Nanobubble Assisted Flotation
Hershey Creamery DAF Retrofit
By Glace Associates, Inc

ABSTRACT

Negatively charged nanobubbles enhance sludge flotation by attaching to polymeric chains and neutralizing particle charges. This improves floc patching and increases float sludge density, producing higher solid concentration in recovered sludge compared to standard dissolved air flotation processes. This document describes a nanobubble air flotation system that was retrofitted into a conventional DAF system to improve the removal of BOD and TSS in creamery wastewater. The nanobubble generator developed by Moleaer, generates and injects negatively charged nano and microbubbles into wastewater that rapidly attach to suspended flocs. Millions of nanobubbles attached to suspended particles provide flotation to the surface where they can be mechanically skimmed off. Limitations of slow rise rates and low gas to liquid ratios are overcome by a significantly more charged surface area, resulting in better collision and nanobubble attachment with floc particles.

KEYWORDS: solid/liquid separations, nanobubble assisted flotation, negative zeta potential, dissolved air flotation, particle collision and attraction.

BACKGROUND

Glace Associates Inc. is a consulting engineering firm based in Pennsylvania who was tasked with identifying new technologies to help their client, Hershey Creamery, reduce wastewater treatment costs. Moleaer's nanobubble generator was selected to replace Hershey's high-pressure dissolution system to improve the BOD and TSS removal in their DAF unit and lower city pretreatment wastewater disposal surcharges. This report authored by Glace, is an independent evaluation of the performance of the nanobubble generator compared to the previous conventional DAF aeration system.

INTRODUCTION

Coagulation, flocculation and flotation is one of the most effective methods to remove fats, oils and grease, suspended solids and colloidal materials from industrial wastewater to reduce bulk contamination. Most colloids, macromolecules and solids in food processing wastewater are of organic nature and have a charge. In order to achieve good floc formation, the surface charge of the particles must be neutralized to allow the particles to adhere together tightly. The tighter the connection, the greater the sludge's solid to water ratio is.

Coagulation is the addition of oppositely charged ions or molecules into the wastewater to neutralize surface charge and destabilize colloidal suspensions to enable slightly larger microflocs to be formed. Flocculants are large polymeric molecules that are added to bind together smaller particle flocs produced by chemical coagulation. They assist in the formation of larger stable flocs which can be more easily removed by various air floatation methods.

In the conventional dissolved-air flotation (DAF) process, water is pressurized and over saturated with compressed air in a pressurization chamber. The supersaturated water is then forced through special orifices where, as the water exits the nozzles, a sudden drop in pressure generates clouds of micro and macro bubbles that rise through the water column. To avoid the discharge orifices clogging with particles, only a percentage of the already cleaned effluent water is utilized in this pressurization loop which is then recycled to the influent wastewater. Incoming flowing particles, already dosed with coagulants and flocculants, come into contact with a curtain of rising bubbles that physically entrain with flocs and force them to rise to the surface. Bubble rising velocity is one of the primary parameters when designing and sizing DAF systems. Most conventional DAF's using high pressure dissolution will aim to deliver an air-to-water ratio of 0.15:1 by volume. The theoretical TSS removal rates of these systems is directly related to the air saturation levels. Consequently, wastewater with more than 1% of total suspended solids is harder to treat because of the limited amount of air you can saturate into water.

The concentration of solids in the sludge float is another important characteristic to evaluate for chemical and flotation performance. Typically, DAFs will produce sludge with a solid concentration between 3% and 10%. A greater concentration of solids in the sludge results in a reduction in sludge volumes, disposal and dewatering costs.

SUMMARY OF MOLEAER XTB NANOBUBBLE GENERATOR

The nanobubbles generated by the Moleaer unit are listed in the system specifications to be ~80 nm in size with more than 200 times the interfacial surface area of micro bubbles. Bubble concentrations range between 100 and 500 million nanobubbles per ml. (Particle Characterization Lab Report, Sep 2017) The zeta potential of these nanobubbles has previously been measured at approximately -19mV in clean water. (Particle Characterization Lab Report, July 2017) The combination of the nanobubble's larger surface area and their negative charge, increases the attraction and collision rate with suspended particles, resulting in a higher percentage of particles attaching to the flocs and consequently removed from the wastewater.

