

# ANAEROBIC DIGESTION - IMPROVING ENERGY EFFICIENCY WITH MIXING

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## ABSTRACT

Anaerobic digesters continue to be a focus for processing wastewater solids to produce a renewable fuel source, digester gas. Effective mixing of the digester contents is important for process stability, maximizing gas production, minimizing scum and foam formation, and preventing solids deposition in the digester. Mixing requires electrical power which is often generated by coal-fired power plants. With the concern regarding electrical power cost and the interest in reducing greenhouse gas emissions, there is a renewed focus on reducing the power required for digester mixing. This paper reports the test results of a new mixing system called the Vertical Linear Motion Mixer (VLMM) manufactured by Enersave Fluid Mixer, Inc which was shown to have comparable performance to other more conventional mixing systems (impeller draft tube mixers) with substantially less electrical power needed. The test results represent testing conducted at the Ina Road Wastewater Reclamation Facility (WRF), located in Tucson, Arizona. One new mixer was retrofitted to a conventional “pancake” digester and compared to an identical digester using five impeller draft tube mixers.

**KEYWORDS:** Anaerobic digestion, mixing, mixer energy efficiency, mechanical mixing

## BACKGROUND

Effective mixing of the contents of an anaerobic digester is important for process stability, minimizing scum and foam formation, and preventing solids deposition in the digester. A more stable digestion process can be maintained with adequate mixing, which provides for a uniform distribution of solids throughout the digester, maximum contact of raw sludge with microorganisms, and prevents thermally stratified sludge layers.

Although most digesters contain some amount of scum and foam, excessive foam accumulation can interfere with gas collection piping and equipment. Scum and foam will accumulate on the liquid surface of the digester where there is inefficient mixing; therefore, sufficient mixing of the digester’s content is one way to reduce foam. Adequate mixing of digester contents can also minimize the deposition of grit and solids on the digester floor, which can reduce the active volume of the digester and result in expensive removal.

Mechanical mixing requires the use of electrical power; consequently, with the concern regarding the cost of electrical power and the interest in reducing greenhouse gas emissions albeit at a wastewater treatment facility or a power generation facility, there is renewed focus on reducing the power required for digester mixing without sacrificing digester performance.

The WRF, located in Tucson, Arizona and operated by the Pima County Regional Wastewater Reclamation Department, is rated for 435 l/s (37.5 mgd) and currently treats approximately 290 l/s (25 mgd). The plant operates four anaerobic digesters to stabilize a combination of primary sludge, waste activated sludge (WAS) from a high purity oxygen activated sludge system (HPOAS), WAS from a biological nutrient removal (BNR) train, and occasionally trickling filter solids from another facility.

The digesters are approximately 27 m (90 feet) in diameter and 12 m (40 feet) deep from the cone bottom to the high water level with an estimated capacity of 5581 m<sup>3</sup> (1,500,000 gallons). All the digesters were originally mixed with four peripheral 15 kW (20 hp) rotary draft tube impeller mixers positioned 90 degrees apart and one 7.5 kW (10 hp) rotary draft tube impeller mixer centered on the digester roof. The total installed power for the mixing system per digester was 67 kW (90 hp).

## **NEW MIXING SYSTEM INSTALLED**

A new mixing system, the VLMM system, uses a horizontal donut shaped thin steel disk, connected to a digester roof supported vertical shaft, and drive Cam-Scotch-Yoke drive to convert rotary motion of a helical-gear motor to vertical motion of the shaft. For the WRF installation, the disk is approximately 2.1 m (7 feet) in diameter and located 5.5 m (18 feet) below the digester liquid surface. The Hydro-disk moves in an “up and down” motion at 0.5 cycles per second. The controlled vertical movement creates strong axial and lateral agitation needed for good mixing of the digester contents. The mixer installed at the WRF and tested was supplied by Enersave Fluid Mixer, Inc. of Oakville, Ontario (Canada). Based on recent applications, installation of this type of equipment requires only one central mixer to fully mix the digester contents.

The new mixer was installed in December 2003 on a trial basis on one of the WRF digesters (Digester 4). The mixer performance was monitored by daily recording of volatile acids, alkalinity, pH, and temperature of the digester contents, and comparing these values with data for the three more conventional impeller draft tube mixed digesters at the plant. The trial continued until May 2005, when the digester was drained to check for possible grit buildup. No solids deposits were found; hence, the innovative mixer surpassed expectations and Digester 4 was returned to service. Figures 1 and 2 show the mixer installed in Digester 4.



**Figure 1. Enersave Fluid Mixer, Inc “Hydro-disk” schematic and installation photo.**

**Figure 2. Digester cover with new mixer and schematic of cam-scotch-yoke drive.**

## **DATA ANALYSIS**

To validate performance of the new disk mixer, a tracer test and a washout test were conducted using a lithium chloride tracer in Digester 4 which was equipped with a single disk mixer and in Digester 2 which was equipped with five impeller mixers. In addition to the analysis of the test results, historical operating data was also reviewed to assess long term performance.

