

BIOAUGMENTATION: THE MATHEMATICS

Operators and managers of industrial wastewater treatment facilities are under increased pressure to meet their effluent quality requirements. This pressure is due to several factors, including environmental restrictions that are tightening allowable final permit levels and increased corporate pressure to maintain total environmental compliance. Many industrial wastewater treatment systems are only marginally capable of meeting the demands under normal or ideal situations. In times of upset conditions, such as high loading or low temperatures, many systems simply cannot provide the desired results without considerable attention and in some cases augmentation with chemical or bacterial additives.

Chemical addition to wastewater systems has been a widely accepted practice for many decades. In some applications, such as oily water clarification and sludge dewatering, ongoing or continuous chemical addition is usually the rule. In areas such as antifoams or secondary clarification polymers, the applications may either be continuous or intermittent.

Over the past twenty years, the addition of selected bacteria to biological treatment systems has become more widely used as a supplement to, or replacement for, many chemical applications. Known as bioaugmentation, this technology offers many benefits, including cost effectiveness, environmental friendliness and an ability to address some problems not solved by chemical addition. Examples of problems not affected by traditional chemical solutions include enhanced soluble Biochemical Oxygen Demand (BOD₅) removal, biological nitrification and recovery of biomass loss due to toxic shocks.

Because the effects of bioaugmentation are sometimes subtle and biological systems are dynamic and ever changing, it has been historically difficult to quantify the impact of bioaugmentation programs. Most documentation of successes utilized before and after data, bestowing some or all of the credit for improvement on the bioaugmentation program. This approach makes for good sales testimonials and case histories, however critics are quick to point out that during many typical bioaugmentation applications, numerous system changes occur (intentional or otherwise) which can also contribute to improvements observed. They also contend that because of a biomass' ability to acclimate to its environment, the indigenous population will eventually optimize itself. A final objective is that the number of bacteria usually applied is not sufficient to have an impact on a system's population. It is this third objection that this article will attempt to address.

In general terms, bioaugmentation applications can be divided into four categories:

1. Rapid building of a biomass during a system start-up or recovery from an upset.
2. Enhancing performance in once-through systems via ongoing supplemental inoculation.
3. Ongoing population enhancement of activated sludge.
4. Solids Reduction

Each of these categories will be discussed in detail and the potential impact of bioaugmentation will be presented in mathematical terms.

RAPID BIOMASS ESTABLISHMENT

Historically, many operators of activated sludge systems have practiced a form of bioaugmentation when they obtain sludge from a neighboring facility with which to seed or reseed their system. While this is a valid and acceptable approach, the use of commercial cultures can be used in conjunction with or in place of acquired sludge. The use of commercial cultures offers several advantages:

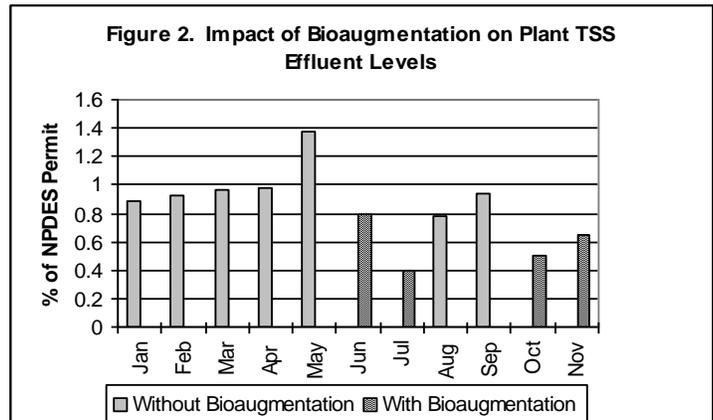
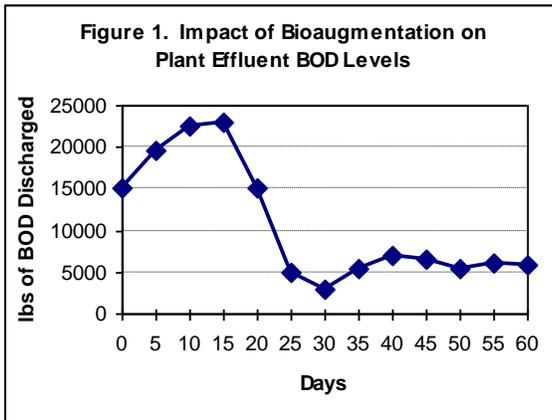
1. The product is readily available and can be kept on hand for quick response. If a plant is geographically isolated, it may be difficult to acquire sludge.
2. The product consistency is assured in terms of concentration of bacteria and types of strains present.

