biological wastewater treatment are the hydraulic retention time (HRT) and the microbial solids retention time (SRT). The HRT is a measure of bioreactor efficiency, whereas SRT determines the solids concentration within the reactor and thus efficiency of biological treatment. The PCAPP ICBs are designed for 4-5 days of HRT and 120-200 days of SRT.

Short HRT bioreactors require a relatively small reactor volume to treat a wastewater for a given flow rate. Short HRT continuous flow stirred tank bioreactors also produce more sludge for a given organic loading and biomass concentration in the reactor.

Long SRT bioreactors promote lower biomass yields per volume of wastewater treated similar to an aerobic sludge digestion system. The yield of biomass in activated sludge systems is known to decline hyperbolically with SRT. For example, an activated sludge process with 5-15-day SRT produces more biosolids than an extended aeration type activated sludge process with 20-30-day SRT. The sludge yield in the ICB system is extremely low because of a very high SRT, which is in the order of 120 to 200 days. Transient environmental conditions such as cycles of oxic and anoxic environments can lead to metabolic uncoupling and cause bacteria to wastefully utilize organic substrates (Golder, 2009).

The sludge yields for several biological wastewater treatment systems, expressed as

kilograms (kg) of volatile suspended solids (VSS) per kg of biochemical oxygen demand (BOD), are compared in Table 1 (Golder, 2009). The ICB sludge yield in Table 1 is not from the ACWA study. This number is based on the ICB experience of Golder Associates, Inc. (Golder) in other wastewater treatment applications.

Table 1. Sludge Yield of Biological Wastewater Treatment Processes (Golder, 2009)

Biological Wastewater Treatment System	Sludge Yield (kg VSS / kg BOD5 removed)
Conventional Activated Sludge	0.4-0.6
Pure Oxygen Activated Sludge	0.3-0.9
High Rate Trickling Filter	0.3-0.5
Rotating Biological Contactors	0.4-0.5
Immobilized Cell Bioreactor	0.07-0.15

The ICB system has a number of proprietary and distinguishing features when compared with other fixed-film bioreactor systems. The ICB utilizes a mixture of two different substrata for immobilization of the reactor biomass. One of the immobilizing substrata is highly reticulated polyurethane foam (2-inch cubes). This component provides a high surface area for biomass colonization. However, the cubes may become coated and the available surface area may be decrease in a highly loaded system. Once the bioreactor is fully colonized, these cubes are completely filled with biomass to a depth of at least one inch. Biomass concentration can be greater than 8,000 mg VSS/L (Golder, 2009).

One of the problems encountered in fixed-film bioreactor systems is mass transfer and distribution of air and nutrient through the packed bed due to plugging and short-circuiting. This problem was addressed in the ICB packing by addition of a second plastic "spacer" media (bio rings), which is a highly open porous packing with void space greater than 90%. This feature insures good distribution of both gas and liquid throughout the ICB's packed bed (Golder, 2009).

Optimum ranges of operating parameters for the ICB are:

- pH: 7 to 8
- Temperature: 60 to 90°F
- Dissolved Oxygen: 2 to 4 mg/L
- Residual soluble NH_3-N in effluent: > 1.0 mg/L
- Residual soluble PO_4-P in effluent: > 1.0 mg/L

PILOT-SCALE ICB DEMONSTRATION

Treatment of hydrolysate by the ICB process was first demonstrated in laboratory-scale tests conducted at the U.S. Army's Edgewood Chemical and Biological Center in 1998, just prior to the start of the ACWA demonstration testing. These initial ICB tests showed that effective treatment of the HD hydrolysate was possible by the ICB process operated at HRTs between 3 and 5 days (Earley, 2003).

As part of the ACWA demonstration program, large scale demonstration tests were conducted using a 1,000-gallon ICB reactor to validate the ICB process performance for treatment of a mixture of HD and tetrytol hydrolysate. The HD was obtained from ton containers and the HD hydrolysate was prepared using the hot water hydrolysis process. The tetrytol was obtained from demolition blocks and the tetrytol (6 weight %) was hydrolyzed in 90°C caustic solution. Results of the testing showed that the ICB process could achieve greater than 99% TDG removal efficiencies. While the tests were considered a success, the ICB system was operated at about 67% of the full-scale design loading (Earley, 2003).

