"Successful Applications of Bioaugmentation for Reducing Sludge Output from Biological Wastewater Treatment Plants and Anaerobic Digestors"

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Abstract: One of the major costs associated with the operation of biological wastewater treatment is the handling and disposal of sludges generated primarily in the conversion of soluble organics as measured by BOD/COD into either carbon dioxide (aerobic) or methane (anaerobic), water and bacterial cells. Often times the sludge generated in either of these processes may be subsequently treated in a digestor to reduce the volatile suspended solids (VSS) volume for disposal. Bioaugmentation with certain microbial consortia has been shown to lower the generation of solids in both aerobic and anaerobic wastewater processes by reducing the yield coefficient (y), as well as enhancing the efficiency of digestors designed to reduce the volume of solids for disposal.

This paper will detail the use of MICROBE-LIFT®/IND, a liquid microbial product, which has been shown to reduce the generation of sludge in: aerobic biological wastewater systems in Austria and Holland; and, to improve the efficiency of anaerobic digestors in Korea, Israel and Colombia. Sludge reduction ranged from 15% to almost 40% and was observed in all applications. In some cases, the improved system efficiency allowed the system to handle additional loadings without physical expansion; while generating significant savings in handling, chemical usage and disposal costs over and above the cost for bioaugmentation. In addition to presenting the statistical data this paper will also propose biochemical mechanisms for how these results are achieved through an analysis of the biochemical processes involved in all of these systems.

Keywords: Aerobic biological treatment, anaerobic biological treatment, anaerobic digestor, bioaugmentation, sludge handling and disposal costs, and sludge reduction.

Background: Since the development of the activated sludge process, suspended growth biological wastewater treatment systems have become the predominant form of secondary treatment for removal of dissolved organics. The primary reason for this is that these systems are generally the most economical way to treat large quantities of polluted water with respect to organic removal.

In aerobic biological processes, the dissolved organics are converted to carbon dioxide, water and bacterial cells according to the following equation:

$$BOD + N + P + O_2 \text{ --------------- } CO_2 + H_2O + Cells$$

Or, in anaerobic processes:

$$BOD \text{ or cells --------------- } CH_4 + H_2S + H_2O + N + P + cells$$

The excess cells that are produced are primarily what comprise the waste sludge, which must be disposed. Many processes have been developed that are designed to reduce the amount of sludge for disposal through breakdown or digestion of the sludge and increasing the dry solid weight of the sludge to further lower the volume of sludge for disposal. Very little attention has been paid to the potential for manipulation of the biomass characteristics to reduce the amount of sludge produced to begin with or to improve the efficiency of digestors.

Pilot studies were conducted in 5,000-liter pilot reactors that remained from the original design work on the digestors. With encouraging results achieved in the pilot trials, field trials were later pursued. Based on successful results at Pusan similar field trials were run in Colombia and at the Hod Hasharon, as well as the Jerusalem Wastewater Plants in Israel. In another application of the product at Deutsch Wagram in Austria, a bioaugmentation program was conducted in 1998 to reduce odors, improve breakdown of oil & grease, and reduce the amount of waste sludge generated at the plant. Based on the success at Deutsch Wagram a trial was undertaken at the municipal wastewater plant in Zutphen, the Netherlands.

City of Pusan

In the pilot trials for the City of Pusan, a 20% improvement was observed in the reduction in VSS. Based on these results, the full-scale reactors were augmented as follows:

MICROBE-LIFT®/IND Application Program

Day	Tank 1	Tank 2	Tank 3	Tank 4	Total
1	6 gal.	4 gal.	3 gal.	4 gal.	17 gal.
4	6 gal	4 gal.	3 gal.	4 gal.	17 gal.
7	3 gal.	2 gal.	1.5 gal.	2 gal.	8.5 gal.
10	3 gal.	2 gal.	1.5 gal.	2 gal.	8.5 gal.
13	3 gal.	2 gal.	1.5 gal.	2 gal.	8.5 gal.
16	3 gal.	2 gal.	.5 gal.	2 gal.	8.5 gal.
19	3 gal.	2 gal.	1.5 gal.	2 gal.	8.5 gal.
22	3 gal.	2 gal.	1.5 gal.	2 gal.	8.5 gal.
25	3 gal.	2 gal.	1.5 gal.	2 gal.	8.5 gal.
28	3 gal.	2 gal.	1.5 gal.	2 gal.	8.5 gal.
31	3 gal.	2 gal.	1.5 gal.	2 gal.	8.5 gal.
34	3 gal.	2 gal.	1.5 gal.	2 gal.	8.5 gal.
Maintenance					
(2x/wk)	1.5 gal.	1 gal.	0.5 gal.	1 gal.	

