TECHNICAL PROGRESS REPORT

Solubility Measurements of Multicomponent Solids via Isopiestic Method

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Introduction

Remediation of radionuclides residing in the Hanford Site vadose zone (VZ) is a challenging task due to the depth of the contaminants, which makes it difficult to reach with near-surface remediation techniques. Uranium is one of the key contaminants of the Hanford Site VZ. Uranyl carbonates are the predominant uranium (VI) aqueous species in Hanford's pore water and due to their high mobility are considered as a potential source of contamination for the underlying aquifer. So, in-situ remediation methods require sequestration of uranium in the subsurface to prevent further spreading of mobile uranium species. The technology under consideration to sequester U(VI) is a manipulation of soil pH via ammonia gas injection by creation of alkaline conditions in the uranium-contaminated soil. The soil pH manipulation causes uranium coprecipitation during mineralogical changes and the formation of uranium-bearing precipitates in the treated vadose zone soil. The injection of reactive gases such as NH₃ can reduce the potential for radionuclide mobility in the subsurface without water addition causing undesired downward migration of contaminants. This technology allows the transformation of mobile uranium species to lower solubility precipitates that are stable in the natural environment (Szecsody et al., 2012). The formation of a relatively insoluble mineral complex that integrates uranium is a desired outcome of the VZ remediation efforts at Hanford because the more immobile the contamination is, the less it will spread in the subsurface. However, there is a need for a better understanding of the stability of the U-bearing precipitates created in the soil as a result of ammonia gas remedial actions. This information would help to accurately predict the mobility of U(VI) in the posttreated vadose zone soil.

Traditionally, solubility measurements are conducted in batch experiments to measure the amount of solute that can be dissolved in a solvent until the system reaches equilibrium (Giammar et al., 2002; Rai et al., 2005; Gorman-Lewis et al., 2008). This method is better suited to measure solubility of minerals with respect to the groundwater saturated conditions; however, it doesn't allow accurately quantifying the solubility of minerals for the unsaturated vadose zone conditions. Evaluation of literature suggests that the isopiestic method can closely mimic the mineral deliquescence process, which refers to the formation of an aqueous solution by the absorption of water by hygroscopic salt minerals (Carroll et al., 2005). Thus, isopiestic measurements may be the most appropriate way to quantify mineral solubility for the unsaturated vadose zone conditions. This method is considered very accurate, helping to make more realistic predictions of contaminant fate and transport in vadose zone environments. Experimental deliquescence data are limited for mixed salts (Gruszkiewicz et al., 2007) and especially scarce for uranium-bearing multicomponent mixtures.

The tendency for solutes to deliquesce depends on their solubility and is influenced by the particular character of solute-solvent interactions described according to Raoult's law in vaporpressure lowering ability. The basic features of the method include isothermal equilibration of samples of known masses and known initial concentrations through a common vapor phase. In the closed system, the solvent is distilled isothermally from one crucible to another until each solution reaches the same chemical potential. All of the solutions at equal vapor pressure or isopiestic equilibrium have the same solvent activities. These conditions can be rewritten as $lna_s=lna_{ref}$. By equilibration, the samples with a standard of known solvent activities under the conditions of the experiment as a function of molality can be used to determine the solvent activity of another solution (Rard, 1985). If two or more solutions of different salts are in isopiestic equilibrium, the osmotic coefficient of a test solution, ϕ_x , is calculated from the reference solution, ϕ_{ref} , from the fundamental equation for isopiestic equilibrium:

$$\phi_s = \frac{v_{ref} m_{ref} \phi_{Rref}}{v_s m_s}$$
 Eq 1

The water activities a_w of the reference solution can be calculated using the following equation:

$$\ln a_w = -0.001 \, v_s m_s M_w \phi_{ref} \qquad \text{Eq } 2$$

Where v_s is the number of ions formed by the complete dissociation of one molecule of the reference standard, and for NaCl and KCl, v=2, M_w is molar mass of H₂O, and φ is the practical osmotic coefficient of the reference standard. Eq. 2 is defined for mixtures, as well as for single-salt solutions (Rard and Platford, 1991). The ratio $(\frac{m_{ref}}{m_s})$ is called the isopiestic ratio. The osmotic coefficient can be measured with 0.1%-0.3% accuracy at molalities down to 0.1 mol/kg. So, all solutions in the isopiestic chamber that are allowed to exchange solvent until isopiestic equilibrium is reached will have the same solvent activity with a value of $(\sum_i v_i m_i)\phi$.

