

## Investigating Oxygen Ingress in the Oil and Gas Industry

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### ABSTRACT

In this review, events leading to ingress of O<sub>2</sub> in various upstream oil and gas systems are investigated. By analyzing reported instances in the literature, factors leading to oxygen infiltration are elucidated. Pipeline maintenance, equipment failures, system design and construction, accidental introductions, chemical injections, and improper protocols are explored and further analyzed to gain a broad understanding of oxygen ingress pathways. The findings of this study raise awareness of O<sub>2</sub> as a contributing factor in the corrosion mechanisms involved in these systems, coupled with preservation of asset integrity.

Keywords: O<sub>2</sub> ingress, Oil and gas systems, Literature review

### INTRODUCTION

Hydrocarbon deposits in geologic reservoirs formed millions of years ago from remains of organic matter buried under layers of sediments. Any O<sub>2</sub> initially present long ago reacted with other compounds leading to its removal as the oil and gas formed; leading to an O<sub>2</sub>-free state. The hydrocarbon contents of these reservoirs being oxygen free, the extraction and transportation infrastructure of the oil and gas industry is also falsely assumed to be void of any O<sub>2</sub>. This false assumption has also prevented thorough mechanistic investigations of the corrosion consequences of O<sub>2</sub> in these oil and gas systems. Throughout literature and by anecdotal accounts, sources of O<sub>2</sub> ingress have been identified. This paper discusses possible causes of oxygen ingress, as well as mitigation strategies.

## OXYGEN INGRESS MECHANISMS

Ingress of O<sub>2</sub> can occur in oil and gas production and transmission systems via numerous pathways. Causes include ingress at the source, fluid injections, maintenance routines, leakage, pumps, or design shortcomings. A comprehensive list of these pathways is listed in Figure 1, each leading to O<sub>2</sub> ingress that could exacerbate corrosion risks for the oil and gas infrastructure; risk generally decreases from left to right across the figure.

