
EC-010 SUPPLEMENTAL READING

Oxidation Does Not Mean Oxygen

Where OIL RIG came from, why the names mislead, and the trap that catches good techs. Companion reading for EC-010 — Oxidation and Reduction Reactions in Corrosion.

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FIELD NOTES FROM RCS

~11 MIN READ

Originally published in Field Notes from RCS at newsletter.rcswv.com — the article this very module prompted. Included with EC-010 as supplemental reading for the Electrochemistry & the Galvanic Series set. Save it, print it, take it to the field.

Last week I was drafting a training module on oxidation and reduction — the two reactions that run every corrosion cell. Somewhere in the middle of it I typed **OIL RIG** for what had to be the hundredth time in my career, and it stopped me.

I learned that mnemonic a long time ago, early in my corrosion career, studying for certification exams. Oxidation Is Loss, Reduction Is Gain — of electrons. I memorized it, I answered the exam questions with it, and I went to work. For years after that I applied it correctly on the job. If you'd asked me which reaction runs at the anode, I'd have had it instantly.

But sitting there typing it into a training module, it occurred to me that I had learned it without ever understanding it. Why is losing electrons called oxidation when there may not be a molecule of oxygen anywhere near the reaction? Why is gaining something called a reduction? Nobody ever explained any of that. The mnemonic worked, the answers were right, and the questions never got asked.

So I went looking. The answers turn out to be a story about two hundred years of chemists and furnace men naming things before anyone knew electrons existed — and once you know where the words came from, the chemistry under your boots makes a lot more sense. More to the point, there's a trap hiding inside the word "oxidation" that catches good techs, and it's worth dragging into the daylight.



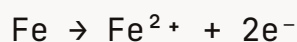
What OIL RIG Says – and What It Doesn't

First, the mnemonic itself, for anyone who needs it. It has outlived generations of chemistry classes because it works:

OIL RIG. Oxidation Is Loss; Reduction Is Gain — of electrons.

- **Oxidation is the loss of electrons.** A metal atom lets go of electrons and leaves the surface as a positively charged ion. This is the metal-loss half — the corrosion you can see, measure, and get called out to deal with.
- **Reduction is the gain of electrons.** Something in the environment picks up the electrons the metal released. No metal is lost on this side; this is the consuming half that keeps the whole process running.

On a corroding steel structure, the oxidation half is always the same reaction at its core:



An iron atom in the pipe wall gives up two electrons and dissolves into the soil as an ion. That is corrosion — that single line is your pipe leaving. The oxidation half runs at the **anode**, the reduction half runs at the **cathode**, and the two are locked together by the electrons passing between them. You cannot have one without the other.

That's what OIL RIG says, and it will keep the two reactions straight every time. What it doesn't say is why those two words mean what they mean. For that you have to go back before the electron — back before anyone knew what was actually being lost and gained.

Why "Oxidation"? Blame the 1700s

Through most of the 1700s, chemistry explained burning with something called the **phlogiston theory**. The idea, formalized by the German chemist Georg Ernst Stahl, was that anything that burned contained a mysterious substance — phlogiston — that escaped during combustion. Wood burns, phlogiston leaves, ash remains. It sounded reasonable, and it was completely wrong.

The man who broke it was the French chemist **Antoine Lavoisier**, and he broke it with an instrument every field tech respects: a scale. Lavoisier weighed metals before and after burning them, carefully, and found that burned metal gets heavier. That's a problem if burning

means something is escaping. Nothing escapes and leaves you with more weight than you started with.

Lavoisier worked out what was really happening: the metal was combining with something in the air. He named that something **oxygen**, and he named the process of combining with it **oxidation**. Rust your iron fence, burn a strip of magnesium, calcine lead in a furnace — in Lavoisier's chemistry, all of it was metal taking on oxygen and forming an oxide. The weight gain was the oxygen's weight.

For the chemistry everyone could see in the late 1700s, that definition worked. Combustion, rusting, tarnishing — the most studied reactions of the day really did involve oxygen. So the name stuck.

It's worth a footnote that Lavoisier got his own word wrong, too. "Oxygen" comes from Greek roots meaning acid-former, because he believed every acid contained it. They don't — hydrochloric acid hasn't got an atom of oxygen in it. The father of modern chemistry named two of our most important words, and both names describe what he could observe rather than what was actually happening. Chemistry kept the words anyway.

