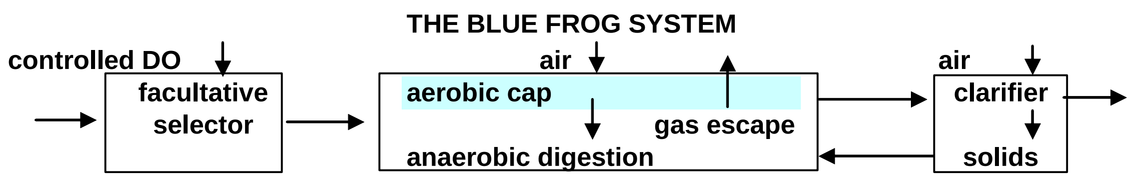
Blue Frog™ System

Dual Zone Facultative Selector/CSTR

The Blue Frog™ System (BFS) is built around three fundamental devices: a dual-zone, facultative-selector/CSTR, a surface-density-reducing aerator/circulator capping an anaerobic digester and an aeration/CSTR clarifier.



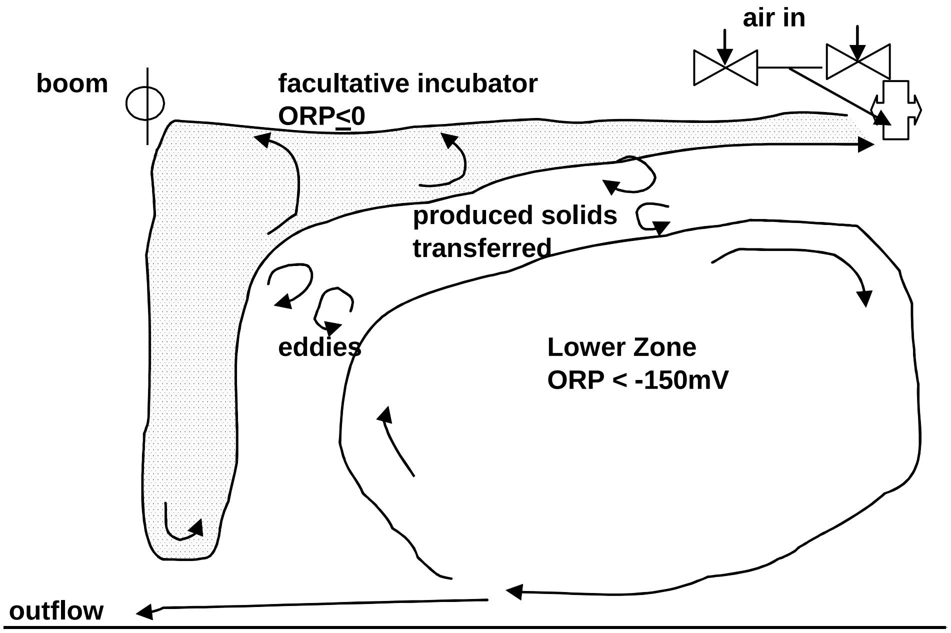
The facultative selector CSTR produces two distinct complete mix zones stacked one above the other: an upper zone with added oxygen and a lower zone without added oxygen. The amount of oxygen added is controlled such that liquefying facultative organisms are selected, not strict aerobes.

The aerator/circulator adds micronized air bubbles to the top three feet of the water column, reducing its specific gravity to .98 with entrained, micronized, residual-nitrogen bubbles. In the aerobic zone, strict aerobes oxidize soluble BOD; produced solids sink to a secondary sludge blanket at the gas/no gas interface; previously-selected facultative organisms liquefy the produced-sludge blanket from the bottom up.

The selector/CSTR mimics the aeration/complete mix strategy inherent in the Activated Sludge Process, except liquefying bacteria are selected for, while the aerator/circulator mimics the stratification strategy inherent in naturally occurring ponds. The aerator/CSTR simulates the secondary clarifier in the Activated Sludge Process, but the amount of sludge removed is trivial compared to the Activated Sludge Process.

At the end of the BFS process, the aerator/circulator is surrounded by a circumferential boom to make an aeration/CSTR. The upper zone specific gravity is .97 and produced solids are transferred to the lower zone rapidly and returned to the lagoon at large. Clarified upper zone water is discharged downstream.

