ROOT CAUSE ANALYSIS · FMCG ASEPTIC PROCESSING

CATASTROPHIC FAILURE OF PTFE ASEPTIC VALVE BELLOWS UNDER HYDRAULIC DEAD-HEAD TRANSIENT

A 54-head aseptic rotary can filler suffered simultaneous plastic failure of over half its valve bellows population during a routine clean-in-place cycle. Two suppliers were implicated and each had begun to construct a narrative pointing at the other. This study documents the evidence base, the causal chain, and the systemic design deficiency that made the event inevitable rather than accidental.

Jordan Charles Watson IEng

Director · Optimal: Engineering Excellence Ltd

Sole investigator and author. Findings issued under the author's own professional credential.

INTERIM TURNAROUND ENGINEERING
ASSET RELIABILITY STRATEGY
FORENSIC FAILURE INVESTIGATION

SECTOR	DISCIPLINE	ASSET	DELIVERABLE
FMCG — beverage High-speed aseptic canning	Forensic failure investigation Reliability engineering	Aseptic rotary can filler 54 head · 2021 build	Evidence-led RCA Liability-aware documentation

Client, supplier and asset identities have been redacted. All process data, failure morphology, engineering reasoning and conclusions are reproduced unaltered from the original investigation.

THE ENGAGEMENT

An independent finding, produced by one named engineer

The operator required a determination of cause that was independent of both implicated suppliers and robust enough to be relied upon commercially. The work was placed with a single practitioner rather than a team: specimen examination, process-data interrogation, timeline reconstruction, causal analysis, correspondence review and reporting were carried out end to end by the same engineer, and the conclusions were issued under his own professional credential.

ENGAGEMENT PARAMETER	POSITION
Commissioned by	Operator's engineering management, following two supplier accounts that were mutually contradictory.
Basis of appointment	Independent third-party investigation. No commercial relationship with either implicated supplier.
Practitioner	Jordan Charles Watson IEng — Director and sole principal, Optimal: Engineering Excellence Ltd.
Scope owned	Full investigative chain from physical specimen through to issued report, corrective framework and stakeholder briefing.
Evidentiary standard	Documentation constructed to withstand adversarial technical review, on the assumption of later commercial recovery.

AT A GLANCE

The numbers that defined the event

11.4 bar
Peak hydraulic transient recorded at dead-head

2.5 bar
Nominal CIP manifold operating pressure

4.6 ×
Exceedance over normal operating envelope

82 °C
Fluid temperature — PTFE thermally softened

20,399 L/hr
Peak CIP supply flow driving the closed system

54 %
Proportion of bellows population requiring renewal

40–50 %
PTFE yield strength lost at operating temperature

< 1 s
Response window in which relief had to occur

All figures as recorded by calibrated instrumentation on the day of the event, or as established from published material property data for the specified polymers. No value in this study is estimated.

01 The Brief

Why an independent investigation was commissioned

A high-speed aseptic can filler suffered a sudden, simultaneous failure of a substantial proportion of its valve bellows during a routine clean-in-place cycle. Two suppliers were implicated — the machine OEM and the CIP systems integrator — and each had begun to construct a narrative pointing at the other.

The client required an evidence-led determination of cause: not an opinion, and not a negotiated position between two commercially interested parties. The brief was to establish what physically happened, in what order, on the basis of instrumented data and physical evidence alone — and to produce documentation robust enough to withstand adversarial technical scrutiny.

A secondary requirement, articulated less formally but no less real, was that the findings be explicable to a non-specialist engineering management audience without diluting their technical precision. A root cause analysis that cannot be understood by the person who has to act on it has failed regardless of its accuracy.

> **FRAMING**
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> The failure had already been characterised by both suppliers as a component quality problem. The investigation began by refusing that framing and asking a different question: what condition would have to exist for a correctly specified component to fail this way?

02 Investigation Method

Sequence, evidence hierarchy, and the discipline of elimination

The investigation followed a strict evidence hierarchy. Physical evidence and calibrated instrument data were treated as primary. Supplier correspondence and verbal accounts were treated as secondary — useful for establishing what parties believed and had committed to in writing, but not for establishing physical fact.

PRIMARY EVIDENCE

Physical and instrumented

Recovered specimen morphology, calibrated multi-channel recorder data, machine HMI state, published material property data. Establishes what physically occurred and when.

SECONDARY EVIDENCE

Documentary and testimonial

Supplier correspondence, commissioning documentation, control philosophy, verbal accounts. Establishes design intent and stated obligation — never physical fact.