Operational data for the period from January 2004 through the middle of April 2007 were used to analyze the performance of the existing mixing system and data from November 2006 through the middle of April 2007 were used to analyze the performance of the new mixing system. The data set included the following daily information:

- Flow from the gravity thickeners to the digesters.
- Total solids and volatile solids concentrations of the gravity thickener discharge.
- Flow from the dissolved air flotation systems.
- Total solids and volatile solids concentrations of the air floatation system solids.
- Flow from each digester.
- Total solids and volatile solids concentrations of each digester.
- Volatile acid concentration for each digester.
- Alkalinity for each digester.

The data collected was used to estimate the following operating parameters:

- Solids retention time (SRT).
- Volatile solids loading rate.
- Volatile solids destruction.
- Volatile acids to alkalinity ratio.

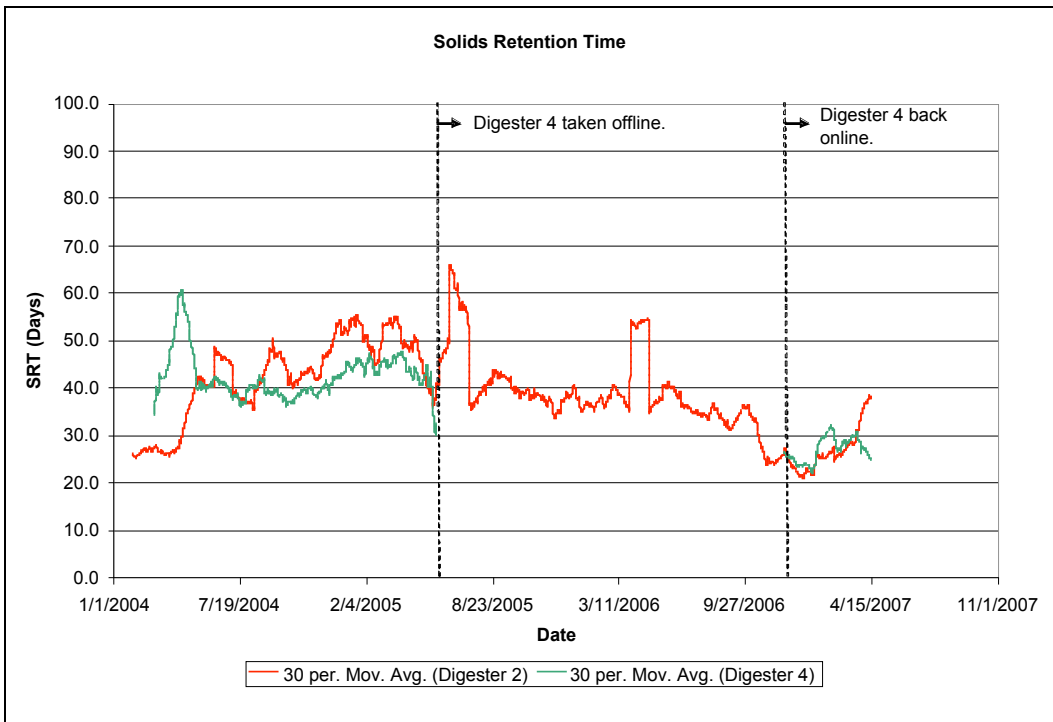
Figure 3 illustrates the solids retention time (SRT) in days for Digester 2 and Digester 4. The data are shown as 30 day moving averages to illustrate the average SRT rather than the day-to-day fluctuation of flow to the digesters. For most of the data evaluation period, the digester SRT was greater than 35 days which is significantly greater than the 15 days required by EPA CFR 503 to produce Class B solids. In the later part of 2006, the SRT decreased to approximately 20 days.

The volatile solids loading rate for each digester is shown in Figure 4. The data has been illustrated based on a 30 day moving average rather than on the individual data points. Over the past three years, the volatile solids loading rate (VSLR) has been steadily increasing. Typical loading for a mesophilic digester is approximately 1.6 kilograms per day of VS per cubic meter (100 pounds of volatile solids per day per 1,000 cubic feet). As indicated on Figure 4, the digesters were lightly loaded through mid 2006. In late 2006, digester loading steadily increased to between 1.28 and 1.44 kg/d VS/m<sup>3</sup> (80 to 90 ppd VS/kcf).

