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Optimization of Pneumatic Conveying System at Ras Lanuf Polyethylene Plant to Reduce Blockages and Production Loss

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ABSTRACT

The Ras Lanuf Polyethylene Plant in Libya, utilizing Dow UNIPOL™ gas-phase technology with a combined capacity of 160,000 tonnes/year, has experienced chronic pneumatic conveying failures following operational restart, resulting in 2,839 downtime hours, 637 blockage incidents, 15,200 tonnes of lost production, and 450 tones of annual material loss. This mixed-methods study integrates quantitative operator surveys (n=32), qualitative technical lead interviews (n=5), multi-year operational data (November 2019–February 2026), and fluid mechanics literature to optimize the conveying system. Findings reveal three interconnected failure mechanisms: low conveying velocity ($v < 20$ m/s) and pipe roughness cause gravitational settling and blockages; high velocities ($v > 30$ m/s) exponentially accelerate angel hair formation (2.7-fold increase) and pipe erosion ($E \propto v^{2.5}$); while pre-blockage pressure drop variability ($CV > 0.20$) predicts blockages within 4 hours with 73% probability. The proposed integrated optimization strategy—comprising section-specific velocity targeting (22–28 m/s), automated SCADA pressure monitoring, bypass air injection at transitions, soft fin inserts, and ceramic-lined bends—is projected to reduce blockages by 50–60%, downtime by 40–50%, recover 160–180 tonnes of resin annually, and restore 2,450–3,266 tonnes of annual production capacity. This research provides the first field-validated empirical dataset from a commercial gas-phase polyolefin plant following extended shutdown, offering petrochemical managers an evidence-based operational roadmap to eliminate unscheduled downtime and ensure manufacturing excellence.

Keywords: Pneumatic conveying, polyethylene plant, angel hair formation, pipe erosion, pressure drop, Ras Lanuf

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1. Introduction

In the rapidly evolving competition landscape in e-commerce, understanding consumer behavior is paramount for businesses seeking to thrive online (Lăzăroiu et al., 2020). Behavioral intention to buy from an online market refers to a consumer's subjective likelihood or willingness to engage in future purchasing behaviors, specifically within online marketplaces or e-commerce platforms (Guo et al., 2021). Similarly, Deng et al. (2021) defined behavioral intention as shaped by the consumer's cognitive evaluations (e.g., perceived value, perceived quality) and emotional responses (e.g., enjoyment, arousal) towards the online shopping experience (Alshohaib, 2024). In addition, behavioral intention encompasses the psychological readiness and predisposition of consumers to engage in online shopping activities, influenced by a combination of internal factors (e.g., attitudes, beliefs) and external factors (e.g., social influence, marketing stimuli) (Venkatesh & Davis, 2000; Liang & Lai, 2002).

The global polyethylene industry depends heavily on reliable, high-capacity material handling systems to sustain continuous chemical production and enforce strict product quality standards. Pneumatic conveying systems represent the primary industrial technology for transporting polymer pellets and powders throughout petrochemical facilities due to their operational flexibility, fully enclosed piping design, and ability to eliminate environmental contamination (Mills, 2016). As global polyolefin demand escalates and quality specifications become increasingly stringent, optimizing pneumatic conveying performance has emerged as a paramount engineering challenge for chemical manufacturers worldwide. Pneumatic transport involves complex two-phase gas-solid fluid mechanics, utilizing compressed air to suspend and propel granular solids through intricate pipeline networks (Mills, 2016; Kuang et al., 2020). Compared to traditional mechanical conveyors, pneumatic systems offer superior product containment, lower contamination risks, and reduced mechanical maintenance overheads (Behera et al., 2022). However, in large-scale petrochemical installations, the operational reliability of pneumatic conveying directly governs plant throughput, overall equipment effectiveness, and financial profitability.

The Ras Lanuf Polyethylene Plant in Libya operates two production lines using Dow UNIPOL™ gas-phase technology, with a combined capacity of 160,000 tonnes/year of HDPE and LLDPE. Following an extended operational shutdown due to regional instability, Line 1 was successfully restarted in November 2019, followed by Line 2 in January 2025. During these post-restart operations, the plant has encountered chronic reliability challenges in its pneumatic conveying infrastructure, which transports extruded pellets from purge bins to storage silos. Specifically, the plant faces three severe interlinked problems: frequent pipeline blockages requiring manual intervention, widespread formation of fibrous polymer strands ("angel hair"), and severe erosive wear at pipeline bends and transition junctions. System blockages induce unpredicted plant downtime averaging 2.4 hours per event, generating substantial material waste during purging and straining maintenance budgets. Angel hair formation—caused by localized thermo-mechanical melting of pellet surfaces during wall collisions—clogs filtration equipment, fouls cyclone separators, and pollutes finished polymer lots (Mills, 2016; Chen, 2014). Concurrently, severe pipe erosion at 90-degree elbows reduces structural pipeline integrity and increases maintenance costs (Uzi et al., 2017). These interconnected failures induce severe pressure drop fluctuations and reduce effective plant capacity by 25% to 30%, resulting in significant economic losses.

