Consideration of Thermal Conditions in Year Round Heap Leach Operation in the Northern Desert Climates

Amy L. Hudson[1], Troy Meyer[2]

[1]Tetra Tech, One Monarch Drive, Suite 202, Littleton, Massachusetts, 01460, USA, amy.hudson@tetratech.com
[2]Tetra Tech, 120 West Park Drive, Suite 204, Grand Junction, Colorado, 80401, USA, troy.meyer@tetratech.com

Abstract Heap leach pad design and subsequent successful operation can be affected by many factors including material properties, ore grade, and climate. Often the climate component can be over looked, but in a northern desert environment that experiences extreme temperature shifts, the design must consider the pad thermal conditions not only for stacking, but also for solution application. The heap leach pad design and operational conditions for a project in northern Mongolia were developed through a combination of variably saturated flow modeling, thermal solution modeling within the heap, and thermal modeling of the solution pond. The project was constructed as designed, and has operated successfully using the suggested thermal conditions.

Keywords heap leach, modeling, unsaturated flow, thermal budget

Introduction

Modeling is often used during the design phase of a project to predict the operational and closure conditions of mining facilities. However, it is less common that the modeling results can be confirmed by the operations of the mine. This project used predictive modeling to design a heap leach pad and pond facility in the Selenge Province of northern Mongolia. The project is an operating gold mine that expanded their operation to include heap leaching, which allowed for the design to be implemented immediately, confirming the modeling results.

The location of the mine offers many challenges for designing the facilities due to the extreme climate of the mine. The temperature fluctuations from summer to winter can be from 40 °C to -40 °C. The goal of the mine was to be able to operate throughout the entire year, utilizing a heap leach pad to extract the gold. In order to accomplish this, the leach solution would have to maintain sufficient heat as it is applied to the facility surface, moves through the ore, and is temporarily held in the pregnant leach solution (PLS) pond. If too much heat is lost, the solution could freeze in the ore creating lenses of ice or rendering the PLS pond inoperable. In order to be conservative in the estimate of heat in the system, this study only considered the thermal conditions of the heap and the solution. Potential geochemical and biological heat sources were not considered.

The design parameters were determined through a series of models of the heap leach facility and the PLS pond. The models utilized were:

- Variably saturated flow modeling of solution application and flow through the heap;
- Thermal modeling of the solution application and transport through the heap; and
- Thermal modeling of the PLS pond.

Model Construction – Heap Leach Facility

VADOSE/W (GEO-SLOPE 2007), a finite-element model was used to simulate the fluid and thermal conditions of the heap leach pad. A combined variably saturated and thermal model was constructed for two cross-sections of the heap leach pad. Two cross-sections were used because of the geometry of the heap, which has areas that will be thinner and could be more susceptible to freezing than the thicker central portions of the heap. Fig. 1 presents the two cross-sections as modeled.

Conceptual model

Based on the design of this heap leach pad, the conceptual model is similar to other heap leach facilities. The water balance of the system consists of precipitation, evaporation, runoff, infiltration, and application of the leach solution. To prevent freezing of the emitter liners and the heap surface, the solution emitters were placed approximately 2.5 m below the top of the ore pile during winter operations to prevent freezing. Fig. 2 shows the conceptual model of the heap leach pad.

Modeling assumptions

As with any complex system, the modeling required some simplifying assumptions to complete the project. For this project, one of the key input parameters of the thermal modeling was the starting ore temperature of the heap. It was assumed that no ore would be placed on the heap during the winter months; however,

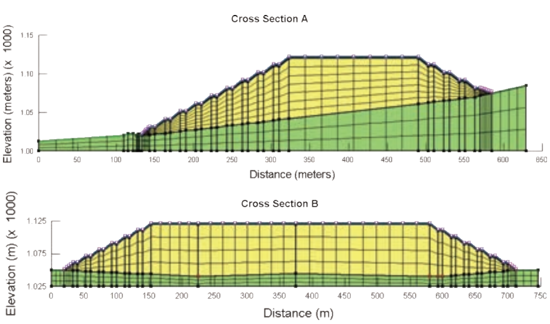

Fig. 1 Facility cross-sections and model construction.

