

# Analysis of Liquid Carryover Causes in Gas Separation Equipment and Modern Approaches to Minimization

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**Abstract**— The article examines the mechanisms that lead to liquid carryover at the gas outlet of gas separation equipment and summarizes engineering approaches that reduce entrainment under variable operating conditions. Relevance stems from the sensitivity of downstream compression, metering, and corrosion control to residual droplets and episodic slugs. Scientific novelty is connected with the integration of separator-zone hydrodynamics, re-entrainment physics on internals, and design–operation coupling for compact and cyclonic devices within a single analytical framework. The work describes the physical origins of carryover (droplet formation, film stripping, secondary atomization, short-circuiting, and maldistribution) and evaluates how internal geometry and operating envelopes govern the transition from stable separation to persistent entrainment. Particular attention is given to re-entrainment limits in vane and baffle channels and to cyclone-geometry effects on split behavior. The study aims to structure diagnostic logic and select mitigation measures grounded in published numerical and experimental evidence. The article targets process engineers responsible for the reliability of gas treatment trains.

**Keywords**— Gas–liquid separation, liquid carryover, entrainment, re-entrainment, separator internals, demister, cyclone separator, flow maldistribution, operational diagnostics, minimization strategies.

## I. INTRODUCTION

A high fraction of liquid phase entering the gas stream downstream of a separator creates process risks for compression and transportation, reduces the stability of treated-gas quality, complicates metering, and increases the likelihood of corrosion and erosion damage in downstream piping and fittings. Gas-condensate field facilities commonly operate under fluctuating flow rates, pressures, and fluid compositions; under such variability, the permissible limits of gas velocity and residence time shift, while the effectiveness of internals depends not only on design ratings but also on cross-sectional phase distribution and the drainage conditions of liquid films.

The present study aims to identify, through analytical synthesis, the causes of liquid carryover in gas separation equipment and to systematize modern approaches for its minimization using published modeling and test results. The objectives are:

- 1) to classify the physical carryover mechanisms—primary droplet entrainment, film stripping, secondary atomization, flow short-circuiting, and phase maldistribution—and relate them to operating factors;

- 2) to compare the sensitivity of different internal devices (cyclonic inlet elements, perforated baffles, mesh and vane-type mist eliminators, and compact multi-stage arrangements) to increasing gas velocity and to impaired drainage;

- 3) to develop an applied set of engineering measures focused on operational diagnostics and on selecting design solutions that limit carryover.

The novelty of the work lies in a unified interpretation of carryover as the outcome of interactions across three levels: inlet phase distribution, hydrodynamics within the separator volume, and liquid re-entrainment processes occurring on internal devices.

## II. MATERIALS AND METHODS

The analytical base relied on recent peer-reviewed studies that quantify the drivers of entrainment and mitigation mechanisms in separators and mist eliminators. D. Chen [1] reported how cyclone-separator geometry alters separation efficiency and liquid entrainment through split-ratio effects; M. Kim [2] examined geometric modifications (slit plates) for zigzag mist eliminators to suppress re-entrainment tendencies at elevated gas velocities; J. Noh [3] experimentally compared wave-plate geometries and linked improved drainage to reduced re-entrainment under regimes where carryover is commonly amplified; O. E. Olaleye [4] used CFD to analyze a compact vertical separator with an inlet cyclone and perforated baffle, clarifying how internal configuration and inlet liquid fraction affect separation behavior; J. Tao [5] focused on baffle-demister performance for small droplets, supporting the interpretation of fine-droplet penetration in high-velocity channels; S. G. Tomescu [6] validated a numerical oil–gas separation model against experimental data, enabling a structured discussion of geometry-driven efficiency shifts; L. Yang [7] synthesized contemporary gas–liquid separation technologies and their applicability limits; R. Zhang [8] analyzed flow-field characteristics in a compact series gas–liquid separator and connected internal flow organization with achieved performance; Z. Zhang [9] experimentally evaluated a novel gas–liquid separator architecture, providing reference evidence for design-driven efficiency differences; R. Zou [10] assessed demister and internal-component impacts in wet gas treatment settings, supporting discussion of internal-component contributions to droplet capture and secondary emissions. In addition, industrial technical documentation describing centrifugal-element separation trays, experimentally derived “effective operating zones,” and isokinetic probing of carryover

using a GPR-420-type device was consulted to align the synthesis with field-oriented diagnostic practice.

