Homogenous Turbulent Mixing for Reducing Entrainment in Copper SX

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ABSTRACT

Freeport-McMoRan Copper & Gold in conjunction with Turbulent Technologies Ltd. (TT), and Tenova Bateman Technologies has tested TT mixing at the Technology Center (TC) Modoc Test Facility. Non-uniform energy dissipation in a primary mix box causes a wide distribution of droplets sizes with fine droplets being the primary concern. Fine droplet sizes do not readily coalesce, and are often the majority source of organic entrainment in aqueous.

TT mixing technology generates homogenous energy dissipation throughout the auxiliary mixer volume, resulting in effective coalescence of fine droplets. Due to higher coalescence rates larger droplets are formed, resulting in more effective phase separation.

Large pilot scale testing occurred at the TC with two trains side-by-side. One train was a control parallel-strip train run with and without hydrofoil auxiliary mixing, whereas the experimental train utilized TT auxiliary mixing technology. Both trains utilized a primary pump mixer with curved vanes at maximum speed to increase the generation of fines. Results, under the conditions tested, demonstrated that TT auxiliary mixers decreased organic entrainment in aqueous by 50-75% as compared to the control train. TT system performance yielded lower organic losses during plant instability due to forced phase continuity changes as compared to primary mixing only.

BACKGROUND

Turbulent Technology Ltd. (TT) auxiliary mixing was tested by Freeport-McMoRan Copper & Gold on a large pilot scale at the Technology Center Modoc Test Facility for several weeks.

Working at the confluence of hydrodynamics, physics, and chemistry, Turbulent Technologies has developed a unique mixing technology based upon a combination of Kolmogorav's theory of isotropic turbulence, surface physical chemistry (DLVO theory, which combines Van der Walls forces and Double Layer theory), and Turbulent Technologies' own proprietary systematic research. TT mixing technology utilizes homogenous energy dissipation throughout the auxiliary mixer volume, resulting in more effective coalescence of fine droplets. For each mixing unit the turbulent energy distribution is optimized to provide necessary conditions for efficient mass transfer, while also creating an emulsion of large droplets. Due to larger droplets being formed, and a narrower droplet size distribution, efficient phase separation occurred.

The experiment was set up on 2 separate extract-strip trains. Each train had an independent organic loop, but PLS and electrolyte was shared. "B" train was the control train. Standard hydrofoil auxiliary mixers were installed in the secondary mix boxes of B train. Baffles in B train were unmodified. In each primary mix box was a standard, curved vein impeller. The test plan was to run both trains in a side-by-side configuration for 8 weeks. The first 4 weeks were run in aqueous continuity and the latter weeks were run in organic continuity before a plant upset was simulated. During this time organic and aqueous entrainment measurements, O/A ratios, organic and crud depths, mixing speed, flows, and extraction efficiency were monitored. All primary impellers were run at 100% throughout the trial. "A" train was the experimental train. TT auxiliary mixers and baffles were installed on both the extract and strip stage secondary mix boxes.

During the trial, flows, O/A ratios, depths and organic composition in each train were maintained as closely as possible. Organic and crud depths, organic and aqueous entrainment, break times, O/A ratios, were monitored regularly. Strip stage O/A ratios were maintained at 1.5 and in organic continuity throughout the test. Any change of O/A is strictly referring to a change in extract stage O/A.

A 0.8 O/A ratio was held for the first 4 weeks. During this time extractor mix boxes were in aqueous phase. For the next 3 weeks, a 1:1 O/A ratio was maintained, with the extractor mix boxes in organic phase. A 0.4 O/A was then briefly targeted to simulate plant upset conditions, but was not sustainable and the trains were reverted to a 1:1 O/A ratio for another week. The final entrainment data was measured at an O/A of 0.7.

