# DISCLAIMER

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# Brewery wastewater reuse for landscape irrigation

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Deliverable 6 – Final Report

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## Introduction

Joshua Tree Brewery (JTB) is a new brew house opening in the Village of Joshua Tree, which is an unsewered community situated at the north entrance of Joshua Tree National Park. The brewery anticipates a starting wastewater flow of 500 gallons per day (gpd) from the brewhouse. The black water generated from the bathroom and kitchen facilities are discharged to an existing septic system.

Given that the brewery will be discharging effluent to a leach pit that is associated with a nitrogen-impacted aquifer, the Joshua Tree Water Basin Authority required that the brewery identify and purchase a wastewater treatment system to address the brew house wastewater.

The specific requirements for effluent discharge into a leach pit include BOD ≤ 50 (milligrams per liter, mg/L), TSS ≤ 30 mg/L and TN ≤ 10 mg/L reported as monthly averages. The Aquacycl pilot system was run to determine how a full-scale system might operate for a 500 gpd installation for carbon removal.

The brewer was generating roughly 50 gallons per week of brew house wastewater throughout the 1-year pilot demonstration. The volume of 50 gallons per week was not enough to run the pilot in a non-stop continuous mode since the treatment capacity is 150 gpd at a flow rate of 0.1 gallons per minute (gpm). Therefore, continuous flow runs were only possible when enough wastewater was available.

When the system was operated under batch mode, the residence time for a single 150 gpd batch was between 7- and 14-days. When operated under continuous mode, the residence time for 150 gpd was 4-hours at a flow rate of 0.1 gallons per minute (gpm).

Effluent samples were collected under every condition to calculate the removal of BOD/COD, TSS and TN over time. Samples were processed according to EPA standard methods at the Aquacycl laboratory facility. Samples were also periodically sent to an EPA-certified analytical lab once per month for additional analysis and confirmation of BOD/COD ratio.

The Aquacycl pilot system consisted of 12 BETT™ reactors that were operated in hydraulic series, maceration pump, transfer pumps, PLC, HMI, feed tanks, microaeration unit, and a collection tank for treated wastewater. Figure 1 shows a schematic (1a) and image (1b) of the pilot unit at JTB.