Despite these critical operational deficits, a systematic, data-driven optimization study tailored to the specific operating context of Ras Lanuf has not been performed. To resolve this industrial problem, this research formulates three primary research questions: (1) What are the primary causes of blockages, angel hair formation, and pipe erosion in the Ras Lanuf pneumatic conveying system? (2) What is the quantitative relationship between pressure drop fluctuations and blockage occurrence within the conveying network? (3) How effective are the proposed optimization measures in reducing production losses and improving system reliability? Correspondingly, the main objective of this study is to optimize the pneumatic conveying system at Ras Lanuf to minimize blockages, reduce angel hair formation, mitigate pipe wear, and recover lost production capacity. Specific research objectives include: identifying primary failure mechanisms through an integrated mixed-methods evaluation; assessing the effect of pressure drop fluctuations on blockage probability; and developing a multi-faceted optimization strategy incorporating conveying velocity control, hardware modifications, and predictive monitoring protocols. Three central hypotheses guide the investigation: H1 states that low conveying velocity and pipeline surface roughness significantly contribute to blockage frequency; H2 states that excessive conveying velocity exponentially increases angel hair formation and pipe erosion; and H3 states that pressure drop variability serves as a statistically reliable precursor for predicting pipeline blockages.

The practical and academic contributions of this study are substantial. Practically, the findings equip Ras Lanuf management with an evidence-based roadmap to eliminate 40–50% of conveying downtime, recover 160–180 tonnes of lost resin annually, and restore 2,450–3,266 tonnes of annual production capacity. Academically, this study advances polyolefin handling literature by providing rare, field-validated empirical data from a commercial UNIPOL™ gas-phase plant operating in a transitional flow regime following an extended industrial shutdown. For the purpose of this study, Pneumatic Conveying System refers to the positive-pressure piping network used to transport polyethylene pellets (Mills, 2016). Blockage is operationally defined as the complete or partial cessation of solid material flow within the pipeline accompanied by a rapid pressure spike (Chen et al., 2025). Angel Hair refers to thin, flexible, fibrous polymer strands generated by thermo-mechanical friction and localized surface melting of pellets during high-velocity impacts (Chen, 2014). Pipe Erosion is defined as the progressive mechanical wear and wall thinning of metallic pipeline walls caused by repetitive solid particle impacts, measured in mm/year (Uzi et al., 2017). Pressure Drop (ΔP) represents the differential static pressure loss across a designated pipeline length, measured in bars or Kilopascals (Behera et al., 2022). Conveying Velocity (v) is defined as the average superficial gas air speed inside the pipeline, expressed in meters per second (m/s) (Wang et al., 2023).

2. Literature Review

Pneumatic conveying technology is fundamental to bulk solids handling across process industries, categorized primarily by gas-solid concentration into dilute-phase and dense-phase flow regimes (Mills, 2016). In dilute-phase conveying, solid particles are fully suspended in a high-velocity gas stream ($v = 15–30 \text{ m/s}$) at low solid loading ratios ($\text{SLR} < 15$), requiring lower operating pressures but exhibiting higher energy consumption and elevated particle degradation rates (Mills, 2016; Kuang et al., 2020). Conversely, dense-phase conveying moves non-suspended materials at low air velocities ($v = 3–15 \text{ m/s}$) and high solid loading ratios ($\text{SLR} > 20$) as moving beds or discrete slugs, minimizing particle attrition and pipe wear but increasing blockage risks during flow interruptions (Behera et al., 2022; Chandra et al., 2018). Advanced Computational Fluid Dynamics and Discrete Element Method (CFD-DEM) simulations demonstrate that gas-solid flow dynamics are strongly governed by fluid drag forces, inter-particle collisions, and particle-wall frictional interactions (Kuang et al., 2020). In commercial polyolefin handling, operating near the boundary between dilute and dense phase introduces severe flow instabilities, where localized particle deceleration causes transient slugging and pressure surges (Behera et al., 2022; Kaur et al., 2017).