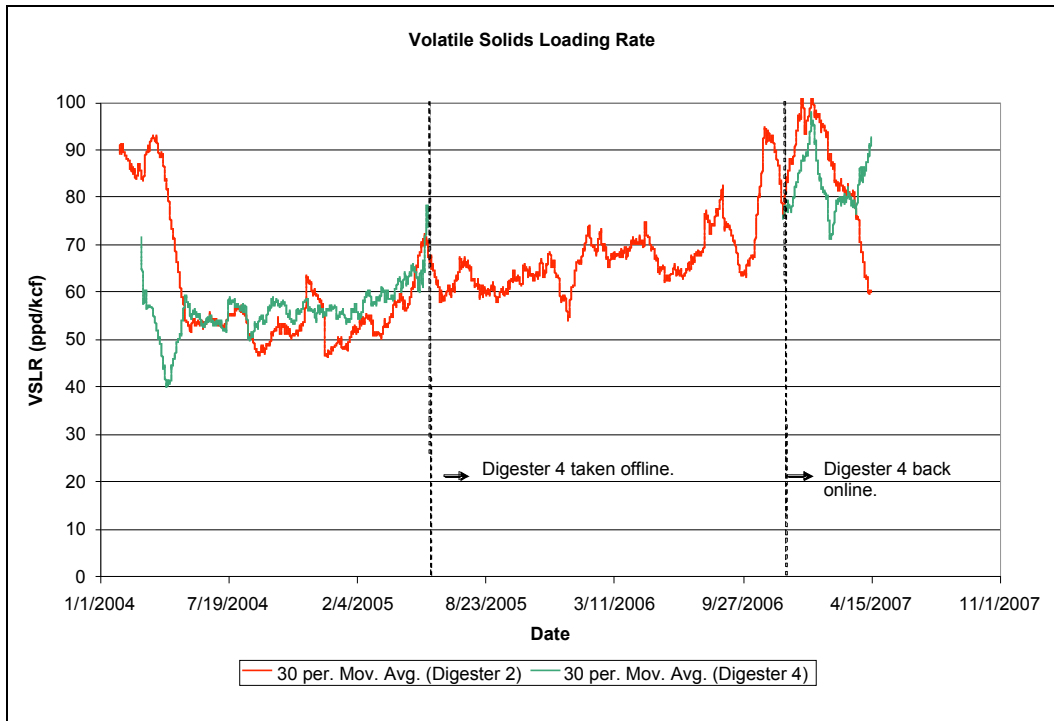
Figure 5 shows the volatile solids reduction (VSR) for the evaluation period. The VSR was calculated by the following equation.

$$VSR = (VS_{in} - VS_{out}) / (VS_{in} - (VS_{in} \times VS_{out})) \times 100$$

Where: VS<sub>in</sub> = volatile solids into the digester expressed as a decimal  
 VS<sub>out</sub> = volatile solids out of the digester expressed as a decimal

