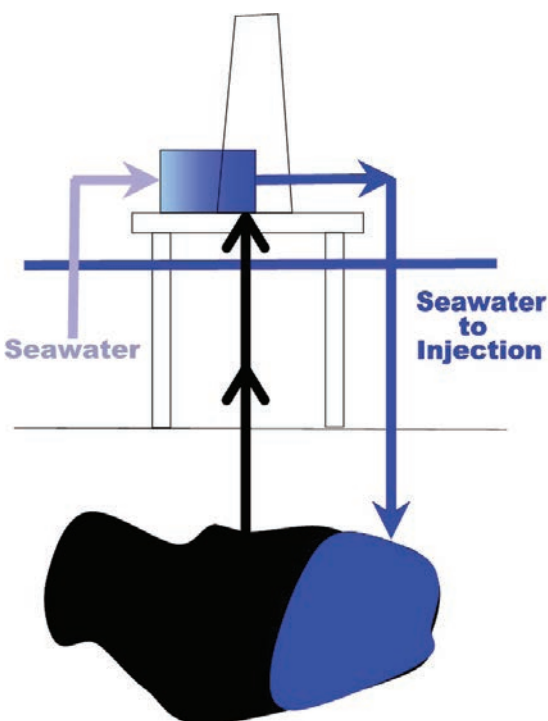


Introduction

Maturing oil fields both onshore and offshore account for the majority of oil production today. Enhanced Oil Recovery (EOR) techniques are important to increase efficiency and total recovery of these assets (reservoirs). EOR can account for 10 to 20% greater total recovery^[1] amounting to billions of dollars of additional production. In order to meet upcoming demand and increased production targets operators plan additional implementations of waterfloods along with the need to improve reliability, uptime and efficiency of the existing systems.

Waterflood or water injection is integral to the overall EOR strategy for subsea developments. Waterflood is performed by injecting water downhole to the bottom of the reservoir to keep reservoir pressure as hydrocarbons are removed and to displace, or “sweep,” the hydrocarbons towards the producing wells. The quality of the injection water is essential for protecting the permeability and quality of the reservoir along with protection of the capital equipment from corrosion and foulants. Oxygen removal and accurate reliable monitoring down to the ppb level is a critical parameter in assessing overall performance of the waterflood operations.



Water Quality

The precise chemical strategy, techniques and unit operations can differ from user to user however the most basic components and key strategies are listed here along with their purpose.

Particulates Removal

- Prevent plugging and fouling of the equipment
- Quality of the well-head permeability

Dissolved Oxygen (O₂) Removal

- Prevent microorganism growth
- Prevent corrosion of the unit operations and high pressure injection well pipe-works

Sulphates (SO₄²⁻) Removal

- Prevents H₂S production (souring of the reservoir) which can occur via bacteria and sulphates under reduced oxygen condition

Chemical Dosing

- Anti-foaming and anti-corrosion
- Scavengers for trace removal of O₂, SO₄²⁻ and residual chlorine

