DEVELOPMENT AND APPLICATION OF A SYNTHETIC HIGH STRENGTH WASTE FORMULATION FOR EVALUATING AEROBIC TREATMENT UNIT PERFORMANCE

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ABSTRACT

Wastewater studies have often used various synthetic wastewater preparations to develop and evaluate new treatment solutions. In 2019 Texas A&M AgriLife Research was awarded a contract by the Texas Commission on Environmental Quality to investigate Aerobic Treatment Unit (ATU) performance under increasing organic strength combined with demand and time dosing schemes. A synthetic high-strength wastewater (SHSW) formulation was required to carry out the research. Several materials and compositions were considered based on cost, availability, ease of handling, and ability to produce organic loads needed to meet experimental plans. Dextrose, skim milk, and a grain-based animal feed were found to meet the desired criteria. Laboratory experiments were used to determine relationships between concentration and the 5-day biochemical oxygen demand (BOD_5) of each material. Two ATUs were installed in parallel at the Texas A&M Onsite Sewage research facility in Bryan, Texas. ATU hydrology was tightly controlled while amendment materials were simultaneously added to the raw waste stream to raise the organic concentration. SHSW amendments of dry animal feed were dispensed by hand while a liquid solution of dextrose and milk was delivered with an automated pumping system. After developing and tuning experimental ATU operational procedures, "high strength" BOD_5 concentrations > 300 mg/L were attained and used to evaluate system performance. In 9 separate, 14-day experiments, the ATU's under investigation successfully treated normal and high strength waste concentrations between 150 and 2900 mg/L BOD_5. There was minimal difference between demand and time dosing.

INTRODUCTION AND BACKGROUND

Onsite wastewater treatment systems are called On-Site Sewage Facilities (OSSF's) in Texas and are regulated by the Texas Commission on Environmental Quality (TCEQ). Texas A&M AgriLife Research partners with Texas A&M AgriLife Extension and Texas A&M University's Biological and Agricultural Engineering Department to provide state-wide research, extension, and educational services related to OSSF. In 2019, TCEQ awarded AgriLife Research a grant to investigate the performance adequacy of Aerobic Treatment Unit (ATU) designs, tested under NSF/ANSI Standard 40 (2018), when used with reduced hydraulic flows, increasing organic strengths and different dosing methods.

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ATU use for treating domestic wastewater in Texas has been increasing since the late 1990's with more than 350,000 permits issued between 1992 and 2017. This represents approximately 43% of all OSSF permits and the number has climbed above 50% in recent years. Concurrently while ATU use has increased, both organic strength and hydraulic flows in ATU's have changed due to the use of water conservation devices and graywater reuse. Influent flow has decreased due to conservation and reuse causing an increase in organic strength or concentration. Research to examine ATU performance and to investigate effects of dosing operations was carried out by AgriLife Research between 2019 and 2021. Project goals were to determine how current trends in water use (i.e., water conservation and greywater reuse) potentially affect ATU treatment efficiency and to determine if the addition of time-dosing to the treatment train could maintain or improve treatment efficiency.

The design and use of synthetic wastewaters for conducting research on various detection or treatment processes is a common practice (O'Flaherty and Gray, 2013). A recent Google Scholar search yielded over 555,000 publications containing the key phrase "synthetic wastewater" most of which described studies investigating a single water-born constituent detection or treatment process. Wittwer and Heger (2011) noted that formal procedures for creating a standardized synthetic high-strength wastewater for general testing are limited and stressed the importance of considering both hydraulic flow and organic concentration to determine organic loading. Constituent mass load is most often expressed in the United States as pounds per day and may be determined from Equation 1 when flowrate is expressed in gallons per day and organic concentration is expressed as milligrams per liter (Tchobanoglous and Burton, 1991).