3. No risk of introducing someone else's problems, such as filamentous or zoogloal bulking into the system.
4. If properly selected, the commercial cultures provide the rapid growth required to return the system to the desired performance levels.
5. Other advantages include time and labor involved with getting a truck and operators, hauling the sludge from place to place, dumping the sludge and re-cleaning the truck so it can be used for its former job.

Some areas where biomass establishment would be needed include:

1. Start-up of a new plant.
2. Re-start following a shutdown or period of reduced production.
3. Following a loss of biomass due to washout or toxic shock.
4. Following the use of chlorination for control of filamentous bulking.
5. During the winter (colder) months when activity of the biomass slows down due to temperature drops (one log growth for each 10 degrees).
6. With the onset of closed loop systems where water recycle is important,

When comparing the use of commercial cultures with trucked in sludge, one has to compare apples to apples. Because of the concentrated nature of the products, many people fail to recognize or appreciate the numbers of bacteria that can be introduced via bioaugmentation, if properly applied. With trucked in sludge, you get mostly water. Even the solids you



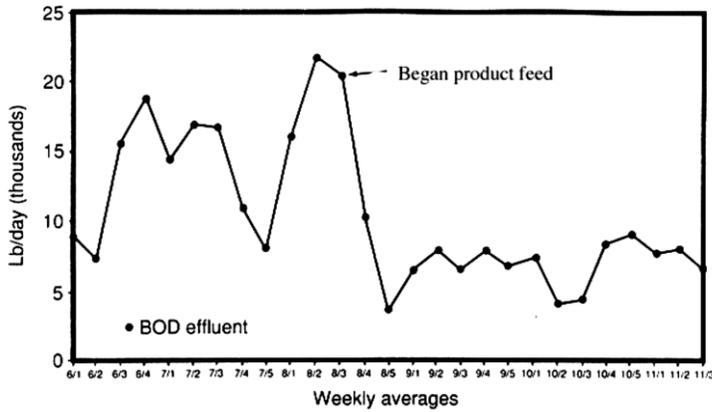
receive are relatively low in actual viable bacteria. What about the stage of growth of the bugs, the presence of filaments, the compatibility of the food sources? Plus there is no guarantee that there are no pathogenic bacteria present. With commercial cultures, the products are highly concentrated, stable, and can actually be "grown up" prior to application, which greatly enhances the cost-effectiveness. Figure 1 shows the grow-up potential of a typical product used for upset recovery. The mathematics are detailed in the Appendix.

Figure 2 shows how 5-10 pounds of a typical dry commercial blend of bacteria can provide as many bacteria as 4000 gallons of activated sludge. Depending on the situation, commercial bacteria may actually be less expensive than acquiring sludge from another plant. Even if the economics favor trucked in sludge, keeping a supply of bacteria on-site for upsets offers benefits. An improved ability to quickly respond can prevent an upset from escalating into a crisis.

SUPPLEMENTAL INOCULATION OF ONCE-THROUGH SYSTEMS

As the name implies, once through systems have little or no recycle to continuously re-seed the aeration basin with bacteria. The primary source of bacteria is the indigenous bacteria in the product plant effluent to be treated. This indigenous population may vary by as much as two orders of magnitude in terms of numbers of bacteria and may also vary in terms of types of bacteria present.

The lack of sludge recycle and the plug flow configuration of most once-through systems means that the system must rely primarily on the bacteria present in the influent to grow, reproduce and degrade organics compounds in the wastewater stream and insufficient time that the system has to offer without causing TSS or BOD problems in the final effluent.



BOD₅ reduction in a once-through system is a function of many factors, including aeration capacity, residence time distribution, nutrient availability and bacterial growth. If the “engineered” aspects of the system, such as flow pattern and aeration capacity are optimized and adequate nutrients are available, then the addition of additional bacteria can boost the bacterial numbers and increase BOD removal across the system. How much additional removal can be obtained will depend on the levels of viable bacteria in the influent, system hydraulic residence time distribution (flow pattern and holding time) and availability of adequate oxygen and nutrients.

While the actual impact of bioaugmentation will vary among different systems, it can be shown that properly applied bioaugmentation cultures can contribute up to an additional 30% to the influent bacteria levels.

Figure 4 in the appendix shows how bioaugmentation can enhance the performance of a system by increasing the number of bacteria available to degrade the various wastewater constituents as well as the types present.