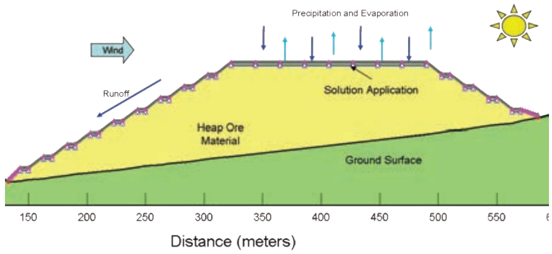

Fig. 2 Conceptual model schematic.

leaching would continue. For this reason, the starting ore temperature is assumed to be equal to the average air temperature for the end of September/early October (the end of ore placement for the year). It is also assumed that no ice lenses will form within the heap material because the material will not be loaded on the pad during the winter months when snow could be trapped within the heap.

The heating of the leach solution is assumed to be 5 °C above the temperature at which it enters the boiler. This corresponds to the heating capacity of the boiler, and provides a target for determining if there is sufficient temperature gain. Two heating scenarios were considered in this modeling effort, a worst case and a typical operating case. As a worst-case scenario, it was assumed that the solution starting temperature would be approximately 0 °C and heated to 5 °C. For a typical operating scenario, it was assumed that the solution was heated from approximately room temperature (20 °C) to 25 °C.

Model input parameters

The following input parameters were incorporated into the VADOSE/W (GEO-SLOPE 2007) modeling:

- Site climate data;
- Solution application rate;
- Current heap leach facility design; and
- Unsaturated flow parameters for the ore material on the heap.

Material properties

The most important input parameters for the modeling are the physical properties of the ore placed on the heap and the ground surface under the heap leach pad facility. These parameters control the flow of water, air, and heat through the heap leach pad. The foundation soils were modeled using a saturated hydraulic conductivity of 10^{-15} m/s. This simulates the plastic liner that will be placed under the heap leach ore pile. The ore material was determined to have a saturated hydraulic conductivity of 10^{-4} m/s. This is equivalent to a uniform sand material which is comparable to the expected grind of the material prior to placement on the heap. The saturated volumetric water content of material will be 35 %. In addition, the thermal conductivity of the ore material was determined to be 9.83 kJ/d/m/°C with a specific heat equal to 1.32×10^3 kJ/m^3.

Boundary conditions

The next most significant input for the model simulations is the application of the boundary conditions. The boundary conditions necessary for this modeling were limited to the application of leach solution and the application of the climate data. The heap leaching operations involves the application of a combination of solutions to the heap surface for controlled infiltration and leaching of the ore. The application rate that will be used is 0.21 m/d. The solution will be applied to the heap using a 60 day leaching cycle (45 days of solution application and 15 days of drain-down). A boundary condition function was developed within the model to simulate this leaching cycle. Because the leach solution emitters will be placed 2.5 m below the surface of the heap, the boundary condition representing the solution application was also applied at that depth below the model surface. The climate boundary condition was applied to the surface of the model.

Climatology

Climate data from the Baruunkharaa meteorological station has a 30 year data set. This station is located approximately 19 km north of the site at an elevation of 810 m. In general, the climate at the mine is characterized by long cold winters and short hot summers. Winter air temperatures can reach -40 °C and summer temperatures can reach 40 °C. The average monthly temperatures range from -24.5 °C in January to 18.3 °C in July.

Model Construction – PLS Pond

A thermal model of the PLS pond was completed to determine how fast the water in the pond would freeze if the pond was stagnant. During operations it is expected that the PLS pond will have active inflow and outflow of solution, helping to keep the water from becoming thermally stagnant. However, the pond may become thermally stagnant if there is a problem with the boilers or the pumping system. Under these conditions, the pond could lose heat rapidly and freeze, severely limiting operations for the remainder of the winter. The thermal modeling of the pond was developed as a heat budget for the system. The heat budget equation used to model the PLS pond is:

$$dH/dt = \Theta_R + \Theta_E + \Theta_L + \Theta_{adv} + \Theta_B \quad (1)$$

Where,
dH/dt = heat budget;
Θ_R = net radiation;
Θ_E = latent heat of exchange;
Θ_L = sensible heat exchange with atmosphere;
Θ_{adv} = net advective exchange;
Θ_B = conduction through bottom sediments.

By modeling the PLS pond using a heat budget approach, the sources of heat loss and gain, and engineering controls could easily be considered.

