FULL-SCALE EXPERIENCE OF DIRECT OSMOSIS CONCENTRATION APPLIED TO LEACHATE MANAGEMENT

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SUMMARY: A full scale 150 m^3 per day leachate direct osmosis treatment system has been operating since June 1998 at the Coffin Butte Landfill near Corvallis, Oregon USA. A 9% sodium chloride solution flowing countercurrently on one side of a semipermeable cellulose acetate membrane extracts water from a less concentrated leachate stream circulated on the opposite side of the membrane. At typical leachate solution strengths, a concentration factor of 10-20 is achieved with DO, with permeate recoveries of 90% to 95%. A reverse osmosis system extracts the water from the brine, and the reconstituted brine is returned to the DO system. The quality of the resulting permeate is improved by using second and third pass RO systems. The final permeate is aerated and then applied year round to a 6-hectare fir plantation for overland flow polishing treatment. The final effluent has consistently met stringent permit limits, which are based on State and Federal ambient chronic fresh water quality standards. Concentrate is solidified using fly ash and Portland cement and returned to the landfill in a solid form.

1. INTRODUCTION

The Coffin Butte Landfill, owned and operated by Valley Landfills, Inc. (VLI), accepts over 1,200 tons per day of municipal and industrial non-hazardous waste. It is located in the Pacific Northwest of the United States, in an area with a coastal maritime climate that receives more than 1,400 millimeters per year of rainfall. For this reason, control of leachate is particularly important. Except for the active area of waste placement, the landfill is covered with high-density polyethylene geomembrane that reduces rainfall penetration into the solid waste. Nonetheless, between 20,000 to 40,000 M^3 per year of leachate are generated by the landfill.

Historically, this leachate has been stored in a 75,000 M^3 open surface holding pond over the wet winter months, upon which 15,000 to 30,000 M^3 of additional rainfall falls, which increases the ultimate volume of leachate. During the dryer summer months, the raw leachate/rainwater from the pond was irrigated onto hay fields. The high nitrogen content in the leachate has been a limiting factor in using the permitted irrigation fields, and the Oregon State Department of Environmental Quality (DEQ) indicated that irrigation of leachate without pretreatment would need to be phased out. As a result, in 1995 VLI began evaluating methods to treat landfill leachate as an alternative to irrigation.

1.1 Identification and Evaluation of Leachate Management Alternatives

A survey of leachate treatment methods used by other landfills around the nation indicated that the preferred alternative for most landfills is to discharge their leachate to local publicly operated treatment works (POTW), when that option was available. Although the Coffin Butte Landfill is located outside any municipal sewer service area, this option appeared reasonable for VLI to explore as well. Two local POTWs and one industrial treatment system at a near-by pulp and paper mill were evaluated. After further investigation, none of these off-site options were found to be either politically or technically unacceptable.

Without off-site options, the focus of necessary turned to on-site alternatives. In considering these alternatives, it was first necessary to define the treatment goals for removing pollutants from leachate. Leachate contains four general types of pollutants:

1. Organic pollutants that create a biological oxygen demand
2. Dissolved heavy metals
3. Nitrogen (organic and inorganic)
4. Inorganic dissolved salts, other than heavy metals, such as sodium chloride/ bicarbonate

Most leachate treatment systems that have been employed in the United States focus on the first three parameters. They have almost no treatment effect on inorganic dissolved solids, and in some cases even increase the dissolved salt concentration. Yet it is the dissolved salts that are the most easily detectable signs of leachate impact in ground water monitoring wells. In addition, the DEQ guidelines for treated water discharges in the Willamette River basin are extremely stringent for dissolved salts. VLI set a goal to significantly reduce the loading of dissolved salts to the environment for the onsite treatment options.

Only two general types of commercially available treatment systems are able to remove salts from a wastewater stream: evaporation and osmotic membranes. The climate of Western Oregon prevented use of year-round leachate recirculation or direct solar evaporation. The purchase of natural gas or electricity to evaporate the annual leachate volume to the atmosphere was not economically feasible. The methane generated by the landfill had already been contractually obligated to a third party for use in electrical power generation and therefore was not available for leachate evaporation. Therefore, atmospheric evaporation was not an option.

