Proceedings of Heap Leach Solutions, 2015
September 14-16, 2015, Reno, Nevada, USA
Published by InfoMine, © 2015 InfoMine, ISBN: 978-0-9917905-8-6

Drying heaps, dumps and piles for closure

Thom Seal, University of Nevada, USA
Tim Kiley, University of Nevada, USA

Abstract

Meteoric water quality is often compromised when flowing through a man-made heap, dump or pile. Meteoric moisture resulting from material absorption of seasonal precipitation remains within the heap, dump or pile with no known method of moisture reduction, in some cases trapped within hundreds of feet of material. These solutions are often not compliant with the various clean water acts, and are not dischargeable. There are many options available to the operator of such a heap, dump or pile, including a variety of covers, such as soil, clay, liners, barriers, solution treatment, etc. These options are expensive: compliance guarantees are sometimes required for years and need maintenance, oversight and often continual reagent addition with respect to water treatment. If a better method existed that would ameliorate the likelihood of leached contaminants affecting drain water quality, the cost benefits could be immense.

Laboratory column experiments simulating in-situ conditions were conducted on various size distributions of rock material wetted to near the drain-down moisture to determine and model the effect of air flow through a post-stimulated heap, dump or pile to dry the material from "the inside out". The Hydro-Jex stimulation re-channels the solution pathways and opens voids connected to the well, allowing for an airflow path with mixing for a radius of up to 150 feet. Forced in-situ injected air circulation in a confined column experiment, measuring the changes in air (i.e. flow, temperature, and humidity) show a drying effect in a column of rock material surrounding a simulated well to below 3% moisture. One of the column zones described by a determined size distribution was dried to 2.2% moisture after being subjected to the circulating airflow for 135 days – a typical Nevada summer.

These experiments suggest that airflow through pipes in a column will dry out the heap, dump, or pile during the warm summer months in excess of the anticipated meteoric season. This method can reduce or eliminate the post-closure solution migration and preclude the need for a surface cover or a water treatment facility. If the moisture in the heap is maintained at less than 3% seasonally then a very precipitous winter season increasing the moisture of the heap, dump or pile from these low values to one greater than a typical drain-down is unlikely in dry climate regions like Nevada.

Introduction

In the spring of 2004 the first Hydro-Jex wells were placed in a mature Carlin-type heap leach pad outside of Carlin, Nevada and the effectiveness of re-leaching was realized (Seal, 2005). Since that time, hundreds of similar casements or wells have been stimulated, realizing millions of dollars in previously unrecoverable revenue for mining companies from stranded inventory in mature heap leaching operations across the central and western USA (Seal et al., 2011). Standard mild steel pipes were sunk and perforated as deep as 500 feet (Seal, 2007).

Thanks to the support of the mining companies operating in Nevada, author and principal investigator, Thom Seal, has been able to test a hypothesis of determining the effect in a laboratory setting of forced air circulation in a Hydro-Jex well, post-stimulation, for the in situ drying of mined material placed in piles. This new technology is called Dry-Jex™ for Drying during air inJection and exhaust.

A brief overview of the Hydro-Jex technology is presented as a platform for the Dry-Jex technology. As the material is stacked higher and a pile grows taller, the material settles and the voidage in the lower lifts compresses with a resultant lower permeability.

The Hydro-Jex technology was invented to mobilize the heap material in situ by injecting high pressure barren solution, which resulted in enhanced gold recovery. It is named for water chemistry (Hydro)-lixiviant solution inJection and metal extraction (Seal, 2004). The technology basically involves drilling and sampling a leach pile and installing a well with zone perforations. The zones are isolated using standard drill tools, and high-pressure solution is pumped in to open solution pathways and channels, achieving improved permeability and three-dimensional leaching (Seal and Fink, 2008).

In addition, any pumpable solution or slurry with reagents can be metered into a specific location in the interior of the heap to remediate any in situ adverse chemical conditions. The horizontal component of the solution profile ranges from a 30 to 48 m (98 to 157 ft) radius, depending on the depth of the targeted zone and the size distribution of the rock in the heap (Seal et al., 2011) (see Figures 1 and 2). In a typical Hydro-Jex treatment, 675 m^3 (24,000 ft^3) of solution is introduced to re-channel the material per zone, which creates a large void space. The zones of a typical Hydro-Jex treatment well are shown in Figure 3. Long after the stimulation, visible water vapor and moisture appeared in a freshly uncapped Hydro-Jex well.

Hypothesis

Normally air diffuses only a few meters into a heap in three years, depending on void space, as shown in Figure 4, which shows the vertical or horizontal depth of an air induced chemical reaction in a typical heap (Bartlett, 1998). Thus there is very little air movement in the interior of a pile. If there is a humidity and temperature differential with the outside air, vapor will "smoke" off the pile, as shown in Figure 5. Hydrogeology principles show that solution in a pile will continue to drain down until the forces of gravity equal the surface tension, thus yielding the drain-down moisture. Experimental tests and field experience have shown that due to capillary properties in small particles, the material will not dry further in the interior of a heap or pile post drain-down, unless an energy source or a change in differential pressure is applied. The solution retention and capillary rise is a function of rock particle size (Bartlett, 1998) (see Figure 6). Like an isolated saturated sponge post drain-down, adding a drop of water to the top will result in a drop of water flowing out of the bottom.

