ImmersaEngineering

INDEPENDENT ENGINEERING REVIEW

Solvent recovery column T-2101 — process design basis, reboiler capability and relief system

Independent review of the design basis, the governing relief case, and the thermal capability of the reboiler circuit, ahead of equipment purchase.

DOCUMENT	**IE-REV-0412**
REVISION	Rev 0 — Issued for client review
DATE OF ISSUE	Specimen — no issue date
CLIENT	Specimen Client (Pty) Ltd — a fictitious entity
FACILITY	Solvent Recovery Unit — Specimen Project
PREPARED BY	ImmersaEngineering — independent review
DOCUMENTS REVIEWED	14
FINDINGS RAISED	6 (3 high · 2 medium · 1 low)

SPECIMEN DOCUMENT

Every entity, project, figure, drawing number and finding in this document is invented for the purpose of illustrating deliverable format and reasoning style. It describes no real facility and reproduces no client material of any kind. It is not engineering advice and must not be relied on for any purpose.

ImmersaEngineering is the independent engineering advisory division of Immersa Hub (Pty) Ltd, reg. 2026/463574/07, Pretoria, South Africa. info@immersaengineering.com · www.immersaengineering.com

Document control

REVISION HISTORY

REV	STATUS	DESCRIPTION	ISSUED
0	Issued for client review	First issue. Findings 01–06 raised against the document register in section 2.	Specimen
—	—	Rev 1 is issued after the client response, recording accept / reject / superseded against each finding.	—

DISTRIBUTION

RECIPIENT	PURPOSE
Client engineering manager	Action and disposition of findings
Client project manager	Programme and cost impact
Design contractor lead process engineer	Technical response, via the client

Priority below is a review-issue priority: it ranks what to resolve first and by when. It is not a risk rating — likelihood, exposure, owners, treatments and residual risk belong to the client's risk process, and section 12.3 records only the residual risk this review leaves behind. Distribution beyond the list above is controlled by the client. This review is prepared for the client named on the cover and for the purpose recorded in section 1 only.

FINDING PRIORITY USED IN THIS DOCUMENT

SEVERITY	MEANING	EXPECTED DISPOSITION
HIGH	Affects safety, statutory compliance, or the ability of the facility to meet its stated production or product-quality basis. Resolution is required before the affected equipment is purchased or before the design is frozen.	Resolve before the next gate
MEDIUM	Affects operability, maintainability, cost certainty or the defensibility of a design decision. Not expected to change equipment selection, but will change a document or a stated basis.	Resolve before detailed design
LOW	Consistency, traceability or documentation. Corrected at the next scheduled revision of the affected document.	Next document revision

Contents

1 Purpose, scope and limitations

1.1 Purpose

This review was commissioned to answer one bounded question ahead of a long-lead equipment purchase: **is the process design basis for column T-2101 and its reboiler circuit sufficient to support the stated production rate, and is the relief system sized against the governing case?**

The review is independent. Neither ImmersaEngineering nor any person contributing to this document holds an interest in the design contractor, in the equipment vendors under evaluation, or in the outcome of the purchase decision.

1.2 Scope

Included in scope:

- The process design basis, feed characterisation and product specifications for T-2101.
- Column and reboiler thermal capability against the stated feed rate and product specifications.
- Relief case identification, selection of the governing case, and the resulting required relief load.
- Line sizing for the reboiler circuit and the overhead system.
- Consistency between the mechanical datasheets, the P&ID and the design basis.

Excluded from scope, by agreement:

- Detailed mechanical design, vessel code calculation and fabrication drawings.
- Control system configuration, instrument specification and functional safety assessment (SIL determination is addressed separately).
- Civil, structural, electrical and layout design.
- Cost estimation and schedule, other than where a finding carries a stated cost or programme consequence.

1.3 Limitation

This review does not transfer or discharge the design responsibility of the client or of the design contractor, and does not constitute certification, approval or statutory sign-off. Section 12 states the basis on which the conclusions are held, and the residual risk that remains after the recommended actions.

2 Documents reviewed

Fourteen documents were provided. Each was reviewed at the revision listed. Findings are traceable to the document and revision in which they were identified.

DOCUMENT	REV	TITLE	FINDINGS
SP-BAS-001	C	Process design basis — Solvent Recovery Unit	01, 02
SP-PFD-101	B	Process flow diagram — recovery column and overheads	—
SP-HMB-101	B	Heat and material balance, cases 1 to 4	01
SP-PID-211	C	P&ID — column T-2101 and reboiler E-2103	04, 05
SP-PID-212	C	P&ID — overhead condenser and reflux drum	02
SP-CAL-044	A	Column hydraulic and tray loading calculation	—
SP-CAL-051	A	Reboiler thermal rating and circulation check	01, 06
SP-CAL-063	A	Relief load determination and PSV sizing	02
SP-CAL-070	A	Line sizing schedule — unit 21	03
SP-DST-2101	B	Datasheet — column T-2101	04
SP-DST-2103	B	Datasheet — reboiler E-2103	06
SP-DST-2104	A	Datasheet — overhead condenser E-2104	—
SP-LAB-018	—	Feed characterisation — laboratory analysis report	01
SP-SIM-101	—	Steady-state simulation model and convergence report	01

3 Basis of review and assumptions relied on

Every assumption relied on in reaching the conclusions is stated below, so that a reader may test it. Where an assumption is later shown to be wrong, the finding that depends on it is identified and can be reopened without re-reading the whole document.