While the O/A changes were being made, mixer speeds were also varied. Most SX plants within Freeport-McMoRan run with no auxiliary mixing, so the majority of the data from the control train was recorded with the auxiliary mixer off. During the first 5 weeks of the test the control auxiliary mixer speed was decreased from 100% to 0%, while the TT auxiliary mixer was varied in frequency per TT recommendations.

RESULTS & DISCUSSION

Entrainment measurements were collected throughout the trial, and are shown in Figure 1 and Table 1. Organic entrainment was consistently lower on the extract stage through the trial on A train (TT auxiliary mixing). Before the auxiliary mixer was shut off, mixing speed on the control train was slowly ramped down (10% the first day, 20% each additional day). TT mixing speed was also varied, but within the power zone recommended by Turbulent Technologies. More data was collected in aqueous continuity due to the daily changes in auxiliary mixing speed. Changing from aqueous to organic phase continuity in extract stage mix boxes (indicated on Figure 1 by the second dashed line) further reduced entrainment on B train (control train). The phase continuity change, however, showed little effect on A train. Despite this effect, A train entrainment measurements continued to be lower than B train. When the trains were set to a 0.4 O/A ratio to simulate an upset, both entrainments rose sharply. While running at this O/A ratio, A train continued showing approximately 50% of the organic entrainment in comparison to B train. Running under upset conditions, however, was not possible to continue for more than a single day, so only 1 data point was recorded during this period. Several days passed before the plant recovered, and the final entrainment measurements were collected at a 0.7 O/A.

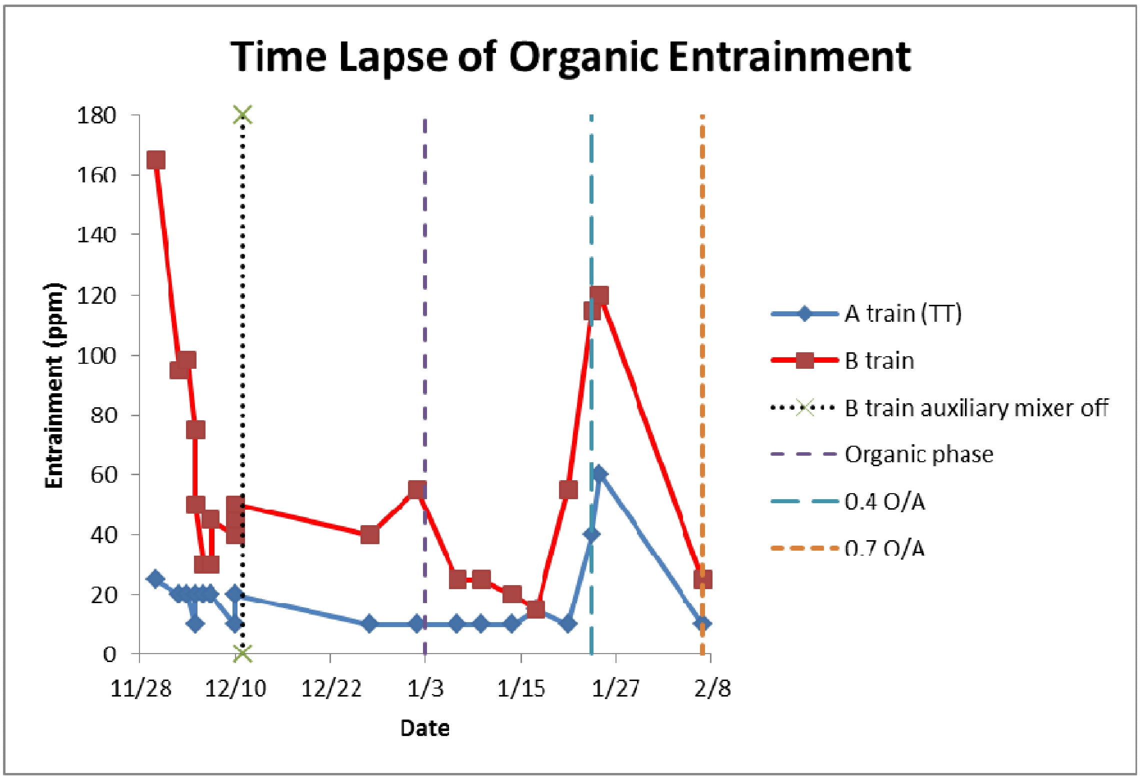

Figure 1: Organic entrainment and major occurrences during trial.

