

A Sustainable Alternative to Froth Flotation

Devin Rowe

Back to the Future, Research Experience for Undergraduates Site
Department of Materials and Metallurgical Engineering
South Dakota School of Mines & Technology
Rapid City, South Dakota 57701

Background

- Froth Flotation is one of the industry's standard ways of concentrating low grade, fine particle sized minerals.
- This process is done by using water as a medium and manipulating the particles surface chemistries into being either hydrophobic or hydrophilic then using air bubbles to separate the hydrophobic particles.
- Since these processes tend to take place in arid areas, it is always desired that water consumption should be reduced whenever possible. In other words, to find a more sustainable process
- The idea is to essentially inverse the process of Froth Flotation, using a fluidized bed reactor. Air becomes the medium that the particles are suspended in and water vapors will selectively condense on particles increasing their mass and enable a separation.

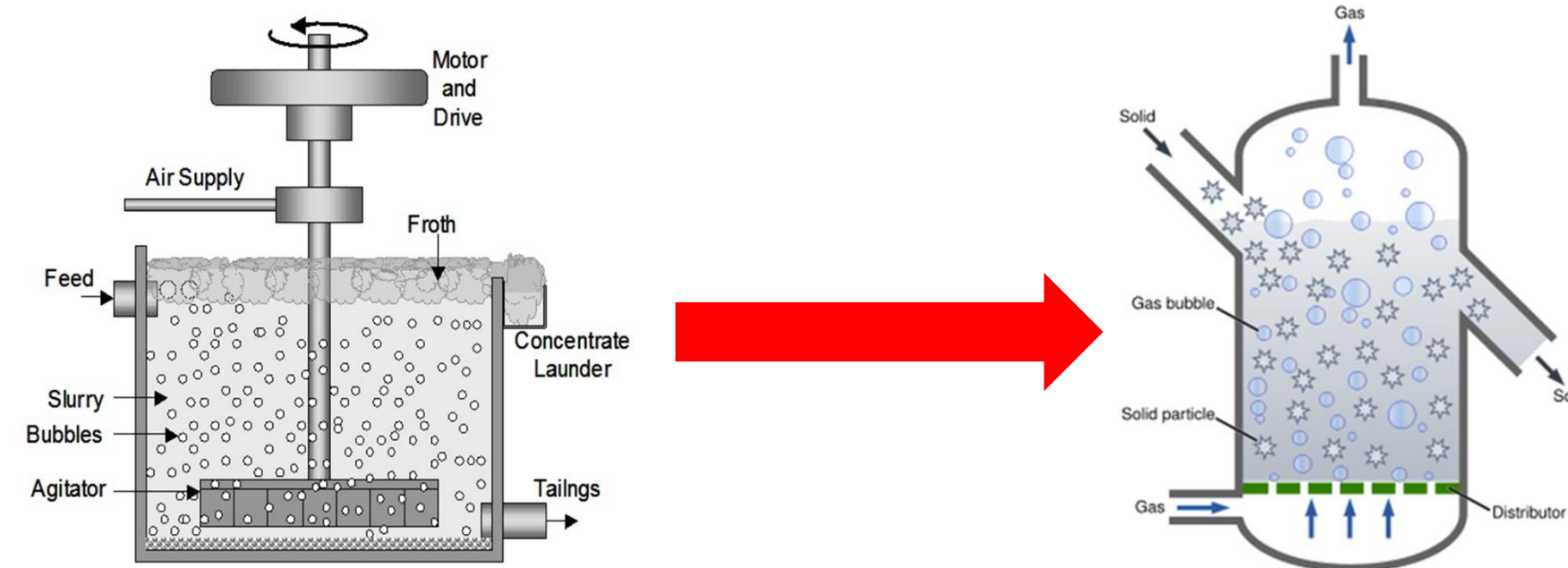


Figure one. (Left) Froth flotation system, (Right) Alternative system.
Images taken from https://en.wikipedia.org/wiki/Fluidized_bed_reactor and <http://www.chinafote.com/group23.html>

Why Bother?

- Fresh water is among the planet's most important resources, as all life on earth depends on it in one form or another for survival.
- In areas where sufficient water supplies are easily accessed, the use of this resource is rarely a concern to the people who live there. However, in areas where water is either difficult to get or limited in supply, its use can be of great concern.
- A Froth Flotation operation can consume enormous volumes of fresh water, 10 Freeport McMoran plants alone used 185 billion gallons of water in 2013.
- These operations often occur in arid areas where water can be in short supply, thus using such quantities can mean that living things may suffer.
- So it becomes apparent that progress should be made towards increasing efficient usage and developing alternative means or processing.
- In the sustainable process water will only be used in the form of vapor, theoretically the water consumption will be a fraction of its well established counterpart.

