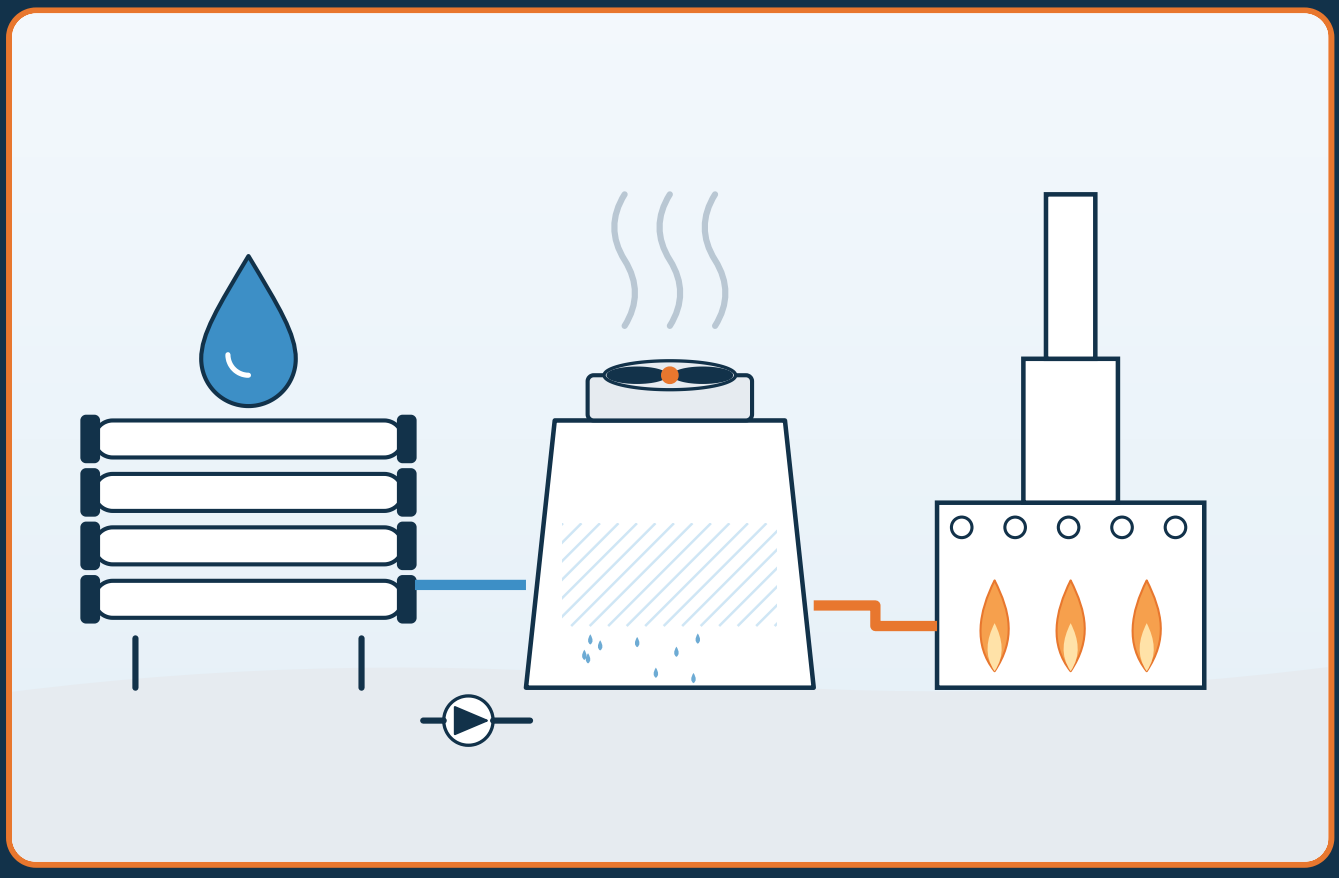
PlantCalcKit

Water Treatment, Utilities and Energy Made Simple

A field guide to plant water, utilities and energy

Reverse osmosis · Wastewater · Cooling water · Steam networks · Refrigeration · Fired heaters · Evaporators · Dryers · Reactors and agitators · Pumps · Filters · Gas and two-phase lines · Plant balances · Energy KPIs



FREE SAMPLER — Chapters 1 to 3

Edition 1.0 · November 2026

PlantCalcKit

Water Treatment, Utilities and Energy Made Simple
A field guide to plant water, utilities and energy
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Written in our own words from published engineering sources, listed in Appendix G. All diagrams, picture pages and charts are original PlantCalcKit artwork; charts are computed from the worked examples. No equipment maker, chemical supplier or brand is named or recommended.

Site W and all its equipment are made up. Every example value is generic; costs and prices are illustrative.

This guide is for training and engineering estimates. It does not replace your equipment maker's instructions, your water-treatment specialist's advice, the published codes and standards, or your plant's approved procedures and safety rules. Where a method follows a code or standard, the calculation is aligned with the publicly documented method; no result in this book claims to meet a code.

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GUIDE

How to use this book

This book explains the utilities and energy users of a process plant in plain words — water treatment, wastewater, cooling water, steam networks, refrigeration, heaters, evaporators, dryers, reactors, agitators, pumps, filters, gas lines and plant balances. You do not need to be an expert. If you can read a gauge and use a calculator, you can follow every example.

Who it is for

- **Plant operators** who run utilities and want to know what the numbers mean.
- **Young engineers** who must check performance, find bottlenecks and write reports.
- **Senior engineers** who want a quick refresher or a training text for their team.

How the book is built

Part	What you learn	Chapters
A	Water: basics, reverse osmosis, wastewater	1 to 5
B	Cooling: cooling water balance, network debottlenecking, refrigeration	6 to 8
C	Heat and process equipment: fired heaters, evaporators, dryers, reactors, agitators	9 to 13
D	Moving fluids and solids: pumps, filters, gas lines, two-phase flow	14 to 17
E	Balances and energy KPIs	18 to 19

Each chapter is short and stands alone. At the back you will find a glossary, an FAQ, units and conversions, a formula sheet, printable checklists, answers to all exercises and quizzes, and the list of sources.

