Methodology and tools for the assessment of oil spills from land pipelines

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Abstract

Increasing activity in pipeline transport of oil products has led to accidents and increasing awareness of operating companies and stakeholders (NGO’s, authorities, public, insurance, …)

Though pipeline transportation is excluded from Seveso II scope, legal requirements in many countries are already requiring risk analysis studies in order to determine both the expected frequency and impact on the surroundings (population, natural environment, heritage, etc.)

The complexity of pipeline design and operation (course, profile, products,...), requires the availability of tools to assess, in a cost effective manner, the volume of spills and the consequences of them.

To satisfy growing legal requirements a tool was developed to analyse the risk arising from existing pipelines, taking into account pipeline profile, product physical properties, pipeline hydraulics (pumps, pressure, flow, …) and multiple leakage scenarios (size and location)

Calculations take into account: leakage under pumping; leakage detection and pumping shutoff time; gravitational emptying; pipeline valve actuation and on-scene actuation.

Results are both numerical and graphical, showing total volumes (pumping and gravitational drainage) and time-varying spilled volume and they are linked, depending on surrounding land use, to either thermal and mechanical consequences or environmental damage index.

Keywords: Pipeline, leak, calculations, oil spill, risk assessment, environmental damage.
1 Background

Activities with potential low frequency and major consequences accidents, are being required with an increasing level of safety analysis in order to assess acceptability of risk and to demonstrate effectiveness safety management systems.

In Europe, Seveso II Directive [1] requires a Safety Report and the implementation of a Safety Management System to demonstrate that planning, design, construction, operation, maintenance, changes and decommissioning are conducted in such manner to prevent damage to the surrounding population and environment. However, it applies only to establishments.

For pipelines, there was a project for the development of a Seveso II-like Directive. However it does not seem it is going to be published in a near future.

On the other hand, liability and public image issues are increasing the awareness of pipeline operating companies to prevent the abovementioned damages.

In such situation both new and existing pipelines are being assessed in order to balance risk and investment and operational costs under circumstances such as:

- Pipeline routing
- Pipeline burial depth
- Wall thickness
- Corrosion protection
- Pipeline signalling
- Pipeline inspection
- Operation monitoring
- Leakage detection systems
- Isolation valves situation and operation
- Emergency response planning
- Biodiversity
- Natural resources
- Neighbouring population

To assess the risk relates to oil spill from pipelines answers to the following steps should be followed:

- What can happen?
- How often?
- How much oil will be finally released?
- What kind of effects can occur?
- How much is the damage?
- What is the risk like?

In this context, the objective of this paper is to show the methodology and the tools developed to address risk calculations for the environment and the population arising from major accidents in oil pipelines.
2 Hazard identification and frequency assessment

This phase has been completed basically upon bibliography study of internationally recognized organizations, such as CONCAWE [2]. Finally it was decided to consider the scenarios shown in table 1.

Table 1: Definition of spill scenarios.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Hole size (% of φ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hole</td>
<td>5%</td>
</tr>
<tr>
<td>Breach</td>
<td>20%</td>
</tr>
<tr>
<td>Rupture</td>
<td>100%</td>
</tr>
</tbody>
</table>

Considerations have been made in order to take into consideration specific conditions such as burial depth, wall thickness and land use.

3 Assessment of the amount of spilled oil

The amount of spilled oil is assessed according to the following stages:

- $t_1$ Time to leak detection, taking into account the expected leakage rate, operation monitoring and land-use. This has been considered from 1 min to hours.
- $t_2$ Time to pump stopping and pipeline ends isolation
- $t_3$ Time for closing intermediate valves, depending on the mode of operation and, in case valves of manually actuated, the location.
- $t_4$ Time for accessing and capping leakage, if possible.

The leakage rate is assessed using the following criteria:

3.1 Leakage rate under pumping ($t_1 + t_2$)

Leakage under pumping is assessed using traditional fluid mechanics models (Bernoulli equation) under the supposition of stationary regime taking into account, fig. 1:

- Pumping performance (Flow/head)
- Actual or projected pressure drop.
- Pipeline geometry (length, diameter and longitudinal profile).
- Leakage point
- Backflow.
- Oil physical properties
Results from this are:
- Leak rate
- Gauge pressure at leak point
- Upstream flow rate
- Downstream flow rate (possible backflow)

3.2 Gravitational emptying of the pipeline ($t_3 + t_4$)

Emptying of pipeline is calculated under the following assumptions, fig. 2:

- Drainage from peak points
- Same liquid level at both sides of leak point during drainage
- Absolute pressure at peak points equals to vapour pressure
- Highly turbulent flow (simplification of pressure drop calculations)
- Continuity of liquid column, except from emptying sections.
- Remaining of liquid under equilibrium level.
- Closing of valves at pre

In this way pipeline is divided into small sections compared to the distance to the point of leak with the same height at edges.
Results from this are:

- Total oil spilled
- Time to emptying
- Time dependant spilled volume

3.3 Tool developed

A tool has been developed to address this issue with the following performance characteristics:

- Pipeline up to 1000 points in longitudinal profile. Pipeline points can be captured from CAD drawings.
- Possibility of analysing accidents in both directions and stand-by.
- Up to 100 points for accident location
- Up to 45 accident product-scenarios.
- Tabular and graphical results, fig. 3

Sample results show the great dispersion of values, depending mostly on pipeline profile and valve location and closing time.

