

TREATING THE SOURCE OF PERCHLORATE-CONTAINING GROUNDWATER IMPACTING LAKE MEAD USING A HIGH PERFORMANCE BIOREACTOR SYSTEM

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ABSTRACT

Perchlorate manufacturing in Henderson, Nevada has resulted in releases of perchlorate into groundwater and Lake Mead via the Las Vegas Wash. The plant was built in the late 1940s and produced ammonium and sodium perchlorate for ultimate use by the U. S. Department of Defense and the National Aeronautics and Space Administration (NASA) until 1998.

Kerr-McGee began removing perchlorate from the groundwater in 1999 near the Las Vegas Wash using a pumping system coupled to ion exchange technology. In 2002, they installed additional wells, pumping systems and additional ion exchange capacity to capture and treat additional water near the perchlorate manufacturing sources. In December 2002, due to the high operating cost of using disposable ion exchange resin, Kerr-McGee initiated the design of a biological treatment process to replace the ion exchange system. A laboratory pilot program was initiated in early January 2003 to confirm the process design, and installation of the full-scale treatment system was completed in December 2003.

The biological treatment process for the Kerr-McGee Henderson site involves the use of two trains of fluidized bed reactors (FBRs) in series. The FBR is a highly efficient fixed-film reactor that utilizes stationary microbes on a hydraulically fluidized bed of media particles. Sand is used as the fluidized bed media in the front train of four FBRs (each 14 ft. in diameter and 30 ft. in height), while carbon is used in the back train of four FBRs (14 ft. in diameter and 26 ft. in height). Perchlorate laden feed water is introduced to the front train of four FBRs, operated in parallel, at a total flow rate of 1,000 gpm, with an upper inlet perchlorate concentration of 400 mg/l. Chlorate and nitrate contaminants also are present in the feed water. The system design influent conditions are shown in Table 1. An electron donor (ethanol) is pumped into each of the front-train FBRs where it is utilized in anoxic, biological reduction processes. The byproducts of the processes are chloride ions, heat generation and additional biomass growth. All water from the front train of FBRs, along with any biomass that is separated from the media, combines together and enters the back train of four FBRs operated in parallel. In these reactors, any remaining concentration of perchlorate is further biologically treated to meet regulatory discharge limits. Contaminant free water from the back train of FBRs proceeds through an aeration system, two dissolved air flotation units and an ultraviolet ray disinfection system, before being released to the Las Vegas Wash.

Solids recovery and filter press systems also are employed at the plant. Figure 6 shows the FBR plant layout and Figure 1 is a photograph of the first stage sand FBRs and electron donor storage tank.

Operation of all of the components of the plant, as well as performance results, will be presented in detail. The FBR plant successfully completed a 35-day composite sampling performance test on November 6, 2004 at approximately 93 percent of the system's maximum design load. During the test all design water quality effluent conditions were met (Table 2).

Figure 1. First stage sand FBRs and electron donor storage.