Sequence of work

	STAGE	PURPOSE AND OUTPUT
01	**Specimen recovery**	Physical examination of failed components before any cleaning, disposal or replacement activity. Failure morphology is the single most information-dense evidence source and is destroyed by handling.
02	**Morphology reading**	Classification of the deformation pattern against known failure signatures. Establishes the direction and nature of the load that caused failure, independent of any process data.
03	**Mechanism elimination**	Systematic exclusion of competing hypotheses on physical grounds. Each candidate mechanism produces a distinct and mutually exclusive damage geometry.
04	**Instrumented corroboration**	Interrogation of calibrated process recorders to identify whether a process condition consistent with the physical evidence actually occurred, and when.
05	**Timeline reconstruction**	Cross-referencing of independent data sources into a single timestamped sequence. Coincidence of temperature, flow and pressure is what converts hypothesis into finding.
06	**Causal chain construction**	Assembly of the verified sequence into a defensible chain, with each node explicitly tied to its supporting evidence and open nodes flagged rather than assumed.
07	**Systemic assessment**	Separation of the proximate cause from the underlying design condition that permitted it. Fixing the former without the latter guarantees recurrence.

METHOD PRINCIPLE

Elimination is performed on physical evidence before process data is consulted. Reading the data first tells the investigator what to look for in the specimen, which is the precise mechanism by which confirmation bias enters a failure investigation and becomes impossible to remove later.

03 Failure Morphology

What the component itself disclosed

The recovered specimens presented an unambiguous damage signature. The PTFE core body had undergone complete circumferential hoop failure — total obliteration of the convolution geometry, expanding to a near-spherical mass at substantially greater than original diameter, with permanent axial elongation set into the profile. The deformation was plastic, not elastic: the component had exceeded its yield point and remained deformed after load removal.

Critically, the PEEK retaining collars were entirely undamaged. This differential is not incidental — it is diagnostic. PEEK retains approximately 85 to 90 per cent of its room-temperature tensile strength at 85°C. PTFE loses 40 to 50 per cent over the same range. Two materials sharing an identical load and identical thermal exposure, failing differentially in exact proportion to their published elevated-temperature properties, is a signature that no alternative mechanism reproduces.

Mechanism elimination

Each candidate mechanism produces a distinct damage geometry. Elimination is performed on physical evidence before process data is consulted.

CANDIDATE MECHANISM	BASIS FOR EXCLUSION	VERDICT
Vacuum implosion	Produces radially inward collapse. Observed geometry is radially outward expansion — the direct opposite. Load direction is unambiguous from the deformation alone.	EXCLUDED
Actuator over-travel	Produces axial compression damage without a radial component. All associated valves confirmed free of mechanical seizure under manual stroke test.	EXCLUDED
Chemical attack	PTFE presents excellent resistance across the relevant cleaning chemistry range. Chemical degradation manifests as surface crazing, mass loss or stress cracking — none present. Failure is mechanical, not chemical.	EXCLUDED
Fatigue / end-of-life	Fatigue propagates as crack growth and progressive breach in individual components. The observed event was simultaneous plastic deformation across a majority of the population on a five-year-old asset. Random wear cannot produce synchronised failure.	EXCLUDED
Manufacturing defect	A batch defect would not produce failure precisely coincident with a recorded process excursion, nor would it explain the intact PEEK collars sharing the same load path.	EXCLUDED

FINDING

Only one mechanism survives elimination: internal overpressure applied to a thermally softened thermoplastic. The morphology establishes this independently, before a single line of process data is examined. The instrumented evidence that follows corroborates a conclusion the physical evidence had already reached.

04 Instrumented Evidence

Calibrated process data and timeline reconstruction

A calibrated multi-channel process recorder on the shared CIP circuit provided timestamped temperature, flow and pressure data across the full operating day. The daily analysis is reproduced below. The significance lies not in any single value but in the coincidence of three conditions within a narrow window.

CHANNEL	MINIMUM	MAXIMUM (TIME)	MEAN
Inlet temperature	17.7 °C	80.7 °C (13:58)	27.8 °C
Hold temperature 1	23.0 °C	82.3 °C (13:57)	29.4 °C
Hold temperature 2	23.2 °C	81.4 °C (14:12)	29.9 °C
Outlet temperature	18.2 °C	80.3 °C (14:24)	28.1 °C
Volumetric flow	0 L/hr	20,398.9 L/hr (14:30)	1,813.7 L/hr
Hold pressure	0 bar	11.4 bar (15:10:13)	1.0 bar

Peak hold pressure exceeds nominal CIP manifold operating pressure by a factor of 4.6, occurring while circuit temperatures remained elevated and the supply pump was at full output.