A comprehensive evaluation was performed of vendors that could meet the treatment goals. Applicable technologies included reverse osmosis (RO), direct osmosis (DO), and vapor recompression mechanical evaporation. Detailed technical and cost evaluations of 21 options using technologies from seven different vendors were performed. Discharge alternatives included storage of effluent during the winter and irrigation during the summer onto hayfields or trees, year-round direct discharge to surface water, or combinations thereof.

Residuals from all the options would result in a concentrated liquid/brine representing from 5 to 25 percent of the original volume, and containing nearly all of the original pollutants present in the leachate. The only viable alternative for managing these residuals is to solidify the material so that it would pass the paint-filter test for on-site disposal back in the landfill. In addition, the solidified concentrate would be stabilized so that the pollutants would have a low potential to leach out again. Methods for solidifying the concentrate ranged from heat-assisted drying, to bulking with dry additives such as waste ash.

1.3 Mechanical Vapor Recompression Evaporation Pilot Testing

A detailed pilot study was performed with a leading mechanical evaporation vendor who had recently installed an evaporator for leachate from an ash landfill. The results of their study indicated that the forced circulation, falling-film evaporator could successfully treat leachate and could achieve high (20X) concentration factors if operated in the seeded-slurry mode. However, the cost of their proposed system was significant. In addition to cost, other considerations were:

- The system cannot be easily expanded or contracted without significant expense.
- Additional treatment would be needed to treat the distillate, which would still contain volatile constituents, such as ammonia and certain organics.
- Lack of full-scale experience on municipal sanitary landfill leachates.

These considerations led VLI to focus exclusively on membrane-based technologies.

1.4 Membrane Pilot Testing

Three membrane-based technologies were selected to operate pilot treatment units at the site, including disc-tube RO, tubular RO, and DO. The RO-based technologies were selected based on full-scale experience in Europe. For brevity, only the DO results are summarized in this paper.

The DO pilot testing occurred in stages over a 3-month period. Leachate directly from the landfill was processed during the first half of the test. During the second half of the test, concentrate from the tubular RO system was further concentrated by the DO system.

A summary of flux performance over time at various feed conductivities for the DO membrane is shown on Figure 1. Limitations in liquid holding volume prevented run times for each stage to exceed 3 to 5 days. Flux decline was not apparent during the early part of the test, during individual stage processing. Leachate was concentrated to 94 percent permeate recovery.