BACKGROUND

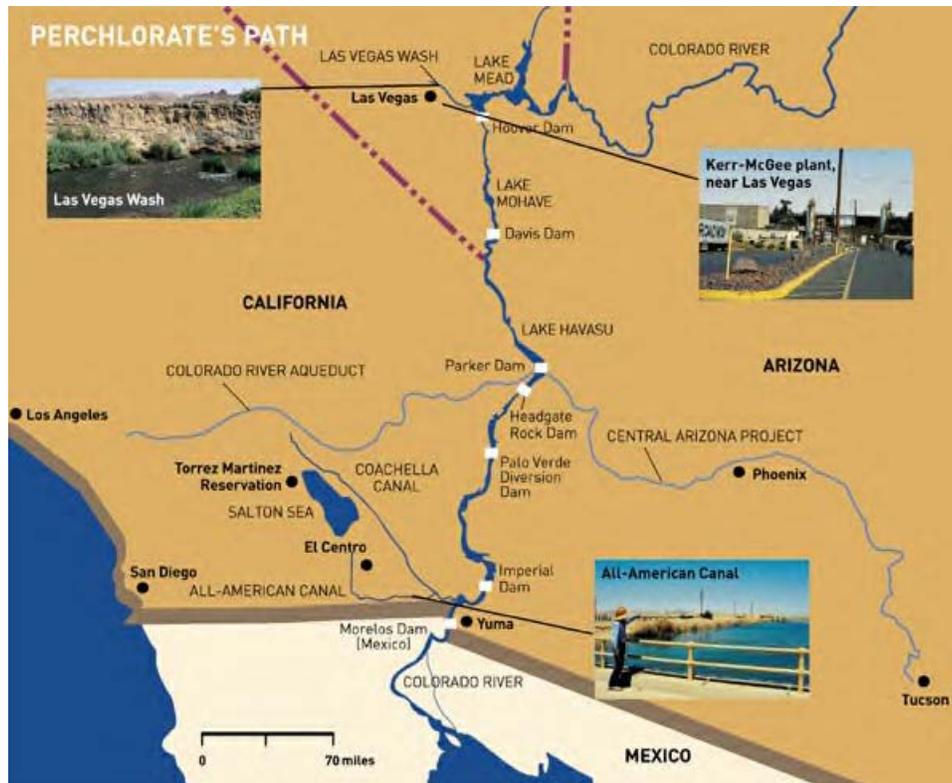
Plant History

Perchlorate manufacturing in Henderson, Nevada has resulted in releases of perchlorate into groundwater and Lake Mead via the Las Vegas Wash. Perchlorate production was initiated at the site in 1945. Full commercial production of ammonium perchlorate was begun in 1951. Kerr-McGee acquired the facility in 1967 where they continued to manufacture ammonium perchlorate until production was shut down permanently in 1998.

In mid-1997, the Southern California Water District discovered perchlorate in the lower Colorado River using improved test methods. Ultimately, the source of the

perchlorate was traced back to the Kerr-McGee Chemical Plant in Henderson, Nevada. Since that time, both the Nevada Department of Environmental Protection (DEP) and U.S. Environmental Protection Agency have worked closely with Kerr-McGee to control and reduce the release of perchlorate as quickly as possible.

Figure 2. Perchlorate Path down the Colorado River (Courtesy of Chemical & Engineering News)



Control Strategy

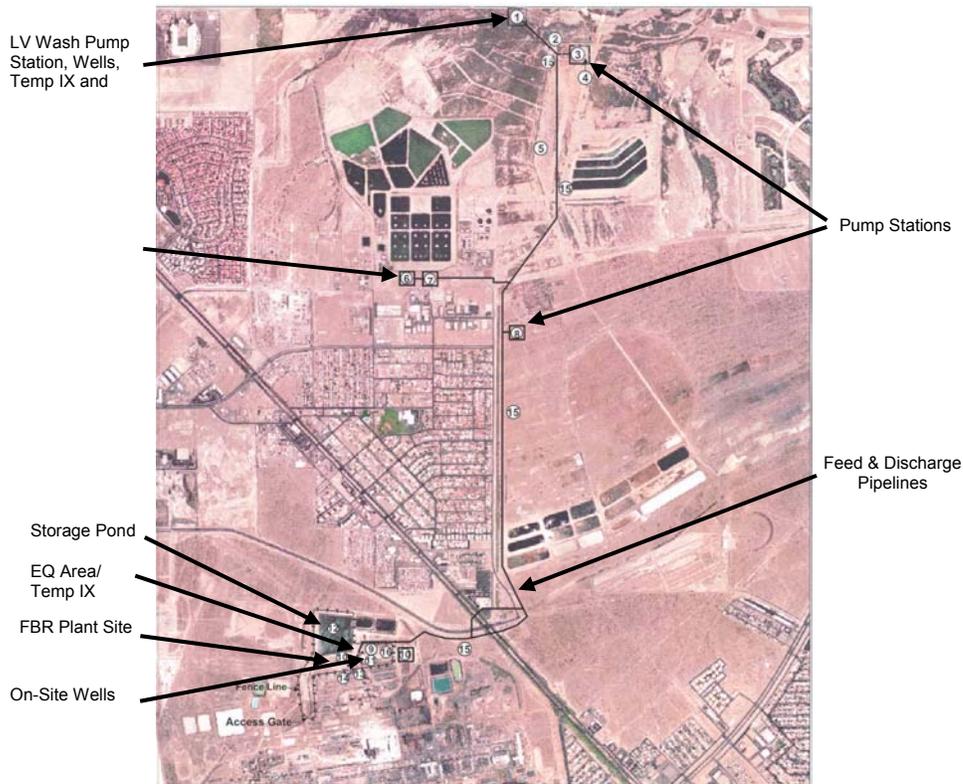
Kerr-McGee began work under a consent order with from the Nevada DEP to install a capture and treatment control strategy in 1999. The groundwater enters the Colorado River through the Las Vegas Wash which feeds into Lake Mead (and subsequently supplies the Colorado River; see Figure 2). The Kerr-McGee plant is approximately 3 miles south of the Las Vegas Wash.