A long-term operation of the 1,000-gallon ICB system at design loading was demonstrated in follow-on ACWA Engineering Design Studies (EDS) conducted from May to October 2000. Over a 4-month test period, the ICB was operated continuously under the proposed full-scale loading and operating conditions. As in previous tests, HD hydrolysate was made using hot water hydrolysis of HD obtained from bulk

containers stored at the Aberdeen Proving Grounds. During this period, the ICB was able to remove TDG to below the level of analytical detection (40 mg/L). Overall chemical oxygen demand (COD) removal efficiency was approximately 90%, which was comparable to that achieved in earlier demonstration testing (Earley, 2003).

The COD/TDG for the hydrolysate tested was 2.5, which is a little higher than the ratio estimated for the PCAPP hydrolysate. The PCAPP design specification indicates that the COD/TDG ratio for the PACPP hydrolysate is expected to be 2.03. The diluted hydrolysate (ICB feed) at the PCAPP will contain 7,000 mg/L TDG and 15,000 mg/L COD.

TEST OBJECTIVES - The EDS ICB testing was designed to achieve the following objectives:

- Demonstrate long-term continuous operation of the ICB system at the proposed ICB operating conditions (e.g., aeration, effluent recycling) of the full-scale system.
- Confirm critical design parameters (e.g., aeration rate) developed during earlier demonstrations.
- Demonstrate effective control of the biomass in the ICB system.
- Demonstrate the effectiveness of the proposed full-scale ICB control strategy.

STARTUP AND VALIDATION TESTS - The EDS ICB testing was divided into two distinct phases, startup and validation. The duration of startup phase was 3 weeks and the duration of validation phase was 18 weeks.

Startup Phase - An important element in biological treatment planning is the time required for system startup. The EDS testing was designed as a model for startup of the full-scale ICB to determine how quickly the biomass can be developed to full capacity and how quickly the design level of performance can be achieved. During the startup phase, the ICB was seeded with activated sludge and then charged with feed and operating in batch mode with increasing feed concentrations. Continuous operation began at design feed concentration with increasing flow rates until a set of standard operating conditions below are attained.

ICB Feed Tank:
- 152 kg/day HD hydrolysate
- 6.8 kg/day tetrytol hydrolysate
- 597 kg/day dilution water

Nutrient Feed Tank:
- 0.2 L/min ammonium bicarbonate
- 0.2 L/min di-basic potassium phosphate

ICB Cells:
- 28 acfm air flow to cell #1 and 14 acfm air flow each to cells #2 and #3
- Control pH between 7 and 7.5 with addition of 10 weight % NaOH solution to recycle loops by monitoring pH with probes in recycle loops of each ICB cell

Validation Phase - The ICB system was operated at a steady-state condition with varying engineering parameters such as aeration and pH control. System restart was also evaluated during this phase.

While adequate aeration is essential to an aerobic biotreatment process, it is also one of the primary operating costs due to the energy consumption and the cost of off-gas treatment. Therefore, it is important to determine the optimum aeration rates. During earlier demonstrations, aeration was provided to the ICB at a rate of 50 scfm, or 15,000 ft^3 of air per kg of HD destroyed. During the EDS testing, the aeration rate was reduced from 50 scfm to 30 scfm to assess the impact on overall ICB performance.

The biodegradation of TDG produces sulfuric acid, which must be neutralized in order to maintain a healthy biomass in the ICB. Therefore, pH control is critical to successful operation of an ICB system treating the HD/tetrytol hydrolysate. There were two methods for pH control in the EDS ICB system. In the first method, pH measurement and NaOH injection were done in each of the ICB cell recirculation loops. In the second method, pH measurement and NaOH injection were done in

each of the ICB cells. The EDS test plan scheduled pH control in the recirculation loops for the first half of the validation phase and in ICB cells for the second half.

The ICB design allows for a quick re-start after a stoppage or shutdown due to the retention of a high concentration of biomass within the immobilizing foam matrix. To demonstrate the ease of re-start, the EDS test plan scheduled a three-day stoppage. ICB feed was stopped and aeration was reduced by 75% during the 11th week the validation phase. Upon restart, the ability of the ICB system to reach full performance was determined by analysis of the process monitoring parameters.

The ICB process was monitored using online instrumentation and sample collection/analysis. Instruments were used in the ICB cells and influent/effluent streams to collect the following data: liquid levels, dissolved oxygen, pH, liquid and gas flow rates, temperatures, and pressures. Aqueous samples were also collected and analyzed determine the concentrations of TDG, COD, ammonia, phosphate, total dissolved solids, total suspended solids, and VSS.