Table 1 shows organic entrainment, mixer speed, and O/A data recorded throughout the trial on both extract stages. Overall, the average organic entrainment measured was significantly lower using TT technology versus the control train.

Table 1: Extractor organic entrainment, O/A, and mixing speed throughout the trial.

Organic Entrainment in Aqueous (ppm)					Mixer Speed	
Date	TT E1A	Control E1B	E1A O/A	E1B O/A	TT E1A (%)	Control E1B (%)
11/30	25	165	0.82	0.82	93	100
12/3	20	95	0.82	0.82	93	100
12/4	20	98	0.82	0.82	85	90
12/5	10	75	0.83	0.83	85	90
12/5	20	50	0.80	0.82	82	70
12/6	20	30	0.83	0.83	82	50
12/7	20	30	0.82	0.80	82	50
12/7	20	45	0.82	0.80	80	30
12/10	10	40	0.82	0.72	80	30
12/10	20	45	0.80	0.72	73	10
12/10	20	50	0.80	0.72	65	0
12/27	10	40	0.78	0.75	65	0
1/2	10	55	0.81	0.74	65	0
1/7	10	25	1.00	0.92	65	0
1/10	10	25	1.00	0.96	65	0
1/14	10	20	1.00	0.92	65	0
1/17	15	15	1.00	0.94	65	0
1/21	10	55	0.92	0.92	65	0
1/24	40	115	0.40	0.38	65	0
1/25	60	120	0.60	0.59	65	0
2/7	10	25	0.70	0.68	65	0
Average	19	58				

Table 2 includes organic entrainment data and mixer speed data for the strip stages throughout the trial. Strip stages are always maintained in organic continuity, and O/A was kept at 1.5 for the duration of the test. Results show that there wasn't an improvement in organic entrainment between TT mixing and the control strip stage. Traditionally, organic entrainment is low in strip stages, and often not a concern. Mixer speeds were adjusted at the same time and increment for strip and extract stages.

Aqueous entrainment in organic was also measured throughout the trial. Aqueous entrainment can negatively affect pH levels in extract stages if it is too high in strip stages, therefore reducing extraction efficiency. This was not exhibited during the trial due to low entrainment levels. Aqueous entrainment data is shown in Table 3. While testing, the VFD on the TT S1A mixer experienced a large power bump from lightning, and was subsequently damaged. Due to the extensive damage, the mixer was not running for several weeks, and only 2 measurements were taken prior to the event. The data collected shows a slight increase in aqueous entrainment in the strip stage, but it is impossible to tell if this trend would have continued through the test. Aqueous entrainment on extract stages was similar. Overall, no benefit to aqueous entrainment reduction was exhibited by TT mixing.

Table 2: Organic entrainment and mixing speed for each strip stage

Organic Entrainment in Aqueous (ppm)			Mixer Speed	
Date	TT S1A	Control S1B	TT SIA (%)	Control S1B (%)
12/4	20	10	85	90
12/5	20	10	85	90
12/5	20	15	82	70
12/6	10	10	82	50
12/7	0	0	82	50
12/7	0	0	80	30
12/10	5	0	80	30
12/10	10	10	73	10
12/10	10	10	65	0
12/27	10	10	65	0
1/2	10	10	65	0
2/7	10	30	65	0
Average	10	10		

Table 3: Extract and strip stage aqueous entrainment in organic.