Load (lbs/day) = flow (gal/day) x concentration (mg/L) x 0.00000834 (unit conversion) [Eq. 1]

Matejcek et al. (2000) recommended supplementing a low-strength influent wastewater stream with simple and complex sugars, proteins, oil, and grease to achieve desired testing characteristics. Wittwer and Heger (ibid.) suggested a 3-step process when developing manufactured wastewater for conducting experimental on-site research; 1) define the desired organic characteristics of the test system, 2) define the hydraulic loading characteristics of the test system, and 3) develop an amendment formulation required to bring test system to desired conditions. They also followed the recommendation of Matejcek and evaluated numerous combinations and ratios of dextrose, skim milk, puppy food, vegetable fat, and animal fat (Heger - Personal communication, 2019).

The NSF/ANSI Standard 40 for residential treatment unit testing protocol defines residential strength influent as a BOD_5 between 100 and 300mg/L and TSS between 100 and 350 mg/L (NSF/ANSI, 2018). To attain higher than normal organic loading under reduced flows, ATU hydraulic flow was tightly controlled with precision pumps and the organic strength of the influent was manipulated through the addition of a synthetic high strength waste formulation (SHSW) to raise BOD_5 and TSS concentrations. Experiments were designed based on reported changes to ATU inflows due to water conservation devices and greywater reuse (TCEQ, 2017). Experimental flow and organic load manipulations were intended to test multiple strength/flow/dosing scenarios and develop a results matrix for future system design and regulatory guidance. Table 1 depicts the planned experimental flow reductions and organic concentration targets.

Table 1. Experimental design – flow reduction and concentration increase to produce theoretical load with the same flow and concentration applied to ATU's receiving different dosing schedules (i.e., demand vs time). Each experiment requires 4 weeks; 1-week equilibration, 2-week sampling, and 1-week review.

Experiment	Flow reduction [%]	Influent Flow [gal/day]	Influent Concentration [mg/L]	Influent Load [lb/day]
1	0% -	225	100 -	0.19
2	0% -	225	300 ↑	0.56
3	20% ↓	180	375 ↑	0.56
4	30% ↓	158	430 ↑	0.57
5	50% ↓	112	600 ↑	0.56
6	50% -	112	800 ↑	0.75
7	50% -	112	900 ↑	0.84
8	50% -	112	1000 ↑	0.93
9	50% -	112	2000 ↑	1.87
10	50% -	112	3000 ↑	3.74

METHODS

Laboratory: Several materials were considered for producing SHSW needed to raise ATU influent organic concentrations. BOD_5 was used as the response variable. Food industry literature was searched for potential amendment materials and published BOD_5 ranges. Animal processing waste (i.e., blood) and dairy products (i.e., milk) were considered first due to reported high BOD_5 demands associated with industry wastewaters (Carawan et al., 1979; Bistillo and Mehrvar, 2017).

Waste blood was found to be problematic from both a supply and a handling perspective. Local producers that could regularly provide similar blood products (i.e., same animal type) were unavailable. Handling was also complicated due to timing (i.e., slaughter and experimental schedules), physical (i.e., collection, transport, storage), and measurement (i.e., volumetric and BOD_5 determination) issues. For these reasons, the use of waste blood products was abandoned.

Various milk products (i.e., whole milk, skim milk, fresh, powdered, etc.) were considered next. Fresh milk products were ruled out due to cost and handling issues. Dried milk products however offered an ideal material from multiple reasons: availability, relatively low-cost, convenient storage, ease of handling, and high BOD_5 and TSS. A low temperature, low-fat dehydrated milk (MMPA Grade-A Low Heat Nonfat Dry Milk: Food Services Direct, Inc.) was selected to provide a combined complex sugar (i.e., lactose), protein, fat, and mineral source.

Dextrose (i.e., glucose derived from corn) has been used in synthetic wastewater formulations (O' Flaherty and Gray, ibid.) and was found to be acceptable as a simple organic substrate for raising ATU BOD_5. Like the powdered skim milk, dextrose offered an ideal material due to its availability, low cost, easy storage, and handling requirements, and similar high BOD_5.