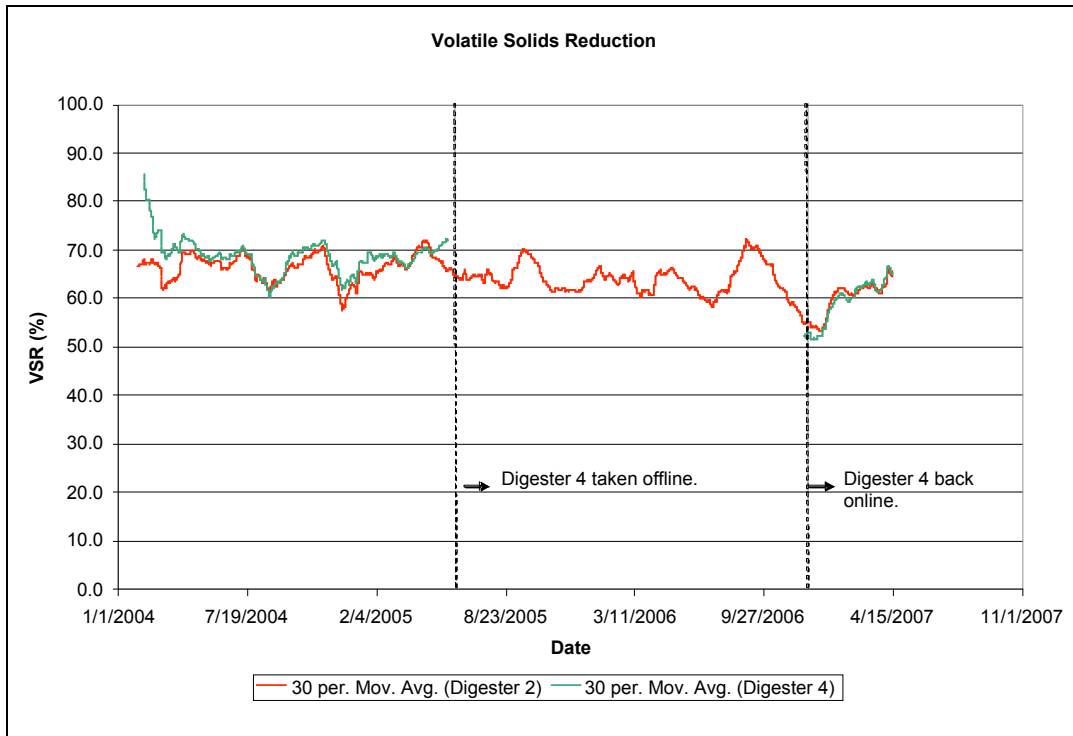


**Figure 3. Historical solids retention time (SRT).**



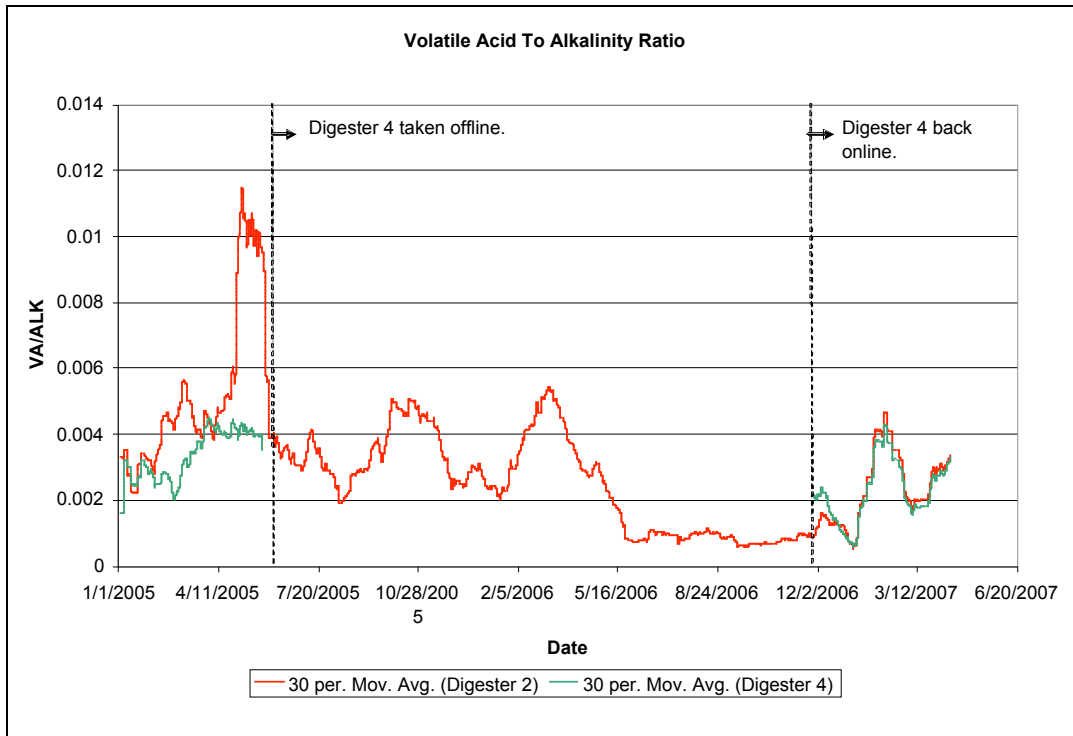
**Figure 4. Volatile solids loading rate.**

Based on the 30 day moving average, the VSR has typically been between 60 and 70 percent which exceeds the performance of most anaerobic digesters that receive both primary sludge and WAS. However, the performance is most likely explained by the large fraction of biodegradable solids fed to the digesters before mid-2006. During that time, primary sludge in combination with WAS from the HPOAS system were fed to the digesters. The HPOAS system operates at a very short SRT (typically around 1 – 2 days) which results in a WAS with a high biodegradable content. In mid-2006, the new BNR treatment train was put in service which operates at a longer SRT, i.e., 7 to 10 days. With the new BNR basins on line, less flow was treated in the HPOAS basins which resulted in an overall reduction in the biodegradable fraction of the solids fed to the digesters and therefore a decline in volatile solids destruction. This is illustrated on Figure 5 by the reduction in VSR in the middle of 2006. Independent of actual performance, it is important to note that the VSR performance for both digesters was equal.



**Figure 5. Volatile solids reduction.**

Figure 6 shows the volatile acids to alkalinity (VA/ALK) ratio which is an indicator of digester stability. When the VA/ALK exceeds 0.1, it is an indication that digester operation may become unstable. A VA/ALK ratio greater than 0.5 typically indicates an upset digester. As shown on Figure 6 the VA/ALK ratio for both Digester 2 and Digester 4 was never greater than 0.012 at any time during the evaluation, which reflects stable operating conditions.



**Figure 6. Volatile acid to alkalinity ratio.**

## TESTING METHODOLOGY

The tracer mixing test in Digester 2 and Digester 4 at the Ina Road WRF was conducted on March 15, 2007. Before starting the test, the mixing system in each digester was verified to be online and operable by observing the mixers. Three background samples were collected before the tracer was added to each digester to verify background concentrations of lithium. The tracer, a lithium chloride solution, was delivered to the site in four 55 gallon drums. A composite sample of each of the drum contents was taken before injection into the digesters to validate the concentration of delivered lithium chloride solution.