Modeling assumptions

For the modeling of the PLS pond, it was assumed that the primary engineering control that would be used to prevent heat loss from the pond would be plastic Bird Balls™. Bird

Balls are small, black hard plastic balls that float on the PLS pond surface, and are the most cost effective solution to year round operations. The Bird Balls™ are assumed to be a complete, single layer on the pond, covering approximately 91 % of the total water surface. The dark color of the balls maximizes the day time heating of the pond and minimizes the heat lost to the atmosphere at night. This can decrease the freezing point of the solution by 10 °C. In addition, the surface evaporation is decreased by 90 % due to the barrier created between the atmosphere and the solution surface. The decreased evaporation is an operational advantage in the winter by minimizing the heat loss, but is also an advantage for this mine during the summer. With potential summer temperatures in excess of 30 °C, the solution will not be subject to the same rate of evaporation as it would be without the cover. For comparison and to justify the added expense of the engineering control, the heat budget model was complete for the water surface of the PLS Pond both with and without the Bird Balls™. (Nelson Environmental, Inc. 2008)

Combined Heap and PLS Pond Thermal Models

The coupled variably saturated and thermal model of the heap leach pad and the heat budget model of the PLS pond were used in combination to optimize the design of the heap leach pad and to define the required operational conditions. The coupled variably saturated and thermal model defined the heat loss that is expected to occur within the heap due to contact with the ore during leaching and provided a starting temperature for the PLS pond. The heat budget model defines the expected heat loss while the solution is exposed to the extreme climatic conditions in the PLS pond.

Modeling results

The results of the coupled variably saturated and thermal modeling showed that the heating of the solution helped to maintain the heat near the emitters, even with near freezing starting ore temperatures and an average winter climate. The model results showed the surface of the heap is frozen during the winter months, but at a depth of 2.5 m there appears to be sufficient heat to prevent the emitters from freezing and becoming inoperable. Under both the typical conditions (heating from 20 °C to 25 °C) and the worst case conditions (heating from 0 °C to 5 °C), the solution lost between 3 °C and 5 °C within the heap material.

The goal of the heat budget model was to determine the amount of time it would take the upper one meter of the PLS pond to freeze if the system became thermally stagnant. Four possible scenarios of the PLS heat budget were modeled:

- Typical conditions with Bird Balls™ on pond surface;
- Typical conditions with open water surface;
- Worst case conditions with Bird Balls™ on pond surface; and
- Worst case conditions with open water surface.

Under the typical conditions heat budget model of the PLS pond, it was assumed that the solution exiting the heap will be at approximately 20 °C (the maximum heat loss resulting within the heap for the typical conditions simulation). Based on the results of the heat budget model, if the PLS pond became thermally stagnant, the upper meter of the pond will begin to freeze in approximately 18 hours. This is based on the pond having a single layer of Bird Balls™ on the surface. If the PLS pond surface is open to the atmosphere, the upper meter of the pond will freeze in approximately 1.5 hours. The model was simulated using 2 °C changes in the surface temperature of the solution. The results of this modeling are presented in Table 1 (PLS pond with Bird Balls™) and Table 2 (PLS pond without Bird Balls™) for the typical conditions scenario.

Ambient Air Temperature Kelvin	Water Surface Temperature Kelvin	Theta R W/m^2	Theta E W/m^2	Theta L W/m^2	dH/dt cal/m^2·sec	Time to Lose 2°C minutes
253.3	293.15	-80	5.1	3965	930	35.8
253.3	291.15	-77	5.1	3766	883	37.8
253.3	289.15	-74	5.1	3567	836	39.9
253.3	287.15	-71	5.1	3368	789	42.2
253.3	285.15	-69	5.1	3169	742	44.9
253.3	283.15	-66	5.1	2970	695	47.9
253.3	281.15	-64	5.1	2771	648	51.4
253.3	279.15	-61	5.1	2572	601	55.4
253.3	277.15	-59	5.1	2373	554	60.1
253.3	275.15	-56	5.1	2174	507	65.7
253.3	273.15	-54	5.1	1975	460	72.4
253.3	271.15	-52	5.1	1776	413	80.6
253.3	269.15	-49	5.1	1577	366	91
253.3	267.15	-47	5.1	1378	319	104.4
253.3	265.15	-45	5.1	1179	272	122.4
253.3	263.15	-43	5.1	980	225	148
					Total time	18.3 hours