3.1 Design conditions taken as given

PARAMETER	VALUE	SOURCE
Feed rate, design	12.5 t/h	SP-BAS-001 Rev C
Overheads product rate, design	8.6 t/h	SP-HMB-101 Rev B
Column top pressure	1.35 bar(a)	SP-BAS-001 Rev C
Column bottoms pressure	1.72 bar(a)	SP-CAL-044 Rev A
Bottoms temperature, design	141.0 °C	SP-HMB-101 Rev B
Reboiler duty required at design feed	2.24 MW	SP-CAL-051 Rev A
Reboiler purchased area margin	15 %	SP-DST-2103 Rev B
Heating medium	LP steam, 6.0 bar(a)	SP-BAS-001 Rev C
Heating medium saturation temperature	158.8 °C	Steam tables
Operating hours per annum	8 000 h	SP-BAS-001 Rev C

3.2 Assumptions relied on

NO.	ASSUMPTION	FINDINGS AFFECTED
A1	At fixed reflux ratio and fixed product specifications, reboiler duty scales approximately linearly with feed rate over the range considered (48 % to 100 % of design).	01
A2	The reboiler is thermosiphon-type with the process side boiling at close to constant temperature, so the effective temperature difference is adequately represented by the difference between steam saturation temperature and bottoms bubble point. **This assumption weakens as the correction is applied.** At 17 mol % heavy ends the bottoms is a wide-boiling mixture and the process-side temperature rises through the exchanger, so the effective mean difference is lower than the bubble-point estimate used here. The consequence quantified in section 6 is therefore optimistic, and the re-rate in action 4 must use an integral or caloric boiling curve rather than a single bubble point.	01, 06
A3	The overall heat transfer coefficient is unchanged between the design case and the degraded case. Any reduction from heavier fouling would worsen, never improve, the conclusion.	01, 06
A4	The heating medium supply pressure is firm at 6.0 bar(a) and cannot be raised without a change to the utility system outside this scope.	01
A5	The laboratory analysis SP-LAB-018 is representative of the feed the facility will receive in normal operation.	01
A6	The net contribution used to express production consequence in section 6 is a client-supplied planning figure and is used only to rank findings, not to value the project.	01
A7	No credit is taken for operator intervention in the relief scenarios evaluated in section 7.	02
A8	The heavies bleed shown on SP-PID-211 is the only outlet carrying heavy ends: the overheads specification excludes them and SP-HMB-101 shows no slipstream or secondary purge. If any further heavy-bearing outlet exists, the steady-state bottoms concentration falls in proportion and finding 01 must be requantified.	01, 06

3.3 Method

Each calculation identified in the register was re-performed independently rather than checked line by line, using the stated design conditions and physical property data, and the result compared with the submitted value. Where the independent result agreed within the tolerance stated in Appendix A, no finding was raised. Where it did not, the difference was traced to its cause before a finding was written.

Documents were reviewed against one another for consistency — datasheet against P&ID, P&ID against design basis, calculation against heat and material balance — because a defensible number recorded in an inconsistent document set still causes the wrong equipment to be purchased.

4 Summary of findings

Six findings are raised, three of them at high severity. They are ranked by consequence rather than by the order in which the documents were read. Three findings are raised at high severity. All three affect an equipment purchase and are recommended for resolution before the relevant purchase order is released.

FINDINGS RAISED	AFFECTING PURCHASE	MARGIN AT RISK	COST TO RESOLVE NOW
6	**3**	**R 69 m**	**R 1.8 m**
3 high · 2 medium · 1 low	Findings 01, 02 and 04	Per annum, finding 01	Incremental, at purchase

NO.	FINDING	SEVERITY	DOCUMENT	SECTION
01	The feed assay used as the design basis excludes heavy ends measured in the characterisation sample. The bottoms bubble point is consequently understated, and the reboiler cannot deliver the required duty at the design feed rate.	HIGH	SP-BAS-001 SP-CAL-051	5 and 6
02	The governing relief case has been taken as blocked outlet. Loss of overhead condensing at maximum reboiler duty produces a larger vapour load, and was not evaluated. The installed relief capacity is below the required load for that case.	HIGH	SP-CAL-063	7
03	The two-phase sizing method used for the reboiler return line is not stated, and the resulting momentum flux exceeds the limit normally applied to this service.	MED	SP-CAL-070	8
04	The relief valve set pressure shown on the P&ID exceeds the design pressure recorded on the column datasheet. No MAWP is stated, so the margin against the vessel's actual limit is unknown.	HIGH	SP-DST-2101 SP-PID-211	8
05	No isolation philosophy is recorded for the reboiler steam side, and the P&ID shows single-valve isolation at a point where entry is foreseeable.	LOW	SP-PID-211	9
06	The process-side fouling resistance selected for the reboiler is optimistic for a bottoms stream carrying heavy ends, and compounds finding 01.	MED	SP-DST-2103	9

THE SINGLE CONCLUSION, IF ONLY ONE IS READ

Findings 01 and 06 have the same root: the bottoms composition assumed in the design is lighter than the composition the facility will actually receive. Everything downstream of that assumption — bottoms temperature, available temperature difference, reboiler area, and therefore sustainable throughput — inherits the error. Correcting the assay and re-rating the reboiler *before* the purchase order is released costs an estimated **R 1.8 million** in incremental exchanger area. Discovering it after commissioning costs an estimated **R 14.2 million** in replacement and installation, a 21-day outage, and the production shortfall quantified in section 6 for every year the constraint remains.

DISPOSITION

Findings are not closed by ImmersaEngineering; they are closed by the client, and the record of that closure sits with the client. Rev 1 records the response against each finding using one of six states, because "closed" on its own hides the difference between a problem solved and a risk accepted: **resolved and independently verified** · **action implemented, not rechecked** · **risk or deviation accepted**, with the accepting authority named · **rejected**, with the technical basis · **superseded** by a document revision · **administratively closed**. Only the first is an engineering resolution.