A series of wells were installed to capture the plume in 3 different locations:

- Las Vegas Wash (“Seep wells”);
- Athens Road;
- On-site Wells (high concentration “source” containing chromium).

An on-site slurry wall was installed to cut off the high concentration plume from further migration. In order to move and ultimately treat the water, 42,000 feet of buried pipe was installed to convey all the well water back to the Kerr-McGee Plant for treatment and to convey treated water back to the Las Vegas Wash. This piping system included three pump stations in order to maintain flow to the plant. At the Kerr-McGee Plant, an 11-acre, 60 million gallon pond was constructed to act as temporary storage and evaporation of the post chrome-treated on-site wells. Lastly, an equalization area was installed to combine all the well sources into a single flow for treatment.

Figure 3. Overall System Map



Initial Treatment

Along with all the collection, conveying and equalization equipment, a temporary ion exchange system was installed to treat the collected water until a permanent treatment technology could be chosen and a plant built. This temporary system treated the lower concentration water from the Seep and Athens Road wells. Water from the on-site wells were treated for chromium removal and then stored/evaporated in the on-site 11-acre pond.

PROBLEM DEFINITION & TECHNOLOGY EMPLOYED

Influent

After combining the three well sources, the following table represents the influent design parameters for the permanent biological treatment system:

Table 1. System Design Influent Conditions

Constituent	Units	Concentrations
Perchlorate, as ion	mg/L as ion	≤ 400
Chlorate, as ion	mg/L as ion	≤ 500
Nitrate, as N ion	mg/L as ion	≤ 50
Chloride	mg/L as ion	≤ 2500
TDS	mg/L as ion	≤ 10,500
Flow Rate	gallons per minute	950 (design average) 1,000 (30-day average)

Effluent

After treatment, the following were the required effluent parameters:

Table 2. System Design Effluent Conditions and 35-day Performance Test Results

Constituent	Units	Concentrations
Perchlorate, as ion	ug/L as ion	≤ 4 ^a
Ammonia-N	lb/day	≤ 20
Total P	lb/day	≤ 20
TSS	mg/L	≤ 135
BOD	mg/L	≤ 25
pH	s.u.	6.5 - 9

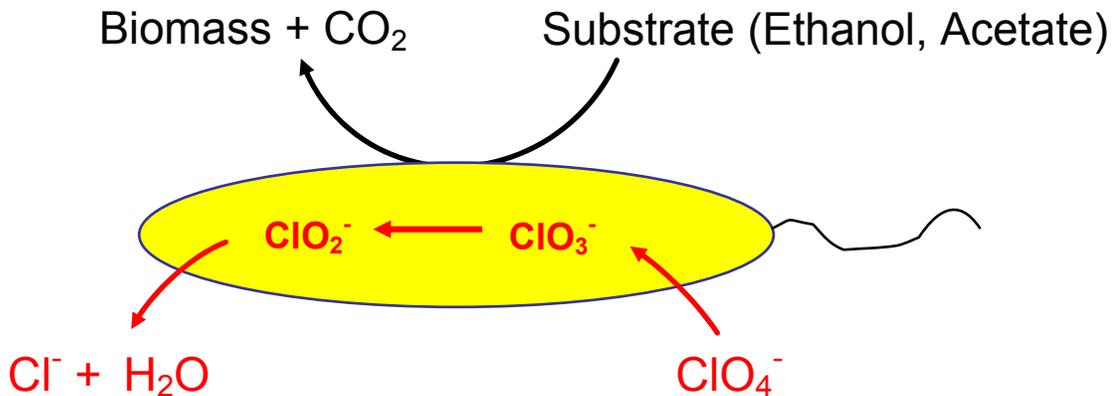
Note: ^a or less than the minimum reporting level “MRL”, as measured by the current EPA Method 314.0, Revision 1, November 1999, whichever is greater. For non-detect samples, daily composite values will be assigned a value of zero for calculating

30 day average. Maximum perchlorate concentration is based on maximum flow of 1,000 gpm.