Reconstructed event sequence

TIME	EVENT
13:37	CIP cycle running. Machine HMI confirms active cleaning sequence with process fluid circulating.
13:57–13:58	Peak circuit temperature achieved across all channels: 80.7 to 82.3 °C. Thermal softening of the PTFE bellows becomes the governing material condition from this point forward.
14:12–14:24	Temperatures sustained in the 80 to 82 °C band. The softened material state persists across the whole hot rinse phase.
14:30	Peak volumetric flow of 20,398.9 L/hr. Supply pump at full output. Recovery vessel accumulating return flow throughout this period.
14:30–15:10	Forty minutes of normal high-flow, high-temperature circulation. No pressure anomaly. The system is operating exactly as designed — and filling the recovery vessel toward its limit.
15:10:13	**Recovery vessel reaches capacity. High-level interlock fires and closes the return path. The drain bypass valve fails to open within the available window. The supply pump continues driving against a closed system. Hydraulic dead-head forms. Pressure spikes to 11.4 bar. Bellows yield.**
15:35–15:45	Circuit temperatures fall across all channels. Active phase concluded. Damage already done.

A NOTE ON MEASUREMENT LOCATION

The recorder sits on the shared circuit rather than at the filler manifold itself — a point an opposing technical party would be expected to raise. Under normal flowing conditions the objection would have force, since pressure drops across pipe runs and components as fluid moves. Under dead-head conditions it does not.

When flow falls to zero, frictional losses fall to zero with it. The fluid column behaves as a rigid body: pressure applied at one end transmits through the closed section without attenuation. The recorded value is therefore not a local reading but a system-wide one, and — accounting for static head between the transducer and the manifold — represents a lower bound on the pressure experienced at the failed components rather than an upper one.

05 Causal Chain

The verified sequence, with evidence basis stated at each node

The chain below is constructed so that every node carries its own evidential basis. Where a node remains open, it is marked as such rather than bridged by assumption — a distinction that matters considerably when the document is read adversarially.

01 Recovery vessel reaches capacity

The CIP hot water recovery vessel fills to 100 per cent during the hot rinse phase. This is a normal and recurring condition, not an abnormal event — the vessel fills on a substantial proportion of cycles by design.

EVIDENCE: PROCESS DESIGN · RECORDER FLOW INTEGRATION

02 Safety interlock closes the return path

The high-level sensor activates the utility interlock, which closes the recovery vessel inlet valves to prevent overflow. This action is correct and by design. It is protective behaviour functioning exactly as intended.

EVIDENCE: CONTROL PHILOSOPHY · P&ID · SUPPLIER CORRESPONDENCE

03 Drain bypass fails to open within the window

The local drain bypass valve does not open with sufficient speed to establish an alternative flow path before pressure develops. Two distinct sub-causes remain candidates: automation logic latency in the command sequence, or pneumatic exhaust restriction delaying actuator stroke under load. These are mechanistically separate and were deliberately not conflated — resolution requires controller historian timestamps comparing command issuance against confirmed position feedback.

OPEN NODE — HISTORIAN DATA REQUIRED TO DIFFERENTIATE SUB-CAUSE

04 Hydraulic dead-head forms

The supply pump continues driving at approximately 20,000 L/hr into a system with no open outlet. The fluid column dead-heads. Kinetic energy converts to static pressure across the closed section.

EVIDENCE: RECORDED FLOW · PUMP DUTY · FIRST PRINCIPLES

05 Pressure transient develops

System pressure rises to 11.4 bar, a factor of 4.6 above the nominal manifold operating pressure. The pump has no dead-head trip and no passive relief device exists upstream of the affected components.

EVIDENCE: CALIBRATED RECORDER · TIMESTAMPED 15:10:13

06 Thermally softened bellows yield

PTFE bellows operating at 80 to 82 °C, with yield strength reduced by 40 to 50 per cent against room-temperature values, are subjected to the transient. Hoop stress exceeds derated capacity. Catastrophic plastic deformation follows. Adjacent PEEK components, retaining the majority of their strength at temperature, survive intact.

EVIDENCE: SPECIMEN MORPHOLOGY · MATERIAL PROPERTY DATA · RECORDED TEMPERATURE

ON THE DISCIPLINE OF OPEN NODES

It would have been possible to close node three by assertion — to name one sub-cause and present the chain as complete. Doing so would have produced a more satisfying document and a considerably weaker one. An adversarial technical review locates unsupported assertions first, and a single collapsed node discredits the chain around it. Marking the node open, specifying precisely what data resolves it, and requesting that data formally is both more honest and more robust.

