IC-003 · MODULE 3 OF 8

CO_2 (Sweet) Corrosion
Chemistry, Drivers & Field Signatures

The first mechanism, taken end to end: why sweet corrosion is acid attack, the one number that measures the threat, what it looks like on steel, and how you carry the read up the chain. The third module of the Corrosion Mechanisms in Pipeline Fluids set.

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

BY THE END OF THIS MODULE

You'll be able to —

- Explain why CO_2 corrosion is acid attack, and recognize the carbonic-acid chain.
- Calculate CO_2 partial pressure and place a line in the three risk zones.
- Read $FeCO_3$ scale as a fragile friend — and explain the temperature paradox.
- Recognize the mesa fingerprint and tell it apart from sour and oxygen damage.
- Spot flow-induced localized corrosion as a flow story, not a program failure.
- Carry a sweet-corrosion signal through the data chain to a clean handoff.

PART 1 · WHAT "SWEET" MEANS

CO_2 corrosion is acid attack — full stop

A NUMBER ON A GAS ANALYSIS

"Couple percent CO_2 — that other line runs fine"

A wet-gas analysis comes back at **2.1% CO_2**. The operator's seen higher run clean elsewhere and figures this line's fine too.

He isn't wrong that he's seen higher CO_2 run clean. He's missing the second number that explains why — and it's sitting right there on the line's paperwork.

The composition number alone can't tell you if a line is corroding. Put it together with one more number and the answer takes ten seconds.

NOTHING MYSTERIOUS ABOUT THE GAS

Dry CO_2 touches nothing. Wet CO_2 makes acid.

CO_2 in the gas phase and bare steel can ride together indefinitely. The trouble starts the moment there's liquid water on the wall.

CO_2 dissolves into that water and a slice of it becomes carbonic acid. The acid releases hydrogen ions, and those ions attack the steel. "Sweet" just means CO_2 is the acid gas running the show — no H_2S in the mix.

> **The takeaway up front:** stop picturing CO_2 corrosion as a gas-phase mystery. It's a wet-system acid problem, driven by how much CO_2 partitions into the water.

THREE LINES OF REACTION — RECOGNIZE, DON'T DERIVE

The carbonic-acid chain

STEP 1 — THE GAS DISSOLVES AND MAKES ACID

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

STEP 2 — THE ACID RELEASES HYDROGEN IONS

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

STEP 3 — THE ACID ATTACKS THE STEEL

$$Fe + 2\,H^+ \rightarrow Fe^{2+} + H_2\uparrow$$

Iron leaves the wall as a dissolved ion; hydrogen bubbles off as gas.

A CO_2 line with wet walls is an acid factory — mild acid, made fresh around the clock, for years.

Sweet corrosion is acid attack.
Sour corrosion is acid attack **plus a hydrogen problem inside the steel.**

Many lines carry both gases. The sour side is the next module.

PART 2 · THE WORKING NUMBER

Partial pressure, and the three zones

THE AMOUNT OF ACID FOLLOWS THE PRESSURE, NOT THE PERCENTAGE

What "partial pressure" means

Every gas in the stream carries a share of the total pressure, sized to how much of the mix it is — so if CO_2 is 2% of the gas, it's carrying about 2% of the pressure. That share is its partial pressure.

THE ONE CALCULATION IN THIS MODULE

$$P_{CO_2} = (\%\ CO_2 \div 100) \times \text{total pressure (psia)}$$

psia = psig + 14.7. The gauge reads above atmosphere; the chemistry feels the absolute pressure.

Pressure is what pushes gas into water. Double the system pressure and you double the push behind every molecule of CO_2 — even if the percentage never moves.

FROM GAS ANALYSIS TO WORKING NUMBER

The same calc, run once

THE LINE

Wet shale gas, **800 psig**, gas analysis shows **1.5% CO_2**.

THE MATH

800 + 14.7 = 815 psia
0.015 × 815 ≈ **12.2 psia**

2% CO_2 at 100 psia is 2 psia — mild. The same 2% at 1,500 psia is 30 psia — high risk. Same gas, fifteen times the threat.

A composition number without a pressure number is half a sentence. Run the arithmetic; it's ten seconds on a phone calculator.