Aqueous Entrainment in Organic (ppm)				
Date	TT E1A	Control E1B	TT S1A	Control S1B
12/5	25	0	50	0
1/2	50	0	200	100
1/7	0	0		
1/10	50	0		
1/14	0	0		
1/17	0	0		
1/21	0	50		
1/24	200	250		
Average	41	38	125	50

Figure 2 illustrates organic entrainment while varying mixing speed at a constant O/A ratio of 0.8. The auxiliary mixer was eventually shut off to represent the majority of full-scale plants within Freeport-McMoRan Copper & Gold. Mixer adjustments were only made during the first two weeks of the test.

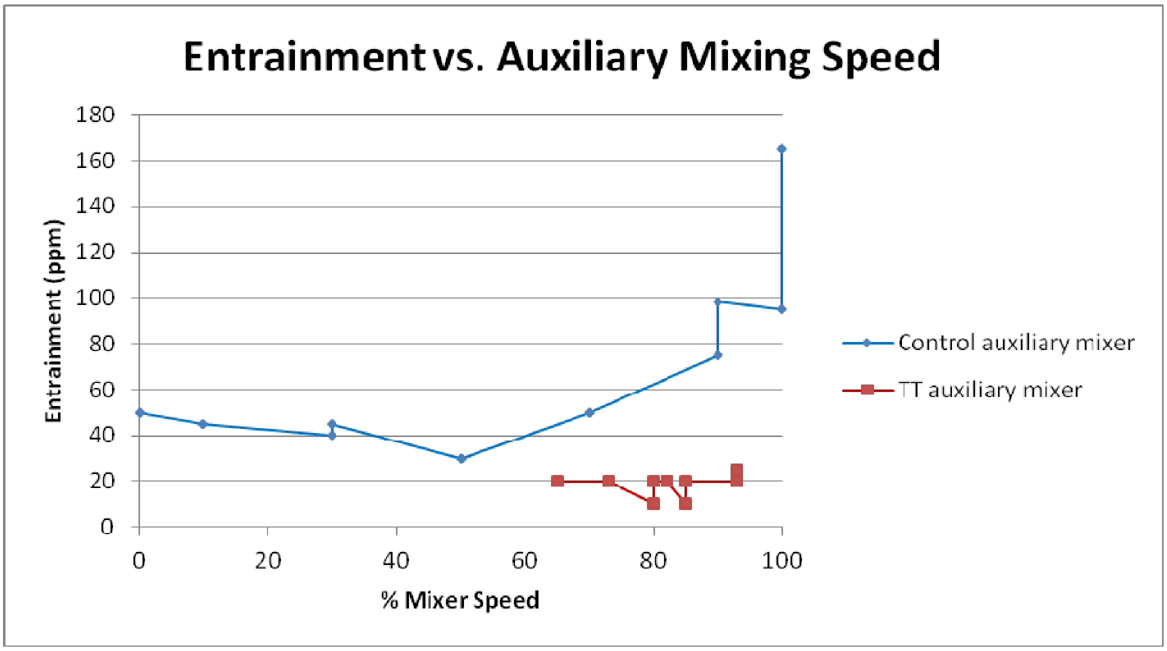

Figure 2: Organic entrainment was measured at a constant O/A ratio while varying auxiliary mixing speed.

Crud volume and break time data is shown in Table 4. Crud was measured on a weekly basis by doing 32-point settler profiles and using Riemann's sum numerical integration to determine overall quantity of crud. The data reported is crud that formed after the initial 0.8 O/A aqueous phase, as well as the 1.0 O/A organic phase. A train generated approximately 29% more crud than B train throughout the trial. Although this is a significantly larger amount of crud, the crud did not have a negative effect on entrainments, and the A train did not experience a crud run throughout the test. The observed increase in crud volume may have been caused by air being incorporated into the mixture due to the small distance from the mixer to the surface of the liquid in the auxiliary mix box. At a production scale installation where the distance from the impeller to the surface of the liquid in the mix box is greater, additional crud formation is not anticipated. Break times were within operator error to be considered equal for both phases. Difference in aqueous continuity average break times were within ± 0.1 seconds after 4 weeks, while organic continuity break times were within ± 3 seconds.