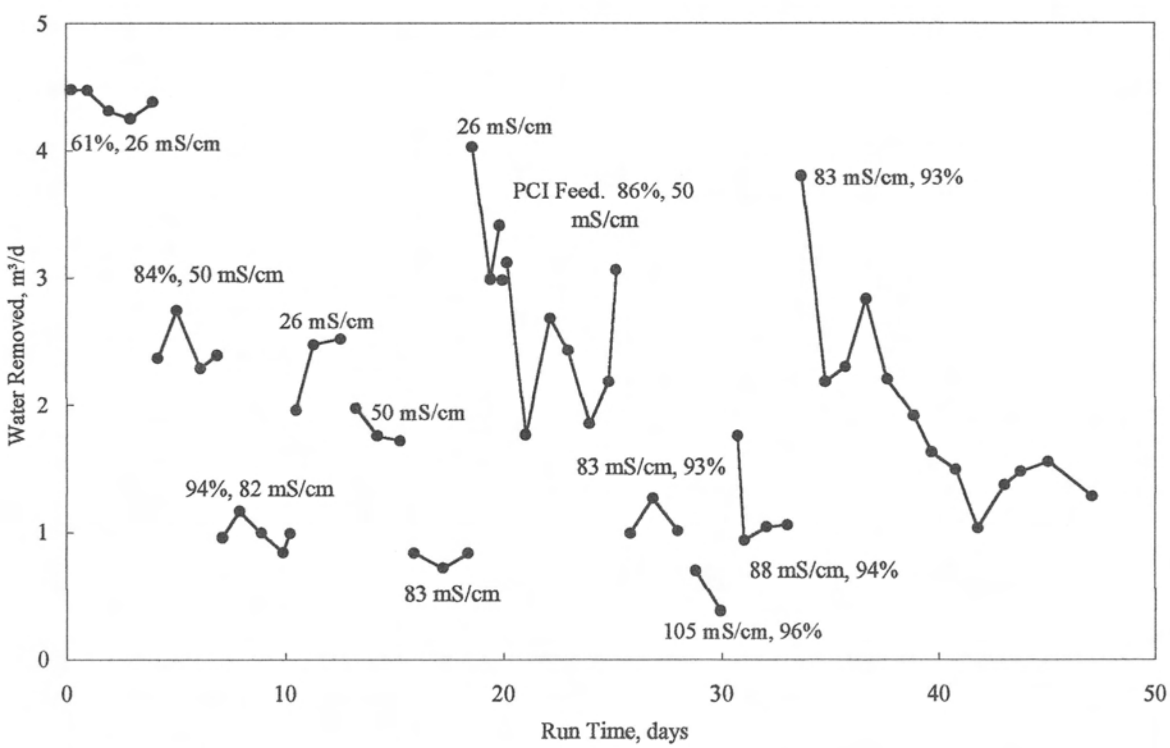

Figure 1. Water Removed Each Day by DO Pilot Plant
(Percentage recovery and final concentrate conductivity set point shown)

Flux decline became apparent on the direct osmosis membrane once the second set of raw leachate was processed. These runs showed fluxes only 50 to 70 percent of the flux during the first run.

Cleaning of the DO membrane occurred only once during the pilot trial. Limited data suggested that flux restoration was complete. The first pass spiral wound RO membranes were never cleaned, but were oversized and did not need cleaning. Flux decline was reported, but the membrane was never cleaned. Down time was limited to anomalies of the pilot plant and occasionally to weekend operator availability. Final permeate quality remained excellent throughout the duration of the tests. Concentration factors (based on original raw leachate) of 94 to 96% were achieved.

After pilot testing was complete, each of the vendors submitted technical and cost proposals. After an analysis of vendor proposals, the standalone DO option was selected for leachate treatment. This selection was based on a number of factors, including price, life cycle cost, vendor responsiveness, and demonstrated ability to process leachate during the pilot testing.

2. FULL-SCALE DIRECT OSMOSIS-BASED SYSTEM DESCRIPTION

Figure 2 shows a block flow diagram of the full-scale treatment system. The sections below describe individual system components.

