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Dissolved Oxygen Management for Improved Wastewater Treatment

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ABSTRACT

Biochemical reactions for wastewater treatment are primarily reactions enabled by microbial metabolic processes. Waste treatment technology seeks enhancement of the reactions through environmental controls, dissolved oxygen levels, and bacterial speciation. In general, the reactions that occur within aerobic systems mineralize carbonaceous material through oxidation and scavenge chemical nutrients while microbial systems of anaerobic conditions produce reduced chemicals for gaseous disposal. These ambivalent environments commonly exist in zones within water mass of natural water bodies but they can be created within contiguous zones of managed waste streams. On meso-scales of time and space, these environments may exist in many locations within a waste stream and change continuously as hydraulic and chemical loading varies.

Microbial population management for treatment optimumization is generally a feedback from control of chemical and physical parameters, although, accelerated population adjustments through culture-dosing to serve transient waste stream qualities is also a management option. Some environmental support for sustained population systems include dissolved oxygen (DO) concentration controls for different treatment objectives along a flow-path. Dissolved oxygen concentration is difficult to measure but optimum control is contingent on continuous measurements.

DO sensor failures caused by biofouling is a common problem in all low-level oxygen environments typical of wastewater streams, however, a new DO measuring technology developed by this author is proved to be practical for advanced wastewater treatment requirements and for strict oxygen management.

Introduction:

Dissolved oxygen (DO) concentrations are water treatment factors for carbonatious and plant-nutrient chemicals and an important factor in waste-solid bacterial uptake. Although atmospheric contact provides some oxygen to support biochemical processes of treatment in waste streams, chemical reaction rates and the metabolic demands of microbial populations are usually larger than supply rates from the surface. However, aerating equipment operations and optimum control of oxygen availability is technically difficult because accurate oxygen

measurement over continuous periods is compromised by oxygen sensor fouling. This paper provides a review of oxygen dependent chemical and biological water treatment technology as an introduction to requirements for new dissolved oxygen management technology.

Recent assessment of eastern U.S. coastal-region natural water quality (U.S. EPA, 1995) identified significant flux of plant-nutrient chemicals from coastal watersheds. Therefore, new limiting requirements for plant-nutrient chemicals discharge are likely. Although polymers and waste-conditioning chemicals are commonly used in wastewater treatment, the relatively large volume of waste solids creates an undesirable solids disposal problem so biological processes are preferred. Oxygen management for biological waste treatment processes vary in different treatment unit-processes, oxygen requirements for solids treatment are different for organic waste chemicals, and management of oxygen levels is commonly required for cyclic changes in waste loading.

Oxygen parameters for solids treatment:

Carbonaceous solids in wastewater create a Biochemical Demand (BOD) for oxygen through reactions that are enabled by bacteria. In general, organic materials are assumed to carry the bacterial inoculants by which they can be reduced and, eventually, a stream of waste-organics would be expected to carry the bacteriological speciation best suited to the stream environment and chemical constituents. However, relative to the time duration of waste within a treatment plant, the evolution of these bacterial populations is slow.

In treatment processing the water environment is managed to optimize the rates and completeness of treatment processes which, for waste-solids treatment, is primarily the control of the microbial populations for reduction and uptake. Within a treatment plant, bacterial populations reflect the characteristic organic materials in the plant through-put, although, bacterial-culture dosing can be a tool for temporary adjustment to loading variations. Although the natural evolution of suitable bacterial populations would require relatively long time periods, accelerated waste reduction is possible through the inoculation of waste inflows with activated-solids. These solids are waste materials, cycled from the waste through-put, that have accumulated the bacterial conditions related to the contingent waste load. However, the inoculated input-loading with these solids results in stimulated chemical oxidation reactions, leading to locally depleted DO concentration, and oxygen demand (BOD) variation from cyclic waste-loading. This oxygen-chemical demand is seldom satisfied by less than continuous DO monitoring and automatic control of oxygenation through feedback from DO measurements.

A part of the treatment process is the separation of waste solids and bacterial colonies from the wastewater through gravitationally controlled settling. Although some solids settling difficulties are associated with physical parameters, most are biological and effected by dissolved oxygen levels. Zoogloeal-type micro-organisms tend to form small clumps of solids; the largest of which have rapid settling rates. However at an extreme, large numbers of small particles are also formed which may be carried by transient flows through settling basins and outflows to produce unacceptable treatment quality by virtue of suspended-solids flow-through. At the opposite extreme, filamentous micro-organisms are associated with "bulking solids" which tend to the formation of large mats of solids. These solids masses tend to trap bubbles, to form floating masses that fail to sink, and to contribute to solids loss with the effluent flows. Since zoogloeal organisms are growth limited at higher dissolved oxygen levels than at levels where filamentous populations are limited, oxygen level management may be used as a control

of solids settling rates. In practice, a microbial population between these extremes is desirable.