Relative humidity, RH, is related to the activity of water through the partial pressure of water vapor as follows:

Where p_w is the partial pressure of water vapor over an aqueous solution and p_w^0 is the partial pressure of water vapor over pure water. The activity of water in aqueous solutions relates to its fugacity by equation (Rard and Clegg, 1997):

$$a_w = f_w / f_w^o \qquad \qquad \text{Eq 4}$$

Where f_w is the fugacity of water vapor over an aqueous solution and f_w^{0} is the fugacity of water vapor over pure water. It is usually assumed that, in ambient temperature and moderate pressure, water vapor behaves ideally and the fugacities can be replaced by partial pressure (Reid et al., 1987):

$$f_w/f_w^o = p_w/p_w^o \qquad \qquad Eq \ 5$$

yielding:

$$RH=a_w$$
 Eq 6

The RH is commonly expressed as a percentage; thus RH%=100* a_w .

This report summarizes preliminary results from isopiestic measurements of the deliquescence behavior of no- uranium multicomponent precipitates combined from major pore water constituents such as Na⁺, SiO₃⁻, Al⁺, NO₃⁻, K⁺, HCO₃⁻, Ca²⁺, and Cl⁻.

Materials and Methods

Rard and Platford (2000) presented detailed general descriptions of the isopiestic method with an emphasis on experimental aspects. In brief, the isopiestic apparatus used for the experiments was fabricated from a pressure pot and contained an aluminum heat-transfer block that has a good thermal conductivity, able to maintain a uniform temperature distribution inside the chamber (Figure 1).



Figure 1. Isopiestic chamber to conduct solubility experiments; aluminum block with holes to hold nickel crucibles.

The aluminum block contained fourteen holes drilled part way through to tightly hold the crucible cups containing standards and multicomponent precipitate samples. Isopiestic method procedures require for the isopiestic cups to be made of material that is chemically inert to the experimental solutions and have excellent thermal conductivity. In the experiments, 15-mL nickel cups were used; to avoid evaporation losses, tightly fitted light nickel lids were immediately added when the chamber was open. Then, the crucibles with lids were placed on balances for weighing. Metler Toledo analytical balances XS205DU with a precision of no less than 1×10^{-5} g were used for weighing the crucibles cups covered with lids (Figure 2).



Figure 2. Analytical balance weighing covered crucible.

The isopiestic method is a mostly gravimetric method that relies on the assumption that only one volatile component is present. The mass of the empty crucible along with the number of moles of electrolyte in each sample was accurately calculated. Therefore, any gains or losses in mass during isopiestic equilibration are only possible due to gains or losses of solvent. The observed changes in mass were used in the calculation of the solution molalities at isopiestic equilibrium (Rard and Platford, 2000).

Every time the system reached equilibrium, the isopiestic chamber was opened to weigh the samples. Then, when the chamber was re-closed, the air was evacuated until the pressure reached around 4.5 kPa (Blanco et al., 2006). After the gas is evacuated in a closed vessel, the volatile component is transported through the vapor phase until the solutions reach equilibrium. The apparatus was equipped with a high accuracy pressure transducer with a range of 0-30 psia (Omega Engineering, Inc.) to provide a measurement of water vapor pressure, allowing for monitoring as the system approached equilibrium. The transducer was connected to the acquisition system to collect vapor pressure data. Labview code, used to record the direct vapor pressure measurements, was updated to show pressure in inches of mercury (in of Hg) and in Torr. The code was also modified to indicate when the system was under vacuum.

The vessel was constantly kept in the environmental chamber to control a stable temperature of 25° C (Figure 3).



Figure 3. Isopiestic chamber to conduct solubility experiments connected to the acquisition system.

