A Solar-Powered EMF Aeration Technology to Enhance Sludge Digestion and Improve Effluent Quality for Water and Wastewater Management

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ABSTRACT
E M Fluids has developed a technology that alters the properties of water on a large scale with minimal energy input. Devices are solar-powered, self-contained systems that enhance the gas transfer rate across the air-water interface — achieved without chemicals or mechanical agitation. Using a pre-calibrated signal (<1W), key physicochemical properties of water are altered resulting in a doubling of gas transfer rate across the air-water interface.
Globally, the EMF aeration device has been deployed at many water and wastewater sites with each achieving reduced accumulation, accelerated organic sludge digestion in-situ and improved water quality. For example, deployments with SANEPAR (a Brazil Utility) at 2 sewage lagoon sites, reported digesting ~5400m^3 of sludge in 5-months and ~3000m^3; an OPEX savings close to half a million USD. Other deployments resulted in prompt elimination or reduction of malodour and an improvement in water quality parameters such as P, N, BOD, COD, TS, and TSS.
The EMF solution helps maintain cleaner, more efficient lagoons and freshwater bodies with minimal effort and infrastructure. Its compact, energy-efficient design also minimizes operational costs, making it an ideal, low-maintenance solution for long-term water and wastewater management.

1. INTRODUCTION
The loading of organic matter and nutrients into a body of water, such as the discharge of sewage into a sewage lagoon or agricultural run-off into a lake/reservoir, creates high oxygen demand. Moreover, eutrophic systems depleted of oxygen are one of the main propagators of harmful algal blooms, a particular concern in the health and normal functioning of a freshwater ecosystem. Depletion of dissolved oxygen in these systems is driven by the degradation of labile organic carbon by aerobic heterotrophic microbes, and the oxidation of reduced chemical species. High, continuous nutrient loading further contributes to eutrophication and production of autochthonous organic matter compounding oxygen stress and the accumulation of sludge and propagation of harmful algal blooms[1,2].

When oxygen is depleted, anaerobic metabolism predominates, which is generally less efficient and results in lower overall metabolic rates in a pond[3], reduced rates of organic matter decomposition, increased return of nutrients into the water column, and more rapid accumulation of sludge in ponds[4]. Moreover, the increased internal load of nutrients coupled with low oxygen results in little retention of inorganic phosphorus and returns reduced nitrogen forms, such as ammonia/ammonium, back into the water column[5]. This shift in the dominant available N source may give a competitive advantage to cyanobacteria relative to more beneficial forms of algae, like diatoms. Further, anaerobic processes contribute to odour and other aesthetic problems. The accumulation of undigested organic matter in sludge creates a reservoir of materials with high biological and chemical oxygen demand[6]. This accumulation of materials with high oxygen demand, and continuous internal nutrient load, can create a perpetual condition of oxygen stress in the pond, and ecosystem function dominated by anaerobic metabolic activities.

Given the central importance of dissolved oxygen in maintaining ecosystem function, including efficient degradation of organic matter in ponds, artificial oxygenation and reaeration have a long history[7]. Strategies include the use of mechanical aerators to mix water, destratification of the water column, and pumping or bubbling of air into the oxygen depleted part of the water column. Various control strategies to contain harmful blooms have also been proposed to date, including chemical treatments (e.g. copper sulfate and oxidizing agents), algicides, and physical treatments (phosphoric clays). Chemical solutions are generally not cost-effective, and in many cases, their approaches require killing the algae, increasing organic load. The nutrients incorporated into this organic biomass are then recycled back into the water column and can perpetuate the algae growth. Mechanical solutions often require installation of expensive infrastructure with associated maintenance needs and generally have high energy demand associated with moving water or pumping air.

The proposed EMF Device is a novel aeration solar-powered technology that does not require permanent infrastructure and is deployed as a small buoy. The proposed technology is a new approach to digest organic matter and a mitigation tool for harmful blooms in water and wastewater applications.

2. DISCUSSION

2.1 EMF as an aeration device

E M Fluids has developed a patented equilibrium modulating (EM) technology which alters the physicochemical properties of water on a large scale with minimal energy input. The EMF device is a solar-powered, self-contained system that naturally enhances the gas transfer rate across the air-water interface without chemicals or mechanical agitation. Using a <1 W pre-calibrated signal as a stimulus, the device modifies the structural arrangement of water molecules, reducing surface tension and viscosity.

Validation of the EMF as an aeration device comes from previous research conducted at Toronto Metropolitan University on gas exchange between air and water, using a combination of laboratory and field studies[8]. Studies show that one device can double oxygen exchange rate across the air-water interface, compared to reference conditions, and can impact an area as large as 50 acres[8,9]. Based on these findings, EMF treatment in an open waterbody, such as a pond, lake, or sewage lagoon would be expected to approximately double gas exchange rate between the air and water. This would support greater delivery of oxygen to water when dissolved oxygen concentrations are below saturation. In waterbodies that support high loading of nutrients and organic matter – thereby generating high biological and/or chemical oxygen demand – the enhanced gas exchange using EMF can satisfy much more of this oxygen demand than passive exchange alone.