### Possible Causes of Oxygen Ingress

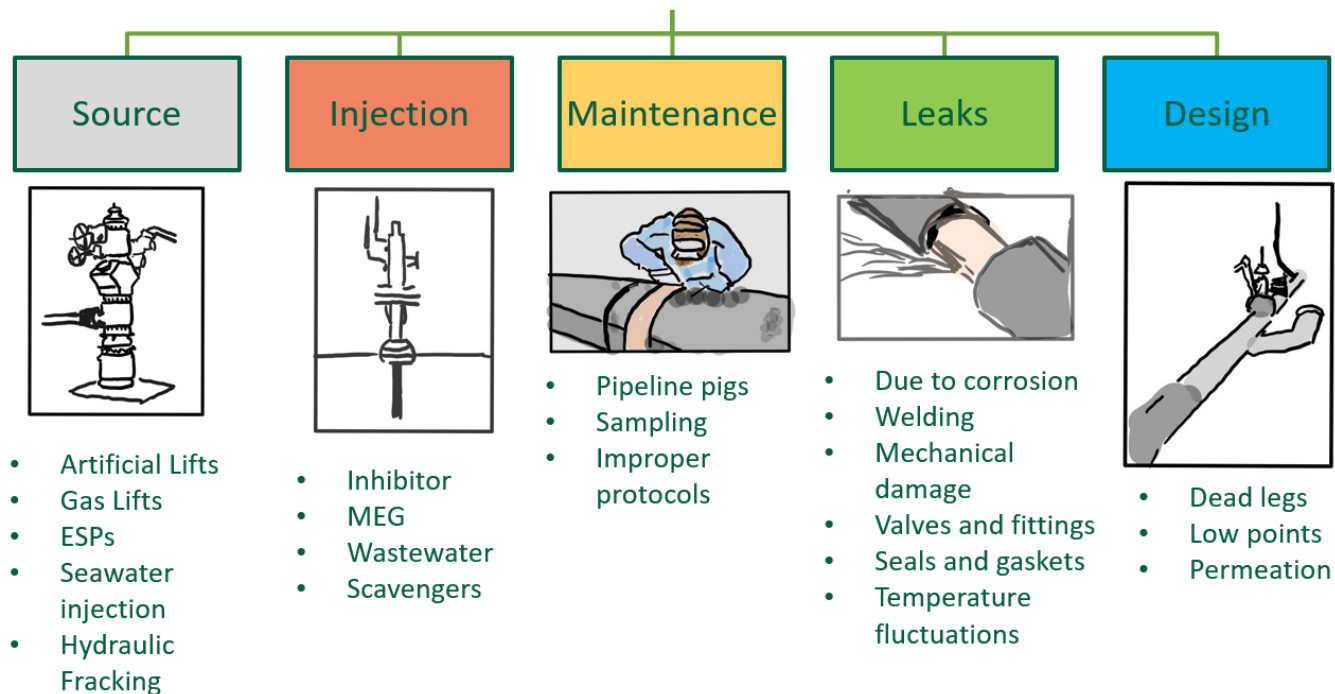


Figure 1. Possible causes of O<sub>2</sub> ingress

#### Artificial Lift

In the early production stage of an oil well, reservoir pressure provides enough force to flow fluids to the surface. However, as wells age the fluid ceases to flow as reservoir pressure decreases. Hence, artificial lift is employed to draw more fluid out of the well and prevent an otherwise premature death of the well. Artificial lift provides the required force for the well to continue to produce and are thus categorized based on the mechanisms they use for this energy transfer. Figure 2 shows different types of artificial lift that are commonly employed for oil wells<sup>1</sup>. Three of the four shown are susceptible to corrosion by O<sub>2</sub> ingress, each is briefly reviewed below.