A DECADES-OLD FIRST-PASS SCREEN FOR CARBON STEEL

Place the line on the scale

< ~7 PSIA

Negligible

Sweet corrosion usually isn't the threat that drives the program.

7 – 30 PSIA

Active management

Credible. Monitoring, sampling cadence, likely an inhibitor program.

> ~30 PSIA

High risk

Expect aggressive damage without strong mitigation or CRA materials.

> **Rules of thumb, not hard lines.** A line at 6.5 psia isn't "safe" and one at 8 isn't "condemned." The zones are triage — they tell you how much attention a line deserves before any deeper work.

The three zones are the industry's general rule of thumb. The operator's own integrity or IC program sets the action thresholds — and where those exist, they govern.

Use the zones to understand the number; act to the program in front of you.

PART 3 · THE SCALE THAT FIGHTS BACK

$FeCO_3$ scale, and the temperature paradox

THE CORROSION MAKES A SCALE THAT CAN THROTTLE THE CORROSION

A fragile friend

THE CORROSION PRODUCT THAT PUSHES BACK

$$Fe^{2+} + CO_3^{2-} \rightarrow FeCO_3$$

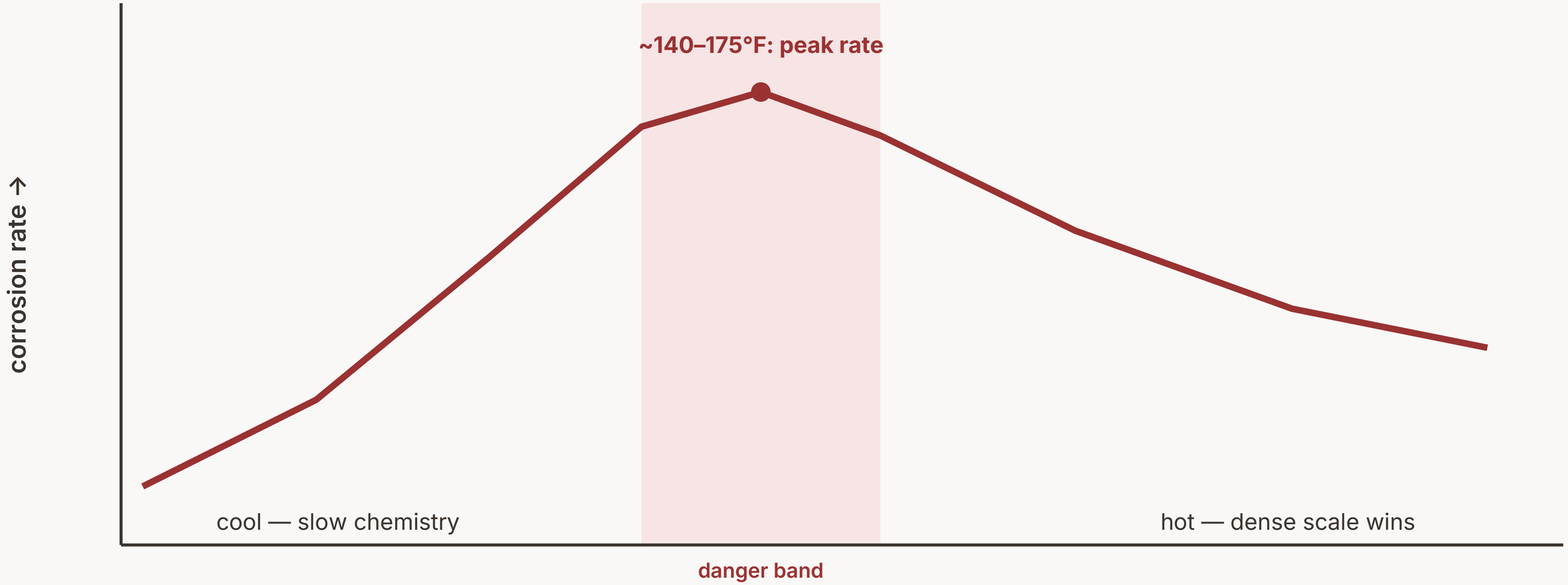
Iron carbonate (siderite) precipitating as a gray scale on the steel.