5 Finding 01 — feed assay excludes heavy ends

FINDING 01 **The design basis feed composition omits components measured in the characterisation sample** HIGH

WHAT WAS OBSERVED

The feed composition tabulated in SP-BAS-001 Rev C contains six components and sums to 100.0 mol %. The laboratory characterisation report SP-LAB-018, from which that table is stated to be derived, reports eight components. Two heavy components present at a combined **0.40 mol %** appear in the laboratory report and do not appear in the design basis table. The simulation model SP-SIM-101 uses the six-component design basis composition.

The omission is not annotated. Nothing in the design basis, the heat and material balance or the simulation convergence report records that components were excluded, or on what grounds. The most likely explanation — that the heavy ends were judged negligible on a mass basis — is plausible, but it is the wrong test for this application.

WHY IT MATTERS

Heavy components entering a column concentrate in the bottoms, and they leave only by whatever route the design provides for removing them. SP-PID-211 shows a single heavies bleed of 383 kg/h off the bottoms circuit, and SP-HMB-101 shows no other heavy-bearing outlet: the overheads specification excludes them and there is no slipstream. At steady state, therefore, every mole of heavy ends entering with the feed must leave in that bleed. The balance is written on a molar basis, because the quantity that sets the bubble point is a mole fraction:

```
Basis   feed mass flow              F    = 12 500 kg/h
        feed average molar mass     M_F  =     88.65 g/mol
                                       (0.40 mol % heavy ends at 250 g/mol,
                                        balance recovered solvent at 88 g/mol)
        feed molar flow             F_n  = 12 500 / 88.65   =  141.0 kmol/h

        heavies bleed mass flow     P    =    383 kg/h      (SP-PID-211)
        bleed average molar mass    M_P  =    115.5 g/mol
                                       (17.0 mol % heavy ends at 250 g/mol,
                                        balance solvent at 88 g/mol)
        bleed molar flow            P_n  =    383 / 115.5   =    3.32 kmol/h

Component balance on heavy ends, MOLAR basis (assumption A8):

        F_n . z_h  =  P_n . x_h
        141.0 x 0.0040  =  3.32 x x_h
        x_h  =  0.564 / 3.32  =  17.0 mol % heavy ends in the bottoms

        Heavies in  = 0.564 kmol/h.   Heavies out = 0.564 kmol/h.   Closes.

The bleed is 2.35 % of feed on a molar basis, 3.1 % by mass. Halving it doubles the
steady-state concentration. SP-BAS-001 records the bleed rate but states no target
composition, no basis for its selection and no operating range.
```

A component present at 0.40 mol % in the feed therefore sits at 17 mol % in the bottoms — a molar concentration factor of forty-two and a half, not the factor of two or three that a reader assuming a simple mass split would expect. That concentration acts precisely where the temperature driving force is smallest, and it is the reason this finding is raised at high severity rather than as an observation on the assay alone.

Re-running the bubble point at the stated bottoms pressure of 1.72 bar(a) with the heavy ends restored gives:

```
Bottoms bubble point, six-component design basis   T_b  =  141.0 °C
Bottoms bubble point, eight-component measured    T_b' =  148.6 °C
Increase                                          ΔT_b =    7.6 K
```

The heating medium is fixed. LP steam at 6.0 bar(a) saturates at 158.8 °C, and assumption A4 records that this cannot be raised within the present scope. The available temperature difference across the reboiler is therefore not a design choice but a subtraction:

```
Design case      ΔT = 158.8 − 141.0 = 17.8 K
Corrected case   ΔT = 158.8 − 148.6 = 10.2 K
Retained fraction of the design driving force = 10.2 / 17.8 = 0.573
```

A 5.4 % shift in bottoms temperature removes **42.7 %** of the reboiler driving force. This is the characteristic behaviour of a low-approach reboiler and is the reason the finding is raised at high severity rather than as an observation: the sensitivity is not proportional, and it is not visible from the temperature figure alone.

WHAT FOLLOWS FROM IT

At constant overall heat transfer coefficient and constant area (assumptions A2 and A3), duty scales with the temperature difference. The purchased reboiler carries 15 % area margin over the 2.24 MW required at design feed:

```
Duty required at design feed rate      Q_r =                      2.24 MW
Installed capability at design ΔT      =  2.24 × 1.15       =  2.58 MW
Installed capability at corrected ΔT   =  2.58 × (10.2/17.8) =  1.48 MW
Sustainable feed rate (assumption A1)     =  1.48 / 2.24       = 66 % of design
```

On this basis the unit as currently specified would be reboiler-limited at approximately **66 % of nameplate feed rate** whenever the feed carries the heavy ends measured in SP-LAB-018. The column itself is not the constraint: the hydraulic calculation SP-CAL-044 shows tray loading within limits at 100 % feed, and no finding is raised against it.

The 66 % is a screening result, not a rating. Scaling duty with a single temperature difference at constant U and A is adequate to show that a constraint exists and roughly where it bites; it is not a thermosiphon rating, which depends on the boiling-side coefficient, the circulation ratio, the temperature profile through the exchanger, static head, pressure drop and vapour fraction. The figure should be read as “materially below nameplate, quantity to be confirmed” until action 4 is complete.

WHERE THIS COULD BE WRONG

If the laboratory sample is not representative — for example, if it was drawn from tankage that had stratified, or after an upstream upset — then assumption A5 fails and this finding falls away. That is the single test that would most efficiently resolve it, and it is recommended as action 1 in section 11: three further feed samples, drawn on separate days from the intended supply route, analysed for the full component slate. If the heavy ends are absent from all three, this finding is withdrawn at Rev 1 and no cost is incurred. A second and independent test is available at no cost at all: if the heavies bleed can be increased, the steady-state concentration falls in inverse proportion, and the constraint eases without buying any surface. Whether the downstream route can accept a larger bleed is a question for the client, and it is asked in section 11.1.

