ADVANCES IN ON-LINE DISSOLVED OXYGEN MEASUREMENT USING LUMINESCENT TECHNOLOGY

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ABSTRACT

Use of online instrumentation for process control purposes is very common in wastewater treatment facilities. At one time, plants used online analyzers and instrumentation for monitoring only. Today, they are critical process control tools. Advances in online instrumentation, have created a new paradigm. Today's instruments are both accurate and reliable. This is particularly true of the newest generation of dissolved oxygen sensors. New sensor technology has been developed that uses optical techniques for DO determination. This new technology plus application case histories will be the focus of this presentation.

Traditional DO measurement technology measures an electric current created as oxygen is reduced at one electrode of the probe and electrons are generated at a second electrode. A DO-selective membrane facilitates oxygen migration to the cell from the sample.

The conventional galvanic style electrochemical DO measuring cell is notorious for measurement error due to contamination through the membrane and, at low oxygen levels, error due to low signal-to-noise ratio. Polarographic-technique DO cells rely on a constant polarizing voltage applied across the electrodes, a technique that makes them less susceptible than galvanic cells to contamination and less likely to reflect error at low oxygen levels.

Non-electrochemical DO measurement technology offers a solution to the shortcomings of traditional electrochemical sensors. New luminescence DO technology relies on the fact that excited luminescent material in the probe sensor emits light as it relaxes at a rate proportional to oxygen concentration. The explanation of the LDO technology is as follows: The LDO sensor is coated with a luminescent material. Blue light from an LED is transmitted to the sensor surface. The blue light excites the luminescent material. As the material relaxes, it emits red light. The time from when the blue light was sent and the red light is emitted is measured. The more oxygen that is present, the shorter time it takes for the red light to be emitted. This time is measured and correlated to the oxygen concentration. Between flashes of the blue light, a red LED is flashed on the sensor and used as an internal reference.

Key installations of Luminescent Dissolved Oxygen (LDO) were made at many sites. For the purposes of this paper, we will discuss two reference sites: Gainesville Regional Utilities (GRU), Gainesville, Florida; and Longmont Wastewater Treatment Plant, Longmont, Colorado. A detailed explanation of the GRU application will be discussed. A shorter explanation of the Longmont will be discussed.

KEYWORDS: Luminescent Dissolved Oxygen (LDO), Dissolved Oxygen (DO), Activated Sludge, Instrumentation, Monitoring

INTRODUCTION

Dissolved Oxygen monitoring throughout wastewater treatment, and particularly in the activated sludge phase, is key to effective and efficient treatment. The activated sludge treatment plant must maintain sufficient DO for the microorganisms that break down organic suspended solids into inorganic byproducts carbon dioxide and water and settleable solids, or sludge. Yet, DO levels that are too high can result in pin floc in clarifiers, severe sludge bulking in some instances, and large amounts of wasted electricity. An in-basin DO measurement system configured to output to a variable frequency drive (VFD) or the plant Programmable Logic Controller (PLC) or Supervisory Control and Data Acquisition (SCADA) system provides efficient, real-time control. Plant experiences with conventional DO technologies have been unsatisfactory. A number of problems including unreliability and high maintenance have plagued wastewater treatment plants.

Dissolved Oxygen (DO) sensor technology has relied upon several technologies for the past fifty years. Galvanic DO units, with and without membranes, depend upon a spontaneous voltage measurement. The next advance was the polarographic DO unit that supplied a voltage to achieve the dissolved oxygen measurement. The next improvement was the three electrode potentiostatic DO units. Unfortunately all these techniques used anodes, cathodes, and electrolytic solutions, which experience high failure rates. Anodes are eventually consumed requiring periodic replacement and downtime. Electrolytic solutions are also consumed, or contaminated and must be replaced. Gases such as hydrogen sulfide can poison the anodes and the electrolyte and require maintenance. Sensor membranes become coated with grease and dirt and require regular changing. All of these problems require sensor calibration. Overall, wastewater treatment facilities have found the maintenance requirements for DO sensors to be unacceptable.