Polyethylene pellets exhibit viscoelastic and thermoplastic properties that make them extraordinarily sensitive to thermo-mechanical degradation during high-velocity pneumatic transport (Wang et al., 2023). When polyethylene pellets impact pipeline walls or adjacent particles at velocities exceeding 28–30 m/s, localized frictional heating raises pellet surface temperatures above the polymer's glass transition and softening point. Softened surface polymer is subsequently drawn into thin, flexible strands by shear forces and air friction, generating "angel hair" (also termed streamers, snakeskins, or fluff) (Mills, 2016; Chen, 2014). Angel hair accumulates systematically within cyclone separators, dust filters, and pipe bends, entangling surrounding pellets and creating web-like structural matrixes that initiate catastrophic pipeline blockages and contaminate finished resin batches (Chen, 2014). Concurrently, high impact velocities drive severe erosive wear across elbows, scaling exponentially with particle velocity ($E \propto v^{2.5}$) and concentrating along outer bend radii (Uzi et al., 2017; Zheng, 2024; Hadžiahmetović et al., 2014).

Pressure drop behavior provides a vital thermodynamic and hydraulic window into internal pneumatic conveying dynamics. Total pipeline pressure loss represents the sum of air acceleration, gas-wall friction, solid particle acceleration, particle-wall friction, and elevation head losses (Wang et al., 2023; Behera et al., 2022). In stable dilute-phase transport, pressure drop remains relatively steady with low-amplitude fluctuations. However, as solid feed rates increase or air velocities approach saltation limits (the minimum velocity required to prevent particle deposition), solid particles drop out of suspension, forming stationary dunes or unstable moving slugs (Chen et al., 2025; Kaur et al., 2017). This flow regime transition induces severe pressure drop fluctuations, characterized by a sharp rise in baseline pressure and an increased standard deviation or coefficient of variation ($\text{CV} = \text{SD} / \text{mean}$) (Chen et al., 2025). Advanced pressure-drop monitoring reveals that progressive material accumulation produces characteristic pressure signatures—specifically a gradual pressure buildup over 2 to 6 hours accompanied by elevated fluctuation amplitudes—which serve as reliable pre-blockage early warning indicators (Chen et al., 2025; Nan, 2025).

To mitigate conveying failures, contemporary industrial literature identifies several hardware and operational optimization strategies. Hardware interventions include bypass pneumatic piping (Chen, 2014), internal soft fins (Yan et al., 2012), optimized long-radius bends ($R/D = 8:1–10:1$) with ceramic coatings (Cai et al., 2014), and swirl flow generators (Yadav et al., 2024). Operationally, implementing automated SCADA-linked variable velocity control based on real-time pressure feedback dynamically balances velocity to avoid both blockage deposition and high-velocity erosion (Nan, 2025; Wang et al., 2023). Table 2.1 synthesizes key empirical literature and positions the current research. Table 1. Is presenting the key findings and research gaps from the recent empirical studies.

Table 1. Synthesis of Key Empirical Literature and Research Positioning

Author(s) & Year	**Research Focus / Methodology**	**Key Findings & Technical Contributions**	**Identified Research Gap & Study Positioning**
Mills (2016)	Pneumatic Conveying Design Guide / Monograph	Categorized flow regimes; established polymer vulnerability to thermo-mechanical shear degradation.	Provides general theory; lacks empirical field data on industrial plant restarts following long shutdowns.

Author(s) & Year	Research Focus / Methodology	Key Findings & Technical Contributions	Identified Research Gap & Study Positioning
Uzi et al. (2017)	Erosion Prediction Models / Empirical Modeling	Proved pipeline erosion scales exponentially with particle impact velocity ($E \propto v^{2.5}$).	Lab models based on fresh, non-degraded pipes; excludes aged, corroded industrial lines.
Kuang et al. (2020)	CFD-DEM Simulation / Dilute-Phase Systems	Showed conveying efficiency and pressure loss are governed by gas-particle coupling and wall impacts.	Theoretical simulation; requires empirical validation from active full-scale commercial plants.
Yan et al. (2012)	Soft Fin Hardware Experiments / Horizontal Pipes	Demonstrated that soft fin inserts reduce pressure drop by 20–25% and improve flow stability.	Evaluated clean laboratory systems; needs field validation under heavy angel hair contamination.
Chen (2014)	Bypass Pneumatic System / Experimental Thesis	Proved bypass air injection lowers minimum dense-phase velocity, preventing severe blockages.	Focuses on coal and general minerals; lacks specific optimization parameters for PE pellets.
Behera et al. (2022)	Fluidized Dense-Phase / Comprehensive Review	Identified pressure drop prediction inaccuracies during transient flow regime transitions.	Recommends field-level empirical studies in the "transitional zone" where standard models fail.
Wang et al. (2023)	Two-Phase Flow Modeling / Horizontal Pipes	Identified 22–30 m/s as the optimal economic velocity range balancing energy and blockage.	Does not account for angel hair formation or internal pipe corrosion following long plant outages.
Nan (2025)	AI Control Techniques / Doctoral Dissertation	Proved automated AI parameter tuning reduces blockages and saves 15–25% conveying energy.	Focuses on algorithmic design; needs operational integration with plant maintenance records.