6 Finding 01 — consequence and sensitivity

The production consequence is expressed below across a range of heavy-ends concentrations, because the measured 0.40 mol % is a single sample and the true operating value is not yet known. The purpose of the range is to show at what concentration the finding stops mattering — which is the number the purchase decision actually turns on.

HEAVY ENDS IN FEED mol %	IN BOTTOMS AT STEADY STATE, MOL %	BOTTOMS BUBBLE POINT, °C	AVAILABLE ΔT, K	REBOILER CAPABILITY, MW	SUSTAINABLE THROUGHPUT	PRODUCT SHORTFALL T/A	MARGIN AT RISK R MILLION/A
0.00 design basis	0.0	141.0	17.80	2.58	100 %	–	–
0.15	6.4	143.7	15.12	2.19	98 %	1 510	4.5
0.28	11.9	146.2	12.64	1.83	82 %	12 548	37.0
0.40 measured	**17.0**	**148.6**	**10.20**	**1.48**	**66 %**	**23 369**	**68.9**
0.55	23.4	151.9	6.95	1.01	45 %	37 872	111.7

Product shortfall is the reduction in overheads product against the 8.6 t/h design rate over 8 000 operating hours. Margin at risk applies the client-supplied planning contribution of R 2 950 per tonne (assumption A6) and is used to rank findings, not to value the project. Steady-state bottoms concentrations assume the 294 kg/h heavies bleed shown on SP-PID-211 is unchanged. Bubble points are the independent check results recorded in Appendix A.

6.1 The shape of the sensitivity

The purchased 15 % area margin is exhausted when capability falls to the 2.24 MW required at design feed, which happens at an available temperature difference of 15.45 K — a bottoms bubble point of 143.4 °C, 5.6 mol % heavy ends in the bottoms, and **0.13 mol % in the feed**. That is one third of what was measured. Above it the loss becomes close to linear in concentration.

This is worth stating plainly because the margin was almost certainly selected as a general allowance for fouling and uncertainty, not as an allowance for a composition error. It is being consumed by the latter, and is consequently no longer available for the former. Finding 06 addresses what happens when fouling then takes what remains.

6.2 Cost of correcting at each stage

POINT OF CORRECTION	ACTION REQUIRED	ESTIMATED COST	OUTAGE
Now, before purchase order	Restore the assay, re-rate, and specify 52 % additional surface on the purchased exchanger (74 % on the un-margined design area) on the same enquiry	R 1.8 m	none
After purchase, before fabrication release	Vendor change order against a released design; re-issue of datasheet and nozzle schedule	R 4.6 m	none
After delivery, before commissioning	Second exchanger procured; piping and structural modification to suit	R 11.5 m	6 days
After commissioning	Replacement exchanger, piping modification, insulation and reinstatement, plus lost production for the period the constraint stands	R 14.2 m	21 days
Difference between correcting now and correcting after commissioning		**R 12.4 m**	**21 days**

Costs are order-of-magnitude screening figures in South African rand at a 2026 base date, ex-works plus installation at the project location, developed for ranking only and carrying an expected accuracy of roughly −30 % to +50 %. They are derived by factored comparison with recent exchanger and installation costs rather than by quotation, and they exclude the annual margin at risk tabulated above. Cost estimation is outside the scope of this review (section 1.2); the figures are provided so the finding can be prioritised, and should be replaced by the project estimate before any decision rests on them.

RECOMMENDATION, FINDING 01

Confirm the feed characterisation against three further samples before the purchase order is released. If the heavy ends are confirmed, restore the full component slate to SP-BAS-001 and SP-SIM-101, re-run the heat and material balance, and re-rate E-2103 against the corrected bottoms bubble point with the fouling resistance from finding 06 applied simultaneously. Specify the exchanger against the corrected duty rather than against the design duty plus a percentage. Separately, record a design basis for the heavies bleed: at present its rate is shown on the P&ID but no target concentration, no basis and no operating range is stated anywhere in the document set, and it is the bleed rather than the assay that sets the steady-state concentration.

7 Finding 02 — governing relief case

FINDING 02 **Loss of overhead condensing was not evaluated, and produces a larger relief load than the case selected** HIGH

WHAT WAS OBSERVED

SP-CAL-063 Rev A identifies four relief scenarios for T-2101 and selects blocked outlet on the overheads as governing, at a required relief load of 30 100 kg/h. Relief valve PSV-2101A is sized on that load.

Loss of overhead condensing — cooling water failure, or condenser fouling to the point of ineffectiveness — is listed in the scenario table but is marked *“not credible, covered by blocked outlet”*. No calculation supports that statement.

A reflux pump trip is listed alongside these as though it were the same event. It is not: the condenser continues to remove heat, the reflux drum inventory buys time, and the column response depends on the trip logic and the drum level. It needs its own causal sequence and a dynamic check, and it is raised here only to say that it has not had one.

WHY IT MATTERS

The two cases do not produce the same vapour load. Blocked outlet was evaluated at the design reboiler duty of 2.24 MW. Loss of condensing must be evaluated at the maximum duty the reboiler can physically deliver, which includes the purchased area margin, and with no credit for operator intervention (assumption A7):

```
Case selected  – blocked outlet, duty 2.24 MW, latent heat 268 kJ/kg (SP-SIM-101, at relieving conditions)
                 W = Q / lambda = 2.24e6 W / 268e3 J/kg = 8.36 kg/s
                 Required relief load = 8.36 x 3600            ≈ 30 100 kg/h

Case omitted   – loss of condensing, duty 2.58 MW (15 % area margin realised)
                 W = 2.58e6 / 268e3 = 9.63 kg/s
                 Required relief load = 9.63 x 3600            ≈ 34 660 kg/h

Installed capacity, PSV-2101A, sized on blocked outlet         ≈ 30 100 kg/h
Shortfall                                                      ≈  4 560 kg/h  (13 %)
```

The installed relief capacity is approximately **13 % below** the load required by the omitted case. The two cases differ because the reboiler margin that is unavailable for production under finding 01 remains entirely available for generating vapour during a relief event — the steam side does not know that the process side is constrained.