The names were assigned by men with scales and furnaces, a hundred years before anyone knew the electron existed.

Why "Reduction"? Ask a Smelter

Here's the part I find genuinely interesting, because the word "reduction" wasn't coined by a chemist at all. It belonged to metallurgy — and it's older than Lavoisier.

For centuries, the men running furnaces described their work as **reducing ore to metal**. The word comes from the Latin *reducere* — to lead back, to restore. Iron in nature isn't metal; it's ore, an oxide, rock that happens to be rich in rusted iron. The furnace restores it — leads it back — to the metallic state. And there was a second, more practical sense to the word that any furnace man could read straight off his scale: the ore loses weight in the furnace. Charge in a ton of ore, draw out considerably less than a ton of iron. The mass was literally reduced — because the oxygen left.

Look at what's actually happening in that furnace, with modern eyes. The iron in the ore is sitting there as ions — iron that gave its electrons away a geological age ago. The furnace, by

way of the carbon in coke, hands those electrons back. Iron ions gain electrons and become iron metal again.

Gaining electrons. That's our cathodic reaction. The smelter's "reduction" — restoring ore to metal, watching the weight go down — and the chemist's "reduction" — a species gaining electrons — turned out to be the same event described from two different directions. The old word was right all along; nobody knew why until the electron showed up.

This is also the cleanest way I know to explain what corrosion is. A steel mill is a reduction plant: it spends enormous energy forcing electrons back into iron ore to make pipe. From the moment that pipe leaves the mill, nature is trying to take the electrons back and return the iron to ore. Corrosion isn't an attack. It's a refund. Rust and hematite ore are, chemically, close cousins — the pipe is just trying to go home.

The mill reduces ore to pipe. The ground oxidizes pipe back toward ore. Everything we do in this trade is about interrupting the round trip.



The Electron Shows Up and the Names Stop Fitting

The definitions you and I memorized arrived after 1897, when J.J. Thomson demonstrated the electron. Once chemists could see reactions in terms of electron transfer, they realized the oxygen-based definitions were too small.

Iron combining with chlorine behaves exactly like iron combining with oxygen — metal loses electrons, partner takes them — with no oxygen involved. Same for sulfur. Same for the hydrogen ions in an acid. Oxygen, it turned out, was never the point. It was just the most common and most visible member of a whole family of **electron acceptors**. The reactions chemists had been calling oxidation for a century were all electron-loss reactions; oxygen merely happened to be the partner in the famous ones.

So the definitions were rewritten around the electron, and they've stood ever since:

- **Oxidation: loss of electrons** — whether the thing taking them is oxygen, chlorine, sulfur, hydrogen ions, or something else entirely.
- **Reduction: gain of electrons** — no matter where they came from.

The names stayed, as names do. Corrosion Basics puts it about as plainly as a textbook can: "The term oxidation is not necessarily associated with oxygen."

That sentence is doing a lot of quiet work, and it brings us back to the right-of-way — because the word that stuck is the word that sets the trap.

Where the Trap Catches You in the Field

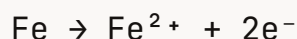
The trap is this: "oxidation" sounds like it needs oxygen, so it's natural to conclude that ground without oxygen is ground without corrosion. If you've carried some version of that belief, you're in the best company chemistry has to offer — Lavoisier carried it too, and he invented the word. This isn't a careless mistake. It's an inherited one. The word itself has been teaching it for two hundred and fifty years.

Let's also be straight about what this article is not saying. Oxygen matters enormously to corrosion — in most ground it sets the pace of the whole cell, which is a big part of why well-aerated soil is often the more corrosive ground, not less. We covered that side of it in "The

Effect of Oxygen on Current Required for Cathodic Protection." There are really two different questions hiding inside this topic, and they have different answers:

- **Can a corrosion cell run here?** Yes — anywhere bare steel touches electrolyte. Oxygen gets no vote.
- **How fast will it run?** Now oxygen votes, and in aerated ground it's usually the loudest voice in the room.

