IC-005 · MODULE 5 OF 8

Oxygen Corrosion in Pipeline Systems

A gas that has no business being in the pipe at all: why it speeds iron loss up, the two-scale numbers you never compare directly, the one mechanism behind most of the damage it does, and how a tech traces a reading back to the leak that's feeding it. The fifth module of the Corrosion Mechanisms in Pipeline Fluids set.

INTERNAL CORROSION TRACK BASICS & THEORY CORROSION MECHANISMS IN PIPELINE FLUIDS ~30 MINUTES

A CUT-OUT SPOOL ON A SWEET GATHERING LINE

Rust-orange mounds where nothing should rust

A section of gathering line comes out for a tie-in. Along the bottom of the bore — the 6 o'clock stretch where water lies — it's crusted with orange mounds. Knock one off and there's a pit underneath, going into good steel.

This is **sweet gas** — mostly methane, a little CO_2, no H_2S — and formation gas carries no oxygen at all. Yet the bottom of this pipe is pitting from the inside.

> The question this cut-out puts in front of you isn't "how bad is it." It's "where is the air getting in?"

BY THE END OF THIS MODULE

You'll be able to —

- Explain why oxygen is an **intrusion, not an ingredient** — and why a reading of it is itself the alarm.
- Describe why oxygen speeds iron loss up, in electron-clearing terms, and why it steers damage toward pitting.
- Keep the gas-side (ppm) and water-side (ppb) oxygen numbers in separate lanes — and know the flags for each.
- Recognize **differential aeration** as the mechanism behind under-deposit attack, crevice corrosion, and gasket-edge pitting.
- Name the mechanical paths oxygen uses to get into a gas system, and read the orange-tubercle field signature.
- Calculate a mass-loss corrosion rate from a coupon and judge it against an investigation threshold.

PART 1 · THE ODD GAS OUT

Oxygen isn't an ingredient — it's an intrusion

PLACING OXYGEN AGAINST THE LAST TWO MODULES

CO_2 and H_2S ride in. Oxygen breaks in.

CO_2 and H_2S come up out of the ground with the gas — ingredients you expect and manage. Oxygen is different in kind: formation gas carries **essentially no oxygen**, and pipeline-quality gas is held to a tight oxygen spec on top of that.

When oxygen shows up inside the line, it almost never rode in with the product. Something let it in — a seal, a blanket, or a purge has failed somewhere upstream.

With CO_2 or H_2S, the gas is a given and the work is managing its effect. With oxygen, the gas being present is the finding.

PART 2 · THE CHEMISTRY, IN FIELD TERMS

What oxygen does to iron

RECOGNIZE IT — YOU DON'T NEED TO BALANCE IT

Every iron atom that leaves sheds electrons

Iron dissolving into water gives up metal one atom at a time, and each atom sheds two electrons that have to go somewhere:

THE REACTION THE WHOLE SET IS BUILT ON

$$Fe \rightarrow Fe^{2+} + 2\ e^-$$

Iron leaves the wall as a dissolved ion and drops two electrons at the surface — the metal-loss event every aggressive fluid is a different way of feeding.

WHY OXYGEN SPEEDS EVERYTHING UP

$$O_2 + 2\ H_2O + 4\ e^- \rightarrow 4\ OH^-$$

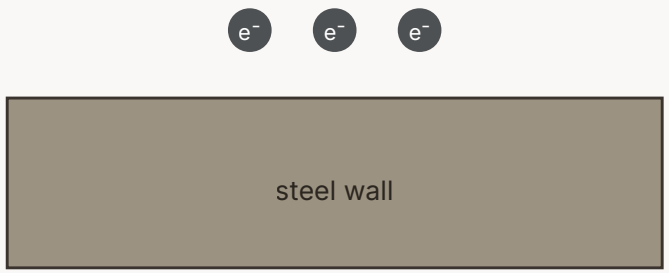
Oxygen is the hungriest taker of those electrons a pipeline is likely to meet — it clears them fast, so iron dissolution keeps running hard.