A grain-based animal feed (GBF) was selected to provide additional BOD_5 to the experimental systems. A modified GBF (PP Lay Crumble – Producers Cooperative, Bryan, Texas) specially designed for amending the Texas A&M Wastewater facility wastewater stream between semesters, when the student population is low, and the treatment plant requires BOD supplementation to keep microbial populations alive. This material also provided some oils, fats, vitamins, and minerals necessary for healthy microbial growth.

No amendment materials specific to fats, oil, and grease were included in the SHSW due to the small amounts already supplied by the milk and GBF materials.

Relationships between concentration and BOD_5 were determined for dextrose, skim milk, and GBF. A concentrated stock solution was prepared by mixing a measured mass of each material in deionized water. Standard curves were prepared from serially diluted stock and analyzed for BOD_5 (Figure 1a-c). The resulting concentration to BOD_5 ratios were used to calculate the amount of each amendment required to produce a desired BOD_5 in the ATU influent stream. The SHSW was delivered through a programmable refrigerated pump (Figure 1-d). Combining amendment stock solutions with carefully controlled ATU influent flows allowed system loading to target experimental BOD_5 values.

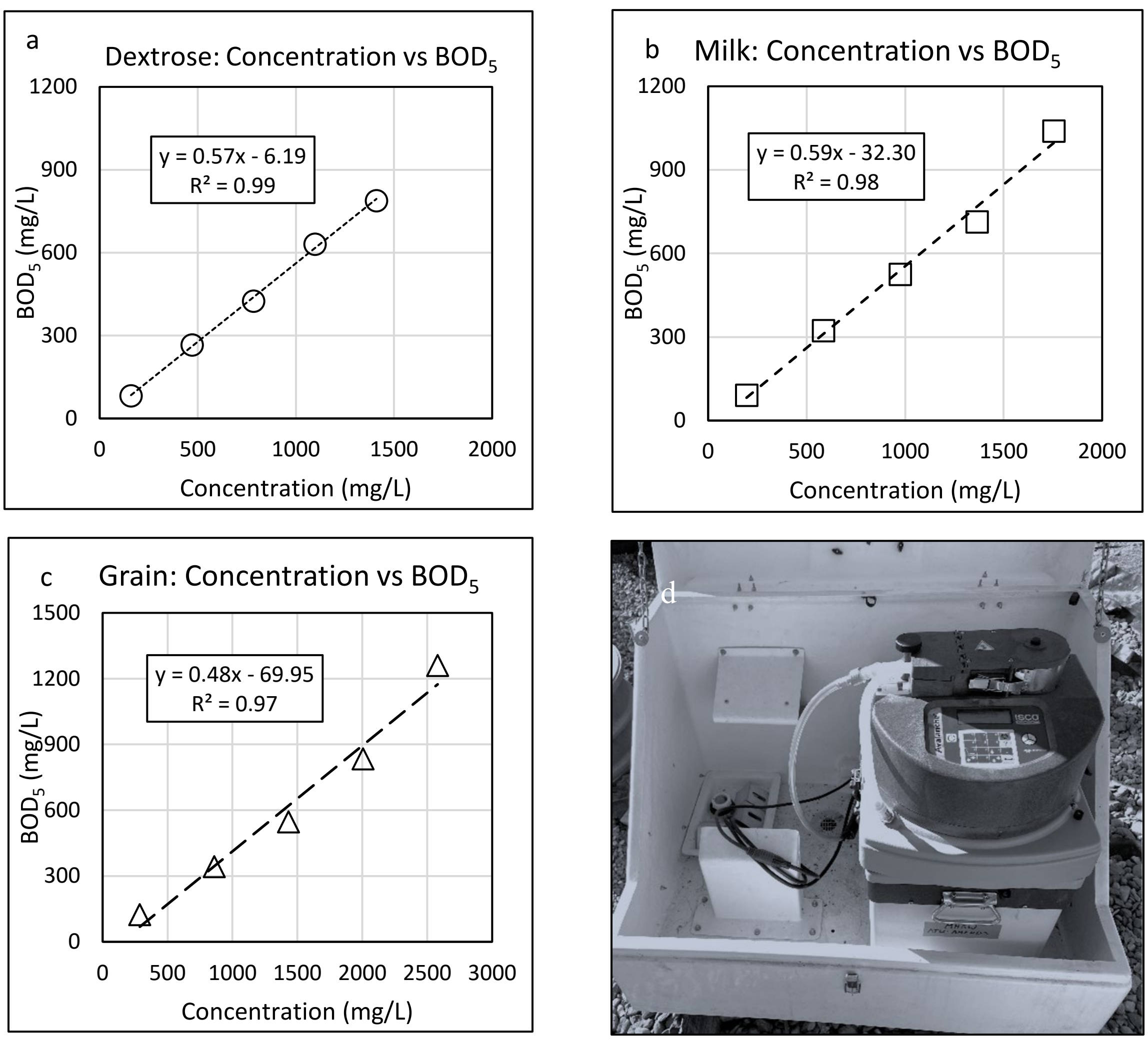

Figure 1: Concentration vs BOD_5 for a – dextrose, b – Milk, and c – Grain, d - ISCO refrigerated pump.

RELLIS campus raw wastewater BOD_5 concentration averaged 185 mg/L over the experimental period. GBF was added to the feed tank to raise BOD_5 concentrations. Daily additions were made by hand to the Feed Tank raised the average BOD_5 influent concentration to 364 mg/L.