The boxes you will see

- **Field check** — a table of what you might see on the plant, what it may mean, and what to check first.
- **Engineer's calculation corner** — a worked example with every step and number, using Site W's equipment.
- **Watch out** — a common mistake or a safety point.
- **Try it** — a short exercise; answers are in Appendix F.
- **Free tools** — QR codes to the free online calculator and the matching Excel toolkit for the chapter.
- **Quick quiz** — five questions to check you have the main ideas.

Site W and the numbers

All examples follow one made-up plant, Site W (Chapter 1). Its numbers are the example cases of the matching PlantCalcKit Excel toolkits, so you can open a toolkit and see the same calculation. Every number in the worked examples was computed with a script, not typed by hand. Costs and prices are illustrative only.

Units

SI units come first, with US customary units in brackets where it helps — for example 3,000 m³/h (13,209 US gpm). Pressures are marked "bar g" (gauge) or "bar a" (absolute). Appendix C has the conversions.

What this book is — and is not

This book helps you understand and check equipment. It is **not** a design code, an approved design calculation or a safety study, and it does not replace your equipment maker's instructions, your plant's approved procedures, your water-treatment specialist or the engineer responsible for the equipment. Where a method follows a published code or standard, we say it is "aligned with the publicly documented method" — that means we used the published equations, not that the result meets the code. Safety-critical items — combustion, runaway reactions, pressure relief, gas lines, refrigerants, confined spaces — are explained so that you can understand and question them; decisions on them belong to the responsible people and procedures at your site.

FREE TOOLS

Free calculators and Excel toolkits

Every chapter ends with two QR codes: a free online calculator for a quick check, and the matching PlantCalcKit Excel toolkit, which carries out the full calculation of the chapter's worked example with the same numbers. The toolkits show every formula, check every input and print a report. Shop pages are information pages; nothing is bought by scanning a code.

All free calculators
plantcalckit.com/tools/

All Excel toolkits
plantcalckit.com/shop/

Ch.	Chapter	Free calculator	Excel toolkit (does the chapter's calculation)
1	Utilities and energy in a process plant	Process engineering unit converter plantcalckit.com/tools/unit-converter/	Process Equipment Energy Consumption **USD 39** plantcalckit.com/shop/process-equipment-energy-consumption-excel/
2	Water basics for operators	Cooling water chemistry and cycles plantcalckit.com/tools/cooling-water-chemistry/	Water Treatment and RO System Performance **USD 49** plantcalckit.com/shop/water-treatment-and-ro-system-performance-excel/
3	Reverse osmosis: flux, recovery and rejection	Cooling water chemistry and cycles plantcalckit.com/tools/cooling-water-chemistry/	Water Treatment and RO System Performance **USD 49** plantcalckit.com/shop/water-treatment-and-ro-system-performance-excel/

PART A

Water

Water basics, reverse osmosis and wastewater

CHAPTER 1

Utilities and energy in a process plant

Every process plant has two halves. One half makes the product. The other half — the utilities — supplies the water, steam, cooling, air, power and fuel that the product half needs, and takes away the heat and waste it does not want. When a utility runs short, production stops just as surely as if a reactor failed.

1.1 What counts as a utility

A utility is any service shared by many users. The common ones are:

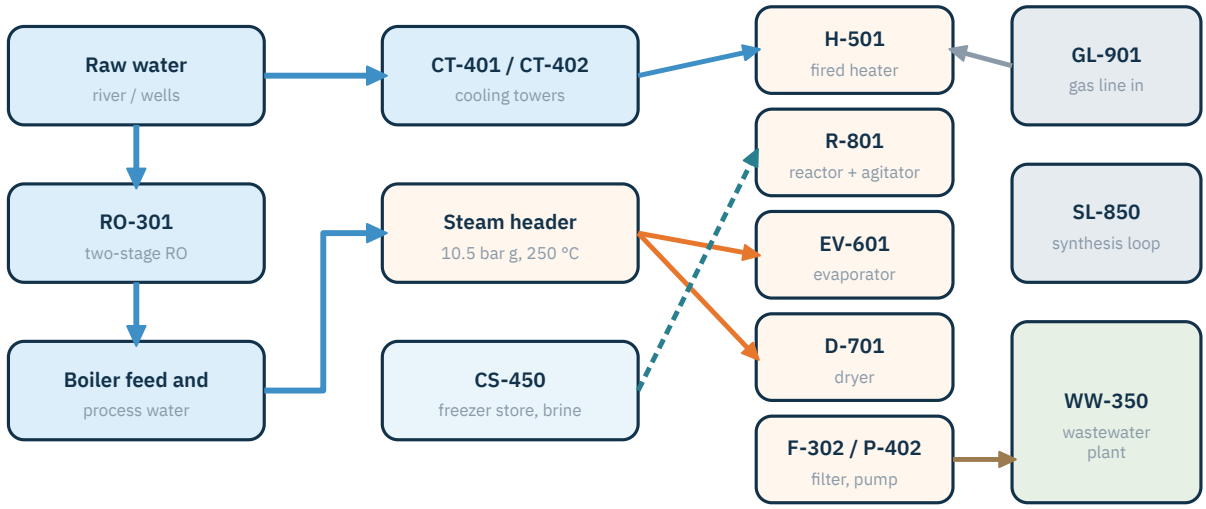
- **Water**: raw water, treated water, demineralised or RO water for boilers and processes.
- **Cooling**: cooling water from a tower, chilled water or brine from a refrigeration plant.
- **Steam and condensate**: steam at one or more pressures, and the condensate that comes back.
- **Fuel**: gas or oil for boilers, fired heaters and dryers.
- **Compressed air and nitrogen**: instrument air, plant air, inert gas.
- **Electricity**: for motors, which drive almost every pump, fan, compressor and agitator.
- **Wastewater treatment**: the last "utility", which cleans what the plant throws away.