The reference standards were used to obtain osmotic coefficients for the low water activity values in the multicomponent salt systems. Stock solutions for standards were prepared by weight using deionized water from a Barnstead NANOpure water purification system or plasma grade water. Initially, the experiments were started with NaCl as a reference. Due to an inability to calculate water activities for the high molality values of NaCl, the experiment was extended to include two new reference standard solutions, calcium chlorine (CaCl₂) and lithium chlorine (LiCl), known for their high solubility. The most soluble is LiCl; its maximum molality to obtain an osmotic coefficient value for the water activity calculations is 19.219 mol/kg. The CaCl₂ and LiCl salts were "ultra dry" grade chemicals with metal-basis purities specified by Alfa Aesar as 0.99 and 0.995, respectively. Powdered salts were received sealed in argon-filled glass ampoules. Preparation of the reference solutions included breaking the glass ampoules and transferring their contents rapidly to polyethylene bottles containing weighed amounts of water. To avoid moisture, two samples of each reference standard solution were prepared in an anaerobic glove box. The masses of the reference standards were measured carefully to limit variations between two identical standard samples: 0.04685g and 0.03465 g for CaCl₂ and 0.02548g and 0.02541g for LiCl.

The multicomponent precipitate samples prepared to measure a moisture-induced phase transformation from solid phase to solution and determine water activity and osmotic coefficient at the deliquescence point were combined from Na⁺, SiO₃⁻, Al⁺, NO₃⁻, K⁺, HCO₃⁻, Ca²⁺, and Cl⁻ ions. All of these elements are found in the pore water of the Hanford Site 200 Area and their

concentrations used for the preparation of experimental mixtures were based on the characterization studies performed by Serne et al. (2008) on vadose zone sediments from borehole 299-E33-45 at the Hanford 200 Area. Uranium (VI) was not included in these experiments. Preparation of the samples started from the stock solutions made in deionized water (DIW) by dissolving preliminary dried in the oven Na₂SiO₃'9H₂O, Al(NO₃)₃ '9H₂O, KHCO₃, and CaCl₂[·]2H₂O salts into 50 mL vials. All multicomponent precipitate samples kept a constant ratio of Si/Al=20 by means of Si and Al concentrations of 100 mM and 5 mM, respectively. Bicarbonate concentrations used for the preparation of the solution mixture were 3 mM and 50 mM. Each bicarbonate concentration was combined with 0, 5, and 10 mM of calcium concentrations. The multicomponent solutions in the amount of 10 mL were prepared directly into the nickel crucibles by mixing the required stock solutions and DIW. The weights of the solutions were recorded using balances with an accuracy of 1x10⁻⁵g. After mixing, all crucibles containing the multicomponent solutions were placed in an oven and dried at 40°C for at least 48h until a stable weight of dried precipitates was obtained. The concentrations of the stock solutions were maintained the same as in the previously conducted studies to investigate the effect of Si and Al concentration ratios on the removal of U(VI) in alkaline conditions. The amounts of each stock solution used in the preparation of six samples are presented in Table 1.

	Amount of Stock Solution and DIW (uL) Na ₂ SiO ₃ ·9H ₂ O = 2368 and Al(NO ₃) ₃ ·9H ₂ O = 1000								
Crucible	Sample KHCO ₃ CaCl ₂ ·2H ₂ O DIW								
7	3 mM KHCO ₃ , no Calcium	75	0	6657					
8	50 mM KHCO ₃ , no Calcium	1250	0	5382					
9	3 mM KHCO ₃ , 5 mM Calcium	75	20	6537					
10	50 mM KHCO ₃ , 5 mM Calcium	1250	20	5362					
11	3 mM KHCO ₃ , 10 mM Calcium	75	20	6537					
12	50 mM KHCO ₃ , 10 mM Calcium	1250	20	5362					

The solute contents in each crucible were calculated as a summation of the total number of moles corresponding to the salt formula. In the experiments, ten nickel crucibles were used; two contained duplicate reference solutions of $CaCl_2$, another two contained reference solutions of LiCl and six contained the multicomponent solids samples. Table 2 summarizes the compositions of the $CaCl_2$ and LiCl reference standards, solute contents, and initial molalities of the reference and experimental samples.