Why oxygen speeds iron loss up — it clears the electrons out of the way

WITHOUT OXYGEN

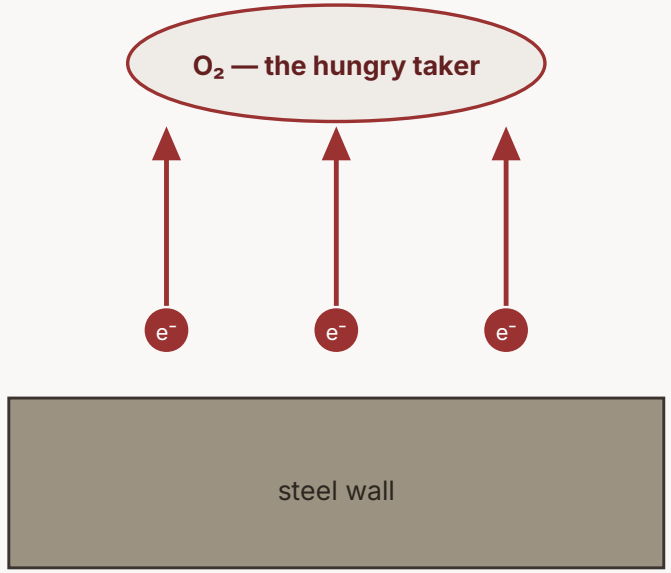
iron loss stalls — the reaction chokes on its own leftovers

electrons pile up — few takers



WITH OXYGEN PRESENT

clears electrons fast — iron loss keeps running hard



Same iron-loss reaction either side. Oxygen just sweeps the traffic jam clear, so more of it runs.

Oxygen doesn't change what corrosion is. It clears the traffic jam so the same corrosion runs faster.

Same iron loss, same reaction the sweet and sour modules taught — just more of it. And it steers the damage toward **pitting**, up to roughly 10× worse alongside CO_2 or H_2S.

PART 3 · READING THE NUMBERS

Two places, two units, one enemy

NEVER COMPARE THESE TWO NUMBERS DIRECTLY

ppm in the gas, ppb in the water

IN THE GAS — PPM

Read off the gas analysis (GC / O_2 analyzer). Native Marcellus/Utica gas ≈ 0. **Flag anything over ~50 ppm** and chase the cause. Hold as low as practicable otherwise.

IN THE WATER — PPB

Dissolved oxygen at the low points, where corrosion happens. Open surface water: **4–12 ppm**. >~50 ppb (0.05 ppm) considered corrosive. Injection target: **~10 ppb**.

> **Don't compare them head to head.** Oxygen-by-volume in the gas and dissolved oxygen in the water are different measurements on different scales. Cold water holds more dissolved oxygen than warm — the same system can run higher in January than July. **Wet + oxygen is the worst combination there is.**

NEVER SOMETHING TO WAVE OFF

Oxygen on the gas report is contamination, full stop

Native gas carries none, so a real reading means air is getting in — an **integrity flag** worth chasing to root cause.

> **And a safety concern.** At high enough levels, oxygen and hydrocarbon together in a pipe is a flammability and process-safety concern in its own right — not only a corrosion problem.

Two places, two units, one enemy. Either reading — gas-side ppm or water-side ppb — is the alarm on a line that should carry none.