Low DO Facultative Incubator



By mixing engineered and natural strategies, required water clean-up is achieved with low energy input; produced sludge is digested in situ and there is no malodor.

This describes the technology surrounding the BFS.

Design Intent

1. Select and then grow liquefaction bacteria (facultative) by controlling ORP to near zero in an inlet continuous mix zone.

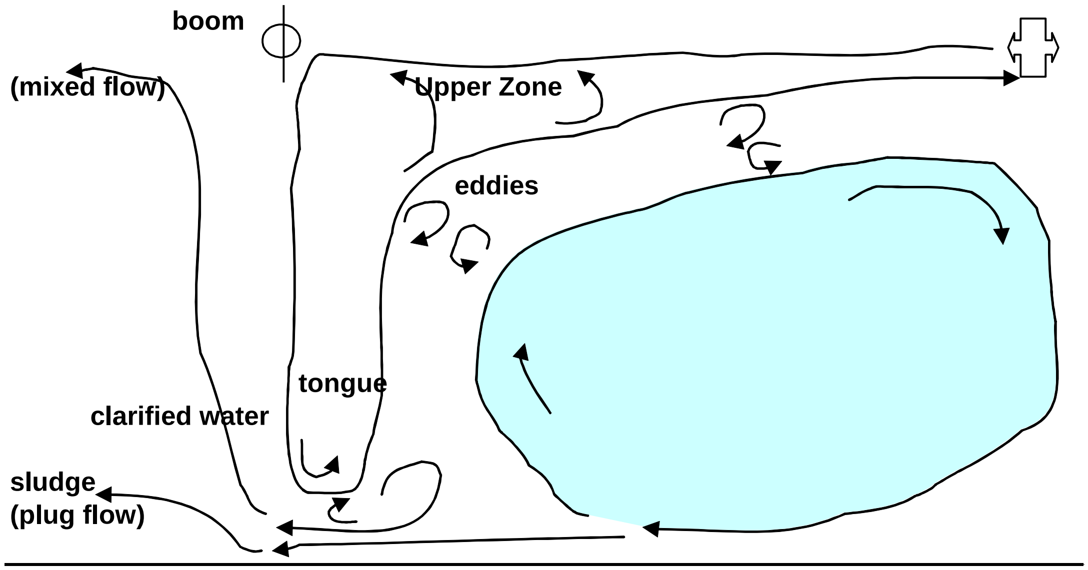
2. Liquefy sulfur-reducing bacteria to eliminate a root cause of malodor and a competitor of methane-producing archaea.

    a. There is no malodor, methane production increases and pH stabilizes near neutral.

3. Transfer selected/incubated fluid to the rest of the lagoon at the sludge/water interface.

    a. Heavier water stays near the bottom; lighter water flows to the surface

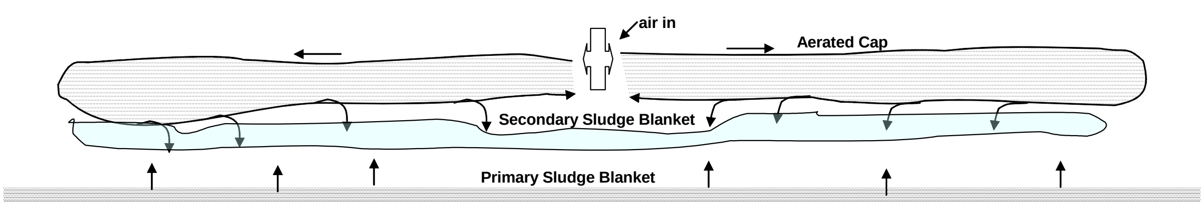
Stratified Flow Leaving CSTR



4. Reduce the specific gravity of the surface water with micronized air bubbles.

    a. Oxidize soluble BOD in the short HRT, low viscosity surface zone

    b. Transfer (sink) surface-produced solids to an intermediate, long HRT, high viscosity secondary sludge blanket.