When that scale lays down tight and well-adhered, it separates water from steel and corrosion can drop by orders of magnitude. But it only forms — and only survives — inside a window of temperature, pH, supersaturation, and flow.

The scale isn't the protection — the conditions that keep it intact are. Move the window off the line and the one that "looked great for years" starts losing wall fast.

HOTTER IS NOT SIMPLY WORSE

The temperature paradox



Hotter isn't always worse. The warm line outcorrodes the hot one.

TWO SEGMENTS, IDENTICAL BUT FOR WALL TEMPERATURE

The warm line is the problem child

SEGMENT A · ~160°F

P_{CO_2} 15 psia, low-alkalinity water. In the heart of the danger band: fast chemistry, scale too poorly formed to help. **Peak-rate attack.**

SEGMENT B · ~265°F

Same P_{CO_2}, same water. Past the peak: a dense siderite jacket throttles the same chemistry. **Substantially lower rate.**

The hotter line is the safer line, at otherwise-identical conditions. With sweet corrosion, you fear the warm line, not the hot one.

PART 4 · FIELD SIGNATURES

What sweet corrosion looks like, and where it lives

ALKALINITY IS THE WATER'S ARMOR

The water decides the outcome

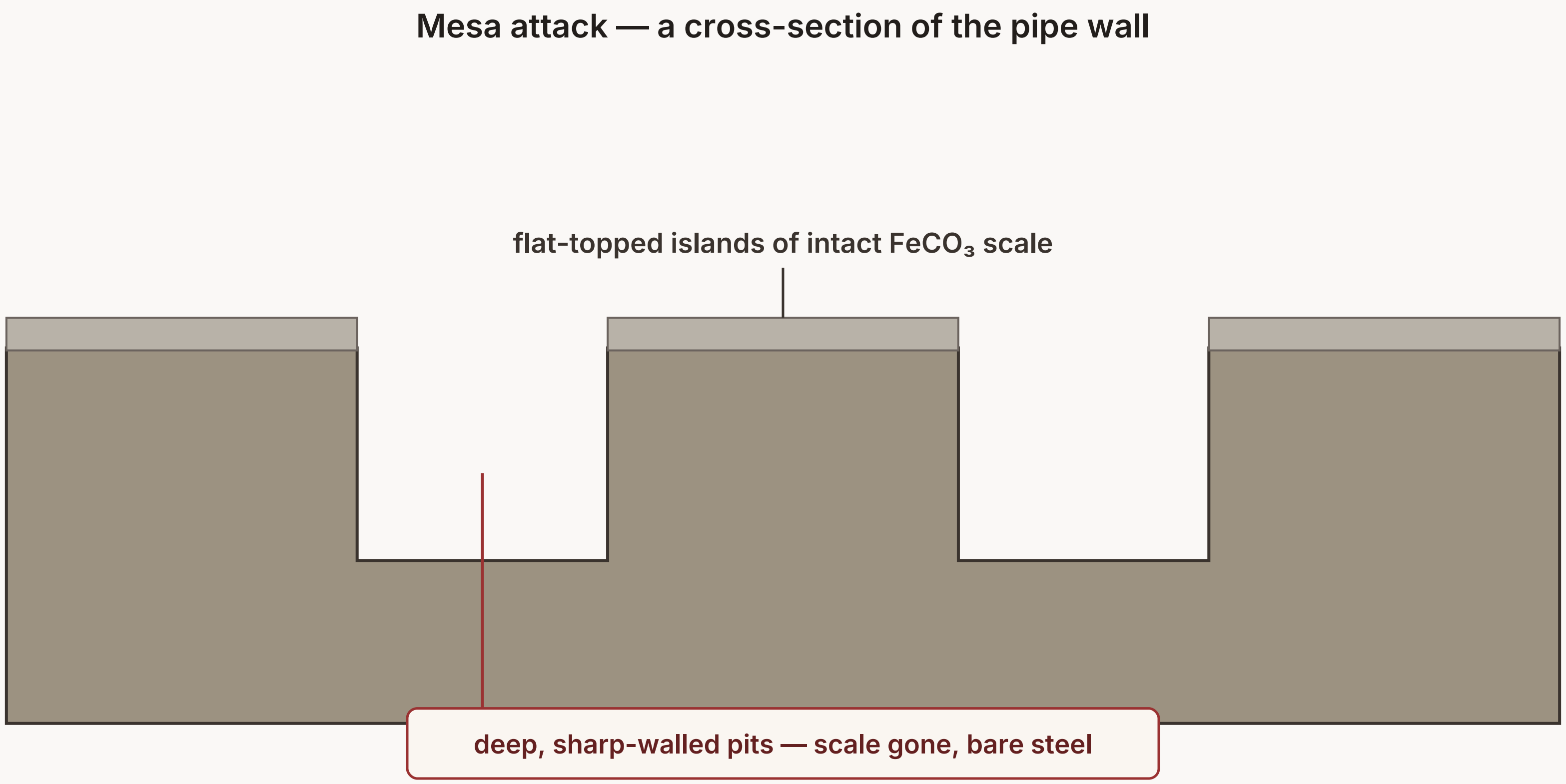
At the same CO_2 partial pressure, fresh unbuffered water can corrode carbon steel **five to ten times faster** than a well-buffered produced water.