The work applied comparative analysis of published experimental and numerical findings, source-based synthesis of mechanism-parameter relations, and engineering generalization to construct cause-and-effect chains that connect operating envelopes, internal-device hydrodynamics, and carryover manifestations. A qualitative consistency check was performed by mapping literature-derived mechanisms onto industrial diagnostic steps described in the technical documentation.

### III. RESULTS

Liquid carryover at the gas outlet emerges when droplet capture and drainage cease to dominate over droplet generation and re-entrainment. Across modern separator concepts, a recurring pattern emerges: the governing factor is not a single “velocity limit,” but rather the interplay between local acceleration zones, phase maldistribution, and the drainage capacity of internals. The literature supports treating carryover as a multi-stage phenomenon: formation of droplets upstream (shear at the gas-liquid interface, impingement on internals), transport through the bulk gas phase, capture on surfaces (vane, baffle, mesh, cyclone wall), transformation into films, and secondary atomization from films under aerodynamic shear. Reviews of separator technologies emphasize that compactness and intensified swirl increase sensitivity to inlet conditions and internal short-circuiting, which raises the probability that droplets bypass capture surfaces or exit before coalescence and drainage are completed [7].

CFD evidence for a compact vertical separator with an inlet cyclone and perforated baffle demonstrates how the internal configuration organizes the flow into zones that either promote coalescence and settling or maintain dispersed droplets within the gas core, with separation outcomes depending on the inlet liquid fraction and internal residence characteristics [4]. This supports an operational interpretation: even when a separator is nominally sized for a target throughput, transient increases in liquid loading, changes in dispersion, or inlet maldistribution can push internal zones to enter a regime where droplets remain suspended long enough to reach the gas outlet. Experimental and validated numerical work on oil-gas separation configurations reinforces that geometry-dependent flow organization and outlet-region behavior can significantly impact performance, making outlet-zone stabilization and avoidance of gas-core distortion practical levers for carryover control [6].

Cyclone-type devices and cyclone-assisted inlet elements offer strong inertial separation; however, they introduce a second pathway for carryover: entrainment through the overflow (gas) outlet, which is caused by the internal swirling structure and split behavior. A geometry-focused analysis of a gas-liquid cyclone separator reveals that performance metrics must account for the entrained liquid carried with the gas stream, not just the nominal separation fraction, and that coordinated tuning of chamber dimensions and outlet geometries is necessary to maintain bounded entrainment while sustaining separation efficiency [1]. This result complements

the vertical-separator findings [4] by indicating that “high separation” in a cyclonic field can coexist with unacceptable carryover if the outlet configuration encourages liquid pickup or if the swirl core destabilizes.

Mist eliminators and baffle/vane channels are often installed as a final barrier, yet their performance is constrained by re-entrainment. Experimental work on wave-plate mist eliminators demonstrates that, under conditions where re-entrainment becomes pronounced, geometric modifications that enhance drainage can preserve or improve overall collection compared to a conventional arrangement, without relying on increased pressure drop as the primary mechanism [3]. A related geometry-based approach for zigzag-type mist eliminators highlights how auxiliary features can alter near-wall flow and droplet trajectories, serving as a design pathway for reducing the propensity for resuspension at higher gas velocities [2]. For small droplets, baffle-demister studies demonstrate that capture efficiency becomes sensitive to internal channel parameters and droplet size, which explains why fine-droplet penetration remains a persistent cause of residual carryover, even when gross separation appears stable [5]. The practical implication is that a separator that “passes” in steady conditions can still fail during high-velocity episodes because the last-stage device enters a re-entrainment-dominated regime, where incremental velocity increases reduce net collection.

Evidence from compact series gas-liquid separators suggests that structured internal staging can achieve high separation values across a range of operating factors, provided the flow field remains organized and the interaction between stages limits bypassing [8]. In experimental assessment of a novel separator concept, the reported performance trend supports the same interpretation: design features that manage internal flow paths and stabilize droplet-surface interactions can enhance robustness, while designs that allow short-circuiting or insufficient drainage amplify carryover risk [9]. In wet gas treatment environments where internal components are assessed as part of system performance, the influence of internal configurations on removal outcomes further supports the conclusion that internal selection and placement materially affect droplet capture and secondary emissions [10].