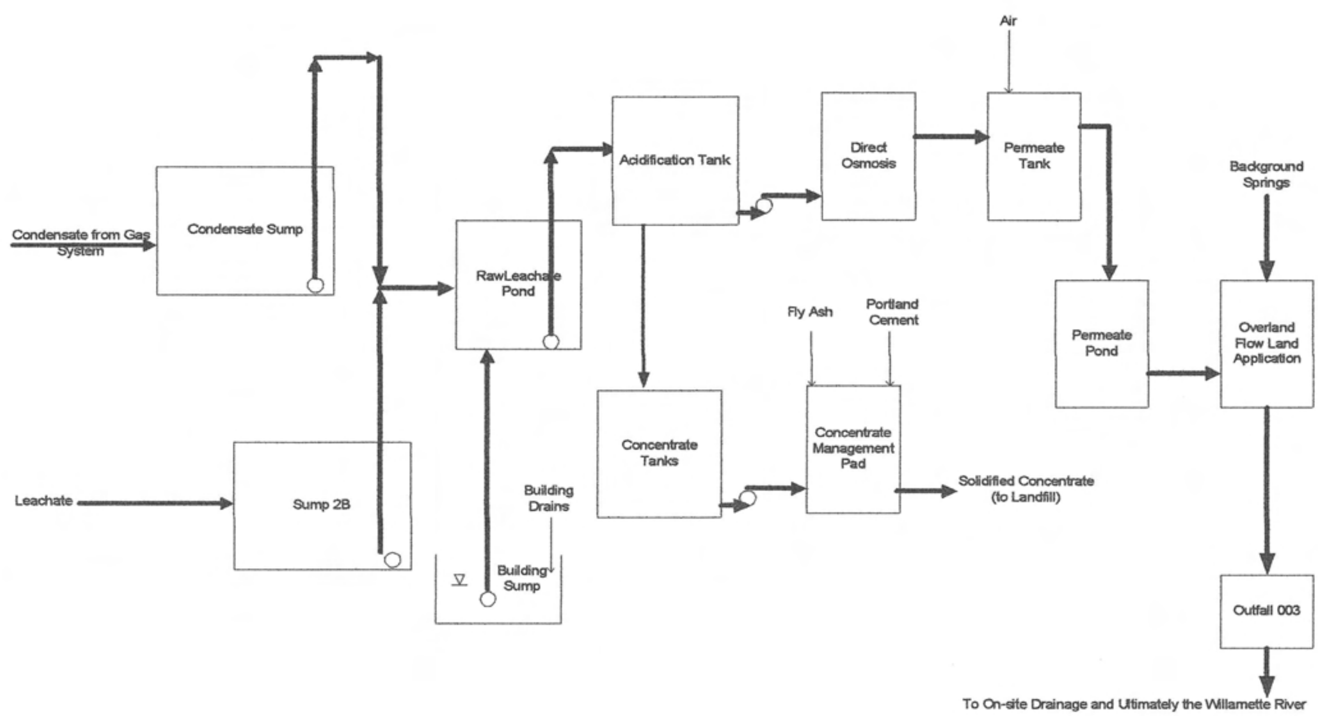

Figure 2 – Block Flow Diagram – Full-Scale Leachate Treatment System

2.1 Leachate Collection

Leachate is collected in the landfill from multiple sumps. Condensate from the landfill gas system is collected separately and treated with the leachate. Each sumps contains duplex electrically driven pumps, with alarm system provided to prevent overflows or spills. High-density polyethylene pipe is used throughout the system to convey leachate and condensate to raw leachate storage.

2.2 Raw Leachate Storage

A 0.5 hectare double lined HDPE surge pond is located near the leachate treatment facility. The 15,000 M^3 surge pond is designed for automatic operation. Dimensions of the pond are 120 by 40 meters. The depth of the pond varies from 7.0 to 7.6 meters deep, including freeboard.

The surge pond is equipped with a leak detection system. The leak detection system will detect leakage, if any, through the primary liner, and prevent leakage from reaching the environment. The surge pond is also equipped with a unique membrane cover, kept buoyant by a fan that pressurizes air into the space between the cover and the pond. This cover prevents rainfall from falling on the stored leachate, minimizing volume.

2.3 Acidification and Feed Tank

Leachate is pumped to the 5 M^3 Acidification and Feed Tank, a mixed, high density polyethylene (HDPE) tank located in a contained and covered area immediately adjacent to the Leachate Treatment Building. Hydrochloric acid (an aqueous solution of 32 percent HCl) is added using air diaphragm pumps based on the pH of the contents of the tank. Acid is required to prevent calcium carbonate scaling, as the leachate is concentrated. The pH set point is 6.0.

2.4 Direct Osmosis Concentration (DOC)

The acidified leachate is pumped from the Acidification and Feed Tank to the DOC System for processing. There are four separate DOC lines, each containing 426 DOC membranes divided into six modules. Each line is fed leachate with a separate 110 liter per minute feed pump. Each feed pump sends acidified leachate through a 50-micron bag filter to an ovehead break tank, which feeds the first of the six DOC modules.

Clean water extraction of the leachate begins by osmotic separation of the clean water molecules from the pollutants in the leachate across the DOC membranes on each plate-and-frame rack. Concentrated sodium chloride brine (also called osmotic agent or OA) is circulated on one side of the membrane, while leachate is circulated on the other side. Since the OA has a much higher ionic concentration than the leachate, water molecules are drawn into the OA by the natural osmotic gradient. The membrane pores are molecularly sized such that the water molecules can pass while ionic molecules are rejected. On the average, roughly 90-95% of the original leachate water volume passes through the DOC membrane and become clean permeate, leaving 5 to 10% of the water volume with essentially all the pollutants (called concentrate).

As the system concentrates the leachate, it passes by gravity from the first DOC module to the second and so forth, through the sixth and final module. Each of the 24 DOC modules is equipped with a 1,140 liter per minute recirculation pump. Recirculation at this rate maintains high leachate velocities in the DOC module, to reduce fouling potential.