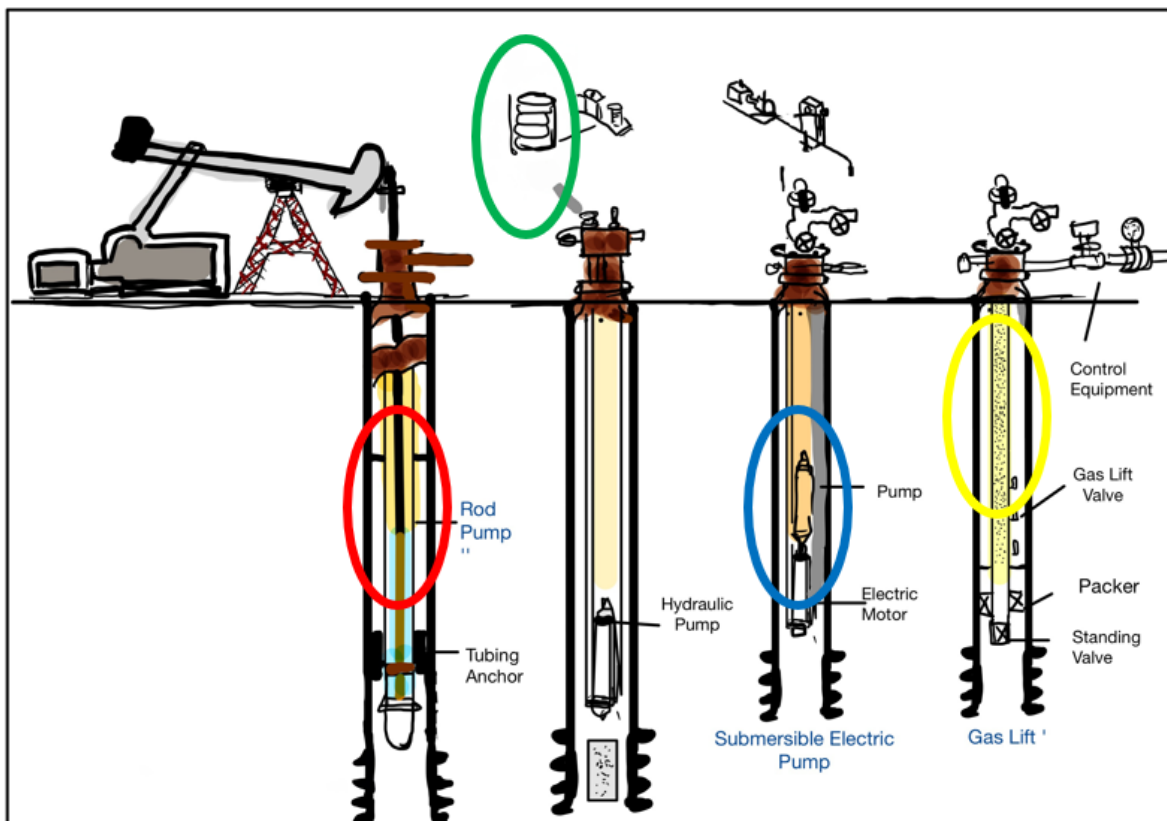


**Figure 2. Schematic representation of Artificial Lift Systems**

**Rod Pumps:** A surface power source consisting of a motor transferring energy through a beam and a crank arm that connects to the downhole pump assembly. Through this transfer, energy is converted into the vertical motion of the fluid. The sucker rod is connected with an internal threaded coupling and is generally located in the area marked by the red circle in Figure 2<sup>2</sup>. O<sub>2</sub>-enhanced corrosion is mainly reported on the sucker rod coupling<sup>3</sup>. Heavy localized corrosion has been reported in the presence of H<sub>2</sub>S.

**Hydraulic Pumps:** A downhole “hydraulic pump” can be a reciprocating piston pump or a jet pump<sup>4,5</sup>. Hydraulic pumps use a high velocity high pressure fluid (oil or water) that is pumped into the well head and which mixes with well fluids entraining them to the surface<sup>6</sup>. The hydraulic fluid that drives the pump is usually returned up the casing-tubing annulus with oil, water, and gas production<sup>7</sup>. Because of this, the injected fluid needs to be O<sub>2</sub>-free. Maintaining such an O<sub>2</sub>-free environment can be very expensive so some pumping sites may neglect such precautions. Such a scenario could cause oxygen contamination of the produced fluid which in turn can potentially cause O<sub>2</sub> accelerated corrosion.

**Electrical Submersible Pump (ESP):** Electrical submersible pumps (ESPs) consist of a submerged motor and a centrifugal pump which are connected to a surface control mechanism and a transformer. ESPs are required to meet high temperature and pressure thresholds, as high voltages and currents are drawn to pump the fluid through a deep-well<sup>8</sup>. Thus, their

method of assembly and quality are critical for the ESP to withstand extreme conditions and avoid contaminants. The seal section between the motor and intake serves as a barrier between the motor and well fluids. Because electricity is used as the power to drive the pump, there is no continuous source of O<sub>2</sub> in this case which would be added to the produced fluids.

**Gas Lift:** In gas-lift wells, gas is injected through the well annulus and into the well tubing at a downhole location. The gas mixes with the fluid in the tubing, decreasing its density<sup>9</sup>. This causes the fluid to rise through the well at even a relatively low bottom-hole pressure. Gas-lift employing the use of air as a lifting medium for oil can face severe problems, not only due to the explosive mixture of air and hydrocarbon but also due to the corrosiveness of O<sub>2</sub><sup>10</sup>. Use of an inert or natural gas avoids explosive risk and mitigates corrosion due to O<sub>2</sub>. Produced natural gas can be repurposed for the purpose of gas lifts and should be kept O<sub>2</sub> free to prevent corrosivity as well as risk of explosion. If precautions for maintaining an O<sub>2</sub>-free injection gas are neglected, contamination of the produced fluid could readily occur.

## Seawater Injection

In offshore oil fields, seawater is injected to maintain pressure and displace hydrocarbons for enhanced and efficient oil recovery. Up to a million barrels of seawater is injected into such wells to maintain adequate pressure<sup>11</sup>. Having an inert purge to remove all dissolved atmospheric oxygen from the seawater is an expensive operation, and if not performed adequately, leads to an ingress of oxygen in the oil well. Injection of huge volumes of oxygenated seawater can risk contaminating the oil well to an irreversible extent.