A synthesis of existing literature demonstrates that while theoretical and laboratory studies cover isolated conveying mechanics, no research to date has evaluated the integrated, synergistic impacts of conveying velocity, pressure drop fluctuations, angel hair formation, and pipe wear within an operating commercial gas-phase polyethylene facility following an extended multi-year shutdown. This study addresses this empirical gap by combining operator survey data, expert technical lead interviews, multi-year plant operational logs, and fluid mechanics theory within a unified, mixed-methods framework at Ras Lanuf.

3. Method

This chapter presents the quantitative and qualitative mixed-methods research methodology utilized to empirically analyze and optimize the pneumatic conveying system at the Ras Lanuf Polyethylene Plant. Adopting a pragmatic and positivist research paradigm, this study integrates quantitative operational data and structured survey metrics with qualitative expert technical interviews to achieve comprehensive methodological triangulation (Creswell, 2014; Saunders et al., 2019). The research design employs a convergent parallel mixed-methods framework, where quantitative operator survey data ($n = 32$), qualitative technical lead interviews ($n = 5$), multi-year plant operational logs (November 2019 to February 2026), and systematic literature data are collected concurrently, analyzed independently, and integrated during interpretation (Creswell, 2014; Tashakkori & Teddlie, 2010). Combining bottom-up operator field experience with top-down process engineering analytics and physical plant data provides a robust, multi-dimensional diagnostic assessment of complex gas-solid conveying failures (Müller & Isermann, 2008).

The research evaluates post-reactor conveying across two parallel production lines at Ras Lanuf (160,000 tonnes/year combined capacity, $80–150 \text{ mm}$ pipe diameters). The target survey population comprised all 45 plant shift operators and maintenance technicians working directly on the conveying lines. A census sampling approach targeted the entire accessible operator pool, yielding 32 completed, fully usable questionnaires (84.2% response rate) (Baruch & Holtom, 2008). For the qualitative component, purposive sampling selected 5 senior technical leads—including Line 1 Process Engineer (15 yrs exp), Maintenance Supervisor (12 yrs exp), Production Manager (18 yrs exp), Reliability Engineer (10 yrs exp), and Process Optimization Engineer (11 yrs exp)—possessing deep institutional knowledge of plant operations and failure histories (Etikan et al., 2016). Quantitative operational data spanning 76 operating months on Line 1 and 14 operating months on Line 2 were extracted from plant SCADA archives, maintenance logs, and quality control records. Table 3.1 outlines the methodological alignment and sampling summary. Therefore, the summary of overall Method is presented in Table 2.

2. Research Methodology, Sampling Strategy, and Data Source Alignment

Research Objective	**Target Variables / Operational Focus**	**Primary Data Source**	**Sampling Strategy & Sample Size**	**Analytical Method**
RO1: Identify root causes of blockages, angel hair & erosion	Blockage locations, angel hair accumulation, pipe wear rates	Operator Survey & Technical Interviews	Census operators ($n = 32$); Purposive technical leads ($n = 5$)	Descriptive statistics (means, %); Thematic qualitative coding
RO2: Assess pressure drop fluctuations & material loss	Pressure drop (ΔP), fluctuation amplitude, downtime, loss	SCADA Historical Data & Maintenance Logs	Multi-year plant logs (Nov 2019–Feb 2026; 76 operating months)	Time-series regression, rolling SD, coefficient of variation (CV)
RO3: Develop & evaluate system optimization strategy	Velocity control, bypass piping, soft fins, predictive SCADA	Integrated Triangulation & Literature Synthesis	78 peer-reviewed articles; Plant operational parameters	Data triangulation, engineering calculations & projection modeling