Utilities are easy to forget because they usually work. But they often use more than half of a plant's energy bill, and many debottlenecking projects turn out to be utility projects in disguise: "we can make 10 % more product — if the cooling water, the steam header and the wastewater plant can take it."

1.2 Meet Site W

To keep the numbers real, this book follows one made-up plant, **Site W**, through every chapter. Site W is generic: it is not any real plant, and every value is an example you should replace with your own data. Figure 1.1 shows how its parts fit together.

Site W — the made-up plant used in this book (every tag is generic)



Blue: water Orange: steam and heat Teal: chilled brine / cooling Grey: gas Brown: wastewater

Figure 1.1 — Site W, the made-up plant used in this book. Each tag (RO-301, CT-401, H-501 ...) comes back in the chapter that treats it.

Tag	Equipment	Chapter
RO-301	Two-stage reverse osmosis unit, 150 m³/h feed	2, 3, 4
WW-350	Activated sludge wastewater plant, 10,000 m³/d	5
CT-401, CT-402	Cooling tower loop; main cooling water network (CW-NET)	6, 7
CS-450	Freezer store with brine-chilled air coolers	8
H-501	Fired heater, 20 MW absorbed duty	9
EV-601	Triple-effect evaporator	10
D-701	Direct-fired rotary dryer	11
R-801, TK-802	Jacketed reactor; agitated blend vessel	12, 13
P-402	Centrifugal cooling water booster pump	14
F-302	Pressure leaf filter	15
GL-901, FL-902	Gas supply pipeline; two-phase flow line	16, 17
SL-850	Synthesis loop (material and energy balance)	18
Site W energy	Twelve big energy consumers	19

Each example uses the same numbers as the example case of the matching PlantCalcKit Excel toolkit, so you can open the toolkit and see every step.

1.3 Five numbers behind every utility

Whatever the utility, the same five questions come up again and again:

1. **How much flows?** Volume flow (m³/h) or mass flow (kg/h, t/h).
2. **At what condition?** Pressure, temperature, quality (salinity, dryness, dew point).

3. **How much energy does it carry?** Flow × specific heat × temperature change, or flow × latent heat.
4. **How close is it to its limit?** Demand ÷ capacity — we call this *utilisation*.
5. **What does it cost?** Energy bought × price, and the carbon dioxide that comes with it.

If you can answer those five questions for each utility, you understand your plant better than most.

1.4 Energy in one line

Most energy calculations in this book use one of three simple forms:

- **Sensible heat**: $Q = m \times c_p \times \Delta T$. Water's specific heat c_p is about 4.18 kJ/kg·K (1 Btu/lb·°F).
- **Latent heat**: $Q = m \times \lambda$. Condensing 1 kg of steam at 4 bar g releases about 2,108 kJ.
- **Power from pressure**: $P = \dot{V} \times \Delta p \div \eta$. A pump that raises 1 m³/s by 1 bar delivers 100 kW of hydraulic power.

Keep the units straight: 1 kW = 1 kJ/s; 1 kWh = 3,600 kJ = 3.6 MJ; 1 tonne of refrigeration (TR) = 3.517 kW; 1 kW = 3,412 Btu/h.

1.5 Utilisation: the debottlenecker's favourite number

Utilisation = demand ÷ capacity × 100 %. A header at 60 % utilisation has room to spare; one at 95 % is the next bottleneck. Chapter 7 ranks every part of Site W's cooling water and steam networks this way. The idea is simple, but it forces you to write down a capacity for every element — pump, tower, pipe, boiler — and that alone often finds the problem.

FIELD CHECK **Utility walk-down**

What you see	What it may mean	First thing to check
Cooling water return hotter than usual	Heat load up, flow down, or a fouled exchanger	Flow to each big user; tower fans running
Steam header pressure sagging at peak	Boiler or letdown at its limit, or a header too small	Boiler load; pressure drop along the header
RO permeate flow falling	Colder water, fouling, or lower feed pressure	Normalise the data first (Chapter 4)
Air compressors loading more	Leaks or new users	Leak survey; demand at night
Wastewater effluent cloudy	Sludge settling poorly, overload	Sludge age, return sludge rate (Chapter 5)

ENGINEER'S CALCULATION CORNER **What does a utility cost? (illustrative)**

Site W's energy survey (Chapter 19) found 5,106,449 kWh of energy bought in one 30-day period, for 205,214 (in the user's currency, illustrative tariffs). The plant made 12,000 t of product, so the specific energy was 425.5 kWh/t against a baseline of 420.0 kWh/t — 1.3 % above target. Three consumers out of twelve used 80 % of the energy. That is the usual pattern: a few big users decide the bill, so start with them.

1.6 Collecting good data

Every calculation in this book starts with plant readings, and most surprises in a performance check come from the data, not the equations. Five habits make the difference:

1. **Take readings at steady state.** Wait until flows and temperatures have been stable for at least an hour; a unit that is still warming up will not balance.
2. **Read everything at the same time.** A flow read at 08:00 and a temperature read at 11:00 do not belong to the same operating point. Use the plant historian and average over the same window — one to four hours is typical.
3. **Write down the units and the basis.** Gauge or absolute pressure? Wet or dry gas analysis? Mass or volume flow? At standard or actual conditions?
4. **Check the instruments you rely on most.** One calibration check of the main flow meter is worth more than ten decimal places in the calculation.
5. **Keep a log.** A number means little alone; the same number every month tells a story. The examples in this book are built so that you can repeat them each month and compare.

When a result looks wrong, go back through these five steps before you suspect the equipment.

Watch out — a utility number is only as good as its meter

Flow meters drift, temperature sensors sit in the wrong place, and analysers need calibration. Before you believe a surprising result, check the instrument. A 2 % flow error can move a calculated efficiency by several points.

TRY IT

Site W raises 5 t/h of steam for a process that runs 8,000 h a year. If steam costs USD 25 per tonne (illustrative), what does that steam cost per year? (Answer in Appendix F.)