PART 4 · THE MECHANISM TO MASTER

Differential aeration

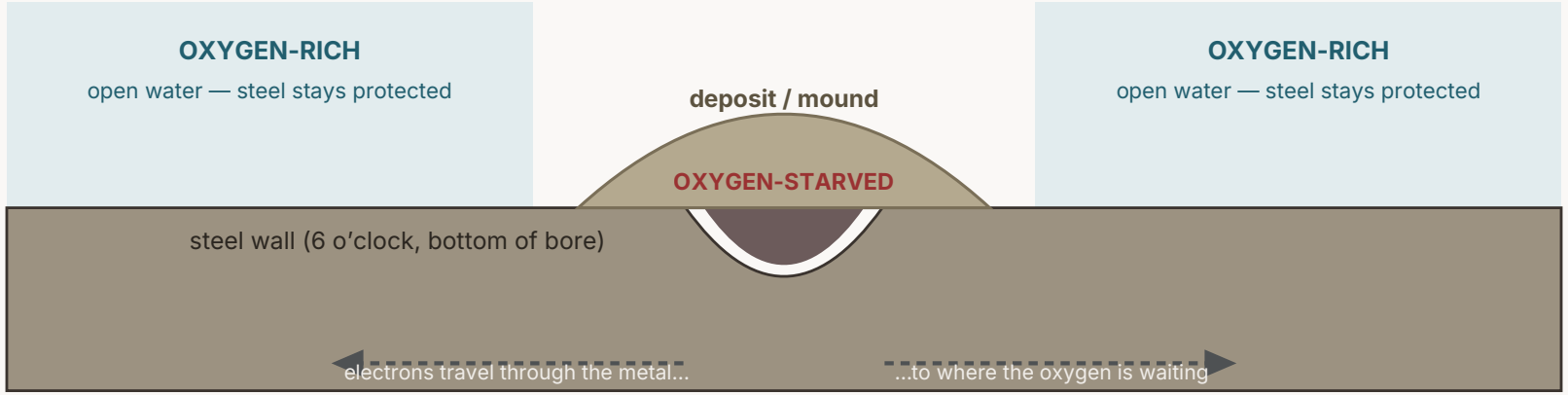
EXPLAINS MORE OXYGEN DAMAGE THAN ANY OTHER IDEA

The starved patch is where iron dissolves fastest

Where a deposit, crevice, or gasket starves one patch of the wall of oxygen, **that oxygen-starved patch** is where iron dissolves fastest — while the oxygen-rich areas nearby stay protected.

> Damage happens under the deposit, even though the oxygen driving it all is coming from the open water nearby.

Differential aeration — the oxygen-starved patch is where iron dissolves fastest



pit grows here — starved of oxygen

Under-deposit attack, crevice corrosion, gasket-edge pitting — one mechanism, many faces.

SAME SETUP, DIFFERENT NAMES IN THE FIELD

Under-deposit attack, crevice corrosion, gasket-edge pitting

01

Under-deposit attack

Pits growing beneath mounds of solids or scale at the low points.

02

Crevice corrosion

Attack in the tight gap of a fit-up, a threaded joint, a lap.

03

Gasket-edge / shielded-spot

Wherever geometry hides a patch of wall from the flow.

Anything that changes how much oxygen reaches one part of the wall versus another can set it up. Uneven oxygen across a surface concentrates the attack.