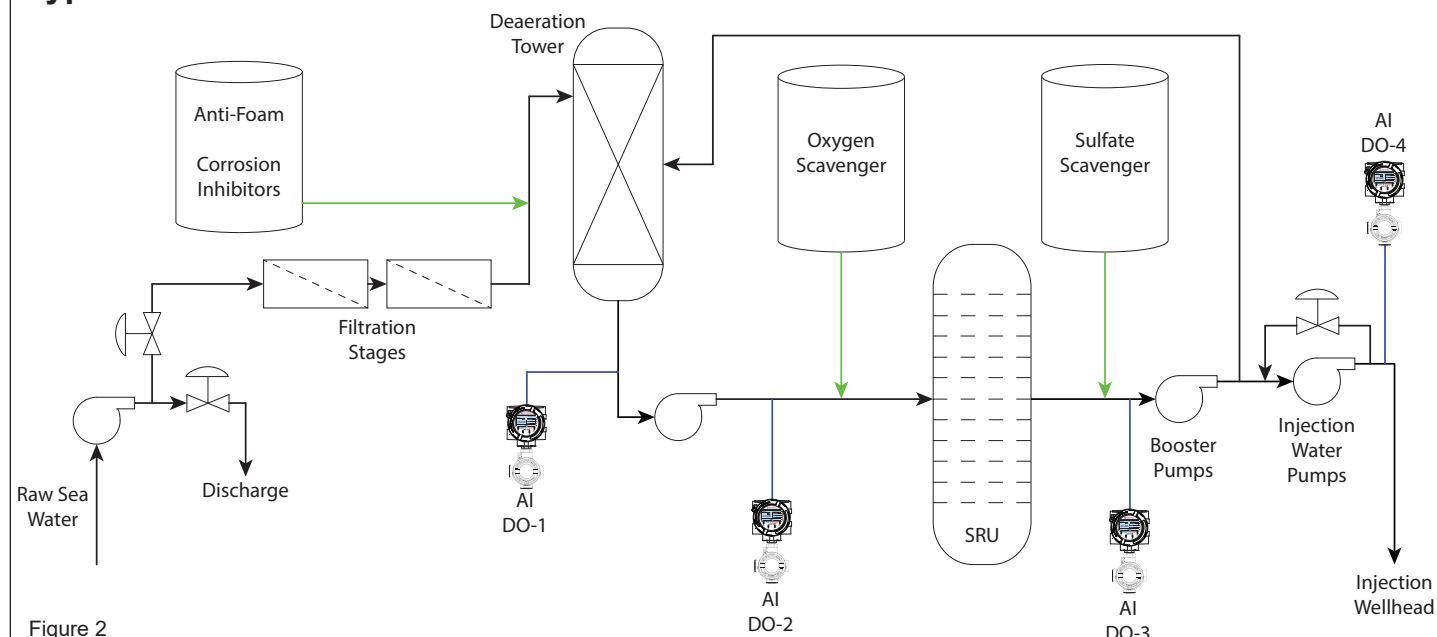
Process Overview

A typical waterflood process (Figure 2) contains several unit operation stages along with chemical treatment additions to achieve the required water quality. In its most basic form it consist of filtration to remove solids, deaeration (DA) or oxygen stripping to reduce the oxygen, sulfate removal unit, along with chemical additions to purify against organism growth (barnacles, mussels, micro-organisms and bacteria) and compliment the above unit operations.

Application Note

Dissolved O₂ in Offshore Waterflood

Typical Waterflood Process



Measurement Points & Ranges (Figure 2)

- DO-1: Monitoring deaeration tower to ensure performance of primary O₂ removal system [0.05 - 1.0 ppm DO]
- DO-2: Monitoring/control of oxygen scavenger chemical addition [0 - 10 ppb DO]
- DO-3: Monitoring for ingress of O₂ at SRU outlet [0 - 10 ppb DO]
- DO-4: Monitoring O₂ in final produced waterflood for water injection [0 - 10 ppb DO]

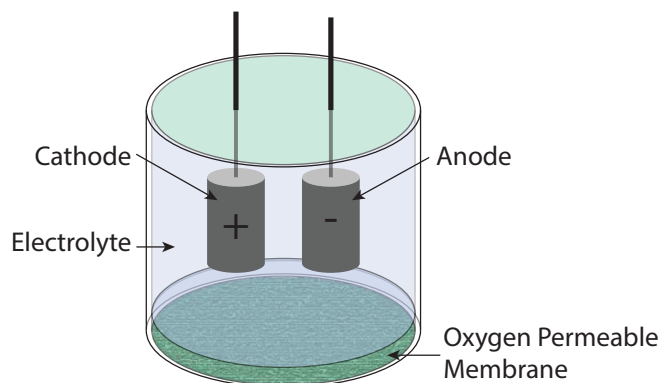
Issues with Traditional Dissolved Oxygen Sensors