Figure 1: Hydro-Jex solution stimulation in a heap with horizontal mixing and channelling

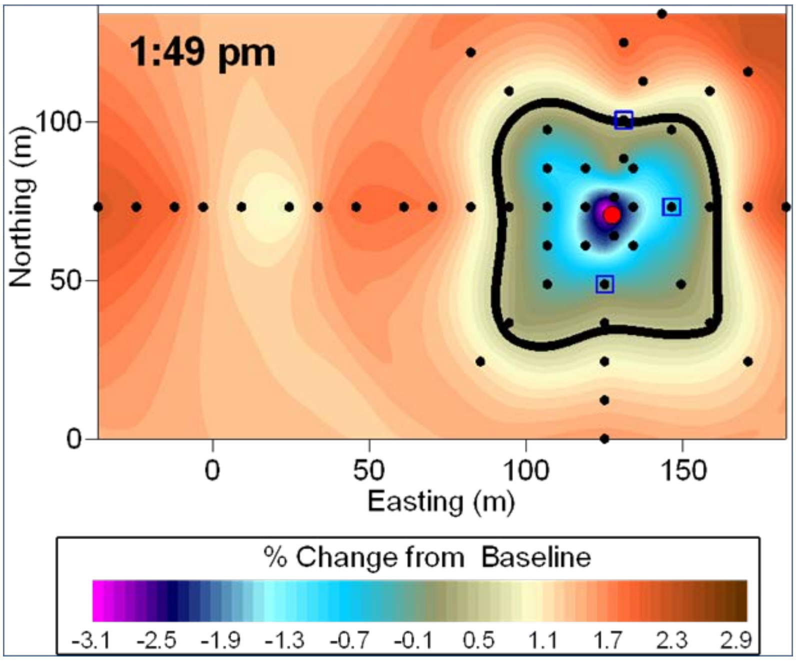


Figure 2: Hydro-Jex solution stimulation in a heap with horizontal mixing and channelling

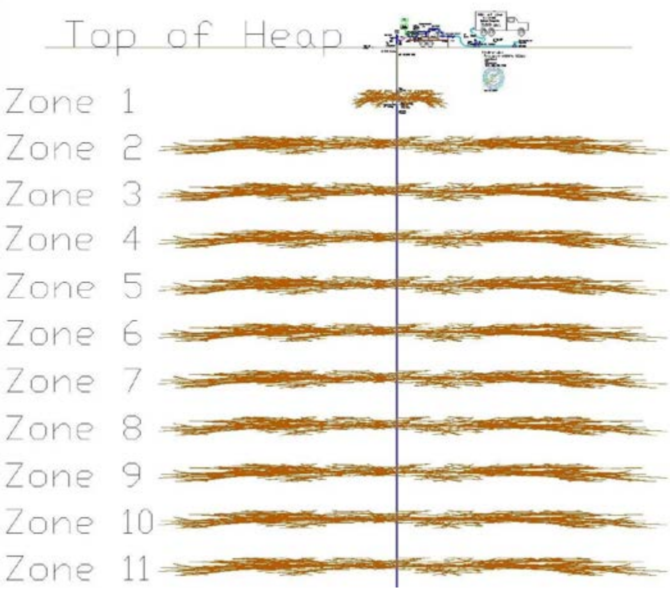
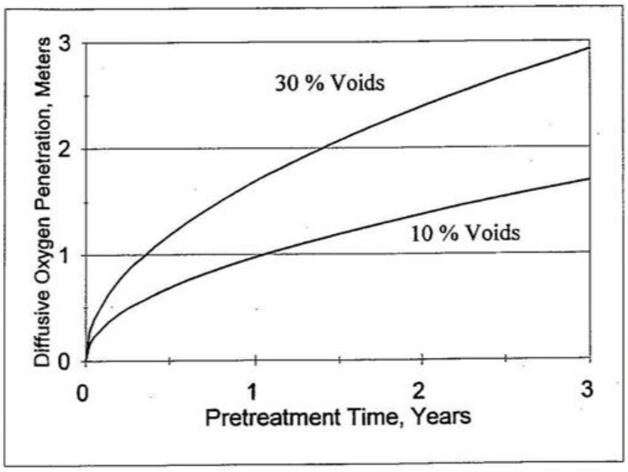


Figure 3: Hydro-Jex zonal treatment in an ore heap

Based upon these observations, it was hypothesized that a forced airflow initiated down the existing well casements post-stimulation, rinsing and during heap closure would impart an energy source of dry circulating air that could activate a drying effect across the layers of material among the opened zones created by Hydro-Jex technology. Though air could not be forced to flow into the fractures and micropores, enough drying of material in contact with the casement perforations and induced void space could initiate drying of material further out by diffusion and suction for perhaps the entire radial distance, thus creating the in situ sponge effect. If a sponge dries in air and regains its ability to absorb and hold water by drying out the capillaries, an ore heap or waste dump could similarly be seasonally dried across large sections of dumped material during warm, dry summer months, allowing it to absorb and retain winter and spring meteoric events, thus reducing, or alleviating altogether, the risk of meteoric water flowing out of the pile into the general environment and/or ground water reserves (Seal, 2014). If there is no water flow from a heap there will be no need for a water treatment plant. This technology can be applied to not only heaps, but waste rock piles and other stacked material found in an arid climate. With this technology, the need for soil covers (US Department of Energy, 2000) is all but eliminated.



Figures 4 and 5: Air diffusion into a heap and vapor smokes off a heap

The obvious logistical issue is: how does an operator force air to circulate down a post-stimulated Hydro-Jex, or other, well? The answer is by using a windmill. Many arid regions experience daily wind events during the heat of the day. This natural cycling of wind velocities with dry air is just the energy source needed to drive the circulation system to dry out the heap or pile. Relying on a natural energy source such as wind power will be inexpensive and efficient, and will require a minimal amount of maintenance; thus it is practical. A typical vertical wind turbine (VWT) can be mounted on the top of a Hydro-Jex well. Often VWTs are limited in electrical production due to changes in wind velocity and resultant uneven electrical production, but with this application all wind velocities can be used to circulate dry air. Usually heaps have minimal wind obstructions, so the VWT will not need to have an elevated profile. VWT devices for this application are shown in Figures 7 and 8. This technology is currently patent pending.

Experimental design

In order to simulate field conditions as much as possible, waste material from the old Virginia City, Nevada Comstock Mine location was gathered and prepared by separation into size fractions and recombining into three distinct "zones" representative of size distributions found in ore heaps and waste dumps. The material acquired for the experiment by author and graduate student, Tim Kiley, had a large fraction of -200 mesh and so was adjusted as follows in Figure 9. Because of the size of the laboratory experiment, only the smaller size fractions of a typical crushed or ROM material were selected and proportioned, thus eliminating the larger material from the experiment. It is hypothesized that this smaller rock fraction will have reduced void space and thus reduced natural diffusion when compared to normal mine ROM and crushed material in heaps and piles. In addition, the smaller size fraction will have higher capillary properties and the clay particles will resist drying and thus inhibit the water vapor from migration and diffusing to the center well where air circulation occurs when compared to heaps.