FREE TOOLS **Do this chapter's calculation**

Free calculator
Process engineering unit converter calculator
plantcalckit.com/tools/unit-converter/

Excel toolkit: Process Equipment Energy Consumption (USD 39)
plantcalckit.com/shop/process-equipment-energy-consumption-excel/
Topics: Energy per consumer · Specific energy · Cost and carbon · EnPI and CUSUM · Top consumers · Savings and payback

QUICK QUIZ

1. Name four utilities found in most process plants.
2. What is "utilisation", and why is a value near 100 % a warning?
3. Write the sensible heat equation and give the specific heat of water.
4. How many kW is one tonne of refrigeration?
5. Why should you check the instruments before believing a surprising utility number?

CHAPTER 2

Water basics for operators

Water treatment has its own language: TDS, conductivity, hardness "as $CaCO_3$", alkalinity, pH. The words sound like chemistry, but the ideas are simple. This chapter gives you just enough to read a water report, convert between units and follow the RO chapters that come next.

2.1 What is in the water

Natural water carries dissolved salts picked up from rocks and soil. The main ones are:

- **Positive ions (cations)**: calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}).
- **Negative ions (anions)**: bicarbonate (HCO_3^{-}), sulfate (SO_4^{2-}), chloride (Cl^{-}), nitrate (NO_3^{-}).
- **Others**: silica, iron, manganese, organic matter and suspended solids (silt, clay).

The total of all dissolved salts is the **total dissolved solids (TDS)**, in mg/L (about the same as ppm for fresh water). Figure 2.1 shows how salty different waters are.

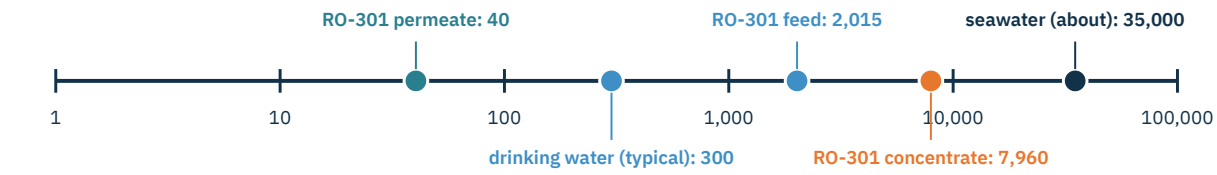


Figure 2.1 — Typical dissolved solids, from RO permeate to seawater. RO-301's feed, permeate and concentrate are marked.

2.2 Conductivity and TDS

Salts make water conduct electricity, so a **conductivity** meter gives a quick, online estimate of salinity. Conductivity is reported in µS/cm (microsiemens per centimetre) at 25 °C.

To turn conductivity into TDS, multiply by a factor k:

TDS (mg/L) ≈ k × EC (µS/cm)

The factor k is usually between about 0.55 and 0.75; it depends on which salts are present. Use the value your laboratory finds for your water. For RO-301 we use k = 0.65:

- Feed: 3,100 µS/cm × 0.65 = **2,015 mg/L**.

The same k does not hold for every stream. RO permeate is richer in sodium and chloride than the feed, so its true factor can differ. That is why a careful RO log records conductivity *and* a laboratory TDS now and then.

2.3 Hardness and alkalinity "as $CaCO_3$"

Hardness is mostly calcium and magnesium — the ions that form scale. **Alkalinity** is mostly bicarbonate and carbonate — the ions that pair with calcium to make calcium carbonate scale.

Both are often reported "as $CaCO_3$". This is a common yardstick: each ion is expressed as the amount of calcium carbonate that would carry the same charge. To get calcium itself from calcium hardness as $CaCO_3$, multiply by the ratio of molar masses, 40.08 ÷ 100.09 = 0.40:

- RO-301 feed calcium hardness 200 mg/L as $CaCO_3$ → 80.1 mg/L of calcium.
- In US practice the same hardness is about 11.7 grains per US gallon (1 gpg = 17.1 mg/L as $CaCO_3$).

2.4 pH in one paragraph

pH measures how acidic or basic the water is: 7 is neutral, below 7 is acidic, above 7 is basic. Each step of 1 is a factor of 10 in hydrogen-ion concentration. pH matters because calcium carbonate is much less soluble at high pH — water that is safe at pH 7.0 may scale at pH 8.0. RO-301's feed is at pH 7.4.

2.5 Osmotic pressure — why RO needs a pump

Put pure water and salt water on two sides of a membrane that passes water but not salt, and water flows *into* the salty side. The pressure needed to stop that flow is the **osmotic pressure**. For dilute salt water it follows the van 't Hoff relation:

$$\pi = \varphi \times v \times c \times R \times T$$

where c is the salt concentration in mol/L, v = 2 for sodium chloride (two ions), φ is an osmotic coefficient a little below 1 (0.93 here), R = 0.08314 L·bar/(mol·K) and T is the absolute temperature.

A rule worth remembering: 1,000 mg/L of sodium chloride at 25 °C has an osmotic pressure of about **0.789 bar (11.4 psi)**. Seawater, at about 35,000 mg/L, is near 27.6 bar. An RO pump must beat this pressure before any water passes — that is what Chapter 3 is about.

FIELD CHECK **Reading a water report**

What you see	What it may mean	First thing to check
Conductivity up, TDS from lab unchanged	Meter drift or wrong temperature compensation	Calibrate; compare with a lab sample
Hardness up after rain or season change	Source water changed	Scaling index of the RO concentrate (Chapter 4)
High silica	Silica scale risk in RO and boilers	Recovery limit from the membrane supplier
Iron above about 0.05 mg/L	Fouling of RO and resin	Pretreatment and filter performance
Turbidity or SDI high	Particles will foul the RO	Media and cartridge filters

ENGINEER'S CALCULATION CORNER **From a conductivity reading to salinity and osmotic pressure**

RO-301 feed reads 3,100 µS/cm at 28 °C.

1. TDS = 0.65 × 3,100 = **2,015 mg/L**.

2. Inside the RO the salt concentrates, so the average salinity on the feed side is higher: **3,728 mg/L** at 75.1 % recovery (Chapter 3 shows how).
3. Osmotic pressure at that salinity and 28 °C: π = 0.93 × 2 × (3,728 ÷ 1,000 ÷ 58.44) × 0.08314 × 301.15 = **2.97 bar**.