Because of the sludge feeding schedule, parallel testing of the digesters was not feasible. Testing of Digester 2 was started at 06:00 hours and testing of Digester 4 started at 12:00 hours by adding 416 liters (110 gallons), the contents of two drums of 40 percent lithium chloride, to each digester. After 4 hours, 8 hours, and 12 hours from the injection time, samples were collected from five locations for each digester and then refrigerated until transferred to the laboratory for analysis. The sample locations, illustrated on Figure 7, were as follows:

- Sample Location A – Discharge of the sludge discharge pump
- Sample Location B – Discharge of the heat exchanger
- Sample Location C – 12.5 feet below the liquid level
- Sample Location D – 7.5 feet below the liquid level
- Sample Location E – 2.5 feet below the liquid level

In addition to the tracer test, samples for total solids and volatile solids analysis were collected after 8 hours of mixing following the start of the lithium chloride tracer test. The samples were collected at the five sampling locations described previously and analyzed at the Ina Road WRF laboratory. The purpose of this test was to show solids uniformity within the digesters.

Temperature profiles were also developed as part of the digester mixer evaluation. Temperatures of the solids samples were taken and recorded using a thermometer. Temperature was also measured at the heat exchanger sampling location, but not included in the data analysis, as the temperature at this point was consistently higher due to heat added to the system at the heat exchanger.

A 30 day washout test was performed to estimate the actively mixed volume of each digester tested. Digester 2 had not been cleaned within the past 5 years whereas Digester 4 was cleaned approximately 1 year earlier; consequently, the apparent mixing performance of Digester 2 could be better as a result of a reduced actively mixed volume rather than the performance of the mixing system in Digester 2.

During the washout test, sludge samples were collected once each day for 30 days at the sample sink in the basement of the digester building and were analyzed for lithium. In addition, the volume of solids fed to each digester was recorded daily using a flow meter located in the digester building.

## **RESULTS**

The digesters have been significantly under-loaded as evidenced by the longer SRT of 30 days and the volatile solids loading rate less than  $0.96 \text{ kg/d VS/m}^3$  (60 ppd VS/1000cf), although toward the end of 2006, flows and loads were more comparable to industry-wide loadings. The results of the data evaluation showed comparable volatile solids reduction in Digester 4 and Digester 2 during the period when both digesters were in service.

The lithium tracer test showed comparable results for Digester 2 and Digester 4. Table 1 summarizes the results of the lithium tracer testing.



**Figure 7. Digester sampling locations**

**Table 1. Lithium tracer test results.**

Time (hrs)	Location	Digester 2			Digester 4		
		Value mg/L	Average mg/L	Difference %	Value mg/L	Average mg/L	Difference %
0	B	0	0	0	0	0	0
4	A	7.6		6.1	8.2		7.0
4	B	7.2		0.6	7.5		-2.1
4	C	7.0		-2.2	7.8		1.8
4	D	6.9		-3.6	7.8		1.8
4	E	7.1	7.16	-0.8	7.0	7.66	-8.6
8	A	7.2		0.6	7.1		-0.3
8	B	7.2		0.6	7.2		1.1
8	C	7.2		0.6	7.1		-0.3
8	D	7.0		-2.2	7.0		-1.7
8	E	7.2	7.16	0.6	7.2	7.12	1.1
12	A	7.9		3.7	7.2		-0.3
12	B	7.5		-1.6	7.2		-0.3
12	C	7.8		2.4	7.2		-0.3
12	D	7.3		-4.2	7.2		-0.3
12	E	7.6	7.62	-0.3	7.3	7.22	1.1

By the fourth hour of the test, all of the samples measured were within 10 percent of the average lithium concentration in both digesters. Consequently, both digesters were considered fully mixed. The similarity of the test results indicates that the two digesters achieved a similar degree of mixing. Neither mixing system showed a distinct advantage over the other in the lithium chloride test.

As discussed previously, solids concentration and temperature were measured throughout each digester to verify that the digester contents were homogenous. The testing showed similar results for both digesters with respect to uniform solids concentration and uniform temperature profile. The solids concentration of all samples were within 10 percent of the average solids concentration as shown in Table 2.

**Table 2. Solids concentration test results.**

Time	Sample Location	Digester 2			Digester 4		
		Total Solids	Volatile Solids	Difference*	Total Solids	Volatile Solids	Difference*
Hour		%	%	%	%	%	%
8	A	1.64	70.4	0.37	1.81	68.5	-0.55

8	B	1.64	69.4	0.37	1.86	69.6	2.20
8	C	1.66	70.4	1.59	1.79	68.4	-1.65
8	D	1.62	70.0	-0.86	1.83	67.3	0.55
8	E	1.61	69.4	-1.47	1.81	71.0	-0.55
* Total solids compared to average							

The temperature profile indicated uniform heating throughout both digesters as shown in Table 3.