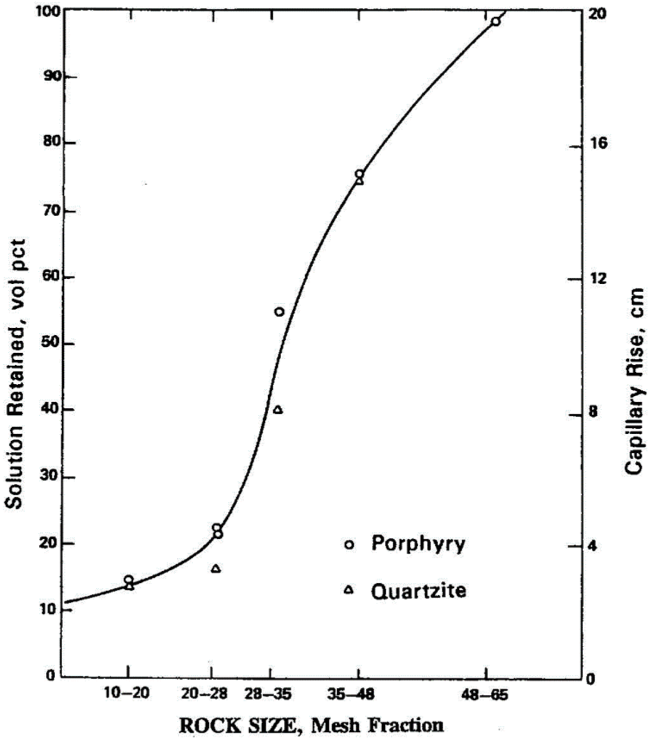
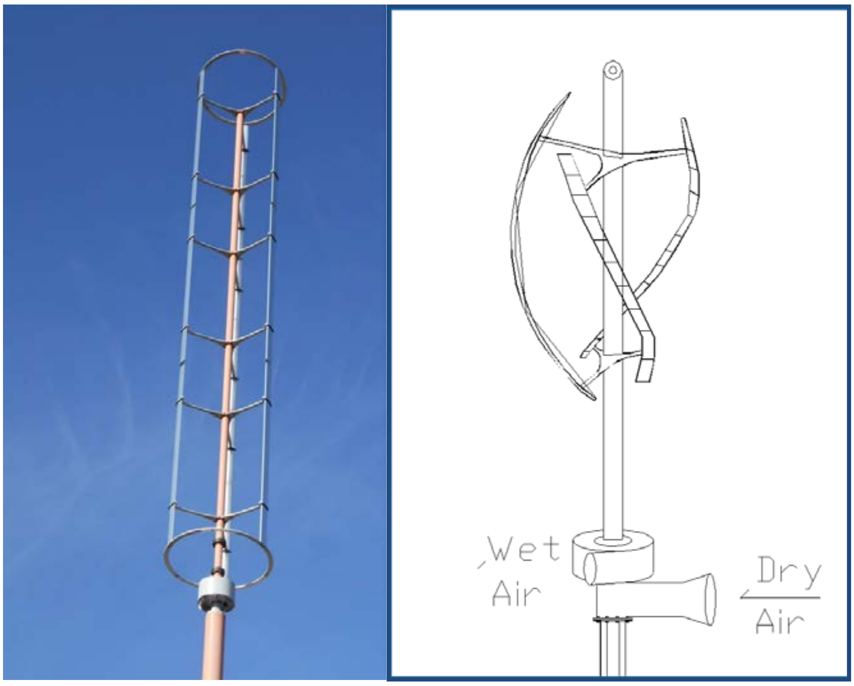


Figure 6: Solution retention, volume % and capillary rise for various rock sizes (Tyler mesh)



Figures 7 and 8: Vertical wind turbines for electricity generation and Dry-Jex design

The experimental results will be biased to a slower rate of drying when compared to field conditions of normal heaps and waste rock piles. Thus, any scale-up of this experiment to actual piles and heaps will likely show a shorter drying time (a faster drying rate) as a function of air circulation movement than observed in these laboratory experiments due to field higher intake air temperatures, void space, and lower relative humidity.

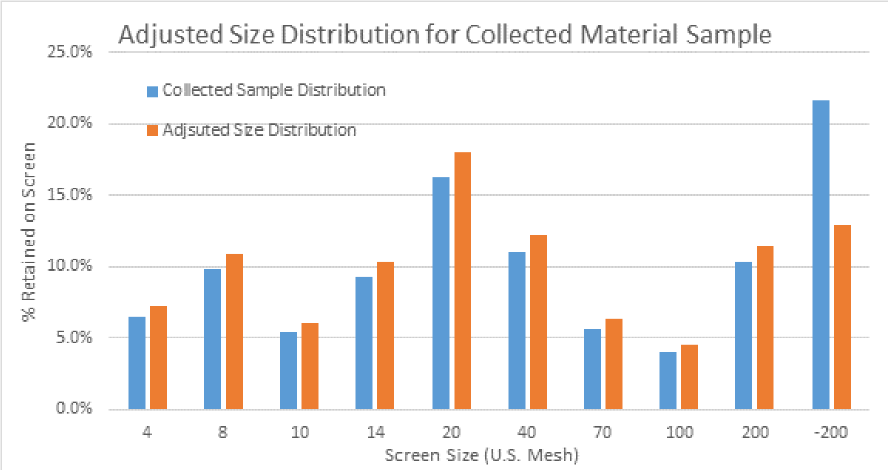


Figure 9: Initial size distribution of material and adjustment for Dry-Jex experiment

The composites created were based on standard (Tyler) sieve sizes in mesh, but due to the large amount of material to be separated into fractions, the Gilson TS-1 Test Screen (sieve shaker) was utilized and the standard mesh sizes adjusted to Gilson screen sizes available.