That is almost three bar of the pump's pressure spent just to stand still.

2.6 Pretreatment: what the RO needs from upstream

Membranes are fine filters for salt, but they are easily blocked by particles, damaged by oxidants and coated by scale. The pretreatment ahead of an RO is there to deliver water the membrane can live with:

- **Particles and colloids** are removed by clarifiers, multimedia filters and, last of all, cartridge filters. The **silt density index (SDI)** measures how fast a small membrane filter plugs; membrane makers usually ask for a low SDI, typically below about 3 to 5 depending on the element, and their limit applies.
- **Chlorine and other oxidants** attack polyamide membranes. Water that has been chlorinated upstream is dechlorinated, often with sodium bisulfite, and an oxidation–reduction (ORP) or chlorine analyser guards the feed.
- **Iron and manganese** oxidise and deposit; they are removed or kept dissolved.
- **Scale-forming ions** are controlled with an antiscalant, acid dosing or softening (Chapter 4).
- **Bacteria** are controlled to slow biofilm growth, without exposing the membrane to oxidants it cannot tolerate.

A good rule for operators: when an RO problem starts, look upstream first. Most fouling begins with a pretreatment upset — a filter that was not backwashed, a dosing pump that stopped, a dechlorination tank that ran empty.

Watch out — "ppm" is not always mg/L

For fresh water, 1 mg/L ≈ 1 ppm. For brines and seawater the density is higher, so mg/L and ppm (by mass) differ by a few per cent. Always write the unit the laboratory used.

TRY IT

A well water reads 1,500 µS/cm. Its calcium hardness is 150 mg/L as $CaCO_3$. Using k = 0.65, estimate the TDS and the calcium concentration. (Answer in Appendix F.)

FREE TOOLS **Do this chapter's calculation**

Free calculator
Cooling water chemistry and cycles calculator
plantcalckit.com/tools/cooling-water-chemistry/

Excel toolkit: Water Treatment and RO System Performance (USD 49)
plantcalckit.com/shop/water-treatment-and-ro-system-performance-excel/
Topics: Recovery and rejection · Net driving pressure · Normalised data · 12-reading log · Energy and scaling · What-if tables

QUICK QUIZ

1. What does TDS stand for, and in what unit is it usually given?
2. Why can the conductivity-to-TDS factor differ between RO feed and RO permeate?
3. What does "as $CaCO_3$" mean?
4. Why does calcium carbonate scale form more easily at high pH?
5. About how much osmotic pressure does 1,000 mg/L of sodium chloride create at 25 °C?

CHAPTER 3

Reverse osmosis: flux, recovery and rejection

Reverse osmosis (RO) pushes water through a membrane that holds back almost all of the salt. It is now the workhorse for boiler feed water, process water and drinking water. Four numbers tell you how an RO unit is doing: recovery, rejection, flux and net driving pressure. This chapter works them out for RO-301.

3.1 How RO works

In osmosis, water moves from the fresh side to the salty side. In reverse osmosis we apply a pressure higher than the osmotic pressure to the salty side, and water moves the other way — out of the salt water, through the membrane, into the permeate (Figure 3.1).

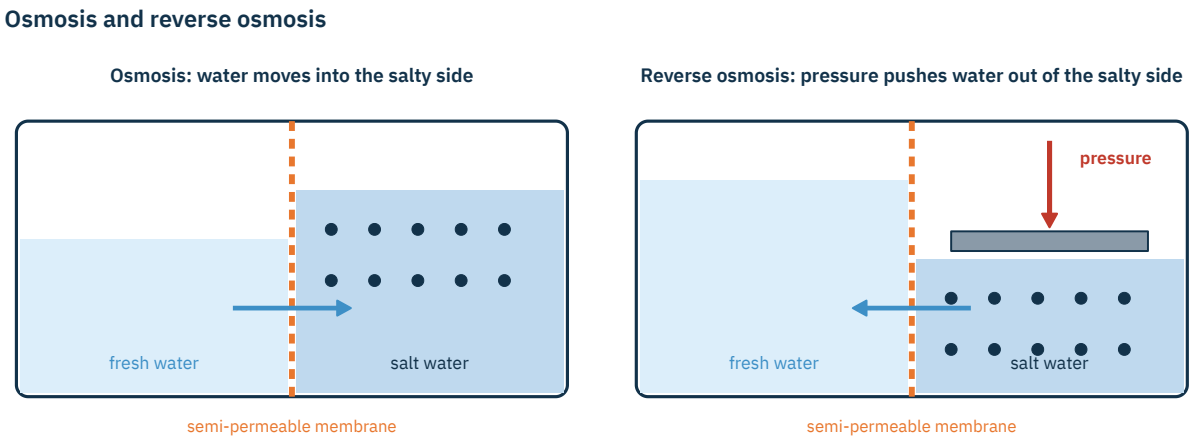
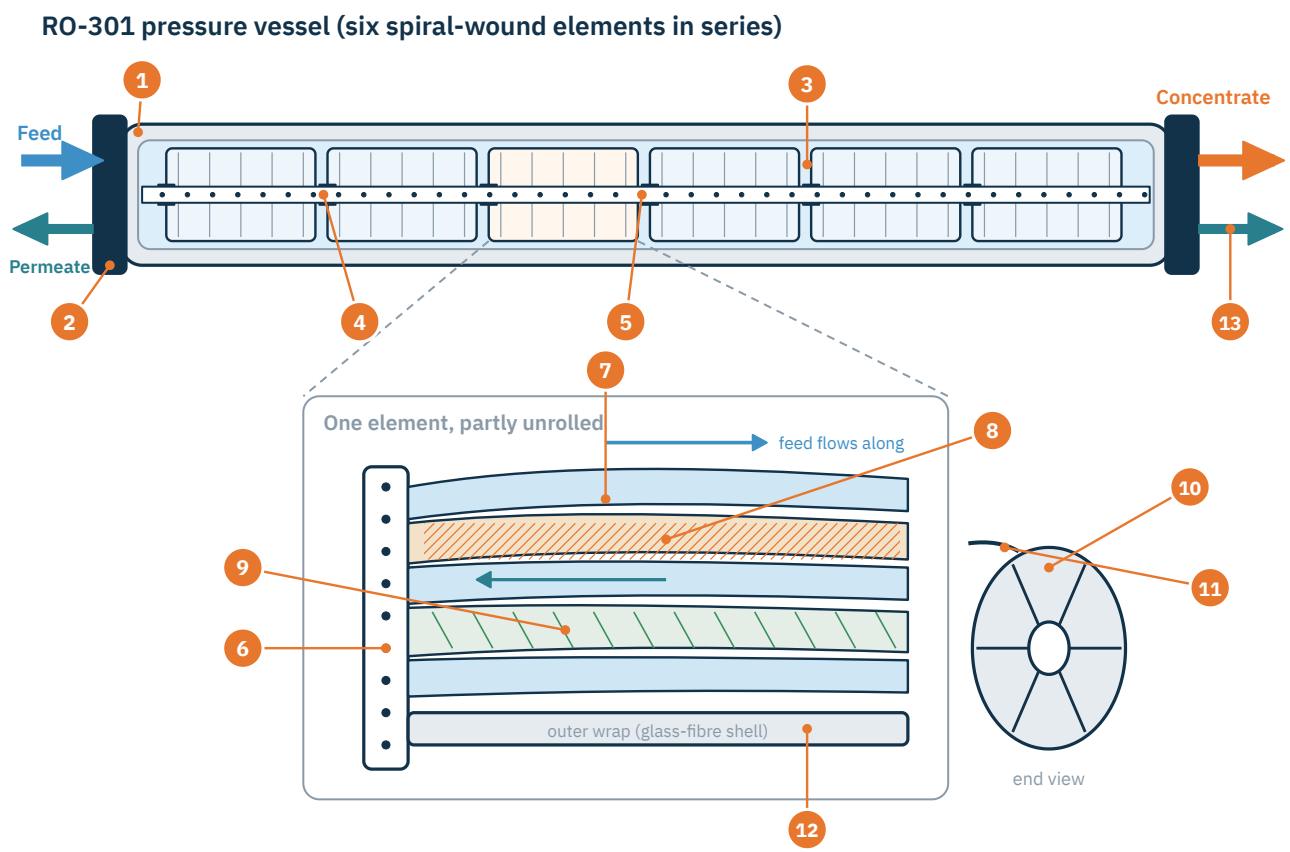