The unit used in this evaluation was a Moleaer 100 XTB with the following specifications:

Pump Flow	100 GPM
Pump Suction	2" NPT (suction pump to generator must be flooded at all times with a min. suction head of 2' of water column)
Pump Hp	3
Pump Voltage	230/460 VAC 60 hz
Pump Discharge	1 ½" NPT (pressure of oxygenated fluid to DAF 22 pig)
Maximum Inlet Temp	140 degrees F
Unit Pump Starter	NEMA 4x
Air Supply Connection	¼" Industrial Quick Connect
Air Pressure Specification	20 CFH @ 120 PSIG
Air Feed Specification	ISO 8573 - 1:2010 Class 1.4.1 - Free from oil & moisture
pH Tolerance	2-10
Skid Dimensions	28.5" L x 19" W x 18" H
Shipping Weight	120 lbs

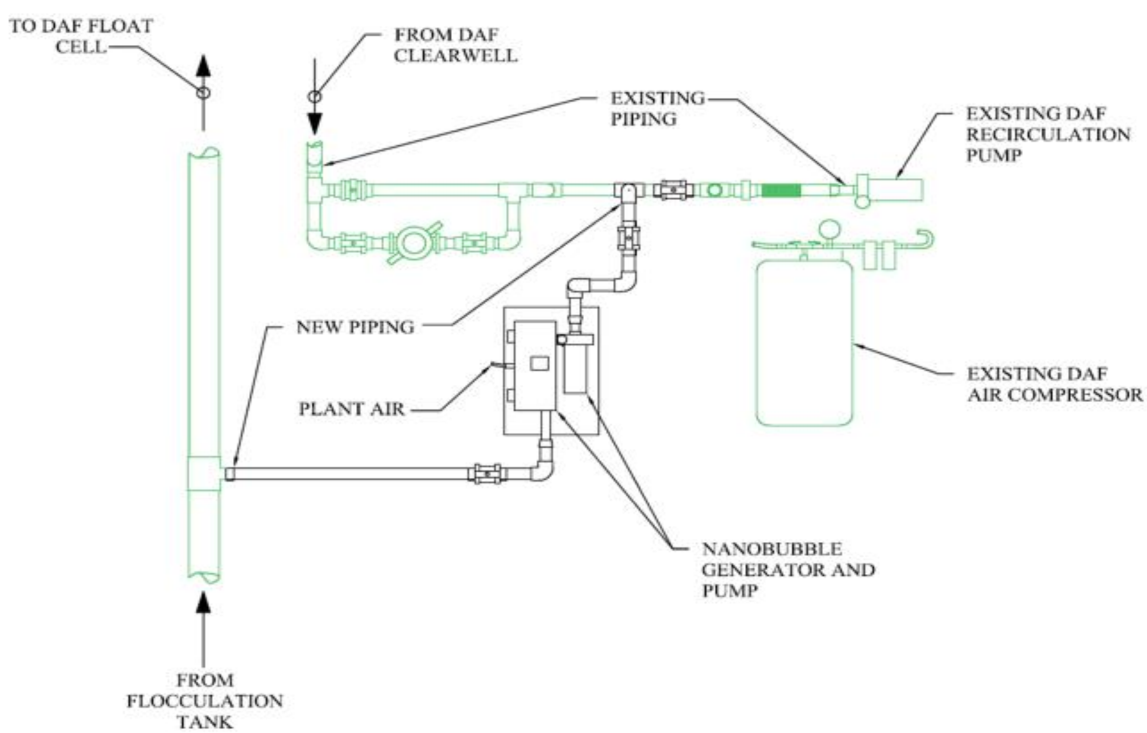
EXISTING DAF SYSTEM:

Treatment Flow Rate	130 gpm
Recycle Flow %	50%
Aeration Method	High-Pressure Dissolution
Recirculation Pump	5 HP
Air Compressor	10 HP
Coagulant	Polyaluminum Chloride (PACI)
Flocculant	Cationic Polymer

MOLEAER NANOBUBBLE XTB INSTALLATION

The installation of the nanobubble generator was straightforward. New 2" PVC piping was cut in with a tee to the existing piping to bypass the old high-pressure dissolution system. 480v, 3-phase power was supplied to the unit control box to provide power to the centrifugal pump and the unit. Plant air from the Hershey production area was utilized to supply the required compressed air to the nanobubble generator.