FBR Treatment Technology

The FBR is a fixed-film bioreactor that fosters the growth of microorganisms on a hydraulically fluidized media. The fluidized media provides an extremely large surface area upon which microorganisms can grow, producing a large biomass inventory. This large biomass inventory provides the system's high volumetric efficiency.

Figure 4. Biological Perchlorate Path

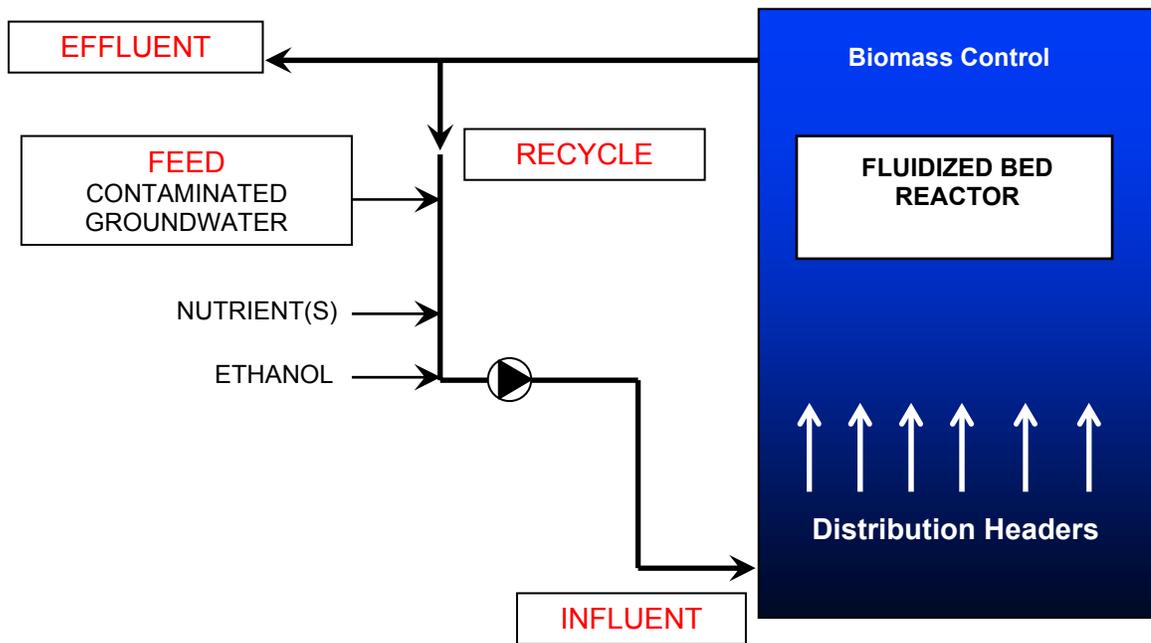


The influent is fed into the lower portion of the FBR where it is mixed with nutrients, a growth substrate (i.e., ethanol), and pH control chemicals. The contaminated water stream flows upward through the reactor at a velocity sufficient to fluidize (expand) the bed, allowing the biomass to come into intimate contact with the contaminants. The long solids retention time characteristic of the system allows for the removal of perchlorate while minimizing process upsets. This process literally breaks the perchlorate down into its innocuous elements.

The anoxic process for destroying perchlorate is essentially the same process used to remove nitrate. In fact, nitrate is commonly present in perchlorate-contaminated streams and must be removed before perchlorate reduction can proceed. This can all be done in a single FBR.

In the case of Kerr-McGee, the high loading dictated use of multiple fluidized bed reactors. Also as a safety measure, a two-step process was adopted with more highly loaded sand media FBRs as a first (or primary) stage followed by carbon based media FBRs in a second (or polishing) stage.