In a particular case, where dissolved oxygen concentration came into importance for solids control, small amounts of activated solids were pumped to combine with in fluent to primary clarifiers in attempt to increase solids settling. The operations created pseudo-bioreactors out of clarifiers that resulted in increased solids separation rates initially but, from accelerated loss of oxygen during warm seasons, denitrification of sludge in the clarifiers caused subsequent resuspension of solids from nitrogen bubbles.

Oxygen parameters for BNR:

Biochemical processes in oxygenated environments are important for biological nutrient removal (BNR). A typical system of unit processes for BNR is illustrated by the Modified Ludzack-Ettinger process (Figure 1; Olsson, 1992). The initial anaerobic zone may include head-works processors and primary clarifiers. Further oxygen reductions for the environment of the follow-on anoxic zone forces denitrification reaction mitigation by heterotrophic bacteria. In the aerobic zone, nutrient-organic nitrogen chemicals are taken into microbial cells and ammonium-nitrogen is oxidized into soluble compounds that are amenable to reduction when recycled back to the anoxic zone. This arrangement of unit processes utilizes advantages of the low oxygen content of inflows as inflow to the anoxic zone. Placement of the aerobic zone upstream of the final clarifier typically improves solids-settling and lowers suspended solids in effluent. As diagramed, cycling of activated solids supplies conditioned microbial populations of heterotrophic bacteria for improved nitrified-compound reduction. The biochemical nitrification rates are highly dependent on DO levels with limiting DO levels as high as 2.5 mg/liter for attached and suspended colonies. The reaction rates are also dependent on temperature, doubling over 10 degree C temperature ranges. A consequence of less than opportune conditions for these reactions is the resulting necessity for longer retention periods and proportional increases in facility holdings for the appropriate retention periods.

The attached microbial films on reactive surfaces in trickling-filter units also require well oxygenated surfaces for organic-nitrogen uptake and nitrification but management of air supply to the filters is partially dependent on parameters of the filter so, aside from the generalities of oxygen supply requirements, trial and error tuning of air supply is required. Greater control of oxygen is possible with use of suspended microbial colonies and, under low oxygen level environment, the same microbial populations that mitigated nitrification may be utilized to strip oxygen from nitrates and denitrify waste through release of nitrogen gas. With improved oxygen monitoring and automatic controls on oxygenation based on feedback from oxygen measurements, zonation of plug flow with regard to oxygen level is practical.

Many existing treatment plants use aeration as a means to locally mix waste streams, an operations practice which came from the relative inefficiency of oxygenation. Since large air volume pumping into waste streams is necessary for oxygen supply, the resulting mechanical agitation of the waste eliminated need for addition mixing. However with treatment targeted to the removal of selected waste chemicals, such requirements as oxygen management become important and the requirements lead to use of mechanical mixing in operational practice. This use of air-forced mixing has lead to maximal power usage in activated-sludge reactors because air bubbles used to force mixing is inefficient.

Improved oxygen monitoring:

To address the developing need for accurate and dependable dissolved oxygen measurement, the author with Science Applications International Corporation developed prototype oxygen monitoring instrumentation which has demonstrated a potential for service in the waste treatment industry. This new technology utilizes biological-fouling control to extend operational life of DO sensors in continuous deployment.

In recent years, high-quality DO sensors have become available on the commercial market which provide reliable measurements during continuous deployment within fully oxygenated surface regions of biological reactors. However these sensors foul rapidly in low oxygen environments and, with the resulting loss of calibration, measured DO becomes unreliable for automatic oxygenation controls. The new oxygen monitoring prototype deployed in the Haddenfield, New Jersey activated-sludge wastewater treatment plant operated with sensor fouling control for one DO sensor and with an unprotected oxygen sensor. As indicated from Figure 2, no change in the fouling-protected sensor calibration was evident during the seven week deployment based on the comparison of sensor measurements with chemical quantitative analysis. A graph of DO measurement differences between the measurements collected from the sensor with fouling protection and measurements from the unprotected sensor (Figure 3) indicates the effect of sensor fouling. After about seven weeks, the differences in measurement between the sensors is about 4.5 mg/liter.