A simplified schematic of the nanobubble generator installation is shown in the diagram below:



AERATION / FLOATION COMPARISON

	XTB Nanobubble Generator	High Pressure Dissolution
Air Flow	20 CFH	14 CFM
Air Pressure	80 PSIG	140 PSIG
Water Flow	100 GPM	65 GPM
Water Pressure	14 PSIG	80 PSI
Pump Motor HP	3	10
Energy Usage (Kw-hr / day)	40	196.9

MOLEAER NANOBUBBLE PERFORMANCE

For this trial, past quarterly operational data for BOD and TSS from 2017 was used as the baseline performance goal. Once the nanobubble generator was operational, representative water samples were collected and delivered to ALS Environmental Lab to analyze BOD and TSS in both the influent and effluent. The percentage of solids in the float sludge was also analyzed to better understand how sludge volume would be impacted by the application of the nanobubbles.

One of the initial objectives was to observe whether the small volume of compressed air utilized by the nanobubble generator would be sufficient to float the solids as effectively as the old DAF system that used much larger volumes of air.

The test results confirm that the nanobubble air flotation method utilized a lower air volume and also provided sufficient flotation. When comparing BOD_5 and TSS removal rates, the nanobubble air flotation method delivered a 37% reduction in BOD_5 and a 24.17% improvement in TSS removal when compared to the existing high-pressure dissolution system. **BOD REDUCTION**

Replacing the high-pressure dissolution system with the nanobubble air flotation system delivered a 37% reduction in BOD_5 surcharges compared to the 2017 operating results. This reduction could potentially save Hershey Creamery over $40,000 per year from reduced surcharges.

$ / 1000 gals discharge over BOD_5 limit | $ 0.0015 | Provided by Hershey 8-20-2018

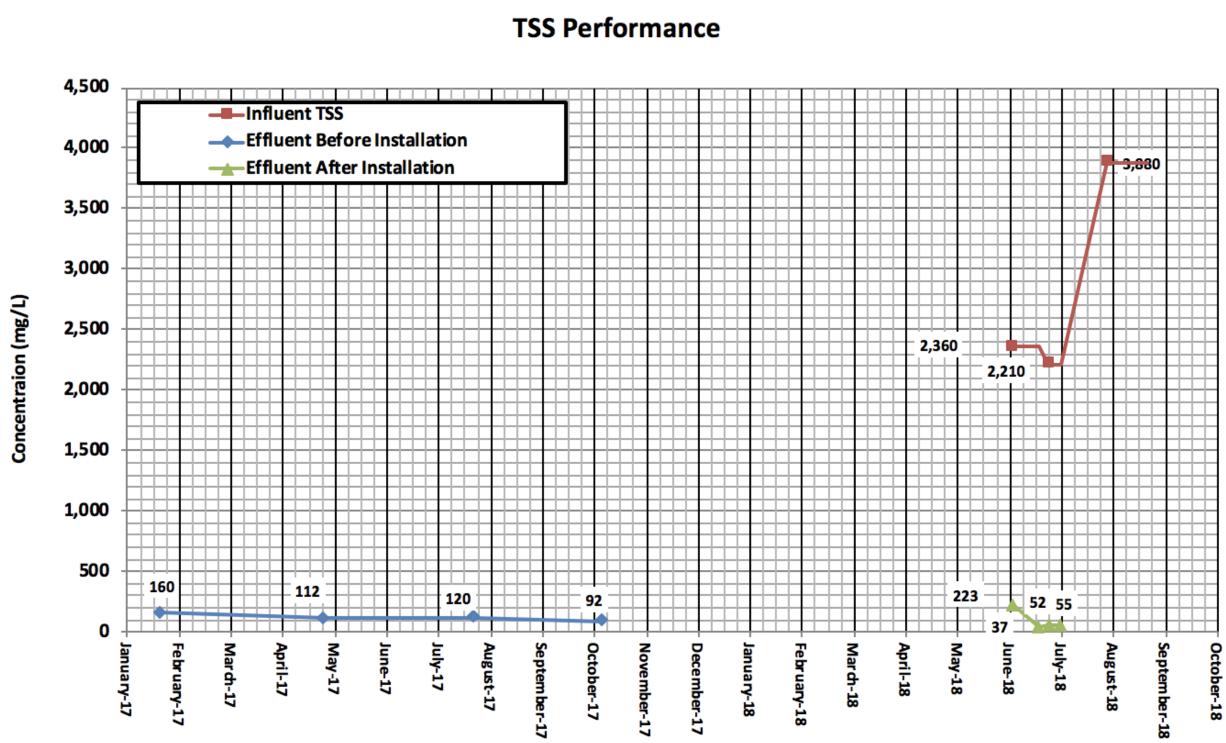
Potential BOD_5 Surcharge Reduction Using Nanobubble Technology