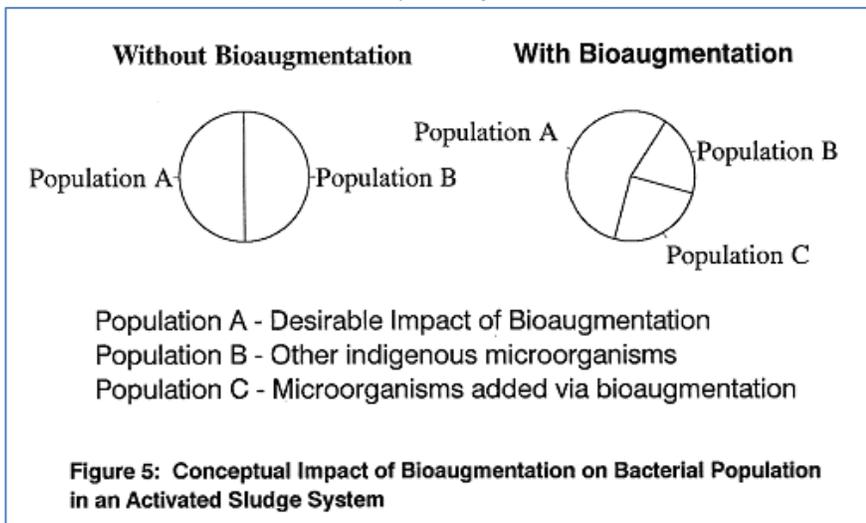
Supplemental bioaugmentation in once-through systems differs from the upset recovery type approach. In once through systems, the bioaugmentation program usually needs to be continued on a regular basis. With no sludge recycle, there is no means for the population to sustain itself and therefore, bioaugmentation may be routinely required to make the process capable. In some cases, the use may be seasonal to address performance problems during winter months or lower effluent BOD permit levels in summer months. There may be TSS problems in once-through during summer months, algae problems or D.O. loss during summer months.

ONGOING POPULATION ENHANCEMENT OF ACTIVATED SLUDGE

The practice of ongoing bioaugmentation in activated sludge processes relies on a simple premise. Even though many strains or species of bacteria can accomplish a given task, they vary in efficiency and speeds with which they degrade various compounds. The goal of ongoing bioaugmentation is to provide additional organisms that are more efficient or effective than the indigenous bacteria at degrading the various organic compounds and producing a settleable biomass. They are usually selected strains that are healthier, sturdier, and more able to withstand shocks better.

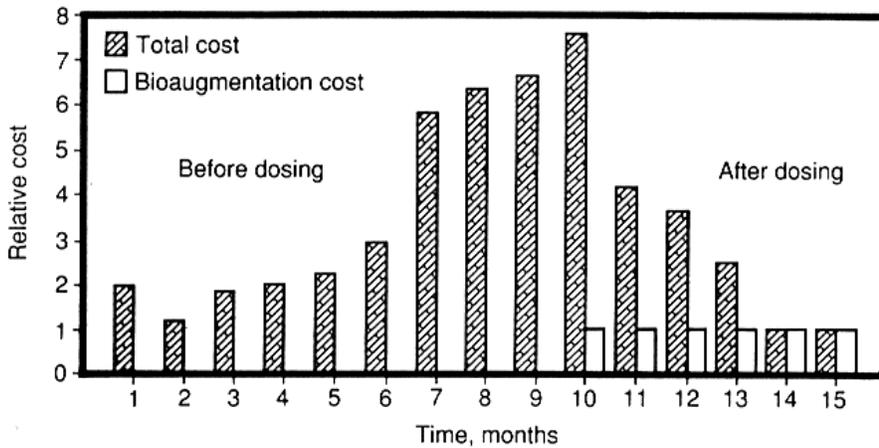
Figure 5 conceptually categorizes the biomass into Population A (desired indigenous microorganisms), population B (other filler, less active or undesirable indigenous microorganisms) and Population C (selected bioaugmentation organisms). The goal of a bioaugmentation program is to enhance the growth of Population A, establish the selected microorganisms of Population C and minimize Population B.

There is the question of why bioaugmentation products must be fed continuously after initial dosing of product in an activated sludge plant. An activated sludge plant is a dynamic system, where bacteria are routinely removed through wasting and additional indigenous bacteria are constantly being introduced via the influent and other sources. Due to system upsets and influent composition changes, a maintenance dosage is required to maintain the desired population diversity.



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Ongoing product requirements of “biomass maintenance” dosages are targeted to maintain bacteria at a pre-determined level. Proper monitoring of the system using statistical process control, combined



with microbiological analyses techniques will provide the information needed to maintain the desired population. By using

microscopic analyses and advanced plating techniques, one can correlate bacterial population characteristics with plant performance for a particular waste treatment system. Because every system is unique, the optimum population will vary from plant to plant.