4 Assessment of consequences and risk for the population

Upon the assessment of oil spilled calculations are made to determine the consequences derived on the population, being considered death as the indicator.

Calculations are made for both individual risk and societal risk following the criteria of The Netherlands [3], AIChE [4] and local authorities requirements.
Figure 3: Total volume spilled upon different scenarios at different points at a 14” gasoline pipeline.

The effects included, depending on the characteristics of the product, are pool and jet fires, flash fires and vapour cloud explosions.

4.1 Individual risk

Individual risk profile is obtained under the supposition of accidents occurring at different points along the pipeline and ‘affecting’ sample points at a perpendicular line to the pipe.

4.2 Societal risk

Societal risk (F-N curve) is achieved by implementing an algorithm to take into account non uniform population distribution.

So, victims (%) are calculated at sample points located at a determined relative position to the point of accident. Then accidents ‘occur’ along the pipeline and victims for each are calculated upon the relative position and the expected population of each real point.
5 Assessment of consequences for the environment

The assessment of environmental consequences derived from chemical (potential) releases is a matter in which small reductions in uncertainty can take a significant increase in resources.

In pipelines this condition is more relevant due to the great variety of topographical, hydrological, geological, hydrogeological, fauna and flora conditions along it.

To deal with this, the Spanish standard UNE 150 008 EX 2000 [5] has been applied as a starting point, in which it is used a screening process to assess environmental consequences under the following formula:

\[
Gravity = I_{\text{amount}} + 2 \times I_{\text{danger}} + I_{\text{extension}} + I_{\text{quality}}
\]  

Each of the addends can vary between 1 and 4 and is determined under non quantified criteria, having then a high degree of subjectivity, obtaining a final value of Gravity in the range 5-20, that is qualified into 5 groups.

This methodology is considered to be in accordance to Spanish Seveso II implementation Competent Authority Guidelines.

In order to cope with these limitations and with the aim of having a method as universal, objective and scaleable as reasonably feasible, the following general criteria have been adopted [6]:

- Division of environment into media, considering air, ground, subsoil, water surface, water column, water bed and shoreline, fig. 4.
- Consideration of different mechanism for dispersion, extension and the effects to living beings and natural resources for each of the media.
- Consideration of the ‘environmental damage’ as the sum of the ‘damages’ to each of the media.
- Consideration of each of the addends as an order of magnitude of the variable which is represented. So, each of the addends is obtained through the following expression:

\[
I_{ij} = A_{ij} + \log_{10}(X_{ij})
\]

where:

- \(I_{ij}\) Value of the index representing the variable \(i\) for the medium \(j\).
- \(A_{ij}\) Parameter for the parameter the variable \(i\) for the medium \(j\).
- \(X_{ij}\) Value of the variable \(i\) for the medium \(j\).

So, f.i., a final difference of 2 units would represent consequences 100 times higher.

General criteria for determining the indexes are:

5.1 Amount of substance

At each medium quantities are estimated based on simple models to analyse transfer between media (point of release, local topography, water bodies, evaporation, solubility, soil permeability, remediation time, etc.). Variable to be considered is always mass.
5.2 Danger of substance

At each media toxicological and eco-toxicological properties are taken into account for each medium together with, if applicable, ability of integration into it (solubility, vapour pressure, etc.).

5.3 Extension of the damage

Depending on the medium, extension is assessed as surface, based on minimum thickness, or volume, based on quantity at medium and (eco-) toxicological properties.

5.4 Quality of the medium

Quality is assessed directly taking into account biodiversity properties (quality and quantity) and natural resources potentially affected (drinking, watering, etc.).

6 Conclusions

Pipeline oil transport, though consider safer than other means of transport, results in a risk potential high consequences for both the population and, especially, the environment, resulting in a great dispersion of values depending on the pipeline profile, valve location and actuation, instrumentation, etc.

Risk assessment can help in making decisions on safety and environmental management, including initial design, revamping, land use planning, public and local contractor awareness and emergency response planning.

The proposed methodology and tools provide a feasible approach to manage safety and environmental risk assessment that can help in identifying and managing weak links.

Efforts are being applied in order to improve scientific and technical performance of the tools, mainly on transport modelling and environment quality assessment.
References