Figure 5. Fluidized Bed Reactor Schematic



TREATMENT PLANT DESIGN OVERVIEW

Introduction

The treatment plant takes its feed from the equalization facility discussed earlier. The major unit operations/treatment vessels are as follows:

1. Four (4) first stage fluidized bed reactors – 14 ft. diameter X 30 ft. straight side with sand media (FBRs 1, 2, 3, and 4);
2. Two (2) first stage separation tanks – 14 ft. diameter X 30 ft. overall height (T-2011 and T-2012);
3. Four (4) second stage fluidized bed reactors – 14 ft. diameter X 26 ft. straight side with granular activated carbon media (FBRs 5, 6, 7, and 8);
4. Two (2) second stage separation tanks – 14 ft. diameter X 26 ft. overall height (T-3011 and T-3012);
5. One (1) aeration tank – 14 ft. diameter X 24.5 ft. straight side (T-401);
6. Two (2) dissolved air flotation (DAF) vessel assemblies – 10.5 ft. W X 10.5 ft. H X 40 ft. overall length (D-501 and D-551);
7. One (1) ultraviolet (UV) disinfection system (X-621);
8. One (1) gravity thickener – 20 ft. diameter X 18 ft. straight (T-602);
9. Two (2) filter press assemblies, 80 cu. ft. each (X-901 and X-902).

Main Feed Stream Treatment

The system is designed to accept feed water at up to 1,000 gpm maximum hydraulic loading. Equalized feed enters the system at the two first stage fluidization pump skids. Individual flow control valves control feed flow splitting to each of the operating first stage FBR vessels. Under normal steady state operating conditions, the total feed flow is equally split between the operating first stage FBR vessels. It is, however, possible to operate with unequal flow splitting or with one of the first stage FBRs off-line.

The system controls provide the ability to set the system feed flow at a constant rate or to control feed flow based on maintaining level in the equalization tanks. A trace element solution is metered into the system feed. The mixture is fed into the feed stream from a separate tank using a metering pump.

First Stage FBR Treatment

Feeds to each operating first stage FBR vessel are combined with recycle flow, ethanol, nutrients solution and pH control solution (i.e., 25% caustic). The caustic and ethanol solutions are, respectively, controlled by pH and optional ORP control systems. The ethanol flow may also be automatically controlled individually to each FBR in proportion to the feed flow to each FBR, which is the typical mode of ethanol flow control. Nutrient solution flow is controlled to each FBR in proportion to the feed flow to each reactor. The FBR vessels contain integral fluidization distribution and effluent collection systems. These internal components are designed to enhance uniform flow distribution. Microorganisms metabolize the ethanol solution and utilize the perchlorate, chlorate, nitrate and oxygen contained in the feed water. These contaminants are converted to harmless minerals in the process. The microbes form a film on the fluidized sand media.

As with virtually all biological processes, an excess biomass byproduct is produced. As biomass accumulates on the FBR media, the fluidized bed height expands. Some excess biomass is removed by the shear that is caused by the normal flow through the bed. Additional excess biomass is removed from the fluidized beds by operation of the Bed Height Control Pumps. These pumps are intended to operate continuously, taking suction from the top of the FBR media bed at the control bed height. The pumping action and flow through a throttling pinch valve at the pump discharge provide shear to remove excess biomass from the pumped media. The separated biomass exits the FBR vessels with the effluent and recycle streams.

The biomass control system also includes provisions for removal of excess biomass from a lower level within the fluidized bed. This system is operator-controlled based on the measured FBR bed height.

Media Separation

First stage FBR effluent flows to centrifugal cone bottom separator vessels. These vessels are designed to capture any media in the first stage effluent and recycle streams. The media return pumps operate on an automated cyclical basis to transfer captured media back to the FBR vessels. The bulk of the water entering the first stage separators is returned to the first stage FBR vessels as recycle. The balance of the water that enters the separators vessel exits to the second stage. First stage treated effluent is removed from the first stage system through level control valves that maintain the separators' water levels at the design set points.

Second stage FBR Treatment

Flow from the first stage system is typically equally split among the four second stage FBR vessels. The second stage FBR vessels contain granular activated carbon (GAC) media. Internal components include a fluidization flow distribution system, recycle and effluent collection systems, biomass separators and an "in-bed biomass control system". The biomass separators include provisions for collection and removal of separated excess biomass. This stream flows to the thickener by gravity at an operator-adjustable flow.

Second Stage Separators

Second stage FBR effluent flows to centrifugal cone bottom separator vessels. These vessels are designed to capture any media in the second stage effluent and recycle streams. Media return pumps transfer captured media back to the FBR vessels. The bulk of the water entering the second stage separators is returned to the second stage FBR vessels as recycle. The balance of the water that enters the separator vessels exits to the aeration vessel.