Figure 1 condenses these literature-supported mechanisms into an engineering map that links separator zones, internal devices, and dominant carryover triggers. It is adapted from the zone logic of compact vertical separators and the technology-level synthesis of separation and re-entrainment pathways [4, 7].

Industrial documentation describing centrifugal-element separation trays indicates that separation effectiveness in such internals is governed by operating speed ranges. That carryover can be quantified by isokinetic probing (e.g., using a GPR-420-type device), which provides a practical route to identifying the onset of a non-effective regime and to setting an operating point within an empirically derived efficient zone.

### IV. DISCUSSION

The assembled evidence indicates that carryover minimization in operating practice should be treated as a two-

layer decision problem: first, suppress the conditions that generate droplets faster than they can be removed; second, ensure that installed internals do not convert captured liquid into a secondary droplet source through re-entrainment. The literature differentiates between “bulk-zone failure” (insufficient residence, sustained dispersion, bypass) and “internal-device failure” (drainage collapse, film breakup, outlet pickup). CFD and validated numerical studies highlight that compact configurations and cyclone-assisted devices are susceptible to changes in the inlet regime and to geometric features that distort the gas core or intensify outlet pickup [1, 4,

6]. Empirical and experimental results for mist eliminators indicate that drainage-oriented geometry modifications shift the boundary at which re-entrainment dominates net removal, which aligns with operational observations that seemingly minor velocity increases can trigger abrupt carryover growth [2, 3].

Table 1 links dominant root causes to field-observable indicators and to diagnostic approaches that are consistent with published mechanisms and with the need for fast engineering decisions.

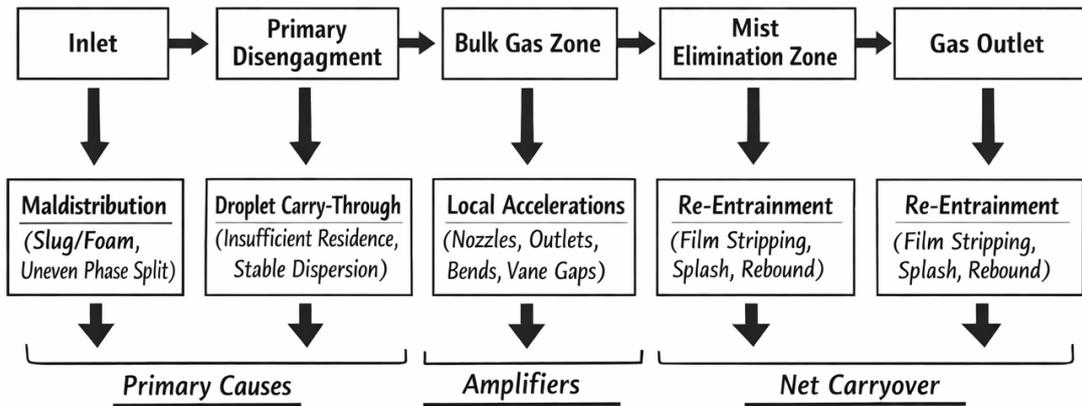


Figure 1. Mechanistic map of liquid carryover formation and amplification in gas separation equipment (adapted from [4, 7])

TABLE 1. Liquid carryover root causes, observable indicators, and diagnostic cues [1–8]

Root cause category	Typical indicator in operation	Mechanistic rationale	Diagnostic emphasis
Inlet maldistribution/short-circuiting	Intermittent spikes in carryover, strong sensitivity to upstream disturbances	A fraction of droplets bypasses settling zones and reaches the outlet before coalescence	Correlate carryover excursions with inlet regime changes; prioritize inlet device and distributor condition
Excess gas-phase velocity in the mist zone	Carryover rises with throughput even if the liquid rate is stable	Droplet capture increases with velocity, but re-entrainment from films increases and can dominate net removal	Identify the velocity window where the net collection peaks; evaluate the re-entrainment onset
Re-entrainment on vane/baffle internals	High carryover despite “clean” bulk separation	Film stripping and splash generate secondary droplets that exit through the gas path	Inspect drainage paths and geometry; assess whether internal design promotes drainage
Cyclone outlet entrainment	High separation fraction with persistent outlet wetness	Internal swirl can entrain liquid into the gas outlet, depending on geometry and split behavior	Evaluate outlet geometry and split ratio sensitivity; consider coordinated geometry tuning
Geometry-dependent flow instability	Abrupt performance deterioration after modifications or fouling	Gas-core distortion and recirculation alter droplet paths and residence	Track performance pre/post changes; combine numerical insight with targeted inspection