5. Digest solids in situ

    a. Produced facultative organisms liquefy produced solids

    b. Indigenous anaerobes produce short chain acids.

    c. Methanogens convert acids and produced hydrogen into methane (without competition from SRB).

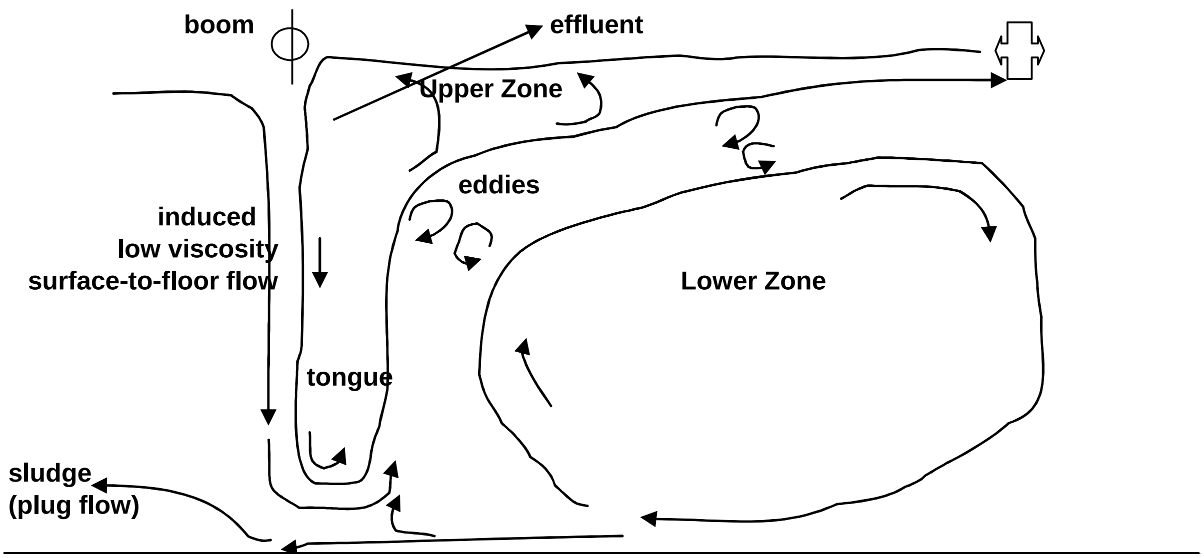
        i. Methane production increases; CO_2 production declines.

6. Clarify effluent by sinking residual solids in a gassy environment.

a. Discharge gassy, clarified water

b. Return solids-rich bottoms to lagoon.

Stratified Flow Entering/Leaving Clarifier



Appendix

Practical Microbiology

1. Obligate aerobes – Strict aerobes which require food, minor nutrients and oxygen to produce new cell bodies (produced sludge) and CO_2.

2. Obligate anaerobes – Strict anaerobes for which dissolved oxygen is toxic.

3. Facultative organisms – Bacteria which can reproduce aerobically or anaerobically. Facultative organisms can shift from aerobic to fermentative respiratory metabolisms as the available oxygen changes. Facultative organisms (and their produced enzymes) liquefy sludge when they are in fermenting mode.

4. Supportive aerobic environment – pH, temperature & oxygen

5. Supportive anaerobic environment – pH, temperature, absence of oxygen, alkalinity, absence of H_2S

6. Bacterial growth goes through 4 growth phases.

    a. Lag phase – bacteria require time to adjust to their environment

    b. Log-growth phase – when bacteria are always surrounded by an excess of food, they grow exponentially.

    c. Declining growth phase – the rate of increase declines because of limitations in the food supply

    d. Endogenous phase – the microorganisms are forced to metabolize their own protoplasm because there is too little available food. Some survive; most are eaten.