Aeration

Nitrate, chlorate and perchlorate are all reduced to effluent design concentrations in the effluent of the second stage FBRs. This stream flows to the aeration tank where fine bubble aeration is used to approach saturation concentrations of dissolved oxygen. The benefits of this aeration process include a reduction in the amount of high-pressure air required in the downstream DAF system, residual oxygen in the water for discharge, and partial oxidation of trace amounts of reduced sulfur that may be present in the second stage FBR effluent. The air effluent from the aeration tank passes through two biofilters prior to discharge to the atmosphere.

Dissolved Air Flotation (DAF)

Aerated water flows to the two DAF systems. The systems are operated in parallel. Flocculation is further enhanced by use of ferric chloride coagulant and a polymer solution that are metered into the liquid upstream of the DAF vessel(s). Coagulant and polymer flows are controlled in proportion to the total system feed flow as measured by the first stage FBR flow meters.

Float material is collected by a skimming mechanism that conveys the skimmed solids stream into a compartment within the DAF vessel(s). The accumulated skimmed solids are removed by automated cyclical operation of DAF float pumps. All float and settled solids are pumped to the thickener for further gravity dewatering.

Effluent Disinfection

DAF effluent flows by gravity into the effluent tank. From there it is pumped through a UV disinfection system, and is discharged under pressure through the effluent pipeline back to the Las Vegas Wash.

Secondary Streams

Thickening

The thickener receives the excess biomass stream from the second stage FBRs and the float and underflow streams from the DAF float pumps. Thickener feed enters a central flocculation zone or detention hood within the thickener. Flocculation is enhanced within the detention hood by variable speed flocculation mixers and provisions for polymer solution feed. Clarified liquid is pumped to the aeration vessel. Settled solids accumulate in the lower section of the thickener. This gravity-thickened stream is periodically pumped out by the thickener underflow pump to the solids conditioning tank and filter presses for further dewatering, or optionally to a truck loading connection for removal as a liquid suspension.

Solids Conditioning and Filter Press

The two filter presses operate as a batch system on a schedule established by the system operators. It is generally preferable to operate both presses in parallel during the batch process.

A predetermined volume of thickener underflow is pumped from the thickener to the conditioning tank. Ferric chloride solution and powdered lime from the hydrated lime storage silo are also added sequentially to the conditioning tank at predetermined dosages. The conditioning tank agitator mixes the suspension.

The conditioned suspension is pumped to the filter presses during the press operation cycle. Filtrate flows by gravity from the presses to the filtrate tank. This filtrate is recovered periodically by automated pumping from the filtrate tank to the aeration vessel.

Chemical Feed Systems

Trace Elements

A trace elements mixture is added to the feed to optimize the performance of the system. The mixture is fed into the feed stream from a separate tank.

Caustic Soda

Caustic soda is used for pH control within the FBRs. Eight electric operated diaphragm metering pumps are used to pump the caustic to each of the eight FBRs. The caustic soda flow to each FBR is controlled by pH sensors located in each FBR influent (i.e. combined feed and recycle) line.

Polymers

Both the DAFs and the sludge thickener use polymers for assistance in separating solids from the liquid stream. A dedicated polymer feed system serves each point of use. A polymer feeder, is used to mix the polymer with service water and to transfer the resulting polymer mix.

Nutrient

Nutrient for the biological reaction consists of a 39% urea/di-ammonium phosphate (DAP) solution. The nutrient is stored in a 4,100-gallon FRP tank. Eight electric operated peristaltic pumps are used to pump the nutrient to the eight FBRs. The rate of nutrient addition to each FBR is in proportion to the feed flow to each FBR, and is operator-adjustable.

Electron Donor

Denatured ethanol (190-proof) is used as the electron donor for the treatment system. The ethanol is stored in a 20,000-gallon double walled tank. Eight electric operated diaphragm metering pumps are used to pump the ethanol to the eight FBRs. The rate of ethanol addition to each FBR is in proportion to the feed flow to each FBR, and is operator-adjustable.

Ferric Chloride

Ferric chloride is used as a DAF coagulant and as a conditioning agent for the sludge prior to feeding the filter presses. It is stored in a 4,400-gallon FRP tank.