Dextrose and milk amendments were added to deionized water to prepare concentrated solution for dispensing directly into the ATU Pump Tank. A ratio of 70% dextrose to 30% milk was found to be effective from both cost and volumetric management perspectives. Amendment amounts required to produce stock solutions at desired concentrations were determined by considering incoming Feed Tank BOD_5 concentration, ATU flow, ATU experimental BOD_5 target concentration, and the amendment dosing schedule. An automated refrigerated water sampler (Avalanche, Teledyne-ISCO, Lincoln, NE) was configured to deliver a specific volume of the concentrated stock to the ATU Pump Tank (i.e., ATU influent) each hour. The sampler was plumbed backward so as to *deliver* a sample rather than *collect* a sample (Figure 1-d). Amendment doses were synchronized with the raw wastewater influent stream. As amendment solution was increased in concentration with each experiment, the change in solution density required ISCO automated dispenser volume adjustments.

Field: Two identical 500 gpd ATU's (Model 500N – Clearstream Wastewater Systems, Inc, Beaumont, TX) were installed and operated in parallel to maximize experimental output and minimize operational variability. Prior to experimental flow reductions, both ATU's were operated at 50% of maximum design flow representing a single-family home (i.e., 225 gpd). The experimental ATU plumbing configuration is shown in Figure 2.

RELLIS Campus raw wastewater was pumped from a lift station to a "Feed Tank" where it was routed to 3 different experimental treatment trains. Flow to the ATU treatment train required volumetric metering in order to calculate the organic amendment dose required to raise BOD_5 to experimental targets. Metering was accomplished by the use of a pump/reservoir/siphon/valve arrangement. The feed pump was activated hourly by a timer to over-fill a 10-gallon reservoir. When the pump cycled off, a siphon was created removing water from the reservoir to a calibrated volume. Finally, a second timer opened an automated valve and delivered the dose to the ATU treatment train. After draining the reservoir, the valve was closed in preparation for the next cycle.