PILOT-SCALE ICB PERFORMANCE

Although both TDG and COD were measured to determine the ICB performance during the pilot testing, TDG is a better performance parameter than COD because COD measurement will have limitations due to interference from high chloride concentration in PCD's wastewater. Standard Methods (1992) does not recommend the use of COD method for wastewaters containing more than 2,000 mg/L chloride. A typical HD hydrolysate contains more than 5,000 mg/L chloride. The PCD wastewater chloride concentration is expected to be between 4,000 and 5,000 mg/L.

To ensure proper system operation, pH and temperature of the ICB were controlled and monitored.

TDG REMOVAL - Figure 1 shows the concentration of TDG in the ICB feed, ICB cell #1, and ICB effluent over the course of the test. The TDG concentration in the ICB feed ranged from 3,911 mg/L to 8,541 mg/L during the validation phase, with a general increasing trend towards the end of the test. The average TDG concentration in the ICB feed was 5,860 mg/L. With only a few exceptions, the TDG concentrations in the ICB effluent were below the analytical detection limit, 40 mg/L, regardless of the feed composition. The average TDG concentration in the ICB cell #1 was 1,040 mg/L, with some results below the detection limit. The ICB cells #2 and #3 were needed to bring the effluent TDG concentration below the detection limit.

COD REMOVAL - Figure 2 shows the COD level in the ICB feed, ICB cell #1, and ICB effluent over the course of the test. The COD levels in the ICB feed ranged from 5,950 mg/L to 18,320 mg/L during the validation phase. The average ICB feed COD concentration was 10,961 mg/L when the ICB feed contained 40 gallons of HD hydrolysate and 15,361 mg/L when the feed contained 50 gallons of HD hydrolysate.

The COD levels in the ICB cell #1 fluctuated between 710 and 8,650 mg/L and the COD removal efficiencies fluctuated between 11% and 93% with an average removal efficiency of 75%. Some of the increases in the COD results corresponded to increases in the COD levels in the ICB feed. The most notable increases in the ICB cell #1 COD levels were observed when the quantity of HD hydrolysate in the ICB feed was increased from 40 to 50 gallons (September 25 to October 2). However, the ICB biomass acclimated quickly to the higher loading, as indicated by the subsequent drop in the ICB cell #1 COD levels.

The following increases in the ICB cell #1 COD concentrations were observed:

1. July 4: The ICB cell #1 COD increased over 5,000 mg/L. This may be due to changing the source of dilution water. Starting on July 2, the evaporator

condensate was used to dilute the ICB feed instead of site water. COD levels returned to normal on July 9 with acclimation of the ICB microorganisms to this new diluent.