Cup #	Standard/Solute Multicomponent	Standard and Sample Weight (g)	Solute Content (Mm)	Pure Water in Sample (µl)	Initial Sample Molality mol/Kg
1	CaCl ₂	0.04685	0.42215	100	4.22
2	CaCl ₂	0.03465	0.31222	100	3.12
3	LiCl ₂	0.02548	0.60103	100	6.01
4	LiCl ₂	0.02541	0.59938	100	5.99
5	Na ₂ SiO ₃ + Al(NO ₃) ₃ + *KHCO ₃	0.19860	0.24206	0.13099	1.85
6	Na ₂ SiO ₃ + Al(NO ₃) ₃ + **KHCO ₃	0.23900	0.30433	1.15473	0.26
7	$Na_2SiO_3 + Al(NO_3)_3 + *KHCO_3 + †CaCl_2$	0.20150	0.24216	0.17987	1.35
8	$Na_2SiO_3 + Al(NO_3)_3 + **KHCO_3 + ^{\dagger}CaCl_2$	0.24340	0.30443	0.16542	1.84
9	$Na_2SiO_3 + Al(NO_3)_3 + *KHCO_3 + {}^{\dagger\dagger}CaCl_2$	0.21020	0.24226	0.15091	1.61
10	$Na_{2}\overline{SiO_{3}}+Al(NO_{3})_{3+}$ **KHCO_{3}+ ^{††} CaCl_{2}	0.25610	0.30453	0.18382	1.67

 Table 2. Reference and Multicomponent Samples - Weights, Solute Content, and Molalities at the Beginning of Experiment

* 3 mM and ** 50 mM of KHCO₃

 † 5 mM and $^{\dagger\dagger}10$ mM of CaCl_2

Deliquescence behavior of multicomponent solids was studied by starting from uranium-free solid salt mixtures via a progressive increase in the relative humidity. It was achieved by incremental addition of 20-50 μ L of DIW water to the standards, helping to increase the humidity of the system and find water activity values closer to the eutonic point, where the lowest relative humidity coexists with a liquid solution.

Results and Discussions

This progress report presents the experimental results on solid-liquid transitions of the synthetic multicomponent precipitate samples prepared from synthetic porewater solutions mimicking conditions at the Hanford Site. Several parameters were taken into consideration for studying deliquescence behavior of dry solids with the most important being water activity and osmotic coefficients. Two samples were prepared for each standard, CaCl₂ and LiCl, and the osmotic coefficients (ϕ_{stand}) were estimated for each standard using an average value between the two samples. At each isopiestic measurement recorded, molalities of standards were interpolated from the literature data (Bert and Nuttall, 1977; and Hamer and Wu, 1972) to obtain their corresponding osmotic coefficients. The water activity (a_w) values for each standard were calculated as follows:

$$lna_w = (\sum_i v_i m_i)\phi \qquad \qquad \text{Eq 7.}$$

The measured water activities of the LiCl- H_2O and $CaCl_2 - H_2O$ against the standards molality values obtained throughout the isopiestic experiments are shown in Figure 4.



Figure 4. Changes of water activities vs. molality for LiCl and CaCL2 standards.

The standards values for molality, osmotic coefficient, and water activity calculated according to the Eq. 2 for each isopiestic measurement are presented in Table 3 and Table 4. The variation between water activity values obtained for the two standards, $CaCl_2$ and LiCl, was calculated as 1.4% (0.848 for CaCl₂ and 0.834 for LiCl). By the end of the experiments, crucibles with LiCl standards showed little corrosion spots inside the cups, which might have contributed to the difference in the osmotic coefficient values between the two standards. While the results for the water activities for both standards are in reasonable agreement, we consider that more accurate data were obtained with $CaCl_2$.

The molality of each multicomponent sample was calculated based on the solute content and water weight measurements. Then, the osmotic coefficients for multicomponent samples (ϕ) were calculated according to Eq.1. The water activities at equilibrium for all multicomponent samples were equal to the water activity of the standard at each isopiestic measurement recorded (Table 3 and Table 4).

a _w CaCl ₂	Na ₂ SiO ₃ + Al(NO ₃) ₃ + KHCO3 (3mM)	Na ₂ SiO ₃ + Al(NO ₃) ₃ + KHCO ₃ (50mM)	Na2SiO ₃ + Al(NO ₃) ₃ + KHCO ₃ * (3mM) + CaCl ₂ (5mM)	Na ₂ SiO ₃ + Al(NO ₃) ₃ + KHCO ₃ * (50mM) + CaCl ₂ (5mM)	Na ₂ SiO ₃ + Al(NO ₃) ₃ + KHCO ₃ * (3mM) + CaCl ₂ (10mM)	Na ₂ SiO ₃ + Al(NO ₃) ₃ + KHCO ₃ * (50mM) + CaCl ₂ (10mM)	Ø CaCl ₂
0.786	1.485	1.820	3.499	2.462	2.803	2.961	1.652
0.798	1.436	1.861	3.424	2.426	2.727	2.929	1.607
0.800	1.303	1.755	3.336	2.331	2.643	2.902	1.602
0.808	1.319	1.803	3.199	2.341	2.585	2.951	1.573
0.808	1.300	1.814	2.470	2.229	2.489	2.881	1.575
0.811	1.259	1.811	1.852	2.235	2.428	2.910	1.564
0.825	1.380	2.050	1.953	2.407	2.592	3.141	1.515
0.834	1.475	2.405	2.084	2.770	2.819	3.566	1.483
0.840	1.587	2.645	2.192	3.029	2.978	3.894	1.458
0.848	1.682	2.985	2.266	3.377	3.193	4.328	1.429