WHAT THIS CALCULATION IS, AND IS NOT

The figures above are a relief *load* screen. They establish that the case selected is not the governing case; they do not size a device. A calculation issued for construction would additionally state the relieving composition and properties, relieving temperature and pressure, the set pressure and accumulation case, superimposed and built-up backpressure, discharge and correction coefficients, the selected orifice and its certified capacity, inlet and outlet pressure losses, and the disposal-system constraint. None of that is within this scope, and the recommendation below asks the contractor to perform it rather than asserting a device size here.

The maximum duty available during relief is also not simply the purchased area margin. It depends on the steam supply and control valve, the exchanger UA at relieving conditions, the process composition, and the boiling temperature at the relieving pressure. The 2.58 MW used above is the installed capability at design conditions and is therefore an upper bound on the vapour generation rate, not a rated duty. The re-rate in action 4 should establish the actual figure.

INTERACTION WITH FINDING 01

If finding 01 is confirmed and the reboiler is enlarged, the relief load for this case rises again in proportion to the new installed duty. The two findings must therefore be resolved together and in that order. Sizing the relief valve against the present exchanger, and then enlarging the exchanger, would reproduce this finding in a new form.

SCENARIO	RELIEF LOAD, KG/H	STATUS IN SP-CAL-063	GOVERNING
Blocked outlet, overheads	30 100	Evaluated	Selected
Loss of overhead condensing, at maximum reboiler duty	34 660	Screened out without calculation	**Governs**
External fire, wetted area basis	25 900	Evaluated	—
Control valve failure open, feed side	12 400	Evaluated	—
Thermal expansion, blocked line	n/a	Evaluated, separate device	—

RECOMMENDATION, FINDING 02

Re-perform the relief load determination for loss of overhead condensing at the maximum duty the installed reboiler can deliver, without operator credit, and repeat it against the corrected exchanger from finding 01 once that re-rate is complete. Where a scenario is screened out, record the calculation or the reasoning that supports the exclusion in SP-CAL-063 rather than a statement alone — an unsupported exclusion is not reviewable, and is the mechanism by which this finding arose.

8 Findings 03 and 04

FINDING 03 **Two-phase sizing basis for the reboiler return line is unstated, and the resulting momentum flux is high** MED

WHAT WAS OBSERVED

The line sizing schedule SP-CAL-070 Rev A lists the reboiler return line 10-PR-2103 as DN 250, with a pressure drop figure but no statement of the two-phase method used. Homogeneous and slip-based methods give materially different answers for this service, and the schedule does not record which was applied, nor the vapour quality assumed.

WHY IT MATTERS

Back-calculating from the stated pressure drop and the heat and material balance gives a vapour mass fraction at the reboiler outlet of approximately 0.34. On that basis:

```
Vapour generated at 2.24 MW    W_v = 2.24e6 / 268e3      =  8.36 kg/s
At the back-calculated quality  W_t = 8.36 / 0.34         = 24.58 kg/s
DN 250 sch 40, ID 254.5 mm      A                         =  0.0509 m²
Mass flux                       G   = 24.58 / 0.0509      =    483 kg/(m²·s)
Two-phase density, homogeneous  ρ_m                       =   24.6 kg/m³
Mixture velocity                v   = G / ρ_m              =   19.7 m/s
Momentum flux                   ρv² = G² / ρ_m            =  9 490 kg/(m·s²)
Limit adopted for this service                            =  6 000 kg/(m·s²)
  source: client piping specification SP-BAS-001 Rev C, cl. 7.4, for
  two-phase thermosiphon return lines. This is a project criterion, not
  a code limit, and it is not the API RP 14E erosional criterion.
```

The calculated momentum flux is approximately 1.6 times the value normally applied as an upper limit for a two-phase line of this configuration. High momentum flux in a return line with two changes of direction upstream of the column nozzle is associated with flow-induced vibration and, over time, with erosion at the bends. Neither is a safety finding at this stage, and neither is certain — but the design as recorded gives no way to demonstrate that it has been considered.

This finding is raised at medium rather than high severity because the correction is a line size change made before piping is released, at low cost. It is raised at all because the omission is of the *basis*, not merely of a number: a reader cannot tell whether the line was sized correctly by a method that is not stated.

RECOMMENDATION

Record the two-phase method, the vapour quality and the momentum flux in SP-CAL-070, and review the line size against a momentum flux limit agreed for the service. Repeat once the reboiler duty is settled under finding 01, since the vapour quality changes with it.

FINDING 04 **Relief valve set pressure on the P&ID exceeds the design pressure on the column datasheet, and no MAWP is stated** HIGH

WHAT WAS OBSERVED

PARAMETER	VALUE	DOCUMENT
Column design pressure	3.5 bar(g)	SP-DST-2101 Rev B
PSV-2101A set pressure	3.8 bar(g)	SP-PID-211 Rev C
Difference	+0.3 bar	—

WHY IT MATTERS

A relief device set above the maximum allowable working pressure of the equipment it protects does not protect it. ASME BPVC VIII Div 1 UG-134 requires the set pressure of a single device not to exceed the MAWP, and API 520 Part I permits accumulation above that only during relief — 10 % for a non-fire contingency, 21 % for fire. At a set pressure of 3.8 bar(g) the relieving pressure with 10 % accumulation is 4.18 bar(g), which is 19 % above the 3.5 bar(g) recorded on the datasheet before any relief event has begun.

SP-DST-2101 records a design pressure but does not state a MAWP, and the two are not interchangeable: MAWP is established by the weakest pressure-containing component at the coincident temperature and is determined by the vessel manufacturer, whereas design pressure is a purchase requirement. Until the manufacturer confirms the MAWP, the size of this discrepancy is unknown, which is the reason it is raised at high severity rather than as a document inconsistency.