2.2 Effect on physiochemical properties of water

The magnitude of the effect of EMF on gas exchange in the open waterbodies (e.g. ponds and lakes) has been more challenging to quantify, as gas flux is driven, not only by the EMF treatment effect, but also by temperature, wind velocity, and the magnitude of disequilibrium[10] in dissolved oxygen, and these parameters change between measurement periods. A more useful parameter for assessing the effect of EMF treatment is the first-order gas transfer rate (K), which is independent of dissolved oxygen disequilibrium and can be corrected for temperature (although K, like flux, is still sensitive to wind velocity)[11].

The first-order exchange rate of gases across the air-water interface (K) is a function of the boundary layer conditions and the physical conditions in air and water, which will affect the boundary layer thickness. For air, the governing physical properties are wind velocity, atmospheric pressure, and partial pressure of the gas. For water, the governing physical conditions are temperature, advective mixing, viscosity, surface tension, and molecular diffusion. EMF treatment of water approximately doubles K. EMF treatment has no impact on the air boundary layer. Various theories, including two-film theory[12], penetration theory[13], surface renewal theory[14], and boundary layer theory, have been proposed to explain interfacial mass transfer coefficient. Lower surface tension and viscosity have been consistently correlated to enhanced interfacial mass transfer rate[15]. Past laboratory studies at Toronto Metropolitan University[16] have demonstrated EMF treatment reduces viscosity and surface tension.

2.3 Application

Field testing already conducted in sewage lagoons, aquafarms, and ponds in Israel, Thailand, China, Brazil, and Canada indicate that the EMF treatment increased dissolved oxygen (DO) availability and alleviated oxygen stress in water bodies. The boost in DO availability, and reduced duration of low DO concentrations at night, support the growth of aerobic bacterial populations which allow for greater processing of organic matter and high nutrient loads. For example, several field demonstrations found a reduction in sludge accumulation, lower levels of total reduced nitrogen and total phosphorus in the water column[9,16]. Nutrient management is particularly important in managing algal blooms. The increased DO availability raises the oxidation-reduction potential (ORP) and the growth of the aerobic nitrification bacteria that supply the ammonia oxidizing enzymes to drive the ammonium-nitrate chemical equilibrium towards nitrate[16]. The lower ammonia availability renders cyanobacteria less competitive against diatoms and green algae, which are preferred food sources for aquatic animals (zooplankton). Additionally, the higher ORP promotes the formation of complex precipitates between the phosphates and available metal ions in the water to reduce the internal loading and bioavailability of phosphorus that would otherwise support bloom growth.

Case 1[9,17]: In 2021, water ponds in Thailand plagued by excessive algae, malodours, poor

water clarity, and mass fish kills were restored with one EMF device within 2 months to healthy phytoplankton levels and water chemistry (decreased ammonium and phosphorous by 80% and 70%, respectively) and clarity, as seen in Figure 1. No mass fish kills were observed during the seasonal waterbody turnover.

Figure 1. Freshwater water pond photos taken before (L) and after (R) a 2-month EMF treatment.

Case 2[16] : A 6-month installation of 10 EMF devices in Thailand reduced the concentration of cyanobacteria by 83% and increased diatom populations by 65% across an almost 4 mile x 2 mile reservoir with 5 incoming rivers, 2 outgoing rivers, and 7 pumping stations for residential drinking water and irrigation.

Case 3[8,9]**:** A 5-month installation in several paired 15-acre lagoons in Ontario, Canada (reference vs EMF treated) demonstrated a suppression in algal blooms in 137 days, 79% decrease in ammonium concentrations, 69% decrease in BOD, 88% decrease in *E.coli* concentrations, and a reduction in overall odour from the lagoons. Moreover, the lagoons with an EMF device showed minimal sludge accumulation (0.2 - 0.5 cm) compared to the reference lagoon (5 cm) over a typical 5-month operating season. This was an active lagoon that continued operations with daily influent without interruption.

Case 4[16]**:** A 5-month installation of one EMF device in a recreational pond managed by one of Brazil's largest sanitation utility companies (SANEPAR) demonstrated a reduction of organic sludge accumulation, a 97% in cyanobacteria, 70% in phosphorus, 55% in BOD, 42% in COD, and 56% reduction in nitrogen concentration. This saved SANEPAR more than $60,000 on sludge management cost (dredging, transportation, disposal etc.).

Case 5[16]**:** Over a 5-month period, two sewage lagoon sites managed by SANEPAR were equipped with EMF technology. EMF device resulted in a halt in new organic sludge accumulation and digestion of previously accumulated organic sludge. Additionally, due to the sludge digestion process increasing, the treatment capacity of the lagoons increased and enhanced the quality of the final effluent. 3,037 m^3 (site 1) and 5,425 m^3 (site 2) of sludge was digested reducing the accumulated sludge volume by over 10% and 11%, respectively.

3. CONCLUSION

The proposed solar-powered EMF aeration technology is a new approach to digest organic matter and mitigation tool for harmful blooms in wastewater and water applications. This novel equilibrium modulated aeration solution overcomes the limitations of other traditional treatment and mitigation methods including large infrastructure changes, chemical and mechanical treatment, and the associated financial and energy costs of each.

A single device can alter the properties of water on a large scale (up to 50 acres) with minimal energy input such that it can reduce surface tension and viscosity and double the gas transfer rate across the air-water interface. Applications include: low cost oxygenation of very large waterbodies, improving waste water processing and lagoon efficiency (sludge management, malodours, and water quality), water remediation (cyanobacteria blooms, mass fish kills, and water quality).

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