Assessment of Failure Frequency Methodology Applied to Dense Phase Carbon Dioxide Pipelines

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Abstract

This paper determines the capability of existing failure frequency models for assessing dense phase CO_2 pipelines. The models are examined in terms of their structure, to highlight the similarities and differences between each; and in terms of their relevance to dense phase CO_2 transportation.

Throughout its design and construction, a pipeline must comply with the relevant design code in order to ensure conformity with pipeline safety regulations, for example in the UK it is PD-8010 (BSI, 2015). This code was originally written to be applied to pipelines transporting products which pose a thermal hazard and there is therefore currently no guidance included in the code for pipelines transporting dense phase CO_2. Where design codes cannot be applied (as in this example), a quantitative risk assessment (QRA) approach is required to ensure the safe design, construction and operation of a pipeline (Barnett, 2014; Cooper, 2014). The requirement to develop a robust QRA methodology for high pressure CO_2 pipelines has been recognised as critical to the implementation of CCS.

The purpose of a pipeline QRA is to determine the risks posed by the failure of the pipeline to people located nearby. The procedure involves the identification of hazard scenarios and considers both the probability and consequences of failure in order to calculate values for the individual and societal risk due to the pipeline. In general a QRA procedure covers the following steps:

i) Identify hazards
ii) Identify failure causes
iii) Calculate the frequency of failure for each cause
iv) Evaluate the consequences of failure
v) Calculate the individual and societal risk a specific locations along the pipeline
vi) Assess the tolerability of the calculated risks by comparison with recognised criteria

In terms of failure causes, pipeline failure can occur due to numerous different mechanisms including third party external interference, corrosion, material or construction defects, natural events and operational error; all of which must be considered as part of the assessment (Goodfellow, 2006). This paper focuses on the most common failure mechanism: third party external interference. For oil and gas pipelines, the frequency of pipeline failure due to third party external interference has traditionally been calculated using models based upon probabilistic, structural reliability methods. These methods are applied by combining the following:

- Limit state functions, the mathematical models which define the conditions for failure;
- Probability distributions based around selected random variables;
- A mathematical technique to calculate the probability of failure (e.g. Numerical Integration, Monte Carlo).

For pipelines, the limit state functions are based on semi-empirical fracture mechanics failure models and the probability distributions are based on pipeline damage and derived from historical operational data. The failure probability is converted into a failure frequency to take into account the regularity of third party external interference damage. The various models currently in use within the oil and natural gas pipeline industry differ in their subtleties, however all are based upon a methodology originally developed in the 1980s.

To calculate pipeline failure frequency due to third party external interference for dense phase CO_2 pipelines, it would be desirable to extend the use of the current pipeline failure frequency methodology. The methodology has been employed for over 25 years, and as a result is tried, tested and well understood. The transportation of dense phase CO_2 by pipeline however requires operational pressures in excess of the CO_2 triple point; potentially up to 200bara. This high design pressure requirement necessitates the use of thick wall linepipe in pipeline construction, potentially with wall thickness dimensions outside of the limits of current operational experience. Consequently, the reliance of the failure frequency methodology on empirical data and semi-empirical relations needs to be examined.

The requirement to develop a robust Quantitative Risk Assessment (QRA) methodology for high pressure CO_2 pipelines has been recognised as critical to the implementation of CCS. Consequently, failure frequency models are required that are appropriate for high pressure CO_2 pipelines. This paper addresses key components from the failure frequency for QRA methodology development, the development of which is shown in Figure 1.

References

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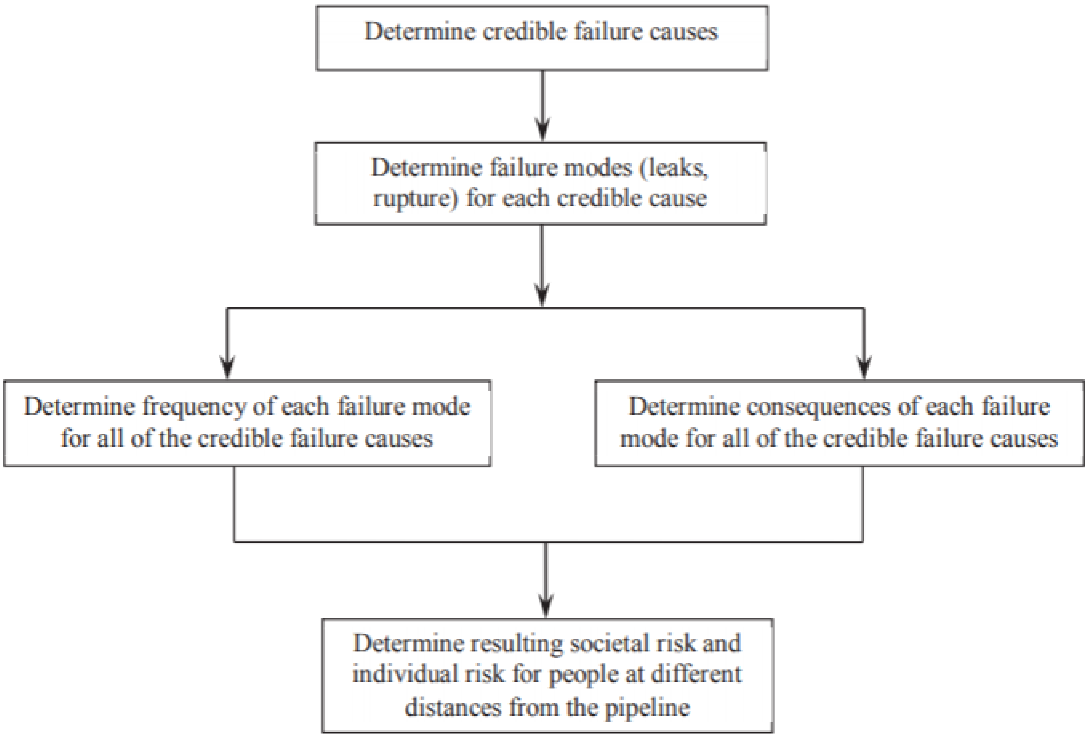

Figure 1: The stages in the development of a QRA for dense phase CO_2 pipelines.