PART 5 · FOLLOW THE AIR

Where oxygen gets in

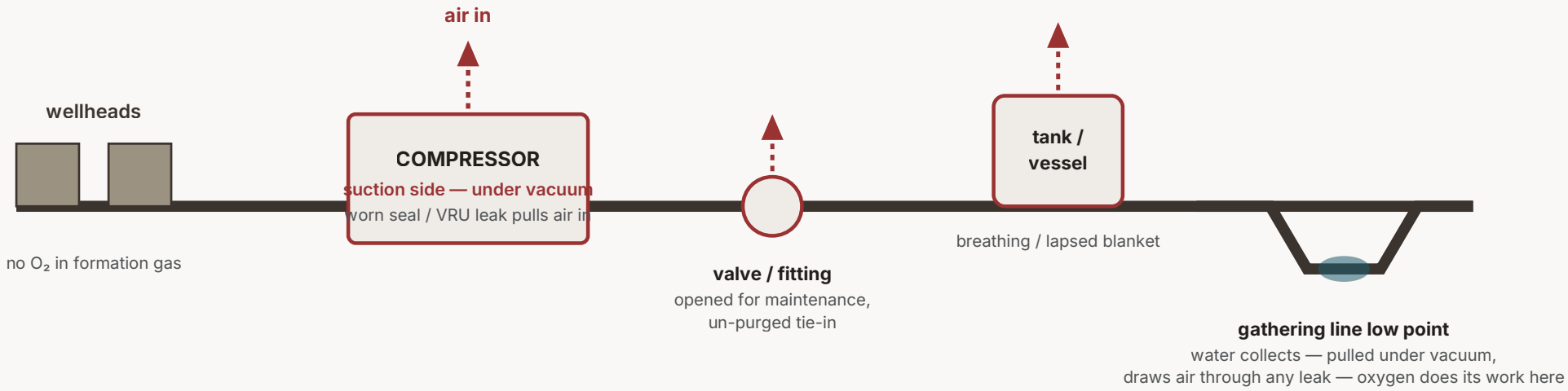
ALMOST ALWAYS A HARDWARE PROBLEM, NOT A CHEMISTRY PROBLEM

The usual suspects on a gas system

- **Compressor and VRU seals** — suction side runs under vacuum; a worn seal or leaking vapor-recovery unit draws air straight in.
- **Valves and fittings opened during maintenance** — a repair, tie-in, or new line without a proper purge leaves air behind.
- **Frac fluid and methanol** — flowback fluids and injected methanol can carry oxygen in with them.
- **Tanks and vessels breathing** — a lapsed gas blanket, or no blanket at all, breathes air on every level change.
- **Low-pressure gathering under vacuum** — a line pulled below atmospheric pulls air in through any leak it has.

Most oxygen ingress is mechanical, not chemical. Solving it starts with finding the leak — chemical treatment comes after, as the polish.

Where oxygen gets in — ingress is mechanical, find the leak first



Almost every entry point is worn, opened, or unfinished hardware — not a change in the gas.

PART 6 · READING AND MEASURING THE DAMAGE

What it leaves behind, and trusting the number

LEARNING TO READ IT SAVES A LAB TRIP

Bulky orange rust, pits underneath

Oxygen's corrosion products are iron oxides — **orange-to-brown** and **bulky**, piling into loose mounds called tubercles, very often with a pit hiding underneath. Alongside that: general thinning at the 6 o'clock, where oxygen-bearing water washes the wall.

> **Reading the color.** Gray-green carbonate scale points at CO_2. Black sulfide points at H_2S. **Bright orange-to-brown, bulky, mounded rust points at oxygen.**

IS THIS READING EVEN REAL?

Clean sampling first, the ratio check second

ON A GAS SAMPLE

The lab compares O_2 to N_2. Air is about 1 part oxygen to 4 parts nitrogen — if the two track that ratio, the bottle caught air; resample. O_2 without air's nitrogen is real line oxygen.

ON THE WATER SIDE

Portable meter or ampoule kit, working down into low ppb. Calibrate the meter the day you use it, and keep the sample off the air.

Clean sampling is the standard; the ratio check is the backstop for a rare bad bottle — not an excuse for sloppy technique. One reading is a note; two that agree are a signal.

PART 7 · CONTROL

Keeping oxygen out, in priority order

CHEAPEST AND MOST EFFECTIVE FIRST

Keep it out, then remove what still gets in

FIRST — KEEP IT OUT

Nearly the whole game on a gas system: sealing, compressor/VRU maintenance, gas or nitrogen blankets, clean purges before a line goes back in service. All mechanical, no chemistry needed.

SECOND — REMOVE WHAT GETS IN

Oxygen scavenger (sulfites/hydrazine) on gas or water. **Vacuum deaeration** is the workhorse on high-volume water systems (produced-water/injection) — not a gas-line tool.

> The cheapest oxygen is the oxygen that never gets in. Chemistry is the polish, not the plan.

ONE FLAG BEFORE WE PUT IT TOGETHER

The oxygen + H_2S trap

Oxygen leaking into a sour system can react part-way with H_2S and throw corrosive **elemental sulfur**. A half-treated sour system can end up worse than one left fully sour or kept fully sweet.