The ATU treatment train consisted of a 1000-gallon septic tank, configured as a 750-gallon "Trash Tank" followed by a 250-gallon "Pump Tank", supplying both ATU's. Separate pumps operated by programmable logic controllers (PLC), with 1 second time resolution, delivered the required daily flow volume as a function of time on/off at a constant pump rate. ATU pump rates were calibrated to ~5 gallons per minute using a pressure regulator/restricted orifice flow regulator arrangement. One ATU unit received a "Demand" dose according to SD40 testing schedule (i.e., 3 doses within a 24-hour period, 35% between 6am and 9am, 25% between 11am and 2pm, and 40% between 5pm and 8pm). The second unit received an equalized "Time" dose (i.e., 1/24 of total daily flow per hour). All individual sub-doses for both systems were held to <10 gallons.

A series of 10 experiments were conducted between December 2020 and August 2021. Each experiment was conducted over a 14-day period with 8 sampling days. Samples were collected on days 1, 2, 6, 7, 8, 9, 13, and 14 of each experiment in order to match laboratory schedules. The

ATU treatment train was sampled at 5 locations including the incoming raw waste stream (i.e., Lift Station), Feed Tank, ATU common influent, Demand dose effluent, and Time dose effluent (Figure 2). On sampling days, grab samples were collected from the RELLIS campus wastewater stream and the Feed Tank. Composite samples (100 ml/hour x 24 hours) were collected from the ATU common influent and separate effluents using automated, refrigerated water samplers (Avalanche: Teledyne ISCO, Lincoln, NE). All collected samples were analyzed by a commercial laboratory for BOD_5 and TSS concentration.

