ENT1099ME05 - Investigation of Leak-Induced Flow Disturbances and Integrity Monitoring in Multiphase Oil and Gas Pipeline Systems

Principal Investigator

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Background of the problem

Background and Rationale

Pipeline transportation remains the preferred method for moving hydrocarbons due to its efficiency and economic advantages. However, multiphase flow systems are complex, involving interactions between gas, liquid phases, turbulence, and transient flow phenomena. These complexities often result in

operational challenges such as:

- Flow regime transitions (stratified, slug, annular, and dispersed flows).
- Pressure oscillations and severe slugging.
- Reduced flow assurance and operational efficiency.
- Leak occurrence and delayed leak detection.
- Increased maintenance and integrity management costs.

• Environmental and safety risks associated with pipeline failures.

Although significant progress has been made in multiphase flow modelling, current leak detection approaches often rely on simplified assumptions, limited experimental data, or data-driven methods that lack strong physical foundations. There remains a significant research gap in understanding how different multiphase flow regimes influence leak signatures, pressure transients, and detectability under realistic operating conditions.

The proposed research aligns with regional priorities in energy sustainability, industrial digitalization, infrastructure resilience, and advanced engineering capability development. It also supports the broader objectives of developing highly skilled engineering graduates capable of contributing to future energy and industrial sectors.

List of publications related to the field

J9. Lakshmi Narayana Gollapudi, Rohan Senanayake, Christina Georgantopoulou, Anil Kumar, Heat enhancement analysis of a differentially heated inclined square enclosure filled with al2o3 nanofluids under three base fluids: water, water–ethylene glycol mixture & ethylene glycol singh4, Journal of Thermal Science (2021). DOI: 10.2298/TSCI210709269G

J8. Christos Manopoulos *, Sokrates Tsangaris, Christina Georgantopoulou, Dimitrios Mathioulakis (2024). Unidirectional Flow through Time Dependent CrossSectional Areas of a Compliant Tube and a Valve: A Nonlinear Model, Vibration 2024, 7(4), 987-998, https://doi.org/10.3390/vibration7040052

J10. Lakshmi Narayana Gollapudi, Rohan Senanayake, Christina Georgantopoulou, Anil Kumar Singh, Numerical Heat Transfer Analysis of Nano-metallic Phase Change Materials in 2D

Square Enclosure with Horizontal Fin for Sustainable Energy Storage, Case studies in Thermal engineering Journal, vol. 28, 101670.

J12. Christina Georgantopoulou, Nikolaos, Vasilikos, George Georgantopoulos, Recirculating flows analysis and estimation inside channels, Matec web of conf, vol. 172, pp. 01001-01009.

J13. Georgantopoulou C., “Inclination Angle Effect and Separation Zones Estimation for Incompressible Flows inside Pipes using Sub-Grids Refinement”, WSEAS Transactions on Fluid Mechanics, Volume 12, 2017, Art. #14, pp. 116-130

Research Objectives and Expected Outcomes

Research Aim

To develop and validate computational models that predict how leaks affect the flow behaviour of oil and gas pipelines carrying multiple fluid phases, and to use these models to improve pipeline monitoring, leak detection, and integrity management.

Research Objectives

The successful candidate will address the following objectives:

1. Conduct a comprehensive review of research on:

• Multiphase pipeline flow.

• Flow assurance challenges.

• Leak detection technologies.

• CFD applications in oil and gas systems.

2. Develop numerical models of gas-liquid multiphase flow within representative pipeline configurations.

3. Investigate the influence of different flow regimes on:

• Pressure distribution.

• Velocity fields.

• Void fraction characteristics.

• Flow stability.

4. Model leak scenarios under varying:

• Leak sizes.

• Leak locations.

• Operating pressures.

• Flow regimes.

5. Identify and characterise leak signatures associated with different multiphase flow conditions.

6. Develop predictive relationships between leak characteristics and measurable flow parameters.

7. Evaluate the generated data to support future digital monitoring and integrity management systems.

8. Produce recommendations for improving leak detection and flow assurance strategies within industrial pipeline networks.