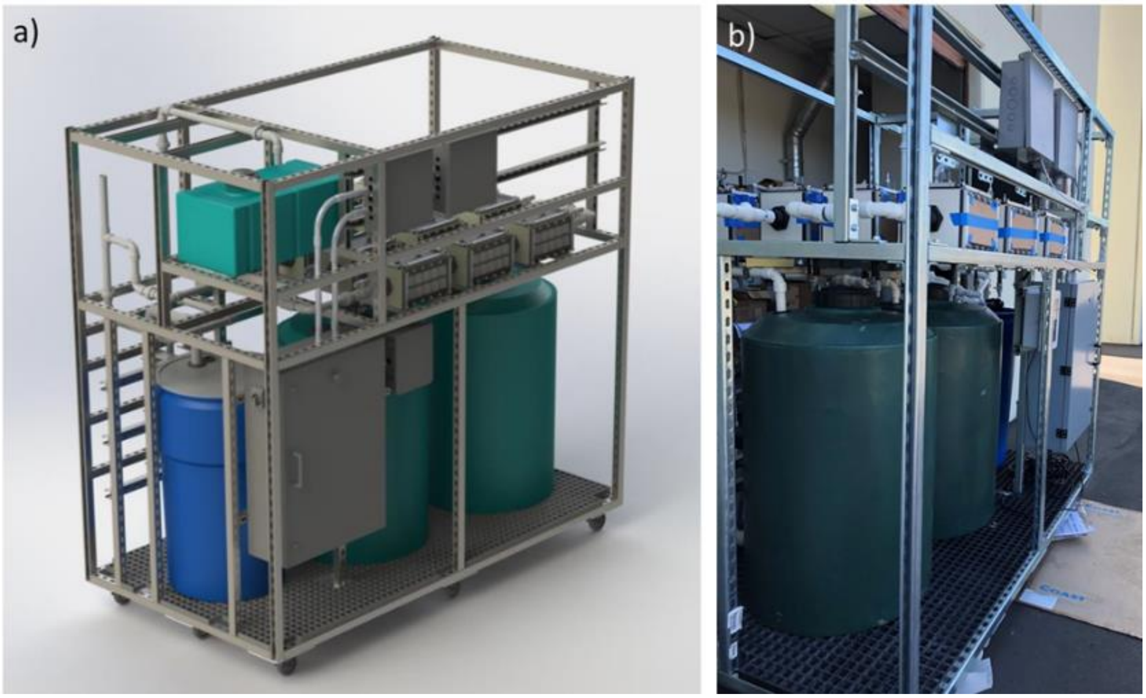



*Figure 1: Aquacycl BETT™ mobile pilot a) schematic and b) actual system.*

The system flow diagram is shown in Figure 2.

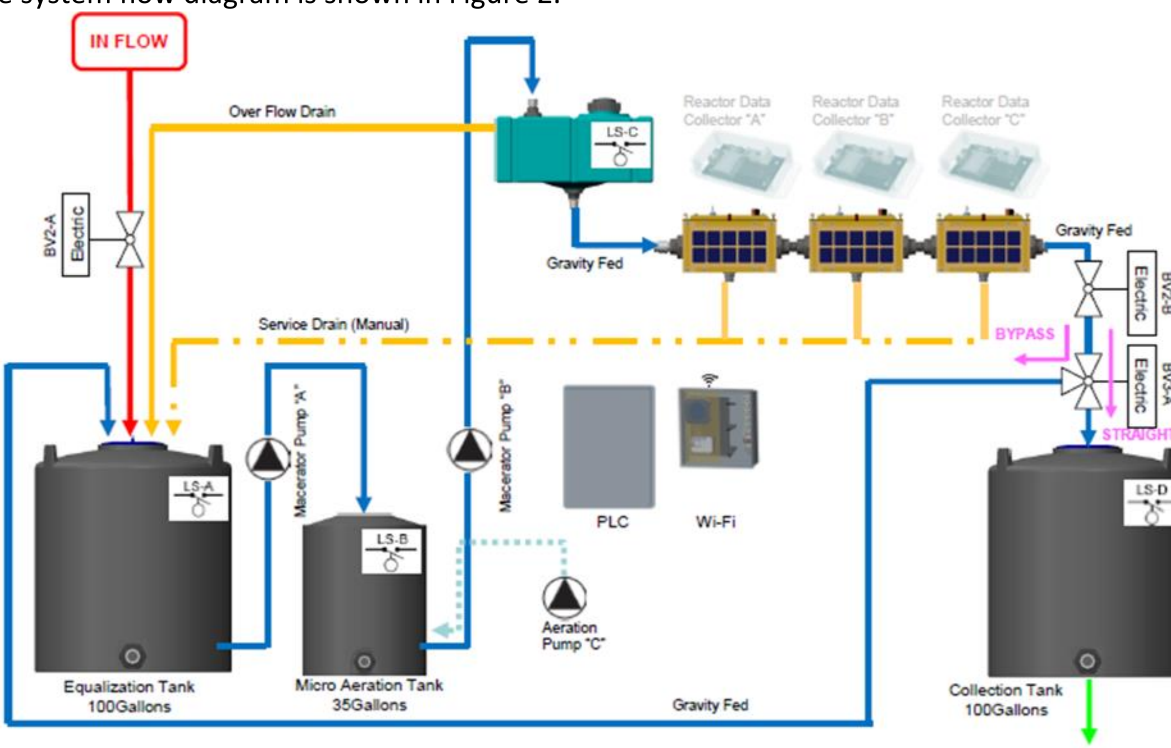



*Figure 2: Aquacycl BETT™ pilot flow schematic.*

To demonstrate irrigation quality reuse water, Aquacycl worked with BioLargo to install an Advanced Oxidation System (AOS) based on iodine chemistry for disinfection. The system was shipped to Aquacycl in mid-March 2019 and the system was installed on March 28, 2019. The treated effluent from the BETT™ system was captured in a 100-gallon collection tank. The AOS was fed from the BETT™ collection tank and operated over a 3-day batch to further treat the water including removal of residual carbon and microbial load. The outflow from the AOS was captured in the AOS collection tank and analyzed for treatment quality. Figure 3 shows the overall treatment scheme.