- Zone 1 Composite Specifications: -40 to +200 Mesh (Top Zone)
- Zone 2 Composite Specifications: -4 to +100 Mesh (Middle Zone)
- Zone 3 Composite Specifications: -4 to +40 Mesh (Bottom Zone)

Adjusted accordingly, the zone composites closely resembled, by similitude, a scaled down size distribution for fine crushed, crushed and ROM for the purposes of experimentation in the lab using a column. No agglomeration was conducted on the samples.

A representative sample of the material used in the experiments was analyzed by a stereomicroscope equipped with digital camera. Micropores in the larger sized fractioned particles were observed, as shown in Figures 10 and 11. The photographs show a degree of microporosity similar to a Carlin-type heap leach ore.

Figures 10 and 11: +4 and +8 mesh representative particle size showing microporosity

The material used in creating the zone composites had the following characteristics as measured and calculated using standard methodology: density of 2.2 g/cm^3; bulk specific gravity of 1.25; and voidage of 0.433 (Geiger and Poirier, 1973). Water drain-down tests for zone composites determined the following percent moisture values: Zone 1 – 21.55%; Zone 2 – 20.02; Zone 3 – 19.06%. These tests verified that the moisture of the material in each zone on loading of the column was close to the maximum saturated drain-down moistures of each zone.

Figure 12: Geo-composite cut to fit column

To simulate the radial voidage caused by the Hydro-Jex stimulation, standard layers of cut geocomposite "rounds" were placed between layers of the composite material, separating each sized zone into three layers, each zone separated by two layers of 6-mil visqueen plastic (see Figure 12). While the depth and placement of the layers and geocomposite sections did not exactly match the scale of the Hydro-Jex well, care was taken to select the radial distances from the small diameter pipe in similitude to provide substantiation for the hypothesis should some or each of the layers dry to a low percentage moisture from pipe to column wall.

To simulate the perforations cut into the casements at the Hydro-Jex sites, holes were drilled into a ½″ galvanized steel pipe that would serve for the in-column casement. The drill holes were spaced to accommodate 3″ layers of material and were covered with screen to further simulate the perforations in the Hydro-Jex casements. The comparison is shown in Figures 13 and 14. Hose clamps were placed below the drill holes to hold the geocomposite sections in place at the drill hole sites.

Figures 13: Perforations in a Hydro-Jex casement

Figure 14: Well perforations for simulated laboratory casement

A 3/8″ inch pipe was inserted into the 1/2″ pipe to serve as a drawtube for the flow of air down the annular area created by the combination of the two pipes. Negative pressure was induced at the top of the 3/8″ exhaust pipe using a standard 3″ bilge fan (Rule 140 Marine Bilge Blower) powered by a 12 V car battery, Figures 15 and 16. A system of reducers connected the fan to the top of the 3/8″ pipe as shown in Figures 15 and 16. A coupler was connected to the top of the fan and a 10″ extension was added on top of the coupler. Several variations of this configuration were attempted before arriving at an arrangement that gave maximum air speed at the extension end. In the final analysis, placing the air speed anemometer (ExTech model # 451126) between the coupler and the extension proved the best for maximum airflow through the system. See Figure 16.

In the first trial, simple gypsum soil moisture blocks (SMBs) were used to measure soil moisture and water potential changes. The gypsum blocks are actually designed to measure water potential or soil suction. The blocks were placed centered, one in each of the 3″ layers. Readings were taken on a digital soil moisture meter (SoilMoisture Equipment, Inc. model 5910-A) and were comprised of values between 100 and 0. After allowing the column to equilibrate for 24 hours the first readings were taken, 96-97 for Zone 1 with the highest initial moisture content and 94-95 for the other two Zones.

The interior of the experiment with the zones and circulating pipe is shown in Figure 17. For Trial #1 of the experiment only the gypsum-style soil potential sensors were used and were placed at varying distances from the wall of column, from within an inch and a half to centered in the layer and to 2 inches from the circulating pipe. The soil moisture sensors and digital soil water potential sensors were added for Trial #2. Holes were drilled to align with the center of the 3″ layer and the sensor wire was lead through the drill hole for connection to reading devices. The hole was sealed with silicone caulking to prevent exposure of the material to outside air.

Specifications for column construction (Figure 17):

1. The column measured 22″ in diameter, 34″ in height, a standard plastic barrel.

Figures 15 and 16: Lab experiment set up: isolated barrel with material in zones with drying fan

2. The central 1/2″ pipe is shown; the smaller, centered 3/8″ pipe is not.
3. The 3/8″ pipe extended 19″ above the top of the column to attach the ventilating components/fan system.
4. Double layers of 6 mil visqueen were used and a larger diameter double layer was stretched across the top of the column and taped to the outside column wall to further prevent evaporation from ambient air.

Measurements for airflow were taken at 12-hour intervals along with the soil water potential measurements in Trial #1. Initially over a larger diameter exhausting port five anemometer readings were taken, one at each quadrant with the anemometer vane at the edge of the exhaust component rim with a final measurement taken at the center. These were then averaged. The addition of a longer exhaust port halfway through the experiment allowed for a single reading due to complimentary diameters. For Trial #2 a laptop was purchased with digital software for the ExTech 451126 and continuous monitoring of the exhaust air speed was made possible.

Due to vagaries in the humidity readings for Trial #2 with the Campbell Scientific HC2S3 Temperature-Humidity sensor, a regimen of taking manual humidity reading with the small weather station was implemented, as in Trial #1, at twice daily intervals. Later, the readings from both humidity sensors were correlated and a correction factor was determined that allowed measured moisture loss to fit with the before and after material experimental percent moisture findings.