Table 4: Crud volume and average break time for aqueous and organic continuities

Crud Volume (gallons)			Break Time (seconds)	
Trial	TT	Control	TT	Control
AC	70	53	88	88
OC	62	41	57	54
Total	132	93	n/a	n/a
Difference (%)	29.3			

Metallurgically, the trains performed equally. This can be attributed to the organic composition and primary mixer speeds. Both trains had an organic composition consisting of 10% reagent, enough to capture the maximum amount of copper in a single stage. This, in addition to having primary mixers run at full speed, resulted in 100% stage efficiency in the primary mix boxes. Metallurgical data from the first 7 weeks of the trial are shown in Table 5.

Table 5: Metallurgical aspects for both trains during testing

Turbulent Technology (A train) vs. Control (B train) (1)					
		AC		**OC**	
Analysis by:	**Aspect**	**Delta**(2)	**% Difference**(3)	**Delta**(2)	**% Difference**(3)
TF Assay	**Recovery %**	-0.08	-0.09%	0.17	0.18%
Casc Assay	**Cu Transfer/vol %**	0.00	2.13%	0.00	-0.9%
Casc Assay	**Fe Transfer/vol%**	0.00	-1.45%	0.00	-1.05%
Casc Assay	**Cu/Fe Selectivity**	1.36	0.60%	0.83	0.91%
Flow Meter	**Organic Flow**	0.13	0.50%	0.00	-0.01%
Flow Meter	**PLS Flow**	0.06	0.21%	0.26	0.93%
Flow Meter	**LE Flow**	0.12	0.84%	0.02	0.36%
Casc Assay	**Recovery %**	-0.23	-0.24%	-0.22	-0.23%

(1) Positive numbers indicate A train greater than B train, negative numbers indicate B train greater than A train

(2) Delta is difference between the average values of each aspect for each train

(3) Relative difference between averages of the trains

The test work has shown that Turbulent Technology auxiliary mixing works well in a large pilot scale extract stage. Robustness to plant upsets, and varying conditions was exhibited throughout the test period. TT auxiliary mixing also exhibited no negative effects metallurgically, although it did show higher crud formation.

CONCLUSIONS

After trialing Turbulent Technologies auxiliary mixing on a large pilot scale level it can be determined that TT mixing has a significant positive impact on extract stage organic entrainment in this setting. Organic reduction in excess of 50% was exhibited at times. There were also no negative effects on metallurgical data. Crud generation was the main concern with TT mixing. More crud formed in the TT extract stage. Although it did not cause a crud run or increased entrainments, it is still something to be monitored at a full-scale. If the crud formed because of the introduction of air via proximity of the impeller to the surface of the liquid level in the auxiliary mix box, then there may be no issue on a large scale. Further large scale testing will confirm or reject this hypothesis.

The pilot scale trial has not shown any benefits for TT mixing in strip stages running under the tested conditions. There was no improvement in organic entrainment, and aqueous entrainment was slightly elevated.

FUTURE WORK

Turbulent Technology auxiliary mixing is to be tested on a large scale SX plant at Freeport-McMoRan Operations. There are crucial measurables in determining expectations and effectiveness. In large scale testing it is expected that changes in flow, reagent concentration, and copper concentration reporting to the SX plant will occur. Crud must be monitored closely, as a higher amount of crud was exhibited at the Modoc Test Facility. Extraction efficiency will also be a vital KPI to monitor. With sudden flow and grade changes, it will be important to observe TT auxiliary mixing extraction efficiency in comparison to standard auxiliary mixing convention. Due to the stage efficiency at the Modoc Test Facility, it was impossible to determine TT effect on extraction efficiency at a pilot scale.