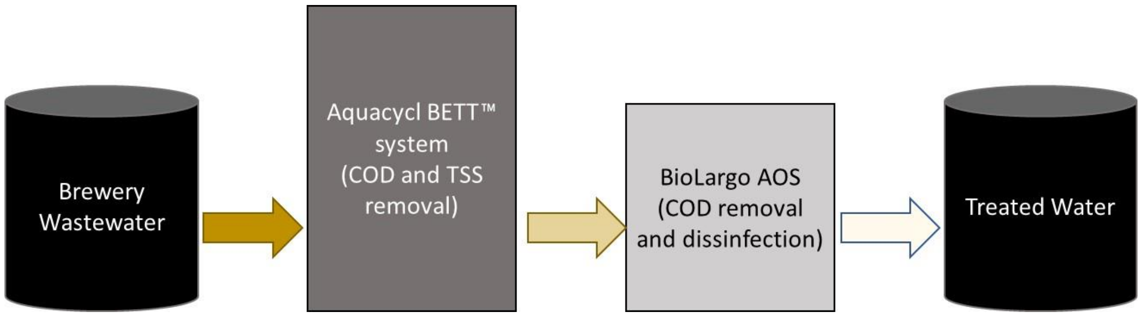



*Figure 3: Treatment scheme for Aquacycl and BioLargo integrated systems.*

Figure 4 shows a picture of the two systems integrated together. The fully integrated BETT™-AOS systems was operated periodically over a five-month period to determine disinfection treatment efficiencies and quality.

*Figure 4: Aquacycl BETT™ and BioLargo AOS installed at Joshua Tree Brewery.*

Aquacycl conducted testing of the JTB BETT™-treated effluents and provided samples to BioLargo to independently evaluate COD removal and disinfection efficiency. Disinfection efficiency was measured by BioLargo using standard plating methods and quantifying the colony forming units (CFU) present per one milliliter of wastewater (CFU/mL) before and after AOS treatment.

Joshua Tree Brewery is not yet open for brewing, so the Aquacycl team was running BETT™ with small batches of wastewater generated by homebrewing in Joshua Tree. Table 1 shows the batch removal results from BETT™ for the months of June and July, corresponding to the timeline that the AOS was operating consistently.

## Batch Treatment results from BETT™

Aquacycl conducted testing of the JTB BETT™-treated effluents for 15 cycles of batch operations (Figure 5).