Which document is wrong determines the correction. If the datasheet governs, the set pressure must come down, the relief calculation is re-performed at the lower set pressure with the consequent loss of relieving capacity, and that loss compounds finding 02. If the P&ID governs, the vessel design pressure must rise, and wall thickness, nozzle ratings and flange class are all affected — which is an equipment-selection change, and therefore has to be settled before the vessel is purchased.

The discrepancy is recorded here rather than resolved, because resolving it is a client decision on the intended design pressure and not a review finding. It is noted that finding 02 requires SP-CAL-063 to be re-performed in any event, and the two corrections are best made in the same revision.

RECOMMENDATION

Obtain the MAWP from the vessel manufacturer, confirm the intended design pressure for T-2101, and check the set pressure plus accumulation against the MAWP rather than against the design pressure. Correct whichever document does not reflect the outcome and re-issue both at the same revision, so the inconsistency cannot survive in a partially updated document set.

9 Findings 05 and 06

FINDING 05 No isolation philosophy is recorded for the reboiler steam side

LOW

WHAT WAS OBSERVED

SP-PID-211 Rev C shows single-valve isolation on the steam supply and condensate return of E-2103. No isolation philosophy document was provided in the register, and the design basis does not state the standard applied for isolation of equipment requiring internal access.

WHY IT MATTERS

A shell-and-tube reboiler on a fouling service will require tube-side access during the life of the facility. Single-valve isolation between a live LP steam header and a vessel that a person may enter is a recognised hazard, and the remedy — positive isolation to the site hazardous-energy standard, which for vessel entry usually means a spade or physical disconnection rather than valves alone — is inexpensive at the P&ID stage and expensive after the pipework is installed.

This is raised at low severity because it is a documentation and P&ID correction at the present stage, not a design error in an executed installation. It is nevertheless recorded because it will not be found later by anyone reviewing calculations.

RECOMMENDATION

Record the isolation philosophy in the design basis, name the hazardous-energy isolation standard applied, state which method is required for entry as opposed to maintenance without entry, and reflect it on the P&ID for E-2103 and for any other equipment on the unit requiring internal access.

FINDING 06 Process-side fouling resistance is optimistic for a bottoms stream carrying heavy ends

MED

WHAT WAS OBSERVED

PARAMETER	SELECTED	SUGGESTED FOR REVIEW
Process-side fouling resistance	0.000 18 m²K/W	0.000 35 m²K/W
Steam-side fouling resistance	0.000 09 m²K/W	0.000 09 m²K/W unchanged
Effect on clean-condition capability	–	see note

The reduction cannot be quantified from the information in the document set: SP-DST-2103 states the fouling resistances but not the clean overall coefficient or the surface area, and the effect of a fouling increment depends on the other resistances in series. The re-rate in action 4 should report it. What can be said without those figures is the direction and that it compounds finding 01.

WHY IT MATTERS

The value selected in SP-DST-2103 Rev B corresponds to a clean organic liquid. The bottoms stream in question concentrates the heavy ends identified in finding 01 by a factor of forty-two and a half, at the highest temperature in the unit. That is the condition under which fouling is expected, and the selected value does not reflect it.

Taken alone, the effect is a further reduction in end-of-run capability, and it would be a routine comment. Taken together with finding 01 it is more serious: it consumes part of what remains of the 15 % purchased margin, and it does so progressively through the run, so the facility would meet its rate at start-up and lose it before the next turnaround. That pattern is difficult to diagnose in operation and is often attributed to the column rather than to the exchanger.

RECOMMENDATION

Re-select the process-side fouling resistance against the corrected bottoms composition, and apply it in the same re-rate performed for finding 01 rather than as a separate exercise. Where operating data for a comparable service is available, prefer it to a tabulated value, and record the source.

10 Observations carrying no action

The items below were examined and no finding is raised. They are recorded so that the boundary of the review is explicit: a reader can see what was looked at and found sound, not only what was found wanting. This is also the record that prevents the same ground being re-reviewed at the next gate.

NO.	ITEM EXAMINED	OUTCOME
O1	Column hydraulic and tray loading calculation, SP-CAL-044	Independently re-performed and reproduces within 3 %: jet flood 78 % and downcomer backup 41 % at design feed. **The endorsement is conditional.** Both results are computed on the six-component basis that finding 01 shows is wrong; at 17 mol % heavy ends the bottoms density, viscosity and surface tension all move, and so do the internal vapour and liquid loadings. Action 5 in section 11 requires this calculation to be re-performed before column internals are purchased. No finding is raised against the method, which is sound.
O2	Overall mass balance closure across the unit	Closes to 0.06 %. No action.
O3	Energy balance closure, cases 1 to 4	Closes to 0.4 % on the worst case. Acceptable for this stage.
O4	Thermodynamic model selection in SP-SIM-101	Appropriate for the component slate and pressure range. Binary interaction parameters are from a regressed set and the source is recorded.
O5	Simulation convergence and tolerance	Converged, tolerances tightened from default, residuals reported. Well documented.
O6	Materials selection for the column shell and internals	Consistent with the process conditions and with the material selections recorded in the design basis. The corrosion assessment those selections cite was not provided and is not in the register at section 2, so this endorsement covers internal consistency only, not the corrosion basis itself.
O7	Overhead condenser E-2104 thermal rating	Adequate at design duty with margin. Note that finding 01, if confirmed and corrected by enlarging the reboiler, will require this rating to be revisited.
O8	Units, significant figures and cross-references within the calculation set	Consistent throughout. Notably better than typical at this stage.
O9	Feed control and level control philosophy as shown on the P&IDs	Conventional and appropriate. Detailed control review is outside this scope.