Expected Outcomes:

The research is expected to generate both scientific and industrially relevant outcomes that contribute to advancing knowledge in multiphase pipeline flow behaviour and leak detection. The project will deliver validated computational tools, new insights into leak-induced flow disturbances, and practical guidance to support pipeline integrity management within the oil and gas sector. The anticipated deliverables include:

• A validated CFD framework for multiphase pipeline leak analysis.

• Comprehensive database of simulated leak scenarios.

• Flow regime and leak signature maps.

• Guidelines for pipeline integrity assessment.

• At least three journal publications in high-impact international journals.

• Conference presentations at international engineering conferences.

• Final doctoral thesis

Research Design & Methodology

Research Methodology

The research will primarily employ numerical techniques supported by numerical analysis and validation studies.

Phase 1: Literature Review and Problem Definition

• Systematic review of recent scientific literature.

• Identification of research gaps.

• Definition of representative industrial pipeline cases.

Phase 2: CFD Model Development

• Geometry creation and mesh generation.

• Selection and implementation of suitable multiphase models.

• Turbulence model evaluation.

• Baseline simulation of multiphase flow regimes.

Phase 3: Leak Modelling and Parametric Studies

• Development of leak scenarios.

• Investigation of:

o Leak size effects.

o Leak location effects.

o Flow regime interactions.

o Pressure transient behaviour.

Phase 4: Analysis and Validation

• Sensitivity analyses.

• Comparison with available literature and experimental datasets.

• Model refinement and validation.

Phase 5: Framework Development

• Development of leak signature maps.

• Establishment of predictive methodologies.

• Recommendations for industrial applications.

Significance and potential impact of research in Bahrain

The research significance of this project lies in its potential to advance both the scientific understanding and industrial management of multiphase oil and gas pipeline systems. Current leak detection and integrity monitoring approaches often struggle to accurately identify leaks under realistic multiphase flow conditions due to the complex interactions between gas, oil, and water phases. As a result, leak events may remain undetected for extended periods, increasing safety risks, environmental impacts, and economic losses.

This research will contribute new knowledge by systematically investigating how different multiphase flow regimes influence leak-induced disturbances, pressure transients, flow stability, and leak signatures. Through the development and validation of advanced Computational Fluid Dynamics (CFD) models, the project will establish a stronger physics-based understanding of leak behaviour in operational pipeline systems, addressing an important gap in current literature.

From an industrial perspective, the outcomes will support the development of more reliable leak detection methodologies and improved pipeline integrity management strategies. The resulting leak signature database, predictive models, and flow-regime maps will provide valuable tools for operators seeking to enhance monitoring capabilities, reduce unplanned shutdowns, and optimise maintenance planning.

The project is particularly significant for the Gulf region, where oil and gas infrastructure remains central to economic growth and energy security.

Alignment with Bahrain's national research strategy

This research aligns strongly with Bahrain's national priorities in energy sustainability, industrial innovation, and infrastructure resilience. As Bahrain continues to develop its oil and gas sector alongside broader economic diversification efforts, there is an increasing need for advanced

engineering solutions that enhance operational safety, reduce environmental risks, and improve the efficiency of critical energy infrastructure.

Pipeline transportation remains a core component of the regional energy system, and ensuring its integrity is essential for protecting both national assets and environmental resources. This project contributes directly to these priorities by developing advanced computational tools for understanding and predicting leak-induced disturbances in multiphase pipeline systems. Improved leak detection and monitoring capabilities can reduce the risk of undetected failures, minimise environmental damage, and support safer and more reliable hydrocarbon transport.

From an industry perspective, the outcomes of this research support the transition toward digitalised and data-informed asset management strategies. The proposed CFD framework, leak signature database, and predictive models can serve as foundational elements for future intelligent monitoring systems and digital twin technologies, which are increasingly relevant to modern oil and gas operations in the Gulf region.

In terms of national research strategy and Economic Development Board (EDB) objectives, the project supports the development of high-value knowledge creation, advanced engineering capability, and skilled human capital. It also contributes to strengthening Bahrain's position as a regional hub for innovation in energy engineering and industrial digitalisation. Ultimately, the research promotes safer operations, technological advancement, and long-term economic sustainability within the energy sector.