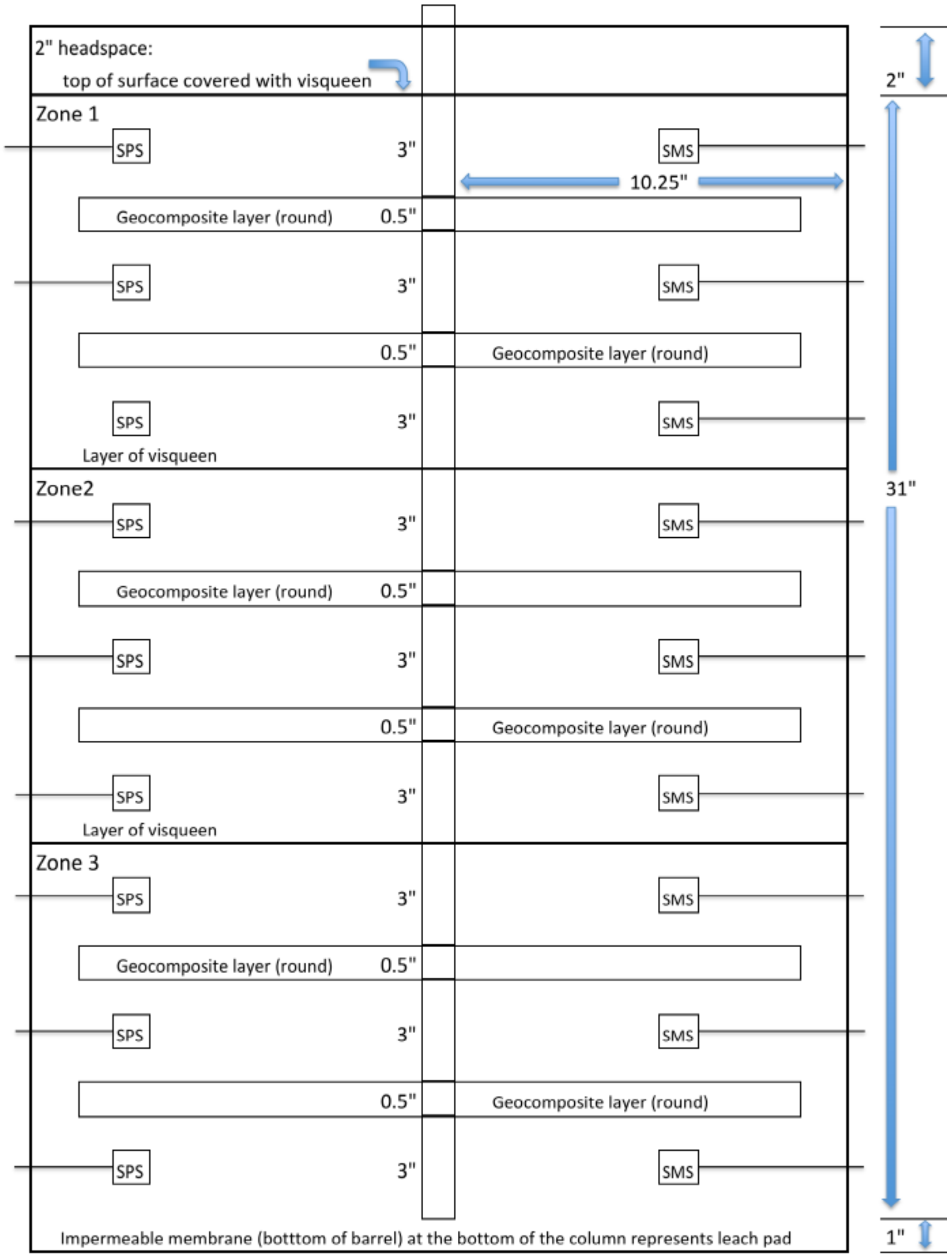


Figure 17: Drawing of experiment showing placement of SMS-soil moisture sensors, SPS-soil water potential sensors

Results and discussion

Table 1: Before and after % moisture content for Dry-Jex Column-Trial #1

Zone	% Moisture (initial)	Average % moisture (final)	Δ % Moisture (loss)
1	20.8%	4.0%	16.7%
2	16.8%	3.2%	13.6%
3	17.1%	3.4%	13.7%
All/Average	18.2%	3.5%	14.7%

At the final % moisture values all of the SMB readings were 0. Trial #1 was conducted over a 97-day period from April 11, 2014 until July 15, 2014. During the 97-day trial, the bilge fan burned out and a replacement was not available for three weeks. During this time the column was kept sealed and the pipes were capped. The total time for the trial, achieving the results described in Table 2, was 77.8 days. In both trials, moisture loss due to airflow drying proceeded from the topmost layer in the column to the bottommost, with some overlap, overlap increasing at the bottom three layers as shown in Figure 18:

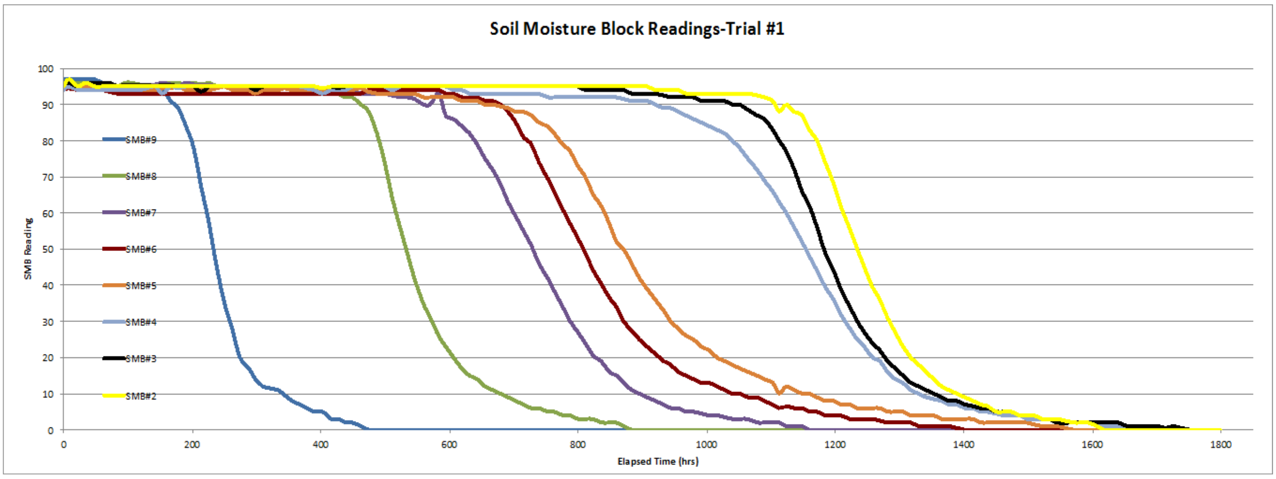


Figure 18: SMB reading vs time for Trial #1, showing decrease in material moisture

For the second trial, soil moisture and soil water potential sensors from Decagon Devices, Inc. were used in place of the SMBs. Data from the soil moisture sensors (SMSs, Decagon Devices, model 5TM) and the soil water potential sensors (SPSs, Decagon Devices, model MPS-6) were read and stored in a Campbell Scientific CR800 data logger, programmed to log and record volumetric water content (VWC) in cubic meters of water per cubic meters of material and soil water potential in kPa. Due to the sensitivity of the digital SMSs and SPSs, the second trial ran longer and achieved a lower final moisture content for the material in the column, Table 2.