Note: This is a generalized estimated based on assumptions from limited historical surcharge and current operating data	**Before NanoBubble**	**After NanoBubble**
Average Flow (gpd)[1]	**75,000**	**75,000**
POTW Limit - BOD_5	**290**	**290**
Average BOD5 Effluent Concen. (mg/L)[2]	**4,555**	**2,958**
Concentration above Surcharge	**4,265**	**2,668**
Operating Days Per Week	**5**	**5**
Days per Month	**22**	**22**
Estimated Gallons per Year Discharged	**19,485,000**	**19,485,000**
Estimated Potential Annual Surcharge	**$124,655.29**	**$77,984.82**
Potential Est. Annual Savings for BOD Surcharges	**$46,670.47**	

[1] *Assumed typical daily process wastewater flow*

[2] *Avg. 2017 concentrations over 4 months compared with 1 month sampling* using Nanobubble technology.

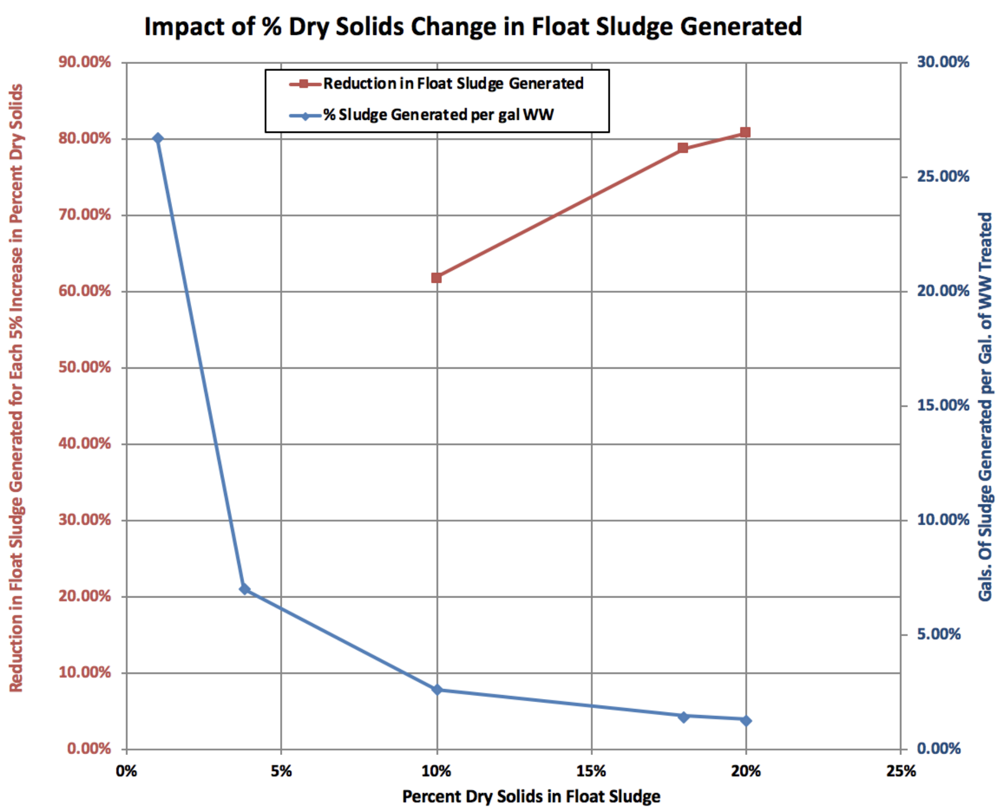
TSS REMOVAL



FLOAT SLUDGE - PERCENTAGE OF SOLIDS AND CONSISTENCY

The float sludge produced by the nanobubble air flotation was observed to be more uniform and consisted of much smaller floc particles than the sludge generated from the previous flotation system. Lab results showed that the percent solids in the float sludge to be unusually high, averaging 19.8% compared to 3-4% in previous years. Despite the high level of solids in the sludge, the operator observed that this denser sludge was easier to pump than sludge previously produced with the high-pressure dissolution system.

The increased sludge density and lower water content in the float sludge could potentially save over $ 40,000 per year in sludge hauling and disposal costs based on historic sludge data.