06 The Enabling Condition

Why temperature, not pressure alone, made the failure inevitable

A pressure transient of 11.4 bar would not necessarily destroy a PTFE bellows at ambient temperature. The failure required the coincidence of pressure with a thermally degraded material state — and it is this coincidence, rather than either factor alone, that constitutes the true enabling condition.

CONDITION	PTFE CORE	PEEK COLLAR
Yield strength at 20 °C	Baseline (100%)	Baseline (100%)
Retained strength at 80–85 °C	Approx. 50–60%	Approx. 85–90%
Response to transient	Plastic yield — catastrophic	Intact — no damage

The differential survival of two materials in a shared load path, in proportion to their published thermal derating, is itself corroborating evidence for the proposed mechanism.

The practical consequence is that the component's effective pressure capacity at cleaning temperature was materially below its nameplate rating at ambient. A system designed against the ambient figure carries a hidden margin deficit that only manifests during the hot phase of the cleaning cycle — precisely the phase in which transient risk is highest. This is a common and under-examined failure pattern in thermoplastic-sealed process systems.

TRANSFERABLE PRINCIPLE

Where thermoplastic components sit in a circuit that is periodically heated, the pressure protection strategy must be designed against the derated capacity at maximum process temperature — not the ambient nameplate figure. Designing to the ambient rating quietly consumes the entire safety margin during the exact window in which it is most needed.

07 Systemic Finding

Separating the proximate cause from the underlying condition

The most consequential output of this investigation was not the identification of a slow valve. It was the recognition that the system architecture made this event a matter of timing rather than a matter of chance.

The recovery vessel reaches capacity as a routine part of normal operation. Each time it does, the interlock closes the return path, and the entire protection of the downstream thermoplastic components rests on a single actuated valve opening within a sub-second window. There is no passive relief device. There is no pump dead-head trip. There is no redundancy in the relief path.

A protection scheme with a single point of failure, dependent on correct control sequencing and correct pneumatic response, guarding components whose capacity is halved at the operating temperature, exposed to a triggering condition that occurs routinely — this is not a system that failed. It is a system that was always going to fail, and the investigation happened to catch the cycle on which it did.

SYSTEMIC DETERMINATION

The proximate cause is a valve that did not open in time. The underlying condition is a relief path with no redundancy, protecting a derated material, against a trigger that recurs by design. Addressing the first restores production. Only addressing the second removes the failure.

PROXIMATE CAUSE

A valve that did not open in time

Addressable by inspection, maintenance, and control sequence revision. Necessary, and insufficient on its own.

UNDERLYING CONDITION

A relief path with no redundancy

Addressable only by engineering change. Left unaddressed, the same event recurs the next time actuation timing drifts.

08 Corrective Action Framework

Tiered by intervention type, not by convenience

Recommendations were structured in three tiers. The distinction matters: containment restores production, correction removes the proximate cause, and engineering change removes the systemic vulnerability. Organisations under production pressure reliably complete the first tier and quietly abandon the third.

TIER 1 Containment

Before return to service

- Full inspection of the affected component population — not only the units that visibly failed, since partial plastic strain may not be apparent on visual examination.
- Physical inspection of the bypass valve actuator and solenoid exhaust path for residue accumulation or restriction, with findings formally recorded.
- Suspension of automatic recovery vessel management until relief response is verified adequate or an interim procedural control is established.

TIER 2 Correction

Removes the proximate cause

- Revision of the control sequence so that the bypass valve is commanded open before, not after, the return path interlock closes. The relief route must be established prior to the closure that necessitates it.
- Timed auto-cycle stroke verification of the bypass valve under operating conditions, benchmarked against interlock response speed, with the result documented as a commissioning record.
- Inclusion of solenoid exhaust path inspection in the planned maintenance schedule at a frequency reflecting the cleaning chemistry exposure.

TIER 3 Engineering change

Removes the systemic vulnerability

- Installation of a passive pressure relief device upstream of the thermoplastic components, set below their derated capacity at maximum process temperature. Passive relief is independent of control logic, actuation timing, and pneumatic supply integrity.
- Configuration of a supply pump dead-head trip on the pressure-rise-at-zero-flow signature, removing the energy source rather than only providing an escape route for it.
- Formal review of pressure protection philosophy across all circuits containing thermoplastic sealing elements exposed to elevated-temperature cleaning cycles.

> **DESIGN PRINCIPLE**
>
> Where the consequence of a protection failure is catastrophic and the triggering condition is routine, protection must not depend on a device that has to actively do something correctly within a narrow time window. Passive relief has no response time, no control dependency, and no failure mode that requires a command to have been issued.