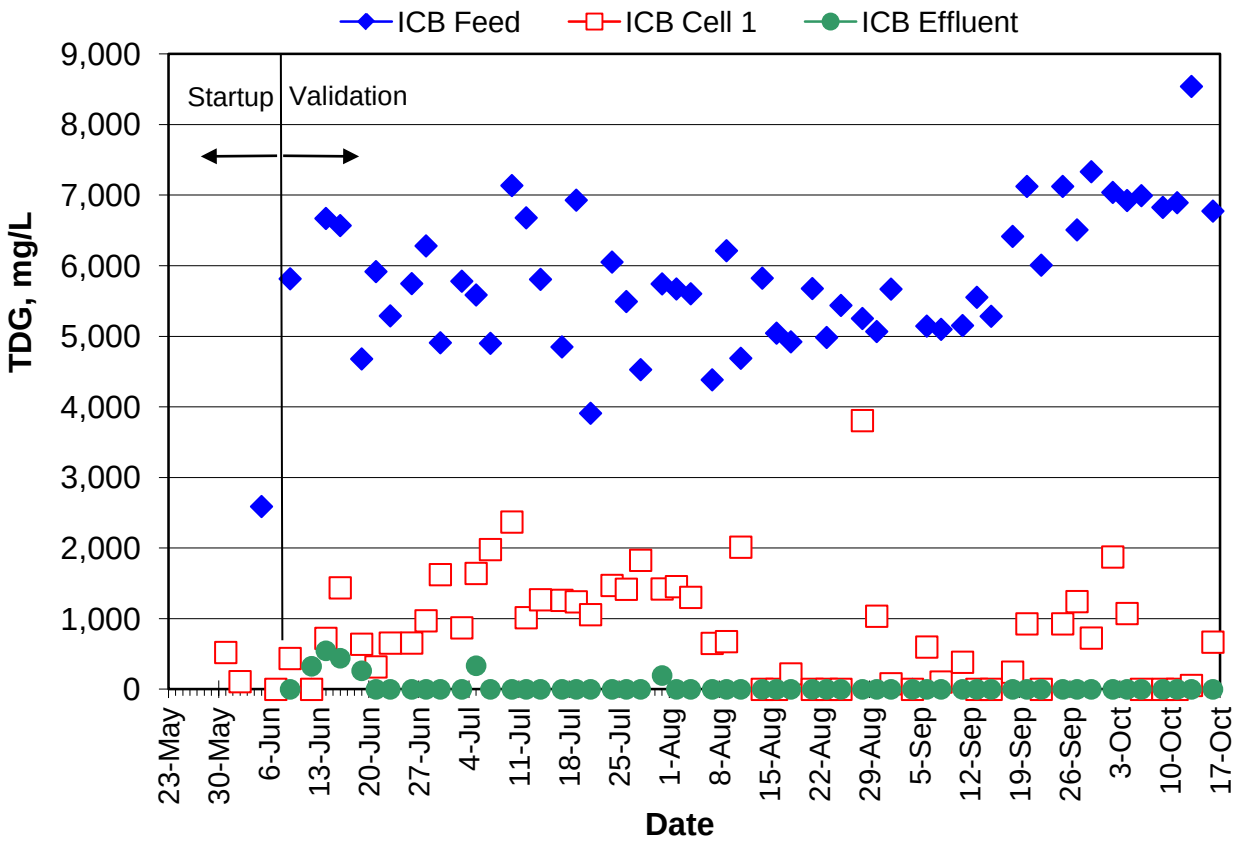

Figure 1. ICB Thiodiglycol Profile (Arthur D. Little, 2002)

2. August 13: The ICB cell #1 COD increased over 5,000 mg/L. This may be due to addition of wood treating steam condensate to the ICB feed. The condensate was produced when wood was treated with steam. Wood condensate was added at 1 gal/day rate from August 13 to 24 at 2 gal/day rate on August 25 and 26.
3. August 26: The ICB cell #1 COD increased to 8,650 mg/L over the weekend of August 26. This was the biggest upset in the ICB cell #1 COD removal performance. The COD removal efficiency dropped from 86% on Friday (25 August) to 58% on Saturday, to 43% on Sunday, and to 11% on Monday. In response, feed to the ICB was stopped on Monday and the ICB liquor was circulated through the ICB cells to equilibrate the content of all 3 ICB cells. By Tuesday (August 29), the COD concentration in the ICB cell #1 returned back to normal and the feed to the ICB cell #1 was started again. This event may have been caused by 3 factors: sloughing of the biomass, aeration problem on August 27, and 2 gal/day wood condensate addition. The data show a rise in the ICB effluent suspended solids concentration on 30

August, which is further indication of biomass sloughing.

4. September 26: Another rise in the ICB cell #1 COD concentration occurred when the loading was increased from 40 to 50 gallons of HD hydrolysate per day starting on September 19. The increase in COD levels appeared proportional to the increase in organic loading.

Despite the wide range of variations in the ICB feed and ICB cell #1 COD levels, the ICB final effluent COD levels remained below 2,000 mg/L from the third day of the validation phase to the end of the test (June 16 to October 17). However, some trends were noted in the ICB effluent COD levels that corresponded with the change in ICB feed composition. A gradual fall in COD levels occurred during the first seven weeks of the validation phase as the ICB biomass became more acclimated to the HD/tetrytol hydrolysate. After introduction of condensate to the ICB feed as dilution water on August 4, the COD levels gradually rose, and then fell as the biomass acclimated to the change in feed.

During the validation phase, the average COD removal efficiencies across the ICB cell #1 ranged from 60% to 90% (averaging at 75%) if upset COD levels mentioned above are excluded. However, the overall ICB COD removal efficiency was not impacted by these upset levels. The COD removal efficiencies of the entire ICB system (across the ICB cell #3) ranged from 85% to 95% (averaging at 90%).