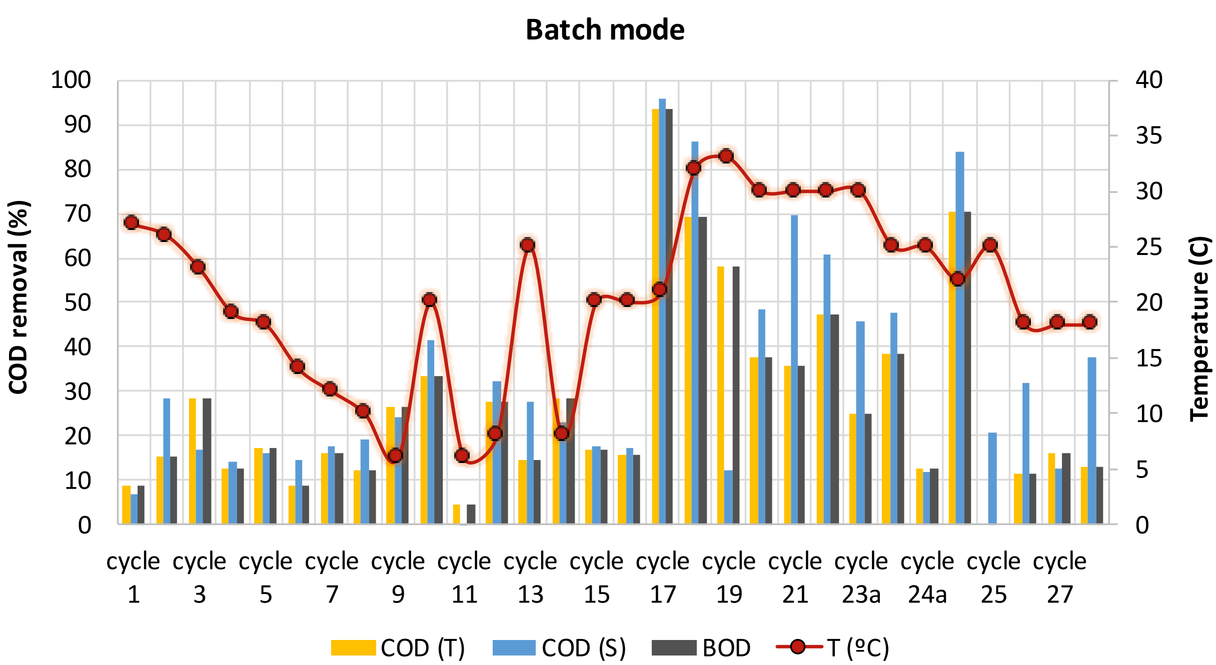



*Figure 5: COD/BOD removal (%) and Temperature as a function of batch cycle number over 1-year.*

Given that the BETT™ system only has twelve BETT™ reactors the %removal of BOD/COD from brewery wastewater was expected to be limited to 10-20%. However, during the warmer summer months, the 12 BETT™ reactors were able to remove a maximum of 93% of BOD and COD during a multi-day batch operation.

However, the BOD discharge concentration still exceeded the 30 mg-BOD/L limit given that only 12 reactors were in the treatment train and the starting concentrations of BOD were inconsistent and significantly high to begin.

With more reactors in a temperature-controlled container, the removal of BOD/COD is expected to consistently exceed 95% and produce effluents containing only 300 mg/L (or less) of total COD that can then be more efficiently treated with tertiary technologies.

The pH and conductivity profiles for BETT™ effluents are shown in Figure 6. The pH ranged between a minimum of 4.76 and a maximum of 10.46, with an average of 7.06 over the year. The conductivity ranged between a minimum of 1.46 mS/cm and maximum of 7.02 mS/cm, with an average of 3.92 mS/cm over the year.