A "Metering Out" air-diaphragm pump is located at the sixth and final DOC module. This pump extracts concentrated leachate from the recirculation loop based on conductivity measurements taken within the loop. The concentrated leachate is sent to the concentrate tank.

Each break tank has an emergency water make-up system, which supplies water based on loss of power or loss of feed. A low level in the break tank opens an emergency water valve. If the water supply is interrupted, a "low level switch" in the emergency water tank shuts down the DOC line. All recirculation pumps and the OA feed pump stop, and all the OA is discharged from the DOC modules to the brine sump. Discharging the brine halts the osmotic action, which stops the concentration of leachate. Upon loss of power, the brine sump valve fails open, also stopping production of concentrated leachate. From the headers, OA is conveyed through the piping into the brine sump.

OA is recirculated from a 23 M^3 HDPE OA tank through each of the four DOC systems countercurrent to the flow of leachate. In this way, the most concentrated OA is concentrate the most concentrated leachate, which optimizes performance.

Acid is added to the OA tank contents to keep pH of the OA within specification. A signal is sent from the recirculation piping to an acid metering pump to control the rate of acid addition.

2.5 Reverse Osmosis (RO) Systems

As the OA extracts water from the leachate, OA becomes more dilute. The RO system extracts the water from the OA and returns the more concentrated OA to the OA tank. The RO system consists of two separate Pass 1 units. Extracted water from both Pass 1 units, called Pass 1 permeate, is sent to the 11.4 M^3 Pass 1 permeate tank, from which it is treated in a Pass 2 RO system. The extracted water from the Pass 2 unit, called Pass 2 permeate, is sent to the 11.4 M^3 Pass 2 permeate tank. Concentrate from the Pass 2 RO system is returned to the OA tank.

Permeate from the Pass 2 RO system is further treated in a Pass 3 RO system. The extracted water from the Pass 3 RO unit, called final or "polished" permeate, is sent to the 38 M^3 Polished Permeate Tank. This permeate has thus passed through four membranes, (one DOC membrane and 3 RO membranes) before becoming polished permeate. The total dissolved solids (TDS) concentration of the final permeate is consistently less than the regulatory limit of 100 mg/l.

2.6 Control and Telemetry

The entire DOC system, as well as most ancillary equipment, is automatically controlled by a Siemens distributed control system (DCS). The Siemens Central Processing Unit (CPU 315-2 DP) allows the system to operate automatically, and to shut down if abnormal system performance occurs. The system is accessed by a human-machine interface, which is essentially a personal computer (PC). The Siemens WinCC software program is installed in the PC and provides the operator interface and extensive data logging capabilities. Averages of several variables are saved every 15 minutes and once a day. TeleDac's WIN911 interfaces with WinCC to annunciate alarms. WIN911 displays the alarms on the screen, pages the in-plant operator or on-call personnel, and calls the operator by a phone that can be heard in the plant. Paging is either by alphanumeric messages or numeric messages. An operator can call in and determine which conditions are alarmed through a Specter Instruments Voice/Dialer card in the PC. Remote access to the operator interface and the Siemens Step 7 ladder logic program is obtained via Symantec's pcANYWHERE 32.

2.7 Overland Flow Polishing Treatment

The final permeate is held in a 1,500 M^3 aerated pond before being pumped to a 6 hectare Douglas fir plantation. Beneficial reuse of the water via natural transpiration occurs during warmer months, and additional natural treatment of the permeate occurs during winter months.

3. FULL-SCALE SYSTEM PERFORMANCE

As of the end of March 1999, the treatment plant had treated over 18,500 m^3 of leachate, achieving an average permeate recovery of 91.9%. The RO system has consistently produced a permeate that has met permit requirements, averaging a final conductivity of 35 µS/cm.

A set point of 85 mS/cm for the concentrated leachate has been shown to give consistent production rates. The first pass RO produces OA averaging about 110 mS/cm, or about 7.5% NaCl by weight, using a feed pressure of 8.1 MPa. Currently, the leachate temperature rises about 25°C due to the energy added by the leachate recirculation pumps and the high-pressure RO pumps. Higher conductivity set points for the concentrated leachate can increase the OA temperature higher than that desired to avoid RO element compaction.