NanoBubble Technology Data To Date

Sludge Sampled	Moisture	Total Solids
6/14/18	82.4%	17.6%
7/5/18	81.4%	18.6%
8/9/18	76.8%	23.2%
Average	**80.2%**	**19.8%**

Baseline Sludge Disposal Costs

Typical Shipment Volume	6,500	gallons	
Typical Disposal Cost per gallon	$ -		Beneficial Use - No Cost
Typical Pickup & Transporation Fee	$ 325.00		

Unit volume analysis of sludge volume generation

System Treatment Flow Rate	1.00	gallon
Average TSS of Influent	2,817	mg/L
Lbs of Solids per gallon of Flow	0.0235	lbs per day per gallon treated
Average DAF Solids Removal Rate	95%	assume removal before and after
lbs DS per gallon wastewater flow	0.02231645	

Potential Annual Savings Analysis for Sludge Disposal [1]

Assume SG of Float Sludge	1.00	Avg. DAF Float	NanoBubble Float
% Solids of DAF Float Sludge		3.8%	19.8%
Gallons of float sludge per lbs of DS removed		0.587	0.113
Gal. Sludge / gal. WW treated		0.070	0.014
% float sludge generated per gal WW treated		7.04%	1.35%
Reduction in Float Sludge Generated		80.8%	
Average Daily Treatment Flow	75,000		
Days per Week Operation	5		
Weeks per Year Operation	48		
Total Est. Annual Treatment Flow (gals)	18,000,000		
Total Est. Annual Float Generated(gals)		1,267,500	243,258
Estimated Annual Offsite Shipments		195	37
Estimated Offsite Disposal Costs		$ 63,400.00	$ 12,200.00
Potential Est. Annual Savings for Sludge Disposal		**$51,200.00**	

[1] *Based on limited historic data on original DAF float sludge % solids concentration and two sludge samples from application of Nanobubble technology.*

ENERGY

The nanobubble generator does not require pumping at pressure. Therefore, the generator can utilize a lower HP pump and run at higher liquid flow rates than conventional flotation systems. Once the nanobubble generator was operational, it was determined that the required compressed air for the unit could be supplied from the plant air instead of utilizing the DAF's existing dedicated air compressor. Shutting off the compressor not only provided energy savings but also significantly reduced the noise pollution in the facility improving the working conditions for the operator.

The projected annual energy savings by replacing the high-pressure dissolution system with nanobubble air flotation are $1,940 as shown in the table below.

Operating Schedule:	10	hrs/day		
	5	days/week		
	50	weeks/Yr.		
BEFORE NANO BUBBLE GENERATOR INSTALLATION				
Reciculation Pump Motor	10	HP	230	V
			1800	rpm
			89.5%	Motor Eff. (%)
			36	FLA
			8.3	kW
			83.4	kW-hrs/day
			20,838	kWh/yr
Air Compressor Motor	2	HP	230	VAC
			1800	rpm
			91.7%	Motor Eff. (%)
			7	FLA
			1.6	kW
			16.3	kW-hrs/day
Estimated Run Time Utilization			75%	
			3,051	kWh/yr
AFTER DAF NANO BUBBLE GENERATOR INSTALLATION				
Reciculation Pump HP	3	at	230	VAC
			1800	rpm
			89.5%	Motor Eff. (%)
			11	FLA
			2.5	kW
			25.0	kW/day
			6,251	kwH/yr
EQ Tank Pump HP	0	at	230	VAC
			1800	rpm
			89.5%	Motor Eff. (%)
			0	FLA
			0.0	kW
			0.0	kW/day
			0	kwH/yr
Air Compressor HP	0	(Used Existing Plant Air)		
Air Pressure to Generator	80	psig		
Compressed Air Utilization	20	cfh		
ESTIMATED KwH SAVINGS*	**17,637**	**kWh/yr**	**74%**	**Savings***

@ $ 0.1100 kWh/yr $ 1,940.10 per year energy savings

** Savings do not account for plant air used for Nanobubble generator. Actual savings will be lower.*

CONCLUSION

The Nanobubble Air Flotation system's reduction in BOD, TSS and increase in the percentage of solids in the float sludge supports the concept that the combination of Moleaer's nanobubble's larger surface area and their negative charge, increases the attraction and collision rate with suspended particles, resulting in a higher percentage of particles attaching to the flocs and consequently removed from the wastewater. The reduction in energy consumption combined with the reduction in surcharges from the city have created significant cost saving potential for Hershey Creamery. Based on the projected BOD reduction, decrease in sludge volume and handling costs, and improvements in energy efficiency, Hershey's decision to replace their high-pressure dissolution system with nanobubble air flotation could have a total projected annual cost savings of over **$100,000.**