7. In activated sludge plants, a selector tank (with controlled dissolved oxygen levels) is often placed before the aeration basin. In the selector tank, abundant food and returned activated sludge (RAS) are mixed. The fastest growing organisms in the RAS enter log-growth because the food-to-microorganism ratio (F/M) is so large that food availability is not rate limiting. The rate of growth is controlled only by the genetics of the selected organisms &/or the DO.

    a. Selector tanks have an HRT (hydraulic retention time) designed to allow the soluble BOD to be oxidized; with too little HRT, "a significant amount of the influent soluble substrate will pass into the main aeration basin" (Metcalf & Eddy); with too much HRT, the "influent soluble substrate is diluted, resulting in too low an F/M ratio".

b. Selector tanks are designed to encourage the growth of low-surface-area, fast-settling floc forming organisms and discourage the growth of high-surface-area, slow-settling filamentous organisms.

   i. In a high soluble BOD environment, organism surface area does not control the rate of nutrient uptake, so low surface area floc formers are selected.

   ii. In a low soluble BOD environment, large-surface-area bacteria (e.g. filamentous) compete favorably as they capture nutrients across their large surface.

c. Selector tanks with high HRT, ORP near zero and excess food select for facultative, liquefying organisms because the rate-limiting available oxygen is too low for strict aerobes but sufficient to keep facultative organisms in their fast-growing aeration mode.

   i. An excess of liquefying organisms is a key first step in increasing in situ sludge digestion.

8. Sludge digestion steps:

a. Liquefaction: Enzymatic hydrolysis & fermentation of fats and complex sugars into water-soluble, basic structural building blocks (e.g. volatile fatty acids and simple sugars).

   i. By putting facultative organisms into log growth in the selector/CSTR, the absolute number of liquefaction organisms far exceeds the norm and much more sludge is liquefied.

b. Acetic acid and hydrogen formation (acidogenesis) by strict anaerobic bacteria.

c. Methane and CO_2 formation (methanogenesis) by other strict anaerobes (archaea). The acid formers and methane formers have a "syntrophic" (mutually beneficial) relationship. The methanogens consume the hydrogen released by the acid formers, allowing the acid formers to produce more hydrogen. If the methanogens are inhibited, the pH drops. When the pH <6.2, the methanogens stop growing.

d. Importantly, SRB (sulfur reducing bacteria (H_2S formers)) compete with the methane formers for the hydrogen produced by the acid formers. If the SRB bacteria were previously liquefied (i.e. eliminated), methane-former growth is increased and the pH rises

   i. Dissolved H_2S is acidic and lowers pH.

e. In prior art sludge digesters, the methane forming step is rate limiting. In the BFS, the liquefaction step is rate limiting because the SRB competition was eliminated.

9. Algae are photosynthetic organisms that use alkalinity (dissolved CO_2) and light to produce cell mass and oxygen.

    a. Algae do not grow at night (no light) or in a low CO_2 environment (no food).

    b. When methanogens do not have competitors, more of the carbon leaves the system as methane. By difference, less carbon leaves as CO_2 so the algae starve.

Key BFS Observations

1. When the selector/CSTR is first started up, it takes 6 days for the surface DO to fall to a new equilibrium.

    a. The microorganisms require a finite amount of time to reach a new equilibrium.

2. Selector/CSTR results for aerate mode are better than in mix mode.

    a. Aerate mode adds more oxygen to the system than mix mode.

        i. The aerate mode DO started @ 1.6 and ended 6 days later @ .3ppm in an industrial lagoon.

        ii. The ORP (aerate mode) in a manure lagoon is always negative.

3. When oxygen is rate limiting, adding more oxygen to the selector/CSTR increases oxygen-consuming microbial activity.

    a. The surface ORP should be close to zero mV to select for facultative liquefying organisms.

        i. If too little oxygen is added, facultative organisms will be in their slow growing mode.

        ii. More HRT is required when ORP is deliberately kept near zero.

    b. In high % soluble environments, using an aerator/circulator rather than just a circulator is advantageous.

        i. The soluble BOD is so reactive that the most of the added DO will be consumed by aerobic organisms. Excess oxygen must be added so facultative organisms will still be selected for.

    c. In a low % soluble environment, the aerator/circulator is disadvantageous.

        i. Excess oxygen transferred to the lower zone will inhibit the growth of true anaerobes.

4. Sludge is digested in situ in manure ponds, industrial lagoons and municipal lagoons.

a. The liquefaction step (hydrolysis and fermentation via facultative organisms) is more productive than in aerobe-rich activated sludge systems.

b. The facultative-organism population, previously increased with limited added oxygen, now ferments more sludge once the environment becomes anaerobic.

i. SRB is liquefied before it produces H_2S.