Figure 3.1 — Osmosis (left) and reverse osmosis (right). The membrane passes water but holds back the salt ions.

Industrial membranes are rolled into **spiral-wound elements**, about 1 m (40 in) long and 200 mm (8 in) across. Six or seven elements sit end to end in a **pressure vessel**. Feed enters one end; concentrate (also called reject or brine) leaves the other; permeate collects in the centre tube. The picture page that follows shows the parts.

PICTURE PAGE 1

RO pressure vessel and spiral-wound element



Cutaway of one RO-301 pressure vessel and an exploded view of a spiral-wound element. Generic arrangement; follow your membrane maker's loading drawing.

No.	Part	What it does
1	**Pressure vessel shell**	Glass-fibre tube that holds the feed pressure; rated for a maximum pressure stamped on the label.
2	**End cap and head seal**	Closes each end; carries the feed or concentrate port and the permeate port.
3	**Spiral-wound element**	The membrane package, about 1 m long; six sit in series in RO-301's vessels.
4	**Permeate collection tube**	Perforated centre tube; clean water spirals in and leaves through it.
5	**Interconnector**	Short coupling with O-rings joining permeate tubes of neighbouring elements; a leaking O-ring lets salt into the permeate.
6	**Centre tube holes**	Where permeate enters the tube from the envelope (leaf).
7	**Membrane leaf**	Two membrane sheets glued on three sides; salt water outside, permeate inside.
8	**Feed spacer**	Plastic mesh that keeps a feed channel open and stirs the water; fouling here raises the differential pressure.
9	**Permeate spacer**	Fine fabric inside the leaf that carries permeate to the centre tube.
10	**Anti-telescoping device**	Spoked end plate that stops the roll from sliding out of shape under flow.
11	**Brine seal**	Lip seal on the element so feed cannot bypass between the element and the vessel wall.
12	**Outer wrap**	Hard shell around the rolled leaves.
13	**Concentrate and permeate ports**	Concentrate goes to stage 2 or to drain; permeate from both ends joins the product header.

3.2 The RO-301 array

RO-301 has two stages in a 2 : 1 "tapered" array: 16 vessels in stage 1 and 8 in stage 2, each with six elements of 37.2 m² (400 ft²). Stage 1 concentrate feeds stage 2, which keeps the water moving fast enough along the membranes to limit fouling (Figure 3.2).

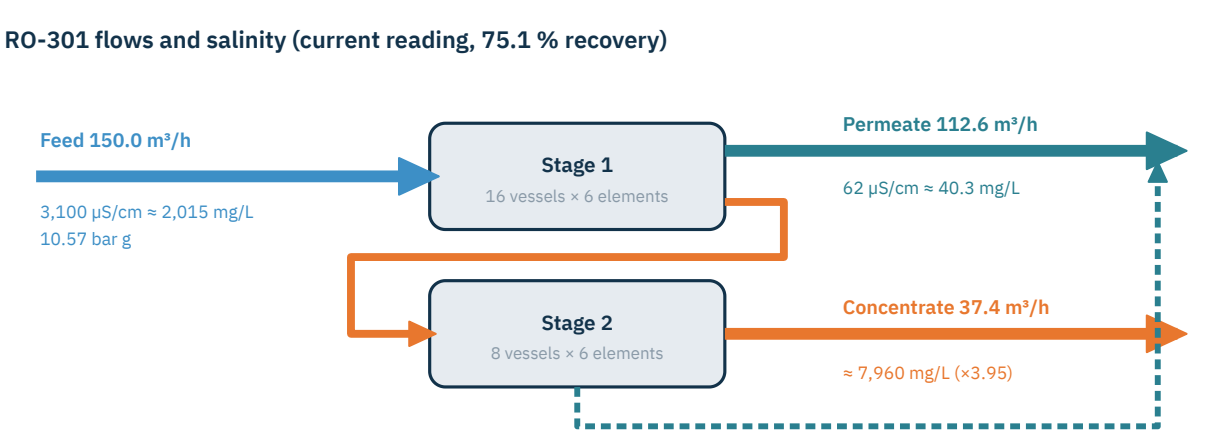


Figure 3.2 — Flows and salinity of RO-301 at the current reading. Salinity in mg/L from conductivity × 0.65.