Data collection instruments included: (1) a 45-item structured operator questionnaire utilizing 5-point Likert scales (1 = "Strongly Disagree" to 5 = "Strongly Agree") covering demographic context, blockage patterns, angel hair formation, pipe erosion, pressure drop monitoring, and operational efficiency; (2) a 21-item semi-structured interview protocol for technical leads; and (3) continuous 1-minute interval SCADA pressure readings and downtime logs. Survey content validity was confirmed by an expert review panel ($\text{CVI} \ge 0.80$) (Polit & Beck, 2006), and double-blind back-translation ensured English-Arabic language equivalence (Brislin, 1970). Scale reliability was confirmed via Cronbach's alpha ($\alpha = 0.84$). Data processing utilized IBM SPSS Statistics (Version 28) for descriptive statistics, frequency distributions, mean score rankings, and cross-tabulations. Qualitative interview transcripts underwent iterative thematic coding (initial, focused, and axial coding) (Braun & Clarke, 2006). Time-series operational data were analyzed for pressure means, standard deviations, and coefficients of variation ($\text{CV} = \text{SD}/\text{mean}$). Findings across all four data sources were integrated using quantitative-qualitative triangulation (Tashakkori & Teddlie, 2010). Ethical approval was granted, ensuring informed consent, complete participant anonymity, and commercial data confidentiality (Resnik, 2020).

4. Data Analysis

4.1 Demographic Profile

A total of 32 completed questionnaires were received from plant operators and technical engineers (84.2% response rate). Table 4.1 details the demographic profile of survey respondents. The sample comprised 90.6% male ($n = 29$) and 9.4% female ($n = 3$) personnel, with an average professional experience of 6.2 years ($SD = 4.8 \text{ years}$). By job role, Operators represented 50.0% ($n = 16$), Process Engineers represented 15.6% ($n = 5$), Operations Supervisors represented 12.5% ($n = 4$), Maintenance Engineers represented 12.5% ($n = 4$), and Instrumentation Engineers represented 9.4% ($n = 3$). In terms of experience, 31.3% ($n = 10$) possessed 6–10 years, 28.1% ($n = 9$) possessed 3–5 years, 25.0% ($n = 8$) possessed 10 years. However, Table 3 is presenting demographic characteristics of all respondents.

Table 2. Demographic Profile of Survey Respondents (N = 32)

Demographic Category	Sub-Category / Cohort	Frequency (n)	Percentage (%)
Gender	Male Female	29 3	90.6% 9.4%
Age Group	18–24 years 25–34 years 35–44 years 45–54 years 55 years or older	3 12 10 6 1	9.4% 37.5% 31.3% 18.8% 3.1%
Educational Level	Diploma / Technical Certificate Bachelor's Degree Master's Degree	14 15 3	43.8% 46.9% 9.4%
Professional Experience	Less than 3 years 3–5 years 6–10 years More than 10 years	8 9 10 5	25.0% 28.1% 31.3% 15.6%

Demographic Category	Sub-Category / Cohort	Frequency (n)	Percentage (%)
Current Job Role	Operator	16	50.0%
	Process Engineer	5	15.6%
	Operations Supervisor	4	12.5%
	Maintenance Engineer	4	12.5%
	Instrumentation Engineer	3	9.4%

Blockage incidence analysis revealed severe operational frequency: 78.1% ($n = 25$) of respondents experienced at least one blockage during their most recent 10 shifts, while 34.4% ($n = 11$) reported multiple blockages per week. Table 4.2 presents reported blockage locations, identifying horizontal-to-vertical transitions as the primary bottleneck (68.8%, $n = 22$), followed by the first bend after purge bins (53.1%, $n = 17$), and distribution points (46.9%, $n = 15$). Descriptive Likert evaluations confirmed high agreement regarding blockage drivers: low conveying velocity scored highest ($M = 4.31, SD = 0.68$), followed by startup/shutdown operations ($M = 4.28, SD = 0.69$), pre-blockage pressure fluctuations ($M = 4.22, SD = 0.71$), overall blockage frequency ($M = 4.12, SD = 0.74$), angel hair contribution ($M = 4.09, SD = 0.77$), and grade transitions ($M = 4.06, SD = 0.81$). Table 3 details blockage descriptive metrics.

Table 3. Descriptive Statistics for Blockage-Related Statements

Survey Statement	Mean Score	Std. Deviation	Interpretation
Low conveying velocity contributes significantly to blockage formation.	4.31	0.68	Strongly Agree
Startup and shutdown operations increase the risk of blockages.	4.28	0.69	Strongly Agree
Pressure fluctuations are usually observed before a blockage occurs.	4.22	0.71	Strongly Agree
Blockages occur frequently in the pneumatic conveying system.	4.12	0.74	Agree
Angel hair accumulation contributes directly to blockage formation.	4.09	0.77	Agree
Grade transitions increase blockage frequency.	4.06	0.81	Agree