5. Ammonia concentration increases.

a. Ammonia is a by-product of sludge digestion.

6. The angle of repose of produced sludge is 5°.

a. Sludge slides off the berms to the flat.

i. Small bubbles are observed only above the flat.

7. True anaerobe population triples in the selector/CSTR.

8. There is no H_2S odor either in the selector/CSTR or downstream of the CSTR.

a. The SRB are liquefied in the CSTR and downstream of the CSTR.

i. The aerobic cap in the CSTR controls incidental malodors.

9. The pH downstream of the selector/CSTR is stable at 7.5 to 7.8. Small bubbles are observed above only the flat section of the lagoon.

a. In the absence of competition from SRB, the methane formers grow rapidly, consuming acid & hydrogen and producing methane gas. Consumption of acid stabilizes the pH @ near neutral.

i. Methane producers are archaea, not bacteria. Bacteria appear to be liquefied; archaea are not liquefied.

10. A secondary sludge blanket forms around the aerator/circulator out to a diameter of 200ft. The depth of clear water visibly increases daily as a just-started-system comes to equilibrium.

a. The aerator/circulator reduces the specific gravity of the surface water. Produced sludge sinks to the secondary sludge blanket.

b. The selected facultative organisms liquefy the secondary sludge blanket from the bottom side of the blanket.

11. The apparent oxygen transfer rate (OTR) is independent of installed horsepower. The OTR is directly proportional to the influent BOD.

a. 85% of the BOD is reduced anaerobically (in a municipal application with 36% soluble BOD).

12. Algae-rich downstream lagoons rapidly become algae-poor.

    a. When the carbon moves from aerobic mitigation (where CO_2 predominates) to anaerobic mitigation (where methane predominates), algae is starved of its carbon source and dies off.

        i. The algae carbon source is CO_2.

13. An aerator/circulator surrounded by a boom functions as a clarifier. Surface-zone water is transferred downstream; produced sludge flows out of the CSTR at the sludge/water interface independent of the surface zone water movement.

    a. Residual soluble BOD is oxidized in the upper zone and the produced sludge is physically transferred to the lower zone, clarifying the upper zone.

Proposed Technical Model

1. The selector/CSTR always has a high F/M ratio because there is no RAS

    a. M is low.

2. HRT in the selector/CSTR is extended (7hr).

    a. Food is never rate limiting because M is low.

    b. Liquefying facultative bacteria are selected because ORP is zero.

3. Fast-growing facultative organisms thrive in an oxygen-lean environment and are selected for in the upper, oxygen-supplied/but-lean zone.

    a. Oxygen is rate limiting on organism growth, not food; fast growing facultative organisms are selected

        i. $DO_{equilibrium} \leq .3max$

4. SRBs are liquefied by the rapid-growing, facultative, liquefying bacteria.

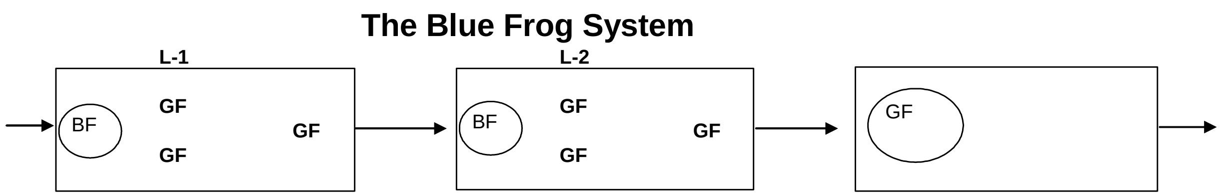
    a. Abundant, produced-fermentation-organisms liquefy the solids.

    b. The increased liquefaction rate is a critical benefit of the BFS.

5. Suspended solids are physically transferred to the lower anaerobic zone, increasing the food in the lower zone.

    a. Density difference is the driving force.