Table 3. Values for water activities, a_w , and osmotic coefficients, ϕ , for CaCl₂ and multicomponent samples

Table 4. Values for water activities, a_w , and osmotic coefficients, ϕ , for LiCl and multicomponent samples

a _w LiCl	Na ₂ SiO ₃ + Al(NO ₃) ₃ + (3mM) KHCO ₃	Na2SiO ₃ + Al(NO ₃) ₃ + (50mM) KHCO ₃	Na2SiO ₃ + Al(NO ₃) ₃ + (3mM) KHCO ₃ + (5mM)CaCl ₂	Na2SiO ₃ + Al(NO ₃) ₃ + (50mM) KHCO ₃ + (5mM)CaCl ₂	Na2SiO ₃ + Al(NO ₃) ₃ + (3mM) KHCO ₃ + (10mM)CaCl ₂	Na2SiO ₃ + Al(NO ₃) ₃ + (50mM) KHCO ₃ + (10mM)CaCl ₂	Ø LiCi
0.768	1.621	1.987	3.820	2.688	3.060	3.233	1.601
0.795	1.466	1.901	3.497	2.478	2.786	2.991	1.465
0.795	1.330	1.792	3.408	2.381	2.700	2.964	1.470
0.798	1.347	1.841	3.268	2.392	2.640	3.015	1.493
0.799	1.328	1.853	2.523	2.277	2.542	2.943	1.502
0.800	1.286	1.850	1.892	2.282	2.480	2.973	1.509
0.824	1.409	2.094	1.995	2.459	2.648	3.209	1.379
0.829	1.507	2.457	2.129	2.830	2.879	3.643	1.410
0.832	1.621	2.702	2.239	3.094	3.041	3.978	1.430
0.834	1.718	3.049	2.315	3.449	3.262	4.421	1.458

The graphical representation of the obtained results is given in Figure 5 and Figure 6. The phase changes are usually visible as breaks in the curve, representing the osmotic coefficient of the solution as a function of relative humidity (Gruszkiewicz et al., 2007). In our case, it occurred for all experimental samples at water activity 0.81%, which correlates to the relative humidity of 81%.



Figure 5. Osmotic coefficient for multicomponent samples as a function of water activities, aw, using LiCl as a standard.



Figure 6. Osmotic coefficient for multicomponent samples as a function of water activities, aw, using CaCl₂ as a standard.

All experimental water activities as a function of total molality for each multicomponent sample were plotted in Figure 7.



Figure 7. Water activities against molalities for the multicomponent samples using CaCl₂ standard.

The results show that the water activities for all multicomponent samples are similar and follow the same trend as the molality of the samples increased. There is some variability in the water activity data for a non-calcium sample comprised of 3 mM of bicarbonate $[Na_2SiO_3+Al(NO_3)_3+3mM \text{ KHCO}_3]$. However, starting from water activity value of 0.81, the visible break in the curve occurs for all samples. These results suggest that as humidity in the system increased, the deliquescence points for all multicomponent samples were obtained for RH $\geq 81\%$.

Figure 8 shows plots of the measured values of the osmotic coefficients against the molality of multicomponent samples. From Figure 8 it can be seen that as ϕ decreased with the increase in samples molality, a change in the slope indicates a possible solid –liquid transition. As an example, an arrow on Figure 8 represents the deliquescence point for the sample that contains Na₂SiO₃+Al(NO₃)+ 50mMHCO₃ and 10mMCaCl₂. Similar changes in slope are visible for other sample compositions presented on Figure 8.