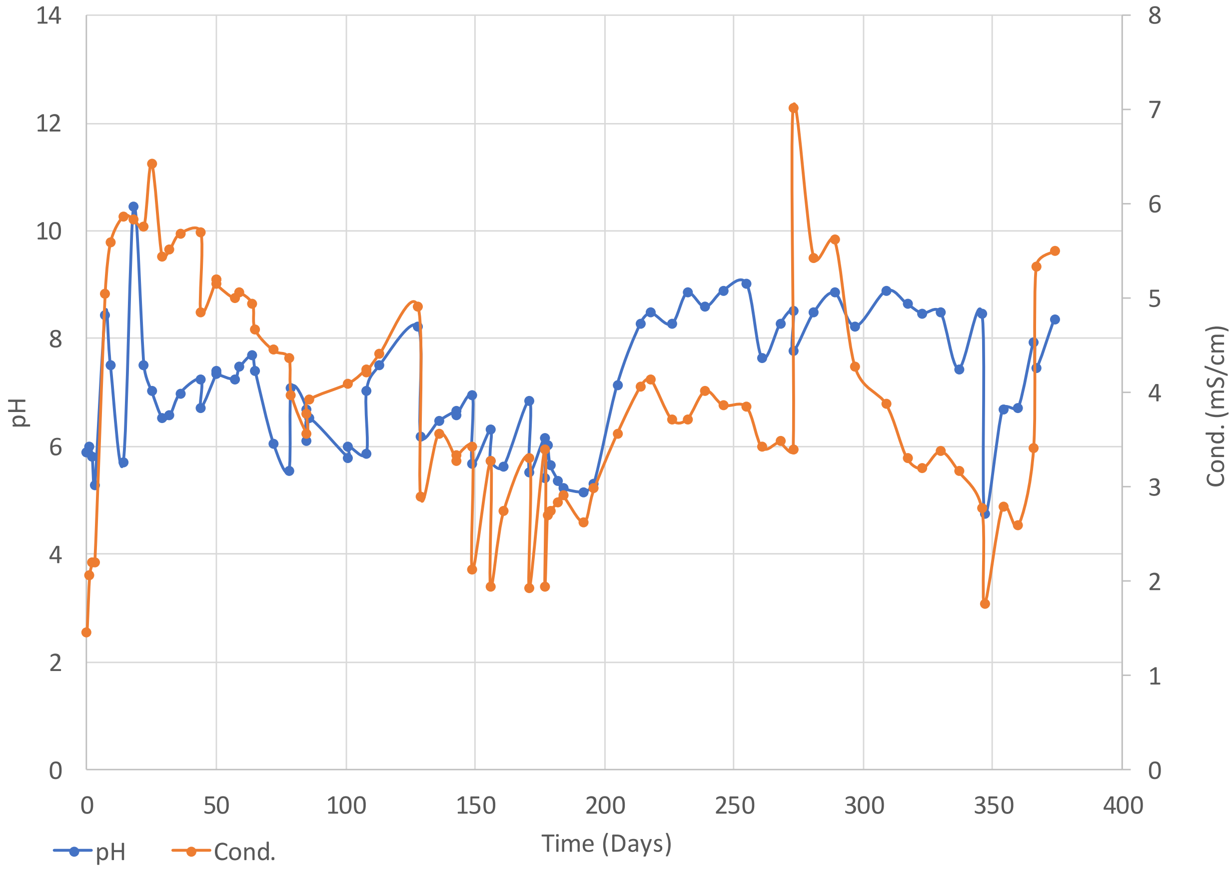



*Figure 6: pH (blue) and Conductivity (orange) readings from the BETT™ pilot system.*

The nitrogen cycle in the BETT™ pilot system showed a typical anaerobic nitrate reduction trend (Figure 7). A majority of nitrate and nitrite was converted into ammonium with each batch. Over the course of one-year operation, the batch cycles showed very reproducible trends with ammonium at a maximum when nitrate and nitrate were both at a minimum for the cycle. However, these data also indicate that additional nitrogen removal technologies will be required as post-treatment to BETT™ in order to accomplish the TN requirement of 10 mg-N/L or less.