ON THE QUALITY OF THE DOCUMENT SET

The calculation set is well ordered, internally cross-referenced and, with the exception of finding 03, states its methods. The findings raised in this review are not the product of careless work. Finding 01 in particular is the kind of error that is almost invisible from inside a project: the assay was simplified once, early, for a defensible reason, and every document downstream inherited it consistently. Consistency is precisely what makes it hard to see from within, and is the reason an independent pass is worth commissioning at this point rather than later.

11 Recommended actions and sequence

The actions below are sequenced rather than listed, because several depend on the outcome of the one before. Action 1 is inexpensive and may remove actions 2 to 5 entirely.

NO.	ACTION	FINDING	BEFORE	DEPENDS ON
1	Draw and analyse three further feed samples on separate days, from the intended supply route, against the full component slate.	01	Purchase order release	—
2	If heavy ends are confirmed, restore the full component slate to SP-BAS-001 and SP-SIM-101 and re-run the heat and material balance.	01	Purchase order release	1
3	Re-select the process-side fouling resistance against the corrected bottoms composition.	06	Re-rate	2
4	Re-rate E-2103 against the corrected bubble point and the corrected fouling resistance together, and specify against the corrected duty.	01, 06	Purchase order release	2, 3
5	Re-perform the column hydraulic and tray loading calculation against the corrected bottoms composition and physical properties.	O1	Internals purchase	2
6	Re-perform the relief load determination for loss of overhead condensing at maximum installed reboiler duty, with no operator credit.	02	PSV purchase	4
7	Obtain the vessel MAWP, check set pressure plus accumulation against it, and correct whichever of the datasheet or P&ID does not reflect the intended basis.	04	Vessel purchase	—
8	Record the two-phase method, vapour quality and momentum flux for 10-PR-2103, and review the line size.	03	Piping release	4
9	Record the isolation philosophy in the design basis and reflect it on the P&IDs.	05	P&ID issue for design	—
10	Revisit the E-2104 rating if the reboiler duty is increased.	O7	Purchase order release	4

11.1 What would change the conclusions

Four outcomes would materially change this review, and each is testable:

- **The feed samples come back clean.** Assumption A5 fails, findings 01 and 06 are withdrawn at Rev 1, the conditional endorsement in O1 becomes unconditional,, and only findings 02 to 05 remain. Finding 02 stands regardless, because the omitted scenario exists whatever the feed contains. Its magnitude does not: the required relief load must be recomputed against whatever maximum duty the corrected exchanger can deliver, which is why action 6 depends on action 4.
- **A higher-pressure heating medium is available.** Assumption A4 fails. Raising the steam supply to 9.0 bar(a) would restore the temperature difference without additional exchanger area. It is not free: it requires the utility system to have the capacity and pressure, and it brings the steam side into a higher design-pressure regime with consequences for the exchanger, the control valve, the condensate system and the steam-side relief. Whether it is available is a utility question outside this scope; whether it is cheaper is a question the re-rate should answer. It is worth establishing before action 4 rather than after.
- **The heavies bleed can be increased.** The steady-state bottoms concentration is inversely proportional to the bleed rate, so doubling it from 294 to 588 kg/h halves the concentration to 8.5 mol % and recovers most of the temperature difference — for the cost of the product lost in the bleed, not the cost of an exchanger. Whether the downstream route can accept it is a client question, and it should be established before action 4.
- **The bottoms specification can be relaxed.** The bubble point is set by the required bottoms purity. If a higher light-key content in the bottoms is commercially acceptable, the required bubble point falls and part of the temperature difference returns. This is a client commercial decision, not an engineering one, and is noted only because it is a lever that exists.

11.2 Suggested re-review point

A short confirmatory review of the corrected documents — the re-run balance, the re-rate and the revised relief calculation — is recommended before the purchase order is released. That is a bounded piece of work against a defined document set and does not require the present review to be repeated.

12 Basis of advice, limitations and residual risk

12.1 Basis

This review has been prepared for the client named on the cover, and for the purpose recorded in section 1.1. It is based on the fourteen documents listed in section 2 at the revisions stated, and on the assumptions listed in section 3.2. It does not extend to material not provided, and no site visit, operating data review or vendor engagement formed part of it.

12.2 Limitations

- The review does not transfer or discharge the design, construction or statutory responsibilities of the client or of the client's contractors.
- It does not constitute certification, approval, or statutory sign-off, and no such sign-off is offered or implied. Where certification is required it is arranged separately and identified in writing beforehand.
- Findings are raised against the documents as they stood at the revisions listed. Later revisions may resolve, alter or introduce findings and are not covered.
- The cost figures in section 6.2 are order-of-magnitude figures developed to rank findings. Cost estimation is excluded from scope and these figures should be replaced by the project estimate before any decision rests on them.
- Findings do not expire. Revalidation is required at twelve months, or on any change to the source documents, the process, the feed, the operating envelope or the applicable code edition, whichever occurs first. An unresolved finding remains unresolved until it is dispositioned by the client.

12.3 Residual risk after the recommended actions

RESIDUAL RISK	WHY IT REMAINS	RATING
Feed composition varies beyond the range sampled	Three samples characterise the intended supply route, not every future supply. A composition envelope, rather than a point value, would be the more durable basis.	MED
Fouling behaviour differs from the selected resistance	No operating data exists for this specific service. The revised value is a considered selection, not a measurement.	MED
Relief scenarios beyond the five tabulated	The scenario set was reviewed as presented and one omission identified. A full hazard study, which is outside this scope, is the appropriate means of confirming the set is complete.	MED
Control and trip functions relied on in operation	Excluded from scope. Assumption A7 takes no credit for intervention, so this review is not sensitive to it, but the facility will be.	LOW
Documents not provided for review	The register in section 2 is what was supplied. Anything outside it is unexamined.	LOW

12.4 Confidentiality

All material supplied for this review is held under the mutual non-disclosure agreement executed before the engagement began, on systems dedicated to review work and separate from any other business. Documents supplied are returned or destroyed at close-out and the destruction is confirmed in writing. No client name, project name, figure or document is reproduced in any marketing, reference or example material, in any form, whether identified or not.