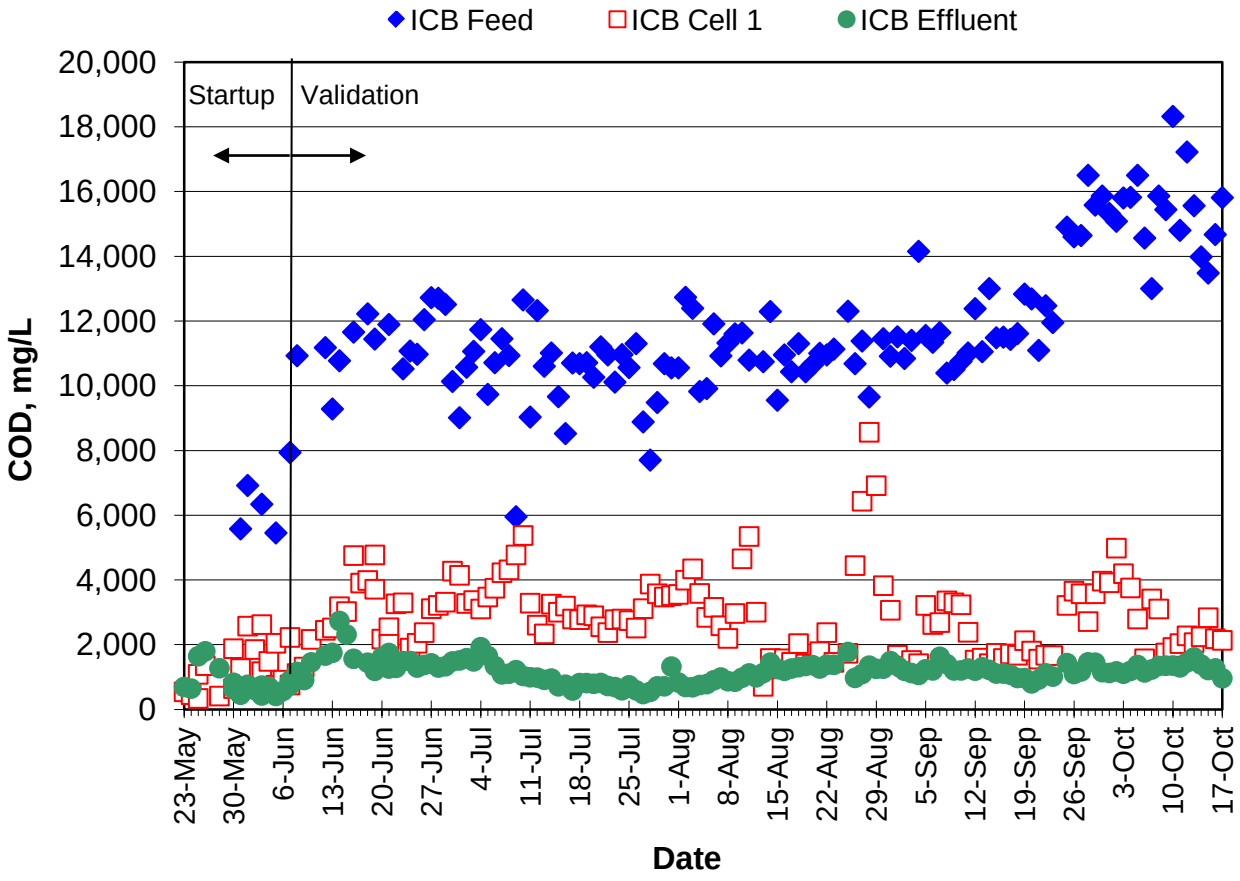

Figure 2. ICB Chemical Oxygen Demand Profile (Arthur D. Little, 2002)

pH AND TEMPERATURE CONTROL - The following two methods were used for pH control in the ICB:

- pH measurement and caustic solution injection in each of the ICB cell recirculation loops. This method was used from June 14 to October 3
- pH measurement and caustic injection in each of the three ICB cells. This method was used from October 4 to October 17 and resulted in larger and less frequent doses of caustic solution than the first method.

Both methods successfully controlled the pH in the ICB, maintaining a pH level between 6 and 9 in the ICB cell #1 and the ICB effluent. The pH variations in the ICB feed, cell #1, and effluent are shown in Figure 3.