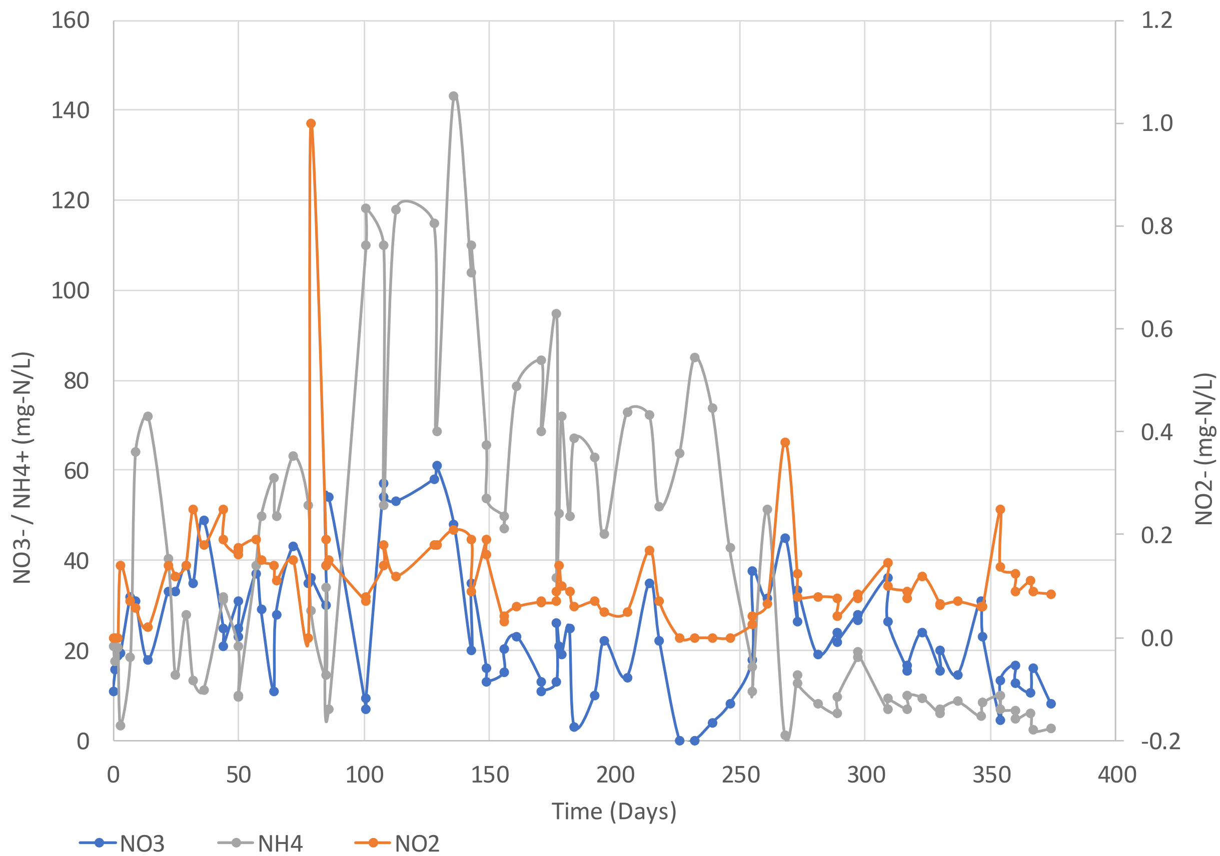



*Figure 7: Nitrate (blue), nitrite (orange) and ammonium (grey) profiles for each batch cycle over one year of operation. Nitrite concentrations are shown on the right axis. The chart shows starting and ending concentrations for each batch cycle.*

TSS removal was inconsistent and inconclusive throughout the test. The Aquacycl team will provide a sedimentation basin, along with other technologies, after BETT™ treatment in order to achieve TSS concentrations that are 30 mg-TSS/L or less.

The sulfur cycle also showed typical anaerobic results (Figure 8). However, it should be noted that the Aquacycl microaeration unit reduced the total sulfur concentrations that were ultimately fed to the reactors in each batch. The microaeration unit also helps to minimize odors for BETT™ operations. The overall sulfate and sulfide values recorded for each initial and final batch cycle concentration are significantly lower than typical brewery wastewater.

