Simulation and Economic Impact Analysis of Pipeline Leakages in Chemical Factories

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Introduction

This project develops a simulation-based framework to detect and analyze pipeline leaks, focusing on pressure drop calculations and mitigation strategies. Using Simulink modeling, it enhances safety, efficiency, and sustainability in chemical operations by addressing leaks promptly and cost-effectively.

Problem Statement

Pipeline leaks in chemical industries cause resource loss, environmental harm, and inefficiency. Current detection methods are slow and unreliable, highlighting the need for a system to quickly detect and analyze leaks for improved safety and efficiency.

Project Scope

This project develops a Simulink-based system to detect and analyze pipeline leaks, focusing on pressure drops and simulation modeling. It aims to enhance safety, efficiency, and reliability while minimizing environmental impact and resource waste.

Constraints

- Lack of real-life data limits validation of simulation outcomes.
- Real pipelines span thousands of kilometers, unlike the scale of this project.
- The simulation focuses solely on pressure drops caused by leaks, excluding normal operational fluctuations.

Specifications

- Detect pipeline leaks within 1 hour.
- Simulate a pipeline length of 1.2 kilometers.
- Maintain a consistent temperature of 25°C.
- Achieve at least 70% medium compatibility.

Equations

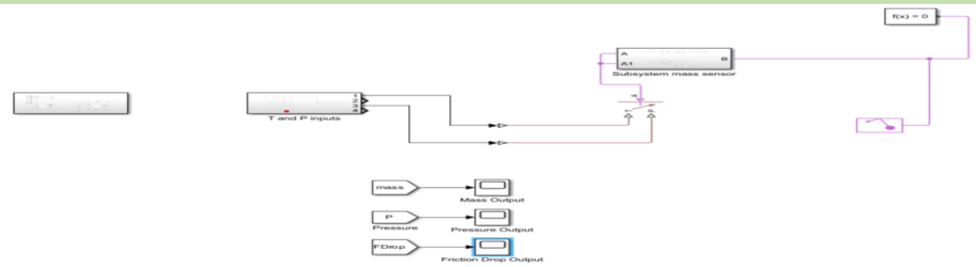
$$\frac{\Delta P}{L} = f_D * \frac{\rho}{2} * \frac{(v)^2}{D_H}$$

Pump Pressure Loss Equations: These equations will allow us to approximate the pressure loss that the pump will introduce

$$\dot{m} = \frac{\pi D_{leak}^2}{4}\sqrt{2\rho(P_{pipe} - P_{atm}} \;, \quad \Delta P = \frac{16\dot{m}^2}{2\rho\pi^2 D_{Leak}^2}, Cost = \rho * \dot{m} * Price\ of\ Ethane$$

Leak loss equation: these equations will allow us to accurately estimate the pressure loss from leak based on the parameters in the following equations

Prototype Design



The simulation model is structured to provide a comprehensive analysis of pipeline behaviour. The subsystem incorporates gas properties to facilitate accurate pressure calculations. The calculated outputs are then fed into the pipeline parameters subsystem, initiating the simulation. Throughout the simulation process, pressure data is continuously captured and stored for subsequent analysis. This systematic approach ensures that all critical variables are accounted for, enabling precise evaluation and interpretation of the results.

Prediction Model

Classification Task: A Random Forest Classifier was trained to detect leaks with an accuracy of 96%.

Regression Task: A Random Forest Regressor was used to predict system pressure values with an R^2 score of 97%.

	precision	recall	f1-score
0	0.93	1.00	0.97
1	1.00	0.91	0.95

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Regression Results:
Mean Squared Error (MSE): 2381471.479176262
R² Score: 0.9997115798781039
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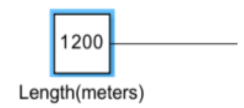
Validation & Testing

Validation for Specification 1, Detect leaks in less than 1 hour: The table illustrates pressure losses and overall system pressure, highlighting the significant difference between friction-only losses and those including a leak. Leak detection is achieved by identifying discrepancies between these losses.

Total Pressure Drop	Pressure Loss Due to Friction	Pressure Loss Due to Leak
33962	29326	4636
35173	30659	4514
36384	31992	4392

Specification 2, Pipeline Length: A 1.2-kilometer pipeline was selected to ensure that pressure drops caused by leaks are clearly observable in the pressure data. Based on the acquired data, this length provides the optimal balance for accurate detection.



Specification 3, Constant Temperature of 25°C: The simulation maintains a constant temperature of 25°C to replicate conditions in existing transport pipelines, ensuring accurate and realistic modeling of pipeline behavior.

Specification 4: Medium Compatibility
The simulation includes a customizable gas properties table, allowing it to accommodate various gases. Any changes to parameters are automatically reflected throughout the system, ensuring a compatibility rate of 70% or higher.

Conclusion

This project can be further enhanced by incorporating real-world data from operational pipelines. Access to such data would improve the accuracy and reliability of the system, allowing for better validation of simulation results and more comprehensive solutions to real-world pipeline challenges.