The trap is letting the second answer bleed into the first — letting "oxygen drives the rate" slide into "no oxygen, no corrosion." Because steel corrodes just fine with no oxygen at all. Waterlogged clay. The bottom of a flooded bore. A sealed crevice under disbonded coating. In every one of those places, iron is still doing the only thing iron ever does at an anode:



The metal-loss reaction doesn't contain oxygen and never did. What changes when the oxygen runs out is the other half — the reduction. The cathode is a chameleon: it runs whatever reaction the environment hands it. In aerated, near-neutral soil, dissolved oxygen takes the electrons ($\text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^{-} \rightarrow 4\text{OH}^{-}$). In acidic or oxygen-dead ground, hydrogen ions take them instead and bubble off as hydrogen gas ($2\text{H}^{+} + 2\text{e}^{-} \rightarrow \text{H}_2$).

The anode never cares what's consuming its electrons. It only cares that something is.

Reading the Oxygen You Can't Measure

Here's where this lands on the job, because nobody carries a dissolved-oxygen meter on the right-of-way. Oxygen is invisible in the ditch, so the working assumption tends to be that it's everywhere — especially anywhere wet. The truth runs the other way. Water is what shuts oxygen out. Oxygen moves through water roughly ten thousand times slower than through air, so saturated ground goes oxygen-dead not despite being wet, but because of it. The waterlogged clay at the bottom of the ditch isn't the safe zone. It's the anaerobic zone.

And the ground will tell you, if you know the signs. You've probably already smelled the most reliable one: that rotten-egg whiff when a bell hole opens in black, blue-gray clay. That's hydrogen sulfide, and it means **sulfate-reducing bacteria** — SRB — are working the site. Those microbes only set up shop where the oxygen is gone, they run their own electron-consuming chemistry, and they accelerate the attack while they're at it. Black iron-sulfide staining on the pipe surface is the same signature. So is pitting that comes out of the ditch

clean and dark instead of heaped over with red-brown rust — the iron dissolved and washed away without ever meeting enough oxygen to build a tubercle.

None of that required a measurement. The ground was telling you the oxygen was gone — and the pipe was corroding anyway.

One honest aside about the disbonded-coating example, because it does double duty in this story. The crevice under a disbondment is where an oxygen-free cell quietly runs — and it's also the one place on that list where cathodic protection may not be able to reach, because the same coating that hides the cell can shield protective current from ever getting to it. Two separate problems, stacked: the missing oxygen doesn't stop the corrosion, and the coating may stop the cure. That second problem deserves more than an aside.

Coming in a future issue — "CP Shielding: When the Coating Protects the Corrosion." Mainly because I really like that title.

Job Titles, Not Part Numbers

Before the payoff, one more thing needs nailing down, because the word "anode" is about to change scale on us — and this is a spot where techs early in their careers get quietly lost. I know, because I was one of them.

Everything to this point has described anodes and cathodes as locations on the same piece of steel. That's the reality on an unprotected pipe: both jobs are worked on one surface, sometimes inches apart. A patch of pipe under a rock shadow runs anodic while the patch beside it runs cathodic, and the roles can trade as moisture, soil chemistry, and seasons shift. Nothing about the steel changed. The job assignments did.

But the first "anode" most techs ever meet is a magnesium bar in a cloth bag — a part on the truck, a line on a material list. So it's natural to file anode as a product category. It isn't. **Anode and cathode are job titles, not part numbers.** The anode is whatever surface is currently losing electrons. The cathode is whatever surface is taking them in. On a bare pipe with no CP, your pipe holds both titles at once, patch by patch, and corrosion happens everywhere the anode title lands.

What a cathodic protection system does is bring in an outside metal to hold the anode title full-time — so that every square inch of your structure can hold the cathode title, and nothing else. The mag bar isn't called the anode because of what it is. It's called the anode because of the job we gave it. (How nature decides which of two coupled metals gets handed the anode job is the galvanic series — a subject that's earned its own issue.)

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Why Cathodic Protection Doesn't Care Either

Follow the logic one more step and you arrive at the reason this isn't trivia.

The iron only gives up its own electrons because the corrosion cell demands them. Cathodic protection works by supplying electrons from outside — from a magnesium anode wired to the line, or a rectifier pushing current through a ground bed. Once electrons are arriving from somewhere else, the iron has no reason to surrender its own. The structure becomes the cathode — every square inch of it holding the one job title where no metal is lost — and the reduction half runs on outside electrons while the metal stays put.