> This isn't a mechanism to work through here — just a tripwire to recognize, and one that deserves a specialist's eye.

PART 8 · FROM SUSPICION TO A PLAN

The data chain and the one calculation

THE SPINE OF THE WHOLE TRACK

Indirect data, the gate, then direct data

- **Indirect data** — the gas-analysis O_2 column vs the 50-ppm flag, read with water content/dew point, CO_2, H_2S, liquids (wet + O_2 is worst). Orange tubercles or rust in a cut-out or on a coupon.
- **Repeatability gate** — one aggressive read is a note; two consecutive reads that agree are a signal worth acting on.
- **Direct data** — coupons at low points and drips come back with a rate.

The move from the hook works in reverse too: find the orange pitting first, then pull the recent gas analyses and read the oxygen column.

THE NUMBER YOU HAND UP

Mass loss to a corrosion rate

THE ONE CALCULATION IN THIS MODULE

$$\text{corrosion rate (mpy)} = (3.45 \times 10^{6} \times W) \div (A \times T \times D)$$

W = mass lost (g) · A = coupon area (cm²) · T = time in service (hours) · D = steel density ≈ 7.87 g/cm³. "mpy" = mils per year, the North American coupon unit. Swap the constant to 8.76×10^{4} for mm/yr.

The tech hands the specialist a clean, repeatable rate; the fix is designed upstream.

IS THIS LINE HOLDING?

A coupon on a gathering-line drip

THE SETUP

Coupon rides a gathering-line drip **45 days**, loses **1.0 g**; area ≈ **40 cm²**. Program flags anything over **5 mpy**.

THE MATH

```
45 × 24 = 1,080 h
rate = (3,450,000 × 1.0) ÷ (40 × 1,080 × 7.87)
= 3,450,000 ÷ 339,984 ≈ 10 mpy (≈0.26 mm/yr)
```

10 mpy against a 5-mpy flag — twice over. Investigate. The fix is designed upstream; the tech hands up the clean, repeatable number.

THE TECH-TO-SPECIALIST HANDOFF

No single number fits every line

There's no single pass/fail number that fits every line — each system sets thresholds that fit its own metal, pressure, and risk.

> Set an **investigation** threshold rather than a hard action limit: a rate that says "something changed, go find out why." That's exactly the tech-to-specialist handoff this set is built around.

BACK TO THE SPOOL — SAME RUST, DIFFERENT EYES

What to remember

- **Back to the hook:** orange tubercles on a sweet line mean air is getting in — check a compressor seal under vacuum first. Pits under them are differential aeration doing its work.
- **Intrusion, not ingredient:** formation gas carries no oxygen; a reading of it is itself the alarm.
- **Electron-clearing:** oxygen is the hungriest electron-taker in the pipe — it clears the traffic jam so the same iron-loss reaction runs faster, and steers damage toward pitting.
- **Two places, two units:** gas-side ppm (flag >50) and water-side ppb (corrosive above ~50 ppb) never compare directly — wet + oxygen is the worst combination.
- **Differential aeration:** the oxygen-starved patch under a deposit, crevice, or gasket is where iron dissolves fastest.
- **The plan:** pull the gas analyses, confirm with a clean bracketed sample, walk the system for the leak, drop coupons, hand up the rate — find the leak before reaching for a scavenger.

FURTHER READING + THE NEXT MODULE

Sources used + where this goes

- **Internal Corrosion Field Guide** — the canonical field reference for this track
- **Field Guide to Internal Corrosion Mitigation and Monitoring for Pipelines**
- **Corrosion Basics: An Introduction**
- **NACE SP0106** — internal corrosion direct assessment for pipelines
- **API RP 1160** — managing system integrity for hazardous liquid pipelines
- **49 CFR Part 192** — gas-pipeline internal corrosion control

UP NEXT

Microbiologically influenced corrosion

The pipe fights back with something alive — and the bacteria that do some of the worst internal damage thrive precisely where oxygen is kept out. Controlling oxygen changes the whole biological picture inside the pipe.