With the introduction and application of Luminescent (optical) technology for DO (LDO), these maintenance problems don’t exist. No membrane, anode, cathode, or electrolyte is used. These LDO units have been installed in all areas in the wastewater treatment plant where DO is measured, but most commonly in aeration tanks and the laboratory. There are currently hundreds of successful LDO applications. Plant experiences have been very positive with great reductions in maintenance requirements and great improvements in reliability and accuracy. Additionally, significant reductions in energy costs have been well documented.

Gainesville Regional Utilities (GRU) serves the city of Gainesville, Florida and portions of Alachua County, Florida with various utility services including wastewater services. There are two wastewater Treatment Plants – **Kanapaha Water Reclamation Facility** (14 MGD) and the Main Street Wastewater Treatment Plant (9 MGD). In 2003, the **Main Street Water Reclamation Facility** was experiencing short run times and extensive maintenance problems with conventional dissolved oxygen analyzers in the aerobic digester. Since the digester application had proven the most difficult application for dissolved oxygen analyzers, a plant test was conducted with this new technology. After extensive testing, the LDO proved superior to conventional technology for dissolved oxygen. The unit proved to be very accurate and required very little maintenance. Energy savings and maintenance savings were dramatic. These cost savings will be detailed. LDO units have been installed in both plants for all of their DO monitoring.

The **Longmont Colorado Wastewater Treatment Plant** decided to replace their conventional DO technology with LDO technology. Blower usage, sensor accuracy, frequency of calibration and cleaning, plant upset conditions, chlorination, and portable DO measurement were compared against those recorded during the use of conventional probes. After three months of in-situ testing, the LDO proved superior. Due to use of the LDO technology, the Longmont WWTP experienced savings in blower output costs, eliminated portable DO monitoring twice per day, eliminated cleaning and calibration of conventional sensors three times per week, and eliminated chlorine dosing costs to correct plant upsets. One blower has been taken out of service due to improved DO control with LDO technology. The actual cost savings will be included.

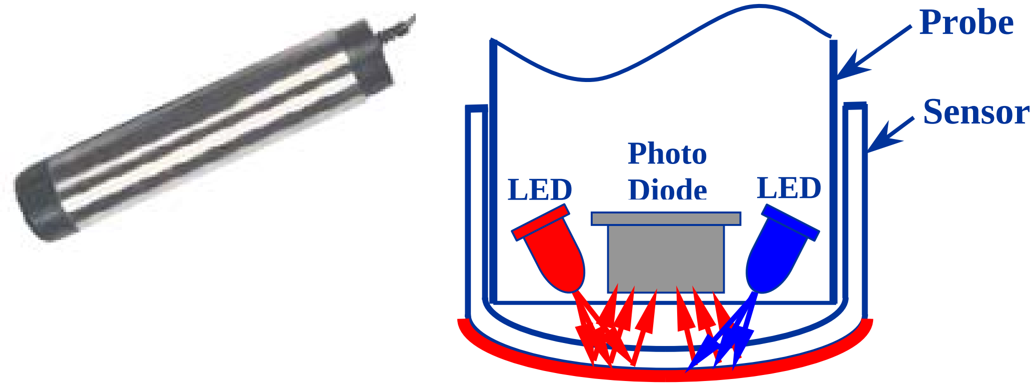
A number of similar successful LDO sensors are installed and in use in North America and the rest of the world.

Results of a comparability study[1] at twelve publicly owned wastewater treatment works in the U.S. industry show the luminescence technique to be more accurate and precise than traditional DO methodologies. Further, operators see significantly less probe maintenance and calibration .

METHODOLOGY

LUMINESCENT DISSOLVED OXYGEN TECHNOLOGY

The newest technology being used for dissolved oxygen measurement and control is the luminescent technology. A sensor is coated with a luminescent material. Blue Light from an LED strikes the luminescent chemical on the sensor. The luminescent chemical instantly becomes excited and then as the excited chemical relaxes, it releases red light. The red light is detected by a photo diode. The time it takes for the chemical to return to a relaxed state is measured. Oxygen has a dampening effect on this reaction. The higher the oxygen concentration, the less red light is given off by the sensor. The oxygen concentration is proportional to the time it takes for the luminescent material to return to a relaxed state. (Figure 1)



Actual Probe and sensor **Schematic Luminescent Reaction**

FIGURE 1: EXAMPLES OF PROBE AND SENSOR PLUS REACTIONS

RESULTS

THE GRU CASE HISTORY

In 2003, GRU was experiencing short run times and extensive maintenance problems with conventional dissolved oxygen analyzers in the aerobic digester in the Main Street Plant. These open aerobic digesters are designed to achieve 33% reduction of solids during optimum runs and 28% solids reduction during normal operating conditions.