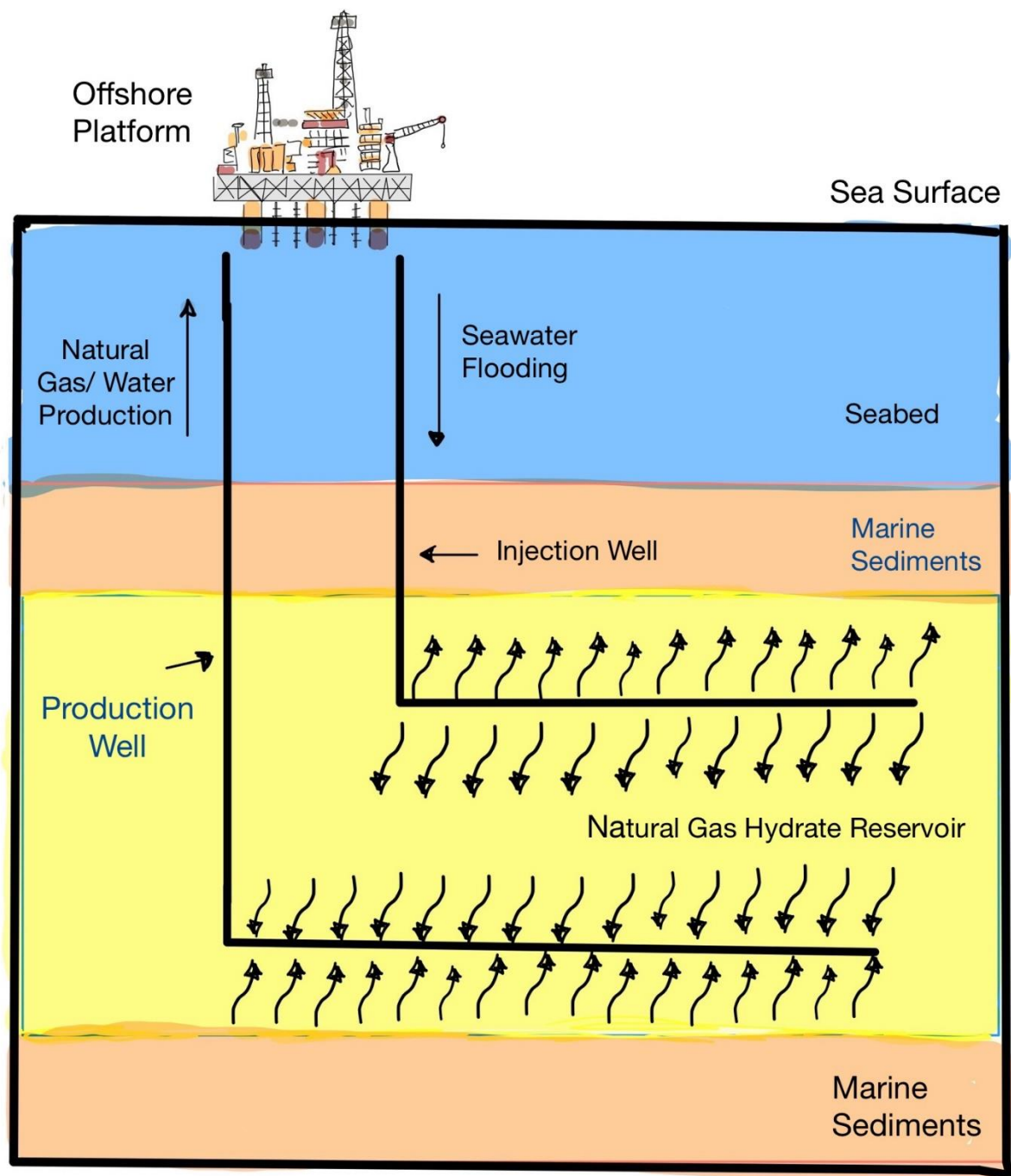


Figure 3. Schematic diagram of seawater injection for offshore wells

## Hydraulic Fracking

A majority of the oil shale deposits have very low levels of permeability for oil/gas<sup>12</sup>. Fracturing via injection of fracking fluids creates pathways for the oil to be more accessible to the wellbore. However, if the fracking fluid has not been deoxygenated to suitable standards, it will provide a pathway for oxygen ingress into the well; see Figure 4.