4.2 Angel Hair Accumulation

Table 4 indicates frequency, and Table 5 presents descriptive statistics of the angel hair evaluation confirming severe degradation: 87.5% of respondents considered angel hair a major operational problem (M = 4.38, SD = 0.65). Table 4.4 outlines accumulation locations, highlighting filters and cyclone separators (75.0%, n = 24), bends/elbows (62.5%, n = 20), and silo inlets (50.0%, n = 16). Likert items showed strong agreement that high velocity increases angel hair (M = 4.28, SD = 0.67), angel hair impairs product quality (M = 4.25, SD = 0.69), and angel hair induces blockages (M = 4.19, SD = 0.76$), while current cleaning effectiveness scored low (M = 3.12, SD = 0.88). Table 4.5 details angel hair metrics. Pipe erosion analysis identified bends as the most damaged sections (68.8%, n = 22), followed by horizontal-to-vertical transitions (46.9%, n = 15). Table 4.6 presents erosion locations. Respondents strongly agreed that erosion is most severe at bends (M = 4.41, SD = 0.65), high velocity accelerates erosion (M = 4.34, SD = 0.69), and erosion increases maintenance costs (M = 4.19, SD = 0.73), while existing prevention measures scored low (M = 3.18, SD = 0.84). Table 4.7 details erosion metrics.

Table 4. Reported Locations of Angel Hair Accumulation (N = 32)

Accumulation Location	Frequency (n)	Percentage (%)
Filters and Cyclone Separators	24	75.0%
Bends and Elbows	20	62.5%
Silo Inlet Points	16	50.0%
Distribution Points	12	37.5%
Inspection Sections	10	31.3%

Table 5. Descriptive Statistics for Angel Hair-Related Statements

Survey Statement	Mean Score	Std. Deviation	Interpretation
Angel hair formation is a major operational problem.	4.38	0.65	Strongly Agree
High conveying velocity increases angel hair formation.	4.28	0.67	Strongly Agree
Angel hair negatively affects product quality.	4.25	0.69	Strongly Agree
Angel hair accumulates mainly in filters and cyclone separators.	4.22	0.71	Strongly Agree
Angel hair contributes to blockage incidents.	4.19	0.76	Agree
Certain polyethylene grades are more susceptible to angel hair.	4.16	0.74	Agree
Current cleaning practices effectively control angel hair.	3.12	0.88	Neutral

Pressure drop evaluations confirmed strong reliance on pressure metrics: respondents strongly agreed that pressure drop is a vital performance indicator (M = 4.41, SD = 0.63), pressure monitoring reduces failures (M = 4.28, SD = 0.68), and pressure fluctuations predict future blockages (M = 4.25, SD = 0.70), while current early warning system capability scored lower (M = 3.47, SD = 0.81). Table 6. presents pressure drop descriptive metrics. Qualitative technical lead interviews (n = 5) provided key mechanistic insights: participants confirmed that blockages develop progressively over 2 to 6 hours as particle deposition restricts pipe cross-sections, triggering positive feedback pressure spikes. Technical leads emphasized that velocity represents a double-edged sword: velocities below 20 m/s induce gravitational settling and blockages, while velocities above 30 m/s cause severe angel hair melting and exponential pipe erosion. Table 7 synthesizes technical lead interview themes.

Table 6. Descriptive Statistics for Pressure Drop-Related Statements

Survey Statement	Mean Score	Std. Deviation	Interpretation
Pressure drop is an important indicator of system performance.	4.41	0.63	Strongly Agree
Pressure monitoring helps reduce system failures.	4.28	0.68	Strongly Agree
Pressure fluctuations can predict future blockages.	4.25	0.70	Strongly Agree
Operators regularly monitor pressure readings.	4.16	0.74	Agree
The current pressure monitoring system provides adequate early warning.	3.47	0.81	Agree

Table 7. Synthesis of Qualitative Interview Themes from Technical Leads (N = 5)

Theme Area	Core Technical Observation	Key Exemplar Quote / Operational Mechanism
Historical Shutdown Impact	Shutdown induced corrosion & internal roughness.	"Before 2011, blockages occurred once every few months. Now it is a weekly occurrence due to corroded pipe walls."
Blockage Mechanism	Progressive restriction over 2–6 hours.	"Blockages start gradually. Pressure builds up for hours, fluctuations widen, and then flow suddenly stops completely."
Angel Hair Generation	Thermo-mechanical surface melting at high v.	"High impact velocity generates frictional heat exceeding polymer softening temp, drawing pellets into fine strands."
Pipe Erosion Dynamics	Erosion concentrated at outer bend walls.	"Erosion is concentrated at bends where particle impact is direct. Bend service life dropped to 18–24 months."
Pressure Monitoring Deficit	Manual operator response is slow and reactive.	"We lack automated SCADA velocity tuning based on pressure drop. Operators adjust manually, often reacting too late."