Materials

Materials for these experiment include the following:

- 1.0-1.2mm x 1" x 3" glass slides
- Enough mica to produce numerous 1-2 square inch pieces
- Deionized water
- Dodecylamine
- Sodium Hydroxide
- Salts-
 - Lithium Chloride, Sodium Chloride, Potassium Sulfate, Magnesium Chloride, Magnesium Nitrate, and Potassium Chloride.
- About 10' of 3/8" x 1/4" clear vinyl tubing, a regulator and dry air tank
- 24 plastic bottle caps about 5/4" in diameter.
- 4" x 125' roll of parafilm.
- Ceramic crucible, 1.25" Di x 1" H

Equipment

Equipment used for conducting experiments and measuring data include:

- Ramé-hart Model 500 Advanced Goniometer with DROPImage advanced v2.4 (p/n 500-F1, s/n 907315)
- Two 1.8" LCD Mini Wireless Electronic Hygrometer
- Sealed constant humidity environment chamber-
 - 4" x 4" x 4" clear glass sports case and stoppers
- SCIOGEX MicroPette Plus Autoclavable pipettor 0.5-10uL and tips.
- Harrick Plasma-plasma cleaner model pdc-001
- Oerlikon leybold vacuum TRIVAC D2,5E

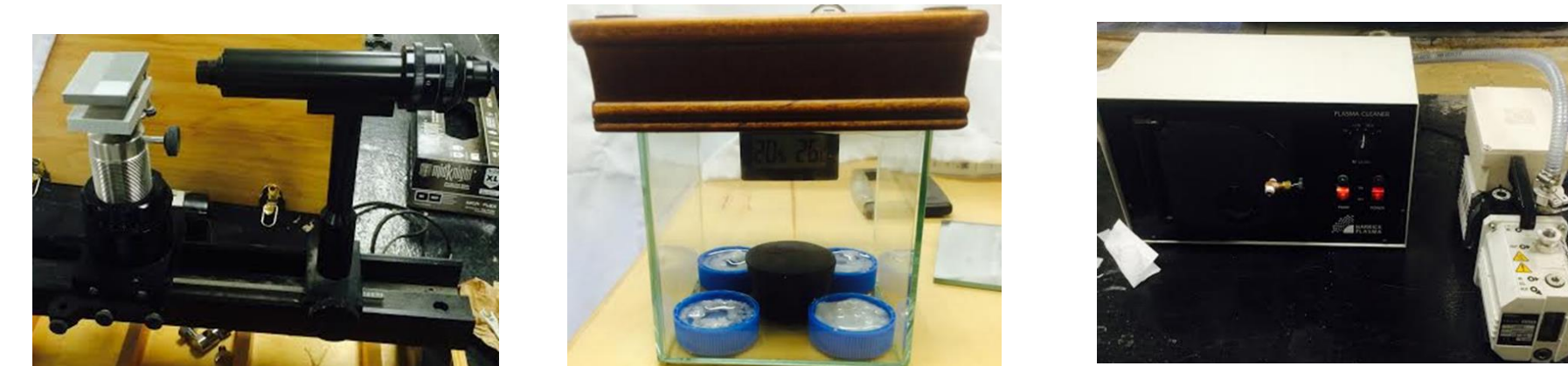


Figure two. (Left) Goniometer, (Center) Sealed humidity chamber, (Right) Plasma cleaning system

