

Guideline to Determine Erosional Velocity for Liquid Hydrocarbon Transmission Pipelines

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ABSTRACT

Erosion can be a major threat to liquid hydrocarbon transmission pipeline integrity if high liquid flow rates are combined with the presence of solid particles. Erosion may cause metal loss to the pipeline and in extreme cases lead to pipeline failure.

There is currently no industry-recognized guidance document or standard for determining erosional velocity limits for liquid hydrocarbon transmission pipelines. Many operators use the general form of the American Petroleum Institute RP 14E equation to determine erosional velocity, but it does not properly address the effect of the key parameters affecting erosion in liquid pipelines and could give erroneous results in some cases.

This paper presents a guideline to determine erosional velocity limits for liquid hydrocarbon transmission pipelines, developed based on a multi-analytical probabilistic approach that integrated results from two industry-recognized erosion prediction models.

The guidance developed allows pipeline operators to reduce capital costs when designing new pipelines or can provide engineering justification for increasing the throughput of existing facilities while maintaining pipeline integrity relative to the threat of erosion.

Key words: Erosion, Simulation and Modelling

INTRODUCTION

Erosion is a major threat to liquid hydrocarbon transmission pipeline integrity when high liquid flow rates are combined with the presence of solid particles. However, there is currently no generally accepted guidance document or standard by which liquid petroleum pipeline operators can define maximum allowable velocities to manage the threat of erosion in their pipelines.

In liquid piping systems where solids might be present, a maximum velocity of 5 m/s (~17 ft/s) is often used by industry as a limit to minimize erosion.¹ The International Organization for Standardization (ISO)⁽¹⁾ 13703 also recommends a maximum velocity of 5 m/s (~17 ft/s) for lines transporting liquids in a single phase by pressure differential, to minimize flashing ahead of the control valve.² For calculating erosional velocity in pipelines with two-phase flow, this ISO standard refers to the equation in the American Petroleum Institute (API)⁽²⁾ Recommended Practice 14E, henceforth referred as the API RP 14E equation.³ However, ISO 13703 standard includes a note indicating that computer-based models that consider the effect of geometry, material type, solids properties, and fluid velocities and properties, can be used as an alternative to the API RP 14E approach, which can be overly conservative for many conditions.²

While some operators have internal company standards to determine their velocity limits for avoiding erosion, other companies use the API RP 14E equation, shown below:

$$v_e = \frac{C}{\sqrt{\rho}} \quad (1)$$

Where

v_e	Is the erosional velocity (ft/s)
ρ	Is the fluid mixture density at flowing conditions (lb/ft ³)
C	Is an empirical constant

For “solids-free” two-phase flow, API RP 14E indicates 100 and 125 to be conservative values of “C” for continuous and intermittent service, respectively. It also states that where solids are present, fluid velocities should be significantly reduced.³ This implies the use of a lower value of “C” when solids are present, but there is no guidance in how to define this value.

Many papers have been published where different “C” values in equation (1) have been defined for specific cases, but not for liquid hydrocarbon pipelines. In general, the approach used by industry has been to determine erosional velocity based on experimental data or modelling, and then back-calculate the equivalent C value based on the API RP 14E equation. In a few cases, lower C values were calculated for systems with sand production, but in most cases the C values were found to be higher than those recommended by API.⁴⁻⁹

The API RP 14E equation, is very simple and widely used but has many limitations.^{10,11} This equation does not recognize the many factors contributing to erosion and usually gives unrealistically low velocity limits.¹² Previous work has concluded that the API RP 14E equation does not adequately represent laboratory and field observations of erosion failures in the oil and gas industry.¹³

Figure 1 shows erosional velocities calculated using equation (1) for the range of densities included in this study, assuming C = 100. It can be observed that the limiting velocity would be predicted to decrease with increasing fluid density, which is contrary to experimental observations.¹⁴

This paper presents a guideline to determine erosional velocity limits for liquid hydrocarbon transmission pipelines, developed as part of a research funded by Pipeline Research Council International (PRCI)⁽³⁾.¹⁵

(1) The International Organization for Standardization (ISO)

(2) American Petroleum Institute (API)

(3) Pipeline Research Council International (PRCI)