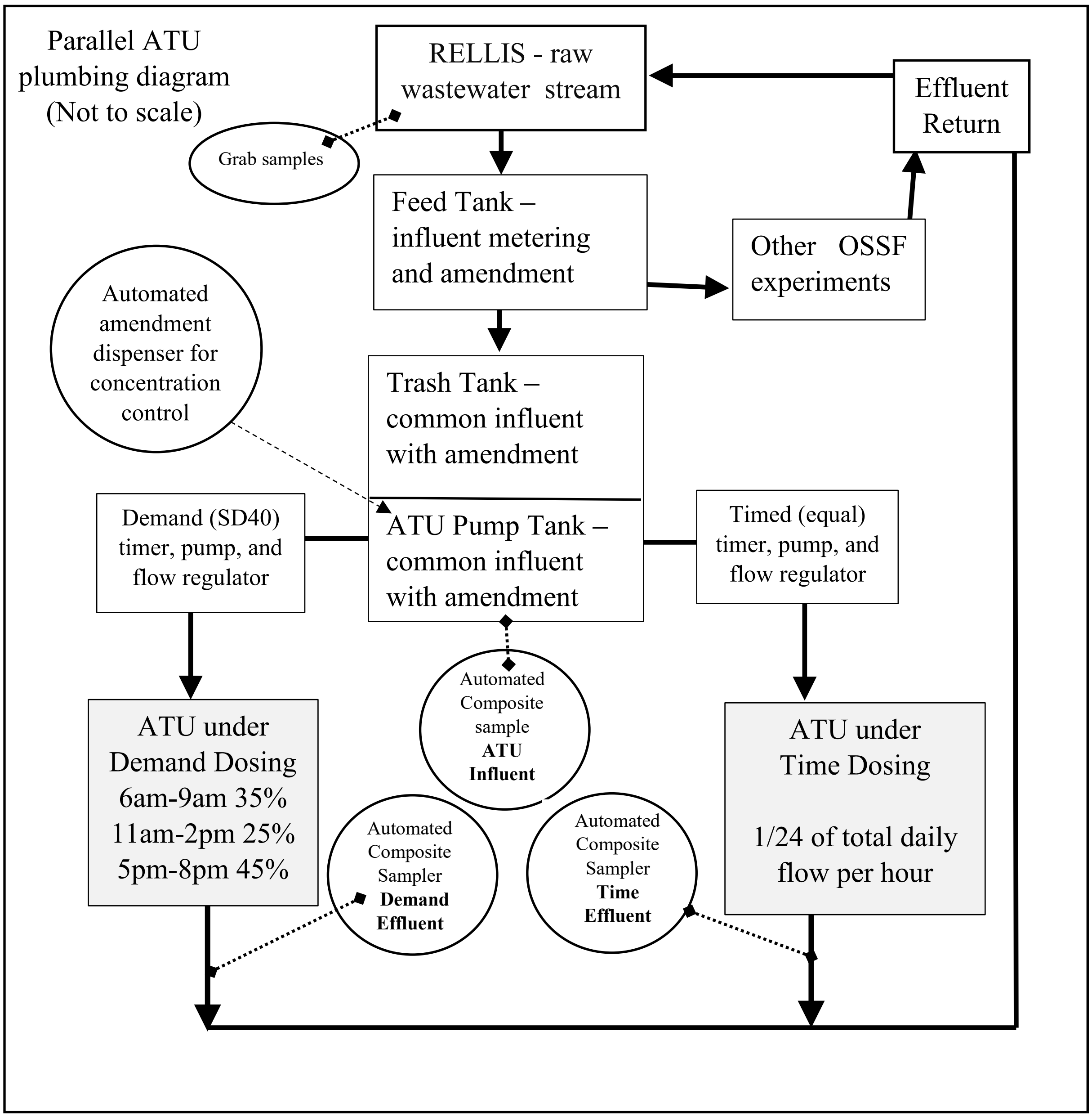

Figure 2. Aerobic treatment train plumbing, amendment, and sampling configuration.

RESULTS AND DISCUSSION

During the experimental period between December 2020 and August 2021, TAMU RELLIS Campus raw wastewater BOD_5 concentrations, measured at the TAMU OSSF Lift Station, were highly variable ranging between 8 and 1260 mg/L and averaging 185 mg/L. Over the 10 ATU experiments performed, influent organic concentrations, measured as BOD_5, were raised between 56% and 1493% above incoming RELLIS Campus raw sewage concentrations, through the addition of SHSW amendments (Table 2). SHSW addition requirement amounts were determined by examining the BOD_5 concentration of each previous experiment, differences between Raw Sewage influent and amended ATU influent concentrations, and laboratory-derived standard curves for amendment materials. Attaining specific experimental targets was elusive.

ATU flows were reduced stepwise from the normal operational rate of 225 gpd to 80% (180 gpd), 70% (158 gpd) and 50% (112 gpd) while organic concentrations were concurrently increased through SHSW additions. Experiment 1 represents a "start-up" period and was used to develop system operational methods, evaluate sampling/dosing/programming procedures, and establish ATU microbial communities. The results of Experiment 1 should not be considered representative (i.e., effluent BOD_5 >40 mg/L and <90% reduction). Conditions observed during Experiments 2, 4 and 5 were considered developmental as influent BOD5 concentrations were below "high strength" (i.e.,) 300 mg/L BOD_5) conditions. Experiments 3 and 6-10 demonstrated that ATUs receiving demand dosing and time dosing were consistently able to treat high strength wastewater (i.e., > 300 mg/L BOD_5) to required standards (Table 3). Although BOD_5 effluent concentrations for Experiment 7 Time Dose and Experiment 10 Demand and Time Dose exceeded 30 mg/L, all exhibited >90% reduction from influent concentrations during the 2-week experiments.

High (>4000 mg/L) to very high (>17,000 mg/L) TSS concentrations were observed in Experiments 8-10 influent (Table 4) however both demand and time dosed ATUs were able to meet treatment specifications. Although included for ATU performance evaluation, TSS was not a major focus of the research.

Table 2. Experiment, number of samples (n), RELLIS Campus raw sewage 5-day Biochemical Oxygen Demand (BOD5) concentration, SHSW amended influent BOD_5 concentration, and amended influent percentage increase.