Condensate, frac flowback, leftover hydrotest water — the "clean" waters are the ones with no carbonate cushion to absorb the acid. The distilled-clean film that condenses on a cool wall has no armor at all, which is what sets up top-of-line corrosion (its own module later in this set).

> **Field move:** when two lines on the same gas behave like strangers, read the alkalinity line on the lab report before you blame anything else.

THE DIAGNOSTIC YOU CAN READ OFF THE STEEL

Mesa attack



Flat tops + sharp pits = the CO_2 fingerprint. Not H_2S black pits, not O_2 tubercles.

THREE MECHANISMS, THREE SIGNATURES

Read the scale, name the chemistry

SWEET · CO_2

Mesa under gray scale

Flat-topped islands of carbonate scale, deep sharp-walled pits between them.

SOUR · H_2S

Black smeared scale

Black iron-sulfide film and the rotten-egg smell. Taught in the next module.

OXYGEN · O_2

Orange tubercles

Orange-brown rust mounds where air got into a system that should be oxygen-free.

None is courtroom proof on its own — but each tells you which chapter of the chemistry to open first.

CO_2 + WATER + CARBON STEEL

Where sweet corrosion shows up

- **Appalachian Basin wet-gas gathering** — Marcellus and Utica, typically 0.5–3% CO_2, water dropping out at every cool point. The everyday version on your work orders.
- **Richer-CO_2 basins** — parts of the Permian and Anadarko run 5–15% CO_2.
- **CO_2-EOR systems** — injection and produced-fluid lines handling the threat at industrial strength.

> **Run the math on a gathering line:** a few hundred to a thousand psig of pressure puts most of these squarely in the active-management zone. Most need a CO_2 program; the ones that don't are very dry or very buffered.

THE FAILURE MODE THAT EMBARRASSES GOOD PROGRAMS

"But our inhibitor program looks fine"

A line is inhibited, residual measures fine, bulk samples look healthy — then an inspection run lights up deep wall-loss patches at an elbow. Everywhere else: clean.

Flow that's gentle on the straightaways gets fast and chaotic where geometry turns — elbows, tees, weld upsets. There it can strip the inhibitor film and scale off one patch while the acid keeps running. That patch corrodes hard while the rest of the line coasts.

Localized damage at fittings, in a line whose bulk numbers look healthy, is a flow story — not a chemistry-program failure. More inhibitor isn't the fix.

PART 5 · FROM A SUSPICION TO A PLAN

The data chain, with CO_2's name on it

THE SPINE OF THE WHOLE TRACK

Five steps, and where you sit in them

01
Indirect data
Gas, pressure, water chemistry, solids.

02
Repeatability gate
Two consecutive reads that agree.

03
Direct data
Coupons: corrosion rate, pitting rate.

04
Prediction
The model, run upstream on your numbers.

05
Mitigation
Designed upstream, executed by you.

This module is the literacy that makes step one worth anything — indirect data that means something, and a read worth handing up.