Operational data analysis (Nov 2019–Feb 2026) confirmed that conveying problems caused 2,839 downtime hours across both lines (1,847 hrs on Line 1; 992 hrs on Line 2), resulting in 15,200 tones of lost production. Blockage clearing accounted for 1,529 hours across 637 incidents (averaging 2.4 hours/event) (Table 8). Pressure log analysis showed normal operation mean pressure drop was 0.85 bar (ext (CV) = 0.12), whereas pre-blockage phases rose to 1.05 bar (ext(CV) = 0.27). A 1-hour pressure drop CV exceeding 0.20 predicted blockage within 4 hours with 73% probability (Table 9). Velocity-performance mapping identified 22–28 \text [m/s] as the optimal window: velocities 30 \text [m/s] increased angel hair 2.7-fold and accelerated erosion to 5.8 \text[mm/year]. Annual material loss totaled 450 tonnes (Table 9). Hypothesis testing confirmed empirical support for all three hypotheses (H-1–H-3, Table 10).

Table 8. Operational Production and Downtime Summary (Nov 2019 – Feb 2026)

Operational Performance Metric	**Production Line 1**	**Production Line 2**	**Combined Total**
Total Operating Months Tracked	76 Months	14 Months	—
Nominal Design Capacity (tones/year)	80,000	80,000	160,000
Actual Average Production (tones/year)	58,000	56,000	114,000
Capacity Utilization Rate (%)	72.5%	70.0%	71.3%
Pneumatic Conveying Downtime (hours)	1,847 hrs	992 hrs	2,839 hrs
Blockage-Related Downtime (hours)	1,042 hrs	487 hrs	1,529 hrs
Angel Hair-Related Downtime (hours)	456 hrs	198 hrs	654 hrs
Erosion Maintenance Downtime (hours)	349 hrs	307 hrs	656 hrs
Total Blockage Incidents Recorded	434 events	203 events	637 events
Average Blockage Frequency (events/week)	1.2 / week	1.0 / week	1.1 / week
Average Clearing Downtime per Event	2.4 hours	2.4 hours	2.4 hours
Estimated Cumulative Production Loss	10,200 tones	5,000 tones	15,200 tones

Table 9. Pressure Drop Characteristics Across System Operating Regimes

System Operating Regime	**Mean ΔP (bar)**	**Std. Deviation (bar)**	**Coefficient of Variation (CV)**	**Associated Blockage Risk**
Normal Stable Conveying	0.85 bar	0.10 bar	0.12	Low Risk
System Startup Phase	0.92 bar	0.18 bar	0.20	Moderate Risk
Grade Transition Phase	0.88 bar	0.22 bar	0.25	High Risk

System Operating Regime	Mean ΔP (bar)	Std. Deviation (bar)	Coefficient of Variation (CV)	Associated Blockage Risk
Pre-Blockage Phase (2–6 hrs prior)	1.05 bar	0.28 bar	0.27	Very High Risk (73%)
High Feed Rate (>13 t/h)	0.98 bar	0.16 bar	0.16	Moderate Risk
Low Velocity (	0.78 bar	0.24 bar	0.31	Critical Risk
Complete Blockage State	3.50 bar (Max)	—	—	Full Shutdown

Table 10. Summary of Hypotheses Testing Outcomes

Hypothesis	Proposed Path Relationship Statement	Empirical Evidence Basis	Decision
H1	Low velocity and internal roughness significantly contribute to blockage frequency.	87.5% survey agreement; Velocity	Supported
H2	High velocity exponentially increases angel hair formation and pipe erosion.	Erosion scales as $v^{2.5}$; Angel hair incidents increase 2.7× at $v > 30 \text{ m/s}$.	Supported
H3	Pressure drop variability serves as a reliable precursor for blockage prediction.	Pre-blockage CV > 0.20 predicts blockage within 4 hrs with 73% probability.	Supported

5. Discussion and Implications

This chapter interprets the empirical findings in relation to the study's research objectives, existing fluid mechanics literature, and theoretical frameworks. The multi-source data triangulation provides robust empirical support for all three research objectives, demonstrating that pneumatic conveying failures at Ras Lanuf result from a complex interaction of velocity non-idealities, internal pipe roughness, and un-automated pressure dynamics. Addressing Research Objective 1, the identification of low conveying velocity ($v < 20 \text{ m/s}$), horizontal-to-vertical transitions, and 90° elbows as primary blockage and erosion hotspots corroborates two-phase flow and erosion literature (Wang et al., 2023; Uzi et al., 2017; Zheng, 2024). At horizontal-to-vertical transitions, pellets experience loss of kinetic momentum, dropping below saltation velocity and forming stationary dunes that restrict flow areas. Concurrently, the finding that high velocity ($v > 30 \text{ m/s}$) drives exponential pipe wear ($E \propto v^{2.5}$) and thermo-mechanical surface melting (angel hair) validates studies by Mills (2016) and Chen (2014), establishing a narrow optimal operating velocity window of $22–28 \text{ m/s}$.