Summary:

Increased oxygen control that is necessary to meet wastewater treatment requirements expected in the future will not be achievable with presently available DO sensor systems. These controls must come from automatic operations of wastewater treatment systems with control based on the properties of the waste stream itself.

Oxygen measurements by the prototype DO monitoring system showed the new technology is capable of managing oxygen over practical periods of waste treatment operations and over maintenance-free periods that are acceptable by the treatment industry.

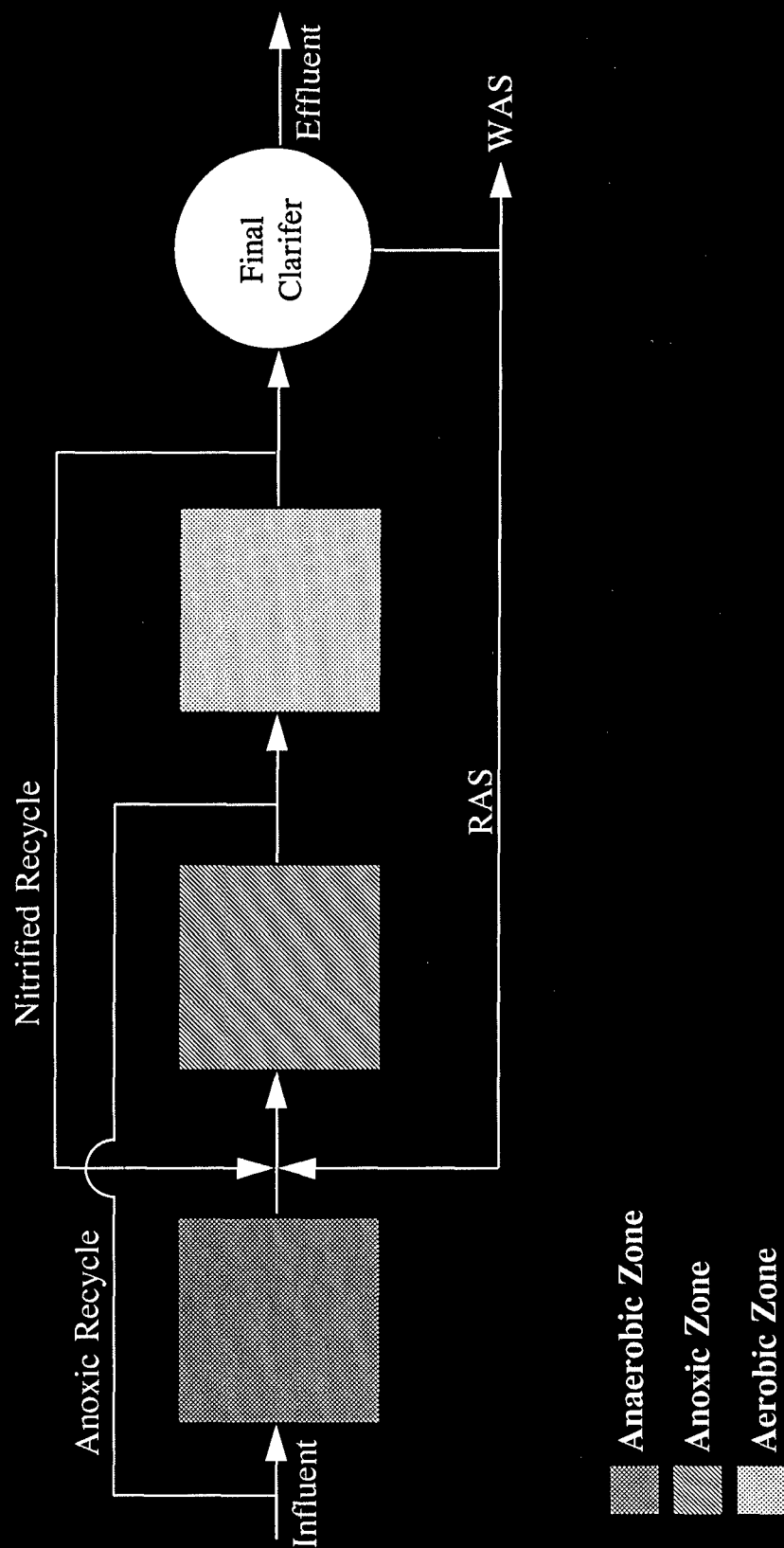
The degree of control of oxygen that is afforded by the new monitoring technology permits further investigation of other factors of biochemical control. This paper has included explanation for microbial control and chemistry that may be managed through optimum treatment environments with oxygen and one can expect that other controls through other factors such as hydraulics, ionic conditions, temperature etc. can lead to further improvements of waste treatment.