Total first 37 days = 127 1/2 gallons
Annual Maintenance = 416 gallons

Results Achieved

Within 90 days the VSS reduction went from 70% of design efficiency to 130% of design efficiency. The plant has continued to use the product with the exception of one year during which an alternate product from a Japanese supplier was used and the plant efficiency returned to the 70% VSS reduction efficiency observed prior to the bioaugmentation with MICROBE-LIFT®/IND. The following year when the MICROBE-LIFT®/IND was again added, the digestors again resumed the 130% VSS reduction observed the first time with the MICROBE-LIFT®/IND.

Background:

Deutsch Wagram

The waste water entering the sewage work at the supply tank is lifted up with screw pumps to the level of the sewage work and passes through a bar screen. A mechanical scraper removes coarse matter removed from the waste water. Then, the wastewater flows through the circular degritter where granular components are separated. Through a distributor structure the mechanical pre-cleaned waste water enters the activated sludge tank with a capacity of 1440 m³. The biological treatment is carried out by the activated sludge process. To cover the oxygen demand, air is supplied with cage rotor aerators into the waste water. In the secondary settling tank, with a capacity of 2.300 m³, the sludge settles down and is separated from the wastewater, treated biologically, then discharged to the receiving water (Rußbach). Through a siphon pipe the settled sludge enters the sludge recycling pump station. With screw pumps the sludge is pumped back into the activated sludge tank.

The quantity of water for a population equivalent of 8.200 is treated in the activated sludge tank, designed for a population equivalent of 6.000. The chemical cleaning is carried out with the addition of iron salts to precipitate phosphorous from the wastewater and is removed with the excess sludge from the process. Nitrates can be removed (denitrification) with high efficiency from the wastewater when operated with that objective. The sludge is thickened in the sludge storage tank and the sludge liquor pumped back into the supply tank. The thickened sludge either can be directly used in agriculture or the produced sludge granulate is scattered on the fields after de-watering with a sludge press.

The plant is operated by an O&M firm from the Netherlands. Located close to a residential area, the plant had regular problems with odors and oil & grease buildup in the head-works and aeration basins despite achieving better than 95% reduction for BOD and TSS. In addition, the plant was expending a significant portion of its operating budget for sludge handling and disposal.

A bioaugmentation program was implemented in 1998 for a period of one year to determine if the bioaugmentation program could consistently reduce the amount of sludge generated in the plant. Improving odors and oil and grease breakdown were secondary objectives but were not considered to be enough on their own to justify the cost of product treatment, approximately US $30,000/ year.

Fig.1: *Wastewater Plant at Deutsch-Wagram*

Deutsch Wagram

Dosages:

Table 1. Average of some main parameters from the annual report of 1997

parameter	average / year	unit	degradation eff.
Waste water /d	1320	m^3/Tag	-
Sludge volume	810,2	ml/l	-
BSB_5: supply	286,3	mg/l	-
BSB_5: discharge	5,4	mg/l	98,0 %
CSB: supply	574,5	mg/l	-
CSB: discharge	39,1	mg/l	92,5 %
NH_4-N: supply	47,5	mg/l	-
NH_4-N: discharge	1,4	mg/l	97,0 %
NO_3-N: supply	33,2	mg/l	-
NO_3-N: discharge	4,8	mg/l	85,5 %
PO_4-P: supply	5,6	mg/l	-
PO_4-P : discharge	0,5	mg/l	91,4 %

Dosage Schedule for MICROBE-LIFT®/IND in the Sewage Work of Deutsch-Wagram:

Dosages were recommended based on loading (COD; BOD5, resp. hydraulic loading) degradation efficiency, problem zones and working capacity.

Dosage schedule for the sewage works of Deutsch-Wagram was developed based on the use of given parameters from operation readings.

Dosage schedule:

1 US gallon = 1 bottle = 3,7853 liter		gallons per month
Initial:	6 gallons	
Next four weeks (once per week):	1.5 gallon	6
Maintenance (once per week):	1 gallon	2

Before initial inoculation, 2 gallons of MICROBE-LIFT®/IND were applied in the pump station, supply tank, and secondary settling tank. The addition was carried out either by direct applying or spraying in a dilution of 1:10 to 1:50 with water in a water can.