An interesting anomaly is that increasing the set point of the concentrated leachate does not significantly reduce production. It appears that removing more water from the most concentrated leachate would slow production; however, the increase in residence time in the final DOC stage causes the temperature of the leachate to increase. This hotter leachate increases the temperature of the OA, which increases the removal of water in the downstream stages. The warmer OA also increases the RO throughput, raising the concentration of the brine. Lowering the set point has the opposite effect, where production can actually decrease when attempting to remove less water from the leachate, because the entire plant runs at a lower temperature. For this reason, a heat exchanger will be added in mid-1999 to transfer heat from the final permeate into the raw, leachate, allowing higher water removal rates at better recoveries during the cooler, wet season.

Contaminant build-up controlled in the OA by sidestream nanofiltration (NF). The small system averages about 6 liters per minute permeate of a nearly pure NaCl solution. The retentate is returned to the leachate surge pond and is reprocessed through the system.

Table 1 – Full-Scale Raw Leachate and Final Effluent Quality

		Raw Leachate		Final Effluent		Max Day. NPDES
Parameter	Units	Average	Maximum	Average	Maximum	Permit Limit
Cadmium	µg/l	4.0	5.0	0.036	0.06	1.8
Chromium (VI)	µg/l	123	175	0.48	1.4	16
Copper	µg/l	18	83	1.7	14	18
Lead	µg/l	5	20	0.08	0.33	5.3
Zinc	µg/l	182	306	1.8	8.4	120
Ammonia Nitrogen	mg/l	265	406	0.8	2.3	2.8
CBOD-5 #1	mg/l	Not measured		3.1	5.0	45
Chloride	mg/l	Not measured		7.9	28.2	378

4. CONCENTRATE MANAGEMENT

Disposal of the concentrate from the treatment system is a significant cost element of overall leachate management. A bench-scale study was performed to evaluate various combinations of drying and stabilizing materials that could be used to solidify the concentrate. Combinations of locally available different solid materials, including Portland cement, cement kiln dust waste fly ash, quick lime, silica fume, bentonite, and other commercially available agents, were mixed in varying proportions with the concentrate, allowing estimates of material quantities, costs, physical properties, and volume.

A full-scale trial was then performed using one of the favored mix designs (a combination of Portland cement, fly ash, and waste silica fume). The dry materials were hand-loaded onto a conveyor belt that fed a concrete mixing truck. The concentrate was pumped directly into the fill hopper of the truck. Approximately 5 M^3 of solidified concentrate was prepared in the field trial.

A sample of the solidified material was subjected to a Toxicity Characteristic Leaching Procedure (TCLP) test to determine whether it would be considered hazardous. All tested parameters in the extract were below the limits for hazardous waste classification.

Based on the successful bench and field trials, the Owner constructed a full-scale concentrate solidification area consisting of the following elements:

- A 39 meter x 12 meter x 150 millimeter thick concrete pad underlain by a PVC liner and liquid collection system, sheltered from rain with a 6.4 meter high metal roof.
- A 50-tonne cement silo.
- A 2.2 M^3 concentrate holding tank.
- A fixed conveyor belt to deliver solid material directly to the fill hopper of the concrete truck.
- A small loader that delivers solid ingredient(s) from bunkers to the conveyor belt feed hopper.
- A concrete mixing truck.

The concentrate, cement, and other dry materials are added in predetermined proportions to the concrete mixing truck. The truck mixes the materials for a minimum of 5 minutes before leaving the concentrate pad and then for another 10 minutes during its drive to the landfill working face, where it discharges the mix into the landfill at the public tipping area. During a typical weekday, approximately 7.6 M^3 of concentrate is converted to 30 M^3 of solidified concentrate. Typically, six truckloads of solidified material are landfilled each weekday.

5. SUMMARY AND CONCLUSIONS

Leachate is a highly variable feedstock that presents a particularly difficult treatment challenge, especially when the effluent quality needs to be better than drinking water. The unique situation faced by VLI required that exotic and relatively expensive treatment be used.

As measured by permeate quality and concentration factor, the new leachate treatment system has performed well. The system now operates unattended during evenings and nights. The system has garnered good acceptance from the regulators and the public. The leachate treatment operation continues to be optimized, with improvements now being designed to allow the system to better handle variability in leachate temperature and composition.