Figure 8. Osmotic coefficient vs. molalities for the multicomponent samples using CaCl₂ standard

The evaluation of the multicomponent samples indicated that the amount of sodium silicate comprises the major molar fraction for about 77-97%, depending on the samples' composition. It might be that the deliquescence behavior of the multicomponent precipitates is governed by the solubility of alkali silicate gel formed by the silicate ion polymerization reaction. The literature data on the deliquescence of polymerized silica is rather scarce and the isopiestic data can provide important insights on the solubility behavior of the multicomponent precipitates created in alkaline conditions as a result of the recrystallization of minerals due to ammonia gas injection in the subsurface. A sample of sodium silicate will be prepared in the next set to compare the solubility of dried silicate solids formed by the silicate ion polymerization with other multicomponent samples.

Fabrication of a new isopiestic chamber

The experiments performed with the isopiestic chamber fabricated from the commercially available pressure pot showed some limitations in the design. The chamber height was tall enough to hold an aluminum block with recessed holes to fit 15-mL crucibles. To reduce the weight of the chamber, the underside of the aluminum block was fabricated with slots, leaving some void space beneath the block. The block was tightly fit inside the chamber; however, it still has the possibility of accumulating water vapor in the voids on the underside of the aluminum block. To avoid this flaw in future experiments and to lower the weight of the chamber, a new design was initiated. In addition, decreasing the void spaces in the chamber and reducing the headspace above the crucibles cups would help to reach system equilibrium faster. Two identical chambers were designed from 6061 T6 aluminum to include 12 recesses for crucible cups in each vessel. The depth of each recess was designed the same (1.26 in) as in the previous chamber

fabricated from the pressure pot. The distance between each row was determined by the dimensions of the nickel crucible lids. The negative rectangular boss was designed to house a sealing gasket of silicone with a shore durometer of 50A. The top and lateral port is for degassing. The lateral port is threaded to receive a 1/4" male NPT thread to add a vacuum rated valve and a hose barb to connect to a vacuum line (Figure 9).



Figure 9. Aluminum block to fit crucible cups.

The underside of this plate consists of slots to reduce the overall weight and 1/4-20 threaded holes to mount the legs as seen in Figure 10.



Figure 10. The underside of the chamber plate.

The design for the top required there to be a head space of about 2 cm above the lids of the crucibles. Since there will be a gasket to seal the chamber, the max height was set to 2 cm (0.787 in) and the minimum depth to about 1.86 cm (0.731 in) to prevent over compression of the gasket.



Figure 11. The full assessbly of the isopiestic chamber with crucibles inside.

On the top of the lid, there is a ¹/₄ NPT port for a gauge. On the bottom portion, there is a boss used to compress the gasket. Finally, for ease of closing the lid, toggle clamps were used and set on the legs as seen in Figure 11. The final assembly drawing is presented in Figure 12. The fabrication of the two new isopiestic chambers was completed and they are undergoing testing (Figure 13).



Figure 12. Drawing of the isopiestic chamber final assembly.



Figure 13. Fabricated new isopiestic chambers to continue the solubility experiments.

Future Work

Future work will focus on the deliquescence experiments using U-bearing solids. Two reference solutions, CaCl₂ and LiCl, will be used to obtain values of osmotic coefficients and water activities for the experimental samples. A new set of dry precipitates, composed of Si-Al-Ca-HCO3 and U(VI), will be prepared to investigate the solid-liquid transitions in the uraniumbearing multicomponent salt systems. The concentration of uranium will be 2 ppm, similar to what was used in the study to investigate the effect of Si and Al concentration ratios on the removal of U(VI) in alkaline conditions by NH3 conducted earlier. Samples will be prepared with the same concentrations, applying a Si/Al ratio of 20 (100 mM of Si and 5 mM of Al), two bicarbonate (3 and 50 mM) and three calcium (5 mM, 10 mM and 15mM) concentrations. A sample will be prepared using 100 mM of sodium silicate to investigate if the solubility for multicomponent samples is following the same trend as for polymerized Si. Sample preparation procedures will follow the same method as for the current study. Dried samples together with calcium chloride and lithium chloride samples will be placed in the isopiestic chamber and kept at a 25°C constant temperature. The isopiestic chamber will be opened to weigh the samples when the system reaches equilibrium in order to investigate the deliquescence behavior of uranium-bearing multicomponent solids. The obtained results will be compared with the deliquescence data obtained for the current study.

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