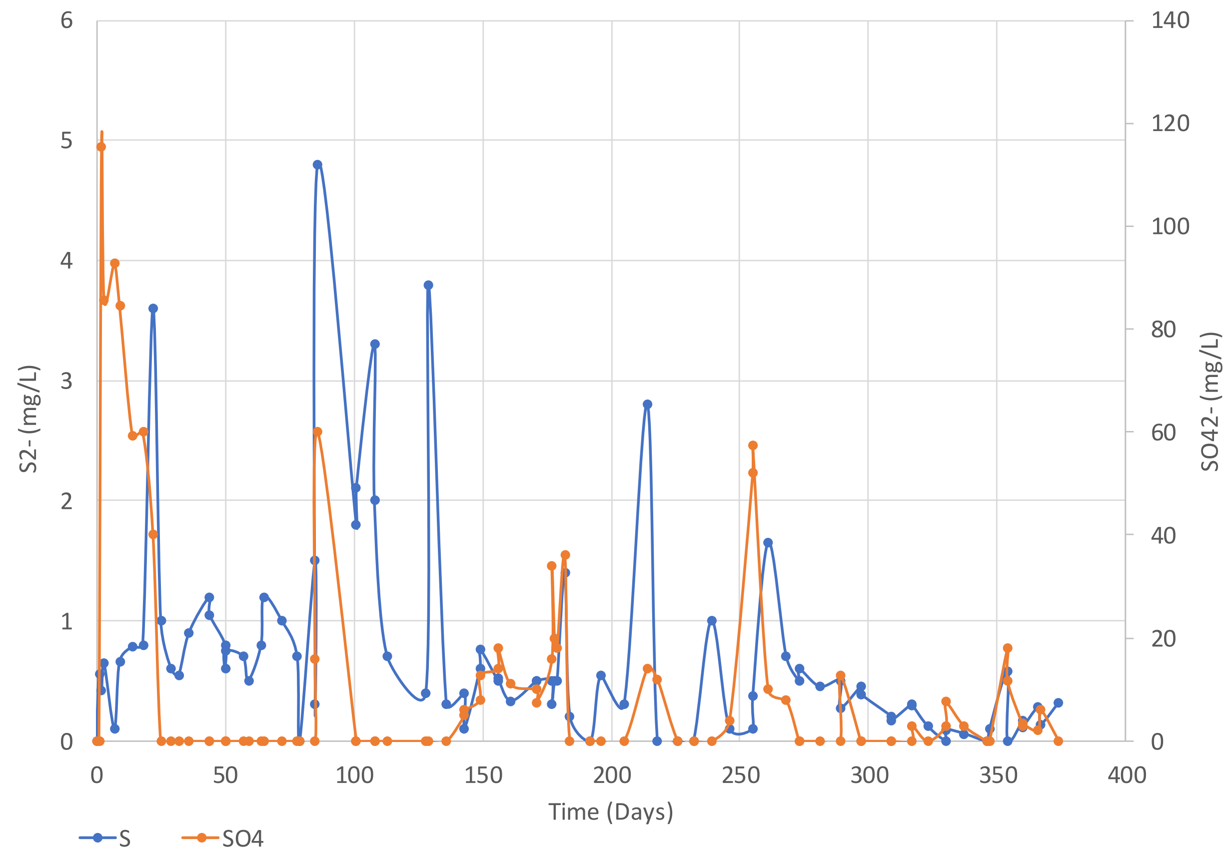


*Figure 8: Sulfide (blue, left axis) and sulfate (orange, right axis) concentrations for each batch cycle.*

The BioLargo AOS system was designed to disinfect wastewater with starting concentrations of 300 mg/L or less (preferably 30 mg/L). Therefore, the Aquacycl team captured BETT™-treated effluent and diluted it to 300 mg-COD/L as a starting feed concentration for the BioLargo AOS unit. All wastewater samples were diluted with tap water and fed to the AOS per BioLargo specifications. Table 1 shows wastewater treatment and disinfection results from samples that were analyzed independently at Aquacycl and BioLargo laboratories.

*Table 1: Wastewater treatment results and disinfection results generated from Aquacycl and BioLargo from samples collected at JTB.*

| **BioLargo data** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Parameter | Units | 6/12/19 to 7/17/19 | | 7/31/19 to 8/6/19 | | 8/6/19 to 8/13/19 | |
| | | Intial | Final | Intial | Final | Intial | Final |
| COD (T) | mg/L | 175 | 71 | 288 | 247 | 251 | 241 |
| SPIRAL PLATING CELL COUNTS ON LBA MEDIA | CFU/mL | 1.15E+07 | 2.55E+05 | 2.00E+06 | 0 | 8.10E+04 | 0 |
| | Log CFU/mL | 7.1 | 5.4 | 6.3 | 0 | 4.9 | 0 |