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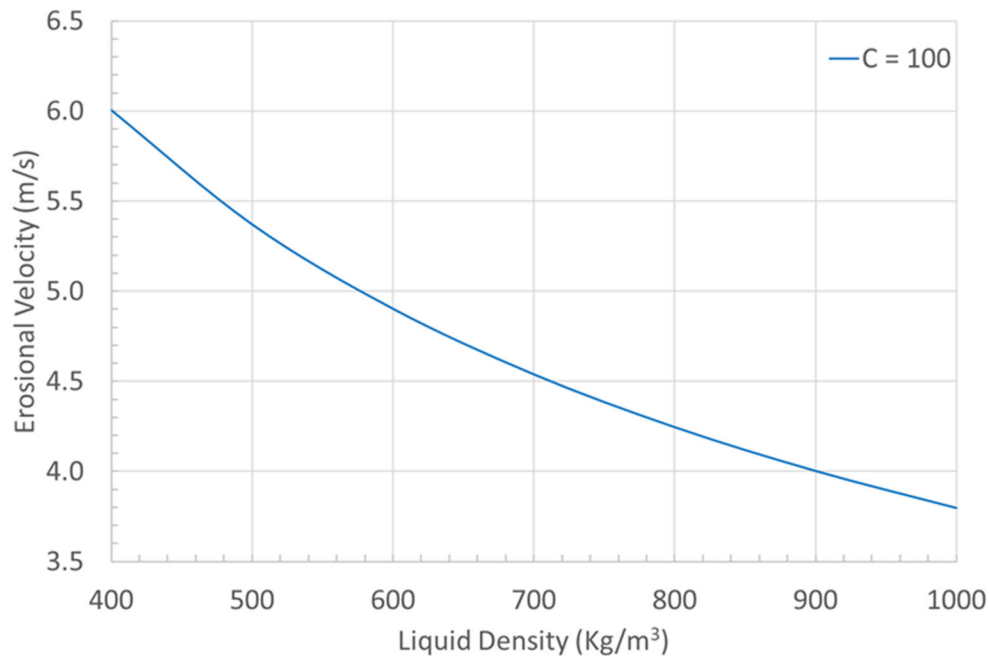


Figure 1: Erosional Velocity based on Equation (1) for the range of densities considered in this work (for comparison purpose only).

METHODOLOGY

The erosional velocity guidelines were developed based on a multi-analytical probabilistic approach that integrated results from two industry-recognized erosional models: The University of Tulsa Sand Production Pipe Saver (SPPS) model¹⁶ and the DNV RP-O501 model¹⁷, henceforth in this paper referred as Model T and Model D, respectively.

Parsi et al presented a comprehensive review comparing different models available to predict erosion rates.¹⁰ The models used in this work were selected based on a literature review and industry experience survey conducted as part of this research.¹⁵

The general approach included the following steps (See Figure 2):

1. Conducting a parametric study of the selected models.
2. Running Monte Carlo simulations with the selected models, creating an Erosion Rate Database.
3. Using the results of all simulations to create a simple classification tree.
4. Combining results of all simulations using a visual interface.
5. Implementing a Bayesian probabilistic model combining all results.

A parametric study was first conducted to evaluate the effect of different parameters on the erosion rates, using values selected to cover the range of conditions of the operators that responded to an industry survey. Results from this parametric study, presented elsewhere, were used to evaluate the relative impact of each parameter on the erosion rate.^{15,18}

Table 1 shows the ranges of the parameters used in the Monte-Carlo simulation. These ranges were selected based on the parametric study, the industry survey results and suggestions from subject matter experts participating in the industry survey. In these models, the radius of curvature (r/D) is shown normalized to the nominal pipe size D .