3.3 Recovery

Recovery is the share of the feed that becomes permeate:

Y = Qp ÷ Qf

For RO-301: Y = 112.6 ÷ 150.0 = **75.07 %**. Brackish-water units usually run at about 65 to 85 %. Higher recovery saves water and pumping, but it concentrates the salts in the last elements, where scale forms first (Chapter 4).

3.4 Rejection and salt passage

Rejection is the share of salt held back. In the field we use the *apparent* rejection from feed and permeate salinity:

Rejection = (1 − Cp ÷ Cf) × 100 %

For RO-301: (1 − 62 ÷ 3,100) × 100 = **98.00 %**. The complement, salt passage, is 2.00 %. Salt passage is the better number for trending: a change from 1 % to 2 % looks small as rejection (99 % to 98 %) but means the permeate is twice as salty.

3.5 Concentrate and concentration factor

What the membrane holds back goes out with the concentrate. A salt balance gives:

Cc = (Qf × Cf − Qp × Cp) ÷ (Qf − Qp)

For RO-301: Cc = (150.0 × 2,015 − 112.6 × 40.3) ÷ 37.4 = **7,960 mg/L**, a concentration factor of 3.95. A quick check: with perfect rejection the factor would be 1 ÷ (1 − Y) = 4.01.

3.6 Flux

Flux is permeate flow per unit membrane area, usually in L/m²·h (often written LMH):

J = Qp ÷ A

RO-301 has 144 elements × 37.2 m² = 5,357 m², so J = 112,600 L/h ÷ 5,357 m² = **21.02 L/m²·h (12.4 gfd)**. Membrane makers give a design flux range for each feed water type; running far above it speeds up fouling.

3.7 Net driving pressure

Water passes the membrane in proportion to the **net driving pressure (NDP)** — the feed pressure left after the losses and the osmotic back-pressure:

NDP = Pf − ΔP/2 − Pp − πfc + πp

where Pf is the feed pressure, ΔP the feed-to-concentrate pressure drop, Pp the permeate pressure, πfc the average osmotic pressure on the feed side and πp the permeate osmotic pressure. Figure 3.3 shows where RO-301's pressure goes.

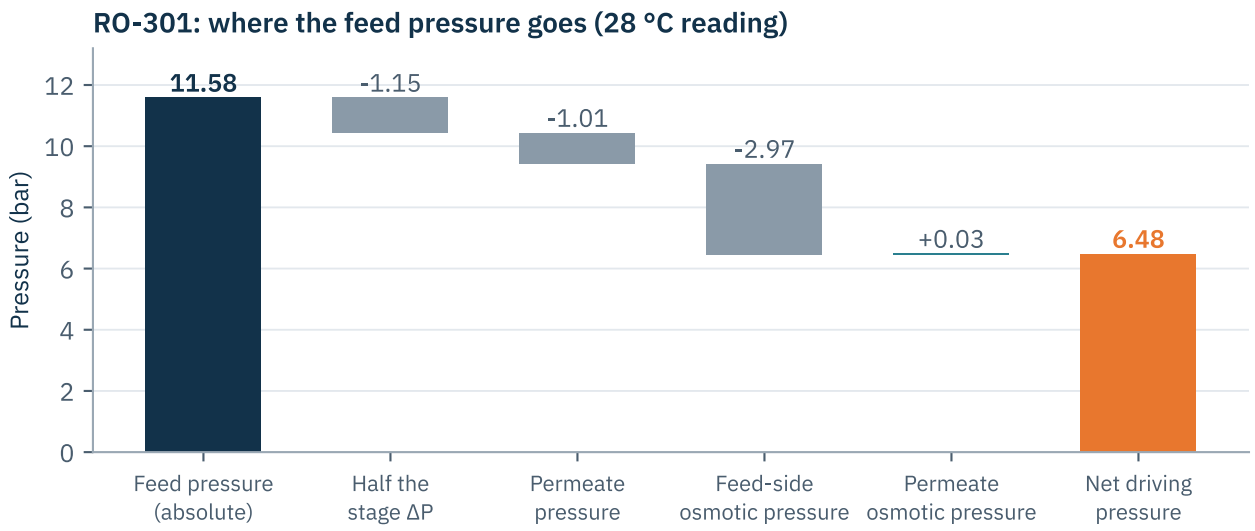


Figure 3.3 — Pressure budget of RO-301 (absolute pressures, bar). Only 6.48 bar of the 10.57 bar g feed pressure actually drives water through the membrane.

ENGINEER'S CALCULATION CORNER **Worked example: RO-301 performance from one log reading**

Reading: feed 150.0 m³/h (660 US gpm), permeate 112.6 m³/h, feed pressure 10.57 bar g (153 psig), total ΔP 2.30 bar, 28 °C, feed 3,100 µS/cm, permeate 62 µS/cm.