Table 2: Before and after % moisture content for Dry-Jex column – Trial #2

Zone	% Moisture (initial)	Ave. % Moisture (final)	Δ % Moisture (loss)
1	19.8%	3.2%	16.6%
2	16.2%	2.4%	13.9%
3	18.3%	2.2%	16.1%
All/Average	18.1%	2.8%	15.5%

Though the logged data showed a significant amount of electronic noise, the potential readings observed in Trial #2 showed a similar pattern of drying in the column from topmost to bottommost layer in succession with overlap as shown below in Figure 19. Three of the SPSs showed a lot of electronic noise as the data was logged and graphed. Only minimal smoothing was done to preserve the integrity of the overall measurement structure.

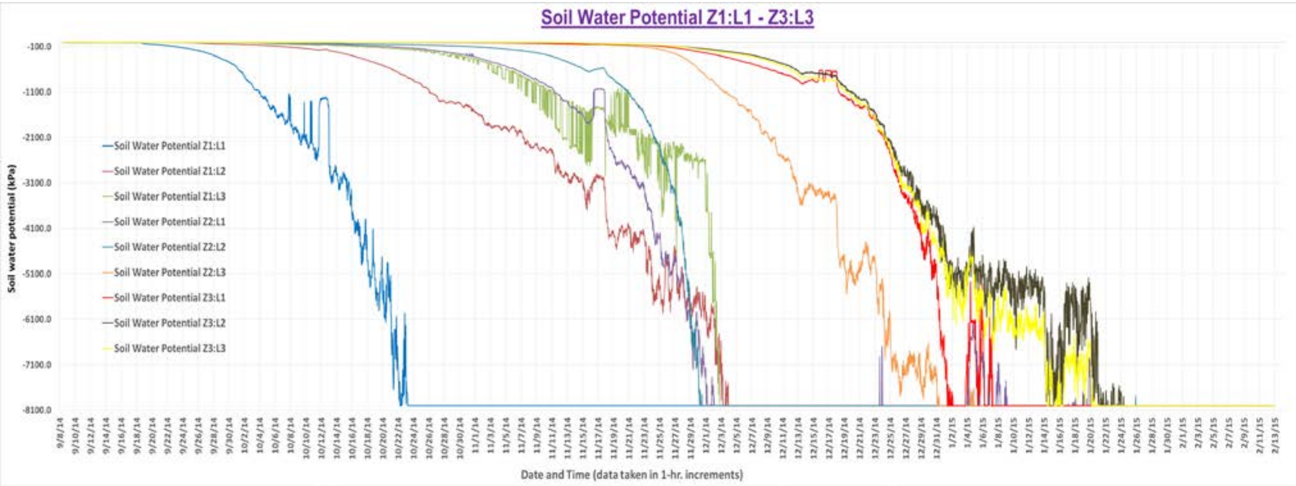


Figure 19: Soil water potential drops versus time for Trial #2

Due to the type of fan used and reducer/component configurations, variations in air speed were recorded. In Trial #1 the system was shut down for three weeks due to inability to replace the burned out fan in a timely fashion. During this time the reducers and other components were removed and the two pipes capped to prevent moisture loss while waiting for a replacement fan. Averaged air speeds versus time are graphed in Figure 20. Though the configuration of the reducers, fan and exhausting ports was kept the same for the times preceding and after the replacement wait-time, the air speed was significantly lower during the last three weeks of the trial. A similar average air speed graph was prepared for Trial #2, shown in Figure 21.

Using the air speed measurements taken through a known area – the vane of the ExTech anemometer - air flow by volume was correlated with intake and exhaust humidity levels to determine a second moisture loss rate, mass of water loss per volume of air by moisture content. These and a more basic rate in mass of water per unit time are shown below in Figures 21 and 22.