Mitigation selection can be justified through a structured comparison of measures based on their dominant mechanism, operational limitations, and expected robustness. The studies collectively support that mitigation effectiveness depends on matching the measure to the failure mode rather than applying generic “capacity reduction.” For example, if re-entrainment dominates, geometry that improves drainage can outperform brute-force velocity reduction because it directly suppresses secondary droplet formation [2, 3]. If cyclone outlet entrainment dominates, coordinated geometric tuning is needed to bound entrainment while retaining separation efficiency [1]. If inlet maldistribution drives excursions, measures that stabilize inlet conditioning and stage organization become primary [4, 8, 9]. Table 2 summarizes these linkages.

In relation to production-technical decision-making, the discussion implies that a practical minimization program should begin by identifying whether the observed carryover is dominated by bulk-zone limitations (residence and bypass) or by internal-device re-entrainment. Industrial documentation for centrifugal-element trays supports an approach where carryover is measured by isokinetic probing and an empirically derived “effective operating zone” is used to place the working point away from boundaries where droplet stripping becomes active. The same logic aligns with the academic evidence that re-entrainment transitions can be abrupt and geometry-dependent, which justifies prioritizing drainage integrity, outlet-zone stabilization, and inlet conditioning in retrofit planning rather than relying solely on a single nominal capacity margin.

TABLE 2. Mitigation measures mapped to dominant mechanisms and practical constraints [1–3; 8–10]

Mitigation measure	Primary mechanism targeted	Evidence base	Main limitation noted in the literature
Drainage-oriented modification of vane/wave-plate geometry	Reduces re-entrainment by thinning films and improving droplet discharge	Experimental comparison of conventional vs modified wave-plate geometry shows improved performance under re-entrainment-significant regimes	Benefits concentrate in regimes where re-entrainment is dominant; requires geometric compatibility with existing housings
Auxiliary flow-guiding elements (e.g., slit-type features)	Alters near-wall flow and droplet trajectories to reduce resuspension likelihood	Geometry proposal and performance-oriented analysis for zigzag eliminators	Effectiveness depends on velocity range and droplet spectrum; needs validation for specific gas compositions
Cyclone geometry coordination (chamber and outlet ratios)	Bounds liquid entrainment at the gas outlet while maintaining separation efficiency	Geometry-parameter influence on separation efficiency and entrainment-linked metrics	Optimization is multi-parameter; risk of pressure-drop penalties if applied without system constraints
Compact series staging / flow-field organization	Suppresses bypass and stabilizes internal flow paths across stages	Flow-field and performance analysis of a compact series separator	Requires maintaining an organized internal flow; susceptible to fouling-induced maldistribution
Re-engineering internal architecture (novel separator concepts)	Enhances inertial capture and staged separation under targeted conditions	Experimental assessment of a novel gas–liquid separator concept	Transferability to field conditions depends on droplet distribution and regime variability
Internal components selection in wet gas treatment trains	Improves droplet capture and limits secondary emissions from internals	System-level assessment of internal component contributions	Results are system-specific; performance depends on upstream chemistry and operating windows

### V. CONCLUSION

The synthesis of published findings suggests that liquid carryover arises from a complex chain of processes: droplet and film generation, transport within the gas phase, capture on internal devices, and subsequent re-entrainment of liquid back into the gas stream. The first objective was met by classifying the governing mechanisms and linking them to operating drivers; inlet phase maldistribution, localized flow accelerations, and deterioration of film drainage emerge as the dominant conditions that shift separation from stable removal to persistent carryover. The second objective was achieved through a comparative assessment of internal sensitivity: cyclonic and compact configurations require control of gas-core stability and outlet-region behavior, whereas wave-plate and baffle/vane mist eliminators are constrained by re-entrainment thresholds that depend on geometry and drainage performance. The third objective was implemented as an engineering decision logic for selecting mitigation measures: when re-entrainment prevails, priority should be given to design solutions that enhance drainage and suppress secondary atomization; when bypass and short-circuiting prevail, emphasis should be placed on stabilizing inlet distribution and structuring staged flow paths; when cyclone-related carryover prevails, coordinated tuning of cyclone geometry and outlet elements is required, with explicit consideration of allowable pressure drop.

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