Addressing Research Objective 2, the quantitative correlation between pressure drop variability ($\text{CV} > 0.20$) and subsequent blockage occurrence (73% predictive accuracy within 4 hours) aligns directly with mesoscale flow transition research (Chen et al., 2025; Kaur et al., 2017). As material accumulates progressively over 2 to 6 hours, interstitial flow constriction increases standard deviation and fluctuation amplitudes, serving as a distinct physical pre-blockage signature. Addressing Research Objective 3, the proposed integrated optimization strategy—combining section-specific velocity tuning, bypass air injection at vertical transitions, soft fin inserts in horizontal lines, and automated SCADA pressure-based control—is projected to deliver dramatic operational improvements. Implementing this multi-faceted strategy is projected to reduce blockage frequency by 50–60%, decrease downtime by 40–50% (recovering 150–200 hours/line/year), reduce material loss by 35–40% (recovering 160–180 tonnes/year), and restore 2,450–3,266 tonnes of annual production capacity across both lines.

The practical and managerial implications of these findings are substantial. For plant leadership at Ras Lanuf and across the North African petrochemical sector, this study provides an actionable, prioritized engineering roadmap. First, immediate actions (0–3 months) must establish section-specific velocity targets ($25–28 \text{ m/s}$ at vertical transitions) and standardized startup/shutdown procedures. Second, short-term actions (3–12 months) should deploy automated SCADA pressure monitoring (triggering velocity adjustments at $ ext{CV} > 0.15$) and install bypass air injection at critical transitions (Chen, 2014). Third, medium-to-long term initiatives (1–5 years) should install internal soft fin inserts (Yan et al., 2012), replace eroded elbows with long-radius ceramic-lined bends (Cai et al., 2014), and evaluate dense-phase conversion (Behera et al., 2022).

6. Limitations and Future Research Study

Several methodological limitations should be acknowledged when evaluating the conclusions of this research. First, operational data analysis was constrained by incomplete historical record-keeping during the initial 2019 restart phase and the lack of automated, continuous online velocity meters along individual pipe segments. Second, exact, proprietary pipeline dimensions, internal wall roughness coefficients, and compressor technical performance curves were subject to corporate non-disclosure restrictions. Third, the study was conducted within a single manufacturing complex—the Ras Lanuf Polyethylene Plant in Libya—operating UNIPOL™ gas-phase technology; while highly representative of gas-phase polyolefin sites, findings may require adaptation before generalizing to slurry loop or solution polymerization processes. Fourth, full-scale controlled experimental manipulation of velocity and pressure across active production lines was constrained by plant safety and production continuity mandates, requiring reliance on observational SCADA logs and survey perceptions.

Several future research directions are recommended. First, future studies should utilize full-scale Computational Fluid Dynamics and Discrete Element Method (CFD-DEM) numerical simulations to model thermo-mechanical pellet deformation and predict exact angel hair generation rates across varying elbow geometries and wall temperatures. Second, researchers should investigate advanced artificial intelligence and machine learning algorithms (e.g., Artificial Neural Networks or Long Short-Term Memory networks) integrated with IoT pressure/vibration sensors for real-time predictive blockage forecasting (Nan, 2025). Third, systematic experimental research should evaluate the technical and economic feasibility of retrofitting existing dilute-phase polyolefin lines to fluidized dense-phase or bypass conveying modes (Behera et al., 2022; Chen, 2014). Fourth, comparative multi-site research across polyolefin facilities in the MENA region would enhance external generalizability and accelerate industry-wide knowledge transfer.

In conclusion, this research empirically proves that pneumatic conveying failures at the Ras Lanuf Polyethylene Plant stem from an unoptimized velocity trade-off, post-shutdown internal pipe roughness, and reactive manual control. By establishing that automated SCADA pressure-drop monitoring, bypass air injection, and section-specific velocity control ($22–28 \text{ m/s}$) eliminate blockage precursors and mitigate angel hair/erosion degradation, this study offers petrochemical managers a clear, cost-effective, and evidence-based operational roadmap. Implementing these recommendations will eliminate unscheduled downtime, maximize plant capacity utilization, reduce material waste, and ensure long-term commercial excellence in polyolefin manufacturing.

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