Notice what that explanation never mentions: oxygen. CP suppresses the anodic reaction — the electron loss — and the anodic reaction is the same in every environment. Which is exactly why CP works in aerated sand, in waterlogged clay, in a flooded bore, and in river-crossing mud that hasn't seen oxygen in thirty years. We're not protecting the pipe from

oxygen. We're protecting it from losing electrons, and that threat exists everywhere the pipe touches electrolyte.

Understand the words and the whole trade lines up behind them. Oxidation is the metal leaving — named for oxygen by a chemist who couldn't have known better, and not actually about oxygen at all. Reduction is the electrons coming back — named by furnace men watching ore lose weight, and the same event a galvanic anode performs on your pipeline every day of its service life. A sacrificial anode is a slow-motion smelter, spending its own metal to keep handing your pipe the electrons it would otherwise surrender.

I memorized OIL RIG to pass an exam. I understand it now because I had to teach it. If there's a lesson in that beyond the chemistry, it's the one worth closing on: the fundamentals you can recite are not always the fundamentals you know — and the gap between the two is usually where the trap is.

Key Takeaways

- **OIL RIG: Oxidation Is Loss, Reduction Is Gain — of electrons.** Oxidation is the metal leaving (the anodic half); reduction is what consumes the electrons it releases (the cathodic half). The two always run together, at matched rates.
- **"Oxidation" was named by Lavoisier in the late 1700s,** when the visible electron-loss reactions — rusting, burning — all involved oxygen. The name is a historical leftover. The modern definition is electron loss, full stop, and oxygen is not required.
- **"Reduction" came from the smelters before the chemists.** Reducing ore to metal — *reducere*, to lead back — describes restoring iron ions to iron metal, and the charge literally loses weight as the oxygen leaves. Gaining electrons and being "led back" to metal are the same event.
- **Corrosion is the mill's work running in reverse.** Metal is refined ore in a high-energy state; rust is the iron returning to something close to the ore it came from.
- **Two questions, two answers.** Can a corrosion cell run here? Yes — anywhere bare steel touches electrolyte, with or without oxygen. How fast will it run? That's where oxygen votes, and in aerated ground it usually votes loudest. The trap is letting the second answer bleed into the first.
- **Wet ground is usually oxygen-starved ground.** Oxygen moves through water roughly ten thousand times slower than through air. The bell-hole tells of an anaerobic cell: rotten-egg smell (SRB at work), black iron-sulfide staining, and clean dark pitting with no rust tubercles.

- **Anode and cathode are job titles, not part numbers.** On an unprotected pipe, both jobs run on the same steel, patches apart. CP hires an outside metal to hold the anode job full-time so the whole structure holds the cathode job.
- **Cathodic protection works in every environment for the same reason.** CP supplies electrons from outside so the iron never has to give up its own. It suppresses the anodic reaction directly — no oxygen in that sentence anywhere.

Referenced Standards & Technical Resources

- Corrosion Basics: An Introduction, 2nd Edition (AMPP) — Chapter 1, "Scope and Language of Corrosion," and Chapter 2, "Electrochemistry of Corrosion"
- Peabody's Control of Pipeline Corrosion, 2nd Edition — Chapter 1, "Introduction to Corrosion," and Chapter 16, "Fundamentals of Corrosion"
- **AMPP SP0169-2024**, "Control of External Corrosion on Underground or Submerged Metallic Piping Systems"
- AUCSC Basic Course materials — corrosion fundamentals curriculum
- Prior Field Notes coverage: "The Parts of the Corrosion Cell and Electrochemical Reactions" and "The Electrochemical Reaction Leading to Corrosion and The Reactions at The Anode Surface"
- **EC-010, "Oxidation and Reduction Reactions in Corrosion"** — the training module that prompted this article, in the External Corrosion track at training.rcswv.com

FROM RCS

Roberts Corrosion Services, LLC

Established in 2011, Roberts Corrosion Services, LLC delivers comprehensive, turn-key cathodic protection and corrosion control solutions nationwide. Our end-to-end expertise encompasses design and inspection, installation and repair, surveys and remedial work. We provide drilling services for deep anode installations and a full laboratory for analysis of samples and corrosion coupons, as well as custom CP rectifier manufacturing.

While our initial focus was on the Appalachian Basin area, we complete field work all over the US. We are a licensed contractor in many states and can complete a wide range of services.

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