Initial treatment, start on 1st April

April 1998, ¼ gallon was applied on the floating layer and the sidewalls of the supply tank near the pump screw in a dilution of 1:10 with water. 4 gallons were applied into the activated sludge tank. On the floating layer of the secondary settling tank ¾ of a gallon was sprayed in a dilution of 1:10.

On April 2, 1998, at 3 a.m. 1 gallon was added at the pump station.

Deutsch Wagram

Dosages:

Next four weeks once per week:

9.4.1998	1 gallon was added into the activated sludge tank
17.4.1998	1 gallon was added into the activated sludge tank
23.4.1998	1 gallon was added into the activated sludge tank
30.4.1998.1	1 gallon was added into the activated sludge tank

Maintenance once per week:

8.5.1998	½ gallon was added into the activated sludge tank
13.5.1998	½ gallon was added into the activated sludge tank
20.5.1998	½ gallon was added into the activated sludge tank
28.5.1998.1	½ gallon was added into the activated sludge tank
6.8.1998	½ gallon

If required (based on seasonally high flow rates) at the pump station, into the supply tank and into the secondary settling tank MICROBE-LIFT®/IND is applied additional.

After collecting one full year's worth of data, it was determined that for the year, under slightly higher flow and organic loading, that the plant had generated 34% less sludge for handling and disposal, reducing the cost for chemical treatment as well as for transportation and disposal. Additional benefits included improved solids settling characteristics as reflected by the SVI, reduction of the odors from the plant and a significant reduction in the oil & grease buildup.

Results:

Table 2. Sludge pressing results: without 24.7.98-1.8.98; with MICROBE-LIFT®/IND 9.12.-17.12.98

Duration of pressing	volume of raw sludge	TS - of press-cake %	press-cake t
28.7.-1.8.97	2083 m^3	26	270,18
24.7.-1.8.98	1330 m^3	31	178,12
- 2 day -	753 m^3	+ 19 absolute	- 92,06
1.12.-10.12.97	2065 m^3	25	208,41
9.12.-17.12.98	1529 m^3	27	194,46
- 1 day	-536 m^3	+ 8 absolute	-13,95

Deutsch Wagram

Results:

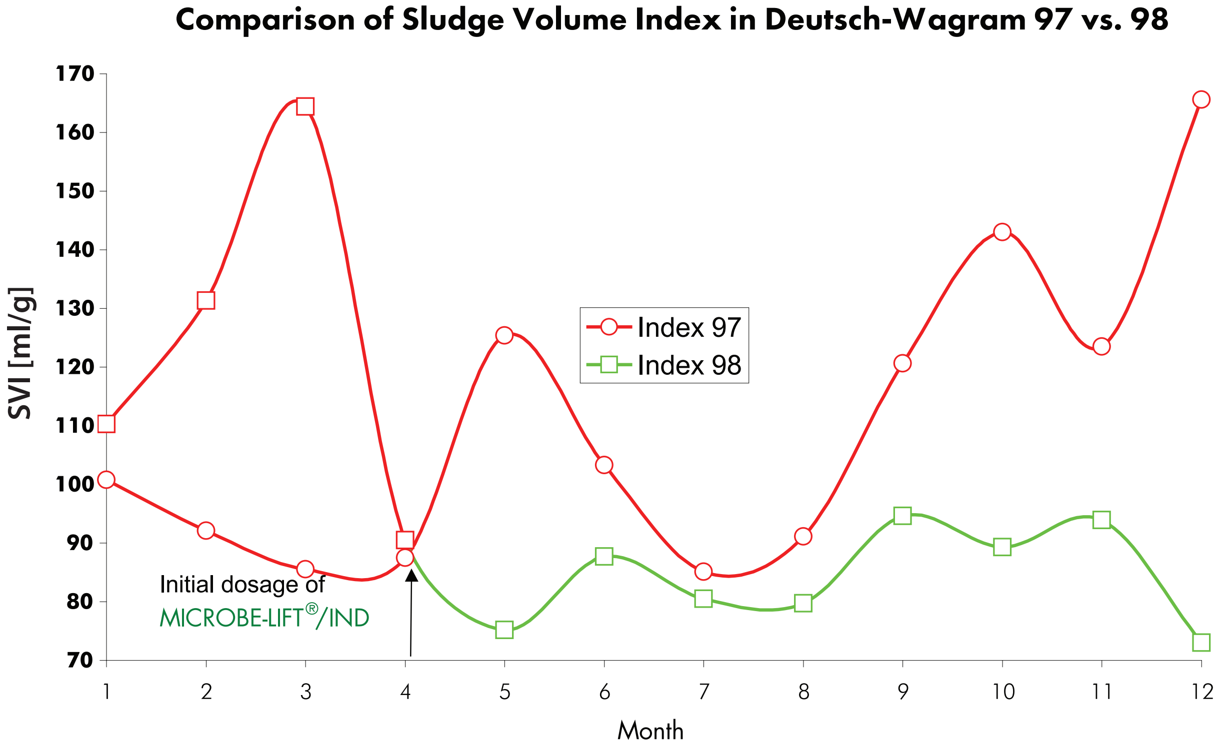

Fig.2: *SVI Data from Deutsch-Wagram*

Sludge handling and disposal costs were reduced by US $160,000 resulting in a net operating cost savings of US $130,000.

Zutphen

Background:

In March, 2006 the City of Zutphen in the Netherlands initiated a 120-day trial augmentation program. Zutphen is a medium sized activated sludge system treating an average of 6,600 M^3 of waste water per day. The plant comprises two parallel trains with segregated recycle lines so that a side-by-side comparison could be conducted. Two products were applied to Train AT2, MICROBE-LIFT®/IND and a natural organic compound found in other applications to potentiate the sludge reduction capabilities of MICROBE-LIFT®/IND Train AT1 was left unseeded as a control.

Results:

Within 60 days, an average reduction in sludge of approximately 20% was observed from the treated train with a maximum reduction of 26% observed late in the latter part of the 60 day period. Between the 60th and 90th day of the trial some settling instability was observed as was typically observed in the transition from cold weather to warm weather operation. Once through the transition the plant quickly stabilized and again a sludge reduction was observed in the treated train, but for this time period was in the 12% to 16 % range. Upon further evaluation of the data and process, it was determined that there was some commingling of the supernatant from the digestors, leading to an inadvertent low-level seed of the control train. While the differential between the seeded and "control" trains had been reduced, a comparison to historical sludge production numbers indicated that both trains were generating on the order of 20% reduction, despite higher hydraulic and organic loadings in 2006.

Table 3: Sludge Reduction Efficiencies at Zutphen

	Zutphen Sludge Reduction Trial Sludge Wasted (Kg)			
	AT1	**AT2**	**Average**	**Average/day**
1 Jan to 13 March	250,597	252,883	251,740	3496
14 March to 16 July	319,136	319,136	319,136	2574
	% Reduction	26.4%		

Colombia

Background:

Ecological Laboratories' Representative in South America was contacted by Empresas Publicas to see if it might be possible to reduce the odors associated with the operation of their anaerobic digestors and also improve the VSS reduction. The facility consisted of two anaerobic digestors of 7,900 M3 each. The average flow rate was 1.8 M3 per second giving an average HRT of 21 days. The VSS reduction being achieved prior to the addition of **MICROBE-LIFT®** /IND was approximately 30% for both reactors.

Results:

The reactors were dosed at rate of 12 mg/L based on the volume of the reactors on the first day followed by dosages of 4 mg/L once per week for the next four weeks and then 1.5 mg/L once per week thereafter on a maintenance basis. Six weeks after the initial dosage VSS reduction had been increased to 37% vs a target of 50% reduction with significant reductions in odors in and around the plant. The improvement allowed the plant to handle the existing load without the immediate addition of a third reactor.

Hod Hasharon - Israel

Background:

The City of Hod Hasharon operates an activated sludge system with anaerobic digestors to reduce the sludge volume before disposal. Average daily flow into the plant is approximately 25,000 M^3/day. Overall performance efficiency of the plant is excellent. Based on results achieved in the anaerobic digestors at Pusan and Empresas Publicas, the Operations Staff at Hod Hasharon made a decision to see if similar results could be achieved in their plant. Unlike the other plants, Hod Hasharon was also interested in whether or not an increase in biogas production could be realized since they recovered the gas and used as a fuel source.

Results:

Compared to historical values from the previous 15 month operating period, during for the first three months of product treatment, with a 1.8% increase in loading to the plant based on a hydraulic and organic basis, the amount of sludge removed from the plant was reduced by 18% with a concurrent increase in biogas of 11.3%. There is a fairly good correlation between the reduction in VSS and the increase in biogas production, making it reasonable to assume that the increase in biogas production is a result of the improved VSS reduction efficiency.

Current treatment, during the summer of 2006, has obtained even better results in the effluent properties of TSS, BOD etc. with sludge reduction over 20%, along with a significant reduction in odor.