6. Fast-growing anaerobe population selected for in the lower zone because of the available food
    a. F/M is large because of sunken solids
        i. Sunken solids increase F.
7. Flow out of the CSTR is at the sludge/water interface below the boom.
    a. The facultative and anaerobic populations are transferred to the strictly anaerobic portion of the water column.
8. Sludge is liquefied and then digested in situ.
    a. Acid formers create acetic acid and hydrogen.
9. Methanogens thrive in the absence of competitive SRB.
    a. pH is stabilized @ near neutral
10. The acetic acid and hydrogen are converted into methane
11. An upper zone "tongue" dips down to the sludge water interface below the boom. Light, clear-water eddies from this current are layered on top of heavy, solids-rich water as they leave the CSTR.
    a. The light stream migrates to the top of the water column downstream of the boom.
    b. The heavy stream stays at the bottom of the water column downstream of the boom.
12. The light surface water is moved by the circulator/aerator.
    a. The light surface current has a short HRT.
13. The heavy current has an extended, plug flow HRT, allowing time for the anaerobic processes to proceed to completion.
14. A selector/CSTR and downstream aerator/circulators form a complete mitigation module. It reduces BOD by 85%. When two are placed in series, each reduces the remaining-BOD by 85% (see Sketch).
    a. Zone 1 remaining BOD = (100%-85%); Zone 2 remaining BOD = (100%-85%)*(100%-85%) = 2.2% remaining BOD.



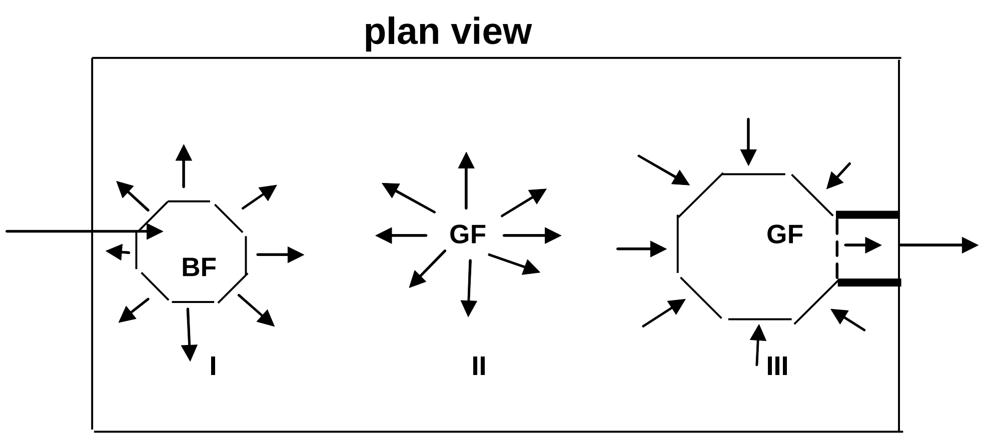
15. A complete system requires an aerator/clarifier/CSTR at the end of the process.

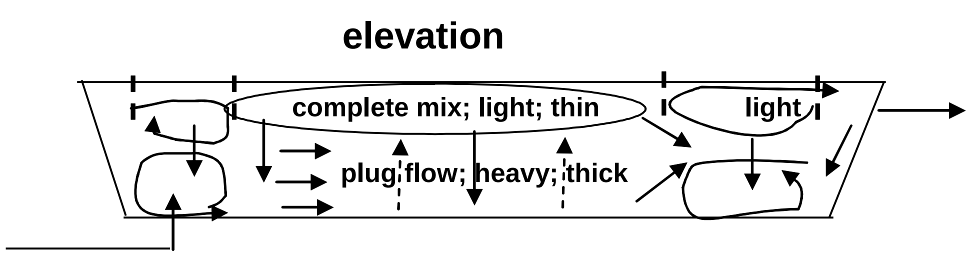
    a. For example, a one lagoon system would be:

        i. An inlet selector/CSTR (Blue Frog/CSTR) - I

        ii. A surface aerator (Gold Frog) - II

        iii. An aerator/clarifier (GF/CSTR), followed by a quiescent polishing area - III





I. Select; incubate; equalize; deodorize
II. Stratify; sink; digest-to-methane
III. Clarify; polish