Experimental Procedure

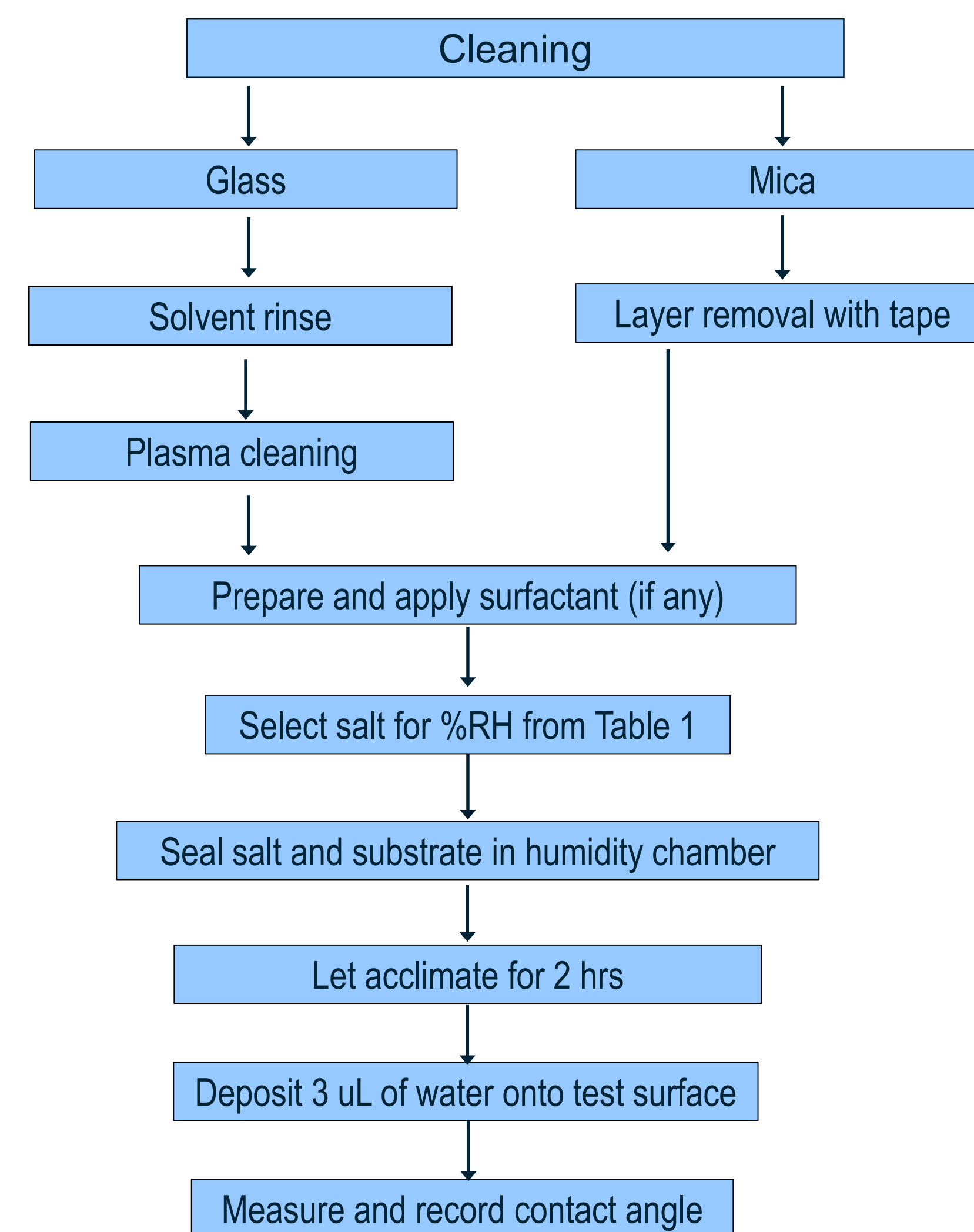


Figure three. Flow sheet of experimental procedure

Table 1. Salt solution humidity table. From ASTM Standards section E-108

Temperature (°C)	Lithium Chloride LiCl, %RH	Magnesium Chloride MgCl ₂ , %RH	Magnesium Nitrate Mg(NO ₃) ₂ , %RH	Sodium Chloride NaCl, %RH	Potassium Chloride KCl, %RH	Potassium Sulfate K ₂ SO ₄ , %RH
20	11.3 ± 0.3	33.1 ± 0.2	54.4 ± 0.2	75.5 ± 0.1	85.1 ± 0.3	97.6 ± 0.5
25	11.3 ± 0.3	32.8 ± 0.2	52.9 ± 0.2	75.3 ± 0.1	84.3 ± 0.3	97.3 ± 0.5
30	11.3 ± 0.2	32.4 ± 0.1	51.4 ± 0.2	75.1 ± 0.1	83.6 ± 0.3	97.0 ± 0.4

Results

Experimentation and data collection is still underway but Tables 2 and 3 show what has been collected so far.

Table 2. Experimental results for glass slides.

Salt	RH (%)	Glass Control			Glass Control 2			Dodecylamine		
		CA AVE	CA Devi	COS(CA)	CA AVE	CA Devi	COS(CA)	CA AVE	CA Devi	COS(CA)
LiCl	18	12.3	3.1	0.98	13.9	2.2	0.97	76.0	2.0	0.24
MgCl ₂	35	11	2.2	0.98	18.0	2.5	0.95	63.9	2.9	0.44
Ambient	52	10.8	1.7	0.98	13.3	0.8	0.97	68.3	3.2	0.37
Mg(NO ₃) ₂	51	15.5	2.5	0.96	11.6	2.5	0.98	36.9	4.6	0.80
NaCl	56	17.9	1.9	0.95	22.7	1.3	0.92	46.2	9.4	0.69
KCl	73	14.3	1.9	0.97	34.8	5.9	0.82	59.6	3.4	0.51
K ₂ SO ₄	81	26.1	7.3	0.90	30.3	1.8	0.86	74.3	2.9	0.27

Table 3. Experimental results for mica sheets.