Typically, electrochemical dissolved oxygen cells have been utilized throughout the industry and have proven very problematic for the waterflood applications. Poor reliability, accuracy and high-maintenance of the electrochem cells left technicians and operators with little faith in the measurement over time. All electrochem cells (Fig. 3) have anodes, cathodes, electrolyte solution and a sensitive membrane in contact with the process. The seawater salinity and process chemicals attack the cell's electrolyte and electrodes causing offsets and requiring frequent calibrations. The fouling present in the process coats the cell membrane also causing errors and high maintenance.

Cost Impact

- Cost to replace the electrochem cells is minimal compared to the high service costs in the offshore industry to perform the frequent calibration and maintenance to keep accuracy and reliability.
- Over-dosing of DO scavengers "just to be sure," causing high chemical cost (\$100's k/yr)
- Over-dosing upsets the targeted

Electrochemical Dissolved O₂ Sensor



- Sensitive to flow and pressure changes
- Membrane sensitive to fouling, coating and attack
- Electrolyte poisoning
- Slow response to ppb after exposure to ppm levels

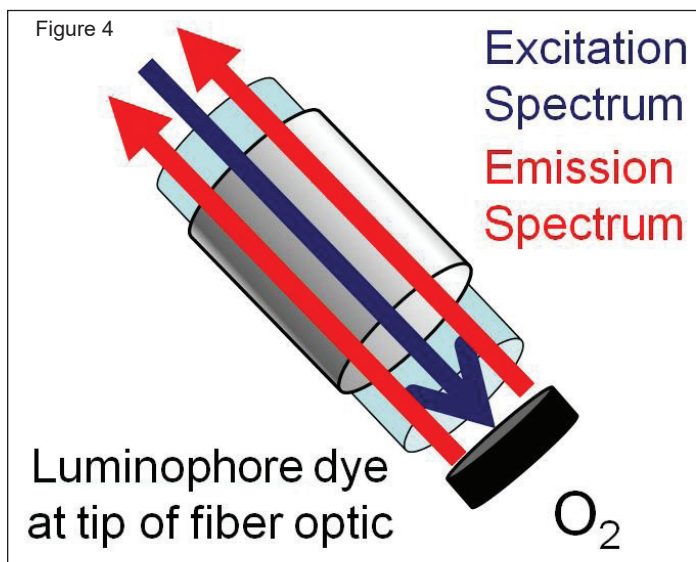
Figure 3

Application Note

Dissolved O₂ in Offshore Waterflood

Using Precision Optical Oxygen Analyzer in Waterflood

Barben Analytical's precision oxygen analyzer, OXYvisor, uses a proven optical luminescence technique (Fig. 4) enabling high accuracy at ppb levels along with high dependability and low maintenance. The analyzer is hazardous area rated and compliant for offshore installation requirements. The sensor is unaffected by flow or pressure in liquid streams and can be placed in a simple sample stream (Fig 5). Coatings on the sensor tip may affect the measurement speed by slowing oxygen diffusion however do not affect accuracy. The optical technology does not contain electrolyte and does not react with the process and therefore the stability is excellent. Under normal "tough," operation users have set calibration periods for 30 or more days depending on expected accuracy.



Analyzer

- Rugged field enclosure - Local Display & HMI
- IP66 & NEMA 4X
- Through-the-glass keypad (no tools or permits required)