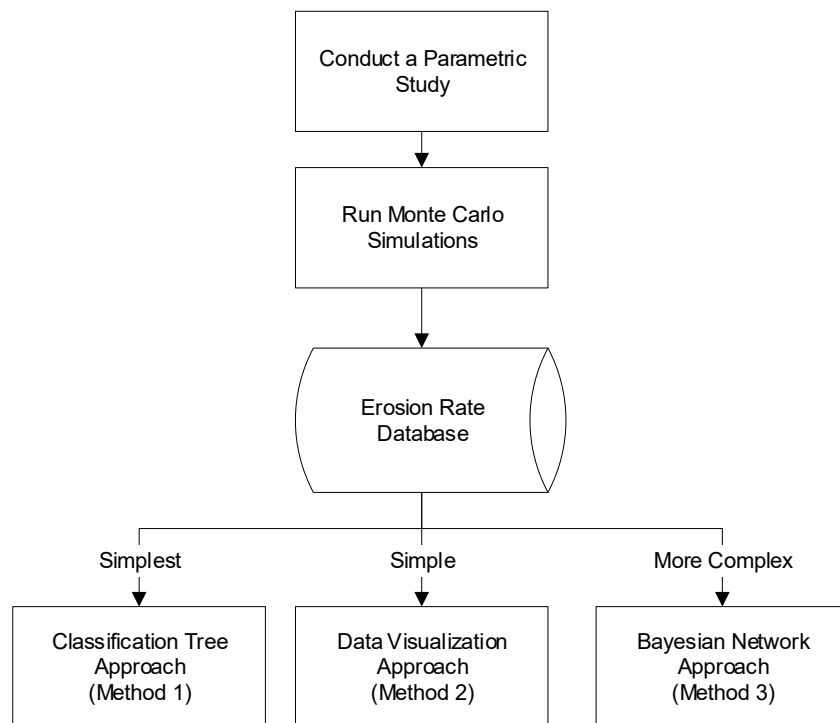


Figure 2: Multi-Analytical Probabilistic Approach Flowchart. The relative ease of application for each approach in the methodology is indicated.

The following parameters were assumed constant: Carbon steel with density of 7850 Kg/m³ and single-phase flow. All runs were conducted at a single particle rate (1 kg/day) as all erosion prediction models assume erosion rates to increase proportionally to the particle rate.

A minimum particle diameter of 0.05 mm (50 µm) was selected to be conservative, consistent with Model T recommendations.

For Model T simulations, a particle sharpness of 0.5 and a relative pipe roughness of 0.001 were assumed. The pipe roughness is used to calculate flow regime and it is not critical for single phase flow simulations.

For Model D simulations, a geometry factor (GF) of 2 was assumed to account for the possibility of having components (e.g., elbows) in one plane less than 10 times the diameter (10D) apart. This factor multiplies the model predictions, as Model D assumes having straight pipe sections larger than 10D between components. In case of having more complex piping geometries, GF values up to 3-4 may be appropriate and computational fluid dynamic (CFD) simulations would be recommended.

For each input range combination, 500 Monte-Carlo simulations were conducted to evaluate the effects of input parameters on the calculated erosion rate. The total number of Monte Carlo simulations run was 31,752,000 for Model T, and 15,876,000 for Model D. There are fewer simulations for model D because it does not consider the effect of particle hardness. The total ~47 million simulations were condensed and summarized into a database table for convenient access.

Table 1. Ranges of the parameters selected for running Monte Carlo simulation

Parameter	Unit	range	
		Model D	Model T
Oil velocity	m/s	[1-3]	[1-3]
		[3-5]	[3-5]
		[5-7]	[5-7]
		[7-9]	[7-9]
		[9-11]	[9-11]
		[11-13]	[11-13]
Pipe diameter	inch	[13-15]	[13-15]
		[3-5]	[3-5]
		[5-7]	[5-7]
		[7-9]	[7-9]
		[9-13]	[9-13]
		[13-17]	[13-17]
Particle diameter	μm	[17-21]	[17-21]
		[21-36]	[21-36]
		[50-250]	[50-250]
Radius of curvature (r/D)	-	[250-500]	[250-500]
		[500-1000]	[500-1000]
		1	1
		1.5	1.5
Particle hardness	Vickers	5	5
		20	20
		N/A	[65-500]
Oil viscosity	cp	[500-2000]	[500-2000]
		[0.4-4]	[0.4-4]
		[4-40]	[4-40]
Oil density	kg/m^3	[40-400]	[40-400]
		[400-600]	[400-600]
		[600-800]	[600-800]
Particle density	kg/m^3	[800-1000]	[800-1000]
		[2000-3000]	[2000-3000]
		[3000-5400]	[3000-5400]
Steel hardness	Vickers	114	114
		131	131
		200	200

Different machine learning approaches were conducted to the erosion data base. These approaches are further described and compared elsewhere.¹⁸ For the erosional guidelines, the following three methods were selected:

1. Method 1: Classification Tree Approach. The erosion database was imported into the MATLAB[†] classification learner, to perform a supervised machine learning using various erosion rate as target variable and the simulation parameters as input variables. The results were truncated and presented in an easy-to-access decision tree.
2. Method 2: Data Visualization Approach. A visualization tool was created using Spotfire[†] software, where the relationship between the erosion rate and the corresponding input parameters in the erosion database can be directly presented.
3. Method 3: Bayesian Network Approach. A Bayesian network model, developed using Hugin[†] Software, was implemented to determine the probability of a certain erosion rate at a given set of conditions, combining the simulation results from both models. The core information used by this

[†] Trade name