The temperature variations within the ICB generally followed seasonal warming and cooling trends, ranging from 74°F in May to 98°F in August as shown in Figure 4. Since the validation testing was conducted from June 14 to October 17, the impact of low temperature on biological activity, and hence ICB performance, could not be assessed.

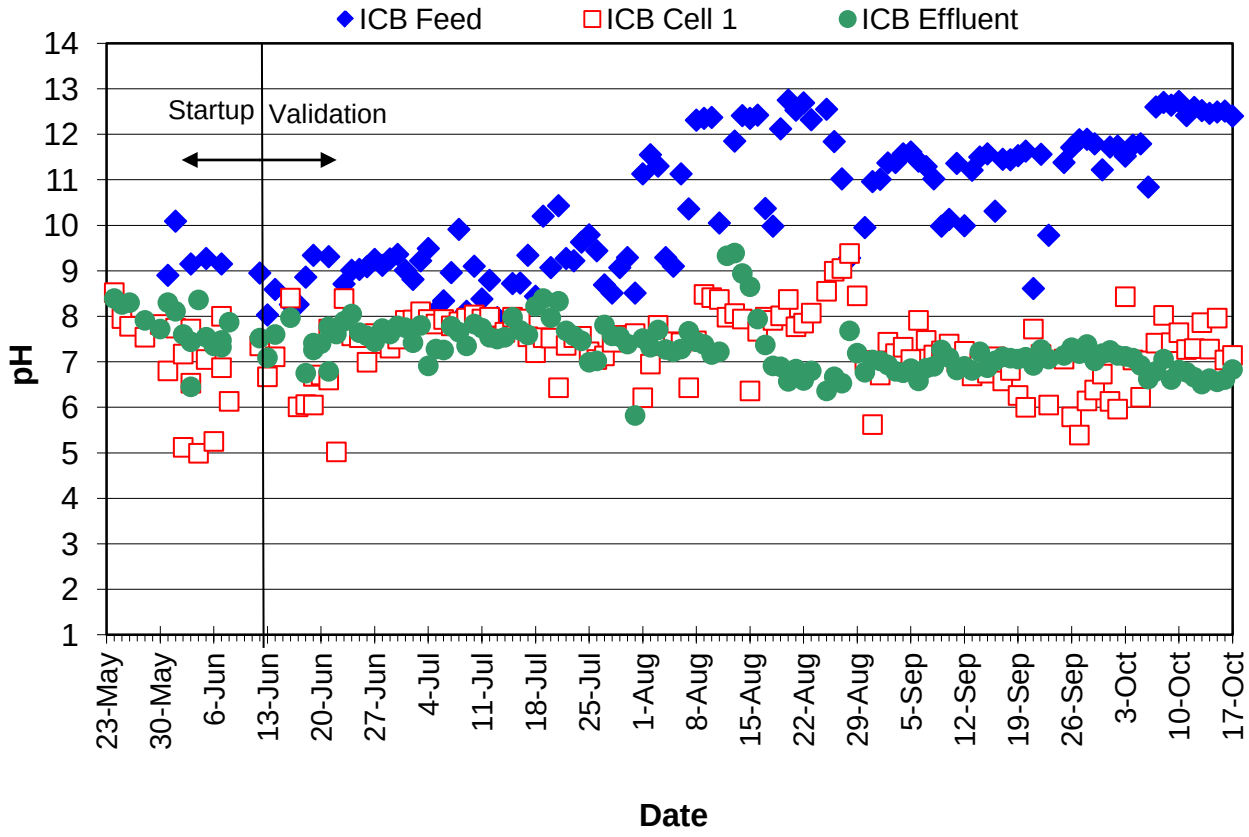

Figure 3. ICB pH profile (Arthur D. Little, 2002)

EFFECT OF HELL MATERIAL - The EDS testing conducted by ACWA validated biological treatment of a mixture of HD and tetrytol hydrolysate by ICB technology. However, the HD hydrolysate used in the previous tests was made from neat agent obtained from ton containers. Because the Pueblo stockpile consists of assembled munitions that contain both liquid agent and heel material, the HD hydrolysate used in the EDS ICB testing was not fully representative of hydrolysate that will be produced during the full-scale operation.

Therefore, ICB testing using HD hydrolysate prepared from liquid agent and heel removed from actual chemical munitions (4.2" HD mortars) was conducted in 2002 to verify the ICB performance with this more representative material. A projectile washout system was used to remove solid material (heel) from munitions. The heel material was then combined with liquid agent drained from the munitions and subsequently neutralized. HD hydrolysate mixed with tetrytol hydrolysate was used in the laboratory-scale ICB tests (Earley, 2003).