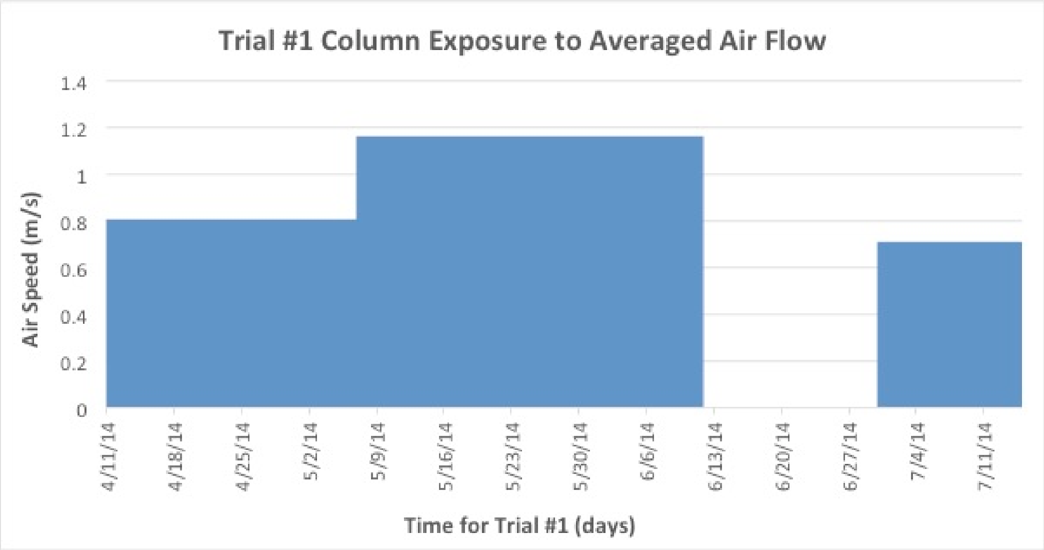


Figure 20: Average air speeds for the duration of Trial #1

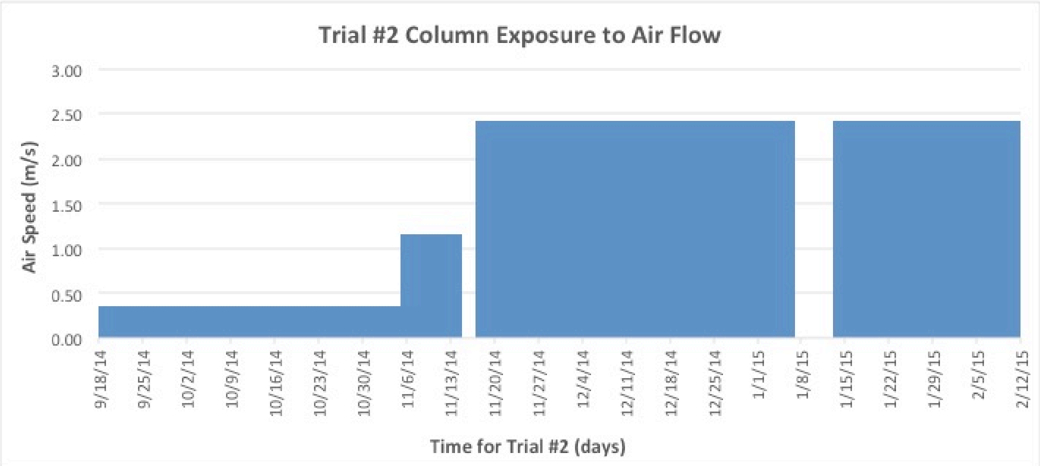


Figure 21: Average air speeds for the duration of Trial #2

During Trial #2, issues with the Zone 3 (bottommost) layers in the column arose, including moisture forced from the composite layers, likely due to compaction, impeded the air flow. The insertion of a Campbell Scientific Temperature-Humidity sensor in the exhaust port caused significant friction effects as well and for during the first month of Trail #2 these issues were ultimately resolved by experimenting with various configurations of the exhaust ports and sensor positions. Eventually the final configuration was adopted and the fastest air speeds of the two trials were realized. Most likely, due to this "slow start" Trial #2 ran 60 days longer overall than Trial #1.

In both trials, an unusually high rate of moisture loss was seen in the first layer followed reasonably similar and likely rates down the column. It is also significant that when the airflow increased the drying rates increased as well.

A possible mechanism by which moisture moved across the layers from column wall to exhaust casement is suggested in Figure 24 (Kiley 2015).

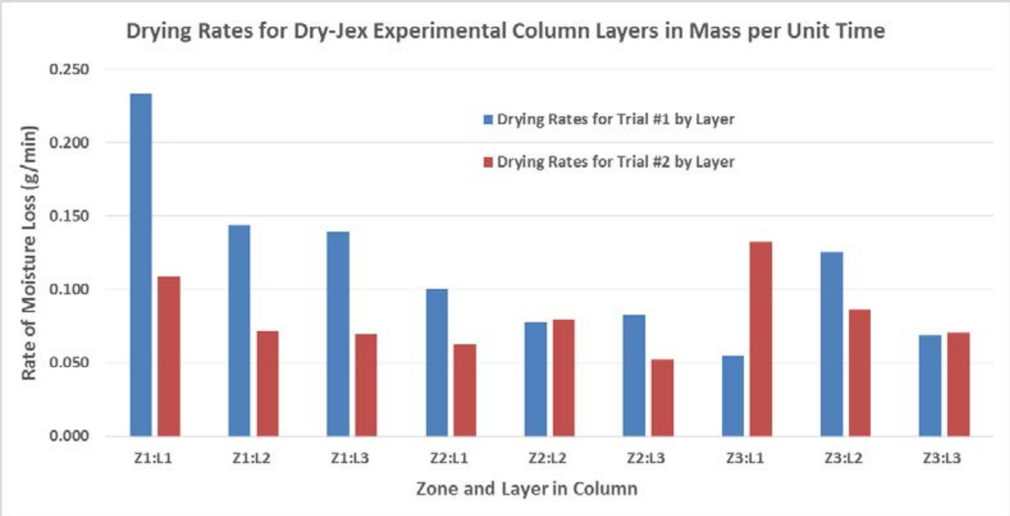


Figure 22: Drying rates for Dry-Jex trials in mass of water loss per unit time (g/min)

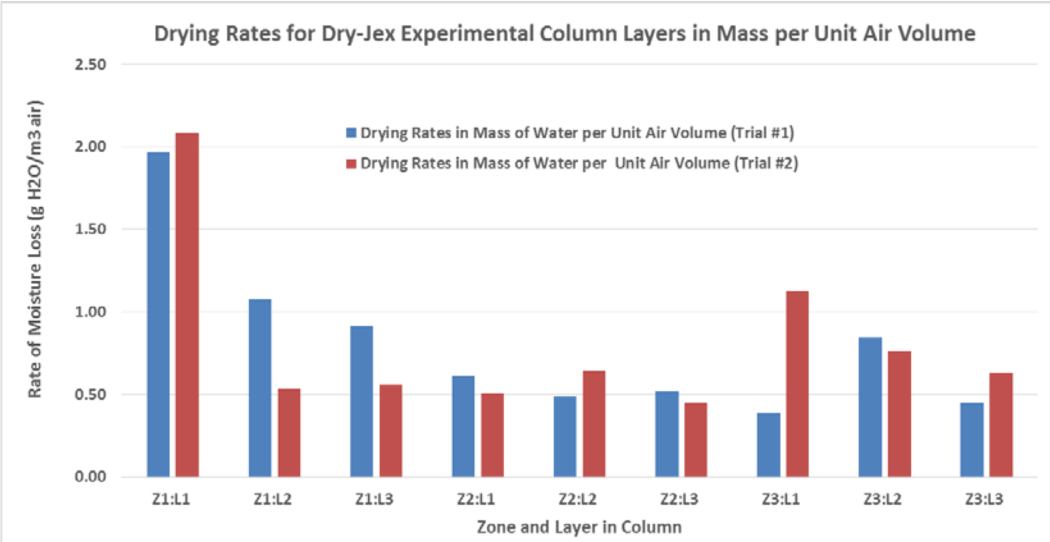


Figure 23: Drying rates for Dry-Jex trials in mass of water loss per unit air flow (g H_2O/m^3 air)