Control was difficult due to the limitation of a 100HP blower with one set-point (on or off). Other limiting factors are pH/alkalinity and pH. With binding constraints on the operation of their blowers, control was difficult without reliable dissolved oxygen measurements.

Prior to the GRU installation of the LDO probes, the plant's experience with conventional dissolved oxygen analyzers had been unsatisfactory. (Figure 2)

FIGURE 2: MEMBRANE PROBE IN GRU MAIN STREET PLANT'S ANOXIC BASIN.

The life of conventional dissolved oxygen sensors was short and the results were unpredictable. The plant desired to use a SCADA control loop for the activated sludge processes. However, lack of reliable dissolved oxygen readings limited the ability to do this.

When GRU became aware of the LDO technology, the digester was chosen as the first test site because the digester application had proven to be the most difficult application for dissolved oxygen analyzers. A LDO probe was installed in one of the digesters ((Figure 3).

FIGURE 3: LDO PROBE IN A DIGESTER AT THE GRU MAIN STREET PLANT.

When the LDO probe was installed, it did not always match the results of the portable dissolved oxygen unit that utilized a membrane probe. These results were compared on a daily basis. For the first few days of the trial, the hand-held unit and the LDO probe tracked perfectly. However, the results quickly began to differ. The Main Street Plant thought that the LDO probe was broken, and removed the probe from the process. They decided to verify the results by doing a side-by-side test in the lab. They soon discovered that the hand-held unit was no longer measuring the temperature correctly and was calibrating to the incorrect temperature. The Main Street Plant quickly re-installed the LDO probe and issued purchase orders for probes for both of their digesters.

After proving the LDO technology on the digesters at the Main Street Plant, GRU installed LDO probes on their aeration basins at both the Main Street and Kanapha plants. (Figure 4)

Figure 4: LDO probe in GRU Main Street Plant’s aeration basin.

Since re-installing the LDO probes at the digesters and installing the LDO on the aeration basins, GRU has greatly increased the control over their process now using an automatic control loop that relies on the dissolved oxygen signal from the LDO. Prior to installing the LDO on the Kanapaha aeration tanks, the dissolved oxygen readings of the aeration basins were 2 to 2.5 ppm. Since installing the LDO, they have been able to set the process at 1.2 ppm of dissolved oxygen. The result has been reduction of labor needed to operate the process, reduction of the amount of power needed to run the plants, and the ability to maintain healthy microorganisms in their process. While the GRU was calibrating the membrane probes weekly and replacing the membranes every two months, the LDO probes are self-calibrating and have required no maintenance or cleaning since installed (approximately 1 year).

With the increased control over their process and the labor savings, the GRU has been able to redeploy operators and reduce the labor required to run the plants from 9 operators to 5. In addition, the GRU has been able to expand their Kanapaha Plant by adding a carousel nitrification process without increasing their electric bill. The addition of the carousel should have increased the energy bill by $15k/month. However, because of the increased efficiencies in the operation of the plant’s aeration processes, the electric bill remained constant (see Table 1).

Table 1: Comparison of Conventional Membrane Technology and LDO Technology.