Average COD removal efficiency of the laboratory-scale ICB treating heel material was 85.5%, which is comparable to average removal efficiency of 90% observed in the 1,000-gal ICB tests under steady-state conditions (Earley, 2003).

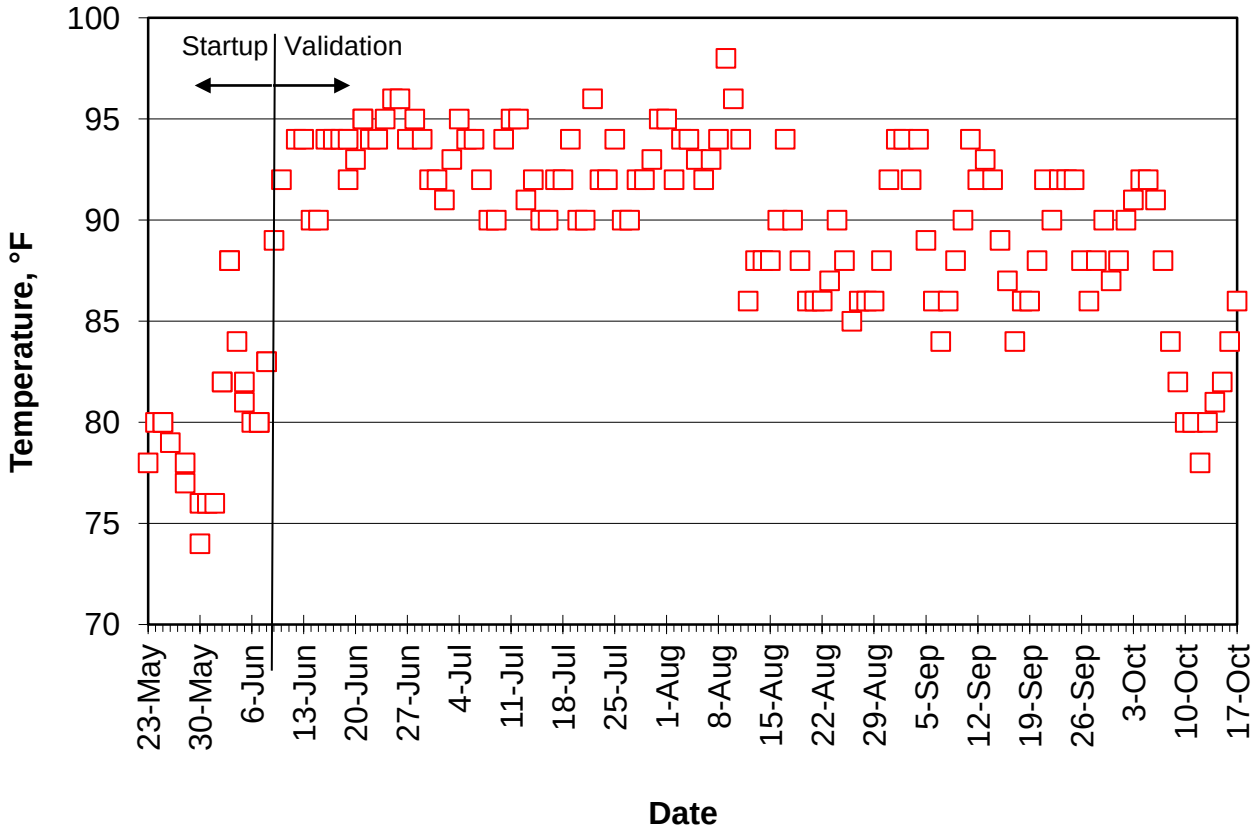

Figure 4. ICB Temperature Profile (Arthur D. Little, 2002)

ICB SYSTEM DESIGN

The Bechtel Team designed the PCAPP ICB system based on the extensive bench- and pilot-scale testing data. Golder led the process design effort as the exclusive licensee to Honeywell for the ICB technology in the U.S. and Canada. The factors considered during the ICB design included reaction kinetics governing the process, oxygen transfer requirements, nature of the wastewater to be treated, and costs of construction, operation, and maintenance.