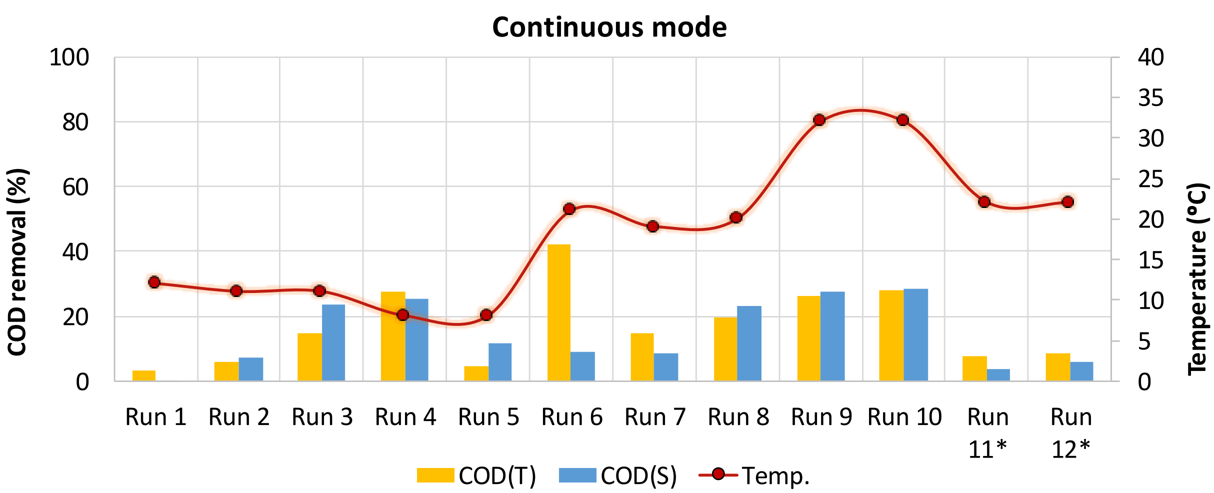
The AOS pilot was very efficient at disinfection; however, additional treatment technologies are required between BETT™ and any disinfection step in order to meet the discharge requirements for BOD, TSS and TKN, and to make disinfection more efficient.

## Continuous flow results from BETT™

The volumes of wastewater produced by the JTB brewery during the course of operation were not enough to sustain continuous flow throughout the evaluation period. However, 12 different continuous flow evaluations (Runs) were conducted over the course of the pilot operation (Figure 9).

Temperature also influenced performance in continuous operations mode. The highest COD removal trends correlated with the highest temperatures. The flow rates for each run varied from 0.1 to 0.2 gpm, with a system hydraulic retention times of 4- and 2-hours, respectively. The applied resistor across all BETT™ reactors was 200 Ohm for Run 1 through Run 7; and changed to 400 Ohm for Run 8 through Run 10. Run 11 and Run 12 were conducted with the reactors under a set-voltage condition, which did not show promising results.

The best continuous flow treatment results were observed during Runs 9 and 10, where the temperature was near 30°C, the applied resistor across BETT™ reactors was 400 Ohm, and the flow rate was 0.15 gpm.




## Future Directions

The 150 gpd BETT™ pilot was designed to validate the carbon removal results obtained in the lab. The batch flow results collected showed better results than what was observed in the laboratory and continue to validate the scalability of the BETT™ systems for reliable BOD/COD removal from high-strength waste streams.

The continuous flow tests revealed excellent treatment performance in very short time frames with instantaneous removals of 2,500 mg-COD/L. These data further prove that BETT™ reactors can be used successfully in practical applications as small-footprint, low-energy, and highly efficient treatment systems. With the integration of more reactors in a given treatment train, it will be possible to accomplish 90-99% removal of COD and BOD.

Post-treatment technologies will always be required after BETT systems to achieve stringent discharge requirements. In the case of Joshua Tree, total nitrogen removal, additional COD/BOD removal and TSS removal will be required and are planned for the full installation at the brewery.

The Advanced Oxidation System (AOS) provided by BioLargo was tested and operated periodically from April 1, 2019 to September 1, 2019 to demonstrate disinfection for irrigation reuse. The results to-date show excellent disinfection capacity from the AOS; however, an additional post-treatment system must be used between BETT™ and the AOS to remove BOD/COD prior to disinfection.