**Table 3. Temperature distribution test results**

Time	Sample Location	Digester 2		Digester 4	
		Temperature		Temperature	
Hour		°C	°F	°C	°F
8	A	35.4	95.7	34.4	93.9
8	C	35.3	95.5	34.2	93.6
8	D	35.4	95.7	34.5	94.1
8	E	35.4	95.7	34.8	94.6

The washout test is most effective when the feed rate to the digesters is constant; however, variations in the daily pumping rate necessitated by the operation of the Ina Road WRF caused a departure from the conventional analysis techniques which utilize real time as a variable. Cumulative sludge pumped and actual digester volume values were substituted for real time and observed digester detention time, respectively. This can be demonstrated by analyzing the stirred reactor volume washout relationship as follows:

$$C = (C_0) (e^{-t/T}) \quad (1)$$

Where, C = Tracer concentration at time (t), mg/L

C<sub>0</sub> = Initial concentration of tracer at time zero, mg/L

t = real time, days

T = Digester hydraulic retention time, days

This equation can be modified by substituting the following relationship for T.

$$T = V/q \quad (2)$$

Where, V = Reactor volume, gallons

q = Sludge flow rate, gallons per day

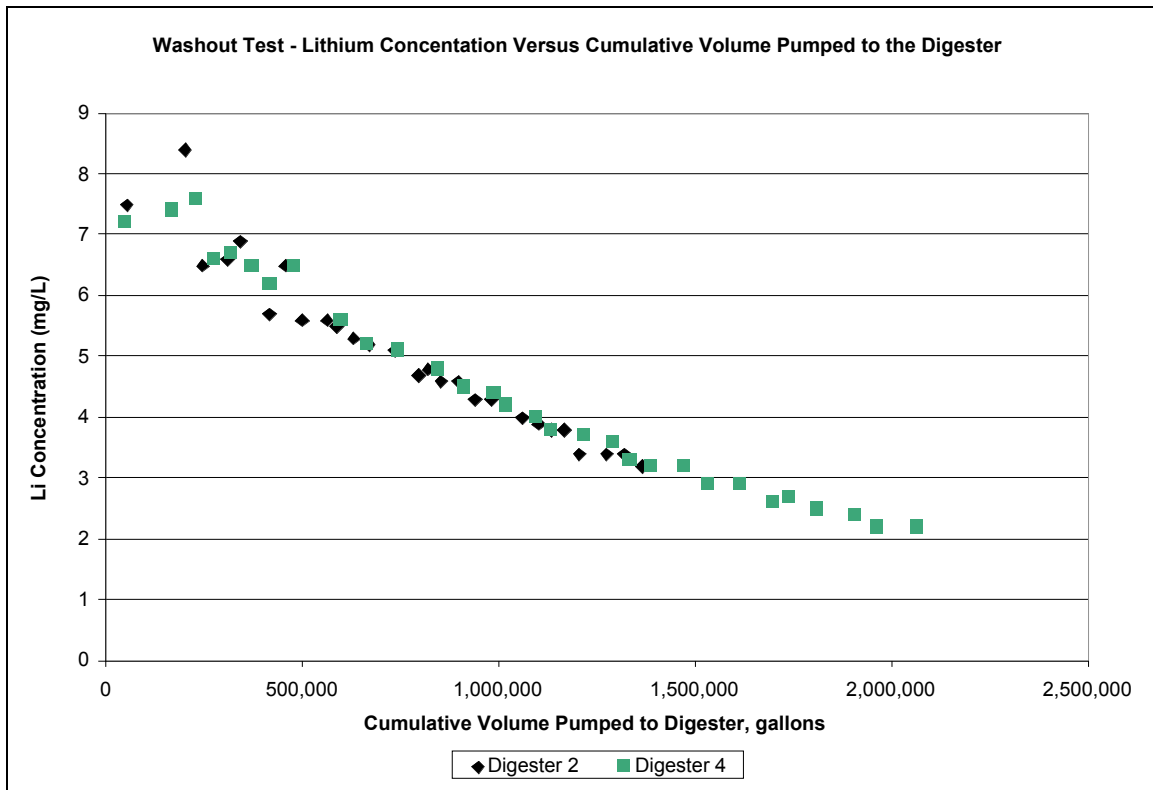
Substitution yields the following:

$$C = (C_0) (e^{-v/V}) \quad (3)$$

Where, v = cumulative sludge feed, gallons

V = actual or active digester volume, gallons

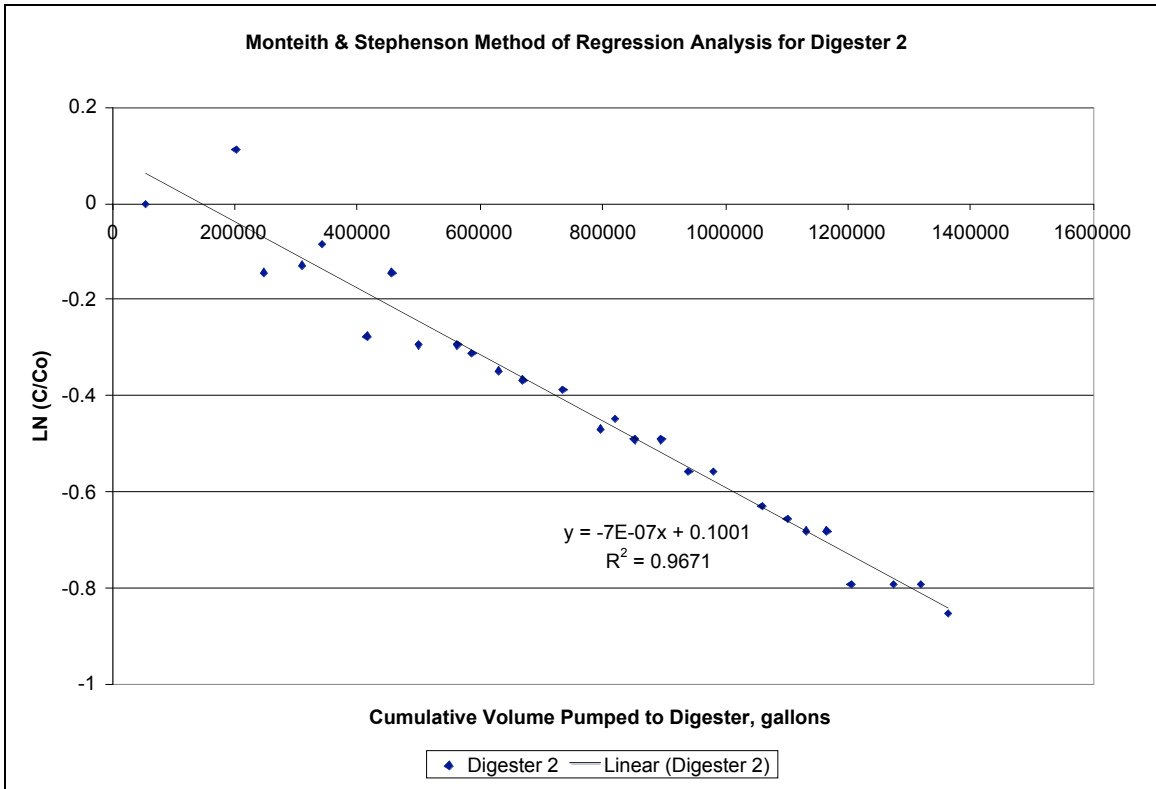
A plot of the measured volume against the cumulative sludge pumped volume to the digester is shown on Figure 8.



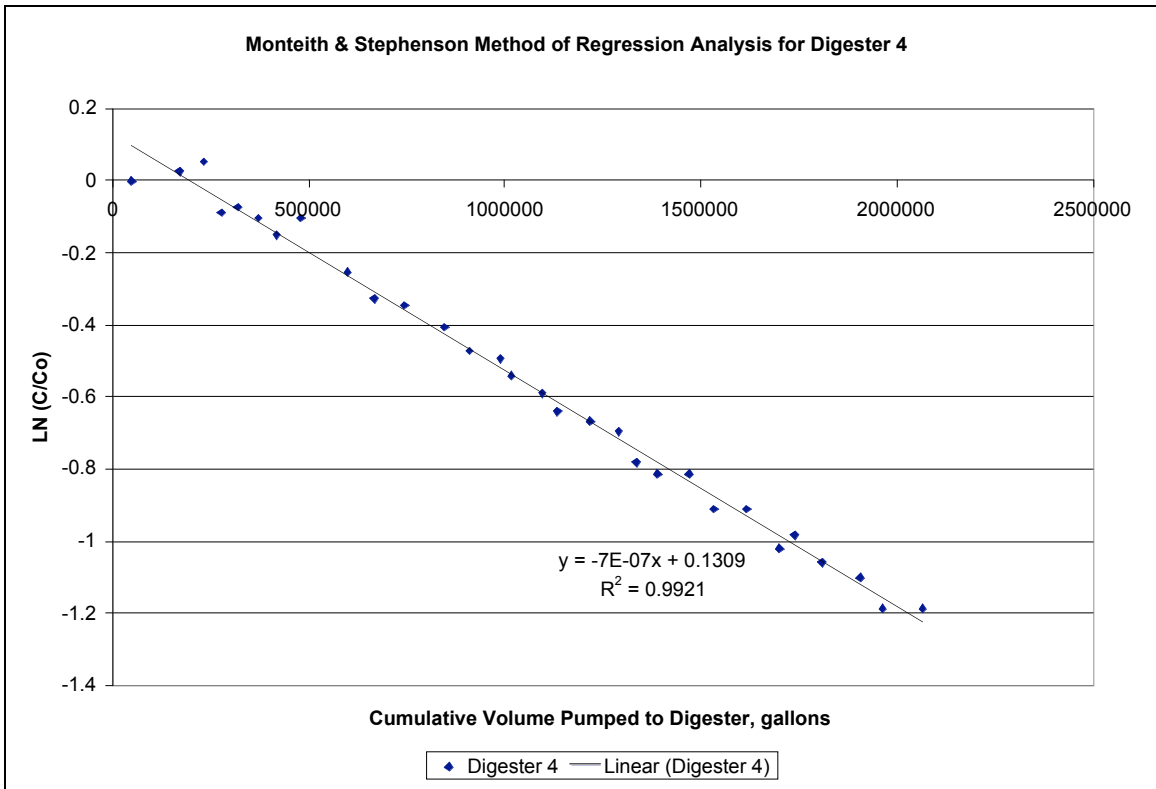
**Figure 8. Washout tracer test results**