WHAT THE SWEET-CORROSION PICTURE IS BUILT FROM

Reading the line for CO_2

- **Gas + pressure** → partial pressure → which of the three zones the line sits in.
- **The water** — pH trending down, dissolved iron trending up (the receipt that metal is leaving), and the alkalinity line saying whether this water has armor.
- **Solids** — grayish carbonate scale in the pig receiver fits the sweet story.
- **The absences** — no H_2S, no black scale, no rotten-egg smell. The absences are what make the case sweet and not sour.

One aggressive sample is a note in the file.
Two consecutive reads telling the same story is a signal.

Sampling has too many ways to lie for one result to move money.

WHEN THE SIGNAL CLEARS THE GATE

Coupons answer what samples can't

Coupons go in where this module says sweet corrosion concentrates — where water lays, where the temperature band is worst, downstream of fittings. Installed and retrieved under pressure, with the line in service.

CORROSION RATE

From weight loss over the exposure — how fast metal is leaving overall.

PITTING RATE

From pit depth and density — whether damage is concentrating into the dangerous localized kind.

A retrieved coupon often comes back wearing the mesa fingerprint under its carbonate scale. The placement and retrieval discipline get their own modules later in the track.

WORTH KNOWING IT EXISTS

The model is the integrity engineer's tool — your data feeds it

The industry has prediction models for sweet corrosion — the best-known is called **de Waard–Milliams** — that take in the very numbers this module taught you to collect (CO_2 partial pressure, temperature, pH) and put out an estimated corrosion rate.

Running and correcting those models is the integrity engineer's work, and the depth of it lives far up the track.

> The model is only as good as the field data that feeds it — and the tech who delivers clean, repeatable, well-documented numbers is the one whose lines get modeled right.

DESIGNED UPSTREAM, EXECUTED BY YOU

Three families of response

CHEMICAL

Inhibitor program

Continuous corrosion-inhibitor injection — the workhorse for sweet systems.

OPERATIONAL

Run it differently

Dry the gas harder; manage velocity and water drop-out.

MATERIAL

Upgrade the steel

Corrosion-resistant alloys where chemistry can't keep up.

Which lever, what product, what dose — designed by the integrity engineer or corrosion specialist. The tech runs the program in the field and keeps the samples coming, because follow-up data is what proves the fix is working.

THE NUMBER THE OPERATOR FIGURED WAS FINE

2.1% CO_2 at 1,000 psig

TEN SECONDS

$$0.021 \times (1{,}000 + 14.7) \approx \mathbf{21\ psia}$$

Middle of the active-management zone — triple the floor of it.

"Two percent" was never the number; twenty-one was. His other line that ran clean? It probably carried its CO_2 at lower pressure — same gas, different push, different answer.

You walked away with a collection plan instead of a guess. That's reading a gas analysis.

CARRY THESE OFF THE MODULE

What to remember

- **Sweet corrosion is acid attack.** Wet CO_2 makes carbonic acid; the H^+ feeds iron dissolution. No water on the wall, no sweet corrosion.
- **Partial pressure is the working number** — mol fraction × psia. Below ~7 negligible, 7–30 active management, above ~30 high risk. The program's threshold governs over the rule of thumb.
- **$FeCO_3$ scale is a fragile friend**, and rates peak in the 140–175°F band — the warm line outcorrodes the hot one.
- **Unbuffered water** corrodes 5–10× faster at the same CO_2; read the alkalinity line.
- **Mesa under gray scale = sweet.** Localized damage at fittings in a healthy-looking line is a flow story.
- **The chain:** indirect → repeatability gate → coupons → model run upstream on your clean data → mitigation designed upstream, executed by you.

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**
- **Internal Corrosion: Sweet and Sour** — Field Notes from RCS
- **Corrosion Basics: An Introduction**
- **NACE SP0106** — Control of Internal Corrosion in Steel Pipelines and Piping Systems
- **NACE SP0110** — Wet Gas Internal Corrosion Direct Assessment
- **49 CFR Part 192** — gas-pipeline internal corrosion control

UP NEXT

The sour side — H_2S corrosion

The next module takes the acid attack you now understand and adds its second, more dangerous trick: hydrogen that gets inside the steel.