Hydrated Lime

The other conditioning chemical for the sludge is hydrated lime. The lime is stored on site in a 30-ton lime silo. The hydrated lime is fed to the conditioning tank in dry form using a screw conveyor.

Hydrogen Peroxide

Hydrogen peroxide is injected into the second stage FBR effluent prior to the aeration vessel. The addition of Hydrogen Peroxide is paced based on on-line sulfide measurement to oxidize residual reduced sulfur.

Utilities

Compressed Air

Compressed air is necessary to operate equipment and instrumentation. Two rotary screw compressors provide this air. These 50-HP compressors can provide 240 ICFM at 110 psig each. All air generated by the compressors flows into a 660-gallon air receiver. Two filters remove remaining water droplets and oil from the air exiting the air receiver. Taking a portion of the total air and drying it with a desiccant type regenerative air dryer, provides instrument air.

Process Air

A dedicated blower provides the process air required for the aeration tank.

Service Water

Treated effluent is the main source of service water for the treatment plant. The service water is tapped on the pressure side of effluent pumps prior to the UV disinfection system. This provides a service water loop at approximately 30 psig. Stabilized lake water is used as makeup to the service water loop. Stabilized lake water is used for the eyewash stations and safety showers within the treatment plant. The safety showers and eye wash stations have scald and freeze protection.

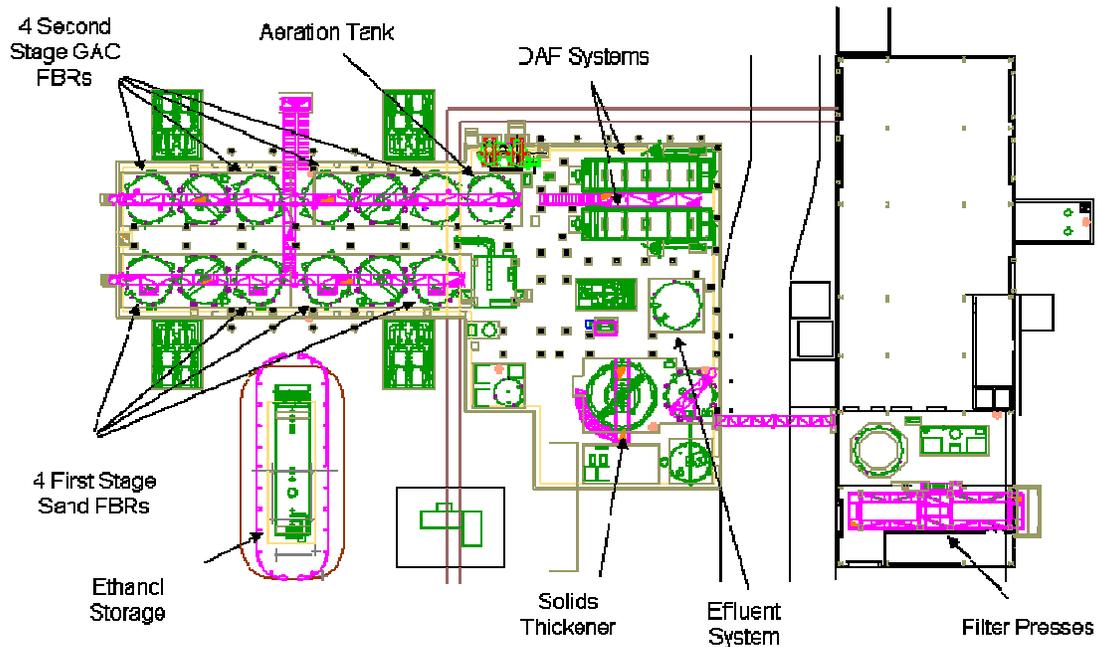
Electric Power

All power to run the equipment for the FBR treatment facilities comes from a motor control center (MCC). The MCC is located in a climate-controlled enclosure in the treatment plant area.

Control System Overview

The electrical control system contains a Siemens PCS7 system with Siemens PLC components. All I/O is contained in a cabinet with NEMA rated terminals for connection of field wiring. All automatic electrical devices (including motors) are controlled through the PLC, and displayed on screen. This includes approximately seventy (70) motors, approximately forty-five (45) 4-20 mA transmitters, and thirteen (13) 4-20 mA control valves. Manual controls are provided where required.