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Figure 1: Unit Processes for Biological Nutrient Removal



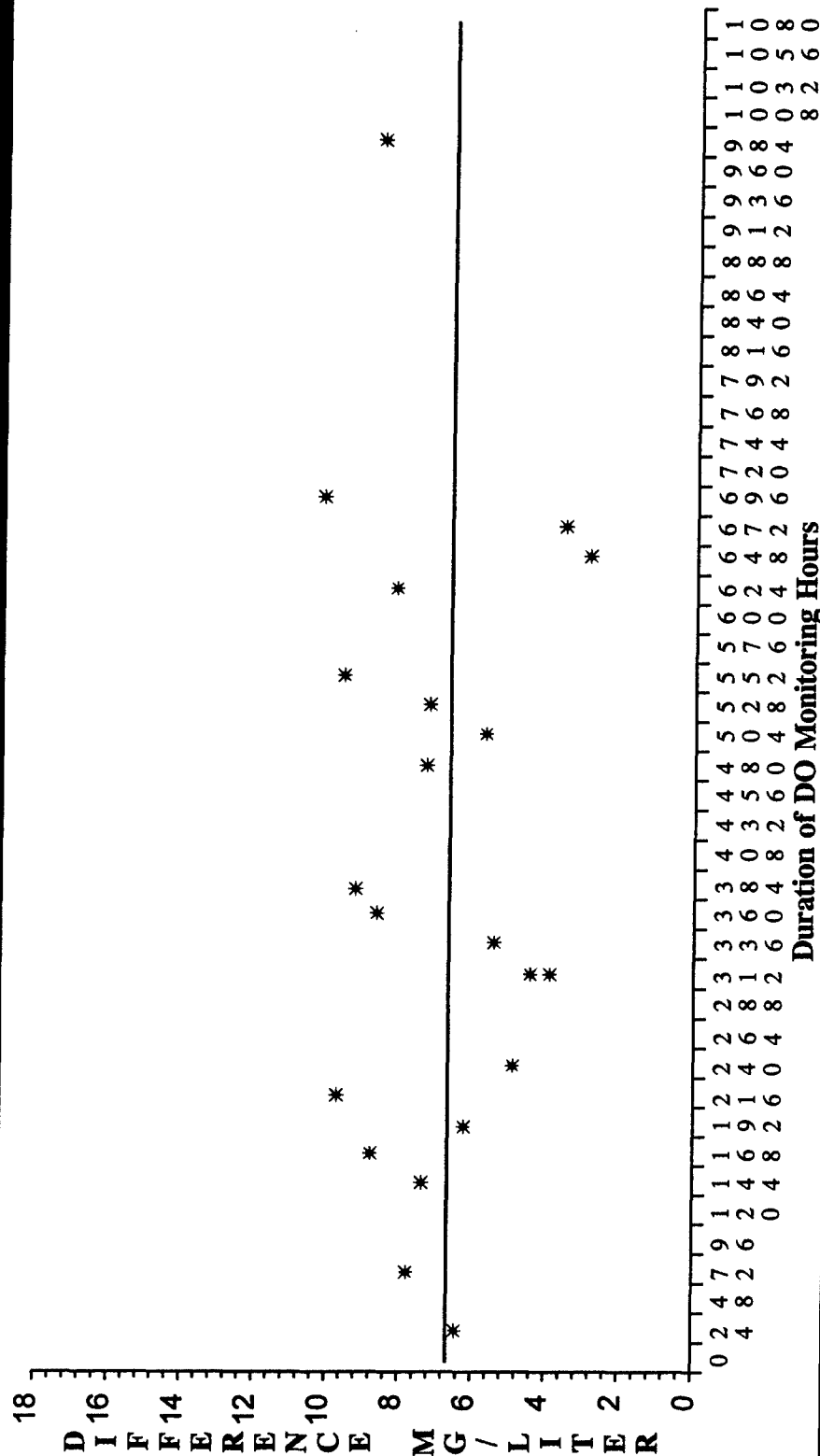
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Dissolved Oxygen Measurements