	Conventional Membrane Technology			**LDO Technology**		
	Frequency	***Assumptions***	***Annual Cost***	***Frequency***	***Assumptions***	***Annual Cost***
Calibration Frequency	Weekly	14 probes 30 min. per calibration $28/hour	$10,192 (labor cost)	Self calibrating	No calibration needed	$0
Maintenance Frequency	Replace membranes every 2 months	14 probes $150/ membrane	$12,600	Replace sensor caps once per year	14 probes at $100/sensor cap	$1,400
Labor	9 operators	Operator cost: $50k/year	$450,000	5 operators	Operator cost: $50k/year	$250,000
Control of aeration process	Too inaccurate to use in PID loop control	Addition of carousel would have added $15k/mo (aerators consume $50/100hp per day)	$180,000	Able to use in PID loop control	Addition of carousel did not add any cost to energy bills due to increased efficiency of aeration	$0
	Total Annual Cost:		$652,792	Total Annual Cost:		$251,400
Total Annual Savings with LDO Probes = $401,392						

The limitation of the 100HP still exists for the aerobic digesters of the Main Street Plant. However, with reliable dissolved oxygen readings, the operators are able to maintain better control over their process. In addition, the reliability of the LDO has changed the control scheme of both the Main Street and Kanapaha plants. Operators are comfortable with the sensor readings and PID control has been instituted. With the combination of the labor savings and energy savings, the GRU will save over $400k per year.[2]

LONGMONT COLORADO CASE HISTORY

Modifications in the process at the Longmont Colorado Wastewater Treatment Plant (activated sludge process with five new aeration basins) resulted in many process changes. The plant handles an average of 7.5-9 MGD of flow per day. The plant is now an activated sludge process that alternates between step feed and contact stabilization. The facility takes in 18-20% of its wastes from industrial sources particularly from the food and dairy industry. One key test program was testing of DO sensors to find DO technology for control of the plant blowers. After a lengthy test program, the best membrane DO technology was chosen and put in service.

FIGURE 5: FOAM (APPROXIMATELY FIVE FEET) IN BASIN 1 IN LONGMONT

Once the selected DO was put in use, problems began to accumulate. The evidence of these problems was shown with a foaming problem in the plant. See Figure 5.
The foaming spread into each of the five basins and the foam in the basins resulted in the basins running over. Eventually, it became evident that the membrane DO instrument was not reading properly. The problem was due to a low DO filamentous bacteria problem. Chlorine was used to combat the problem. The actual DO was much lower than recorded on the membrane DO. This led the plant to then investigate the new LDO technology. The successful application of the LDO technology in this plant resulted in, not only the solution of the foaming problems due to accurate DO readings, but also significant cost savings.

Those savings are summarized below:

- Reduced blower output from 14K to 12K scfm
- Reduced blower usage

- •Eliminated twice a day portable DO testing
- •Maintenance for cleaning 3X week eliminated
- •Now visually check and wipe off once per month
- •Reduced chlorine dosing ($3000.month) due to upsets
  - –Problems from various low DO filament strains
  - –Chlorine used to control filaments

The final installation of LDO technology resulted in a cost savings of $70,000 per year.[3]

DISCUSSION AND CONCLUSIONS

First installations of luminescent dissolved oxygen sensors are only are few years old. Side by side comparisons in test situations versus conventional membrane technologies has resulted, in most cases, in the selection of this technology for the final installations. These selections have been made based on accuracy, reliability, low maintenance and the overall value of these new systems. The future applications for DO measurement in most plants will be with this new luminescence technology. Acceptance has been widespread and is growing. This technology offers clear maintenance advantages. Cost savings will often be part of the decision to convert to this technology. Return of investment analysis of each application will generally show that the cost savings are real. Field testing of these systems will reveal that these savings can be validated and included in the management decision to make the conversion from conventional membrane technology to luminescent dissolved oxygen technology.

Field testing or demonstrations of new LDO technology will reveal additional benefits. One such benefit is quick startup time. There is no lag time and no equilibration time in starting the LDO probe. The T90 for the LDO sensor is 30 seconds. The sensor is calibrated at the factory and does not require field calibration. The unit can be compared to standard field testing such as, comparison to handheld devices, air calibration, and laboratory procedures (Winkler Method) as required by regulatory agencies.

The large shift from conventional membrane dissolved oxygen sensor technology to luminescent dissolved oxygen technology is well established. Many of the first adopters were large wastewater treatment plants with projects to update and replace their older DO systems. Now the wastewater industry is becoming widely aware of this new technology and adopting it. This trend will continue until the luminescent DO technology becomes the standard DO technology for wastewater treatment.

REFERENCES

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