Table 1 *Results of typical conditions model for PLS pond with Bird Balls™*

Ambient Air Temperature K	Water Surface Temperature K	Theta *R* W/m^2	Theta *E* W/m^2	Theta *L* W/m^2	dH/d*t* cal/m^2·s	Time to Lose 2°C minutes
253.3	293.15	-157	51	23790	5661	5.9
253.3	291.15	-146	51	22596	5378	6.2
253.3	289.15	-135	51	21402	5095	6.5
253.3	287.15	-124	51	20208	4812	6.9
253.3	285.15	-114	51	19014	4529	7.4
253.3	283.15	-104	51	17820	4246	7.8
253.3	281.15	-94	51	16626	3963	8.4
253.3	279.15	-84	51	15432	3680	9.1
253.3	277.15	-75	51	14238	3397	9.8
253.3	275.15	-66	51	13044	3114	10.7
253.3	273.15	-57	51	11850	2831	11.8
					Total time	1.5 hours

Table 2 *Results of typical conditions model for PLS pond with open water surface.*

Under the worst case conditions heat budget model of the PLS pond, it was assumed that the solution exiting the heap will be approximately 2 °C. Based on the results of the heat budget model, if the pond became thermally stagnant, the upper meter of the pond will begin to freeze in approximately 11 hours. This is based on the pond having a single layer of Bird Balls™ on the surface. If the PLS pond surface is open to the atmosphere, the upper meter of the pond will freeze in approximately half an hour. Even with these less than ideal conditions, the modeling showed sufficient heat to maintain operations if the pond does not remain stagnant for a long period of time. The results of the worst case conditions modeling are presented in Table 3 (PLS pond with Bird Balls™) and Table 4 (PLS pond without Bird Balls™).

This modeling only considered a single cycle through the system. Cumulative cooling impacts were not considered, but could impact the long term operation of the system. If too much heat is lost throughout the system, and it cannot be recovered through the use of a boiler, the time before the pond begins to freeze will be decreased. This is particularly important for the worst case conditions.

Conclusions

The modeling completed for the design of this heap leach facility suggested that even under the climatic conditions of Northern Mongolia, a heap leach pad can be operated year round if the proper engineering controls are utilized. It is critical that the solution be as warm as possible when applied to the heap, but the heat that is added by the boiler is expected to be

Ambient Air Temperature Kelvin	Water Surface Temperature Kelvin	Theta R W/m^2	Theta E W/m^2	Theta L W/m^2	$\frac{dH}{dt}$ cal/m^2·sec	Time to Lose 2ºC minutes
253.3	275.15	-56	5.1	2174	507	65.7
253.3	273.15	-54	5.1	1975	460	72.4
253.3	271.15	-52	5.1	1776	413	80.6
253.3	269.15	-49	5.1	1577	366	91
253.3	267.15	-47	5.1	1378	319	104.4
253.3	265.15	-45	5.1	1179	272	122.4
253.3	263.15	-43	5.1	980	225	148
					Total time	11.4 hours

Table 3 *Results of worst case conditions model for PLS pond with Bird Balls™.*

Ambient Air Temperature Kelvin	Water Surface Temperature Kelvin	Theta R W/m^2	Theta E W/m^2	Theta L W/m^2	$\frac{dH}{dt}$ cal/m^2·sec	Time to Lose 2ºC minutes
253.3	275.15	-66	51	13044	3114	10.7
253.3	273.15	-57	51	11850	2831	11.8
					Total time	22.5 min

Table 4 *Results of worst case conditions model for PLS pond with open water surface.*

completely lost before the solution exits the heap. If the solution exiting the heap is 20 °C, then the pond will not freeze unless it becomes thermally stagnant for a period of 18 hours with an air temperature of -20 °C. If the solution temperature is approximately 2 °C when it leaves the heap and the air temperature is -20 °C, then the time before freezing is reduced to 11 hours. The pond will be susceptible to freezing should a problem occur with the pumps or the boiler. For this reason, the pumps and a backup system are the most critical components of the leaching system for successful winter operations.

The heap leach pad and associated PLS pond were constructed as suggested by the modeling results and operated for a one year period. The constructed facility included the boiler to add 5 °C of heat to the leaching solutions, emitters buried 2.5 m below the surface to prevent freezing, and a single layer of BirBalls™ placed on the PLS pond surface. This combination of engineer controls proved to be an effective means of achieving year round operations, even under the extreme climate conditions of a northern desert.

References

GEO-SLOPE International Ltd. (2007). Vadose Zone Modeling with VADOSE/W: An Engineering Methodology. Alberta:GEO-SLOPE.

Nelson Environmental, Inc. (2008). Bird Ball™ Cover System. www.nelsonenvironmental.com/TechProd6_BirdBalls. Information verified 14 July 2008.