Site specific conditions required the following changes to the original design:

- Improved design changes to the internal structures of the ICB tanks
- Use of centrifugal blowers for aeration
- Identification of better paint systems
- Improved instrumentation and control

- Improved fabrication processes

A simplified version of the full scale ICB system is shown in Figure 5. Figure 6 shows a picture of one ICB module with 4 ICB reactors after the fabrication was completed in Colorado Springs, Colorado, before shipping to the project site in Pueblo, Colorado.

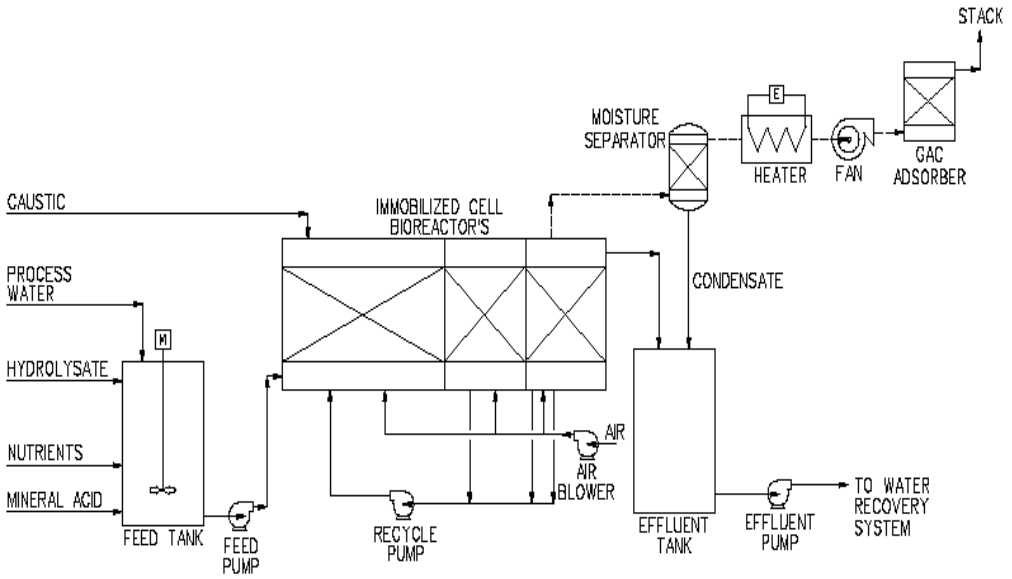

Figure 5. A Simplified Block-Flow Diagram for the ICB System

Figure 6. One of the 4 ICB Modules at the Fabrication Shop Staging Area in Colorado Springs, Colorado (Golder, 2009).

The ICB system was designed to treat a maximum TDG concentration of 7,000 mg/L in diluted hydrolysate feed. At the loading level resulting from 7,000 mg/L TDG concentration, the ICB will achieve a minimum of 95% TDG removal efficiency at the design flow rate and 98% removal efficiency at the normal flow rate. Based on the multiple testing scenarios, the ICB had HRTs ranging from 3.6 to 4.8 days to accomplish the target TDG removal efficiencies. Each ICB is designed to have a working volume of 41,800 gallons. The total number of ICBs was calculated to be 16 for processing the allowable TDG load based on the volumetric production rate of hydrolysate, the required hydrolysate dilution rate, and the effective HRT range. The TDG load was determined using the mass of agent and the maximum processing rate of munitions.

The 16 ICB reactors were divided into 4 modules of the same size. Each module consists of one feed tank with agitator, one feed pump, two air blowers, four bioreactors, one recycle pump per bioreactor, one moisture separator, one effluent tank, one effluent pump, two nutrient feed pumps, and one mineral acid tote package. Each module also incorporates an off gas treatment system, which consists of one offgas heater, one offgas fan, and two activated carbon filters to reduce and mitigate nuisance odors.

The air requirements were specified by Golder based on the organic loading and maintaining a minimum of 2 mg/L dissolved oxygen concentration in the ICB cells.

The pH of hydrolysate would normally between pH 10 and 13 and buffered. This high pH hydrolysate is neutralized with the production of sulfuric acid from biodegradation of the TDG during normal operation. However, this is not the case at startup when the ICB biomass is in acclimation period. Therefore, pH needs to be adjusted by acid addition so that a normal aerobic biological activity is possible. When biodegradation of TDG begins, acid addition should be discontinued to prevent inhibition of biological activity in the ICB cells due to low pH.

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