1. Recovery Y = 112.6 ÷ 150.0 = **75.07 %**.
2. Salinity (k = 0.65): feed 2,015 mg/L, permeate 40.3 mg/L. Rejection **98.00 %**.
3. Average feed-side salinity, using the log-mean form for salt that rises along the vessel: Cfc = Cf × ln[1 ÷ (1 − Y)] ÷ Y = **3,728 mg/L**.
4. Osmotic pressures (φ 0.93, 28 °C): πfc = **2.97 bar**, πp = 0.032 bar.
5. NDP = (10.57 + 1.013) − 1.15 − 1.013 − 2.97 + 0.032 = **6.48 bar (94.0 psi)**.
6. Flux = **21.02 L/m²·h**.
7. Feed pump: hydraulic power = 150 ÷ 3,600 × 10.57 × 100 = 44.0 kW; with 80 % pump and 94 % motor efficiency the electrical input is 58.6 kW, so the specific energy is 58.6 ÷ 112.6 = **0.52 kWh/m³** (1.97 kWh per 1,000 US gal).

The unit is making its design output. But is it healthy? A single reading cannot say — Chapter 4 compares it with the start-up baseline.

FIELD CHECK **RO daily checks**

What you see	What it may mean	First thing to check
Permeate flow down, feed pressure same	Colder water or fouling	Normalise for temperature (Chapter 4)
Permeate conductivity up	Scaling, membrane damage, O-ring leak, or higher feed salinity	Normalised salt passage; per-vessel conductivity
Stage 1 ΔP rising	Particle or biological fouling of feed spacers	Cartridge filter ΔP, SDI, biocide practice
Last stage ΔP rising	Scale forming where salt is strongest	Concentrate scaling index; antiscalant dose
Feed + permeate ≠ concentrate	A flow meter is wrong	Flow balance before any other calculation

3.8 Energy and energy recovery

The feed pump is the main energy user of an RO. Its power is roughly feed flow × feed pressure ÷ efficiency, so the specific energy rises with pressure and falls with recovery (less feed per m³ of permeate). For brackish water like RO-301 the specific energy is around half a kWh per m³; seawater units, which must beat about 27.6 bar of osmotic pressure, need several times more.

In seawater RO the concentrate leaves at high pressure, and an **energy recovery device** returns most of that pressure to the feed. Brackish units sometimes use a turbine or a booster between stages. The toolkit adds an optional recovered power term so you can see the effect on specific energy.

Three practical ways to save RO energy: keep the membranes clean (fouling raises the pressure needed), run the recovery the antiscalant allows, and use a variable-speed drive rather than a throttled pump discharge.

Watch out — never dead-head an RO

Closing the concentrate valve with the high-pressure pump running can over-pressure the vessels and crush elements. Follow the start-up and shutdown sequence in your operating procedure, and flush with permeate before long stops so concentrated brine does not sit in the elements.

TRY IT

A small RO takes 100 m³/h of feed at 2,000 mg/L and makes 72 m³/h of permeate at 30 mg/L. Work out the recovery, the rejection and the concentrate salinity. (Answer in Appendix F.)

FREE TOOLS **Do this chapter's calculation**

Free calculator
Cooling water chemistry and cycles calculator
plantcalckit.com/tools/cooling-water-chemistry/

Excel toolkit: Water Treatment and RO System Performance (USD 49)
plantcalckit.com/shop/water-treatment-and-ro-system-performance-excel/
Topics: Recovery and rejection · Net driving pressure · Normalised data · 12-reading log · Energy and scaling · What-if tables

QUICK QUIZ

1. Define recovery and give RO-301's value.
2. Why is salt passage a better trend number than rejection?
3. What happens to concentrate salinity as recovery rises?
4. Write the net driving pressure equation in words.
5. RO-301's flux is about 21 L/m²·h. What does flux tell you, and why does it matter?

APPENDIX G

Sources

Every chapter was written in our own words from the published references below. No text, tables or figures were copied; all diagrams and charts are original PlantCalcKit artwork, and the charts were computed from the worked examples. Where a method follows a code or standard, the calculation is aligned with the publicly documented method; that is not a claim that any result meets the code. Book citations give title, edition and chapter; method names (Darcy, Colebrook, Langelier and so on) are the usual names of published equations.

General (all chapters)

- *Perry's Chemical Engineers' Handbook* (Perry, Green and Maloney, eds), 7th ed., 1997 — sections 1 (conversion factors), 2 (physical and chemical data), 6 (fluid and particle dynamics), 10 (transport and storage of fluids, pumps), 11 (heat-transfer equipment, refrigeration, evaporators), 12 (psychrometry, evaporative cooling and solids drying), 18 (liquid–solid operations: agitation, jackets of agitated vessels, filtration), 22 (alternative separation processes, membranes).
- *Unit Operations of Chemical Engineering* (McCabe, Smith and Harriott), 7th ed. — ch. 5–6 (fluid flow), 9 (agitation), 15–16 (heat transfer, evaporation), 24 (drying), 30 (filtration).
- IAPWS-IF97 Industrial Formulation for the thermodynamic properties of water and steam (revised release 2007) — all water and steam properties.
- NIST Special Publication 811, *Guide for the Use of the International System of Units* — unit conversions.

Chapter 1 — Utilities and energy

- *Guide to Energy Management* (Capehart, Turner and Kennedy), 8th ed. — energy accounting and utility systems.
- *Elementary Principles of Chemical Processes* (Felder, Rousseau and Bullard), 4th ed., ch. 7 — energy balances in simple form.

Chapter 2 — Water basics

- *Standard Methods for the Examination of Water and Wastewater*, 23rd ed. — methods 2510 (conductivity), 2340 (hardness), 2320 (alkalinity), 2330 (calcium carbonate saturation).
- *Electrolyte Solutions* (Robinson and Stokes), 2nd ed. — osmotic coefficients of sodium chloride solutions.
- *Water Chemistry* (Snoeyink and Jenkins), 1980 — carbonate chemistry, ionic strength from TDS.

Chapter 3 — Reverse osmosis basics

- *Membrane Technology and Applications* (Baker), 3rd ed., ch. 2 and 5 — solution–diffusion transport, reverse osmosis, concentration along a module.
- Wijmans and Baker, "The solution–diffusion model: a review", *Journal of Membrane Science* 107 (1995) 1–21.
- ASTM D4516, *Standard Practice for Standardizing Reverse Osmosis Performance Data* — definitions of recovery, rejection and the average feed-concentrate salinity.

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