09 Outcome and Method Notes

What the engagement delivered, and what it taught

Delivered

DELIVERABLE	CONTENT
Causal determination	A six-node causal chain, each node evidenced, with the single unresolved node explicitly marked and the specific data required to close it identified.
Evidence package	Physical specimen documentation, calibrated instrument data, and supplier correspondence analysis, assembled under a single traceable reference structure.
Formal data requests	Structured requests issued to both implicated suppliers, each specifying exactly which data item resolves which open question, with defined response windows.
Corrective framework	Three-tier action plan separating containment, correction and engineering change, with the systemic recommendation stated in terms that survive the return-to-production pressure that typically buries it.
Stakeholder translation	A plain-language explanation of the hydraulic mechanism, developed so that non-specialist management could understand and defend the finding without recourse to the technical author.

Method notes

Three observations from this engagement have proved transferable to subsequent forensic work.

01 **Read the specimen before reading the data.**

Physical morphology is the least corruptible evidence available and it is destroyed by handling, cleaning and replacement activity. Establishing the load direction and mechanism from the component itself, before consulting process data, guards against the confirmation bias that follows from knowing what the data says first.

02 **Suppliers write your case for you.**

In correspondence composed to deflect responsibility, technically competent parties routinely state the design intent of their own equipment in unambiguous terms. A supplier explaining what their valve should do, in the course of arguing that the fault lies elsewhere, has documented the standard against which their equipment is subsequently measured. Their own written words carry evidential weight that no third-party assertion matches.

03 **Distinguish the cause from the condition, and say so plainly.**

The proximate cause answers the question the client asked. The underlying condition answers the question they will ask after the next failure. A report that delivers only the first is technically correct and practically worthless within eighteen months.

10 The Practitioner

Who performed this work, and on what basis it can be relied upon

This investigation was carried out end to end by a single named engineer. There was no research team, no junior drafting layer, and no partner who sold the work and then handed it on. The specimen examination, the process-data interrogation, the timeline reconstruction, the causal chain, the correspondence analysis and the report were the work of one practitioner, and the conclusions were issued under his own professional credential.

That is a deliberate operating model rather than a constraint of scale. A forensic finding is only as defensible as the continuity of judgement behind it: the engineer who reads the specimen has to be the same engineer who reads the recorder trace, because the diagnostic value sits in the relationship between the two and does not survive being passed between people. Where a document may later be read adversarially, a single accountable author with a protected professional title is a materially stronger position than a corporate signature.

BASIS OF RELIANCE	POSITION
Professional credential	Incorporated Engineer (IEng). Findings, and any attribution of responsibility flowing from them, are signed off personally.
Independence	No commercial relationship with either implicated supplier, and no interest in the outcome beyond the accuracy of the determination.
Sector experience	Fourteen years in Tier-1 UK manufacturing and logistics operations, including Unilever, AstraZeneca and Royal Mail, across FMCG, food and pharmaceutical environments.
Technical core	Reliability Centred Maintenance, asset reliability strategy, and forensic diagnosis of complex failed systems in regulated, high-consequence plant.
Documentation standard	Every claim of fact traceable to a named instrument, timestamp or document. Gaps stated as gaps. No conclusion carried by assertion.

Engagement models

MODEL	WHERE IT APPLIES
Forensic failure investigation	Single-asset root cause analysis to evidentiary standard, where liability, insurance recovery or supplier dispute is live or foreseeable.
Asset reliability strategy	Criticality assessment and failure-mode-driven maintenance strategy under RCM, replacing inherited schedules with defensible intervals.
Interim turnaround engineering	Embedded engineering leadership on site where a function is under-resourced, mid-transition, or carrying an unresolved reliability problem.
Technical review and second opinion	Independent review of an existing investigation, specification or supplier position, where the client needs to know whether a finding holds.

OPTIMAL ENGINEERING

ENGINEERING EXCELLENCE

THE POSITION

Most reliability problems in Tier-1 manufacturing are not diagnosed to the point of removal. They are contained, attributed, and left in place to recur on a longer interval. The work above is what the alternative looks like: a mechanism established from physical evidence, a chain that states its own gaps, and a recommendation written so that it survives the return-to-production pressure that normally buries it.

Engagements are taken on an interim or project basis in FMCG, food and pharmaceutical manufacturing across the UK.

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PRACTICE AREAS

Forensic failure investigation

Asset reliability strategy

Reliability-centred maintenance

Interim turnaround engineering

OEE and margin squeeze recovery

Transformational change

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This document is prepared as a technical portfolio record. It does not constitute legal advice. Liability determinations in the original investigation remained subject to outstanding data retrieval and legal review at the point of issue.