As material near the pipe dried, suction causes micro-evaporation above and below the geocomposite layers causing water in wetter, neighboring areas to transport across. Thus a "Zone of Influence" (ZoI) was created, likely in toroidal volumes, nearest to the pipe, initiating diffusive effects within each layer. Motion of water and micro-evaporation across the layer proceeded in horizontal flows towards this ZoI, rather than in vertical movement toward the geocomposite. Further testing would need to be accomplished using many microsensors along proposed pathways.

Nevertheless, it is clear that this kind of minimal, non-treated (ambient) airflow down a long pipe with only a small exposure to fractures in material can affect a large evaporative outflow of moisture from wetted material if sufficient void spaces connect the material to the well bore. The experiments conducted at UNR proved that forced dry air will dry a zone of material from the drain-down moisture to about 3% moisture. The applications to the mining industry for drying out heaps, waste dumps and piles could prove significant.

Conclusions and recommendations

Further design work is underway to maximize the VWT design and improve the efficiency of the Dry-Jex technology. There are new radical VWT designs that show simplicity and potential adaptability to the Dry-Jex system, which would be the best application for wind energy. The apparatus can be easily bolted onto a Hydro-Jex well head and can be constructed of recyclable plastic with natural brown, tan and light green colors to blend with the natural topography.

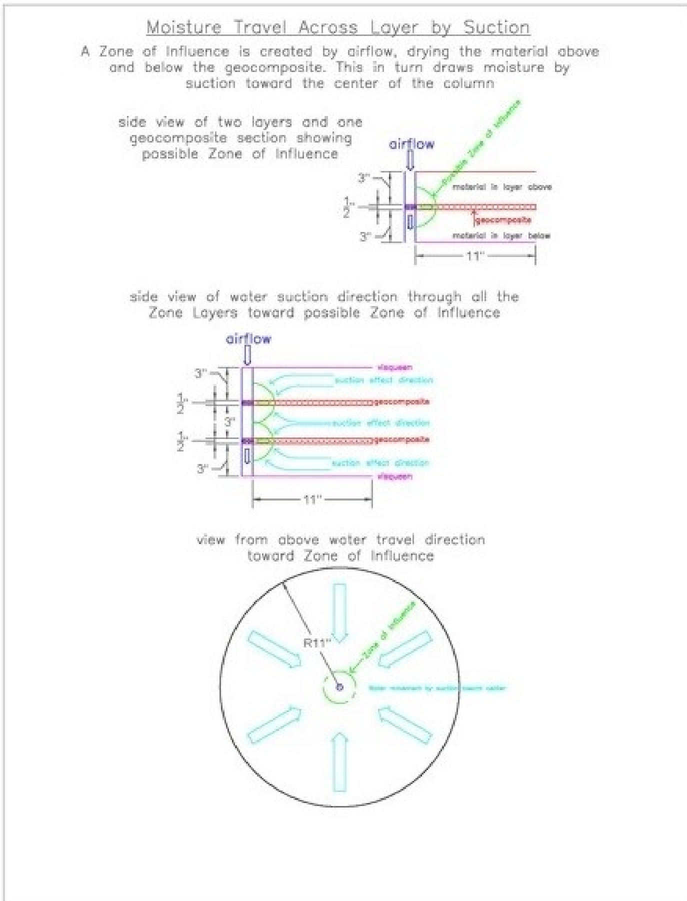


Figure 24: Moisture travelling across layer by suction

References

Bartlett, R.W. 1998. Solution mining, leaching and fluid recovery of material, 2nd edition, The Netherlands: Gordon and Breach Science Publishers.

Geiger, G.H., and Poirier, D.R. 1973. Transport phenomena in metallurgy, Reading, Massachusetts: Addison-Wesley Publishing Company.

Kiley, T. 2015. In situ moisture control by dry air circulation to ventilated heaps, dumps and piles for environmentally-sound reclamation: Dry-Jex (patent pending), a proprietary technology, Master's thesis, University of Nevada, Reno.

Seal, T. 2004 Enhanced gold extraction in cyanide heap leaching using Hydro-Jex technology, Doctoral dissertation, University of Idaho, USA.

Seal, T. 2005. Reduction of gold inventory in cyanide heap leaching, Society of Mining, Metallurgy and Exploration Annual Meeting. Englewood, Colorado: Society for Mining, Metallurgy and Exploration.

Seal, T. 2007. HYDRO-JEX: Heap Leach pad stimulation technology: ready for world wide industrial adoption, SME Annual Meeting. Englewood, Colorado: Society for Mining, Metallurgy and Exploration.

Seal, T. and Fink, J. B. 2008. Integrating hydro-fracturing technology and geophysics into 3D mapping and extraction of metals in heap leaching: Hydro-Jex and high resolution resistivity™, SME Annual Meeting: pp. 1–5, Englewood, Colorado: Society for Mining, Metallurgy and Exploration.

Seal, T., Winterton, J., and Rucker, D. 2011. Hydro-Jex © operations at Anglogold Ashanti's Cripple Creek and Victor Gold Mine, Society for Mining, Metallurgy and Exploration (SME): Annual Meeting. Denver, Colorado: Society for Mining, Metallurgy and Exploration, Inc.

US Department of Energy. 2000. Cover Alternative Landfill: Subsurface Contaminants Focus Area and Characterization, Monitoring, and Sensor Technology Crosscutting Program. Washington.