Hazardous Area Approvals

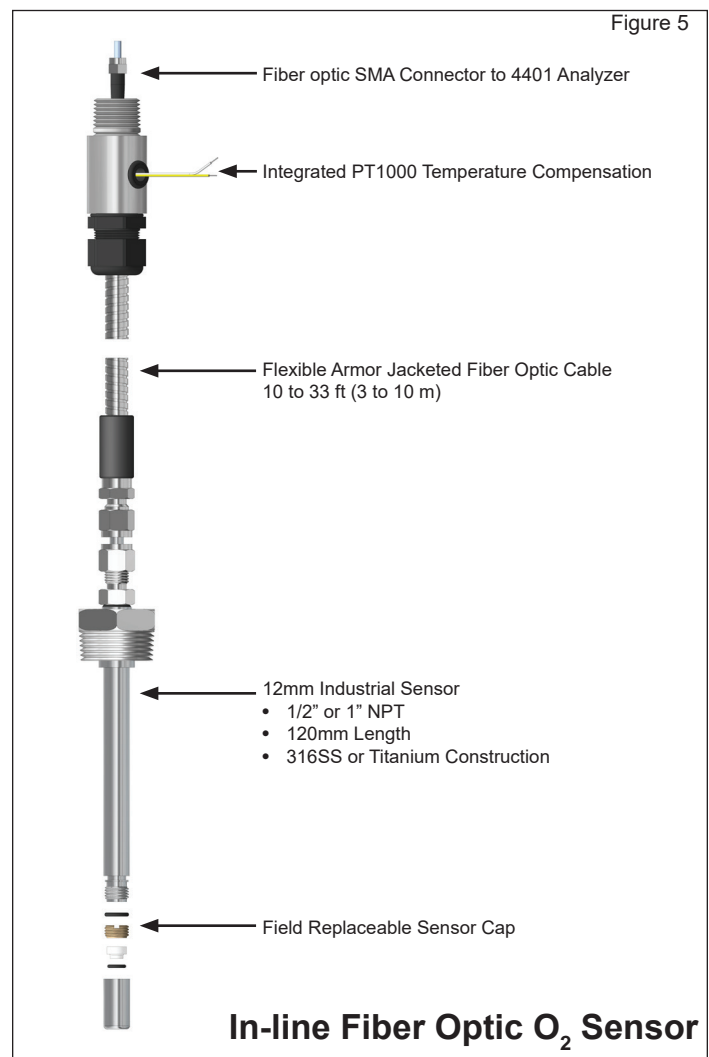
IEC Ex, ATEX, NA - Zone 1 & Zone 2 IIC

cULus (NRTL) - Class I, Div 2, Groups A, B, C, D T4



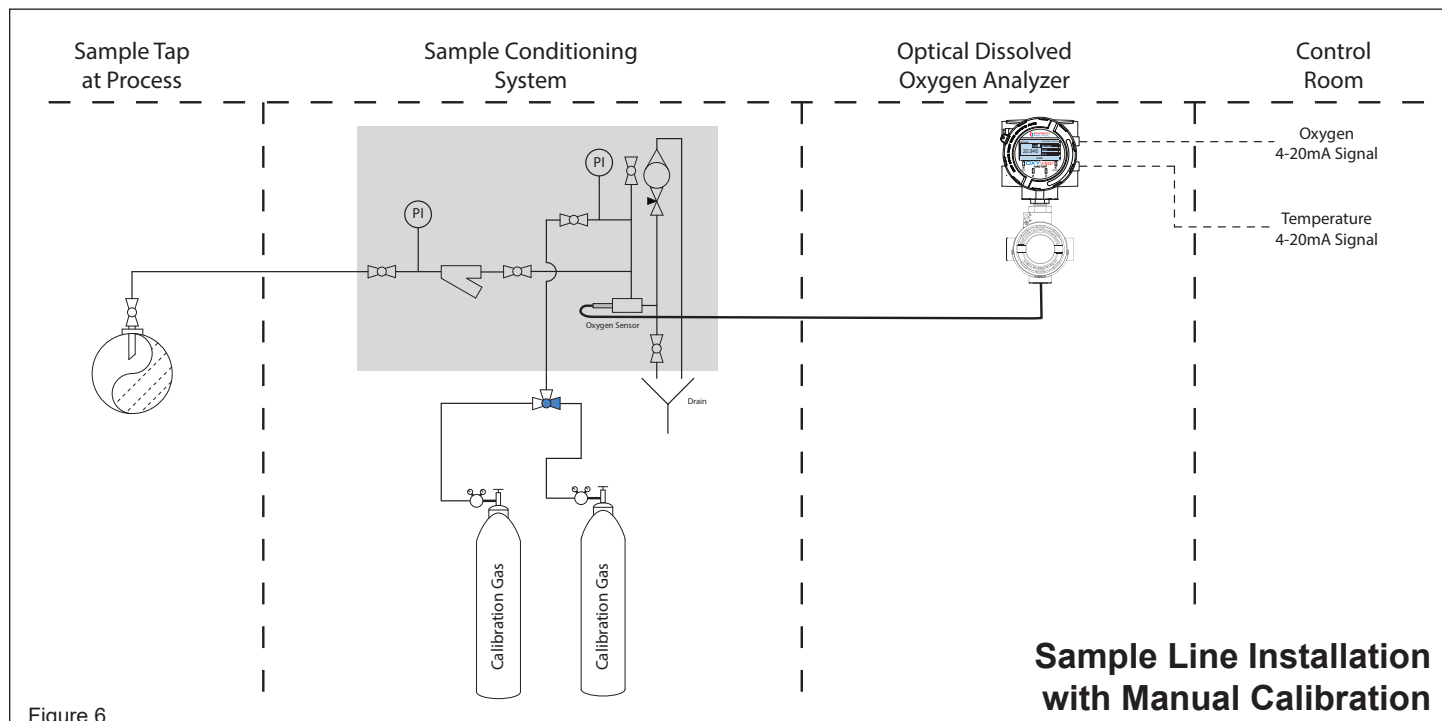
Sensor and Features and Performance

- No membranes to foul or electrolyte to poison
- Limit of detection = 1 ppb DO, Accuracy = +/- 1 ppb or 3% of concentration
- Excellent long term stability, < 2 ppb drift in 30 days at 1 min sampling interval
- Fast response: gas phase T90 < 6sec, Liquid Phase T90 < 30sec
- Simple, replaceable sensor cap (lifetime expectancy is 6 months to 2 years, depending on active Cl2)
- Industrial format rated for pressures up to 1,500 psig @ 50°C
- Measurement accuracy is independent of flow velocity and line pressure allowing simple installation
 - Directly into sample line (only pressure reduction required for sample > 1,500 psig)
 - Simple sample and manual calibration station ensures quick, simple, repeatable calibration (Figure 6)



Application Note

Dissolved O₂ in Offshore Waterflood



Additional Offshore Applications – Gas Phase O₂ Analysis in ppm to % level

The same analyzer and techniques can be used to measure O₂ in gas phase analysis in hydrocarbons, natural gas, methanol and nitrogen streams.

- Waterflood systems with countercurrent gas stripping in place of DA tower the OXYvisor is ideal for these applications:
 - Nitrogen header for ppm to % level O₂ in gas phase
 - ppm O₂ in nitrogen generation and catalyst with methanol
 - ppm O₂ in natural gas
- Nitrogen tank blanketing - % O₂
- [Vapor recovery units – ppm to % O₂](#)

Contact Us

Barben Analytical is a leading supplier of analytical measurement technology targeting the industrial marketplace. It is a wholly owned subsidiary of AMETEK, Inc., a leading global manufacturer of electronic instruments and electromechanical devices.

AMETEK has over 15,000 colleagues at more than 120 manufacturing locations around the world. Supporting those operations are more than 100 sales and service locations across the United States and in 30 other countries around the world.

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References: [1] US Department of Energy, Washington DC (2011), "Enhanced Oil Recovery/ CO2 Injection." <http://www.prnewswire.com/news-releases/eor-enhanced-oil-recovery-worldwide-131130908.html>

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