Table 4: Operating Data from Hod Hasharon

BIO-GAS	Solids Vs WAS	SOLIDS Tons	% SOLIDS	Dry Sludge	Sewage in m3	RAS m3	WAS m3	
126635	0.42%	139	16.20%	858	796800	255870	32745	1/28/2004
106633	0.45%	129	16.60%	775.5	738833	243050	28593	2/28/2004
115413	0.44%	141	16.10%	874.5	774194	212910	32289	3/28/2004
112470	0.32%	118	15.60%	759	746850	238970	37522	4/28/2004
111817	0.42%	156	14.80%	1056	756214	230610	36870	5/28/2004
119430	0.34%	125	13.50%	924	730080	218740	36847	6/28/2004
159154	0.37%	122	14.20%	858	644940	193520	32969	7/28/2004
131719	0.46%	164	15.50%	1056	695370	212240	35870	8/28/2004
150030	0.38%	136	14.70%	924	677590	213870	35351	9/28/2004
147219	0.41%	153	15.00%	1023	730670	231090	37845	10/28/2004
138930	0.51%	151	15.80%	957	602680	182340	29630	11/28/2004
140585	0.45%	154	16.10%	957	742290	265340	34018	12/28/2004
140864	0.46%	144	15.60%	924	715640	332910	31392	1/28/2005
131488	0.39%	132	16.00%	825	755250	345860	33830	2/28/2005
142383	0.33%	141	15.30%	924	706748	365820	42207	3/28/2005
139350	0.29%	143	18.90%	759	763127	329610	49042	4/28/2005
151032	0.27%	146	19.20%	759	724080	324160	53732	5/28/2005
144330	0.31%	152	20.90%	726	715070	305420	48967	6/28/2005
								7/28/2005
								8/28/2005
								9/28/2005
								10/28/2005

Conclusion: Hypothetical Mechanisms for Observed Reduction in Sludge Generation

When growing microorganisms in an aqueous organic medium the carbon contained in the organics can end up being incorporated into new biomass (heterotrophic uptake), cell byproducts such as biopolymers or enzymes, or carbon dioxide. In fermentation technology, it is not uncommon to improve yields of fermentation products, which can be byproducts of bacterial metabolism, such as xanthan gum or biomass such as yeast, through manipulation of the process or the biomass itself. There are numerous examples of this in the production of antibiotics and enzymes. Typically, if the biomass is the desired end product, the system whether a batch or continuous fermentation is operated at a high F/M ratio, which maximizes the yield of cells since the cells are in log growth more of the time. This is consistent with Monod Kinetics, which suggests that growth rate increases with increasing substrate concentration until it reaches a point where the population cannot grow any faster dues to limitations such as mass transport or inhibition.

At the other end of the spectrum, when the cells operate in a substrate poor environment, the majority of substrate is used to satisfy the cell maintenance energy and there is little left over for new cell synthesis. This phenomenon is utilized in the process design for extended aeration systems, which produce less sludge but typically at a higher energy cost.

Until now, there have been few documented cases of sludge reduction through bioaugmentation but based on the example of the fermentation industry, there was always reasons to believe that sludge reduction was possible through biomass manipulation. Initial observations of sludge reduction were made serendipitously during programs in which bioaugmentation was used to enhance the reduction of refractory organics or enhance the overall efficiency of the systems with respect to organic removal efficiencies normally on the basis of BOD or COD reduction.

In most cases, some percentage of organic removal efficiency was achieved resulting in an equilibrium concentration of organics equivalent to that of the effluent in most suspended growth systems, especially those operating as CSTRs. Just as biomass in a fermentation would show lower yields of biomass when operated in a substrate poor environment, so does the biomass in a suspended growth system operating at a lower equilibrium F/M resulting in a lower yield coefficient for the system.

It also appears possible through bioaugmentation, along with the addition of natural supplements containing humic acids, that we can also enhance the cell digestion process.

We have certainly demonstrated the effectiveness and market potentials in our European trials for odor control and sludge reduction at municipal wastewater treatment facilities. We are in the final stages, and we are confident of the out-come, and therefore will be in a position to capitalize on these successful trials by mid-year. Projecting the business opportunity based on sludge reduction in the European domestic sewage market alone, our near-term target would be to take our success in Holland to the balance of Western Europe, and then expand to Eastern Europe, Asia, the Middle-East, and Central and South America. Similar business could be possible in urban areas (municipal treatment plants) in your market, or on a smaller scale in village septic lagoons and aeration ponds.

For more information on MICROBE-LIFT® Technology contact
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