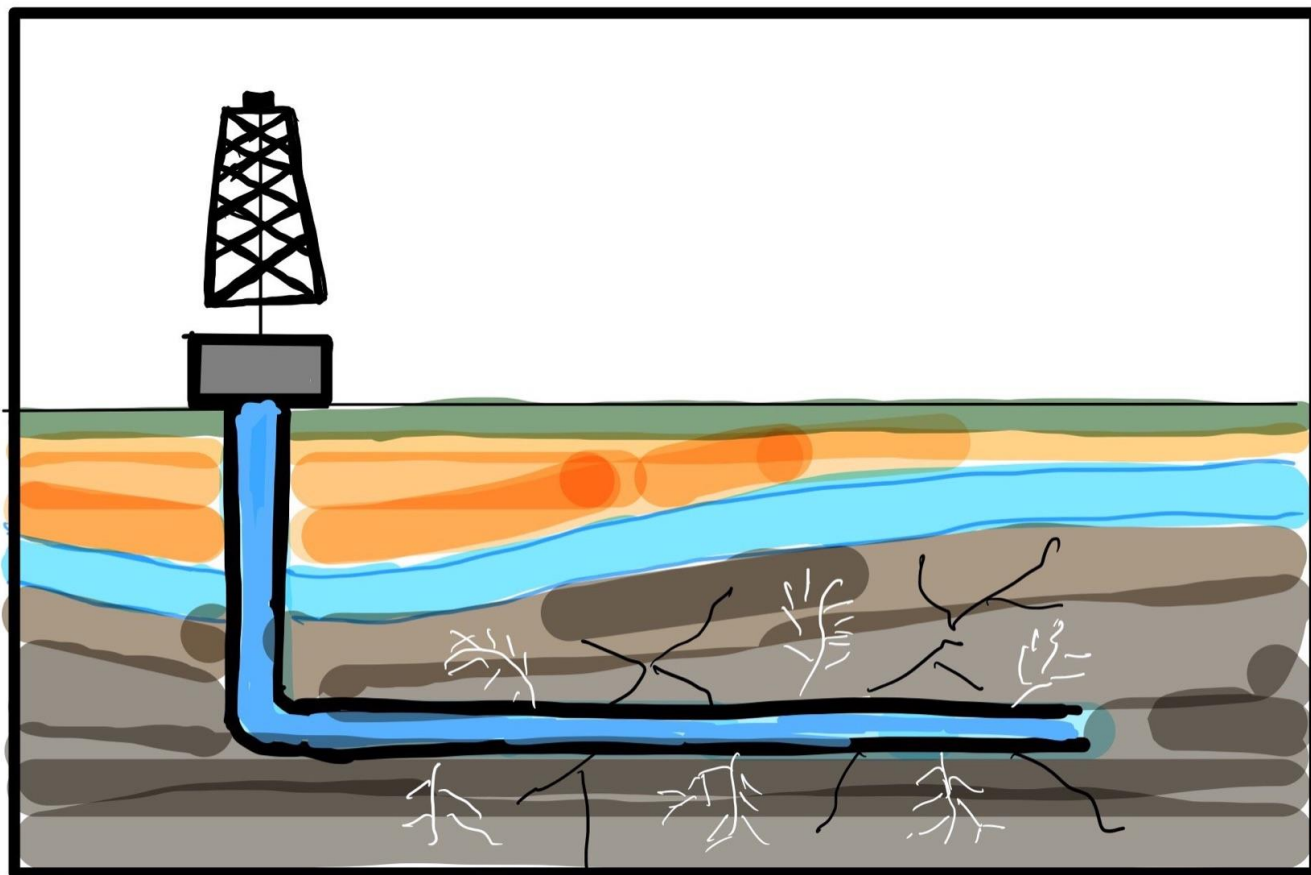


Figure 4. Schematic diagram of hydraulic fracking of shale oil reservoir

## Corrosion Inhibitor Injection

Corrosion inhibitors are stored in storage tanks from where they are injected downhole or into pipelines through various fittings, see Figure 5. If proper care is not exercised, the inhibitor in the storage tank itself might get exposed to the atmosphere, causing  $O_2$  to get dissolved into the inhibitor formulation prior to its application. Furthermore, injection of inhibitor through a compromised fitting might be another cause of  $O_2$  ingress in the pipeline<sup>13</sup>. These  $O_2$  levels can vary from ppm to ppb levels and could be consumed at the source of injection itself, thus leading to corrosive attack at the point of injection. However, this is thought to be a lower risk situation as the concentrations of inhibitor applied are in a ppm range. To test this, calculations were made using a pipe flowing with 100% water that is oxygen free and an injected water