Figure 6. Treatment Site Plant



PROJECT IMPLEMENTATION AND OPERATION

Project Schedule Overview

- Began process design Dec. 2002
- Began laboratory pilot Jan. 2003
- Began civil & mechanical design May 2003
- Mobilized to the site June 2003
- Completed installation Dec. 2003
- Completed mechanical shakedown Jan. 2004
- Inoculated system and began groundwater treatment Jan. 2004
- Completed ramp-up of off-site well water and completely shut down Ion exchange July 2004
- Added on-site well water and pond water Sept. 2004
- Completed system acceptance test Nov. 2004

Project Team

The project team was made up of 4 companies - (1) Kerr-McGee who was the client, (2) Shaw Environmental who was responsible for the Process Design, Pilot, Mechanical Design, Reactor Supply, & Start Up Assistance, (3) US Filter who was

responsible for I & C Design, Aeration and DAF Supply, Start Up Assistance and (4) Veolia Water who was responsible for Civil Design, Construction, Balance of Equipment Supply & Plant Operation.

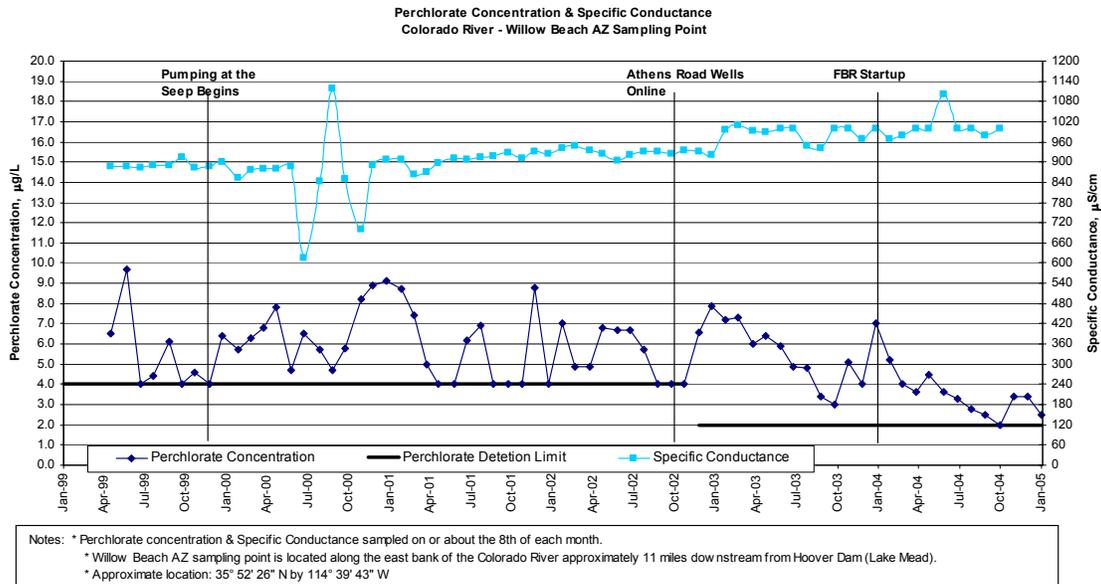
Progress to Date

By the end of 2004, the Kerr-McGee control strategy with biological treatment was completely place and operational. The FBR system currently treats all the captured well water and has begun treatment of the stockpiled water in the holding pond. The biological system treats approximately 1,000 gallons per minute of combined well and holding pond water, and has consistently discharged less than 18 parts per billion of perchlorate.

Effects on the Colorado River

Since implementing the control and treatment strategy in 1999, peak perchlorate concentrations along the Colorado River have dropped from 10 ppb to about 2 ppb. The most dramatic declines in perchlorate concentrations along the Colorado River occurred after installing the FBR treatment system (see Graph 1). Since initiating groundwater flow through the FBRs, the three lowest concentrations ever measured at the Willow Beach, Arizona sampling point, located below the Hoover Dam on the Colorado River, were from August through October 2004, at 2.8, 2.0 and 2.0 ppb, respectively. Further declines are expected.

Graph 1. Perchlorate Concentration at Willow Beach AZ Sampling Point



ACKNOWLEDGEMENTS

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REFERENCES

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