Salt	RH (%)	Mica Control			Mica Control 2			Dodecylamine		
		CA AVE	CA Devi	COS(CA)	CA AVE	CA Devi	COS(CA)	CA AVE	CA Devi	COS(CA)
LiCl	15	10.0	3.0	0.98	21.1	11.8	0.93	46.8	16.3	0.68
MgCl ₂	37	16.2	8.4	0.96	14.9	12.4	0.97	62.4	18.0	0.46
Ambient 1	50	14.0	6.0	0.97	18.5	6.6	0.95	39.6	8.0	0.77
Mg(NO ₃) ₂	49	8.0	2.7	0.99	18.6	4.3	0.95	73.2	14.8	0.29
NaCl	68	9.0	2.6	0.99	11.0	5.1	0.98	36.1	8.2	0.81
KCl	84	9.3	4.2	0.99	15.6	6.0	0.96	44.4	6.1	0.71
K ₂ SO ₄	98	12.4	6.4	0.98	0.0	0.0	1.00	60.5	18.1	0.49

Discussion

Amongst the controlled data, the wettability of the two substrates appear to remain relatively unchanged by increasing or decreasing the level of relative humidity. A statement that seems untrue at face value as some of the contact angles are twice as large as some of the others in the same control group. But if the cosine of the contact angle is considered instead (which is an indication of the substrates surface energy established by the Young's equation, Eq 1) the deviation of the controlled groups are very small, on the order of two decimal places.

$$\cos \theta = \frac{(\gamma_{sa} - \gamma_{sl})}{\gamma_{la}} \quad (\text{Eq 1})$$

Where: θ is the contact angle, γ_{sa} , γ_{sl} , and γ_{la} are the solid-air, solid-liquid and liquid-air interfacial tensions respectively.

The deviation of the contact angle in the mica data are quite large both amongst its own controlled data and the glass with one deviating by as much as 12 degrees. This is chiefly caused by the irregularities on the mica's surface. Instead of lab grade mica which would have been uniform across the surface, natural mica was used. This means the surface could have cracks, upturned edges and overlapping layers, so naturally contact angles would differ across the same surface.

The control groups did not show any clear trends for changes in wettability by either increasing or decreasing the relative humidity.

Following the surface treatment with dodecylamine, the wettability's of both glass and mica decreased significantly as expected. While changing the level of relative humidity did not show a noticeable trends for the mica surface, the glass surface seemed to follow a parabolic curve with the lowest contact angles being around 60 %RH and becoming increasingly hydrophobic as the humidity is increased or decreased.

Conclusion

This research is still ongoing but as of yet there is no significant data that suggests a silicate's surface wettability is affected by different levels of relative humidity.

That said, since there are still many tests to be performed it is not possible to declare this alternative to froth flotation feasible or unfeasible.

Future Work

This project is still in it's very early stages and the results so far do not indicate if the alternative separation is feasible or not. Thus many more experiments will be needed before any full scale test can be done. Some such experiments may include the following.

•Irregular surfaces

Currently the substrates being tested are relatively flat and uniform, but if this idea is ever to get off the ground then material with irregular surfaces, such as those common to mineral particles following steps of comminution, will have to be tested as well.

•Multi-mineral systems

Although more than one mineral is being tested now, each one is isolated from the other. It will eventually become necessary to see how things may change if more than one mineral is present throughout the experiment.

•Different modes of surfactant application

Presently it is unknown how surfactants will be applied to the surfaces of minerals on when a bench scale test is in order. Some surfactants may be mixed with the ground material in a dry state before entering the reactor, while other might be sprayed on while in the reactor.

•Bench scale tests with fluidized bed reactor

This would be the last experimental stage before full scale. At this point it will be come possible to see in what manner will the system be ran to perform a separation

Acknowledgement

Research made possible by NSF Grant No. 1460912

A special thanks to those who had helped

- Dr. Alfred Boysen; Professor, Department of Humanities
- Dr. William Cross; Associate Professor, MET Department
- Dr. Jon Kellar; Professor/Douglas Fuerstenau Professor, MET Department
- Dr. Michael West; REU Site Director, Head of MET Department
- John Handley; Research Partner

Works Cited

- Standard Practice for Maintaining Constant Relative Humidity by Means of Aqueous Solutions. (1998). In Annual book of ASTM standards (Vol. 11.03, pp. 781-783). West Conshohocken, Pennsylvania: ASTM International.
- Cobb, W. (2014). CDP 2014 Water 2014 Information Request. Retrieved June 29, 2015, from <http://www.fcx.com/sd/pdfs/ProgrammeResponseWater-2014.pdf>