Impact of Bioaugmentation on Total Chemical costs

SUMMARY

While the acceptance of bioaugmentation continues to grow, there are those that remain skeptical regarding the scientific validity of this approach. The mathematical examples in this article are not intended to provide definitive proof of the effectiveness or legitimacy of bioaugmentation. Rather, they were developed to provide the reader with a new and different perspective of the technology.

Explaining why a biological system performance varies from day to day can be as difficult as trying to explain why a particular sports team wins or loses. In both cases, there are numerous factors that affect the final outcome, and many of those factors are not fully understood or appreciated. Bioaugmentation should be applied in only those cases where it is a technically correct approach. It is critical to keep both the potential benefits and the limitations of bioaugmentation in perspective when applying this technology. If this perspective is maintained, than bioaugmentation can help provide solutions to many wastewater treatment problems.

Appendix

IMPACT OF FEEDING ONGOING BIOAUGMENTATION TO A ONCE-THROUGH LAGOON: THE ARITHMETIC

Assumption: 40 MGD flow
 Adequate aeration and holding time
 Essentially plug flow
 10 lbs/day Biological product (70 growth factor/ 6×10^9 cfu/g average count)

Case 1: Influent TVC of 1×10^7 cfu/ml

Daily inoculation of indigenous organisms = 1.5×10^{18} cfu
 Additional bacteria due to Biological product feed = 1.9×10^{15} cfu
 Minimum contribution of Biological product = 0.13%

Case 2: Influent TVC of 1×10^5 cfu/ml

Daily inoculation of indigenous organisms = 1.5×10^{17} cfu
 Additional bacteria due to Biological product feed = 1.9×10^{15} cfu
 Minimum contribution of Biological product product = 12.7%

RANGE OF POPULATION CONTRIBUTION OF BIOLOGICAL PRODUCT IN A ONCE-THROUGH LAGOON SYSTEM

Assumptions: 10 MGD flow
 5 lb/day Biological product feed

Range of Indigenous Inoculations: 3.785×10^{15} - 3.785×10^{17} cfu/day

Range of Biological product inoculation: 5.675×10^{14} - 1.43×10^{15} cfu/day

Minimum Contribution of Biological product: 0.14%

Median Contribution of Biological product: 2.6%

Maximum Contribution of Biological product: 38%

COMPARISON OF RESEEDING WITH Biological product VS. TRUCKING IN SLUDGE: THE ARITHMETIC

1 truck load of Activated Sludge = 4000 gallons

(4000 gals/truck) (3785 ml/gal) (5×10^7 cfu/ml) = 7.57×10^{14} cfu/truck
typical

Biological product in Biofeeder

A) No Grow-up

(1 lb Biological product) (454 grams/lb) (5×10^9 cfu/gram) = 2.27×10^{13} cfu/lb
grow-up product specification

= 333 lbs Biological product = 1 truck

B) Using Biological products and with an 8 hour grow-up time period

(1 lb Biological product) (10) (454 grams/lb) (5×10^9 cfu/gram) = 2.27×10^{13} cfu/lb
grow-up product specification

$(7.57 \times 10^{14}) \div (2.27 \times 10^{13}) = 33$ lbs Biological product C = 1 truck

C) Using Biological products and with a 16- 24 hour grow-up time period (1.5 logs)

(1 lb Biological products) (50 growth factor)(454 grams/lb)(5×10^9 cfu/gram) = 1.135×10^{14} cfu/lb
grow-up product specification

(7.57×10^{14}) cfu/truck \div (1.135×10^{14}) cfu/lb = 6.7 lbs Biological product = 1 truck

IMPACT OF FEEDING BIOAUGMENTATION TO AN ACTIVATED SLUDGE SYSTEM: THE ARITHMETIC

Assumptions: 1 mgd flow w/0.5 mgd recycle

1 mgv under aeration

5×10^7 cfu/ml TOC in AB

2 lb/day Biological product feed

Approach 1: Relative to biomass in basin

(1 mgv) (3785 ml/gal) (5 x 10⁷ cfu/gram) = 1.9 x 10¹⁷ cfu
 2 lb Biological product = 2.27 x 10¹⁴ cfu or 0.1 % of biomass (1000 ppm)

Approach 2: Relative to recycle

(0.5 mgd) (3785 ml/gal) (1 x 10⁸ cfu/gram) = 1.9 x 10¹⁷ cfu
 2 lb Biological product = 2.27 x 10¹⁴ cfu or 0.1 % of biomass (1000 ppm)

Approach 3: Relative to influent inoculation

(1 mgd) (3785 ml/gal) (1 x 10⁶ cfu/gram) = 3.785 x 10¹⁵ cfu
 2 lb Biological product = 2.27 x 10¹⁴ cfu or 6.0 % of daily inoculation

Total Systems Approach