Ridgewood, NJ WWTP Summer 1994 Differences, Protected-Chemical Measures

Figure 2: Dissolved Oxygen Measurements by Sensor with Biofouling Control
Compared to Chemical Quantitative Oxygen Measurements



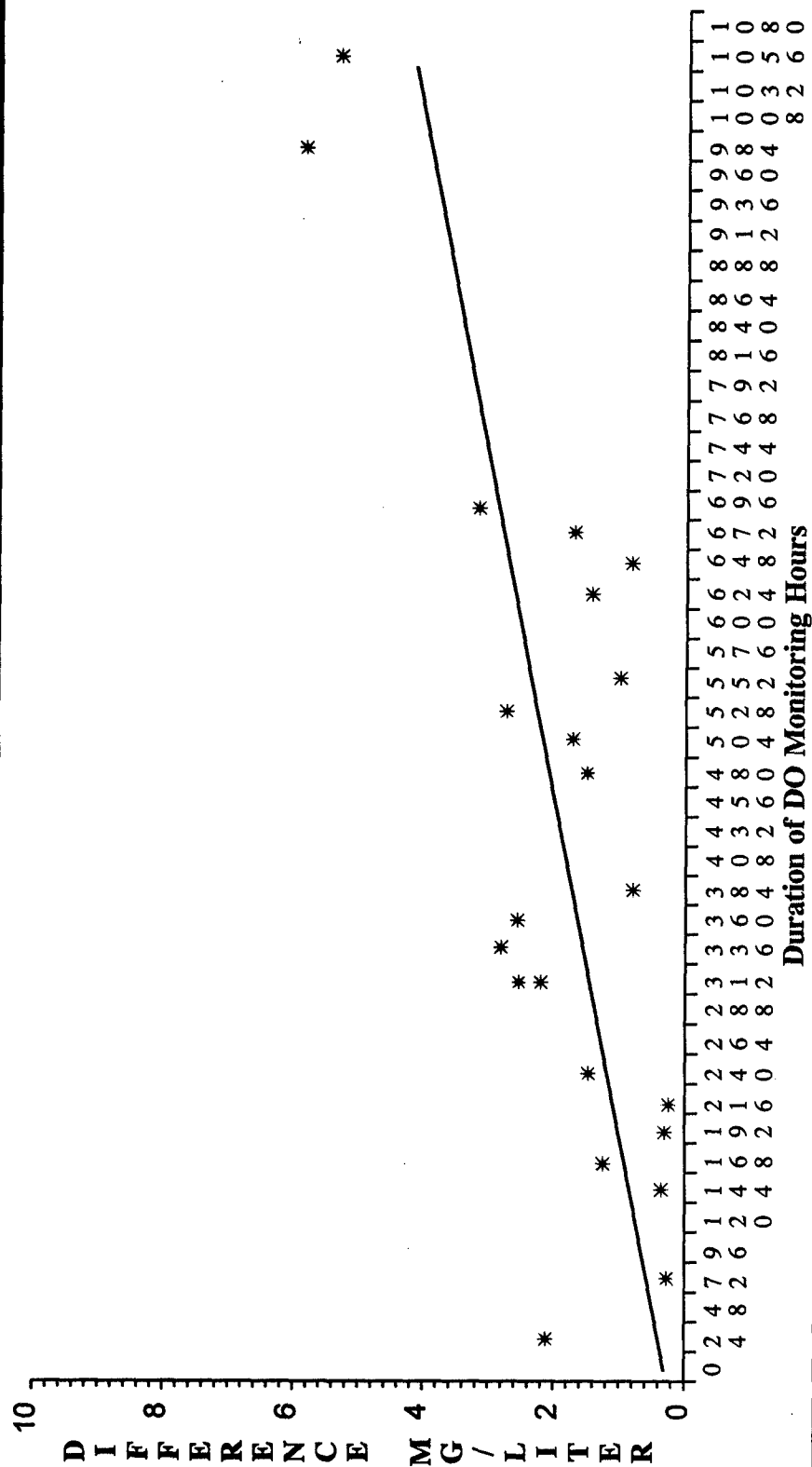
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Dissolved Oxygen Measurements

Ridgewood, NJ WWTP Summer 1994 Differences, Protected-Unprotected Sensors

Figure 3: Dissolved Oxygen Measurement Differences Between a Sensor with Biofouling Control and One Without Fouling Control



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