Prepared by — ImmersaEngineering
Independent review. Signature withheld in this specimen.

Checked by — ImmersaEngineering
Independent check. Signature withheld in this specimen.

SPECIMEN DOCUMENT

Every entity, project, document number, figure and finding in this document is invented to illustrate deliverable format and reasoning style. It describes no real facility, reproduces no client material, and is not engineering advice.

Appendix A — independent check calculation extract

The extract below records the two checks on which finding 01 rests, at the level of detail needed for a reader to reproduce them. The full check set is issued as a separate calculation file with the review.

A.1 Bottoms bubble point, corrected composition

```
Basis       bottoms pressure          P   = 1.72 bar(a)
            feed mass flow            F   = 12 500 kg/h
            feed molar mass           M_F = 88.65 g/mol   (0.40 mol % at 250,
                                                           balance at 88)
            feed molar flow           F_n = 141.0 kmol/h
            heavies bleed             P_b = 383 kg/h      (SP-PID-211)
            bleed molar mass          M_P = 115.5 g/mol
            bleed molar flow          P_n = 3.32 kmol/h
            heavy ends in feed        z_h = 0.40 mol %    (SP-LAB-018)

            The bleed is the only heavy-bearing outlet (assumption A8), so at
            steady state the molar component balance gives

                F_n . z_h = P_n . x_h
                141.0 x 0.0040 = 3.32 x x_h
                x_h = 17.0 mol % in the bottoms

            Cross-check as a plausibility bound.  For a heavy end of negligible
            volatility in an IDEAL solution, Raoult with Clausius-Clapeyron gives

                dT_b = (R.T^2 / dHvap) . ln(1 / (1 - x_h))
                     = (8.314 x 414.15^2 / 35 000) x ln(1 / 0.830)
                     = 40.74 x 0.1863  =  7.59 K

            which agrees with the full bubble-point solution below.  This is a
            PLAUSIBILITY CHECK, not a bound: activity coefficients above unity,
            association, or finite heavy-component volatility can move the result
            in either direction, and the 35 kJ/mol latent heat is a representative
            value for the solvent rather than a measured property of an identified
            controlling component.  At 1 mol % the same expression gives 0.41 K, so
            it is the accumulation and not the feed concentration that makes this
            finding material.
```

A.2 Reboiler capability at the corrected bubble point

```
Basis       steam saturation temperature   T_s = 158.8 °C at 6.0 bar(a)
            duty required at design feed   Q_r = 2.24 MW
            purchased area margin                = 15 %
            installed capability at design ΔT   = 2.24 × 1.15 = 2.58 MW

Method      Q = U · A · ΔT with U and A held constant (assumptions A2, A3),
            so capability scales directly with the temperature difference.

            ΔT_design    = 158.8 - 141.0 = 17.8 K
            ΔT_corrected = 158.8 - 148.6 = 10.2 K

Result      capability, corrected = 2.58 × (10.2 / 17.8) = 1.48 MW
            sustainable feed rate = 1.48 / 2.24           = 65.9 %
                                                           ≈ 66 % of design

Sensitivity a ± 1.0 K uncertainty on T_b' moves the sustainable feed rate
            between 60 % and 72 %.  The conclusion — that the unit is
            reboiler-limited well below nameplate — holds across that band,
            which is why the finding does not depend on the precision of T_b'.

Not checked circulation stability of the thermosiphon at the reduced driving
            force.  This is noted for the re-rate: at 10.2 K the circulation
            ratio should be confirmed rather than assumed.
```

A.3 Tolerances applied in this review

QUANTITY	AGREEMENT ACCEPTED WITHIN
Temperature	± 1.0 K
Duty and heat load	± 3 %
Relief load	± 5 %
Line pressure drop	± 10 %
Mass and energy balance closure	± 0.5 %

A difference inside the stated tolerance is not reported as a finding. A difference outside it is traced to its cause before a finding is written, so that the finding describes the cause and not the discrepancy.

A.4 Reproducing these checks

The two checks above are reproducible *by a reader holding the source documents listed in section 2* together with the check calculation issued separately with this review. They are not reproducible from this extract alone: the component slate, the full compositions, the thermodynamic model and its interaction parameters, and the exchanger rating basis live in those documents and are not restated here. Nothing proprietary to any vendor, and no correlation outside open literature, was used. The intent is that the client's own engineers, or the design contractor, can repeat the work and reach their own conclusion rather than accept this one.

INPUT REQUIRED	SOURCE USED, AND WHAT AN INDEPENDENT REPEAT WOULD NEED
Component slate and feed composition	SP-LAB-018 as reported, all eight components, mole basis
Thermodynamic model and parameters	As selected in SP-SIM-101, unchanged, so that composition is the only variable between the two bubble point results
Bottoms pressure and draw rate	SP-CAL-044 Rev A and SP-HMB-101 Rev B
Steam saturation temperature	Standard steam tables at the stated supply pressure
Reboiler duty, area margin	SP-CAL-051 Rev A and SP-DST-2103 Rev B

Where a repeat produces a materially different result, the difference is of more interest than either result on its own, and is the appropriate subject of the response at Rev 1.

END OF SPECIMEN DOCUMENT

This document illustrates the format, structure and reasoning style of an ImmersaEngineering review deliverable. It is entirely invented. Actual engagements are scoped to the client's document set and the deliverable is sized to the question — a single calculation may be answered in three pages, and a full design package may run considerably longer than this.