The washout tracer test data were analyzed using several methods. The first method included the daily calculation of hydraulic retention time and averaging all hydraulic retention time values for the duration of the test. The average hydraulic retention time value was divided by the theoretical hydraulic retention time to calculate the percentage of actively mixed digester volume. The active volume for Digester 2 was calculated to be 106 percent and the active volume for Digester 4 was 115 percent.

This calculation yielded results that are clearly not representative due to the changing daily feed rate; consequently, a second analysis was conducted using a method described by Monteith and Stephenson (M&S). The model developed by M&S can be used to directly estimate the active volume. This method of analysis should be employed when there is a dead zone within the digester as well as the potential for some portion of the influent flow to short circuit the actively mixed zone. The slope of the regression line representing the natural log of the tracer concentration ( $C$ ) divided by the initial concentration ( $C_0$ ) against the cumulative volume ( $v$ ) is equal to the negative reciprocal of the actively mixed volume. A chart of this relationship is shown on Figure 9 for Digester 2 and on Figure 10 for Digester 4.



**Figure 9. Estimated active volume for digester 2.**



**Figure 10. Estimated active volume for digester 4.**

The estimated active volume was 96.4 percent for Digester 2 and 101.7 percent for Digester 4. While the calculated active volume for Digester 4 exceeded 100 percent which is impossible; the active volume estimations for each digester are within 5 percent of each other, and within the accuracy of the analytical method. It would also be expected that Digester 2 has a slightly smaller active volume, since it had not been cleaned before the test. Based on the results of the washout test, the disk mixer in Digester 4 provided sufficient mixing to maintain an active volume close to 100 percent which is a good indication of efficient mixing.

The unit power requirement for the disk mixing system was considerably lower than that of the existing impeller mixing system. Unit power, defined as the power rating of the mixing equipment divided by the digester volume (kW/m<sup>3</sup> or hp/1000cf), is often used to compare power used for mixing. Table 4 provides a comparison of the unit power requirements of the disk mixer with various other types of mixing systems.

**Table 4. Comparison of mixing energy requirements.**

Type of Mixing Equipment	Unit Power Rating	
	kW/m <sup>3</sup>	hp/1000cf
Hydro-disk	1,316	0.05
Impeller draft tubes	12,112	0.46
Other mechanical mixing*	5,226 to 26,330	0.2 to 1.0
Gas draft tubes*	5,266 to 7,899	0.2 to 0.3

\*EPA Design Information Report.

Based on the test results using the trial installation the disk mixer at the Pima County WRF, the disk mixer provides comparable mixing to impeller draft tubes and possibly other mixing systems, but at a fraction of the power requirement typically associated with digester mixing. It is important to note that the digesters were not highly loaded with respect to VSLR nor were they operated at high solids concentrations. Modifications of either of these parameters may or may not impact performance of the disk mixer.

## CONCLUSIONS

Based on the evaluation of historical data, the mixing test, and the washout test, the performance of the innovative mixing system was equal to that of the existing draft tube mixing system. The following are specific conclusions from the testing:

- All tracer samples and solids samples showed comparable results between Digester 2 and Digester 4 which used impeller mixers and disk mixer, respectively. All samples were within 10 percent of the average concentration of samples from the five sampling ports of each digester for the specified period.
- The temperature profile of the digester contents showed uniform heating throughout both digesters tested.

- The disk mixer required 10 % (7.5 kW) of the energy required for the impeller draft tube mixers (67 kW) yet achieved comparable mixing.
- The operation and maintenance requirements and costs are expected to be reduced with the disk mixer based on the number of mixers (one disk mixer compared with five impeller draft tube mixers. The mechanical simplicity of the disk mixer is also expected to lower maintenance requirements in comparison with other mixing systems.

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