Exp	n	Average Raw Sewage Influent BOD_5 [mg/L]	Average SHSW Amended Influent BOD_5 [mg/L]	SHSW Amended Influent Percentage increase from initial
1	8	56	230	311%
2	8	82	163	99%
3	6	123	403	228%
4	8	120	201	68%
5	8	122	190	56%
6	8	261	461	77%
7	8	210	548	161%
8	8	136	650	378%
9	8	60	956	1493%
10	8	344	2943	756%

Table 3. Experiment, number of samples (n), flow reduction by percent and average influent flow rate, influent 5-day Biochemical Oxygen Demand (BOD_5) concentration, influent organic load, Demand Dosed ATU effluent BOD_5 concentration and percent reduction, and Time Dosed ATU effluent BOD_5 concentration and percent reduction.

		Common inflow (supplying both ATUs)				**Demand Dose ATU**		**Time Dose ATU**	
Exp	n	Experimental Flow Reduction [% of normal]	Average Influent Flow [gal/day]	Average Influent BOD_5 [mg/L]	Average Influent Load [lb/day]	Average Effluent BOD_5 [mg/L]	Average Effluent BOD_5 Reduction	Average Effluent BOD_5 [mg/L]	Average Effluent BOD_5 Reduction
1	8	100% -	225	230	0.43	42	82%	42	82%
2	8	100% -	225	163	0.31	21	87%	18	89%
3	6	80% ↓	180	403	0.60	21	95%	21	95%
4	8	70% ↓	158	201	0.26	20	90%	22	89%
5	8	70% -	157	190	0.25	29	85%	26	86%
6	8	50% ↓	111	461	0.43	23	95%	12	97%
7	8	50% -	112	548	0.51	25	95%	31	94%
8	8	50% -	114	650	0.62	25	96%	19	97%
9	8	50% -	113	956	0.90	15	98%	12	99%
10	8	50% -	114	2943	2.80	34	99%	31	99%

Table 4. Experiment, number of samples, flow reduction by percent, and average influent flow rate, influent Total Suspended Solids (TSS) concentration, Demand Dosed ATU effluent TSS concentration and percent reduction, and Time Dosed ATU effluent TSS concentration and percent reduction.

		Common inflow (supplying both ATUs)			**Demand Dose ATU**		**Time Dose ATU**	
Exp	n	Experimental Flow Reduction [% of normal]	Average Influent Flow [gal/day]	Average Influent TSS [mg/L]	Average Effluent TSS [mg/L]	Average Effluent TSS Reduction	Average Effluent TSS [mg/L]	Average Effluent TSS Reduction
1	8	100% -	225	53	40	25%	52	2%
2	8	100% -	225	74	21	72%	12	84%
3	6	80% ↓	180	138	18	87%	18	87%
4	8	70% ↓	158	131	9	93%	20	85%
5	8	70% -	157	347	26	93%	24	93%
6	8	50% ↓	111	506	12	98%	11	98%
7	8	50% -	112	1886	18	>99%	19	>99%
8	8	50% -	114	4468	9	>99%	15	>99%
9	8	50% -	113	4115	8	>99%	26	>99%
10	8	50% -	114	17530	22	>99%	28	>99%

CONCLUSIONS

A synthetic high strength wastewater formulation was used to raise BOD_5 of Texas A&M University RELLIS Campus wastewater in order to test the performance of ATU's operated under reduced hydraulic flow, increasing organic load, and different dosing schemes (i.e., Demand verses Time). ATU daily flows were reduced stepwise from 100% to 80%, 70%, and 50% of normal operating flow by plumbing control. Predicting and achieving experimentally designed specific BOD_5 concentration targets was not possible due to system operational variation and laboratory results lag-times (i.e., system condition was not known until 6 to 7 days following BOD_5 sample collection). However, in 6 of 10 separate experiments, organic loading was increased to "High Strength" concentrations (i.e., >300 mg/L BOD_5) through the addition of amendments including dextrose, milk, and a grain-based animal feed. In 9 of 10, separate, 2-week experiments, effluent BOD_5 and TSS concentration differences, between both Demand dosed and Time dosed ATU's, were minimal and met or exceeded ATU design performance specifications.

LITERATURE

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